STATE OF OREGON
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PRELIMINARY GEOLOGY AND GEOTHERMAL RESOURCE POTENTIAL OF THE ALVORD DESERT AREA, OREGON

by

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1980

DISCLAIMER

This report has not been edited for complete conformity with Oregon Department of Geology and Mineral Industries standards. Data in this document are preliminary and are subject to change upon further verification.

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INTRODUCTION

The Alvord Valley is a complex, sinuous, elongate north-to-northeast trending graben valley in the northeastern part of the Basin and Range province in southern Harney County, southeastern Oregon (Figure 1). It is roughly 70 miles long and has a maximum width of about 10 miles near the Alvord desert. The broad, flat valley (4,040 ft elevation) is bounded on the west by an impressive tilted fault block mountain belt (Pueblo and Steens Mountains) where elevations reach 9,760 ft along a steep, eroded escarpment. The southern part of the valley extends into Nevada and some maps call this part the Pueblo Valley. To the southeast, the valley is bounded by the Trout Creek Mountains (7,800 ft) and to the northeast by lower elevation rolling hills and plateaus more typical of the Owyhee Upland topography. At the extreme north and northeast on the Harney-Malheur County border, the valley narrows and merges into the Sheephead Mountains.

The valley is essentially flat with interior drainage toward two ephemeral lakes, Tum Tum at the south end and Alvord in the central portion, which are only a few feet deep and have areal extent which vary with seasonal rainfall and stream flow. A larger playa called the Alvord Desert covers about 250 km^2 in the north-central part of the valley.

This part of southeastern Oregon has a semi-arid climate with wide variations in temperature. The necessity of irrigation and short growing limits agriculture to hay and grain. The most important industry is cattle grazing. Population density in this remote area is very low, less than 1 per square mile, and there are only two small settlements other than isolated ranches, Denio on the Nevada border at the extreme south end of the valley, and Fields, 20 miles north of Denio.

The part of the Alvord Valley geothermal area evaluated for this report is

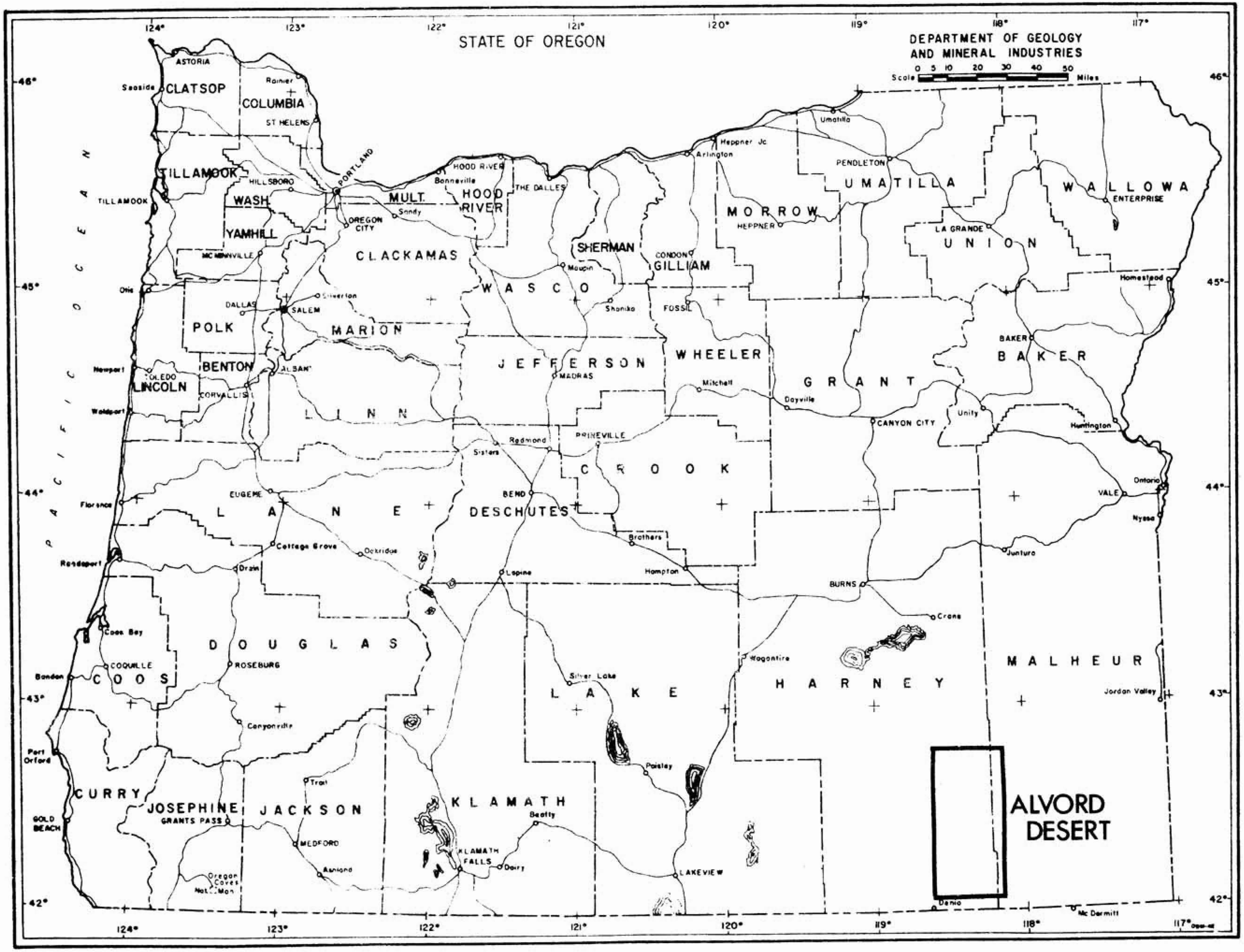

Figure 1: Map showing location of study area.

covered by the Adel AMS quadrangle, 1:250,000 and by ten 7½ (1:24,000) United States Geologic (USGS) topographic maps: Fields, Borax Lake, V Lake, Andrews, Alvord Hot Springs, Wildhorse Lake, and the Alberson, N.E., N.W., S.W., and S.E. The area covers about 550 square miles (1,430 km^2) and includes all of the Alvord Valley north of Fields; the Steens Mountain escarpment as far north as Wildhorse Lake and the northeast branching valley that includes Mickey Spring near the Harney-Malheur County line.

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GEOLOGY

Introduction

The geologic map in Plate I has been taken directly from the Walker and Repenning (1965) reconnaissance map of the Adel AMS sheet. Ten days were spent in the Alvord Valley field-checking areas where the geology is complicated or where structural relationships are not clear. Some samples were taken for K/Ar dating as well, but these data are not, as yet, available.

Volcanic stratigraphy

Regional studies and other reports on the area to the south and west of the Alvord Valley show the basement rocks to be an assemblage of Paleozoic and Mesozoic metamorphic and granitic intrusive rocks. Moderate to steeply dipping Permian and Triassic metamorphic rocks include quartzites, graywacke sandstone, greenstone, sericite schist, quartz-muscovite schist, argillite, and minor marble. Cretaceous-age gneissic granodiorite and quartz diorite are intrusive into the metamorphic rocks.

In the study area, the rocks are all volcanically derived and of Miocene and younger age. As pointed out by Williams and Compton (1953) and Avent (1969), a truly impressive display of Tertiary volcanic rocks is exposed in the eastern escarpment of the Steens Mountains. Baksi (1967) has suggested that it may be one of the world's largest single exposures of successive Tertiary lavas. Fuller (1931) was the first to describe the sequence in detail, and he divided them as follows:

(1) The oldest, a sequence of light-colored, fossiliferous silicic tuffs and sediments, claystone, opaline chert, and conglomerate in thin to thick beds totalling 500 to 800 feet and named the Alvord Creek Formation. There has been much controversy about the age of the Alvord Creek Formation, but K/Ar dates of 21 m.y. by Evernden (1964)

Formation. There has been much controversy about the age of the Alvord Creek Formation, but K/Ar dates of 21 m.y. by Evernden (1964) and the determination that the Steens lava flows are all pre-Pliocene have established a lower Miocene age for the Alvord Creek Formation.

(2) Overlying the Alvord Creek Formation are rhyolite and dacite flows, ash-flow tuff, and interbedded tuffs and breccia totalling 1,000 to 1,500 ft thick. These rocks are named the Pike Creek Formation.

K/Ar age data have established a lower to middle Miocene (?) age for the Pike Creek rocks. Additional rock samples are being analyzed for this study to confirm this age.

(3) The next youngest part of the sequence comprises two locally extensive and thick (900 ft+) andesite flows with spectacular columnar jointing overlain by thin andesite and basalt flows and clastic material of variable thickness. Fuller (1930) called these rocks the Steens Mountain Andesitic Series. The relationship of this assemblage (total thickness $\sim$2,000 ft) with the underlying Pike Creek and Alvord Creek Formations is not certain; however, it has been assigned a late Miocene age.

(4) Unconformably above the irregular andesitic flows and pyroclastic rocks of the Steens Mountains series are thick sections of the Steens Basalt. The Steens Basalt consists of as much as 5,000 ft of thin, regularly bedded flows of porphyritic to aphyric olivine tholeite to high alumina basalt. Most workers now agree that the Steens Basalt section was erupted regularly and rapidly over a short period of geologic time during the late Miocene from local fissure vents. K/Ar dates of 14.5 m.y. to 16 m.y. indicate that the Steens Basalt is a lateral time equivalent of part of the

Columbia River Basalt Group.

(5) Minor amounts of rhyolite and dacite flows and ash-flow tuffs are present above the Steens Basalt. These are shown as *Ttr* on the geologic maps. Their age is not known, but is probably late Miocene or early Pliocene.

East of the Alvord Valley the structural and topographic elevation of the fault blocks decreases so that younger volcanic rocks mantle the early Tertiary section. However, at the northeast end of the valley, Steens Mountain Basalt is still the prominent rock type. Walker and Repenning (1965) show the Steens Basalt dipping to the south and successively overlain by *Taf*, a series of platy andesite flows and flow breccia; *Ttr*, ash-flow tuff and rhyolite-dacite masses; *Tst*, tuffaceous siltstone, sandstone, and conglomerate; and *Tb*, dark gray dense mesa capping basalt flows. All of these heterogenous volcanic rocks are probably of late Miocene and Pliocene age.

The mountain flanks and basin are draped and filled with a variety of Plio-Pleistocene and Holocene alluvium. The oldest of this kind of deposit (*QTst*) is present near Fields to the south, and occurs as tilted, uplifted, low rolling hills adjacent to the mountain fronts. The deposits are chiefly massive to crudely layered, somewhat consolidated, colluvium and conglomerate. Avent (1965) described this poorly sorted, crudely stratified sedimentary unit in detail and proposed the name Tum Tum Conglomerate. An age of middle to latest Pliocene has been suggested. Landslide debris (unit *Qls*) along the base of mountain fronts and some of the playa lake silt and sand deposits (unit *Qp*) have been delineated where conspicuous, Quaternary alluvial fan deposits, fluvial and lake gravel, sand, silt, and evaporite deposits have not been differentiated and are shown as *Qal* on the geologic maps.

Detailed descriptions of individual formations have been published by many authors listed in the references at the end of this report.

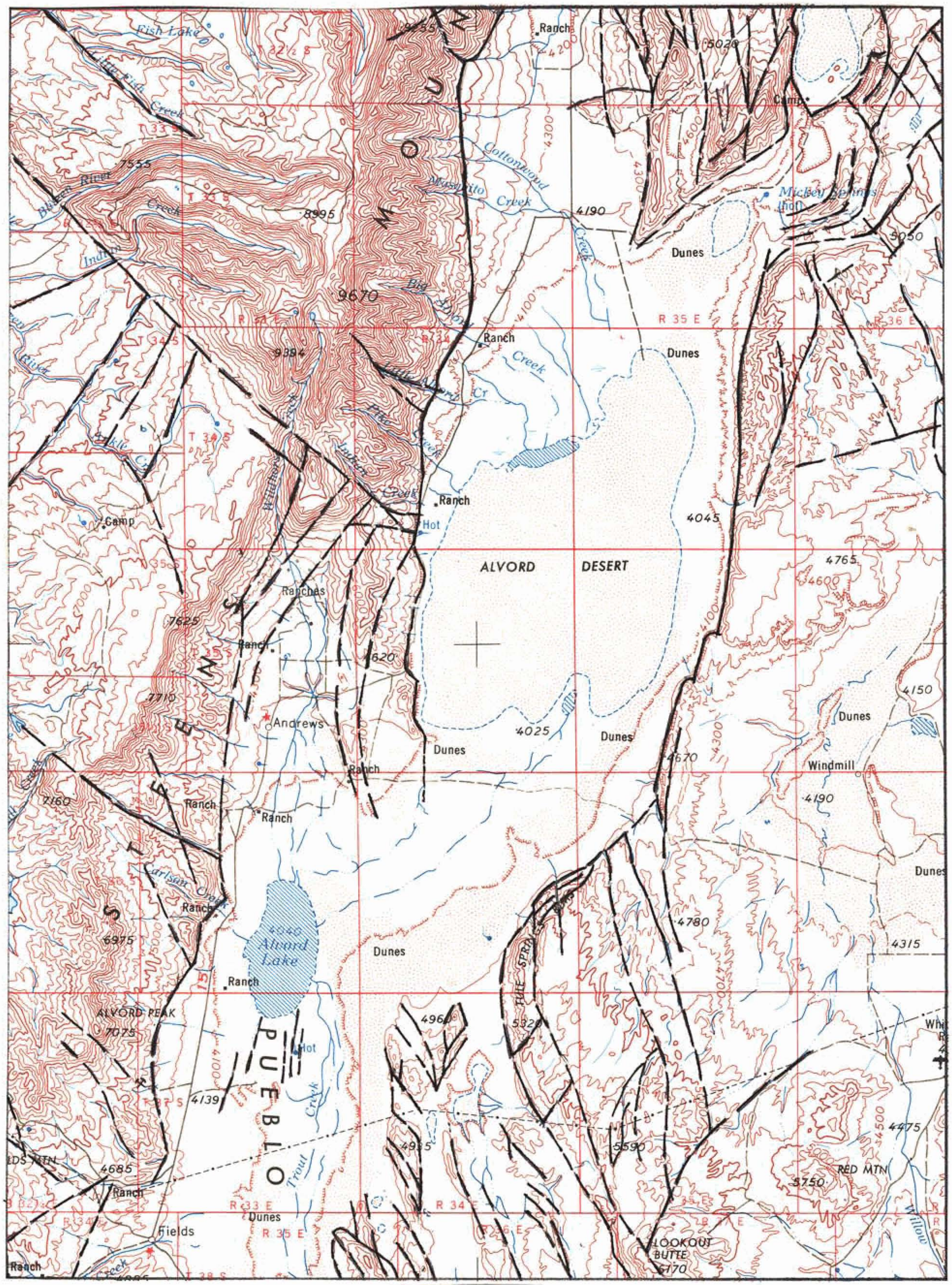
As a convenience for compiling the geologic map, the silicic rocks of the Alvord Creek Formation and Pike Creek Formation have been combined as well as the andesite and basalt flows of the Steens Mountain Volcanic Series and the Steens Basalt.

