ELECTRICAL RESISTIVITY SURVEY

and

EVALUATION OF THE GLASS BUTTES GEOTHERMAL ANOMALY

LAKE COUNTY, OREGON

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STATE OF OREGON

DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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ABSTRACT

A dipole-dipole electrical resistivity survey was made at Glass Buttes, a silicic volcanic dome located along the Brothers fault zone in central Oregon, to evaluate the technique and to study the Glass Buttes geothermal anomaly. An a-spacing of 2,000 feet with separations between electrode pairs ranging from 2,000 to 12,000 feet and a frequency of 0.125 hertz were used. The survey revealed marked resistivity contrasts and outlined a broad area at depth underlain by material having a resistivity value interpreted to be less than 5 ohm meters. A near-surface layer with resistivity values exceeding 300 ohm meters generally coincides with the outline of the silicic volcanic rocks.

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INTRODUCTION

Glass Buttes is a small west-northwest trending mountain range located in northeastern Lake County in Central Oregon (see figure 1). The range is 12 miles long in an N70W-S70E direction and 6 miles wide in a N30E-S30W direction. It lies in parts of T. 23 and 24 S., R. 22, 23 and 24 E. The nearest towns are Burns, which lies about 50 miles to the east, and Bend, which is 80 miles to the northwest. The area is accessible by U.S. Highway 20 which parallels the northern flank of the range.

ACKNOWLEDGEMENTS

The present study was undertaken in cooperation with the U.S. Energy Research and Development Administration's Los Alamos Scientific Laboratory located at Los Alamos, New Mexico. Drs. Donald W. Brown and Paul R. Kintzinger initiated and were involved in the planning of the geophysical program and provided guidance throughout. Mr. R.E. Corcoran, State Geologist, initially suggested the Glass Buttes area as a test site.

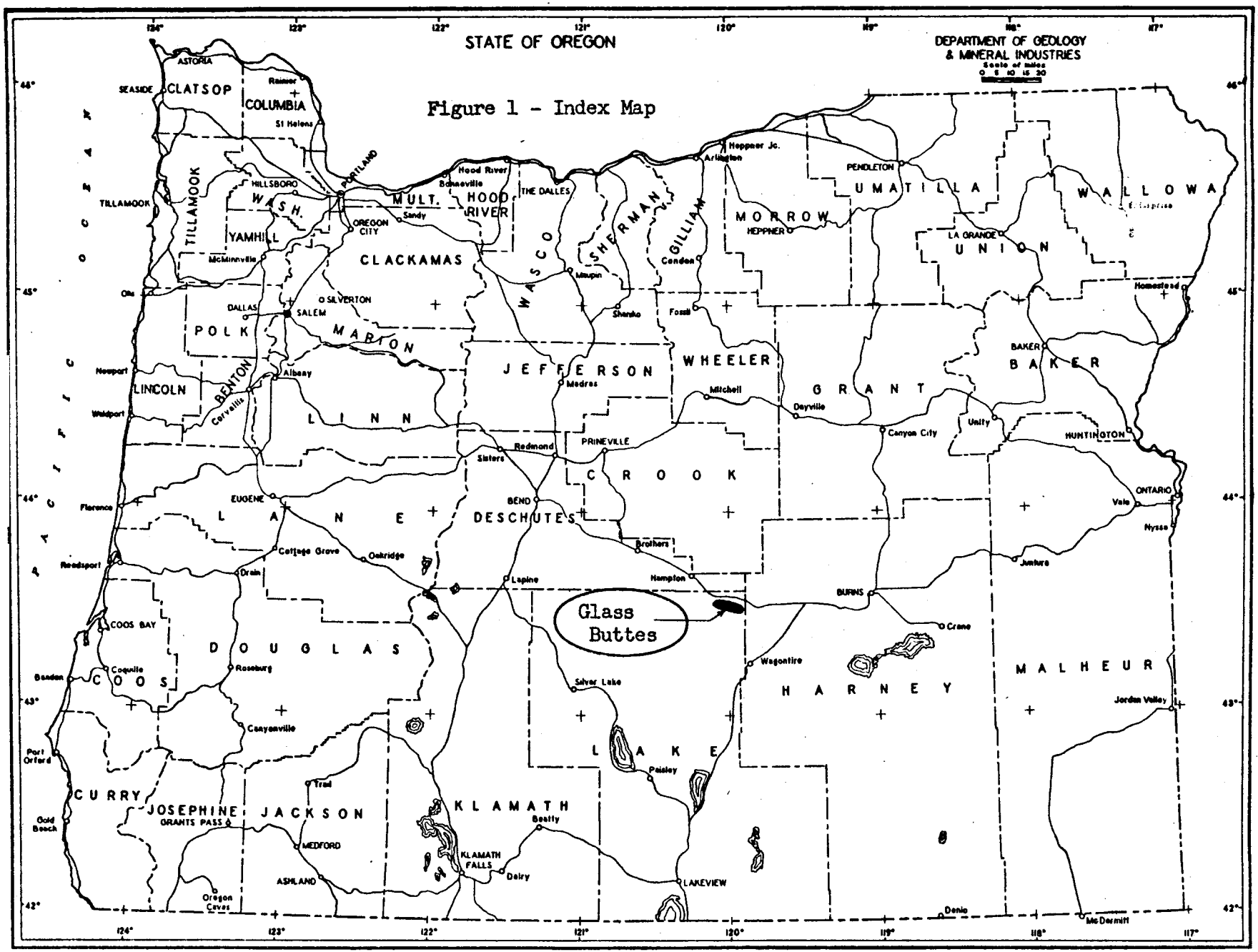
STATE OF OREGON
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Figure 1 - Index Map
Glass
Buttes
ASTORIA
SEASIDE
CLATSOP
COLUMBIA
TILLAMOOK
WASH.
MULT.
HOOD
RIVER
WASCO
SHERMAN
GILLIAM
MORROW
UMATILLA
WALLOWA
UNION
BAKER
YAMHILL
CLACKAMAS
POLK
MARION
JEFFERSON
WHEELER
GRANT
LINCOLN
BENTON
LINN
CROOK
LANE
DESCHUTES
DOUGLAS
COOS
CURRY
JOSEPHINE
JACKSON
KLAMATH
LAKE
HARNEY
MALHEUR
PACIFIC OCEAN
PORTLAND
SALEM
EUGENE
BEND
PRINEVILLE
MEDFORD
KLAMATH FALLS
LAKEVIEW
BURNS
ONTARIO
HUNTINGTON

GEOLOGY

The Glass Buttes area lies in the High Lava Plains physiographic province, a broad upland underlain by volcanic and sedimentary rocks ranging in age from Eocene to Recent. The geology of the region surrounding Glass Buttes has been mapped by Greene et al. (1972) and Walker et al. (1967). These studies show Glass Buttes to consist of silicic volcanic rocks of dacitic to rhyolitic composition. Obsidian from the silicic complex at Glass Buttes has been potasium-argon dated at 4.9 ± 0.3 million years by Walker (1974). The flanks of the range are composed of tuffaceous sedimentary rocks, basalt and andesite, all of Pliocene age and alluvium and basalt of Quaternary (?) age.

