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PRELIMINARY GEOLOGY AND  
GEOTHERMAL RESOURCE POTENTIAL  
OF THE  
SOUTHERN HARNEY BASIN,  
OREGON

by

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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.

## CONTENTS

INTRODUCTION . . . . .	1
GEOLOGY . . . . .	3
Introduction . . . . .	3
Volcanic stratigraphy . . . . .	3
Structural geology . . . . .	8
GEOPHYSICS . . . . .	11
WATER CHEMISTRY . . . . .	12
GEOTHERMAL-GRADIENT AND HEAT-FLOW DATA . . . . .	25
CONCLUSIONS AND RECOMMENDATIONS . . . . .	30
BIBLIOGRAPHY OF THE HARNEY BASIN . . . . .	31
APPENDIX A: Formulas used in calculations . . . . .	37
APPENDIX B: Geothermal-gradient data . . . . .	39

## ILLUSTRATIONS

### FIGURES

1. Map showing location of study area, southern Harney Basin, Oregon. 2

### TABLES

1. Radiometric (K/Ar) ages of selected rocks, southern Harney Basin .	4
2. Bulk chemical composition of selected rocks, southern Harney Basin	6
3. Spring and well chemistry, southern Harney Basin . . . . .	13
4. Geothermetric calculations of minimum reservoir temperatures for thermal waters, southern Harney Basin . . . . .	19
5. Geothermal-gradient data, southern Harney Basin . . . . .	26

### MAPS (folded, in envelope)

Plate I. Geologic map of the southern Harney Basin, Oregon  
(northwest quarter)

Plate II. Geologic map of the southern Harney Basin, Oregon  
(northeast quarter)

Plate III. Geologic map of the southern Harney Basin, Oregon  
(southwest quarter)

Plate IV. Geologic map of the southern Harney Basin, Oregon  
(southeast quarter)

Plate V. Lineament map of the Harney Basin, Oregon

Plate VI. Aeromagnetic map of the southern Harney Basin, Oregon

Simple Bouguer gravity anomaly map of the Harney Basin, Oregon

Aeromagnetic map of the Harney Basin, Oregon

## INTRODUCTION

The study area is located at the southern end of a large, quasi-circular topographic low in central eastern Oregon known as the Harney Basin (Figure 1). Limits of the study area were arbitrarily determined according to the boundaries of available U.S. Geological Survey (USGS) topographic maps as  $43^{\circ}00'$  on the south,  $43^{\circ}30'$  on the north,  $118^{\circ}30'$  on the east, and  $119^{\circ}30'$  on the west. This study, performed under U.S. Department of Energy Contract No. DE FC07-79ET27220, was undertaken to estimate the geothermal potential of the area, using various methods including compilation of existing data, reconnaissance geologic mapping, lineament analysis, well and spring geochemistry, and accrual of geothermal-gradient data.

Geographically, the study area is comprised of a roughly circular, relatively flat, closed drainage basin that covers an area of  $21,000 \text{ km}^2$  ( $8,100 \text{ mi}^2$ ). Included within the basin are volcanic mounds surrounded by mountainous highlands. Drainage within the basin is into several closed desert lakes, including Malheur, Harney, and Mud Lakes, through Silvies River from the north, Donner und Blitzen River from the south, Warm Springs Creek from the west, and Malheur Slough from the east. Total relief within the basin is less than 9 m (30 ft), total relief in the highlands more than 500 m (1,600 ft). The only population centers are the small farming communities of Crane, Princeton Post Office, and Diamond, all in the eastern portion of the study area. The remainder of the southern basin is comprised of swampy bird habitats, cattle ranches, and range land.

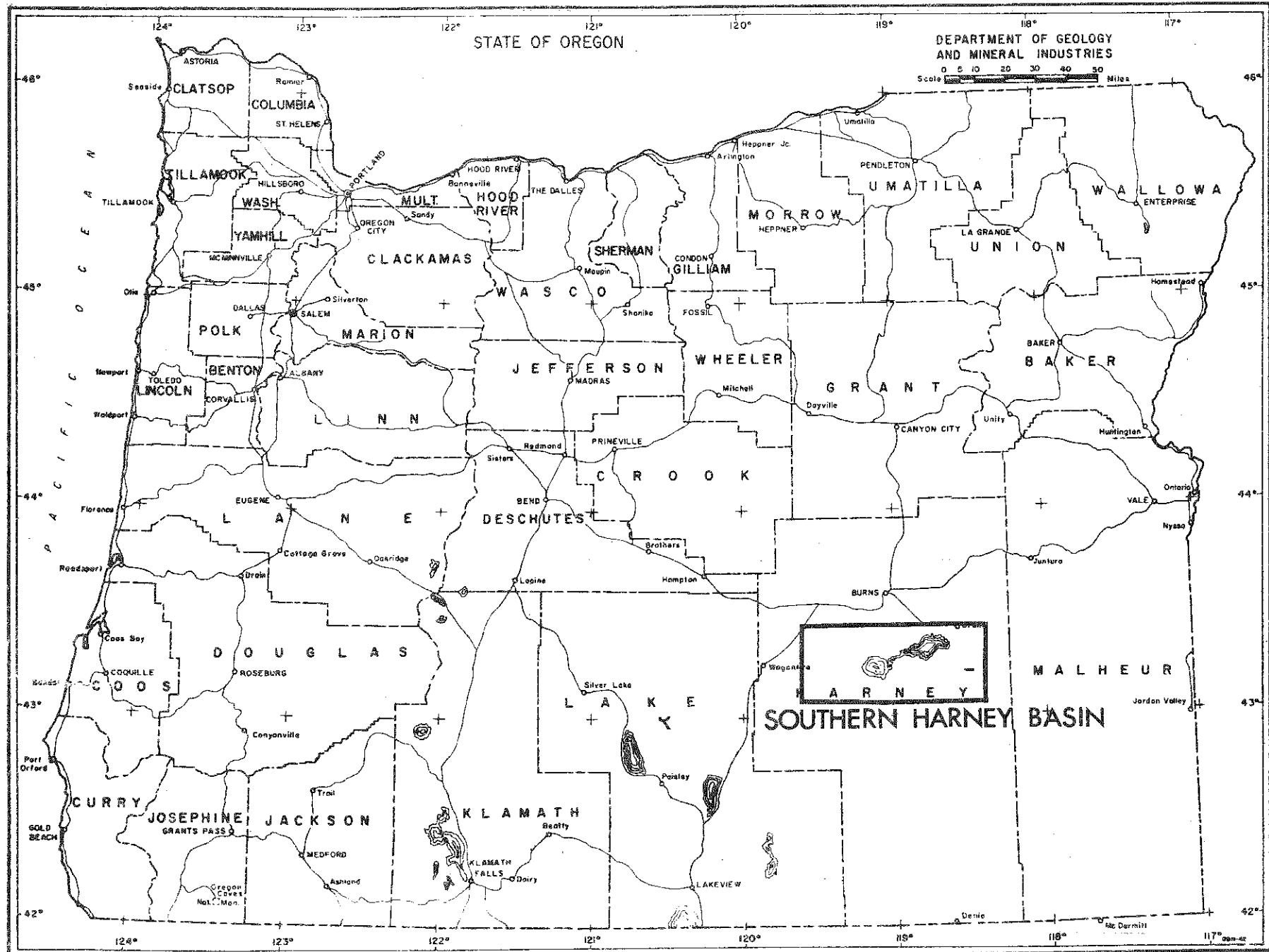


Figure 1: Map showing location of study area.

## GEOLOGY

### Introduction

The geologic study of the area (Plates I-IV) consisted of (1) a field check and minor revisions of a study of the western half of the area by Parker (1974), and (2) an original reconnaissance study of the eastern half of the area during the fall of 1979 and spring of 1980. Quadrangles mapped in reconnaissance include the Crane and Lawen 15-minute quadrangles and the Jackass Butte, Jackass Butte N.E., Diamond Swamp, Diamond, Adobe Flat, Barton Lake, and Coyote Buttes  $7\frac{1}{2}$ -minute quadrangles. Lithologies were based on hand specimen identifications, limited K/Ar ages (Table 1), and available bulk chemistry (Table 2). Areal extents of various units and specific points were located by using Brunton compass and pacing; data were plotted on USGS quadrangle maps without the aid of aerial photos.

### Volcanic stratigraphy

The geology of the southern Harney Basin is comprised of a framework of two flat-lying, extensive, late Miocene ash-flow sheets onlapping a regional unit of early Miocene flood basalts. The ash flows, in order of increasing age, are the Rattlesnake and Devine Canyon Ash-flow Tuffs (Walker, 1979). They are separated by discrete fluvial-lacustrine sedimentary units, flood basalts and their vents, and silicic intrusions. Trace-element studies by Parker and Armstrong (1972) indicate that the ash-flow tuffs, the silicic intrusives, and the related mafic flows of the area form a bimodal compositional assemblage. Though detailed relationships are unclear at this time, at least one and possibly two calderas are present in the study area, one located beneath Malheur and Harney Lakes being the source of the Rattlesnake ash-flow sheet (Blank, 1974; Walker, 1979). The oldest unit recognized in the field is that of the early Miocene flood basalts found along the eastern

Table 1. Radiometric (K/Ar) ages of selected rocks of the southern Harney Basin

<u>Sample no.*</u>	<u>Location</u>	<u>Rock type</u>	<u>Age**</u>	<u>Stratigraphic unit</u>
PA-300	119°04'18" 43°03'06"	Basalt	<sup>w</sup> 8.8±1.4 my	Tmbh
PA-311B	119°22'23" 43°09'03"	Welded tuff	<sup>w</sup> 8.6±0.2 my	Tmtd
PA-146	119°21'11" 43°13'80"	Rhyolite	<sup>w</sup> 8.4±1.3 my	Tmto
PA-119	119°13'30" 43°14'19"	Rhyolite	<sup>w</sup> 8.2±0.12 my	Tmtp
PA-250	119°03'45" 43°02'27"	High Al basalt	<sup>w</sup> 7.9±0.9 my	Tmbh
PA-316D	119°08'45" 43°17'02"	Rhyolite	<sup>w</sup> 7.8±0.5 my	Tmro
PA-243	119°03'45" 43°04'56"	Welded tuff	<sup>s</sup> 7.1±0.10 my	Tmtr
G-165-68	118°34'48" 43°24'48"	Basalt	<sup>p</sup> 6.91±1.09 my	Tmbd
PA-330	119°22'23" 43°09'03"	Welded tuff	<sup>w</sup> 6.7±0.4 my	Tmtr
PA-311G	119°22'23" 43°09'03"	Welded tuff	<sup>w</sup> 6.6±0.2 my	Tmtr
W-2-70	119°18'00" 43°28'48"	Rhyodacite	<sup>a</sup> 6.5±0.3 my <sup>b</sup> 6.1±0.2 my	Tmrp
PA-6-70	119°27'51" 44°46'54	Welded tuff	<sup>a</sup> 6.4±0.2 my	Tmtr
PA-214	119°18'00" 43°30'18"	Rhyolite	<sup>w</sup> 5.6±0.4 my <sup>b</sup> 6.4±0.2 my	Tmrp
PA-160	119°28'00" 43°16'30"	Andesite	<sup>w</sup> 5.8±0.8 my	Tmbi
PA-41	119°06'34" 43°20'24"	Alkali basalt	<sup>w</sup> 2.8±0.2 my	Qtb
PA-158	119°12'00" 43°13'48"	Rhyolite	<sup>w</sup> 2.1±0.24 my <sup>b</sup> 2.7±0.4 my	Qtr

\*References: PA - from Parker and Armstrong, 1972; G - from Greene and others, 1972; W - from Walker and others, 1974; SH - from samples taken for this report, unpublished analyses by University of Utah Research Institute (UURI) Stan Evans and Duncan Foley, analysts.