Structural geology

The Alvord Valley is in the northern part of the Basin and Range Province. Prominent horst and graben features of the area are characteristic of the rest of the province and are the result of considerable east-west extension during the late Cenozoic.

An examination of ERTS Landsat color imagery of southeastern Oregon tends to confirm the observations of early day observers (Russell, 1884, and Waring, 1904) who suggested that the Steens-Pueblo Mountain range is the western flank of an arch, the keystone of which dropped down to form the Alvord Valley. The photos show that a large part of the high Steens have been an elongate low, dome-shaped mass before it became the complex horst and graben structure it is today. A set of NNE and NNW trending faults is well developed, especially at the north end of the Alvord Valley (Figure 2).

Lawrence (1976) interpreted the pattern of faulting in the Basin and Range of southeastern Oregon as zones of east-west extension that lie between prominent right-lateral wrench faults which trend N. 50° W. to N. 60° W. The Steens-Alvord area lies between Lawrence's "Vale" zone to the north and another that Lawrence calls the "Eugene-Denio" zone to the south. Farther west, the northward extension of the Basin and Range topography is terminated by the "Brothers" fault zone which Lawrence interprets as ending at or near the range-front of the Steens Mountains.



ADEL, OREGON

1955
Revised 1970

Scale 1:250,000

CONTOUR INTERVAL 200 FEET

Figure 2. PHOTO-LINEAMENT MAP OF THE ALVORD DESERT AREA

Displacements on the range-front faults are estimated to be as much as 10,000 feet along the west side of the Alvord Valley and much less along the east margin where the escarpment is much lower. A large tilted block is suggested by a reversal of dips in the foothills west of the valley from the mouth of Wildhorse Canyon southward to Fields. Generally, the massive Steens Mountain block tilts to the west at 5^{o} or less. The east-facing escarpment and frontal fault zone generally trends about N. 5^{o} E. but have sections where the trend approaches N. 25^{o} E.

Most of the elevation of the range appears to have occurred before the onset of glaciation. Glaciation has left large u-shaped canyons and cirques in the high Steens, such as Keiger Gorge.

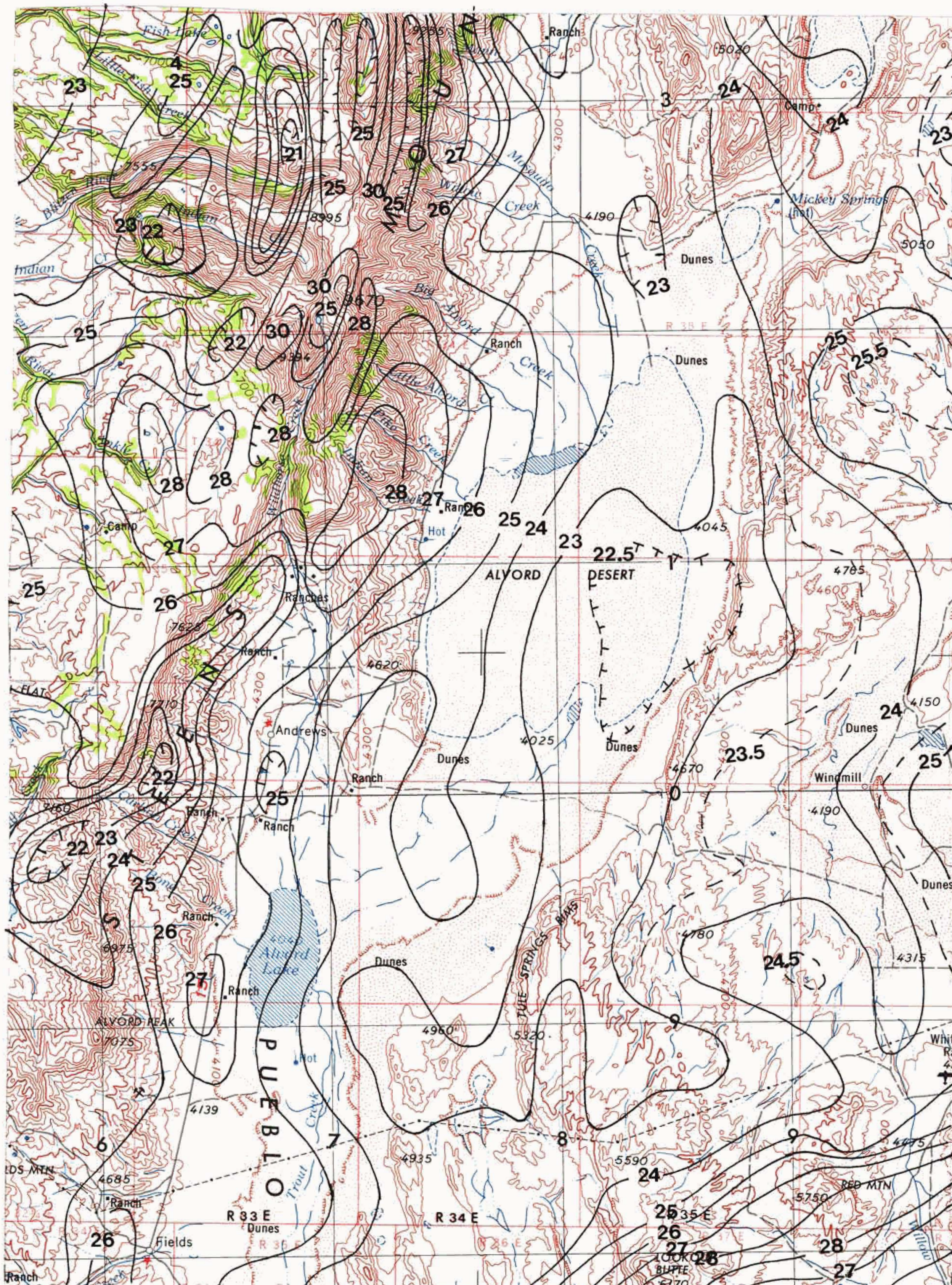
The Pliocene-Pliestocene Tum Tum conglomerate has also been deformed and uplifted. Quaternary alluvial fans also appear to have been slightly uplifted and erosionally cut into scarplets and low ridge-like deposits (Cleary, 1976) indicating that many of the faults in the area are still active. Such faults continually create fracture permeability for deep circulation of geothermal water.

GEOPHYSICS

A number of geophysical studies were available for evaluation in this report. They are a regional aeromagnetic survey performed by the USGS in 1972 (Figure 3); an audio-magnetotelluric survey performed by Long and Gregory of the USGS in 1975, presented at the 7.5 and 27 hertz bands (Figures 4 and 5); gravity and truck-mounted magnetic profiles performed by Griscom, Andrew and Conradi of the USGS in 1975 (not included with this report); and a Bouguer gravity anomaly study performed by Cleary, 1974a, of the University of Montana (Figure 6).

Owing to its small scale, the regional aeromagnetic study (Figure 3) is difficult to interpret on a site-specific basis. The Steens Mountain fault escarpment on the western edge of the map is indicated by a sharp change from smooth contours, indicative of a deep alluvial valley, to a strong north-to-northeast trend of short-period, elongated maxima and minima. This area of elongated anomalies is coincident with the complexly northeasterly and northwesterly faulted Steens Mountains. The mountains are composed mainly of relatively highly susceptible lavas with minor non-susceptible rhyolites and tuffs along the range front. The valley is characterized by smooth contours trending north to northeasterly with a closed minimum centered on the eastern portion of the Alvord Desert, probably indicating that bedrock beneath the valley fill is dipping to the northeast. This trend begins to show increasing positive gradients to the south and east along the Trout Creek Mountains and Sheepshead Mountains front.

Detailed, continuous, truck-mounted, magnetic profiles performed by Griscom, Andrew, and Conradi (1975) taken through Borax Lake, Mickey Hot Springs, and Alvord Hot Springs show much more detail. These traverses, in conjunction with their gravity traverses, indicate that each hot spring is coincident with a



ADEL, OREGON
1955
REVISED 1970

Scale 1:250,000
CONTOUR INTERVAL 200 FEET

TOTAL FIELD AEROMAGNETIC ANOMALY MAP

-27— 100 Gamma contour
-24.5- - - 50 Gamma contour
TOTAL READING = NUMBER x 100

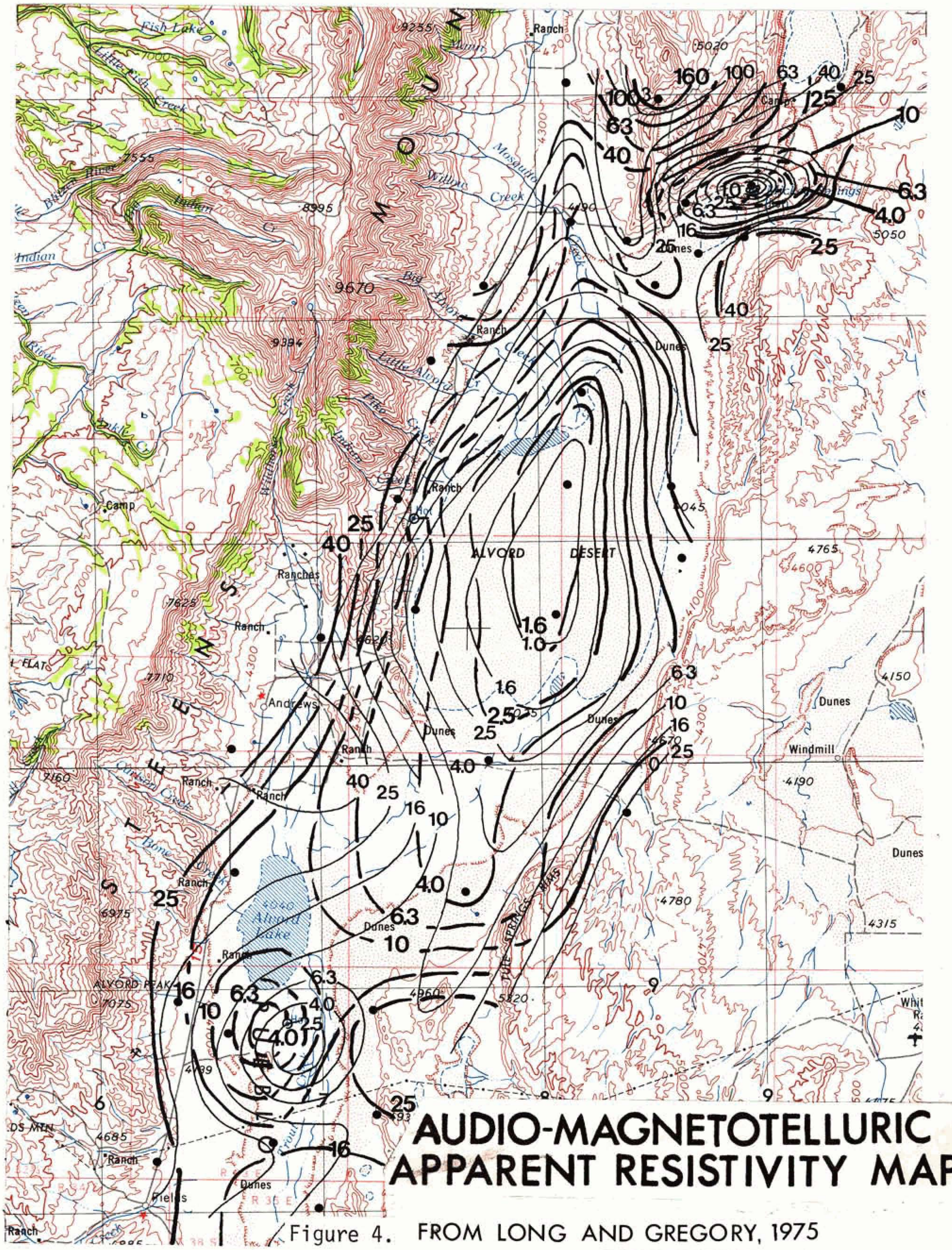
Figure 3.

geophysical anomaly which is interpreted to be a fault. Their study also concludes that many of the faults mapped for this study extend into the valley beneath the fill. The reader is directed to their publication for detailed discussion of their study.

An audiomagnetotelluric apparent resistivity study of the Alvord Valley performed by Long and Gregory (1975) delineates three areas of high conductance (Figures 4 and 5). These areas show up as small resistivity minima surrounding Hot Borax and Mickey Springs, and a large resistivity minimum surrounding the Alvord Desert playa. The minima surrounding the two hot springs are seen throughout the frequency spectra at both shallow and extreme depths. In both cases, the anomaly broadens and centers on surface hot springs at the higher end of the frequency spectrum (i.e., shallower probing). The anomaly at Mickey Springs shifts very little, and does not broaden a great deal at high frequencies, suggesting a more direct path to the surface for ascending waters and probably a shallower depth to source. This assumption is reinforced by geologic mapping which indicates less depth to bedrock than for the other springs, and a high orifice temperature which may indicate a shorter path to the surface.

The anomaly surrounding Hot Borax Lake shows some displacement toward the valley bounding faults at lower frequencies (i.e., deeper probing), and a decrease in the size of the anomaly. This may indicate that thermal water exits the range-front fault in a limited area at depth and migrates down the hydrologic dip toward the center of the basin, where it finally appears as a zone of widely scattered hot to warm springs.