A petrographic study of Glass Buttes was made by Waters (1927) who subdivided the volcanic rocks into three periods, an initial series of basalt flows followed by a sequence of dacite and andesite termed the Glass Buttes Series and finally a sequence of younger basalt flows.

Glass Buttes lies on a major northwest-trending structural lineament of regional extent termed the Brothers fault zone (Walker, 1974). The Brothers fault zone, consisting of parallel and partly en echelon high angle faults, extends across central Oregon from the Cascade Range on the west to the Steens Mountains on the east. Recent studies have indicated that the Brothers fault zone is colinear with and possibly a portion of a more extensive lineament continuing as far southeast as central Nevada and termed the Oregon-Nevada lineament (Stewart et al, 1975). In Oregon the Brothers fault zone is marked by several centers of basaltic and silicic volcanism including Glass Buttes.

HYDROLOGY

The hydrology in the Glass Buttes area is poorly known. The static water level has been measured in seven wells (Trauger, 1950 and Pulfrey, 1975) as tabulated below.

TABLE I - GROUNDWATER DATA

Well	Collar Elevation		Section	Twp.	Range	Static water level
Woolman	4506 feet	(1373 m)	SE¼, SE¼, 13	23 S.	21 E.	240 ft. (73 m)
Pausch	4600 "	(1402 m)	SE¼, SE¼, 32	23 S.	22 E.	533 (162)
Glass Buttes	4750 ± 100 ft	(1450 m)	SW¼, NE¼, 27	23 S.	23 E.	462 (141)
Ryan	4900 ± 100	(1490 m)	SW¼ (?), 27	23 S.	23 E.	509 (155)
Pausch	4650	(1417 m)	SE¼, NE¼, 18	24 S.	22 E.	290 (88)
DeWitt	4655	(1418 m)	SW¼, NW¼, 23	24 S.	22 E.	300 (91)
Bush	4950 ± 100	(1500 m)	SE¼, SE¼, 9	24 S.	23 E.	462 (141)

Chemical data on the water from these wells are not available. The temperature gradient is known only for the Ryan well which has a linear gradient of 190°C/Km above the static level with a sharp inflection in the gradient at that level (Bowen, 1975). Below the static level the Ryan well has an irregular gradient with a bottom hole temperature of 118°F (48°C) at a depth of 721 feet (220 m). Trauger (1950) reported a water temperature of 64°F (18°C) for the Woolman well. The temperature in both the Ryan and Woolman wells is anomalously high.

GEOPHYSICS

The electrical geophysical program described herein was undertaken (1) to obtain sub-surface geologic information over the thermal anomaly detected earlier (Bowen et al, 1975), (2) to test the dipole-dipole technique in a structurally complex area marked by lateral resistivity variations and (3) to develop conceptual ideas on the type of geothermal resource present at Glass Buttes. The geophysical program consisted of 28 line-miles of electrical resistivity surveying using a dipole-dipole array with colinear electrode pairs at an "a-spacing" of 2,000 feet (610 m), separations between electrode pairs varying from 2,000 feet (n of 1) to 12,000 feet (n of 6), and a frequency of 0.125 hertz. A single Schlumberger array was used for a depth sounding designed to evaluate the thickness of a near-surface higher resistivity unit. Survey lines were generally oriented north-south and N30E-S30S, i.e., roughly perpendicular to the structural trend of the area except for line 5 which was run sub-parallel to the predominant trend of faulting in the range.

The electrical surveying was performed by Phoenix Geophysics, Inc. of Tucson, Arizona. Further details of technique, data, and interpretation are provided in a report by Phoenix Geophysics attached as Appendix A.

GEOTHERMAL ENERGY POTENTIAL

The regional geothermal energy potential of central Oregon was discussed by Groh (1966) and later by Walker (1974). Groh noted the association of Quaternary volcanism and faulting and Walker described a progressive westward decrease in the age of silicic volcanism along the Brothers fault zone, a major regional lineament which crosses the Glass Buttes area. The Glass Buttes thermal anomaly was described briefly by Bowen et al (1975).

The Glass Buttes geothermal anomaly is poorly defined and the nature of the heat source and heat transfer mechanism are problematical. Geothermal systems are conceptually described as (1) hydrothermal convection systems (2) hot igneous systems or (3) conduction-dominated areas (White and Williams, 1975). Hydrothermal systems are further sub-divided into vapor-dominated and hot water dominated systems and the hot igneous systems may be either partly molten or hot dry rock systems. An understanding of the nature of a geothermal system is desirable for the design of efficient exploration to evaluate the system and ultimately is needed for reaching conclusions regarding the energy production potential of a system. Smith and Shaw (1975) included Glass Buttes in an evaluation of igneous-related geothermal systems of western United States. Based on estimates of age, magma volume and cooling rates, they concluded that Glass Buttes possibly had residual magmatic heat and noted that further study was needed.

There are no active hot springs or fumeroles in or near the Glass Buttes area possibly a reflection, in part, of a relatively deep water

table. Published temperature gradient data at Glass Buttes consists of a single hole located in the SW¼ (?), section 27, T. 23 S., R. 23 E. at the Glass Buttes mercury mine. A gradient of 190° C/km was measured in this well as described above.

Glass Buttes has been the site of past hydrothermal activity as evidenced by the presence at the east end of the range of pervasive rock alteration and low grade mercury mineralization (Brooks, 1963 and Ross, 1941). The alteration includes argillization and opalization of the silicic volcanic host rocks with cinnabar mineralization localized along northwest striking fractures and breccia zones which are parallel or sub-parallel the regional trend of the Brothers fault zone.. The low resistivity values (less than 5 ohm-meters) detected by the dipole-dipole surveying suggest that at least a portion of the Glass Buttes area could be underlain by a hot water system; however, the geophysical data are only permissive in this respect. If the high geothermal gradient in the Ryan well is due to convecting groundwater, the pattern of lower resistivity zones may be partly or wholly an expression of relatively low termperature fluid rather than any high temperature geothermal resource.

The zone of 30-60 ohm-meter resistivity values detected between stations 220 E and 300 E on line 5 could be a less permeable unit such as a shallow intrusive body extending to depth. Temperature gradient data are lacking for this resistivity unit but it represents a potential hot dry rock target which might be tested by shallow gradient drilling. The resistivity contrasts may be partly due to hydrothermal alteration as argillic alteration is both intensive and extensive in the eastern portion of the survey area.