\*\*w-- whole rock age; s - sanidine age; a - anorthoclase age; b - biotite age;  
p - plagioclase age; ps - partial separation age.

Table 1. Radiometric (K/Ar) ages of selected rocks of the southern Harney Basin--Continued

<u>Sample no.*</u>	<u>Location</u>	<u>Rock type</u>	<u>Age**</u>	<u>Stratigraphic unit</u>
PA-14	119°00'23" 43°26'24"	High Al basalt	<sup>w</sup> 2.6±0.3 my	Qtb
G-32-67	119°00'30" 43°27'00"	Basalt	<sup>w</sup> 2.38±0.07 my	Qtb
SH-4	118°56'45" 43°2'00"	Andesite	<sup>p</sup> 16.7±0.6 my	Tmba
SH-12	118°50'22" 43°15'40"	Basalt	<sup>w</sup> 2.91±0.38 my	Qtb (?)
SH-105	118°30'55" 43°14'45"	Rhyodacite	<sup>w</sup> 11.3±0.5 my	Tmrdr
SH-106	118°30'54" 43°21'53"	Basalt	<sup>p</sup> 11.1±1.3 my	Tmba
SH-106A	118°30'05" 43°21'45"	Basalt	<sup>ps</sup> 9.44±0.8 my	Tmba
SH-113	118°53'06" 43°08'13"	Basalt	<sup>ps</sup> 8.07±0.69 my	Tmbhv

\* References: PA - from Parker and Armstrong, 1972; G - from Greene and others, 1972; W - from Walker and others, 1974; SH - from samples taken for this report, unpublished analyses by University of Utah Research Institute (UURI) Stan Evans and Duncan Foley, analysts.

\*\*w - whole rock age; s - sanidine age; a - anorthoclase age; b - biotite age;  
p - plagioclase age; ps - partial separation age.

Table 2. Bulk chemical composition of selected rocks of the southern Harney Basin. (Letters at top of each column indicate sample number and map symbol for stratigraphic unit. All values are in weight percent.)

<u>Compo-</u> <u>nent</u>	<u>*P-159</u> <u>QTb</u>	<u>P-194</u> <u>QTmv</u>	<u>P-14</u> <u>QTb</u>	<u>P-40</u> <u>QTmv</u>	<u>P-58</u> <u>QTb</u>	<u>P-181</u> <u>QTb</u>
SiO <sub>2</sub>	48.5	48.6	48.7	48.7	48.9	49.1
TiO <sub>2</sub>	3.51	0.87	1.43	1.97	1.47	1.60
Al <sub>2</sub> O <sub>3</sub>	12.6	16.9	17.4	16.3	14.0	15.4
FeO (Total Fe)	13.4	9.0	10.2	9.7	10.8	9.4
MgO	6.2	9.1	8.4	8.9	11.0	7.5
CaO	9.7	12.4	11.2	12.0	10.3	10.9
Na <sub>2</sub> O	3.8	2.6	2.8	2.4	2.3	3.2
K <sub>2</sub> O	1.15	0.29	0.29	0.26	0.38	0.32
Total	98.26	99.47	100.42	99.97	99.15	97.10
	<u>P-212</u> <u>QTb</u>	<u>P-300</u> <u>Tmbh</u>	<u>P-73-4</u> <u>Tmbh</u>	<u>P-52</u> <u>QTb</u>	<u>P-41</u> <u>QTb</u>	<u>P-250</u> <u>Tmbh</u>
SiO <sub>2</sub>	49.5	49.5	49.5	50.0	50.1	50.2
TiO <sub>2</sub>	1.45	1.72	1.93	1.36	1.70	1.38
Al <sub>2</sub> O <sub>3</sub>	14.8	15.4	15.5	15.6	15.0	17.1
FeO (Total Fe)	11.0	12.0	12.0	10.3	11.0	10.4
MgO	7.9	8.2	6.5	10.0	7.1	8.2
CaO	10.9	10.5	11.0	10.2	10.6	11.2
Na <sub>2</sub> O	3.5	3.1	3.4	2.8	3.0	2.7
K <sub>2</sub> O	0.32	0.42	0.32	0.34	0.80	0.35
Total	99.05	100.84	100.15	100.60	98.50	101.53
	<u>P-184</u> <u>QTb</u>	<u>P-199</u> <u>QTmv</u>	<u>P-193</u> <u>QTmv</u>	<u>P-44</u> <u>QTmv</u>	<u>P-206</u> <u>QTmv</u>	<u>P-185</u> <u>QTb</u>
SiO <sub>2</sub>	50.2	50.4	50.8	51.0	51.2	51.7
TiO <sub>2</sub>	3.27	1.52	1.14	0.83	1.17	2.82
Al <sub>2</sub> O <sub>3</sub>	13.1	14.7	14.9	15.6	14.4	13.6
FeO (Total Fe)	13.7	11.0	10.5	9.2	9.8	12.6
MgO	5.5	8.0	7.9	8.5	8.2	5.6
CaO	9.0	11.5	12.3	12.5	11.8	8.5
Na <sub>2</sub> O	3.9	3.4	3.1	3.0	3.0	3.8
K <sub>2</sub> O	1.04	0.35	0.21	0.19	0.53	1.28
Total	99.71	100.87	100.64	100.63	100.13	99.50

\*References: P - from Parker, 1974; G - from Greene, 1973.

Table 2. Bulk chemical composition of selected rocks of the southern Harney Basin--Continued. (Letters at top of each column indicate sample number and map symbol for stratigraphic unit. All values are in weight percent.)

<u>Component</u>	*P-278 <u>Tmbh</u>	P-160 <u>Tmbi</u>	P-197 <u>QTmv</u>	P-245D <u>Tmtd</u>
SiO <sub>2</sub>	52.6	57.6	63.7	71.3
TiO <sub>2</sub>	1.07	1.25	0.75	0.35
Al <sub>2</sub> O <sub>3</sub>	15.5	14.7	12.2	13.4
FeO (Total Fe)	10.0	8.6	6.0	4.5
MgO	6.8	4.2	4.1	0.41
CaO	10.6	7.0	10.2	1.9
Na <sub>2</sub> O	3.2	4.2	1.9	3.85
K <sub>2</sub> O	0.82	2.0	1.9	6.0
Total	100.59	99.55	100.75	101.71
<u>Component</u>	P-146 <u>Tmro</u>	P-119 <u>Tmtp</u>	P-215 <u>Tmrp</u>	
SiO <sub>2</sub>	73.2	73.8	73.9	
TiO <sub>2</sub>	0.47	0.13	0.28	
Al <sub>2</sub> O <sub>3</sub>	13.5	11.7	13.6	
FeO (Total Fe)	2.65	3.0	1.7	
MgO	0.6	0.15	0.5	
CaO	1.41	1.2	1.90	
Na <sub>2</sub> O	3.9	4.45	3.4	
K <sub>2</sub> O	4.71	4.5	4.58	
Total	100.12	97.93	99.76	
<u>Component</u>	P-245L <u>Tmtr</u>	P-214 <u>Tmrp</u>	P-290 <u>Tmtr</u>	
SiO <sub>2</sub>	75.0	76.0	76.4	
TiO <sub>2</sub>	0.20	0.08	0.13	
Al <sub>2</sub> O <sub>3</sub>	11.8	12.9	11.7	
FeO (Total Fe)	2.7	0.75	2.7	
MgO	0.15	0.4	0.7	
CaO	0.6	1.6	0.35	
Na <sub>2</sub> O	3.12	3.4	4.4	
K <sub>2</sub> O	6.3	4.88	4.28	
Total	99.87	100.01	100.66	

\*References: P - from Parker, 1974; G - from Greene, 1973.

portion of the mapped area. Dates in adjacent areas indicate ages of 12.1 to 20.2 m.y.; a date taken for this report from Jackass Butte in the south-central portion of the map yielded an age of 16.7 m.y. The youngest rocks are the basalts associated with the Holocene Diamond Craters vent area for which there is a reported date of  $15,000 \pm 2,000$  years, as determined by hydration rind method (Norm Peterson, 1980, personal communication). These youngest rocks directly overlie a second set of young flood basalts which issued from vents mapped immediately south of Malheur Lake along what is probably a ring fracture zone of the caldera mentioned above. A third group of young lavas are the extensive flood basalts which issued from the Dog Mountain-Freeman Butte area. They have been eroded to form reverse topographic features such as Wrights Point and were dated by Parker (1974) at 2.6 to 2.8 m.y. The extensive age determinations available for this study (Table 1) indicate a strong relationship between age of basaltic eruption, age of silicic event, and, in two cases, age of ash-flow eruption. These age/modal relationships are shown in the time-rock charts on the accompanying geologic maps (Plates I-IV). There are still, however, numerous small phreatic and subaqueous vents which do not have lavas that can be dated and whose absolute age relationships, therefore, are unclear and which may, in some cases, be of very young age.

#### Structural geology

Faulting in the southern Harney Basin follows two general trends. The first is the Basin-Range trend (approximately north-south) which occurs in only a limited area immediately north of Crane in the extreme northwest corner of the map. The age of this normal faulting is not clear. However, it does cut the youngest unit present (6.1 m.y.).

The second trend is the Brothers fault zone trend ( $N.25^{\circ}-35^{\circ}W.$ ), which dominates the remainder of the map and cuts all bedrock units present,

including the 15,000-year-old Diamond Craters. All motion in this trend appears to be dip-slip. However, the presence of lateral-slip or oblique-slip faulting cannot be ruled out. Several authors (McLeod and others, 1975) feel the Brothers fault zone may be, in fact, the surface expression of a right-lateral wrench system at depth.

The intersection of the two fault trends is in the southeast corner of the map (Plate IV), in the Riddle Mountain-Diamond Craters area (a portion of which remains unmapped). This area is a fault-shattered zone which shows considerable coxcomb-like faulting on small spacing with short-period monoclinal folding and rotating of the discrete blocks between individual faults. Two adjacent structural domes also occur in this area, connected from dome crest to dome crest by a horst-like fault ridge and separated by one, and possibly two, small structural basins. At the leading edge of this zone is the Diamond Craters vent area, which, in itself, is cut by several faults of the Brothers trend. Structural interpretation of this complex area is difficult. It seems that the structures are controlled by a local compressional regime and that Diamond Craters is, in some way, closely related to the intense faulting and folding.

Folding in the southern Harney Basin, with the exception of that previously described, is generally in the form of broad, shallowly dipping anticlines and synclines plunging toward the center of the basin. One such fold in the Crane area plunges west toward the basin. Here, the older ash-flow units and basalts have been down-folded and infilled with 6.1-m.y.-old basalts. This age is slightly younger than the 6.5-m.y. age of the Rattlesnake Ash-flow Tuffs (Walker, 1979), and the down-folding may have been in response to caldera formation and subsequent volume loss.

A lineament study (Plate V) prepared for this report shows a general one-to-one correspondence of structural trends with the mapped fault trends. It also shows a number of lineaments which cross the alluvial-filled basin but which could not be traced through geologic mapping.

Individual blocks within the fault zones, in general, dip back toward the center of the basin. However, during the mapping project, a number of blocks that dipped away from the basin were found. The basin itself has been formed by downwarping which began during middle to late Miocene (Walker, 1979). The process was caused by loss of material through volcanic eruption of the extensive ash-flow sheets and numerous flood basalts and, to a lesser extent, by the loss of material volume due to loss of stored heat (Blackwell, 1980, personal communication).