The third anomaly surrounding Alvord Valley is probably due to highly conductive layers of evaporite-rich sediments and saline waters buried beneath the playa floor. This anomaly probably masks any anomaly which may be associated with Alvord Hot Springs, found to the west of the Alvord Desert, although



AUDIO-MAGNETOTELLURIC APPARENT RESISTIVITY MAP

Figure 4. FROM LONG AND GREGORY, 1975

ADEL, OREGON
1955
REVISED 1970

CONTOUR INTERVAL 200 FEET
Scale 1:250,000

• Station location
Resistivity in ohm-meters

2.5 Telluric line north-south
6.3 Telluric line east-west

27 HERTZ

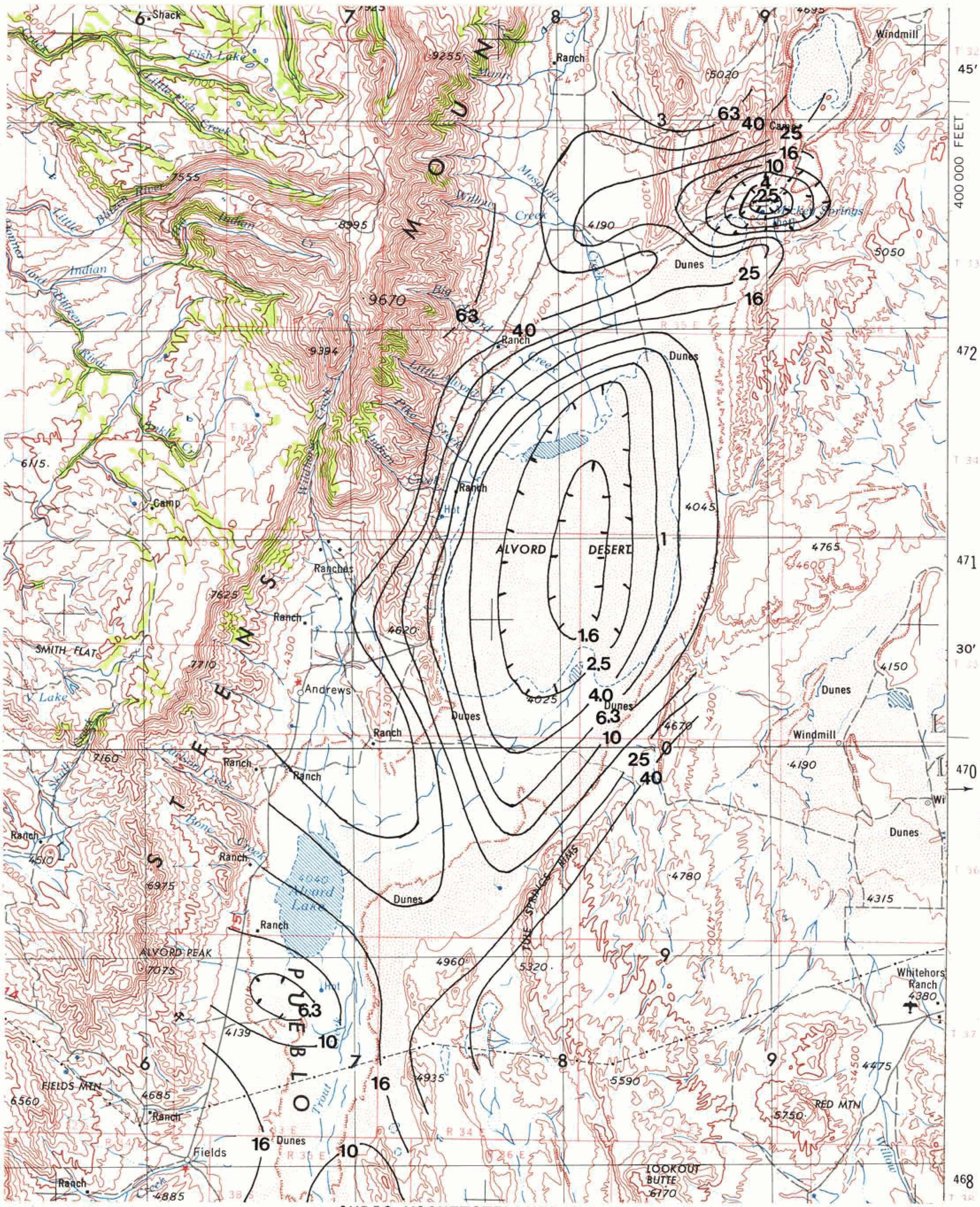


Figure 5.

AUDIO-MAGNETOTELLURIC
APPARENT RESISTIVITY MAP

From Long and Gregory, 1975

ADEL, OREGON
1955
Revised 1970

Scale 1:250,000
CONTOUR INTERVAL 200 FEET

7.5 HERTZ

a slight amount of offsetting towards the springs is seen in the higher frequencies which may be caused by surface effects around the springs.

The final geophysical study evaluated for this report is a simple Bouguer gravity map developed by Cleary (1976a) of the Alvord Valley (Figure 6). This map, which is discussed in detail in his thesis, indicates that the valley is a complex graben. Cross-sections from his report are presented on the accompanying geologic maps (Plate I-II) and indicate that a number of the valley bounding and intersecting faults continue under the valley fill, where they probably control the observed geothermal system. Cleary also describes some contemporary seismic events and graben-bounding structures that he interprets to be active.

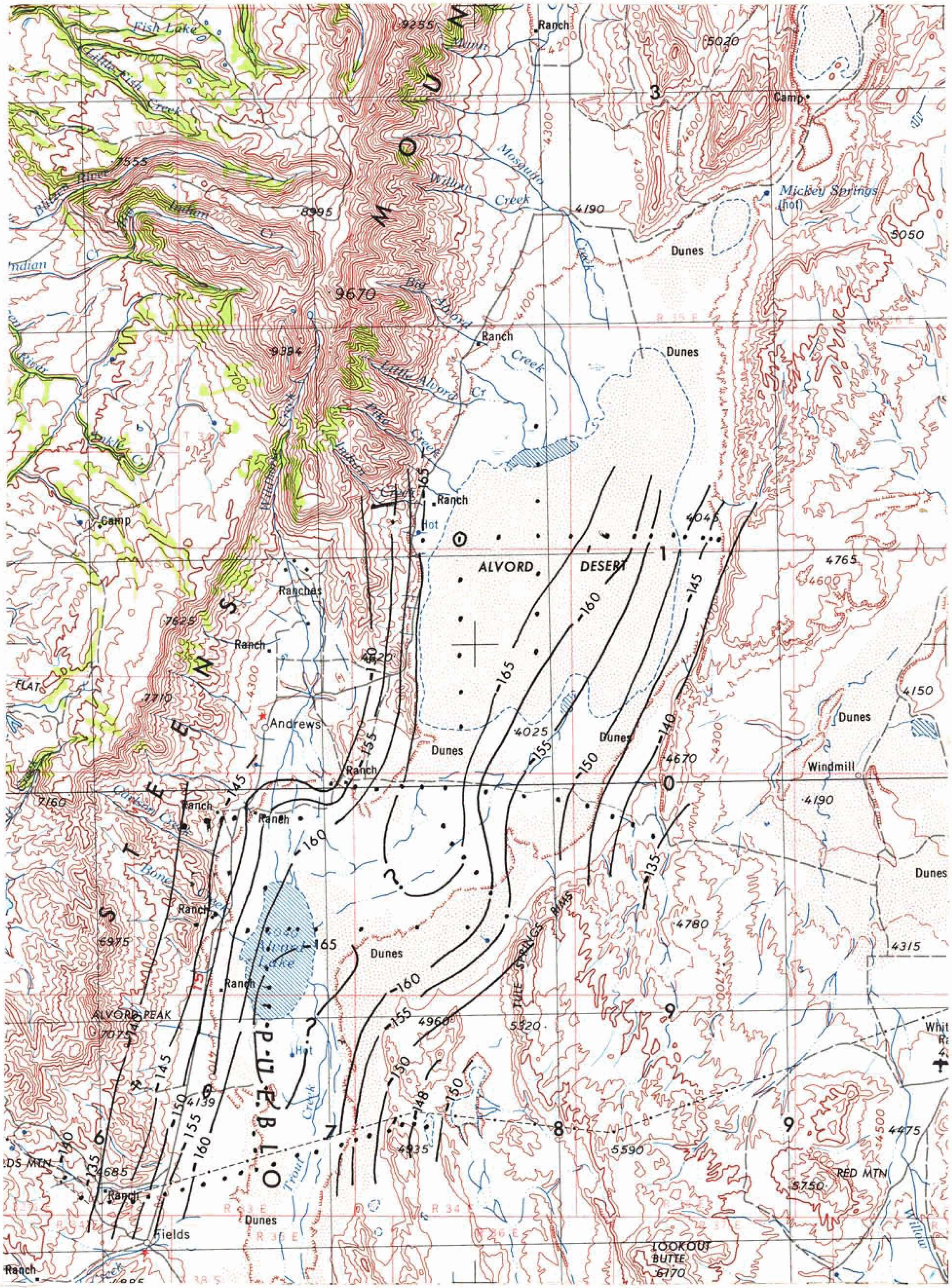


Figure 6. SIMPLE BOUGUER GRAVITY MAP OF THE ALVORD DESERT AREA, OREGON (From Cleary, 1976a)

• - Gravity stations
⊙ - Gravity base stations
-150 - Gravity contours in mgals

WATER CHEMISTRY

During the period of this study, six springs were sampled and their waters analyzed. Together with published analyses (Mariner and others, 1974, 1980; and USGS and DOGAMI, 1979), a total of twenty-seven analyses are available for evaluation (Table 1). Field reconnaissance indicates a considerable number of thermal anomalies; however, a large number of these springs and wells were unlocatable, not flowing or unsampled owing to time constraints.

Sampling temperatures during field collection ranged from near boiling (100^{o}C) for Alvord Hot Springs, Mickey Hot Springs, and Hot Borax Lake down to 6^{o} C for Burke Spring.

The thermal waters can best be described as neutral to slightly alkaline, mixed-ion bicarbonate water typical of hot-water systems found throughout the Basin-Range province. Preliminary analyses of the available data indicates that two species of water are present, (1) the Mickey Springs group and (2) Alvord Springs and Hot Borax Lake, with the Mickey Springs group showing slightly higher estimated reservoir temperatures (Table 2).

The four hot springs or groups of hot springs in the study area (Plate III) are rather widely separated along a northeast trend from just west of Fields (Pedro Spring) in the south-central part of the valley to Mickey Springs about 35 miles to the northeast. In addition to being widely separated, the springs also appear to be in different environments, although all are localized by faults or fault zones. Pedro Spring, the least hot (27^{o} C), emerges from basalt flows of the horst block. Borax Hot Lake is in the center of the valley and has a linear north-south string of spring orifices, some of which are near boiling temperatures. These orifices are probably associated with a buried valley-bounding fault which was discussed in the geophysics section of this report. The Alvord Hot Springs occur at the base of the Steens Mountain escarpment and are probably controlled by a major frontal fault. Mickey Spring, the northernmost is also the hottest in the Alvord Valley, and it is the only hot spring in the eastern part of the valley. There, several spring orifices, bubbling mud pots, and steam vents occur in a 1- to 2-acre area of tufa mounds adjacent to a large northeast-trending fault block.

Table I. Spring and well chemistry of the Alvord Desert area. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Burke Spring	Blair Spring	Cold Spring	Antelope Hot Springs	Pedro Spring
Location	37S/33E/ 6CBa	36S/33E/ 28Bbb	35S/33E/ 34Dcb	35S/26E/ 32Ba	37S/32 3/4E/ 36Bc
Date sampled	5/80	5/80	5/80	8/48	5/80
Temp. (^{o} C)	6	10	10	40	27
pH	7.9	8.0	7.8	8.3	9.2
Conductance µmhos/cm	289	385	240	876	220
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	157_c	208_c	121_c	nt	62_c
Hardness as mg/l $CaCO_3$	156	173	101	nt	5
Total dissolved solids	206	260	174	695	145
SiO_2	47.2	42.8	44.6	168	48.8
Na	8.1	20.6	12.3	191	31.4
K	1.5	3.3	0.7	13.0	0.3
Ca	28.6	29.6	24.0	10.0	0.7
Mg	17.5	24.0	11.0	2.5	0.3
Cl	2.5	4.1	3.3	64	5.4
As	0.017	0.009	0.005	nt	0.008
B	<0.200	0.23	<0.200	1.5	<0.200
Li	<0.1	0.17	<0.1	nt	<0.1
F	0.2	0.3	0.1	3.6	0.3
Fe (total)	0.44	0.14	0.36	0.02	0.70
Al	0.48	<0.1	0.13	nt	0.64
HCO_3	nt	nt	nt	376	nt
PO_4	0.066	0.039	0.051	nt	0.042
SO_4	5.34	10.2	6.6	57	8.1
NO_3	0.21	0.41	0.38	0.2	<0.02
NH_3	0.05	0.06	0.05	nt	0.04

Table 1. Spring and well chemistry of the Alvord Desert area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Mickey Hot Springs	Mickey Hot Springs	Mickey Hot Springs	Mickey Hot Springs
Location	33S/35E/ 13B	33S/35E/ 13B	33S/35E/ 13B	37S/32 3/4E/ 28Ba
Date sampled	7/71	/72	9/76	5/80
Temp. (^{o} C)	85	73	86	87
pH	8.5	8.0	8.31	8.9
Conductance µmhos/cm	2200	2490	2200	2300
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	630_c	nt	804_c	1340_c
Hardness as mg/l $CaCO_3$	nt	nt	nt	6
Total dissolved solids	1748	nt	nt	1733
SiO_2	167	200	214	102
Na	478	550	550	512
K	20	35	31	30.9
Ca	1.0	0.9	1.0	2.4
Mg	1.2	0.1	<1.0	3.6
Cl	230	240	240	291
As	2.5	0.01	nt	0.210
B	9.2	10.5	11.0	11.7
Li	<0.2	1.1	0.9	0.90
F	19.6	16	16	8.3
Fe (total)	0.06	<0.02	nt	0.60
Al	<0.01	0.058	nt	1.3
HCO_3	nt	774	nt	nt
PO_4	1.3	0.74	nt	0.300
SO_4	205	230	210	212
NO_3	0.02	nt	nt	<0.02
NH_3	0.02	0.39	<0.5	0.06

Table 1. Spring and well chemistry of the Alvord Desert area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	O'Keefe Spring	Alvord Hot Springs	Alvord Hot Springs	Alvord Hot Springs
Location	37S/32 3/4E/ 28Ba	34S/34E/ 32Db	34S/34E/ 32Db	34S/34E/ 32Db
Date sampled	5/80	11/55	/72	9/76
Temp. (^{o} C)	10	82.2	76	78.5
pH	7.9	7.3	6.73	6.89
Conductance µmhos/cm	243	4490	4590	4070
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	120_c	nt	1196_c	1230_c
Hardness as mg/l $CaCO_3$	103	nt	nt	nt
Total dissolved solids	174	2910	nt	nt
SiO_2	40.8	135	120	128
Na	14.1	1040	960	1000
K	0.8	66	69	63
Ca	26.6	0.9	1.0	2.4
Mg	8.5	1.0	2.2	2.6
Cl	4.0	760	780	770
As	0.014	nt	0.04	nt
B	<0.200	28	30	36
Li	<0.1	nt	2.1	1.9
F	0.2	7.2	10.2	11.0
Fe (total)	<0.05	0.09	0.12	nt
Al	<0.1	nt	0.003	nt
HCO_3	nt	nt	nt	nt
PO_4	0.052	4.5	0.43	nt
SO_4	6.4	211	220	180
NO_3	0.98	1.1	nt	nt
NH_3	0.04	nt	0.90	<0.5