CONCLUSIONS AND RECOMMENDATIONS

The present study indicates that the dipole-dipole technique can provide useful sub-surface information in evaluating a structurally complex volcanic area such as Glass Buttes.

The resistivity results suggest that the lithologic units at Glass Buttes are generally horizontal or sub-horizontal in the survey area with steep contacts between units. The contrast between the high resistivity surface layer and the much lower resistivity underlying material is likely due to a combination of geologic and hydrologic factors.

The existence of an abnormally high geothermal gradient at Glass Buttes may be due to (1) residual magmatic heat associated with igneous activity, (2) deep convection of groundwater perhaps along fault zones, or (3) a combination of these factors. If the heat source is magmatic, it is still not certain whether the geothermal system is a hot dry rock system, a hot water system, a vapor-dominated system, or a combination of these types. The limited geophysical data collected to date do not conclusively provide a basis for selecting among these alternatives. It is entirely possible that the anomalously high temperature gradient in the Ryan well is due to deep circulation of groundwater and may not represent significant geothermal energy potential.

Further investigation of the Glass Buttes geothermal anomaly will ideally require several approaches. Additional temperature gradient and heat flow data are needed to evaluate the resistivity variations detected during the present geophysical study. Geochemical geothermometry on sub-surface fluids is desirable but interpretation of silica geothermometry

should take into consideration the opalite alteration associated with mercury mineralization and the widespread volcanic glass. Additional resistivity surveying is needed including more detailed evaluation of the near surface high resistivity layer. Detailed geologic mapping to constrain future geophysical interpretations is essential. Ultimately expensive deep drilling will be required to test the geothermal potential of the Glass Buttes area but additional geological, geochemical and geophysical work and shallow temperature gradient drilling are needed before the deeper drilling could be justified.

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APPENDIX

PHOENIX GEOPHYSICS INC.

REPORT ON A

RECONNAISSANCE DIPOLE-DIPOLE RESISTIVITY SURVEY

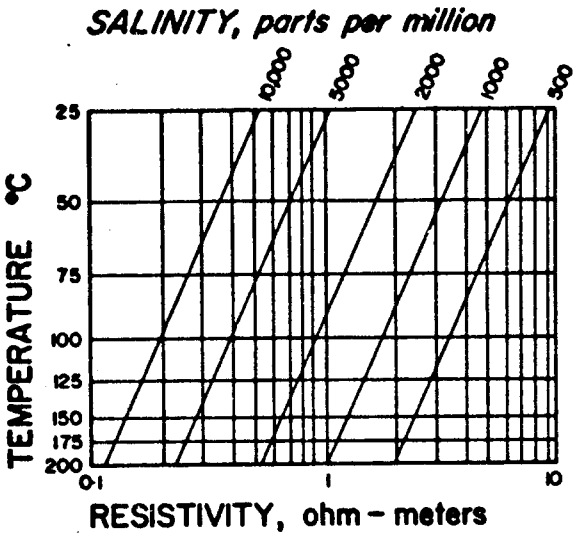
IN THE

GLASS BUTTES AREA

LAKE COUNTY, OREGON

FOR

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

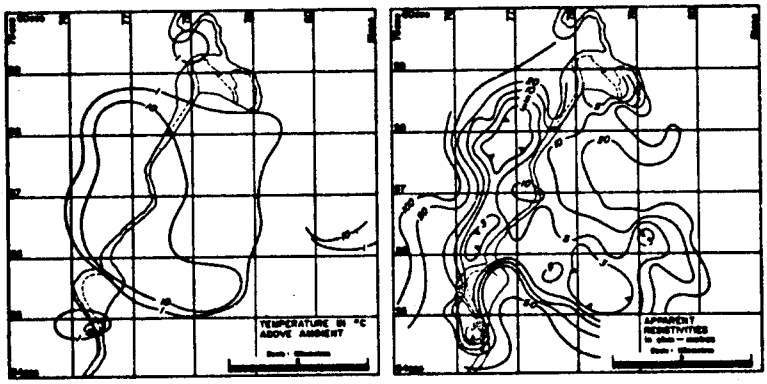


VARIATIONS OF SOLUTION RESISTIVITY
WITH TEMPERATURE AND SALINITY

FIG. 1

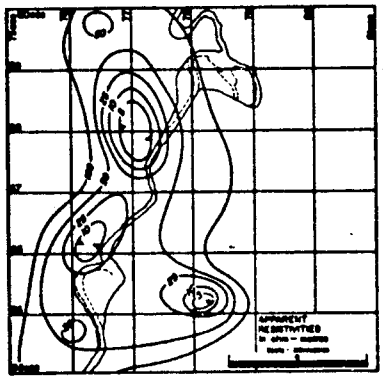
GEOPHYSICAL SURVEY

BROADLANDS AREA, NEW ZEALAND



A. TEMPERATURE AT 15m DEPTH

B. APPARENT RESISTIVITY SURVEY USING WENNER CONFIGURATION A = 180m.



C. APPARENT RESISTIVITY SURVEY USING LOOP TO LOOP ELECTROMAGNETIC METHOD

FIG. 2

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NOTES ON GEOTHERMAL EXPLORATION USING THE RESISTIVITY METHOD

Many geophysical methods have been tried in the exploration for geothermally "hot" areas in the upper regions of the earth's crust. The only method that has been consistently found to be successful has been the resistivity technique. In this geophysical method, the specific resistivity (or its reciprocal, the specific conductivity) of the earth's subsurface is measured during traverses over the surface.

The principle of the technique is based on the fact that the resistivity of solution-saturated rocks will decrease as the salinity of the solutions is increased and/or the temperature of the system is increased (see Figure 1). Therefore, volumes of the earth's crust that contain abnormally hot and saline solutions can often be detected as regions of low resistivity.

The resistivity measurements are usually made using grounded current and potential electrodes, but some useful data can sometimes be obtained using electromagnetic techniques. The field data shown on plan maps in Figure 2 are from the Broadlands Area in New Zealand; in this area there are substantial flows of hot water and steam at the surface.

The results show resistivity lows measured with a Wenner Configuration Resistivity Survey and a loop-loop electromagnetic survey. The anomalous pattern is much the same in both cases and the regions of low resistivity correlate well with the areas of increased rock temperature.

If the rock volume saturated with hot solutions does not extend to the surface it will be necessary to use large electrode intervals to detect the resistivity lows. The resistivity data shown in "pseudo-section" form in Figure 3 is from Java. Along this line there are two deep regions of low resistivity detected for the larger electrode intervals used. Zone A is associated with surface manifestations of geothermal activity. The source of the resistivity low at Zone B is unknown.