## GEOPHYSICS

The only available geophysical survey for the southern Harney Basin is an aeromagnetic survey flown in 1972 by the USGS (Plate VI). Because of the dramatic contrast between the relative magnetic susceptibilities of mafic and silicic lavas, a good correlation between structure and rock type and magnetic trends is clearly apparent. On the eastern portion of the map and correlative to the mapped Basin-Range fault trend discussed earlier in this report, a strong north-south magnetic trend occurs. Anomalies, both maxima and minima, elongated in a north-south direction along this trend probably indicate the numerous juxtaposed fault blocks which were found during this study. The central portion of the aeromagnetic map is dominated by intensive maxima over Diamond Craters and Coyote Buttes and a large oval minimum over Malheur Lake. The maxima are probably due in part to localization of mafic vent material at or near the surface at Diamond Craters and Coyote Buttes. Surface mapping also indicates a number of small, isolated phreatic cones and vents and extensive silification which may indicate a mafic intrusive buried beneath the ridge at Coyote Buttes. The oval minimum seen between the two maxima is in all likelihood the site of the caldera for the Rattlesnake Ash-flow Tuff (Blank, 1974), which erupted approximately 6.5 m.y. ago (Walker, 1979). This minimum is cut by a northwesterly trending ridge of magnetic maxima which may be a zone of post-Rattlesnake faulting. The remainder of the map is dominated by the Brothers fault zone trend with isolated maxima and minima centered over mapped silicic and mafic volcanic vents.

Detailed interpretation of structures and geothermal systems cannot be made on the basis of a single aeromagnetic survey. Proposals for future geophysical studies are included in the Conclusions and Recommendations of this report.

## WATER CHEMISTRY

During the period of this study, 22 wells and springs were sampled and their waters analyzed. Together with existing published analyses (U.S. Geological Survey and Oregon Department of Geology and Mineral Industries, 1979; Leonard, 1970), a total of 28 analyses were available for evaluation (Table 3). These analyses were then used to calculate minimum reservoir temperatures (Table 4), using standard formulae for geothermometry. The methods used in these analyses, together with references, are included in this report as Appendix A. Published reports on the hydrology of the Harney Basin (Piper and others, 1939; Leonard, 1970) show a considerable number of thermal anomalies. However, many of these wells and springs either could not be located, were not flowing at the time of the study, or were inaccessible because of weather conditions or the owners' refusal to allow sampling.

Sampling temperatures during field collection ranged from 76<sup>0</sup>C and 67<sup>0</sup>C for Crane Hot Springs and Harney Lake Hot Springs, respectively, down to 15<sup>0</sup>-20<sup>0</sup>C for wells and springs bordering Harney Lake. The natural water of the study area can best be described as generally high in magnesium, calcium, and boron, and low in chloride and bicarbonate. On the basis of preliminary evaluation of the available data, two, and possibly three, groups of waters are recognized. The first are from the wells and springs near the town of Crane and the surrounding area and appear to have moderate total dissolved solids (184-564 mg/l), high Ca:Mg ratios for the cooler waters (4.1-13), consistently moderate silica throughout the sampling temperature range (56.2-93.2 mg/l) and consistently high amounts of calcium for the cooler waters (13-28.6 mg/l). Calculated minimum reservoir temperatures for these waters (Table 4) are also consistently in the 90<sup>0</sup>-120<sup>0</sup>C range. Geologic control for these waters is difficult to define in relation to the reconnaissance study;

Table 3. Spring and well chemistry of the southern Harney Basin area. All measurements are in mg/l, except for pH or as indicated. nt = not tested; tr = trace.

	Dunn Ranch Well #1	Dunn Ranch Well #2	Soldier Spring	Water Tank Spring	Unnamed Spring
Location	26S/30E/ 33Ddd	26S/30E/ 33Ddd	27S/29 E/ 14 Ccb	27S/30E/ 8Add	27S/29½E/ 35Cbb
Date sampled	5/80	5/80	10/80	10/80	10/80
Temp. (° C)	26	19	19.5	20.6	14.5
pH	9.7	9.0	8.03	8.7	7.85
Conductance μmhos/cm	1095	1038	610	1350	2510
Alkalinity $X_h$ as mg/l $\text{HCO}_3$ $X_c$ as mg/l $\text{CaCO}_3$	457 <sub>c</sub>	416 <sub>c</sub>	nt	nt	nt
Hardness as mg/l $\text{CaCO}_3$	<1	4	<15	<15	205
Total dissolved solids	747	695	452	788	1580
$\text{SiO}_2$	120	29.4	30	33	39
Na	238	250	80	288	500
K	1.5	1.2	<2.72	<2.72	18
Ca	<0.01	0.9	1	2	34
Mg	<0.01	0.3	<0.544	<0.544	19
Cl	69.3	22.8	36	122	604
As	0.086	0.036	<0.600	<0.680	<0.680
B	2.76	3.85	0.8	4.3	6.8
Li	<0.1	0.2	<0.054	0.17	0.19
F	9.0	10.3	2.1	8.0	2.8
Fe (total)	<0.05	0.10	<0.027	<0.027	<0.027
Al	<0.10	0.10	<0.680	<0.680	<0.680
$\text{HCO}_3$	nt	nt	nt	nt	nt
$\text{PO}_4$	0.030	0.015	nt	nt	nt
$\text{SO}_4$	25.6	47.0	20	28	92
$\text{NO}_3$	<0.02	<0.02	nt	nt	nt
$\text{NH}_3$	2.34	0.96	0.4	0.3	1.3

Table 3. Spring and well chemistry of the southern Harney Basin area--Continued.  
 All measurements are in mg/l, except for pH or as indicated. nt = not tested;  
 tr = trace.

	<u>Soldier Well</u>	<u>Sage Hen Creek Well</u>	<u>Crane Spring</u>	<u>Crane Spring</u>	<u>Crane Spring</u>
Location	27S/29 $\frac{1}{2}$ E/ 15Bdd	24S/30E/ 24Bcb	24S/33E/ 34Caa	24S/ 33E/ 34Caa	24S/33E/ 34Caa
Date sampled	10/80	5/80	8/31	9/68	'72
Temp. ( $^{\circ}$ C)	19.5	23	49	80	78
pH	7.99	7.9	nt	8.3	8.1
Conductance $\mu\text{mhos}/\text{cm}$	270	151	nt	814	810
Alkalinity $X_h$ as mg/l $\text{HCO}_3$ $X_c$ as mg/l $\text{CaCO}_3$	nt	67 <sub>c</sub>	nt	nt	202 <sub>c</sub>
Hardness as mg/l $\text{CaCO}_3$	70	18	nt	nt	nt
Total dissolved solids	236	125	nt	536	nt
$\text{SiO}_2$	51	41	nt	80	83
Na	52	25.6	nt	170	170
K	7	1.6	nt	3.6	3.9
Ca	13	6.4	2	3.8	3.7
Mg	4	0.5	nt	0.2	0.1
Cl	26	3.6	82	78	79
As	<0.680	0.030	nt	nt	0.09
B	0.6	<0.20	nt	6.2	7.9
Li	<0.054	<0.1	nt	nt	0.09
F	0.5	0.5	nt	9.3	9.0
Fe (total)	<0.027	<0.05	nt	0.02	<0.02
Al	<0.680	<0.10	nt	nt	0.022
$\text{HCO}_3$	nt	nt	173	199	202
$\text{PO}_4$	nt	0.033	nt	nt	0.09
$\text{SO}_4$	15	11.8	80	81	86
$\text{NO}_3$	nt	<0.02	1.4	nt	nt
$\text{NH}_3$	tr	0.03	nt	nt	3.2

Table 3. Spring and well chemistry of the southern Harney Basin area--Continued.  
All measurements are in mg/l, except for pH or as indicated. nt = not tested;  
tr = trace.

	<u>Crane Spring</u>	<u>Island Ranch Well</u>	<u>Unnamed Spring</u>	<u>Long Hollow Well</u>	<u>Barnyard Spring</u>
Location	24S/33E/ 34Caa	25S/32E/ 7Bab	26S/29E/ 31Cca	26S/ 34E/ 8Bdd	27S/29E/ 6Aaa
Date sampled	5/80	8/69	5/80	5/80	5/80
Temp. ( <sup>o</sup> C)	76	41	21	25	22
pH	8.2	9.3	8.0	7.8	8.1
Conductance μmhos/cm	750	1450	275	366	285
Alkalinity $X_h$ as mg/l $\text{HCO}_3$ $X_c$ as mg/l $\text{CaCO}_3$	169 <sub>c</sub>	nt	105 <sub>c</sub>	105 <sub>c</sub>	112 <sub>c</sub>
Hardness as mg/l $\text{CaCO}_3$	8	nt	60	115	35
Total dissolved solids	564	957	233	282	237
$\text{SiO}_2$	93.2	54	80.2	75.8	62.4
Na	160	386	38	28.8	52
K	3.5	4.4	5.5	5.6	4.3
Ca	3.6	0.5	12.2	28.6	8.0
Mg	0.1	0.2	5.5	4.5	2.7
Cl	88	9	23.5	35.5	23.5
As	0.145	nt	0.023	0.016	0.035
B	8.67	nt	0.65	0.70	0.64
Li	0.1	nt	<0.1	<0.1	<0.1
F	9.0	19	0.3	0.3	0.6
Fe (total)	<0.05	nt	<0.05	0.20	<0.05
Al	0.10	nt	<0.10	0.38	<0.10
$\text{HCO}_3$	nt	674	nt	nt	nt
$\text{PO}_4$	0.050	nt	0.032	0.084	0.034
$\text{SO}_4$	78	8	11.8	28.2	11.3
$\text{NO}_3$	0.05	0.1	0.72	0.02	0.67
$\text{NH}_3$	0.73	nt	0.06	2.77	0.05

Table 3. Spring and well chemistry of the southern Harney Basin area--Continued.  
All measurements are in mg/l, except for pH or as indicated. nt = not tested;  
tr = trace.

	<u>Warm Spring in Harney Lake</u>	<u>Unnamed Spring</u>	<u>Railroad Well</u>	<u>Harney Lake Hot Spring</u>	<u>Harney Lake Hot Spring</u>
Location	27S/29½ E/ 36Cab	27S/29½E/ 34Da	25S/34E/ 7Ddd	27S/29½E/ 36Dda	27S/29½E/ 36Dda
Date sampled	5/80	5/80	5/80	8/31	'72
Temp. (° C)	22	21	17	59	68
pH	8.7	7.9	8.2	nt	7.26
Conductance μmhos/cm	9280	297	238	nt	2970
Alkalinity $X_h$ as mg/l $\text{HCO}_3^-$ $X_c$ as mg/l $\text{CaCO}_3$	2000 <sub>c</sub>	103 <sub>c</sub>	91 <sub>c</sub>	nt	nt
Hardness as mg/l $\text{CaCO}_3$	23	58	27	nt	nt
Total dissolved solids	10615	251	184	nt	nt
$\text{SiO}_2$	89.6	63.6	56.2	92	92
Na	2220	36.8	39.6	622	630
K	68	6.4	2.5	12	13
Ca	1.5	13.1	8.7	13	12
Mg	3.3	5.5	1.1	3	1.8
Cl	2400	25.0	7.4	562	590
As	1.745	0.025	0.033	nt	0.6
B	53.4	0.61	0.55	nt	11
Li	1.0	<0.1	<0.1	nt	0.45
F	8.9	0.4	0.5	nt	3.3
Fe (total)	70.0	<0.05	<0.05	0.03	0.05
Al	125	<0.10	<0.10	nt	0.005
$\text{HCO}_3^-$	nt	nt	nt	601	566
$\text{PO}_4$	1.190	0.032	0.027	nt	0.092
$\text{SO}_4$	474	12.9	18.4	140	140
$\text{NO}_3$	0.03	0.75	0.03	0.5	nt
$\text{NH}_3$	1.46	0.04	0.04	nt	1.8

Table 3. Spring and well chemistry of the southern Harney Basin area--Continued.  
 All measurements are in mg/l, except for pH or as indicated. nt = not tested;  
 tr = trace.