Table 1. Spring and well chemistry of the Alvord Desert area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Spring N.W. of Borax Lake	Spring N.W. of Borax Lake	Hot Borax Lake #2	Hot Borax Lake #3
Location	37S/38E/15	37S/38E/15	37S/33E/15	37S/33E/15
Date sampled	5/57	/72	9/53	9/53
Temp. (^{o} C)	87	96	29.4	73.9
pH	7.5	7.3	7.7	7.6
Conductance µmhos/cm	2190	2020	2227	2050
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	nt	nt	nt	nt
Total dissolved solids	1520	nt	1559	1440
SiO_2	160	160	184	119
Na	426	450	488	430
K	29	28	23	27
Ca	9.6	14	17	15
Mg	tr	0.3	tr	tr
Cl	265	250	286	255
As	1.0	nt	nt	nt
B	15	15	17.9	12
Li	tr	0.51	<1.5	<1.5
F	6.5	7.2	8.0	7.0
Fe (total)	tr	<0.02	nt	nt
Al	tr	0.02	nt	nt
HCO_3	nt	nt	nt	nt
PO_4	1.4	1.2	nt	nt
SO_4	328	434	343	319
NO_3	tr	nt	2.5	1.2
NH_3	0.69	0.17	nt	nt

Table 1. Spring and well chemistry of the Alvord Desert area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Hot Borax Lake #4	Hot Borax Lake #5	Hot Borax Lake #1	Unnamed hot spring near hot lake #3
Location	37S/33E/15	37S/33E/15	37S/33E/15	37S/33E
Date sampled	9/53	6/61	1/72	9/76
Temp. (^{o} C)	79.4	31.1	36	91
pH	8.1	7.8	7.28	7.94
Conductance µmhos/cm	2160	2410	2410	1990
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	434
Hardness as mg/l $CaCO_3$	nt	nt	nt	nt
Total dissolved solids	1520	1680	nt	nt
SiO_2	173	193	190	189
Na	456	516	500	460
K	30	27	31	29
Ca	14	16	16	15
Mg	0.3	0.5	0.3	0.3
Cl	270	305	300	270
As	nt	nt	0.01	nt
B	14	18	16.6	15
Li	<1.5	nt	0.65	0.5
F	7.0	9.7	9.0	7.5
Fe (total)	nt	nt	<0.02	nt
Al	nt	nt	nt	nt
HCO_3	nt	nt	nt	nt
PO_4	nt	2.2	0.89	nt
SO_4	339	367	350	nt
NO_3	1.3	nt	nt	nt
NH_3	nt	nt	nt	nt

Table 1. Spring and well chemistry of the Alvord Desert area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Unnamed hot spring near hot lake #4	Unnamed hot spring near hot lake #5	Unnamed hot spring near hot lake #6
Location	37S/33E	37S/33E	37S/33E
Date sampled	9/76	9/76	9/76
Temp. (^{o} C)	97	90.5	86
pH	7.36	7.04	8.67
Conductance µmhos/cm	1840	1910	2040
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	389	420	423
Hardness as mg/l $CaCO_3$	nt	nt	nt
Total dissolved solids	nt	nt	nt
SiO_2	169	154	157
Na	435	435	450
K	24	26	26
Ca	13	15	14
Mg	0.2	0.3	0.3
Cl	250	250	250
As	nt	nt	nt
B	14	15	14
Li	0.5	0.5	0.55
F	7.6	7.0	7.7
Fe (total)	<0.02	nt	nt
Al	0.028	nt	nt
HCO_3	nt	nt	nt
PO_4	nt	nt	nt
SO_4	nt	nt	nt
NO_3	nt	nt	nt
NH_3	<0.5	nt	nt

Table 1. Spring and well chemistry of the Alvord Desert area--Continued. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Unnamed hot spring near hot lake #7	Unnamed hot spring near hot lake #8
Location	37S/33E	37S/33E
Date sampled	9/76	9/76
Temp. (^{o} C)	97	84
pH	7.26	7.48
Conductance µmhos/cm	1840	1890
Alkalinity X_h as mg/l HCO_3	372	386
X_c as mg/l $CaCO_3$		
Hardness as mg/l $CaCO_3$	nt	nt
Total dissolved solids	nt	nt
SiO_2	163	164
Na	425	440
K	24	25
Ca	12	12
Mg	0.2	0.2
Cl	250	250
As	nt	nt
B	14	15
Li	0.45	0.45
F	7.4	7.5
Fe (total)	<0.02	nt
Al	nt	nt
HCO_3	nt	nt
PO_4	nt	nt
SO_4	nt	nt
NO_3	nt	nt
NH_3	<0.05	<0.05

Table 2. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Alvord Desert area.

	Burke Spring	Blair Spring	Cold Spring	Antelope Hot Springs	Pedro Spring	Mickey Hot Springs '71
Flow rate liters/min.	nc	nc	nc	114	nc	nc
Measured temperature ^{o}C	6	10	10	40	27	85
Na:K ^{o}C	224	212	138	149	53	120
Na:K:Ca 1/3 β ^{o}C	157	165	113	168	81	179
Na:K:Ca 4/3 β ^{o}C	15	41	5	137	47	271
Na:K:Ca Mg corrected ^{o}C	21	nc	35	104	nc	110
SiO_2 conductive ^{o}C	99	95	96	168	101	168
SiO_2 adiabatic ^{o}C	100	96	98	159	101	158
SiO_2 chalcedony ^{o}C	69	64	66	146	71	145
SiO_2 opal ^{o}C	-16	-20	-19	45	-15	45

*Methodology for calculations presented in Appendix A. nc = not calculated.

Table 2. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Alvord Desert area--Continued.

	Mickey Hot Springs '72	Mickey Hot Springs '76	Mickey Hot Springs '80	O'Keefe Spring
Flow rate liters/min.	nc	nc	nc	nc
Measured temperature °C	73	86	87	10
Na:K °C	145	138	142	138
Na:K:Ca 1/3 β °C	207	198	192	114
Na:K:Ca 4/3 β °C	330	312	262	7
Na:K:Ca Mg corrected °C	nc	nc	73	54
SiO_2 conductive °C	180	185	138(?)	93
SiO_2 adiabatic °C	168	172	134(?)	94
SiO_2 chalcedony °C	159	164	112(?)	62
SiO_2 opal °C	56	61	18	-22

*Methodology for calculations presented in Appendix A. nc = not calculated.

Table 2. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Alvord Desert area--Continued.

	Alvord Hot Springs '55	Alvord Hot Springs '72	Alvord Hot Springs '76	Alvord Hot Springs '80
Flow rate liters/min.	nc	1875	nc	nc
Measured temperature ^{o}C	82.2	76	78.5	72
Na:K ^{o}C	145	153	144	150
Na:K:Ca 1/3 β ^{o}C	193	198	192	195
Na:K:Ca 4/3 β ^{o}C	252	253	252	246
Na:K:Ca Mg corrected ^{o}C	nc	166	157	155
SiO_2 conductive ^{o}C	155	148	151	145
SiO_2 adiabatic ^{o}C	147	141	145	139
SiO_2 chalcedony ^{o}C	130	122	126	119
SiO_2 opal ^{o}C	33	26	30	24

*Methodology for calculations presented in Appendix A. nc = not calculated.

Table 2. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Alvord Desert area--Continued.

	Spring N.W. of Borax Lake '57	Spring N.W. of Borax Lake '72	Hot Borax Lake #2 Spring '53	Hot Borax Lake #3 Spring '53
Flow rate liters/min.	71	56	nc	109
Measured temperature °C	87	96	29.4	73.9
Na:K °C	149	144	127	144
Na:K:Ca 1/3 β °C	183	176	161	175
Na:K:Ca 4/3 β °C	193	178	162	173
Na:K:Ca Mg corrected °C	nc	nc	nc	nc
SiO_2 conductive °C	165	165	174	147
SiO_2 adiabatic °C	156	156	164	141
SiO_2 chalcedony °C	142	142	152	122
SiO_2 opal °C	42	42	51	26

*Methodology for calculations presented in Appendix A. nc = not calculated.

Table 2. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Alvord Desert area--Continued.

	Hot Borax Lake #4 Spring '53	Hot Borax Lake #5 Spring '61	Hot Borax Lake #1 Spring '72	Unnamed hot spring near hot lake #3 '76	Unnamed hot spring near hot lake #4 '76
Flow rate liters/min.	nc	1687	13,000	nc	nc
Measured temperature °C	79.4	31.1	36	91	97
Na:K °C	147	133	143	144	136
Na:K:Ca 1/3 β °C	179	168	176	176	169
Na:K:Ca 4/3 β °C	182	174	181	178	172
Na:K:Ca Mg corrected °C	nc	nc	nc	nc	nc
SiO_2 conductive °C	170	177	176	176	169
SiO_2 adiabatic °C	160	166	165	165	159
SiO_2 chalcedony °C	148	156	155	154	146
SiO_2 opal °C	47	54	53	53	46

*Methodology for calculations presented in Appendix A. nc = not calculated.

Table 2. Geothermetric calculations* of minimum reservoir temperatures for selected thermal waters of the Alvord Desert area--Continued.

	Unnamed hot spring near hot lake #5 '76	Unnamed hot spring near hot lake #6 '76	Unnamed hot spring near hot lake #7	Unnamed hot spring near hot lake #8 '76
Flow rate liters/min.	nc	nc	nc	nc
Measured temperature ^oC	90.5	86	97	84
Na:K ^oC	141	139	138	138
Na:K:Ca 1/3 β ^oC	172	172	171	172
Na:K:Ca 4/3 β ^oC	171	174	174	177
Na:K:Ca Mg corrected ^oC	nc	nc	nc	nc
SiO_2 conductive ^oC	163	164	166	167
SiO_2 adiabatic ^oC	154	155	157	157
SiO_2 chalcedony ^oC	139	141	143	144
SiO_2 opal ^oC	40	41	44	44

*Methodology for calculations presented in Appendix A. nc = not calculated.

GEOTHERMAL GRADIENT AND HEAT FLOW DATA

Temperature gradient and heat flow results for the Alvord Valley area of Oregon are shown in Table 3. Included in the table are the township/range-section and the latitude and longitude location of each hole. In addition the hole name, date of logging used, collar elevation, bottom hole temperature, maximum depth, corrected temperature gradient and (where available) corrected heat flow are shown. In addition to these data the depth interval and average thermal conductivity used for calculation of the gradient and heat flow are shown. The table values are given in SI units. To transform units, 1×10^{-6} cal/cm^{2}sec (HFU) = 41.84 mWm^{-2}, 1×10^{-3} cal/cm sec^{o}C (TCU) = 0.4184 Wm^{-1}K^{-1}. Also 1^{o}C/km = 1mKm^{-1} = 18.2^{o}F/100 ft. The temperature-depth measurements for each hole have been open-filed at the DOGAMI office in Portland, and can be obtained by contacting that office. Corrected gradient and corrected heat flow are values for which the topographic effects have been removed. These are not significant for the sites studied.

The holes are ranked in terms of the quality of the gradient or heat flow information, from high quality (A), to good quality (B), to marginal quality (C), to data with some problems (D), to data for which no useful temperature gradient or heat flow can be estimated (X). Heat flow values in geothermal systems are indicated by a G. All holes have been plotted on an AMS Base presented as Plate I. Only 8 holes are shown in Table 3 in this area. The regional data in south central Oregon are sparse (Blackwell et al., 1978). Four heat flow measurements have been published by Sass et al., (1976) and are included on the table. These holes were drilled specifically for heat flow, and thermal conductivity measurements were made on core and cutting samples from the holes. For the water wells only estimated thermal conductivity values

*Written by Dr. David D. Blackwell, Southern Methodist University

Table 3. Geothermal-gradient data, Alvord Desert area, Oregon.

Twn/Rng- Section	N Lat. Deg.Min.	W Long Deg.Min.	Hole # Date	Collar Elev.	Bottom Temp. (°C)	Depth Interval (m)	Avg. TC $Wm^{-1}K^{-1}$	# TC	Uncorr. Gradient °C/km	Corr. Gradient °C/km	Corr. HF mWm^{-1}	Q HF
33S/35E- 14DA	42-40.60	118-21.60	MH-2	1235	21.40	10.0 30.0			294.9 .8	294.9 .8		G
						30.0 35.0			255.0 2.0	255.0 2.0		G
						10.0 35.0	.92		289.2 .8	289.2 .8	268	G
33S/34E- 24AB	42-40.00	118-27.23	MCW 7/20/73	1290	11.90	25.0 240.0						X
33S/35E- 23ACB	42-39.70	118-21.50	MH-1	1225	19.10	40.0 51.0	.92 .01	6	146.2 .6	146.2 .6	134	G
35S/35E- 31CDD	42-32.20	118-26.60	AD-2	1220	15.50	59.0 96.0	.89 .01	19	58.5 .3	58.5 .3	52	A
35S/34E- 2BA	42-32.20	118-29.20	AD-1	1220	17.70	54.9 61.0	.86 .01	7	73.9	73.9	64	A
						88.4 95.7	.85 .01	9	78.6 .3	78.6 .3	67	A
						55.0 96.0	.85 .01	16	75.8 .3	75.8 .3	65	A
37S/36E- 28AB	42-18.24	118-16.70	G-11 7/30/73	1366	17.48	10.0 25.0	.96 .21		130.6 13.7	130.6	126	G
38S/37E- 24BA	42-15.81	118-19.15	SP-10 7/28/73	1430	20.45	10.0 100.0	.96 .21		83.9 1.2	83.9	79	B
38S/37E- 23CC	42-15.27	118-20.79	DH-19 7/28/73	1430	16.73	10.0 50.0	.96 .21		88.5 3.9	88.5	84	B

are available and the quality of the data is quite low. Because of the sparsity of data very little can be said in detail about the potential of the area. In general, the heat flow values and geothermal gradients appear to be quite high and, except for the remoteness of the area, there might be good potential for usable low temperature water to be found at leass than 1.5 km depth. Extensive gradient drilling has been carried out by exploration companies in the search for high temperature geothermal resources. These data are not available, as they are proprietary.

CONCLUSIONS AND RECOMMENDATIONS

This reconnaissance study of the Alvord Valley has defined two geothermal systems worthy of further investigation. Those are the (1) Mickey Hot Springs area in the northern end of the Valley, and the (2) Alvord-Hot Borax Lake area in the central and southern end of the Valley. Surface indications are that both of these areas have high estimated reservoir temperatures and may represent the surface manifestations of a system at depth which has temperatures high enough for direct utilization and possibly electrical power production. Recommendations for site-specific analyses for these two very important areas should be carried out under one field program, and are listed as follows:

1. Detailed (1:24,000 or less) geologic and photogeologic mapping of the areas immediately adjacent to the spring zone with emphasis on recognition and mapping of active and/or thermal structures.
2. Detailed sampling and analysis of hot and cold springs including isotopic analysis, to determine precise subsurface conditions.
3. Closely spaced gravity stations to be coupled with existing stations and reduced to complete site-specific Bouguer and residual anomaly maps to provide for detailed analysis of subsurface thermal structures.
4. A contemporary seismic study and a microseismic study using an array of high-gain seismometers to determine seismicity of the Valley and relation of active faults to the geothermal regime.
5. A program of 20 to 30 500-ft gradient/stratigraphy holes followed by a program of 5 to 10 2000-ft gradient holes to refine the evaluation of the Alvord Valley geothermal model for deep production drilling.