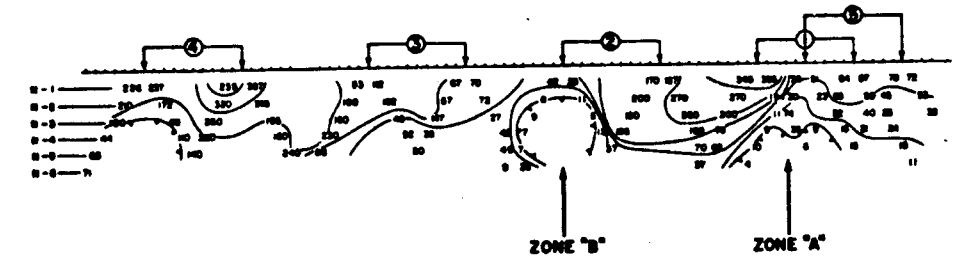
If the abnormally hot region occurs in a sedimentary basin, the general resistivity level can be quite low, due to the high porosity in normal sediments. This is the case in the Imperial Valley of California. The resistivities shown in Figure 4 are from an area near El Centro, California. The largest electrode separation used was 12,000 feet.

The results show a two-layer geometry with the upper layer having a thickness of approximately one-half electrode interval (i.e. 1,000 feet). The resistivity in the upper layer is 3.0 ohm-meters; the resistivity of the lower layer is 1.5 ohm-meters. Due to the small resistivity contrast, additional measurements would be necessary to determine the possible geothermal importance of the lower resistivity layer at depth.

The results shown in Figure 4 are from a dipole-dipole electrode configuration survey. Our dipole-dipole data is plotted as a "pseudo-section" for several values of n; the separation between the current electrodes and potential electrodes, as well as the location of the electrodes along the survey line, determine the position of the plotting point. The two-dimensional array of

APPARENT RESISTIVITY SURVEY, DIENG PLATEAU AREA, JAVA, INDONESIA

Pseudo Section Plotting Method Along Dieng–Batur Road



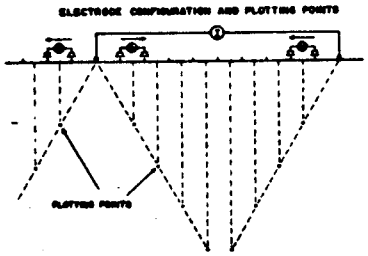
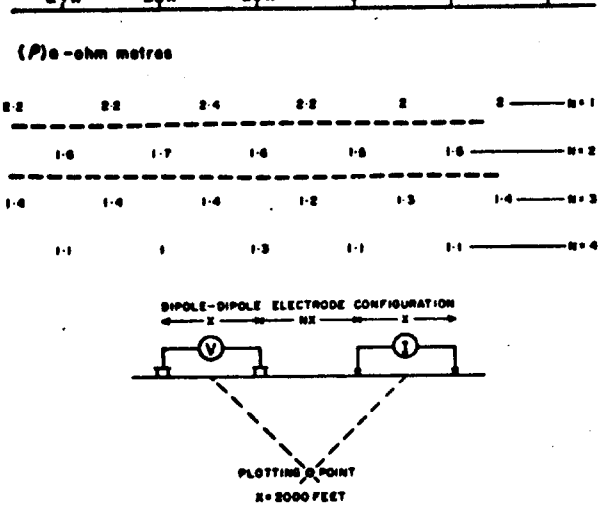


FIG. 3

RESISTIVITY SURVEY, IMPERIAL VALLEY–CALIFORNIA.

LINE–"O", FREQUENCY–0·125 Hz.



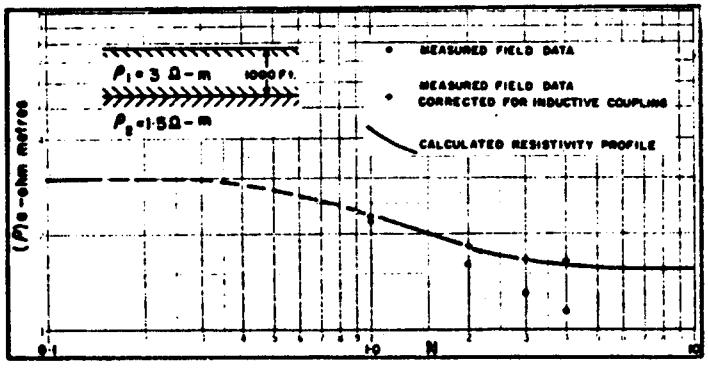
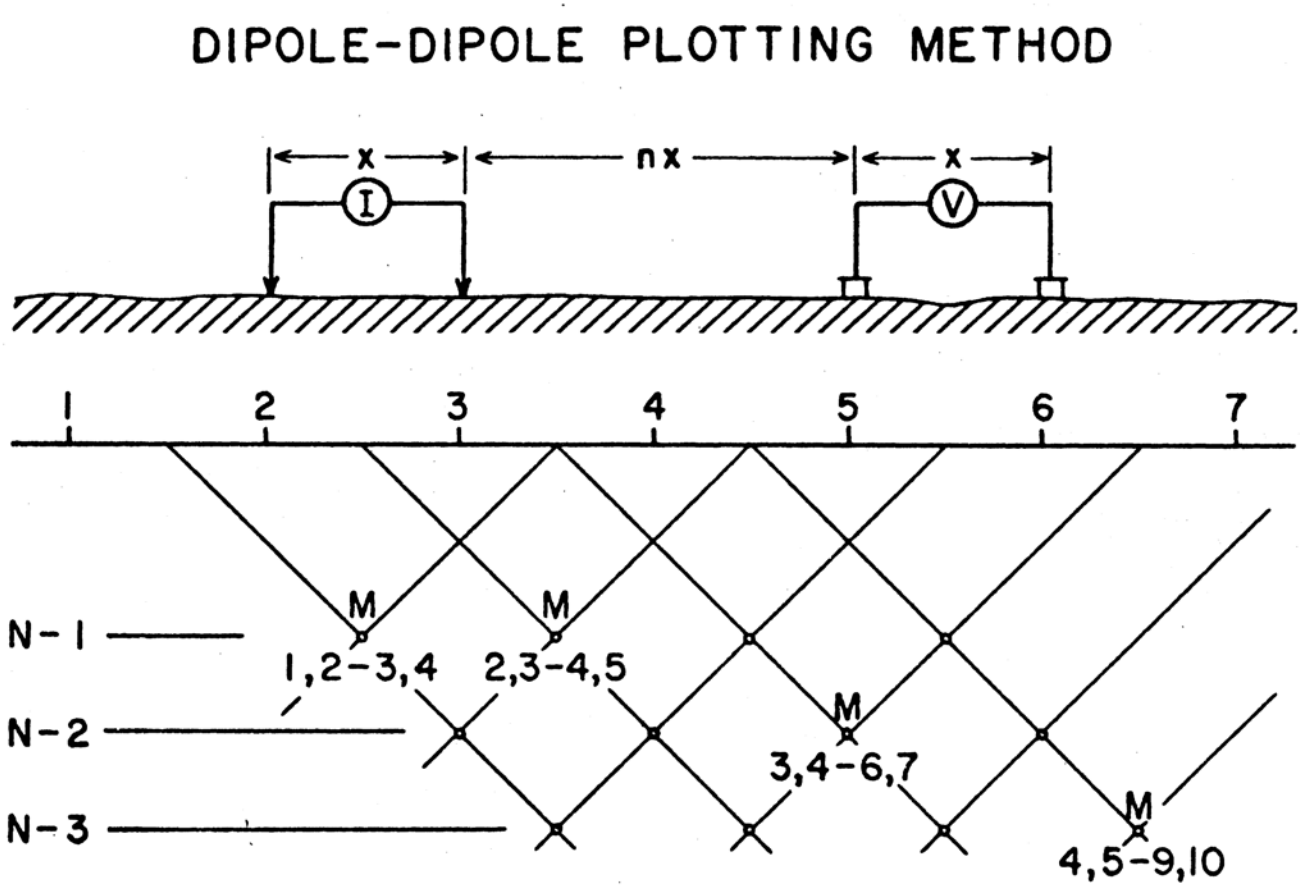