	<u>Harney Lake Hot Spring</u>	<u>00 Station Spring</u>	<u>Adobe Flat Well</u>	<u>Thompson Well</u>	<u>Harney Lake Spit Spring</u>
Location	27S/29½E/ 36Dda	26S/28E/ 36Bdd	27S/34E/ 17Cbd	26S/33E/ 13Acc	27S/29½E/ 34Dbb
Date sampled	5/80	5/80	5/80	5/80	10/80
Temp. (°C)	67	23	17	24	14.5
pH	7.7	8.0	8.1	7.8	8.5
Conductance μmhos/cm	2700	228	312	442	1090
Alkalinity $X_h$ as mg/l $\text{HCO}_3$ $X_c$ as mg/l $\text{CaCO}_3$	493 <sub>c</sub>	85 <sub>c</sub>	120	122	nt
Hardness as mg/l $\text{CaCO}_3$	43	44	99	82	30
Total dissolved solids	1777	186	237	341	654
$\text{SiO}_2$	102	68	80.8	83.2	45
Na	53	31.2	25.4	63	208
K	12	4.1	5.7	8.1	9
Ca	12.8	10.8	26.4	19.9	4
Mg	2.1	3.9	3.1	4.9	2
Cl	623	17.6	11.4	55.8	163
As	0.915	0.019	0.014	0.024	<0.680
B	12.07	0.45	0.27	1.24	2.7
Li	0.4	<0.1	<0.1	<0.1	0.11
F	3.0	0.2	0.4	0.3	1.5
Fe (total)	0.56	<0.05	<0.05	<0.05	<0.027
Al	0.62	<0.10	0.10	<0.10	<0.680
$\text{HCO}_3$	nt	nt	nt	nt	nt
$\text{PO}_4$	0.294	0.031	0.029	0.013	nt
$\text{SO}_4$	119.3	6.7	19.9	45	58
$\text{NO}_3$	0.02	0.50	0.51	0.92	nt
$\text{NH}_3$	1.01	0.05	0.06	0.04	1.1

Table 3. Spring and well chemistry of the southern Harney Basin area--Continued.  
 All measurements are in mg/l, except for pH or as indicated. nt = not tested;  
 tr = trace.

	<u>Eagles Nest Spring #1</u>	<u>Eagles Nest Spring #2</u>	<u>Bathtub Spring</u>
Location	27S/29½E/ 25Aad	27S/29½E/ 25Ada	27S/ 29½E/ 28Cac
Date sampled	10/80	10/80	10/80
Temp (°C)	41.7	28.1	51.1
pH	7.12	9.18	6.87
Conductance μhos/cm	4750	1150	3900
Alkalinity $X_h$ as mg/l HCO <sub>3</sub> $X_c$ as mg/l CaCO <sub>3</sub>	nt	nt	nt
Hardness as mg/l CaCO <sub>3</sub>	154	<15	170
Total dissolved solids	3110	632	2096
SiO <sub>2</sub>	55	35	87
Na	1207	240	682
K	14	<2.72	32
Ca	30	1	37
Mg	15	<0.544	13
Cl	466	68	848
As	1.0	<0.680	1.0
B	17.1	3.1	13.2
Li	0.69	0.07	0.87
F	2.1	7.2	1.8
Fe (total)	<0.027	<0.027	0.14
Al	<0.680	<0.680	<0.680
HCO <sub>3</sub>	nt	nt	nt
PO <sub>4</sub>	nt	nt	nt
SO <sub>4</sub>	320	23	50
NO <sub>3</sub>	nt	nt	nt
NH <sub>3</sub>	5.6	1.5	1.5

Table 4. Geothermetric calculations\* of minimum reservoir temperatures for selected thermal waters of the southern Harney Basin

	Dunn Ranch Well #1	Dunn Ranch Well #2	Soldier Spring	Water Tank Spring	Unnamed Spring	Soldier Well
Flow rate liters/min.	100+	10	<1	20	5	40
Measured temperature °C	26	19	19.5	20.6	14.5	19.5
Na:K °C	38	28	109	52	112	197
Na:K:Ca 1/3 β °C	78	60	139	100	143	179
Na:K:Ca 4/3 β °C	75	34	124	122	130	89
Na:K:Ca Mg corrected °C	NC	NC	64	NC	113	59
SiO <sub>2</sub> conductive °C	148	79	79	83	91	127
SiO <sub>2</sub> adiabatic °C	141	82	83	86	93	124
SiO <sub>2</sub> chalcedony °C	122	47	48	52	60	99
SiO <sub>2</sub> opal °C	26	-34	-33	-30	-23	-13

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

Table 4. Geothermetric calculations\* of minimum reservoir temperatures for selected thermal waters of the southern Harney Basin -- Continued

	Sage Hen Creek Well	Crane Spring	Crane Spring	Crane Spring	Island Ranch Well	Eagle's Nest Spring #1
Flow rate liters/min.	50	100+	100+	100+	40	40
Measured temperature °C	23	80	78	76	41	41.7
Na:K °C	144	86	90	87	59	60
Na:K:Ca 1/3 β °C	136	120	124	121	120	100
Na:K:Ca 4/3 β °C	51	109	113	109	196	99
Na:K:Ca Mg corrected °C	124	NC	NC	NC	115	40
SiO <sub>2</sub> conductive °C	93	125	127	133	105	106
SiO <sub>2</sub> adiabatic °C	95	123	124	129	106	106
SiO <sub>2</sub> chalcedony °C	62	97	99	106	76	77
SiO <sub>2</sub> opal °C	-21	6	8	13	-11	-10

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

Table 4. Geothermetric calculations\* of minimum reservoir temperatures for selected thermal waters of the southern Harney Basin -- Continued

	Eagle's Nest Spring #2	Bathtub Spring	Unnamed Spring	Long Hollow Well	Barnyard Spring	Warm Spring in Harney Lake
Flow rate liters/min.	5	50	<1	pumped	100+	<1
Measured temperature °C	28.1	51.1	21	25	22	22
Na:K °C	59	127	203	228	162	104
Na:K:Ca 1/3 β °C	109	160	178	181	158	138
Na:K:Ca 4/3 β °C	140	160	79	59	84	131
Na:K:Ca Mg corrected °C	40	60	43	56	53	108
SiO <sub>2</sub> conductive °C	86	130	125	122	112	131
SiO <sub>2</sub> adiabatic °C	89	126	123	120	112	128
SiO <sub>2</sub> chalcedony °C	55	102	97	94	83	104
SiO <sub>2</sub> opal °C	-27	10	6	4	-5	11

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

Table 4. Geothermetric calculations\* of minimum reservoir temperatures for selected thermal waters of the southern Harney Basin -- Continued

	Unnamed Spring	Railroad Well	Harney Lake Hot Spring	Harney Lake Hot Spring	Harney Lake Hot Spring	00 Station Spring
Flow rate liters/min.	100	pumped	100+	100+	100+	100+
Measured temperature °C	21	17	59	68	67	23
Na:K °C	218	145	82	85	244	196
Na:K:Ca 1/3 β °C	190	207	100	143	188	170
Na:K:Ca 4/3 β °C	92	336	52	220	58	70
Na:K:Ca Mg corrected °C	38	136	82	105	113	50
SiO <sub>2</sub> conductive °C	113	107	133	133	138	117
SiO <sub>2</sub> adiabatic °C	112	107	129	129	134	115
SiO <sub>2</sub> chalcedony °C	84	78	105	105	112	88
SiO <sub>2</sub> opal °C	-4	-9	13	13	18	-1

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

Table 4. Geothermetric calculations\* of minimum reservoir temperatures for selected thermal waters of the southern Harney Basin -- Continued

	Adobe Flat Well	Thompson Well	Harney Lake Spit Spring
Flow rate liters/min.	pumped	pumped	<5
Measured temperature °C	17	24	14.5
Na:K °C	242	194	122
Na:K:Ca 1/3 β °C	268	176	119
Na:K:Ca 4/3 β °C	311	87	37
Na:K:Ca Mg corrected °C	148	68	61
SiO <sub>2</sub> conductive °C	126	127	97
SiO <sub>2</sub> adiabatic °C	123	124	98
SiO <sub>2</sub> chalcedony °C	98	99	67
SiO <sub>2</sub> opal °C	7	NC	-18

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

however, preliminary examination seems to indicate the waters are controlled by intersection of Basin-Range faulting and the Rattlesnake collapse caldera, previously described in the section on geology. The difference in chemical character of various Harney Basin waters is probably due to a difference in chemical composition of rocks in the recharge zone and duration of subsurface circulation.

The second group of waters is from the area surrounding Harney Lake in the southwest corner of the study area. These waters are generally higher in total dissolved solids (233-10,616 mg/l), lower in Ca:Mg ratios (0.45-6.1), inconsistent in silica concentrations through the sampling temperature range (29.4-120 mg/l), lower in calcium content (0.1-37 mg/l), and slightly inconsistent in calculated minimum reservoir temperatures. Geologic control for these waters is likewise difficult to define; however, preliminary indications seem to show they are controlled by the intersection of the Rattlesnake collapse caldera and the Brothers fault zone structural trend. Differences in chemical constituents are probably due to the relative abundance of sediments and silicic rocks through which the water must circulate before it reaches the surface.

Detailed geochemical sampling of springs and wells throughout the southern Harney Basin is needed before a realistic thermal-regime model can be attempted. This is apparent in a cursory examination of estimated reservoir temperatures (Table 4), some of which are nearly 400<sup>0</sup>C, which indicates that a large number of springs and wells have either reacted strongly with wall rock or mixed with meteoric or shallow evaporite-rich water while ascending.

### GEO THERMAL-GRADIENT AND HEAT-FLOW DATA\*

The temperature-gradient and heat-flow results for the south Harney Basin are as shown in Table 5. Included in the table are the township/range-section and latitude and longitude location of each hole. In addition, the hole name, date of logging used, and collar elevation are included for each hole. The bottom hole temperature, maximum depth, corrected temperature gradient, and, where available, corrected heat flow are printed in blue on Plates I-IV. These values are also listed in the table, as are the depth interval and average thermal conductivity used for calculation of the gradient and heat flow. The values are given in SI units. To transform units, the following conversion factors were used:  $1 \times 10^{-6} \text{ cal/cm}^2 \text{ sec}$  (HFU) =  $41.84 \text{ mWm}^{-2}$ ,  $1 \times 10^{-3} \text{ cal/cm sec}^{\circ}\text{C}$  (TCU) =  $0.4184 \text{ Wm}^{-1}\text{K}^{-1}$ , and  $1^{\circ}\text{C}/\text{km} = 1 \text{ mKm}^{-1} = 18.2^{\circ}\text{F}/100 \text{ ft}$ . Corrected gradient and corrected heat flow are values for which the topographic effects have been removed. These are not significant for most of the sites studied.

