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Informal Report

MASTER

**A Time Domain Survey of the
Los Alamos Region, New Mexico**

University of California

LOS ALAMOS SCIENTIFIC LABORATORY

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A Time Domain Survey of the Los Alamos Region, New Mexico

Williston, McNeil and Associates *

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Fig

A TIME DOMAIN SURVEY OF THE LOS ALAMOS REGION, NEW MEXICO

by

Williston, McNeil and Associates

ABSTRACT

A time domain electromagnetic sounding survey of the region surrounding the city of Los Alamos, New Mexico was carried out. The results show that a linear trough, trending northeast-southwest runs beneath the city. The southern boundary is somewhat to the south of the city, the northern boundary was not established. The geoelectric section consists of three layers and the total thickness of the section is in excess of 3 000 m. The resistivities of the second layer are as low as $2.5 \Omega \text{ m}$. If the salinities are in the region of 7 000 ppm, the resistivities could indicate that water with a temperature of 150°C may be found at a depth of 3 000 m.

I. INTRODUCTION

Williston, McNeil & Associates carried out a time domain electromagnetic (TDEM) survey in and about the city of Los Alamos, New Mexico. The purpose of the survey was to study the geothermal potential of the area. A single electrical dipole source was established to the south of the area of interest and 50 receiver sites were occupied (Plate 1). The recording locations were specified by some of the staff of the Los Alamos Scientific Laboratory (LASL). The results of the survey are presented on a base map supplied by LASL at a scale of 1:24 000. Plates 1, 2, and 3 are in a pocket on the inside back cover of this report.

II. METHOD

The TDEM sounding technique measures the time rate of decay of the vertical component of the magnetic field generated by a square wave of current injected into the earth by an electric dipole source (Fig. 1).¹ A single-source dipole 0.6 km long of #2 A.W.G. wire was used; power was supplied by a 200-kW diesel generator and the resulting current square wave attained up to 350 A peak to peak. The transmitted signal was measured by a single-axis cryogenic magnetometer employing a Josephson junction in a liquid-helium-filled dewar. This instrument has an effective area of 23.4 km^2 ; attenuation and filtering are selectable. Cryogenic

Fig. 1.

Time-domain electromagnetic sounding: equipment schematic.

magnetometers have significant advantages over the induction loops used during the development of the TDEM method. The two major advantages are much greater ease of setting up and greatly increased effective areas.

While penetration of an electromagnetic wave is basically controlled by skin depth, the offset distance is also a factor. As the distance between the source and the measuring point is increased, the lower frequencies, i.e., those with greater penetration, predominate more in the received signal. It is possible to distinguish horizontal boundaries to depths of between 1/3 and 1/2 of the offset distance. In Plate 1, it can be seen that offset distances of between 3 km and 15 km were attained. The voltage measured at the receiver is

$$v(t) = \frac{3 ALI \cos \theta}{2 R^4} \rho_a, \quad (1)$$

where

$v(t)$ = voltage at any given time after the initiation of the transient,

A = effective area of the receiver in square meters,

L = source length in meters,

I = current in source in amperes,

ρ_a = apparent resistivity in ohm meters,

θ = angle between vector from source to receiver and perpendicular bisector of source, and
R = distance between source center and receiver in kilometers.

Equation 1 shows that signal strength is azimuthally dependent, and it decreases from the perpendicular bisector of the source dipole to the sides.

In the field, the data were recorded using a digital data retrieval system based on an LSI 11 computer. Subsequent processing of the signal involves deconvolution of the signal response of the recording equipment and logarithmic filtering to remove noise. Finally, the voltage-versus-time curve is transformed into a resistivity-versus-time curve using Eq. (1). The voltage-versus-time curve and resistivity-versus-time curves are shown in Appendix B.

The interpretation of the curves was carried out using a computer inversion program that is based on a layered-earth model. This program inverts the resistivity-versus-time curve to a series of discrete layers which are characterized by thickness and resistivity (Appendix A). These geoelectric layers may or may not coincide with actual rock units. To be completely diagnostic, the TDEM soundings must be related to well log information. In each sounding interpreted in the present survey, the lowermost layer is a resistor deeper than whose surface no further geoelectric layers can be distinguished. This lowermost layer is known as electrical basement. However, it may not coincide with basement as it is known to a geologist--meaning that granitic or metamorphic rocks are present. For example, limestones and dolomites will appear as electrical basement because of their high resistivity as will any other rock provided there is sufficient resistivity contrast of about 10 to 1 between the rock and the layer immediately above.

III. RESULTS

Four geoelectric parameters are presented in Appendix A. They are resistivity and thickness of the first geoelectric layer, and resistivity and thickness of the second geoelectric layer. Also listed in Appendix A is the percentage error in the fit of the inverted model.

In Plate 1 is shown the depth to the electric basement. The principal feature of Plate 1 is a well-defined trough with an axis running northeast-southwest. In the center the trough is 3 435 m deep. It shallows to the northeast, but the coverage is not sufficient to say whether or not it is a closed feature. To the west, near the junction of East Jemez Road and Trinity Road, the transients all have reversed initiations (soundings 110-116). This behavior indicates that there is a strong lateral increase in resistivity to the west. The boundary between the two resistivity zones is probably a fault.