FIG. 4

data is then contoured (see below). The contour plots are not sections of the



electrical properties of the earth; they are convenient graphical representations of the measurements made. However, with experience the contour patterns can be interpreted to give some information about the source of the anomaly.

If the contour patterns indicate very simple geometries, more quantitative interpretations can often be made. For instance, if the contours are horizontal for a lateral distance of four to six electrode intervals, a horizontally layered geometry is indicated. In this situation, theoretical type-curves for dipole-dipole measurements in a layered geometry can be used in "curve fitting" techniques to give the true resistivities and depths for the earth.

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INTRODUCTION

At the request of Mr. Donald Hull, geologist with the Oregon Department of Geology and Mineral Industries, Phoenix Geophysics has completed a Reconnaissance Dipole-Dipole Resistivity Survey in the Glass Buttes area, Lake County, Oregon. The survey area is located in T23S, T24S and R22E, R23E and R24E of Lake County.

The Glass Buttes area is reported to be underlain by Recent volcanics. There are no surface manifestations of thermal activity but previous investigations by the Oregon Geological department indicates this area may have geothermal potential.

The purpose of the Reconnaissance survey was to locate and delineate low resistivity zones that might indicate areas of concentrated thermal activity. Measurements were made with 2000 foot dipoles at one-through-six dipole separations along four widely spaced lines. A frequency of 0.125 Hz was used in order to minimize attenuation of electric field due to eddy current dissipation of energy and at the same time avoid telluric noise.

The survey was conducted by Mr. Robert Anderson, geophysicist, under the supervision of Mr. Donald Hull.

PRESENTATION OF RESULTS

The resistivity survey results are shown on the following data plots in the manner described in the notes which accompany this report.

Line	Electrode Intervals	Dwg. No.
0(test)	2000 feet	R-U-5010-1
1	2000 feet	R-U-5010-2
3	2000 feet	R-U-5010-3
5	2000 feet	R-U-5010-4

Included on each data plot is an interpreted true resistivity section of the survey data. These sections have been compiled with the aid of two-dimensional theoretical curves, three dimensional model studies and a computer program for the direct inversion of apparent resistivity data for layered media.

Also enclosed with this report is Dwg. No. RP-U-5010, a plan map of the survey area at a scale of 1" = 2000' showing the location of the survey lines. The definite, probable and possible Resistivity low anomalies are indicated by bars, in a manner shown in the legend, on the plan map as well as on the data plots. These bars represent the surface projection of the anomalous responses as interpreted from the location of the transmitter and receiver electrodes when the anomalous values were measured.

Since the Resistivity measurements is essentially an averaging process, as are all potential methods, it is frequently difficult to exactly pinpoint the source of an anomaly. Certainly, no anomaly can be located with more accuracy than the electrode interval length. In order to locate sources at some depth, larger electrode intervals must be used, with a corresponding increase in the uncertainties of location. Therefore, while the center of the indicated anomaly probably corresponds fairly well with source, the length of the indicated anomaly along the line should not be taken to represent the exact edges of the anomalous material.

The anomalies shown on the plan map are designated apparent depths of shallow, moderate, or deep. At larger dipole separations a greater volume of rock is averaged, in lateral extent as well as depth. Thus, the source of a deep-appearing anomaly detected along a single line may be at shallow depth to one side of the line. The data plots, therefore, cannot represent true depth. Depths can be calculated from the apparent resistivity data in the case of ideal horizontal layers, but even this calculation depends on an assumed resistivity contrast between the zone at depth and the overlying rock. Although ambiguous, the following simple depth designations are useful for correlating or comparing anomalous zones obtained on adjacent survey lines.

	Apparent Depth (dipole separations)	Drill Hole Depth (in dipole lengths)
Shallow	1 - 2	1/2 - 1
Moderate	2 - 3	1 - 1-1/2
Deep	3 - 5	1-1/2 - 2+

Thus, a shallow zone is one detected at a one-to-two dipole separation and should be tested by a drill hole from a half-to-one dipole length deep.

DISCUSSION OF RESULTS

The dipole-dipole resistivity survey of the Glass Buttes area has been conducted along three widely spaced, generally north-trending lines and one east-west line. It is normally quite difficult to correlate data along near parallel lines when these are so widely spaced and also difficult to correlate data on intersecting lines when one line possibly parallels the geologic trend and the other line traverses this trend. However, definite low-resistivity anomalous responses have been located during this survey which could be grossly projected to cover an area of approximately 12 square miles centered beneath Glass Buttes.

Generally the anomalies have a true resistivity less than five ohm meters and are overlain by a comparatively high resistivity layer varying in thickness from 300 feet to 2000 feet. A Schlumberger depth sounding on Line 0 indentifies two high-

resistivity surface layers having a total thickness of approximately 650 feet. These two layers cannot be differentiated in the dipole-dipole data when employing a 2000 foot separation.

A discussion of the survey results along each line follows:

Line 0 (Test)

The portion of this line, north of station 60S, was surveyed during a short test in September 1975, to determine if the dipole-dipole technique could efficiently and effectively detect resistivity variations in the Glass Buttes area. The original data is reproduced herein along with the extension of this line to the south.

A near surface resistivity high occurs between 60N and 80S, which reportedly is coincident with recent rhyolitic flows. This suspected flow is approximately 1000 feet thick between 40N and 40S and exhibits either a physical change in electrical properties or an increased thickness between 60S and 80S. This flow material is also evident between 140S and 160S and it may also be exposed on the surface between 80S and 140S but has an undetectible thickness (ie less than 400 feet thick) for 2000 foot dipole separations.

The rock type underlying the suspected rhyolite has a comparatively uniform resistivity of approximately 20 ohm meters. Since geothermal areas universally, have a true resistivity of less than 10 ohm meters, this area cannot be considered economically important, but it may be indicative of an area of inactive thermal conditions in the subsurface.