The holes are ranked in terms of the quality of the gradient or heat-flow information: high quality (A), good quality (B), marginal quality (C), data with some problems (D), and data for which no useful temperature gradient or heat flow can be estimated (X). All thermal-conductivity measurements were made on cutting samples.

Most data in the south Harney area have been obtained in holes drilled as water wells or mineral exploration holes, so the thermal-conductivity values are estimated (parenthesis) or based on one or two cutting samples from surface spoil piles. Several holes were drilled and the results published by the USGS (holes S1, S2, S3, MR-1, and MR-2 in Sass and others, 1976). Holes prefixed BFZ-75 were drilled by DOGAMI (BR-75 holes in Hull and others, 1976). The background gradient and heat flow for the area are about  $60-80^{\circ}\text{C}/\text{km}$  and  $60-80 \text{ mWm}^{-2}$ . Several anomalous

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Table 5. Geothermal-gradient data, south Harney Basin, Oregon

Twn/Rng- Section	N Lat. Deg. Min.	W Long Deg. Min.	Hole #	Collar Date	Bottom Temp. (°C)	Depth Interval (m)	Avg. Wm <sup>-1</sup> K <sup>-1</sup>	# TC	Uncorr. Gradient °C/km		Corr. Gradient °C/km	Corr. HF mWm <sup>-2</sup>	Q HF
									TC	°C/km			
24S/33E- 9D	43-30.00	118-39.00	53		1255	40.0 203.0	.88		82.0 1.0	82.0 1.0	71	A	
24S/32E- 23DD	43-28.30	118-43.90	*LAWEN		1256	20.91	75.0 150.0	( .96)	60.9 7.4	60.9	59	B	
24S/34E- 19C	43-29.00	118-35.00	52		1262	60.0 183.0	.88		69.5 .5	69.5 .5	63	A	
24S/33E- 35AD	43-26.60	118-36.80	CRANE 7/21/75		1257	20.27	30.0 85.0	( .96)	80.0 7.1	80.0	75	B	
25S/31E- 4BB	43-26.20	119-	1.10	BFZ-7511 9/16/75	1262	11.49	42.5 60.0	1.30	5	30.9 2.5	42	C	
25S/33E- 3BD	43-25.90	118-38.50	BFZ-7501 11/22/75		1274	16.04	10.0 28.6	1.00	2	188.3 18.9	188.3	188	B
25S/33E- 10BA	43-25.23	118-38.30	ADAMS 5/14/80		1259	50.22	37.0 37.0					X	
25S/33E- 11BBB	43-25.20	118-37.70	ROSSBERG 6/12/75		1257	15.75	.0 65.0	( .96)		60.0- 70.0	60.0- 70.0	58	C
25S/33E- 9CA	43-24.73	118-39.78	WSB-1 5/14/80		1250	17.82	.0 65.0		( 59.0)	( 59.0)		D	
25S/33E- 10CD	43-24.48	118-38.52	WSB-3 5/14/80		1254	14.01	10.0 51.5			45.3 5.9		C	
25S/33E- 9CD	43-24.45	118-39.28	ARFORD 3 5/14/80		1250	27.95	.0 165.0		( 84.0)	( 84.0)		D	
25S/33E- 9CC	43-24.45	118-40.05	ARFORD 2 5/14/80		1250	22.30	.0 61.0		(136.0)	(136.0)		D	
25S/33E- 11CD	43-24.40	118-37.18	WSB-4 5/ 8/80		1254	11.62	10.0 57.0			9.2 2.5		X	
25S/33E- 16AB	43-24.32	118-38.53	ARFORD 1 5/14/80		1250	18.83	5.0 107.5		> 45.0			D	
25S/31E-	43-22.00	119-	2.00	S1	1266	50.0	.88		81.0	81.0	71	B	

Table 5. Geothermal-gradient data, south Harney Basin, Oregon--Continued

Twn/Rng- Section	N Lat. Deg.	W Long Deg.	Hole = Date	Bottom Elev.	Depth (m)	Temp. (°C)	Interval (m)	Avg. Wm <sup>-1</sup> K <sup>-1</sup>	TC	#	Uncorr.	Corr.	Corr.	Q HF	
											190.0	Gradient °C/km	Gradient °C/km	HF mWm <sup>-2</sup>	
21D												1.0	1.0		
26S/30E- 3BB	43-21.10	119- 7.00	BFZ-7510 9/16/75	1273	13.30		7.5 30.0	1.00	8		47.6	47.6	( 46)	C	
25S/34E- 31CC	43-20.25	118-35.25	WINDYPT1 5/ 8/80	1257	11.28		10.0 30.0				7.2 1.4			X	
26S/33E- 2CD	43-20.22	118-36.70	WINDYPT2 5/ 8/80	1253	19.46		10.0 58.0				86.4 4.2			C	
26S/33E- 11DC	43-19.25	118-36.43	WINDYPT3 5/ 8/80	1252	15.53		5.0 45.0				85.2 3.9			B	
26S/33E- 13DA	43-18.52	118-34.93	N TIPSON 5/ 8/80	1257	22.31		10.0 52.0				109.0 37.0			C	
26S/30E- 20DC	43-17.70	119- 8.70	BFZ-7508 9/29/75	1250	12.26		10.0 25.0	1.09	6		69.7 1.8	69.7	75	C	
26S/33E- 35CC	43-15.78	118-36.97	DAVIS 1 5/ 7/80	1254	10.86		10.0 34.5				12.5 1.8			X	
27S/30E- 13CD	43-13.18	118-56.00	HP-10 6/ 8/73	1280	23.30		25.0 60.0	.96 .13			130.4 2.5	119.6 2.4	( 117)	B	
							60.0 130.0	1.30			61.6 1.5	58.4 1.4	( 75)	B	
27S/32E- 23BB	43-13.12	118-44.20	VOLTAGE 5/13/80	1335	22.46		100.0 190.0	( .96)			67.8 .8	68.8	66	B	
27S/29E- 21AC	43-13.00	119-14.80	BFZ-7509 9/29/75	1400	13.18		12.5 45.0	1.63	13		54.2	54.2	88	B	
27S/33E- 20DB	43-12.68	118-37.52	BECKLEY 5/13/80	1285	11.62		10.0 60.5				1.1 3.8			X	
27S/30E- 19DC	43-12.60	119- 2.20	HP 0/ 0/71	1250	22.50		46.0 108.0	( .96)			131.3	131.3	126	B	
27S/30E- 21DDB	43-12.53	118-59.72	HP-48 7/25/73	1289	29.89		10.0 35.0	1.30 .08	9		223.2 8.5	223.2	( 289)	C	
							35.0 110.0	.96 .04	19		132.8 1.0	132.8	130	C	
27S/30E- 27ACA	43-12.05	118-58.71	HP-1 7/26/73	1320	21.62		10.0 65.0	.96 .13			160.0 1.8	162.8	155	C	

Table 5. Geothermal-gradient data, South Harney Basin, Oregon--Continued

Twn/Rng- Section	N Lat. Deg. Min.	W Long Deg. Min.	Hole # Date	Collar Elev.	Temp. (°C)	Bottom Depth (m)	Depth Interval (m)	Avg. TC Wm <sup>-1</sup> K <sup>-1</sup>	# TC	Uncorr.	Corr.	Corr. HF mWm <sup>-2</sup>	Q HF
										Gradient °C/km	Gradient °C/km		
						65.0	75.0	1.30		55.0	2.9	( 71)	C
27S/30E- 26DCB	43-11.52	118-57.24	HP-2B 7/26/73	1340	17.38	10.0	57.2	.96 .13		117.9	1.4	126	B
27S/30E- 36BAC	43-11.25	118-56.50	HP-11 8/8/75	1258	14.63	10.0	45.0	1.09	4	73.1	1.3	79	B
27S/33E- 33CB	43-10.80	118-39.60	BFZ-7502 11/22/75	1282	11.29	10.0	30.0			( -1.3) 4.3	-1.3		X
27S/30E- 36CC	43-10.60	118-57.00	BFZ-7507 9/16/75	1259	16.12	10.0	67.5	.96	2	88.4	2.1	84	B
28S/30E- 13DA	43- 8.20	118-56.30	HP-12 7/22/75	1265	13.45	20.0	25.0	( .96)		82.0			X
28S/32E- 36CC	43- 5.30	118-43.10	BFZ-7503 9/16/75	1277	13.80	20.0	37.5	1.30	5	( 39.4) 5.4	39.4	50	C
28S/32E- 6B	43- 5.30	118-49.40	MR-1	1262		37.5	60.0			( 2.4) 2.1	2.4		C
						56.4	64.0	.92 .07	4	89.0 1.0	89.0 1.0	82	A
						40.0	91.0	.92 .07	4	96.0 .6	96.0 .6	88	A
						.0				92.0	84		A
29S/31E- 2B	43- 5.20	118-50.90	MR-2	1260		57.9	62.5	.99 .02	4	65.0 2.0	65.0 2.0	64	A
						89.3	92.0	.93 .03	4	83.0 3.0	83.0 3.0	76	A
						60.0	100.0	.95 .02	8	74.2 .8	74.2 .8	71	A
						.0				87.0	71		A
29S/32E- 34DC	43- 10	118-44.90	BFZ-7504 9/16/75	1326	17.13	10.0	25.0	1.63	4	84.0 5.1	84.0	138	A
						25.0	52.0	1.09	3	140.2 7.7	140.2	155	A
						.0				88.0	146		A

holes are found near Coyote Buttes (Bowen and others, 1976), and hole BFZ-7504 near the southern part of the Basin has a very high heat flow (Plate IV).

## CONCLUSIONS AND RECOMMENDATIONS

The reconnaissance study performed for the southern Harney Basin has tentatively identified two geothermal resource areas based on geology, geophysics, geochemistry, and sparse geothermal-gradient data. They are (1) the area surrounding the town of Crane (Plate II) and (2) the area immediately surrounding Harney Lake (Plates I, III, and IV). Preliminary results indicate both of these areas may have reservoir temperatures in the moderate range (100-150°C). Site-specific analyses of these two areas should be carried out in one field program and include the following recommendations:

1. Detailed (scale of 1:24,000 or less) geologic and photogeologic mapping of Crane and Harney Lake geothermal areas -- to identify and evaluate active thermal structures and areas of recent hydrothermal alteration.
2. Detailed sampling and analysis of hot and cold springs and wells, including isotope and gas analyses -- to determine fluid flow directions and provenance and to determine precise reservoir conditions.
3. Closely spaced complete Bouguer and residual gravity anomaly studies -- to delineate possible active thermal structures or intrusives below surface units.
4. Several resistivity traverses (either dipole-dipole, roving dipole, or telluric) normal to mapped structures -- to further define the thermal regime.
5. A micro-earthquake/contemporary seismic study of the entire Harney Basin, making use of a high-gain seismometer array -- to define the seismicity of the area in relation to geothermal systems.
6. A program of twenty to thirty 500-ft gradient/stratigraphy holes, followed by a program of five to ten 2,000-ft holes -- to model heat flow and directly test geothermal aquifers.

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## APPENDIX A

### Formulas used in calculations

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

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

where  $F(T) = \log(\text{Na}/\text{K}) + [\beta \log(\sqrt{\text{Ca}}/\text{Na})]$ ,  
 $\beta = 1/3$  if  $t > 100^{\circ}\text{C}$ , and  $4/3$  if  $t < 100^{\circ}\text{C}$ ,  
 $t^{\circ}\text{C}$  = 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,

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

where  $R$  = magnesium correction ratio expressed in equivalents,

$\Delta t_{\text{Mg}}$  = the temperature correction that is subtracted from  
the Na:K:Ca 1/3  $\beta$  calculated temperature,

$T$  = Na:K:Ca 1/3  $\beta$  calculated temperature in  $^{\circ}\text{K}$ .