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APPENDIX A

Formulas used in calculations

Na:K (revised): $$t\,^{o}C = \frac{1217}{\log (Na/K) + 1.483} - 273.15$$ (Fournier, 1979)

Na:K:Ca: $$t\,^{o}C = \frac{1647}{2.24 + F\,(T)} - 273.15$$ (Fournier and Truesdell, 1973),

where $F\,(T) = \log (Na/K) + [\, \beta \log (\sqrt{Ca}/Na)\,]$,
β = 1/3 if t> $100^{o}C$, and 4/3 if t <$100^{o}C$,
$t^{o}C$ = calculated reservoir temperature,
and concentrations are expressed in molality.

Magnesium correction ratio:

$$R = \frac{(\text{milliequivalents Mg})}{(\text{milliequivalents Mg}) + (\text{milliequivalents Ca}) + (\text{milliequivalents K})} \times 100$$

If R <5 or >50, no calculation was made. For R between 5-50,

$$\Delta t_{Mg} = 10.66-(4.7415)\,(R) + [(325.87)\,(\log R)^{2}] - [(1.032 \times 10^{5})\,(\log R)^{2}/T] - [(1.968 \times 10^{7})\,(\log R)^{2}/T^{2}] + [(1.605 \times 10^{7})\,(\log R)^{3}/T^{2}],$$

where R = magnesium correction ratio expressed in equivalents,
Δt_{Mg} = the temperature correction that is subtracted from the Na:K:Ca 1/3 β calculated temperature,
T = Na:K:Ca 1/3 β calculated temperature in ^{o}K.

Or Δt_{Mg} can be obtained by using the graph compiled by Fournier and Potter (1979).

SiO_2 temperature calculations (Fournier and Rowe, 1966):

SiO_2 (conductive), $$t^{o}C = \frac{1309}{5.19 + \log (SiO_2)} - 273.15$$

SiO_2 (adiabatic), $$t^{o}C = \frac{1522}{5.75 + \log (SiO_2)} - 273.15$$

SiO_2 (chalcedony), $$t^{o}C = \frac{1032}{4.69 + \log (SiO_2)} - 273.15$$

SiO_2 (opal), $$t^{o}C = \frac{731}{4.52 + \log (SiO_2)} - 273.15,$$

where SiO_2 is expressed in mg/l.

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APPENDIX B

Geothermal Gradient Data

LOCATION: WH .EHORSE , OREGON
HOLE NUMBER: 38-37325
DATE MEASURED: ODGMI

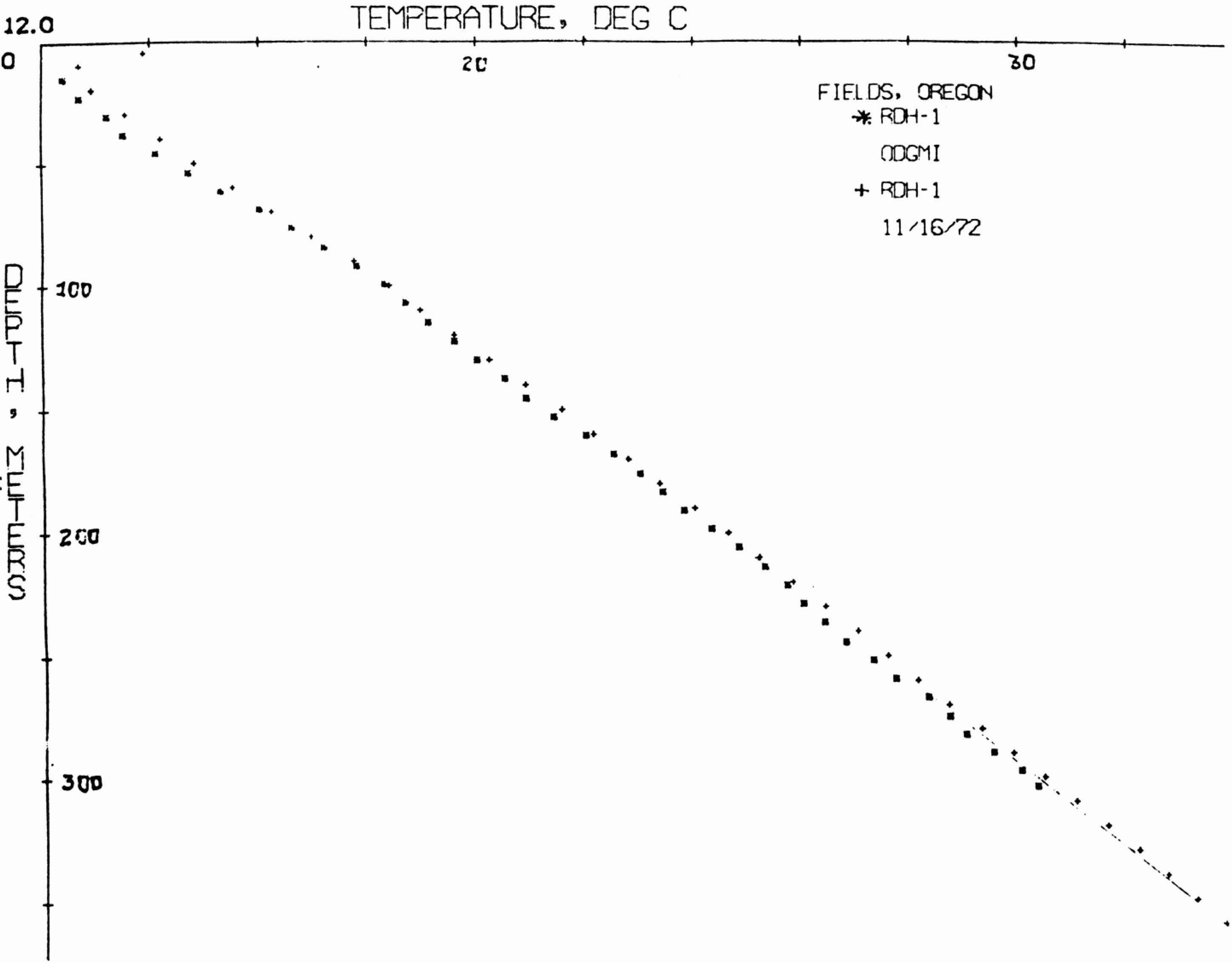
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	FEET/DEG F
30.5	100.0	20.800	69.44	.0	.0
59.4	195.0	24.100	75.38	114.0	16.0
89.9	294.9	25.200	77.36	36.1	50.5
120.4	394.9	27.600	81.68	78.7	23.1
150.9	494.9	29.300	84.74	55.8	32.7

LOCATION: FIELDS, OREGON ✓
HOLE NUMBER: RDH-1
DATE MEASURED: 11/16/72

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT FEET/DEG F
5.0	16.4	13.880	56.98	.0	.0
10.0	32.8	12.680	54.82	-240.0	-7.6
20.0	65.6	12.930	55.27	25.0	72.9
30.0	98.4	13.530	56.35	60.0	30.4
40.0	131.2	14.180	57.52	65.0	28.0
50.0	164.0	14.810	58.66	63.0	28.9
60.0	196.8	15.520	59.94	71.0	25.7
70.0	229.6	16.240	61.23	72.0	25.3
80.0	262.4	16.970	62.55	73.0	25.0
90.0	295.2	17.740	63.93	77.0	23.7
100.0	328.0	18.390	65.10	65.0	28.0
110.0	360.8	18.960	66.13	57.0	32.0
120.0	393.6	19.580	67.24	62.0	29.4
130.0	426.4	20.230	68.41	65.0	28.0
140.0	459.2	20.890	69.60	66.0	27.6
150.0	492.0	21.560	70.81	67.0	27.2
160.0	524.8	22.150	71.87	59.0	30.9
170.0	557.6	22.780	73.00	63.0	28.9
180.0	590.4	23.370	74.07	59.0	30.9
190.0	623.2	24.000	75.20	63.0	28.9
200.0	656.0	24.620	76.32	62.0	29.4
210.0	688.8	25.210	77.38	59.0	30.9
220.0	721.6	25.820	78.48	61.0	29.9
230.0	754.4	26.410	79.54	59.0	30.9
240.0	787.2	27.010	80.62	60.0	30.4
250.0	820.0	27.570	81.63	56.0	32.5
260.0	852.8	28.120	82.62	55.0	33.1
270.0	885.6	28.700	83.66	58.0	31.4
280.0	918.4	29.300	84.74	60.0	30.4
290.0	951.2	29.880	85.78	58.0	31.4
300.0	984.0	30.440	86.79	56.0	32.5
310.0	1016.8	31.010	87.82	57.0	32.0
320.0	1049.6	31.600	88.88	59.0	30.9
330.0	1082.4	32.170	89.91	57.0	32.0
340.0	1115.2	32.690	90.84	52.0	35.0
350.0	1148.0	33.250	91.85	56.0	32.5
360.0	1180.8	33.780	92.80	53.0	34.4
370.0	1213.6	34.320	93.78	54.0	33.7
380.0	1246.4	34.620	94.32	30.0	60.7

LOCATION: FIELDS, OREGON
HOLE NUMBER: RDH-1
DATE MEASURED: ODGMI

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT FEET/DEG F
15.2	50.0	12.400	54.32	.0	.0
22.8	74.9	12.700	54.86	39.4	46.2
30.5	100.0	13.200	55.76	65.5	27.8
38.1	125.0	13.500	56.30	39.4	46.3
45.7	150.0	14.100	57.38	78.7	23.1
53.3	175.0	14.700	58.46	78.7	23.1
61.0	199.9	15.300	59.54	78.7	23.1
68.6	224.9	16.000	60.80	91.9	19.8
76.2	249.9	16.600	61.88	78.7	23.1
83.8	274.9	17.200	62.96	78.7	23.1
91.4	299.9	17.800	64.04	78.7	23.1
99.1	324.9	18.300	64.94	65.6	27.8
106.7	349.9	18.700	65.66	52.5	34.7
114.3	374.9	19.100	66.38	52.5	34.7
121.9	399.9	19.600	67.28	65.6	27.8
129.5	424.9	20.000	68.00	52.5	34.7
137.2	449.9	20.500	68.90	65.6	27.8
144.8	474.9	20.900	69.62	52.5	34.7
152.4	499.9	21.400	70.52	65.6	27.8
160.0	524.9	22.000	71.60	78.7	23.1
167.6	549.9	22.500	72.50	65.6	27.8
175.3	574.9	23.000	73.40	65.6	27.8
182.9	599.8	23.400	74.12	52.5	34.7
190.5	624.8	23.800	74.84	52.5	34.7
198.1	649.8	24.300	75.74	65.6	27.8
205.7	674.8	24.800	76.64	65.6	27.8
213.3	699.8	25.300	77.54	65.7	27.7
221.0	724.8	25.700	78.26	52.4	34.8
228.6	749.8	26.000	78.80	39.4	46.3
236.2	774.8	26.400	79.52	52.5	34.7
243.8	799.7	26.800	80.24	52.8	34.5
251.5	824.8	27.300	81.14	65.3	27.9
259.1	849.8	27.700	81.86	52.5	34.7
266.7	874.8	28.300	82.94	78.7	23.1
274.3	899.8	28.700	83.66	52.5	34.7
281.9	924.8	29.000	84.20	39.4	46.3
289.6	949.8	29.500	85.10	65.6	27.8
297.2	974.8	30.000	86.00	65.6	27.8
303.3	994.8	30.300	86.54	49.2	37.1


TEMPERATURE, DEG C
12.0
.0
20
30
FIELDS, OREGON
* RDH-1
ODGMI
+ RDH-1
11/16/72
DEPTH, METERS
100
200
300

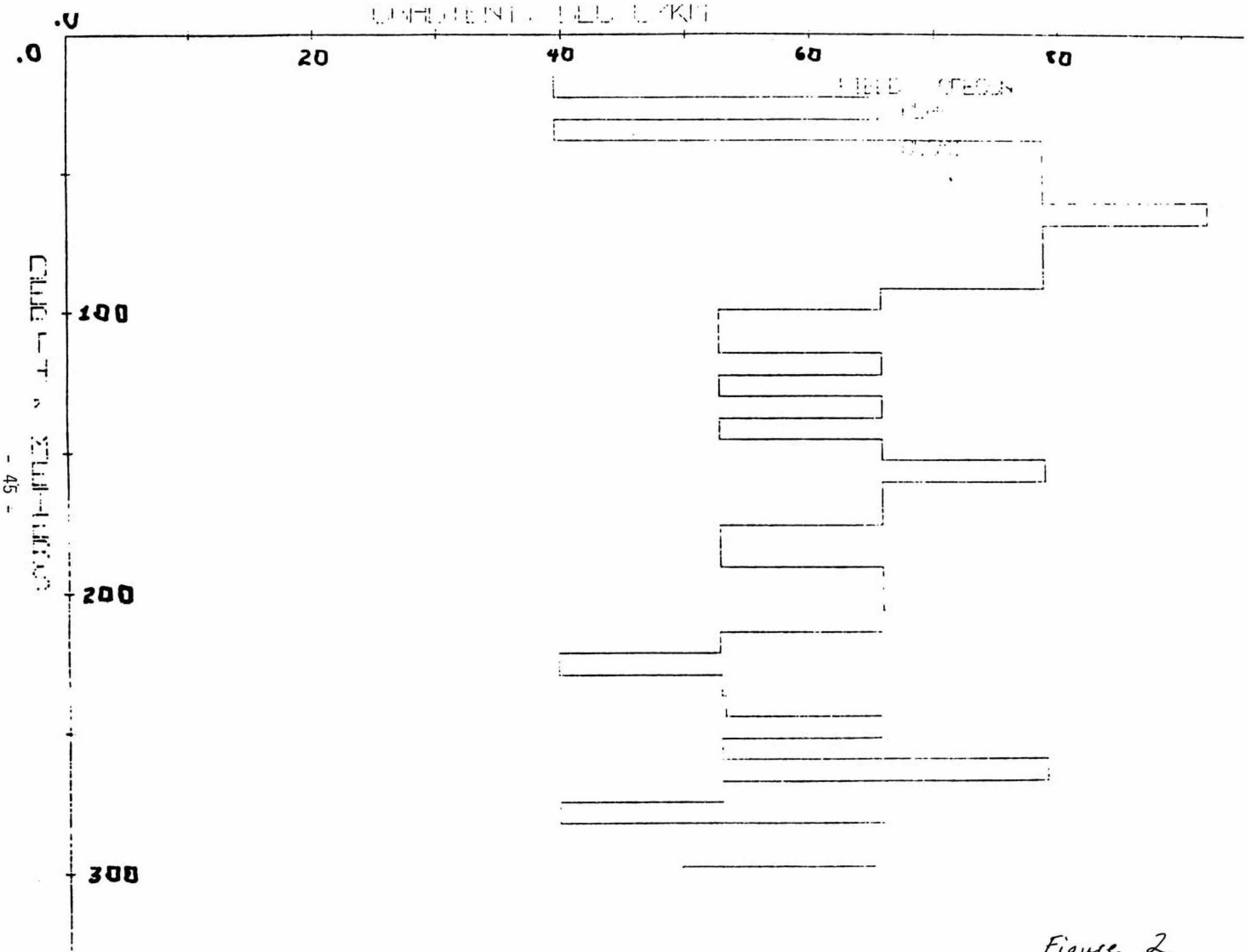


Figure 2

LOCATION: TROUT CREEK, OREGON
HOLE NUMBER: 38-37S24
DATE MEASURED: 7/28/73

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	FEET/DEG F
10.0	32.8	13.040	55.47	.0	.0
15.0	49.2	13.530	56.35	98.0	18.6
20.0	65.6	13.890	57.00	72.0	25.3
25.0	82.0	14.170	57.51	56.0	32.5
30.0	98.4	14.490	58.08	64.0	28.5
35.0	114.8	14.840	58.71	70.0	26.0
40.0	131.2	15.230	59.41	78.0	23.4
45.0	147.6	15.640	60.15	82.0	22.2
50.0	164.0	16.080	60.94	88.0	20.7
55.0	180.4	16.500	61.70	84.0	21.7
60.0	196.8	16.940	62.49	88.0	20.7
65.0	213.2	17.390	63.30	90.0	20.2
70.0	229.6	17.830	64.09	88.0	20.7
75.0	246.0	18.320	64.98	98.0	18.6
80.0	262.4	18.780	65.80	92.0	19.8
85.0	278.8	19.260	66.67	96.0	19.0
90.0	295.2	19.760	67.57	100.0	18.2
95.0	311.6	20.180	68.32	84.0	21.7
100.0	328.0	20.450	68.81	54.0	33.7