A resistivity contact occurs in the vicinity of 100N with less than 15 ohm meter material occurring to the north. The shallow depth possible anomaly between 100N and 120N represents less than 10 ohm meter material which may warrant additional work. If the resistivity contact in the vicinity of 100N actually represents a fault, the near-surface possible anomaly may represent thermal fluids ascending the fault.

A shorter interval dipole survey would better define this anomaly.

Another resistivity contact occurs in the vicinity of 80S which may also represent a fault, however, no low resistivity responses are associated with this proposed fault.

The resistivity low occurring at depth beneath 40N and 60N probably represents an area of low resistivity to the side of this line. This appears to be a typical "bull's eye" response that represents an "off the end" anomaly.

A Schlumberger depth sounding was completed on this line centered on station 0. The data and interpretation of this sounding are shown on Figure 1. The best fit for this data with theoretical curves indicates a three layer geometry having a resistivity contrast of 1 : 3 : .1 with the upper layer having a true resistivity of 315 ohm meters. Data supplied by Mr. Donald Hull indicates that the total thickness of the upper two layers appears to correspond with the depth to the water table in this area.

Line 1

This line, surveyed along the west side of the area of interest was suspected to provide only a background response. Near surface resistivity highs are again present along this line but a moderate to deep, definite anomalous response occurs at 40S to 90S and is open beyond the south end of the line. This anomaly appears deeper between 40S and 30N but is interpreted only as a possible anomaly between 40S and 10N.

The true resistivity of the definite anomalies is approximately five ohm meters.

Line 3

Low-resistivity anomalies have been located along this line from 0 to at least 260N and may possibly extend beyond 260N.

The generalized resistivity cross-section idicates that the near surface high-resistivity layer varies in magnitude and thickness along this line. This layer

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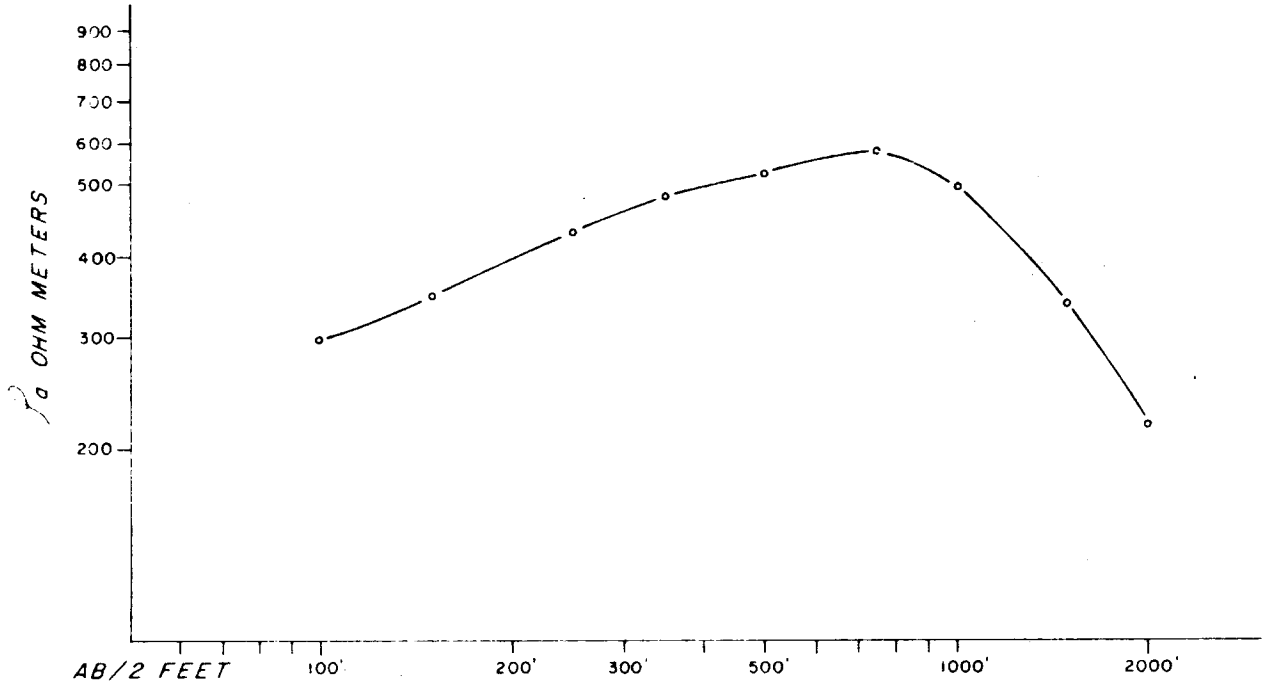
SCHLUMBERGER DEPTH SOUNDINGS



CALCULATED THICKNESS AND RESISTIVITY

THICKNESS IN FEET	RESISTIVITY ρa-OHM METERS
H_1 = 125'	ρ_1 = 315
H_2 = 525'	ρ_2 = 945
H_3 = ∞	ρ_3 = 31.5

FREQUENCY: 0.125 HZ. *DATE SURVEYED: NOV, 1975*

LINE 0

OREGON DEPARTMENT OF GEOLOGY & MINERAL INDUSTRIES

GLASS BUTTES AREA, LAKE COUNTY, OREGON

FIGURE 1

could possibly have a fairly uniform true resistivity and vary in thickness more prominently than has been interpreted. Geological investigations in this area could determine if a uniform layer exists in this area.

Some of the lowest resistivity measurements obtained during this survey occur on this line between 40N and 120N at depth. The true resistivity of this definite anomaly is shown as less than five ohm meters but probably this response is as low as two ohm meters. This anomaly definitely warrants additional work which may include drilling.

The interpreted definite anomaly located between 210N and beyond 260N is at shallow to moderate depth and underlain by higher resistivity material. Temperature gradient holes in this area may determine if this anomaly represents a geothermal source.

The moderate depth anomaly located between 160N and 180N appears to be an off-the-end response which may require further investigation since the true resistivity is less than five ohm meters.

There is a slight indication that a high resistivity layer exists at depth (at least 4000 feet deep) between 140N and 240N. This deep layer is not shown on the generalized section because its true resistivity is undeterminable.

Line 5

A broad definite anomaly, with a true resistivity of less than five ohm meters occurs at moderate depth from 110E to beyond 100W. This anomaly is again overlain by a high resistivity layer of varying thickness which exhibits a wide variation in electrical properties. The anomaly also exhibits some resistivity variations and the most conductive responses are located between 0 and 20W and 30E to 70E at moderate depth.

The east end of the line, east of 140E, is unanomalous and could be considered to represent background response in this area.