Or  $\Delta t_{\text{Mg}}$  can be obtained by using the graph compiled by Fournier and Potter (1979).

$\text{SiO}_2$  temperature calculations (Fournier and Rowe, 1966):

$\text{SiO}_2$  (conductive),  $t^{\circ}\text{C} = \frac{1309}{5.19 + \log(\text{SiO}_2)} - 273.15$

$\text{SiO}_2$  (adiabatic),  $t^{\circ}\text{C} = \frac{1522}{5.75 + \log(\text{SiO}_2)} - 273.15$

$\text{SiO}_2$  (chalcedony),  $t^{\circ}\text{C} = \frac{1032}{4.69 + \log(\text{SiO}_2)} - 273.15$

$\text{SiO}_2$  (opal),  $t^{\circ}\text{C} = \frac{731}{4.52 + \log(\text{SiO}_2)} - 273.15$ ,

where  $\text{SiO}_2$  is expressed in mg/l.

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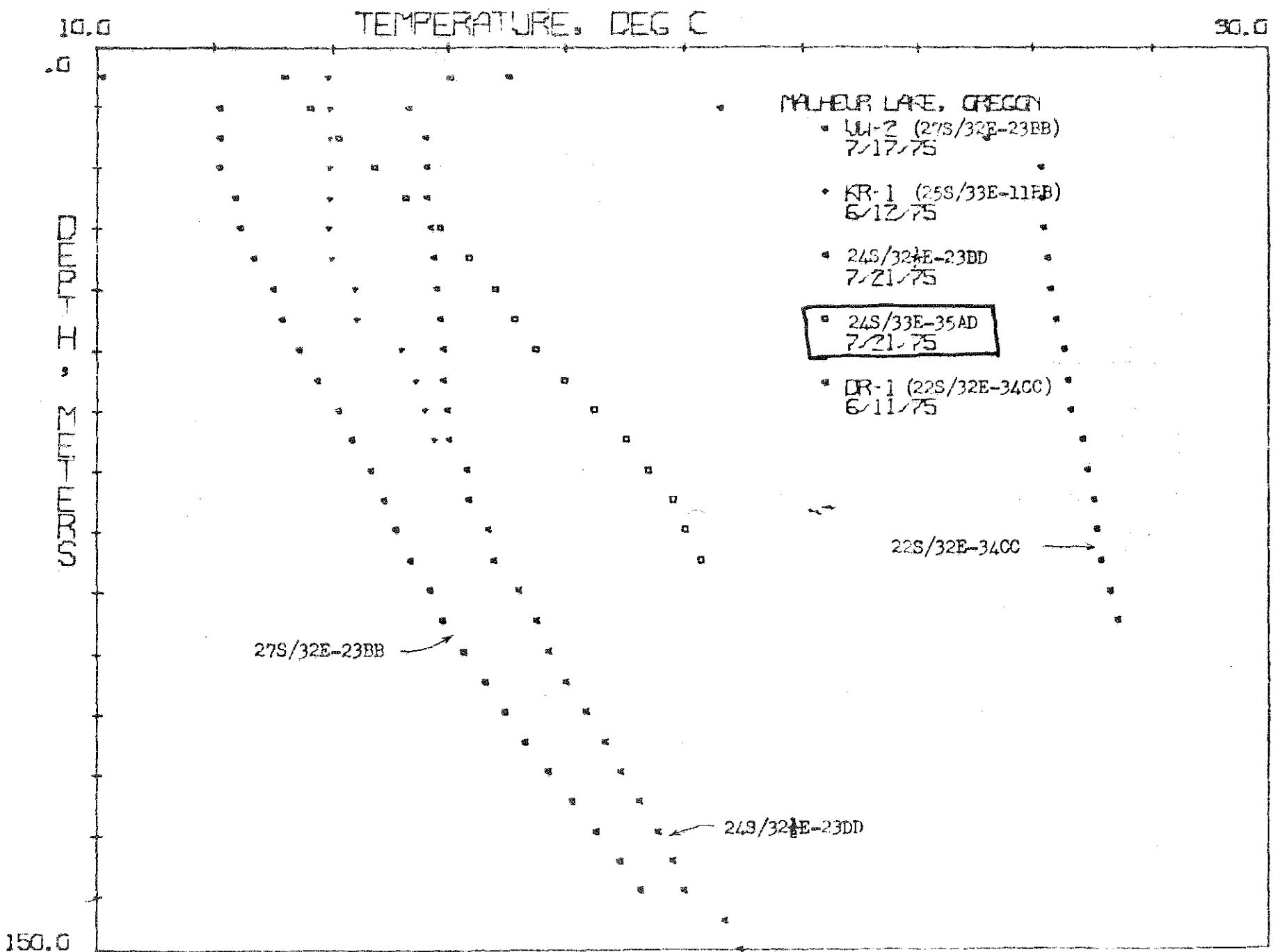
APPENDIX B  
Geothermal-gradient data

LOCATION: CRANE, OREGON  
24S/33E-35AD

HOLE NUMBER:

DATE MEASURED: 7/21/75

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
5.0	16.4	13.230	55.81	.0	.0
10.0	32.8	13.640	56.55	82.0	4.5
15.0	49.2	14.140	57.45	100.0	5.5
20.0	65.6	14.750	58.55	122.0	6.7
25.0	82.0	15.290	59.52	108.0	5.9
30.0	98.4	15.870	60.57	116.0	6.4
35.0	114.8	16.350	61.43	96.0	5.3
40.0	131.2	16.810	62.26	92.0	5.0
45.0	147.6	17.130	62.83	64.0	3.5
50.0	164.0	17.480	63.46	70.0	3.8
55.0	180.4	17.980	64.36	100.0	5.5
60.0	196.8	18.470	65.25	98.0	5.4
65.0	213.2	19.010	66.22	108.0	5.9
70.0	229.6	19.380	66.88	74.0	4.1
75.0	246.0	19.800	67.64	84.0	4.6
80.0	262.4	20.000	68.00	40.0	2.2
85.0	278.8	20.270	68.49	54.0	3.0



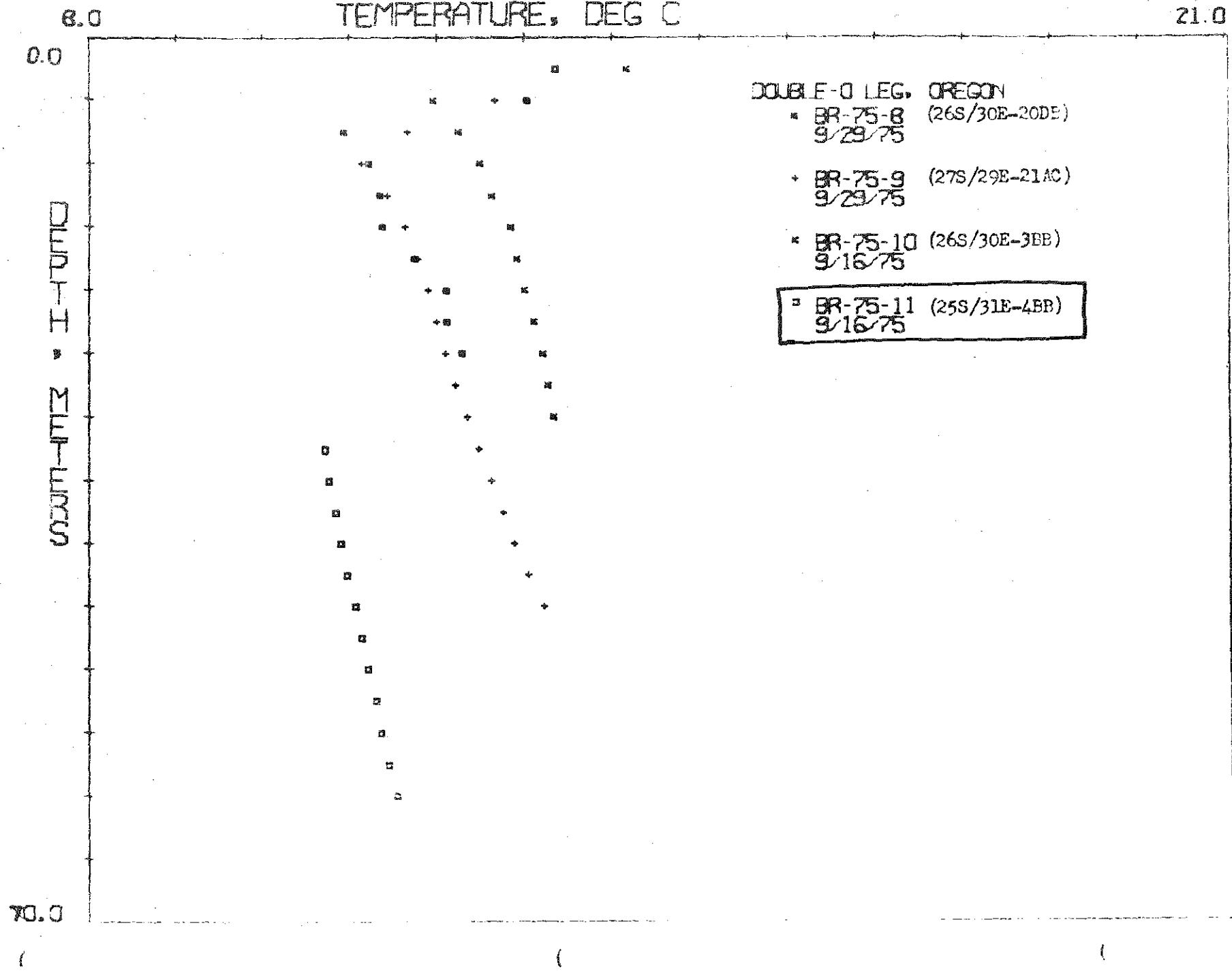
LOCATION: DOUBLE-0 LEG, OREGON  
25S/31E-4BB

HOLE NUMBER: BR-75-11

DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEO THERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	13.340	56.01	.0	.0
5.0	16.4	10.510	50.92	-11.32.0	-62.1
7.5	24.6	10.240	50.43	-108.0	-5.9
10.0	32.8	10.460	50.83	88.0	4.8
12.5	41.0	10.480	50.86	8.0	.4
15.0	49.2	10.490	50.88	4.0	.2
17.5	57.4	10.490	50.88	.0	.0
20.0	65.6	10.540	50.97	20.0	1.1
22.5	73.8	10.540	50.97	.0	.0
25.0	82.0	10.550	50.99	4.0	.2
27.5	90.2	10.600	51.08	20.0	1.1
30.0	98.4	10.650	51.17	20.0	1.1
32.5	106.6	10.700	51.26	20.0	1.1
35.0	114.8	10.750	51.35	20.0	1.1
37.5	123.0	10.810	51.46	24.0	1.3
40.0	131.2	10.880	51.58	28.0	1.5
42.5	139.4	10.950	51.71	28.0	1.5
45.0	147.6	11.030	51.85	32.0	1.8
47.5	155.8	11.100	51.98	28.0	1.5
50.0	164.0	11.180	52.12	32.0	1.8
52.5	172.2	11.270	52.29	36.0	2.0
55.0	180.4	11.320	52.38	20.0	1.1
57.5	188.6	11.410	52.54	36.0	2.0
60.0	196.8	11.490	52.68	32.0	1.8