Insofar as geothermal exploration is concerned, the deeper layers are normally more interesting than the shallow. In Plate 2 the thickness of the second layer, i.e., the one immediately above electrical basement, is shown. The thickest part of layer two coincides with the deepest part of the total section as shown in Plate 2. The layer thins rapidly to the south and to the southwest. Its maximum thickness is in excess of 2 000 m.

The resistivities of the first layer are quite variable (Appendix A) and are not presented in map form. However, the second layer resistivities show a variation that is consistent with their depth of burial within the trough. These resistivities are shown in Plate 3. The major feature is a low of less than $2.5 \Omega \text{ m}$ in the center part of the prospect. The resistivities increase away from this central low. To the northeast there is an increase to $3.5 \Omega \text{ m}$, whereas to the west the resistivities increase to greater than $7 \Omega \text{ m}$. The lowest resistivities are coincident with the axis of the trough.

IV. CONCLUSIONS AND RECOMMENDATIONS

Underneath the city of Los Alamos there is a deep trough or graben that extends to the northeast away from the town. The graben is in excess of 3 000 m deep and is made up of two geoelectric layers. The upper layer is variable in resistivity and thickness (Appendix A). The second and lower layer is over 2 000 m thick and has resistivities that are as low as $2 \Omega \text{ m}$. The low-resistivity zone (less than $5 \Omega \text{ m}$) lies in the middle of the graben. These resistivities are typical of a fine-grained rock of either sedimentary or volcanic origin. However, the resistivities are too low to be those of rock containing fresh water, the interstitial fluid must be affected either by salinity or by an increase in temperature. The low resistivities indicate that the rocks must have a porosity of greater than 20 percent. For example, if the rock has a formation factor of 10 and the pore waters have a salinity of 7 000 ppm, then the temperature would be 150°C . In the volcanic terrain surrounding Los Alamos, it is quite conceivable that such temperatures could be reached toward the bottom of a 3 048-m (10 000-ft) bore hole.

Electromagnetic transients may be transformed from curves of voltage versus time to resistivity versus time using one of two asymptotic formulas. The formula used to convert the curves in this report is the "early time" or "far zone" formula in which the receiver locations must be at a distance of several source lengths from the transmitter. The soundings which lie between the source and Pajarito Road do not fulfill this criterion. In order to interpret them, they will be reprocessed using the late time asymptotic approximation and then interpreted in terms of geoelectric layers. Until these results are available, it is suggested that the results of the TDEM survey be extended using other geophysical techniques such as gravity.

REFERENCE

1. N. Harthill, "Time-Domain Electromagnetic Sounding," IEEE Trans. GE-14, 256-260 (1976).
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APPENDIX A

<u>Station No.</u>	<u>ρ_1 Ohm-m</u>	<u>h_1 Meters</u>	<u>ρ_2 Ohm-m</u>	<u>h_2 Meters</u>	<u>Error %</u>
101	16.41	1607	5.07	490	6.06
102	15	1661	2.41	281	4.22
103	12.5	1676	3.12	305	6.31
104	9.64	2035.8	3.81	340	5.2
105	10.63	1416	4.66	886.8	3.28
106	8.03	1457.3	4.26	873	5.55
107	7.00	1360.1	4.29	750.4	7.56
108	9.72	1270.5	3.37	847.0	2.27
109	34.70	207.5	4.67	500	11.23
110	Reversed initiation				
111	Undetermined				
112	Reversed initiation				
113	"	"			
114	"	"			
115	"	"			
116	Undetermined				
117	7.47	1074.3	3.00	1014	2.09
118	7.00	1050	5.07	847	3.21
119	7.22	1125.1	2.42	700	2.67
120	9.72	1050	2.1	700	1.92
121	8.47	1158	2.1	790	1.8
122	7.2	1081.9	2.6	851.5	1.95
123	6.42	1200	1.26	999.4	22.4
124	8.03	1392	2.1	847	2.12

Station No.	ρ_1 Ohm-m	h_1 Meters	ρ_2 Ohm-m	h_2 Meters	Error %
125	7.22	1204.3	2.54	1147	2.19
126	8.82	1286	1.66	700	1.62
127	8.96	1339	2.1	965	1.07
128	27.12	1229.6	6.5	2205.8	3.73
129	13.59	1147	3.9	1855.9	2.31
130	16.8	1366	7.0	1415	6.32
131	1431.0	680	10	1185	8.22
132	Reversed initiation				
133	Undeterminable with far zone approximation				
134	"	(see text)			
135	"				
136	"				
137	"				
138	"				
139	"				
140	"				
141	"				
142	Reversed initiation				
143	27.12	1300	6.5	1270.5	1.76
144	23.2	1530.7	6.5	1400	1.35
145	43.7	1064	6.64	2213.8	4.17
146	14.76	1297	3.5	1706	4.05
147	10.84	1128.9	3.21	1400	5.11
148	43.37	1071.4	6.05	2000	4.63
149	52.05	1690	7.0	1583	7.73
150	59.7	330.2	14.91	2046.9	3.54