LØCATIØN: WH. EHØRSE, ØREGØN
HØLE NUMBER: 38-37S24
DATE MEASURED: ØDGMI

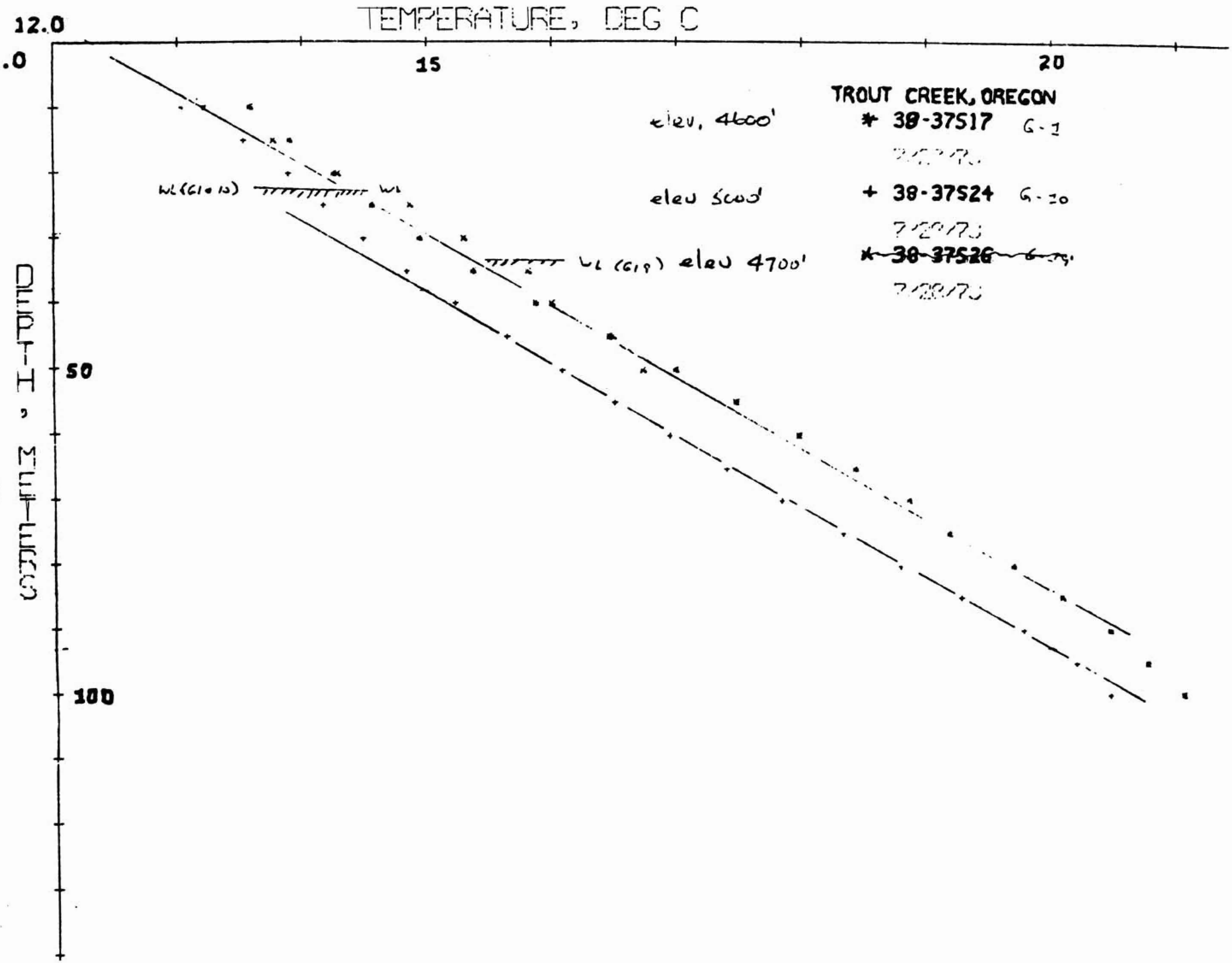
DEPTH	DEPTH	TEMPERATURE		GEØTHERMAL GRADIENT	
METERS	FEET	DEG C	DEG F	DEG C/KM	FEET/DEG F
30.5	100.0	14.300	57.74	.0	.0
39.1	128.4	14.800	58.64	57.7	31.6
69.5	227.9	17.700	63.86	95.6	19.1
100.0	327.9	20.500	68.90	91.9	19.8

LOCATION: TROUT CREEK, OREGON ✓
HOLE NUMBER: 38-37S26
DATE MEASURED: 7/28/73

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	FEET/DEG F
10.0	32.8	13.220	55.80	.0	.0
15.0	49.2	13.770	56.79	110.0	16.6
20.0	65.6	14.290	57.72	104.0	17.5
25.0	82.0	14.870	58.77	116.0	15.7
30.0	98.4	15.300	59.54	86.0	21.2
35.0	114.8	15.810	60.46	102.0	17.9
40.0	131.2	16.000	60.80	38.0	48.0
45.0	147.6	16.490	61.68	98.0	18.6
50.0	164.0	16.730	62.11	48.0	38.0

LOCATION: TROUT CREEK, OREGON
HOLE NUMBER: 39-37S17
DATE MEASURED: 7/27/73

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	FEET/DEG F
10.0	32.8	13.580	56.44	.0	.0
15.0	49.2	13.900	57.02	64.0	28.5
20.0	65.6	14.250	57.65	70.0	26.0
25.0	82.0	14.560	58.21	62.0	29.4
30.0	98.4	14.940	58.89	76.0	24.0
35.0	114.8	15.370	59.67	86.0	21.2
40.0	131.2	15.870	60.57	100.0	18.2
45.0	147.6	16.460	61.63	118.0	15.4
50.0	164.0	16.990	62.58	106.0	17.2
55.0	180.4	17.470	63.45	96.0	19.0
60.0	196.8	17.970	64.35	100.0	18.2
65.0	213.2	18.420	65.16	90.0	20.2
70.0	229.6	18.850	65.93	86.0	21.2
75.0	246.0	19.170	66.51	64.0	28.5
80.0	262.4	19.680	67.42	102.0	17.9
85.0	278.8	20.070	68.13	78.0	23.4
90.0	295.2	20.450	68.81	76.0	24.0
95.0	311.6	20.750	69.35	60.0	30.4
100.0	328.0	21.040	69.87	58.0	31.4
105.0	344.4	21.230	70.21	38.0	48.0
110.0	360.8	21.450	70.61	44.0	41.4


TEMPERATURE, DEG C
12.0
.0
15
20
50
100
DEPTH, METERS
TROUT CREEK, OREGON
elev. 4600'
* 38-37S17 G-1
elev 5000'
+ 38-37S24 G-20
x 38-37S26
WL (G18)
elev 4700'
WL

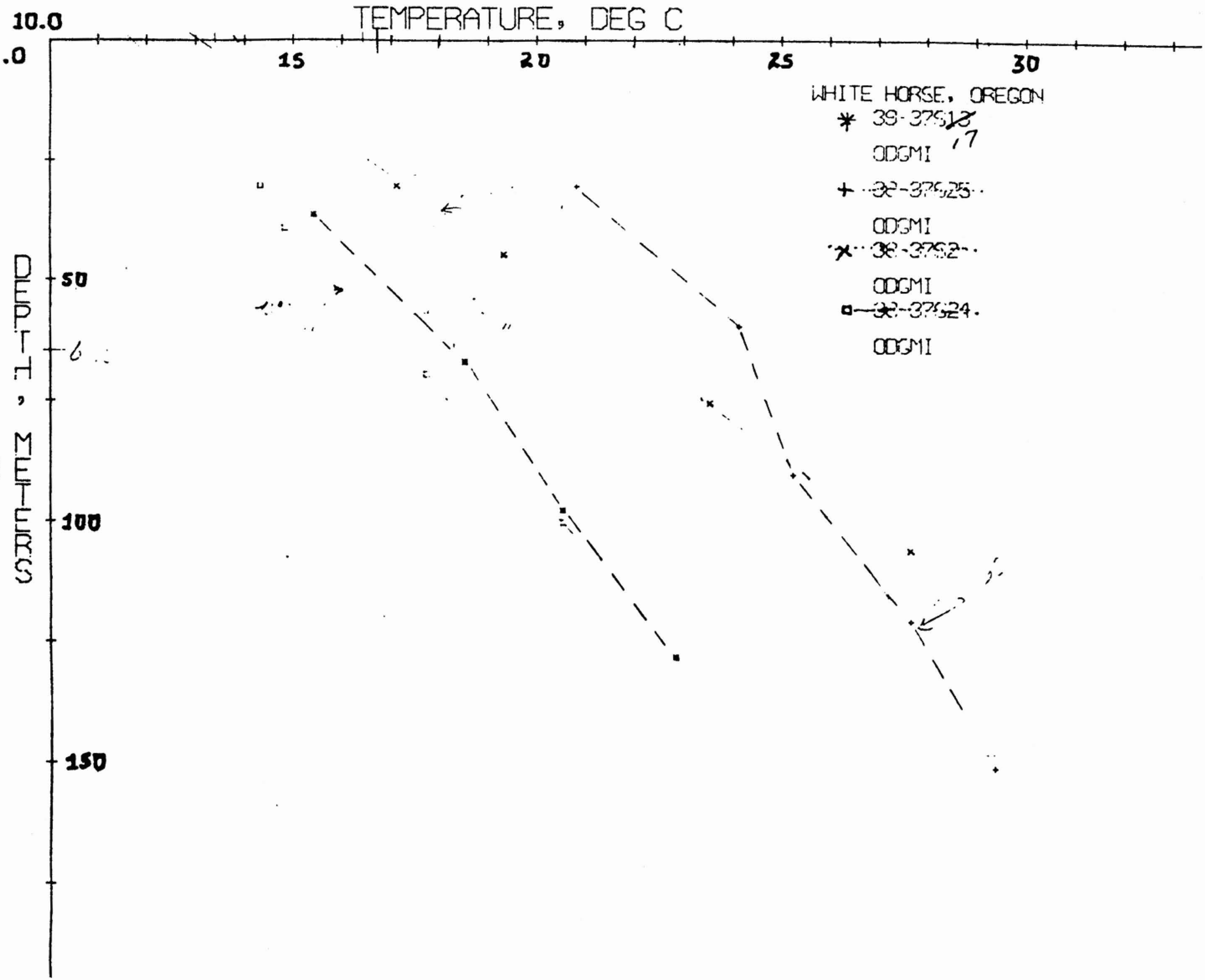
STEENS PROSPECT 2

LOCATION: WH. EHORSE, OREGON
HOLE NUMBER: 3?-3752
DATE MEASURED: ODGMI

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	FEET/DEG F
30.5	100.0	17.100	62.78	.0	.0
44.8	147.0	19.300	66.74	153.5	11.9
75.3	247.0	23.500	74.30	137.8	13.2
105.8	346.9	27.600	81.68	134.5	13.5

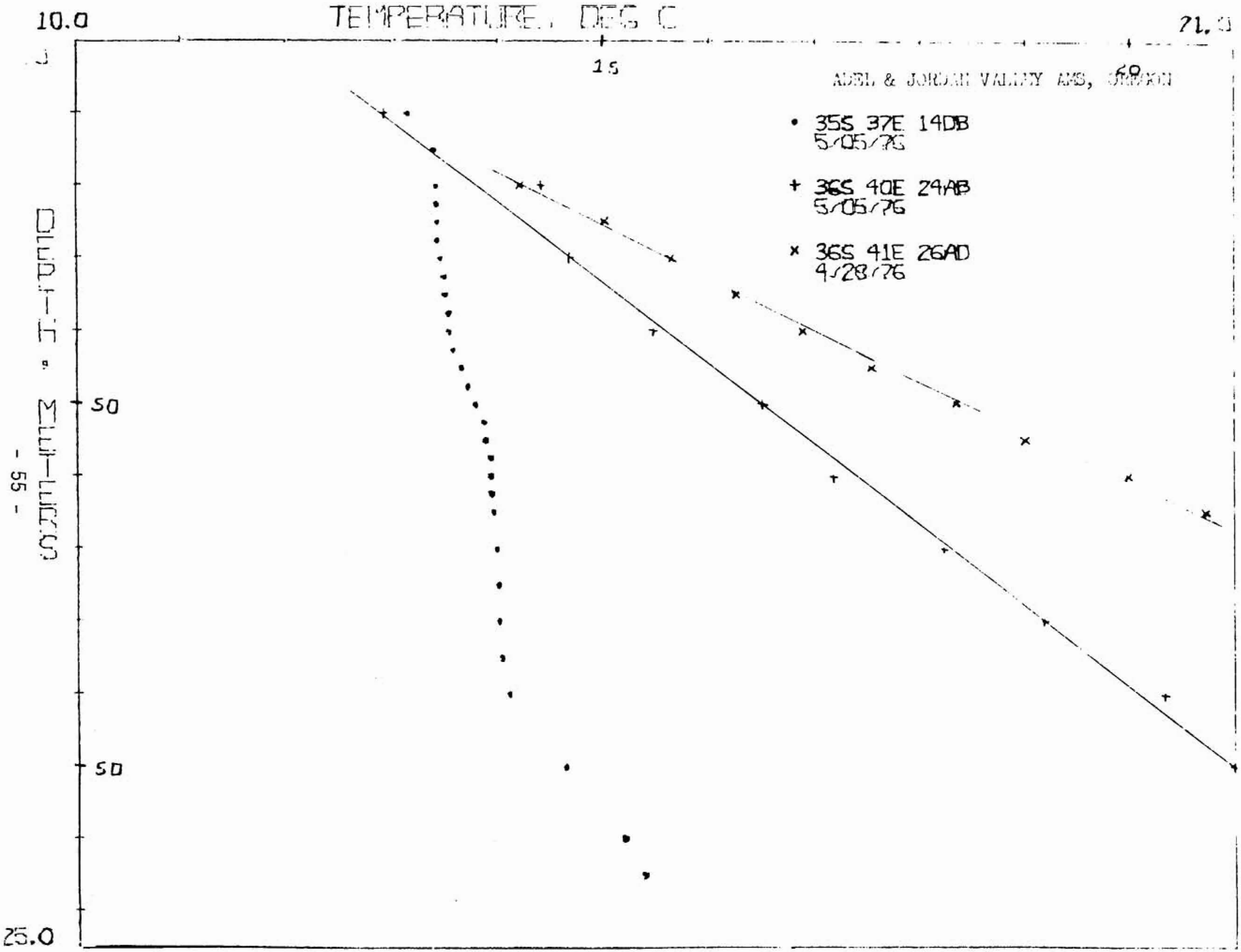
LOCATION: WHITE HORSE, OREGON
HOLE NUMBER: 39-37S~~13~~ 17
DATE MEASURED: 0DGMI

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT FEET/DEG F
36.6	120.0	15.400	59.72	.0	.0
67.1	220.0	18.500	65.30	1[illegible]1.7	17.9
97.5	319.9	20.500	68.90	65.6	27.8
128.0	419.9	22.800	73.04	75.5	24.1