TEMPERATURE, DEG C



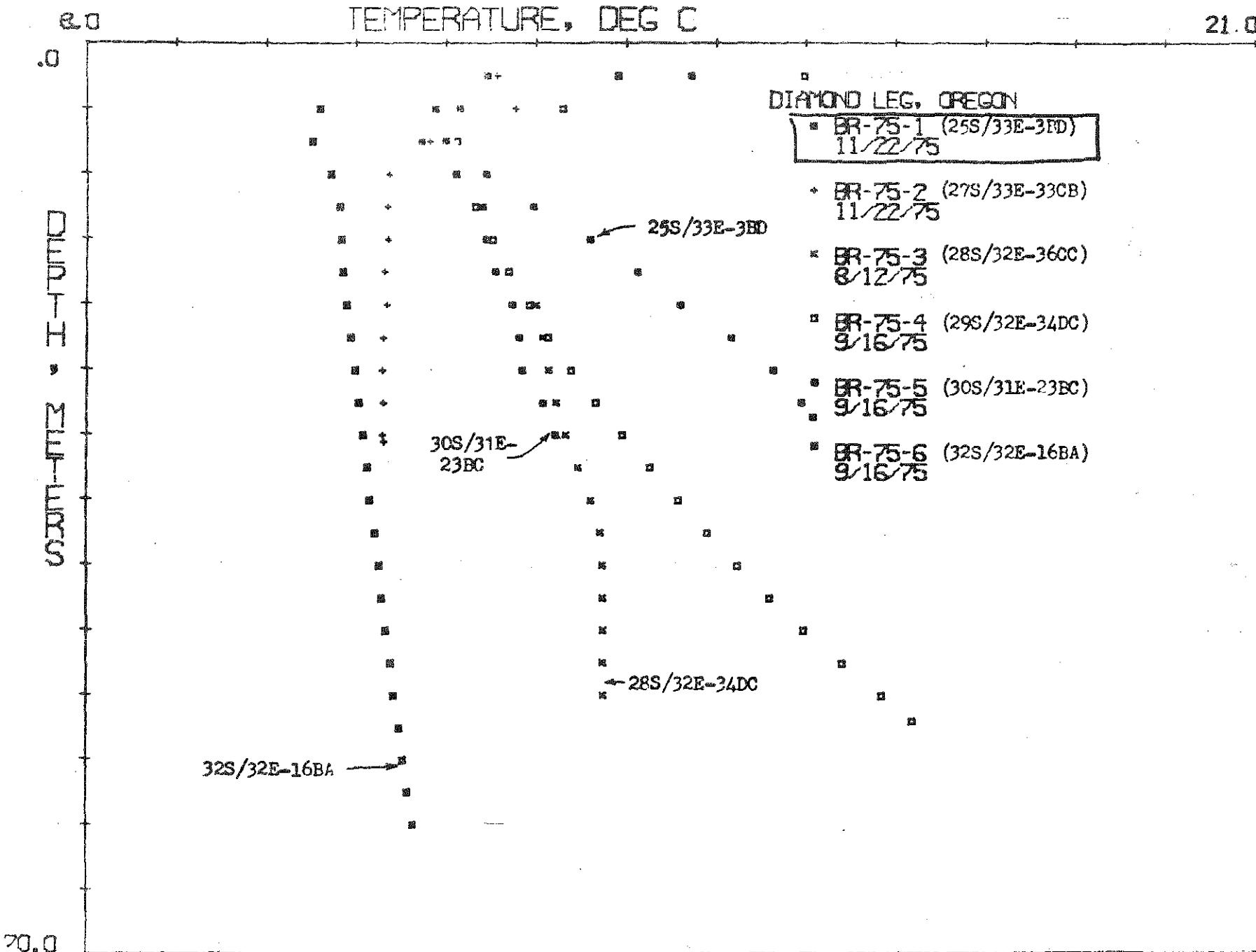
LOCATION: DIAMOND LEG, OREGON

25S/33E-3BD

HOLE NUMBER: BR-75-1

DATE MEASURED: 11/22/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.450	54.41	.0	.0
5.0	16.4	12.150	53.87	-120.0	-6.6
7.5	24.6	11.980	53.56	-68.0	-3.7
10.0	32.8	12.430	54.37	180.0	9.9
12.5	41.0	12.950	55.31	208.0	11.4
15.0	49.2	13.580	56.44	252.0	13.8
17.5	57.4	14.090	57.36	204.0	11.2
20.0	65.6	14.570	58.23	192.0	10.5
22.5	73.8	15.130	59.23	224.0	12.3
25.0	82.0	15.600	60.08	188.0	10.3
27.5	90.2	15.910	60.64	124.0	6.8
28.6	93.8	16.040	60.87	118.2	6.5



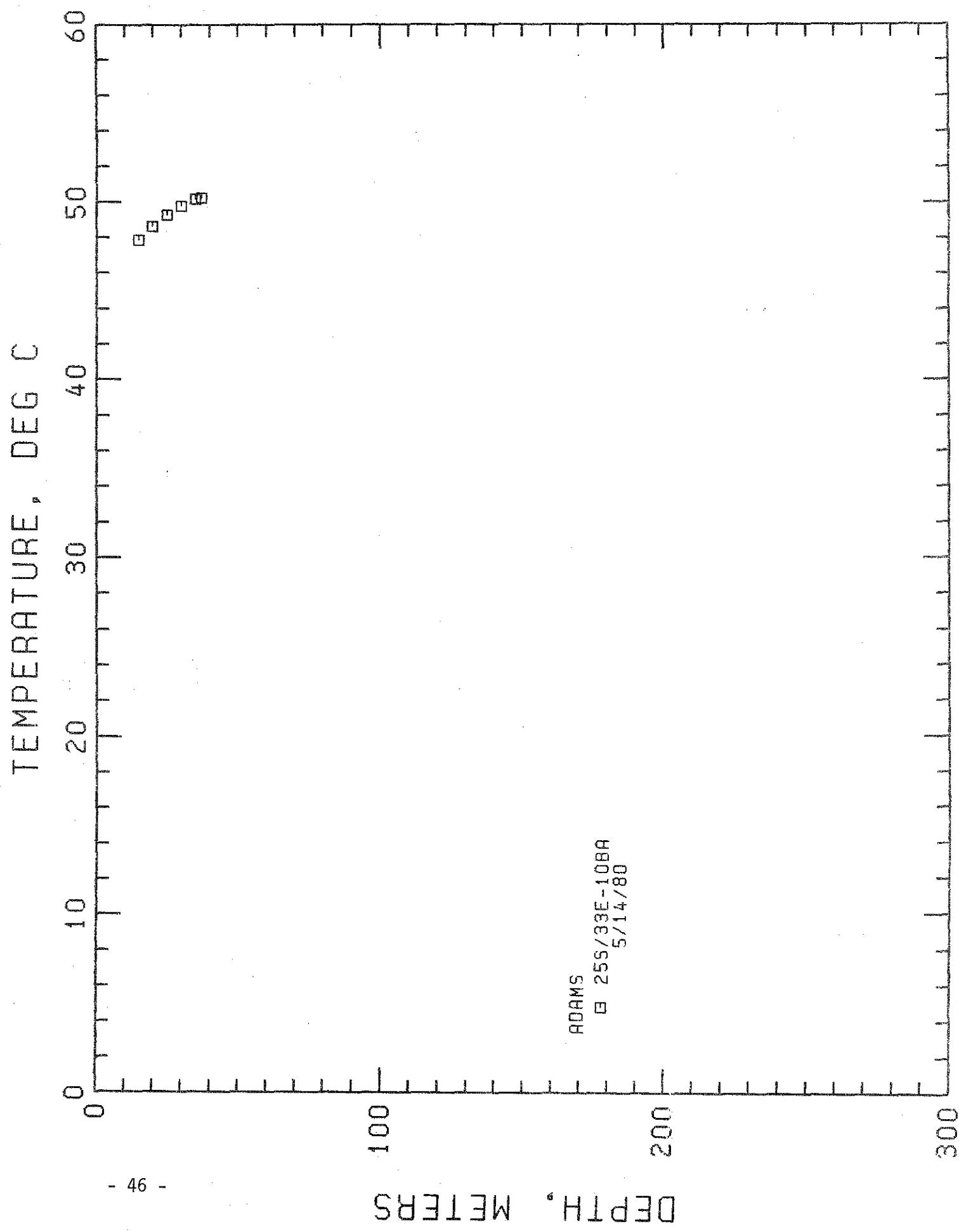
LOCATION: BURNS AMS, OREGON

255/33E-10BA

HOLE NAME: ADAMS

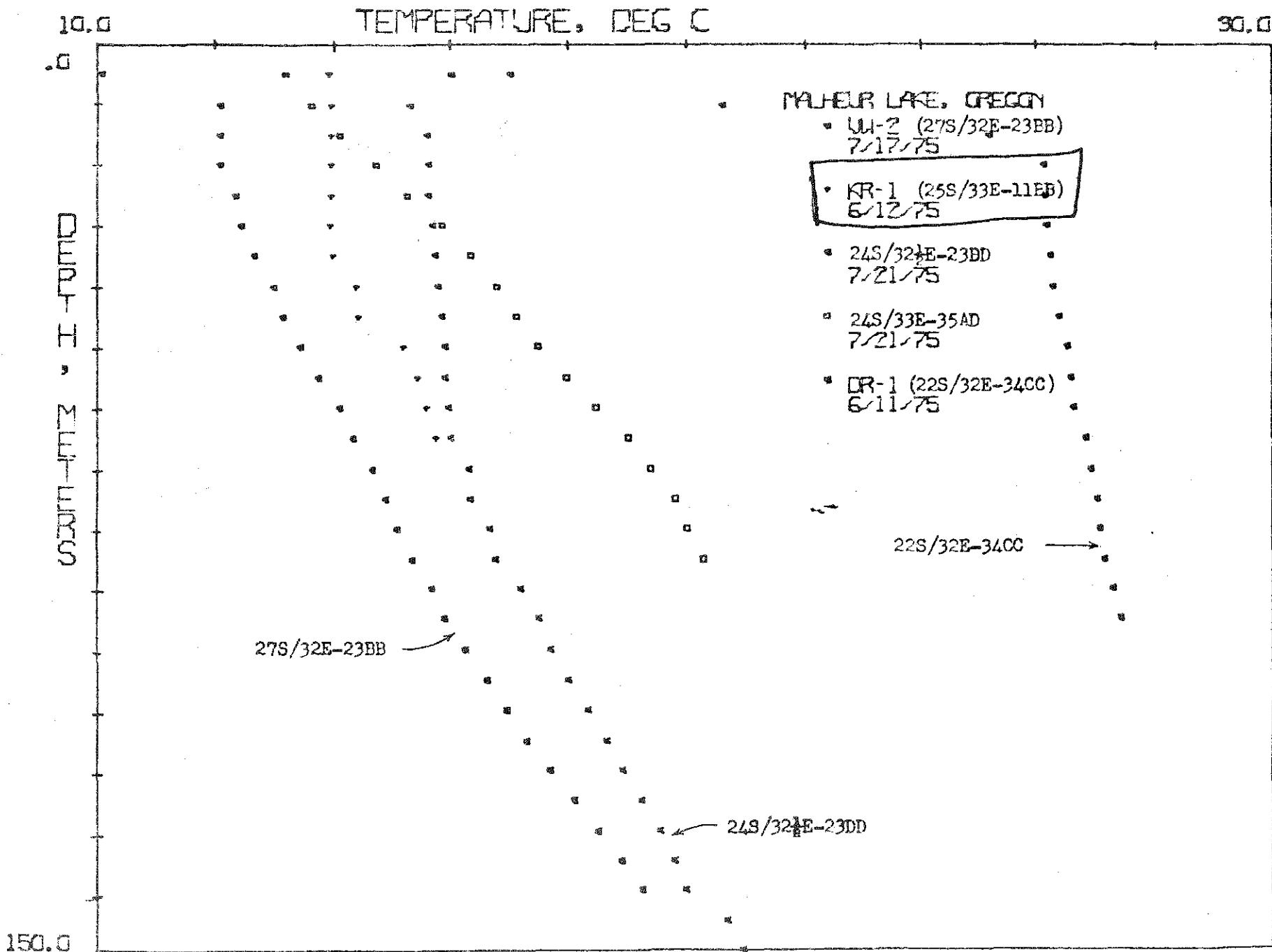
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEO THERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
15.0	49.2	47.860	118.15	0.0	0.0
20.0	65.6	48.620	119.52	152.0	8.3
25.0	82.0	49.260	120.67	128.0	7.0
30.0	98.4	49.790	121.62	106.0	5.8
35.0	114.8	50.170	122.31	76.0	4.2
37.0	121.4	50.220	122.40	25.0	1.4