The resistivity high at moderate depth beneath 240E to 260E is an oddity and could possibly represent an intrusive plug. A similar response, located on Line 0 beneath 140S to 160S did not exhibit any continuity with depth, but this deep-seated resistivity high may represent an area of high heat flow. Additional work in this area appears warranted.

CONCLUSIONS AND RECOMMENDATIONS

The reconnaissance dipole-dipole survey of the Glass Buttes area has located several definite low-resistivity anomalies which may represent an area of increased thermal activity encompassing approximately 12 square miles and centered beneath Glass Buttes. The anomalous responses have a true resistivity of less than five ohm meters which is approximately three to four times lower than background resistivities in this area.

Generally the entire survey area is underlain by a near-surface high resistivity layer with varying thicknesses between 300 feet to 2000 feet. This layer probably represents recent volcanic flows which may form an impermeable cap over the proposed thermal area and explain the absence of any surface manifestations.

The apparent resistivity data plots show at several locations within the anomalous responses that the N=6 measurement is higher than the N=5 measurement. This suggests that the anomalous response is underlain by a layer of higher resistivity and thus restricted in depth extent. However, this deep high-resistivity layer is probably at a depth greater than 4000 feet, and this allows the anomalous source to have a maximum thickness of approximately 3000 feet.

Additional work in this area is warranted.

Several temperature gradient holes should be considered in the area of the anomalous resistivity response shown on the plan map RP-U-5010. If increased temperature gradients are observed, several additional resistivity survey lines should be considered to more accurately outline the area of low resistivity.

Upon completion of the recommended additional work, a complete correlation of all available geology, geochemistry and geophysics should be undertaken prior to the selection of a drill hole location to test the anomalous areas. If a test well is immediately considered, the resistivity survey results indicate that the most conductive areas within the anomalous responses are located on Line 3 between 40N and 120N, Line 5 between 30E and 70E and on Line 5 centered at station 0.

This report is respectfully submitted for your consideration.

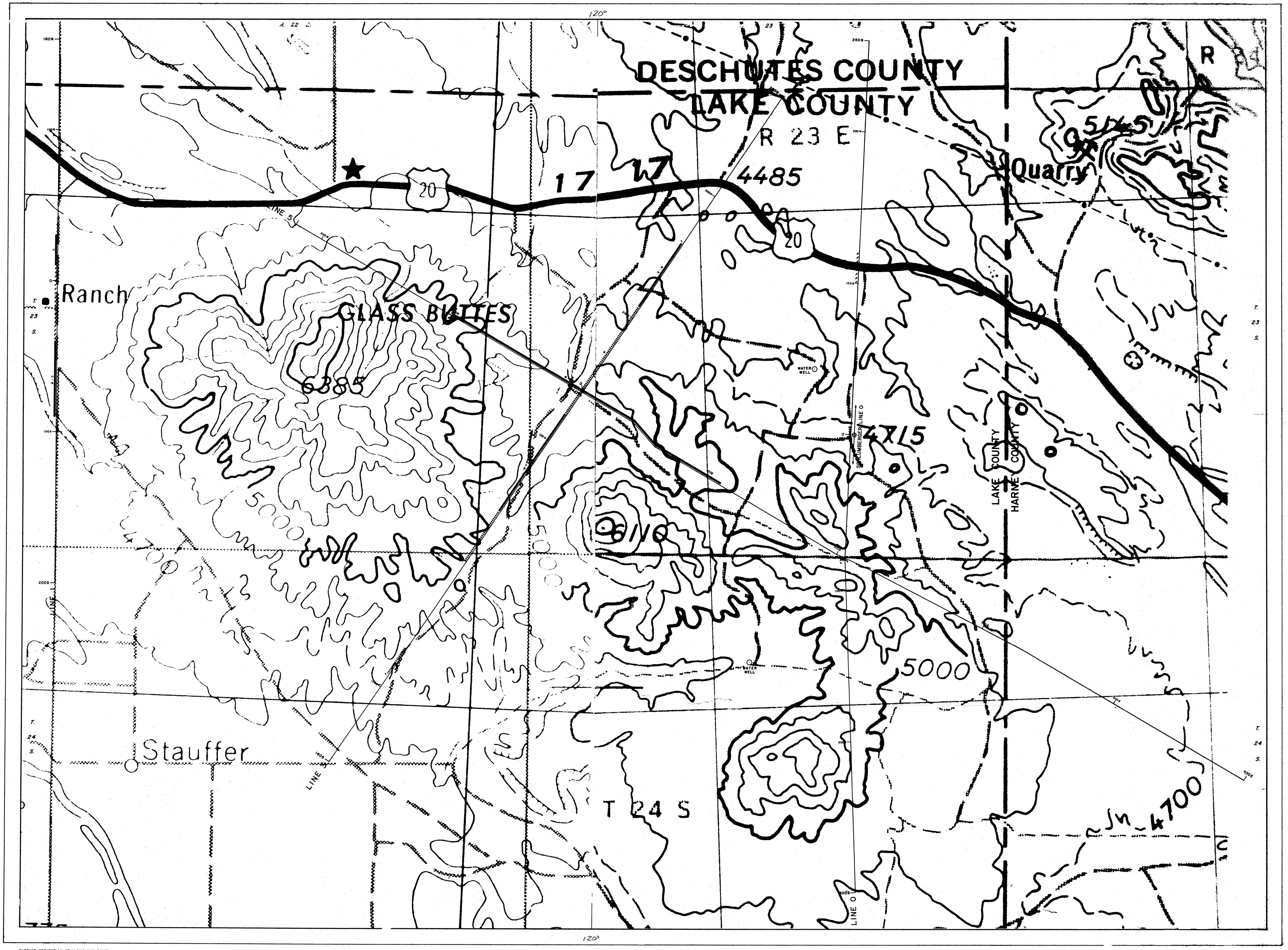
PHOENIX GEOPHYSICS INC.