TEMPERATURE, DEG C
10.0
.0
15
20
25
30
WHITE HORSE, OREGON
ODGMI
ODGMI
ODGMI
ODGMI
50
100
150
DEPTH, METERS

LOCATION: ADEL A[illegible]S, OREGON
35S/37E/14DB
HOLE NUMBER: [illegible]
DATE MEASURED: 5/ 5/76

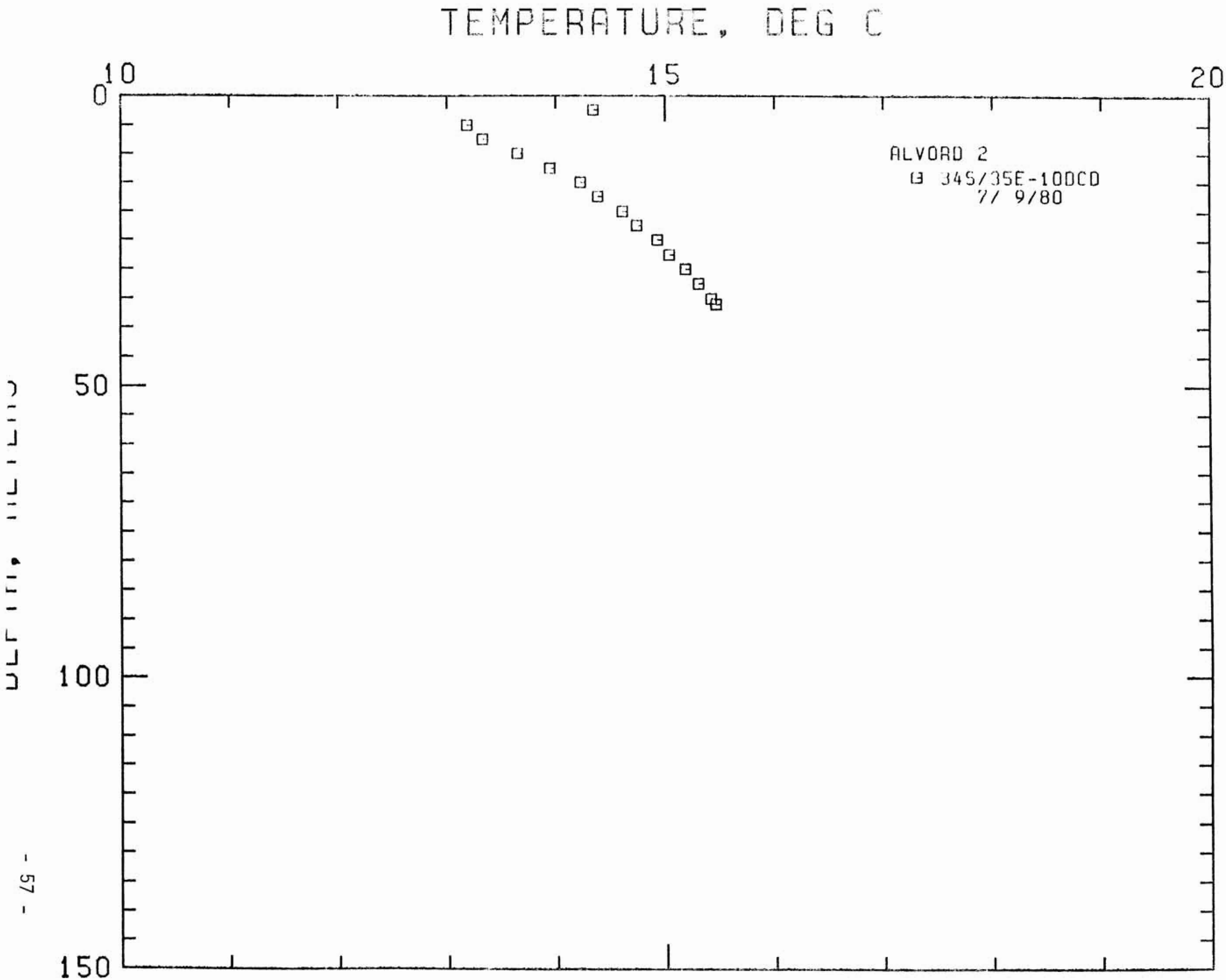
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
10.0	32.8	13.150	55.67	.0	.0
15.0	49.2	13.410	56.14	52.0	2.9
20.0	65.6	13.420	56.16	2.0	.1
22.5	73.8	13.430	56.17	4.0	.2
25.0	82.0	13.430	56.17	.0	.0
27.5	90.2	13.440	56.19	4.0	.2
30.0	98.4	13.460	56.23	8.0	.4
32.5	106.6	13.490	56.28	12.0	.7
35.0	114.8	13.510	56.32	8.0	.4
37.5	123.0	13.540	56.37	12.0	.7
40.0	131.2	13.550	56.39	4.0	.2
42.5	139.4	13.580	56.44	12.0	.7
45.0	147.6	13.660	56.59	32.0	1.8
47.5	155.8	13.710	56.68	20.0	1.1
50.0	164.0	13.790	56.82	32.0	1.8
52.5	172.2	13.870	56.97	32.0	1.8
55.0	180.4	13.890	57.00	8.0	.4
57.5	188.6	13.940	57.09	20.0	1.1
60.0	196.8	13.940	57.09	.0	.0
62.5	205.0	13.950	57.11	4.0	.2
65.0	213.2	13.960	57.13	4.0	.2
70.0	229.6	13.980	57.16	4.0	.2
75.0	246.0	14.000	57.20	4.0	.2
80.0	262.4	14.010	57.22	2.0	.1
85.0	278.8	14.030	57.25	4.0	.2
90.0	295.2	14.100	57.38	14.0	.8
100.0	328.0	14.630	58.33	53.0	2.9
110.0	360.8	15.190	59.34	56.0	3.1
115.0	377.2	15.390	59.70	40.0	2.2



10.0
TEMPERATURE, DEG C
15
20
35S 37E 14DB
5/05/76
36S 40E 24AB
5/05/76
36S 41E 26AD
4/28/76
50
50
25.0

LOCATION: ADEL AMS, OREGON
34S/35E-10DCD
HOLE NAME: ALVORD 2
DATE MEASURED: 7/ 9/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	14.350	57.83	0.0	0.0
5.0	16.4	13.190	55.74	-464.0	-25.5
7.5	24.6	13.330	55.99	56.0	3.1
10.0	32.8	13.650	56.57	128.0	7.0
12.5	41.0	13.950	57.11	120.0	6.6
15.0	49.2	14.230	57.61	112.0	6.1
17.5	57.4	14.390	57.90	64.0	3.5
20.0	65.6	14.610	58.30	88.0	4.8
22.5	73.8	14.740	58.53	52.0	2.9
25.0	82.0	14.930	58.87	76.0	4.2
27.5	90.2	15.040	59.07	44.0	2.4
30.0	98.4	15.190	59.34	60.0	3.3
32.5	106.6	15.310	59.56	48.0	2.6
35.0	114.8	15.420	59.76	44.0	2.4
36.0	118.1	15.470	59.85	50.0	2.7


TEMPERATURE, DEG C
10
15
20
0
50
100
150
ALVORD 2
345/35E-10DCD
7/ 9/80

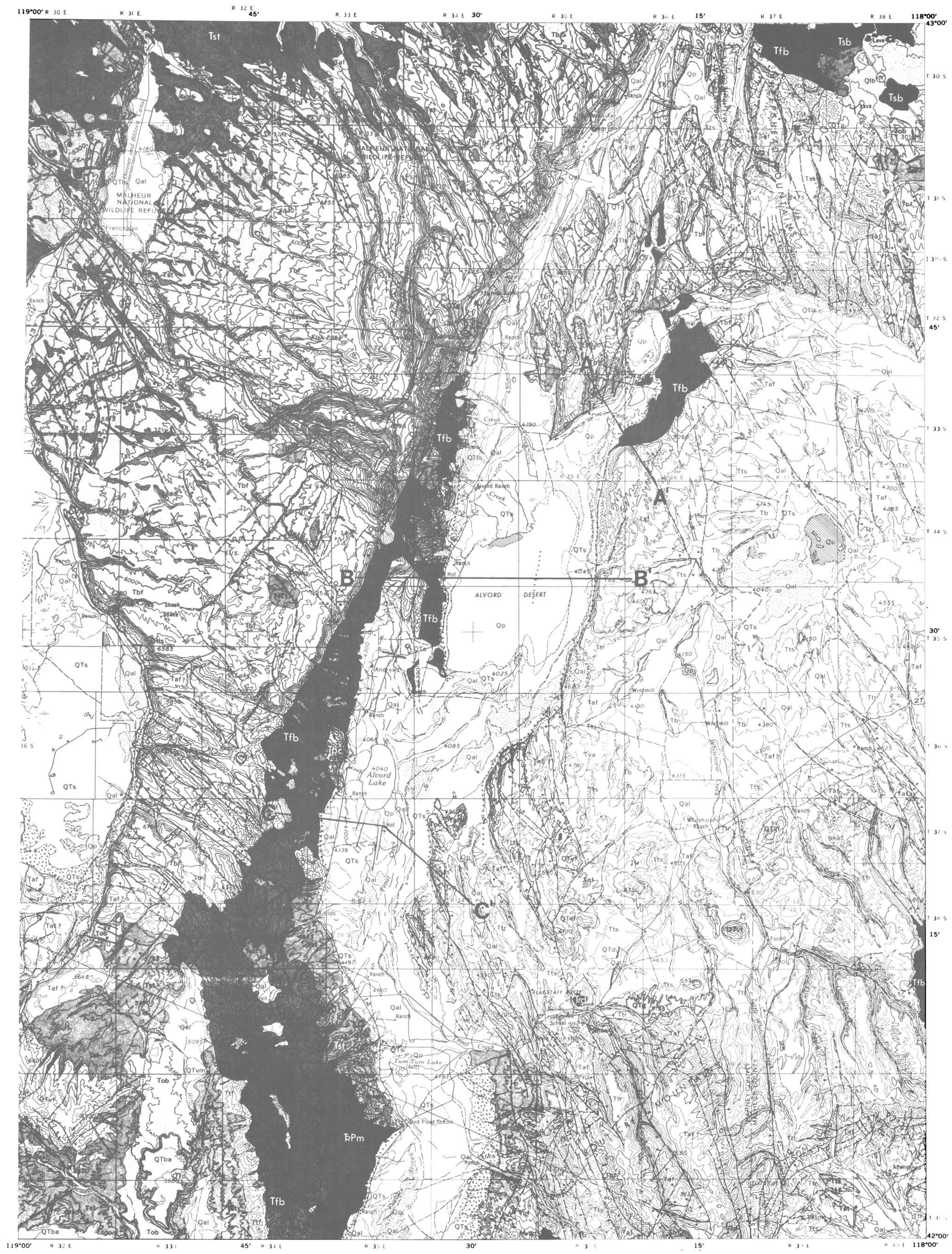
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

PLATE I

OPEN FILE REPORT #0-80-10

Reconnaissance Geologic Map of the Alvord Desert, Harney and Malheur Counties, Oregon

Geology modified from Walker and Repenning (1965)



Base from Army Map Service, 1:250,000, 1958; limited revision by U.S. Geological Survey, 1962

Scale 1:250,000

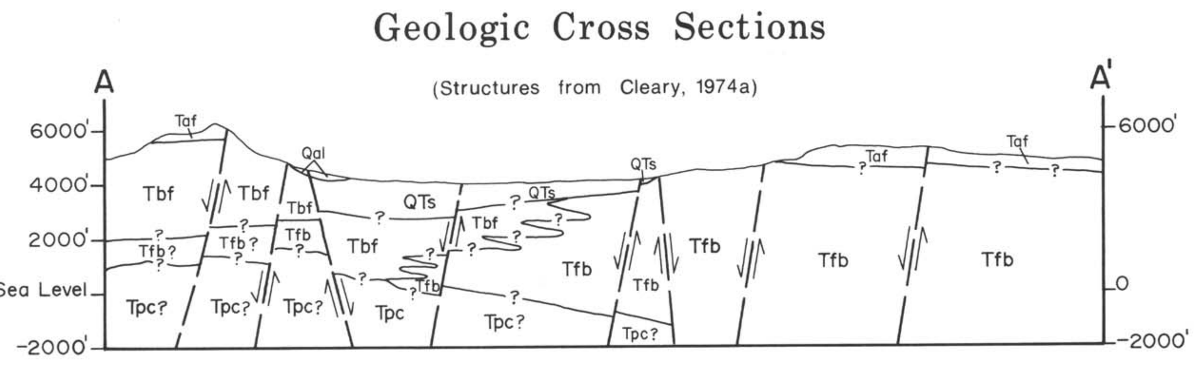
5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers
5 0 5 10 15 Nautical Miles