APPENDIX B

VOLTAGE-VERSUS-TIME CURVES AND RESISTIVITY-VERSUS-TIME CURVES

LOS ALAMOS - STA 1 - 06 APR 78
DIST 5180. M, 2 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 2 - 06 APR 78
DIST 5070. M, 12 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 3 - 06 APR 78
DIST 4940. M, 3 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 4 - 06 APR 78
DIST 4880. M, 9 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 5 - 6 APR 78
DIST 4800. M, 6 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 6 - 6 APR 78
DIST 4800. M, 2 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 7 - 6 APR 78
DIST 4760. M, 16 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 8 - 6 APR 78
DIST 4840. M, 11 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 9 - 6 APR 78
DIST 5300. M, 17 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA10 - 6 APR 78
DIST 5550. M, 21 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 11 - 6 APR 78
DIST 6520. M, 7 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 12 - 06 APR 78
DIST 7240. M, 2 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 13 - 06 APR 78
DIST 7320. M, 8 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 14 - 07 APR 78
 DIST 8590. M, 41 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 15 - 07 APR 78
 DIST 7090. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 15 - 07 APR 78

LOS ALAMOS - STA 16 - 07 APR 78
DIST 6100. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 17 - 07 APR 78
DIST 4150. M, 16 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 18 - 07 APR 78
DIST 4100. M, 34 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 19 - 07 APR 78
DIST 4230. M, 8 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 20 - 07 APR 78
DIST 4310. M, 11 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 21 - 07 APR 78
DIST 4480. M, 8 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 22 - 07 APR 78
 DIST 4650. M, 5 STACKS, LPF 10 KHZ, SYS. 1

LOS ALAMOS - STA 23 - 07 APR 78
 DIST 4880. M, 6 STACKS, LPF 10 KHZ, SYS. 1

LOS ALAMOS - STA 24 - 07 APR 78
DIST 4990. M, 9 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 25 - 07 APR 78
DIST 5140. M, 8 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 26 - 07 APR 78
 DIST 5410. M, 8 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 27 - 07 APR 78
 DIST 5410. M, 8 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 28 - 08 APR 78
DIST 7240. M, 9 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 29 - 08 APR 78
DIST 8160. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 30 - 08 APR 78
DIST 7988. M, 5 STACKS, LPF 18 HZ, SYS. 1

LOS ALAMOS - STA 31 - 08 APR 78
DIST 9118. M, 12 STACKS, LPF 18 HZ, SYS. 1

LOS ALAMOS - STA 32 - 08 APR 78
 DIST 8760. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 33 - 08 APR 78
 DIST 8250. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 34 - 08 APR 78
DIST 4780. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 35 - 09 APR 78
DIST 2670. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 36 - 09 APR 78
 DIST 2420. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 37 - 09 APR 78
 DIST 2400. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 38 - 09 APR 78
DIST 1830. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 39 - 09 APR 78
DIST 3090. M, 6 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 40 - 09 APR 78
DIST 9510. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 41 - 09 APR 78
DIST 4630. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 42 - 09 APR 78
DIST 5530. M, 5 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 43 - 11 APR 78
DIST 9450. M, 11 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 44 - 11 APR 78
DIST 10100. M, 12 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 45 - 10 APR 78
DIST 11500. M, 14 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 46 - 10 APR 78
DIST 12400. M, 13 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 47 - 10 APR 78
DIST 13200. M, 10 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 48 - 10 APR 78
DIST 12040. M, 13 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 49 - 10 APR 78
DIST 10360. M, 11 STACKS, LPF 10 HZ, SYS. 1

LOS ALAMOS - STA 50 - 10 APR 78
 DIST 19360. M, 6 STACKS, LPF 10 HZ, SYS. 1

PLATE I

WILLISTON, McNEIL & ASSOCIATES

LOS ALAMOS PROJECT
TDEM SURVEY
Depth to Electrical Basement

129 Sounding Number R = Reversal
● Sounding Location U = Undetermined
3003 Depth in Meters

SCALE: 1" = 2000'

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PLATE II

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LOS ALAMOS PROJECT

TDEM SURVEY

Second Layer Thickness

129 Sounding Number
 • Sounding Location
 1856 Thickness in Meters

SCALE: 1" = 2000'

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106°22'30"

106°17'30"

150
14.9

106°15'

106°12'30"

7

149
7

148
6

144
6.5

145
6.6

146
3.5

147
3.2

15°32'30"

15°50'

35°50'

106°20'

106°17'30"

106°15'

106°12'30"

PLATE III

WILLISTON, McNEIL & ASSOCIATES

LOS ALAMOS PROJECT
TDEM SURVEY
Second Layer Resistivity

129 Sounding Number
● Sounding Location
3.9 Resistivity in ohm-m

SCALE: 1" = 2000'

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