Bruce S. Bell
Geologist

Dated: December 12, 1975

PHOENIX GEOPHYSICS

RESISTIVITY SURVEY
PLAN MAP



SURFACE PROJECTION OF ANOMALOUS ZONES

DEFINITE
PROBABLE
POSSIBLE

APPARENT DEPTH

S = shallow
M = moderate, D = deep
C = contact, F = fault

OREGON DEPARTMENT OF GEOLOGY & MINERAL INDUSTRIES

GLASS BUTTES AREA, LAKE COUNTY, OREGON

SCALE

FEET 2000 0 2000 4000 6000 8000 10,000 FEET

1 INCH EQUALS 2000 FEET (APPROX.)

DWG. RP-1J-5040

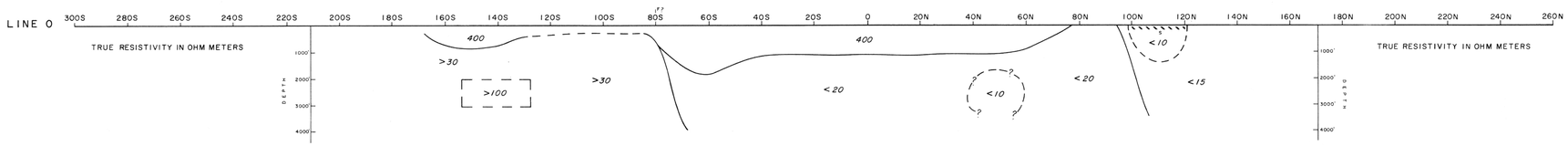
DWG. R-U-5010-X

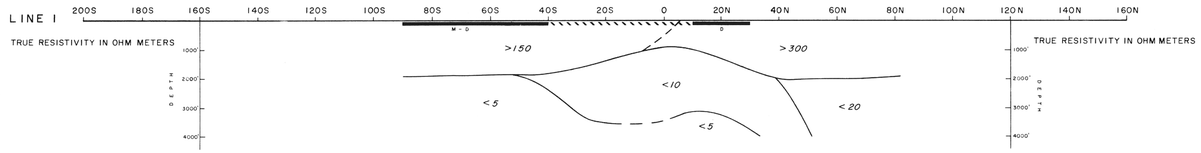
PHOENIX GEOPHYSICS

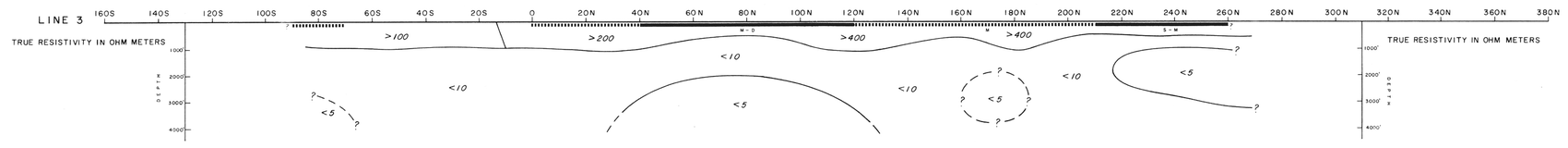
RESISTIVITY SURVEY

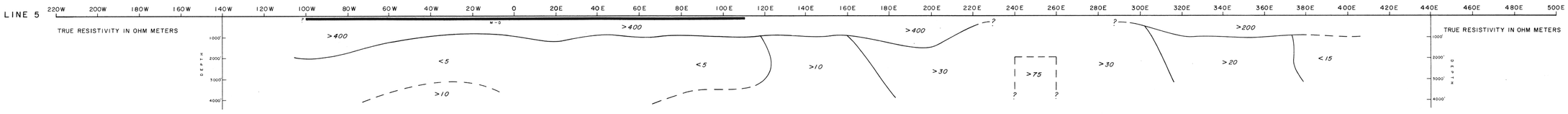
GENERALIZED RESISTIVITY SECTIONS

O-76-01









SURFACE PROJECTION OF ANOMALOUS ZONES

DEFINITE ——————

PROBABLE ,,,,,,,,,,,,,,,,

POSSIBLE \ \ \ \ \ \ \ \

OREGON DEPARTMENT OF GEOLOGY & MINERAL INDUSTRIES

GLASS BUTTES AREA, LAKE COUNTY, OREGON

SCALE

FEET 2000 0 2000 4000 6000 8000 10,000 FEET

1 INCH EQUALS 2000 FEET

DATE SURVEYED: NOV., 1975

APPROVED: Donn S. Vickerman

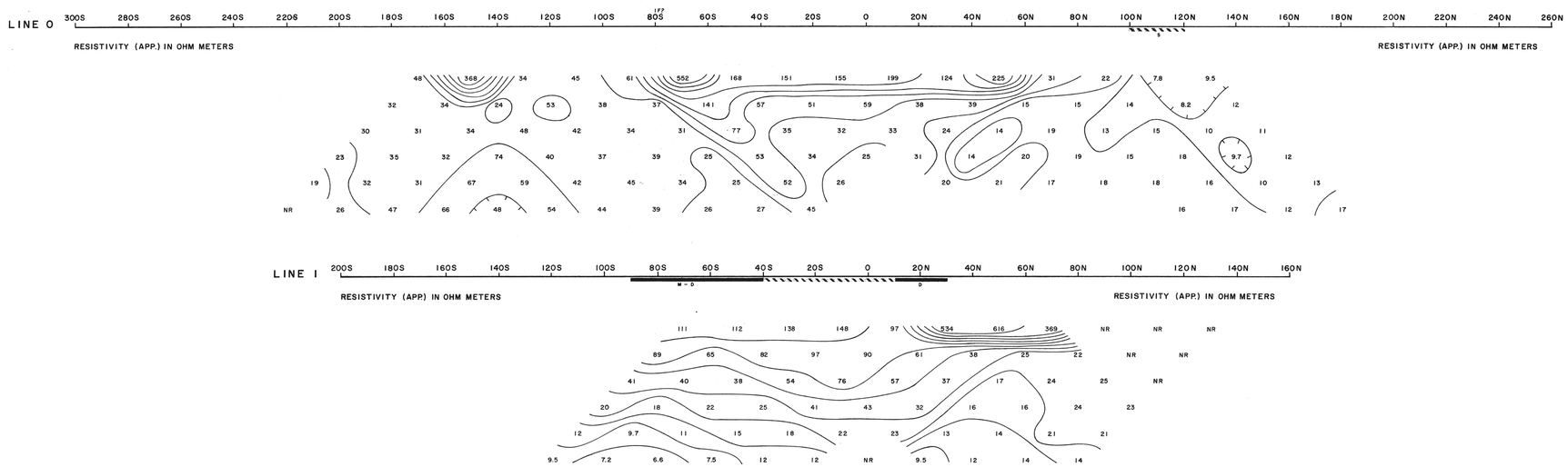
DATE: 12/12/75

DWG. R.-U.-5010-X

PHOENIX GEOPHYSICS

RESISTIVITY SURVEY

PSEUDOSECTIONS



SURFACE PROJECTION OF ANOMALOUS ZONES

DEFINITE

PROBABLE

POSSIBLE

FREQUENCY: 0.125 HZ.

NOTE: CONTOURS AT LOGARITHMIC INTERVALS 1. - 1.5 - 2. - 3. - 5. - 7.5 - 10

OREGON DEPARTMENT OF GEOLOGY & MINERAL INDUSTRIES

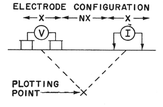
GLASS BUTTES AREA, LAKE COUNTY, OREGON

SCALE

FEET 2000 0 2000 4000 6000 8000 10,000 FEET

1 INCH EQUALS 2000 FEET

ELECTRODE CONFIGURATION



DATE SURVEYED: NOV, 1975

APPROVED: Bruce S. Rice

DATE: 12/12/75