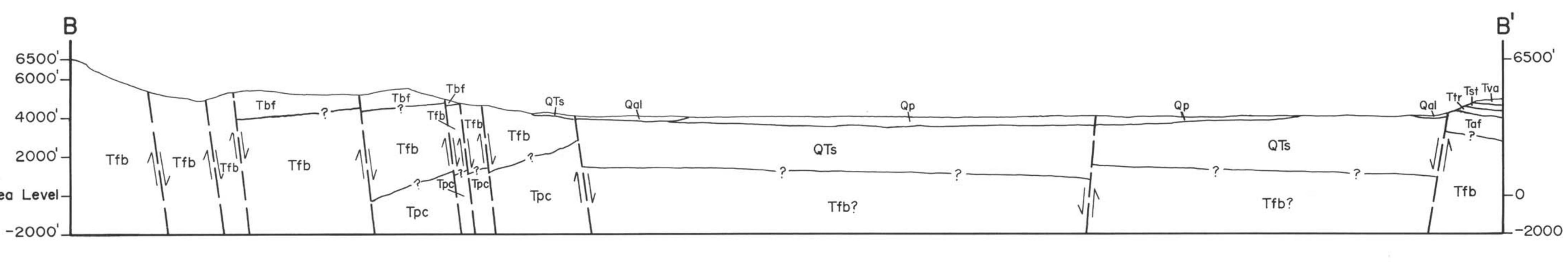
CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

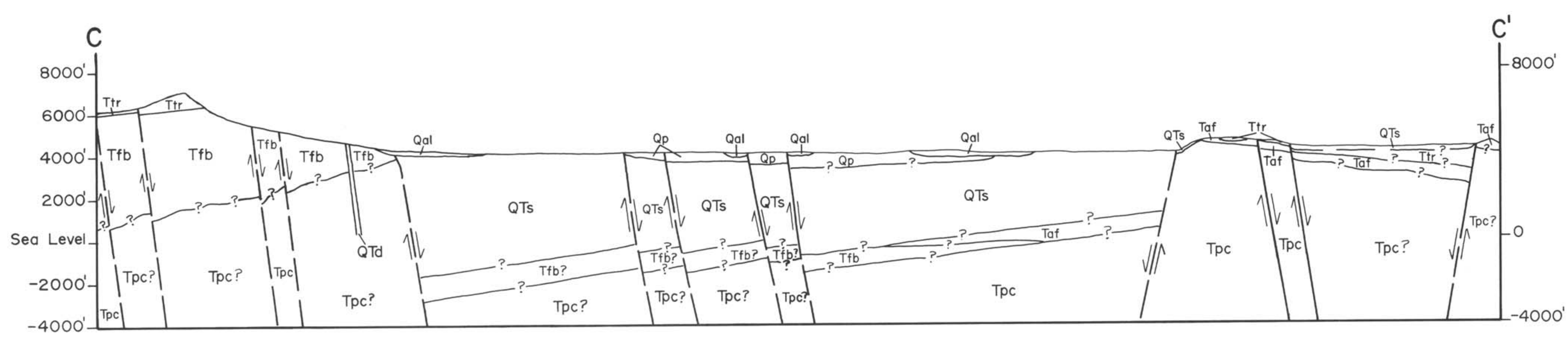
Based on reconnaissance and photogeologic mapping by G. W. Walker, 1959–62, C. A. Repenning, 1961–62, and D. H. Lindsley, 1959 and 1961

Geologic Cross Sections

(Structures from Cleary, 1974a)







EXPLANATION

Qp — Playa deposits: Clay, silt, sand, and some evaporites

Qal — Alluvium: Unconsolidated fluviatile gravel, sand, and silt. In places, includes talus, slope wash, fanglomerate, some small areas of exhumed late Pleistocene and Recent lake beds, and windblown sand. Large areas of windblown sand designated by stipple pattern

QTls — Landslide debris: Mostly unstratified mixtures of basaltic and tuffaceous sedimentary bed rock. In places includes disordered fault blocks, basalt rubble, and talus. Age, mostly Pleistocene; probably includes Pliocene and Recent deposits

Qlb — Late basalt flows: Thin flows of olivine-bearing, diktytaxitic basalt. Commonly highly feldspathic. Age, late Pleistocene or Recent

QTba — Basalt and andesite: Flows mostly of diktytaxitic olivine-bearing basalt and minor basaltic andesite commonly vesicular or scoriaceous but locally dense or platy; generally nonporphyritic; dips less than 5 degrees. Minor interbeds of tuffaceous sedimentary rocks. Age, late Pliocene and Pleistocene

Sedimentary deposits:

QTs — Lacustrine, fluviatile, and aeolian sedimentary rocks, interstratified tuff, ashy diatomite, and unconsolidated clay, sand, silt, and gravel. Includes some small masses of hot spring sinter and tufa. Mostly confined to pluvial lake basins

QTg — Pediment or fluvio-glacial gravels that lie about pluvial lake levels

Tuffaceous sedimentary rocks, tuffs, and interbedded basaltic and andesitic flows:

Tsb — Tuffaceous siltstone, sandstone, conglomerate, tuff, and interbedded basalt or andesite flows, flat to gently dipping. May intertongue with upper part of *Tb*. In places subdivided into the following units:

Tst — Semiconsolidated lacustrine tuffaceous sandstone and siltstone, ash and ashy diatomite, conglomerate and minor fanglomerate, boulder-bearing slope wash, vitric-crystal and vitric-lithic tuff, pumice lapilli tuff, and tuff breccia; stratigraphic location uncertain, may be equivalent in part to Pike Creek Formation

Tob — Mostly thin, vesicular, subophitic to intergranular, diktytaxitic basalt flows, gray to black, containing small to moderate amounts of olivine that is fresh or slightly altered to iddingsite. Flows locally consist of platy olivine-bearing andesite or basaltic andesite

Tb — Basalt: Basalt flows, generally dipping 5 to 10 degrees. Some major topographic rims capped by these flows. Basalt is commonly highly feldspathic, contains small to moderate amount of slightly altered olivine, and exhibits both subophitic and diktytaxitic textures. Flows locally porphyritic. May intertongue with lower part of *Tsb*. Age, late Miocene and early Pliocene

Tuffaceous sedimentary rocks, tuffs, and silicic flows:

Ttf — Tuff of rhyolitic and dacitic composition, tuffaceous sedimentary rocks, and areally restricted rhyodacitic flows. Some tuffs partly to densely welded. Laps on unit *Tfb* with slight angular discordance. Age mostly middle(?) and late Miocene but may contain some clastic rocks that are early Pliocene. In places, subdivided into the following units:

Tts — Mostly fine-grained tuffaceous sedimentary rocks and tuffs representing flood plain or shallow lake deposits. In southeastern part of quadrangle contains more abundant lake beds, including interlayers of ashy diatomite locally with fish and plant remains

Ttr — Partly to densely welded tuffs and areally restricted rhyolite or dacite flows. Most glass partly or completely converted to alkali feldspar and cristobalite either from gas phase alteration or devitrification. Grades laterally into exogenous domes *QTvf*. Shows both conformable (interfingering) and unconformable relations with unit *Tts*. Locally grades downward into andesites of *Taf*

Flows and flow breccias:

Tfb — Basalt and andesite flows and flow breccias that are variable in texture and mineral composition. Minor interbeds of tuffaceous sedimentary rocks, tuff, scoria, and, near top of unit, some local layers of silicic volcanic rocks. Shows unconformable relations with underlying Pike Creek Formation. Age, middle(?) and late Miocene. In places subdivided into the following petrographic units:

Taf — Mostly platy andesite flows but contains some flows of porphyritic olivine basalt, basaltic and andesitic flow breccias, and minor amounts of interbedded tuffaceous sedimentary rocks and tuff. Near top of unit, some local layers of silicic (dacitic?) tuffs, breccias, and brecciated flows (?)

Tbf — Massive basalt flows and minor interbeds of tuff and scoria. A few flows are uniformly fine grained with pilotaxitic texture; most are subophitic or diktytaxitic and many are porphyritic; plagioclase (An 60-70) is dominant phenocryst in porphyritic phases. Many flows, particularly high in section, are highly feldspathic; most contain small to moderate amounts of olivine commonly altered to montmorillonite or illite or to "iddingsite." In thick, very widespread lens or attenuated layers which show both conformable (interfingering) and unconformable relations with unit *Taf*

Tpc — Pike Creek Formation: Mostly well-lithified and altered silicic tuffaceous sedimentary rocks, but including some tuffs and tuff breccias and intrusive and extrusive masses of rhyolite. Age, late Oligocene(?) and early(?) Miocene

Mzqd — Intrusive rocks: Granodiorite and quartz diorite, partly gneissic. In places, cut by pegmatite stringers. Also includes some "intrusive" masses of quartz albite

TR Pm — Metamorphosed sedimentary and volcanic rocks: Mixed assemblage of silicic grits, (sub)graywacke, porphyritic mafic flows, calc-hornfels, quartz muscovite schist, muscovite-chlorite-actinolite schist, and epidiorite

QTd — Dikes, sills, and necks: Mostly basalt or gabbro but includes some andesite. Age, Miocene, Pliocene, and Pleistocene(?)

QTp — Pyroclastic rocks of basaltic cinder cones: Mostly unconsolidated, reddish, fine to coarse scoriaceous basaltic ejecta. Age, Miocene(?) Pliocene, and Pleistocene(?)

Rocks of stratovolcanoes and domes:

QTv — Agglomerate, breccia, scoria, cinders, ash, flows, and intrusive masses forming constructional volcanic features. Age, Miocene, Pliocene, and early Pleistocene(?). In places divided into:

QTvf — Mostly large complex exogenous domes and related flows and flow breccias of rhyodacitic composition. Includes small vent areas composed largely of breccia and coarse, highly altered welded tuff

QTvm — Mostly stratovolcanoes dominantly of basaltic or andesitic composition

Volcanic and sedimentary rocks:

Tva — Flows of platy andesite, basaltic andesite, and glassy black or gray dacite or rhyodacite. Age, mostly late Miocene or early Pliocene

Tvb — Thin, discontinuous basalt flows

Tvp — Tuffaceous sedimentary rocks and tuffs

Trd — Intrusive rhyolite and dacite: Plugs, small endogenous domes, and intrusive breccias of rhyolitic to dacitic composition, and a little soda rhyolite. Age, Miocene and Pliocene

Contact

Long-dashed where approximately located; short-dashed where inferred

Fault

Dashed where approximately located; dotted where concealed or inferred. Bar and ball on downthrown side

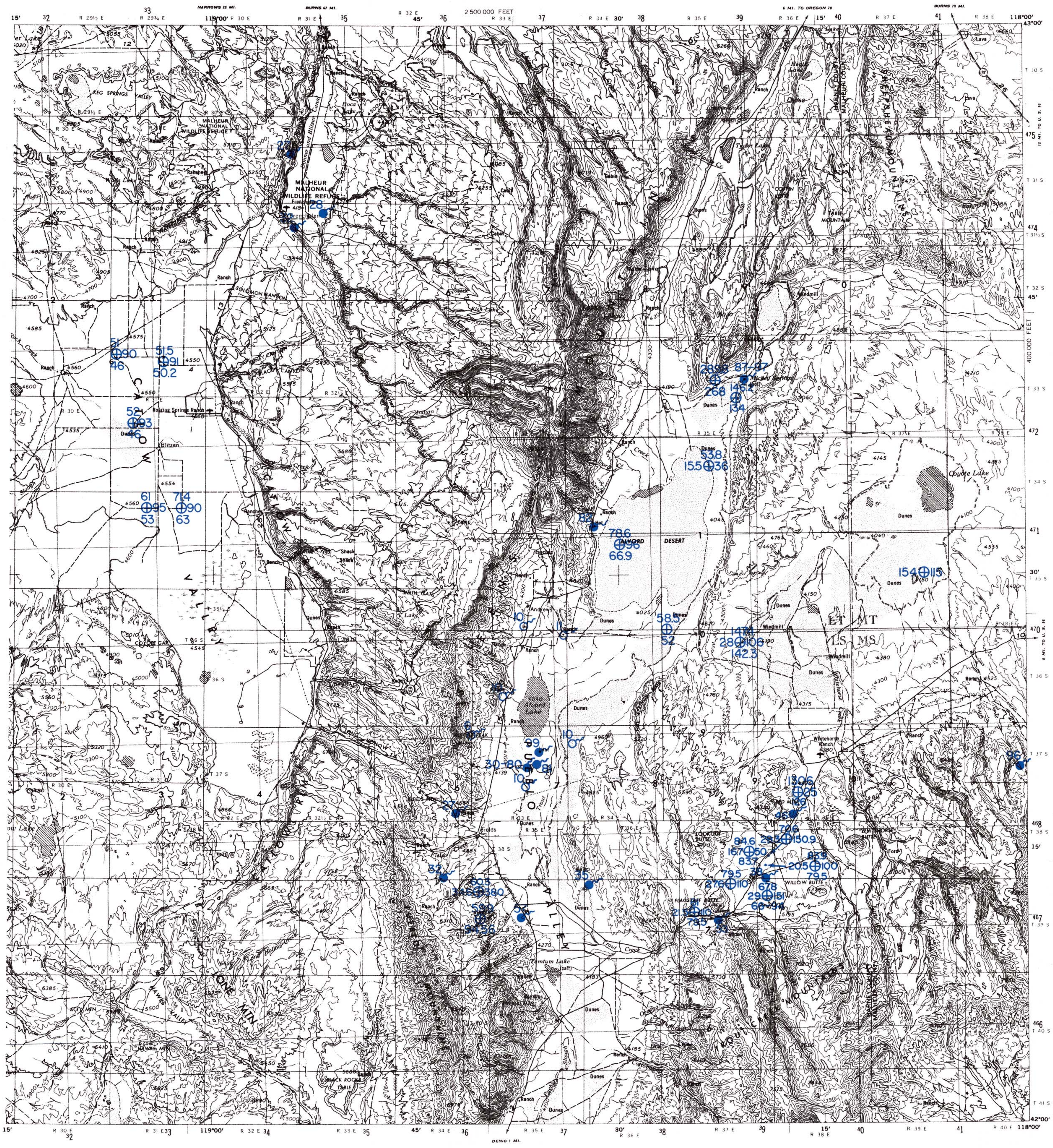
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

PLATE II

OPEN FILE REPORT #0-80-10

PRELIMINARY GEOTHERMAL RESOURCE MAP OF THE ALVORD DESERT AREA, OREGON

Compiled by John R. Petros



EXPLANATION

80 — GRADIENT (°C Km^{-1})
150 — DEPTH PROBED (m)
⊕ — HOLE LOCATION
83 — HEAT FLOW (mWm^{-2})
22.1 — BOTTOM HOLE TEMP. (°C)

38 — THERMAL SPRING
WATER TEMP. (°C)

10 — COLD SPRING
WATER TEMP. (°C)

Prepared by the U.S. Army Topographic Command (BEART), Washington, D.C. Compiled in 1955 by photogrammetric methods from aerial photographs taken 1953. Photographs field annotated 1955. Revised by the U.S. Geological Survey 1970.

Area covered by dashed light-blue pattern is subject to controlled inundation

100,000-foot grids based on Oregon coordinate system, south zone

Location of geodetic control established by government agencies is shown on corresponding 1:250,000-scale Geodetic Control Diagram

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometres

5 0 5 10 15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

Map prepared by
STATE OF OREGON
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