LOCATION: CRANE, OREGON  
25S/33E • 11888  
HOLE NUMBER: KR-1  
DATE MEASURED: 6/12/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	13.950	57.11	.0	.0
10.0	32.8	13.970	57.15	4.0	.2
15.0	49.2	13.970	57.15	.0	.0
20.0	65.6	13.970	57.15	.0	.0
25.0	82.0	13.980	57.16	2.0	.1
30.0	98.4	13.960	57.13	-4.0	.2
35.0	114.8	13.990	57.18	6.0	.3
40.0	131.2	14.030	57.90	80.0	4.4
45.0	147.6	14.040	57.99	10.0	.5
50.0	164.0	15.200	59.36	152.0	8.3
55.0	180.4	15.440	59.79	48.0	2.6
60.0	196.8	15.610	60.10	34.0	1.9
65.0	213.2	15.750	60.35	28.0	1.5



LOCATION: BURNS AMS, OREGON

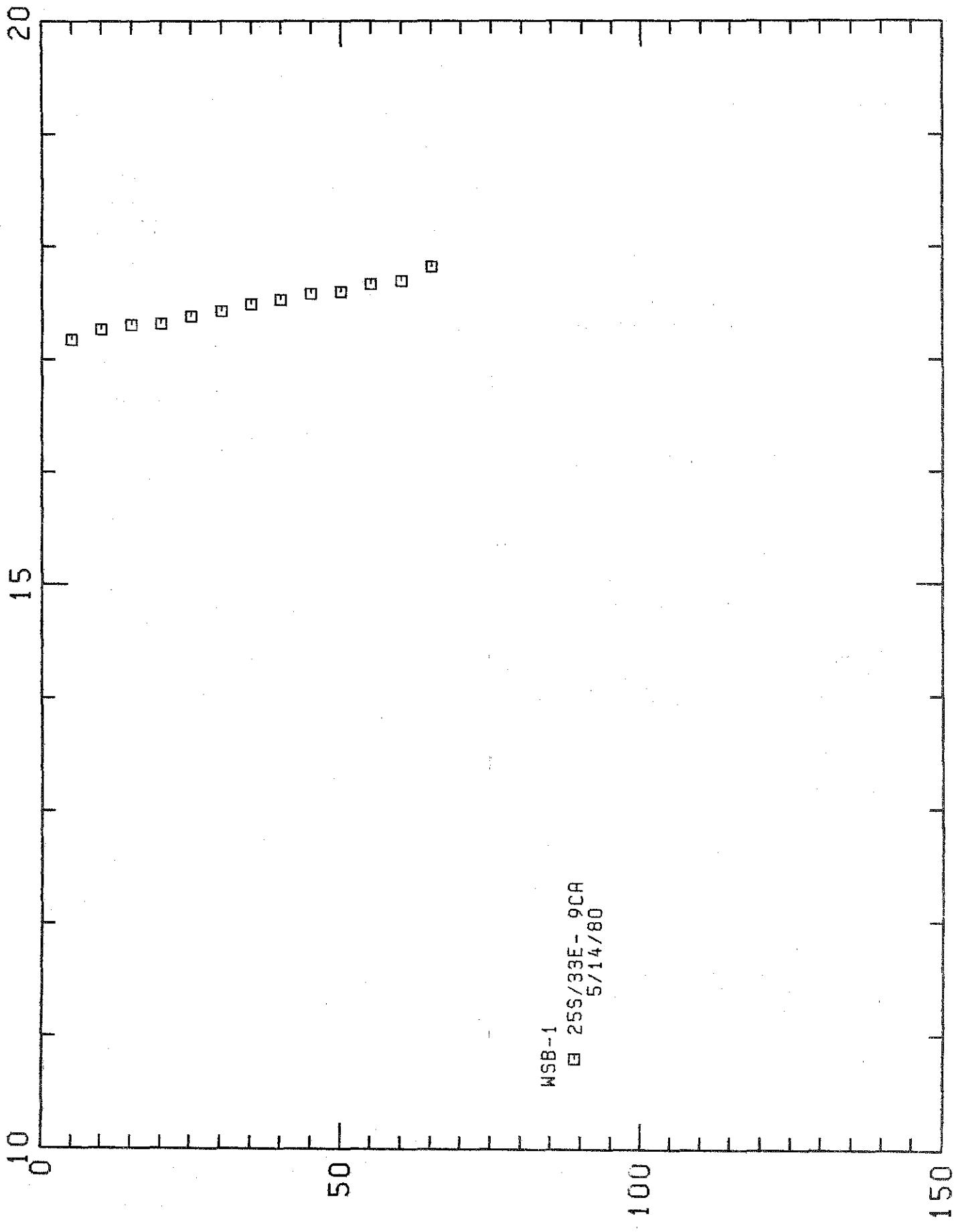
255/33E- 9CA

HOLE NAME: WSB-1

DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
5.0	16.4	17.180	62.92	0.0	0.0
10.0	32.8	17.270	63.09	18.0	1.0
15.0	49.2	17.310	63.16	8.0	0.4
20.0	65.6	17.320	63.18	2.0	0.1
25.0	82.0	17.380	63.28	12.0	0.7
30.0	98.4	17.430	63.37	10.0	0.5
35.0	114.8	17.490	63.48	12.0	0.7
40.0	131.2	17.530	63.55	8.0	0.4
45.0	147.6	17.580	63.64	10.0	0.5
50.0	164.0	17.600	63.69	4.0	0.2
55.0	180.4	17.670	63.81	14.0	0.8
60.0	196.8	17.700	63.86	6.0	0.3
65.0	213.2	17.820	64.08	24.0	1.3

TEMPERATURE, DEG C



DEPTH, METERS

LOCATION: BURNS AMS, OREGON

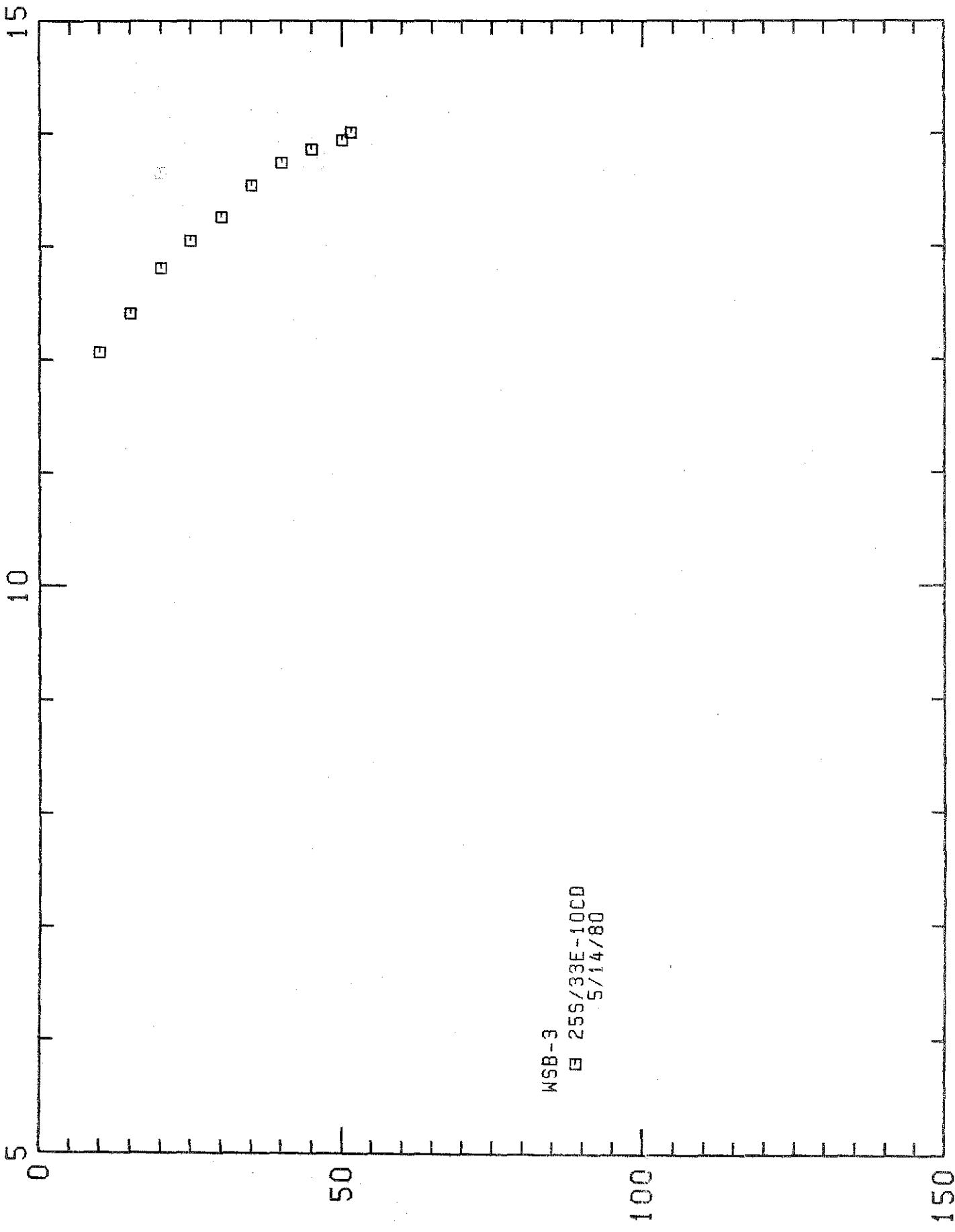
25S/33E-10CD

HOLE NAME: WSB-3

DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEO THERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	12.070	53.73	0.0	0.0
15.0	49.2	12.410	54.34	68.0	3.7
20.0	65.6	12.810	55.06	80.0	4.4
25.0	82.0	13.050	55.49	48.0	2.6
30.0	98.4	13.260	55.87	42.0	2.3
35.0	114.8	13.540	56.37	56.0	3.1
40.0	131.2	13.740	56.73	40.0	2.2
45.0	147.6	13.860	56.95	24.0	1.3
50.0	164.0	13.940	57.09	16.0	0.9
51.5	168.9	14.010	57.22	46.7	2.6

TEMPERATURE, DEG C



WSB-3  
25S/33E-10CD  
5/14/80

DEPTH, METERS

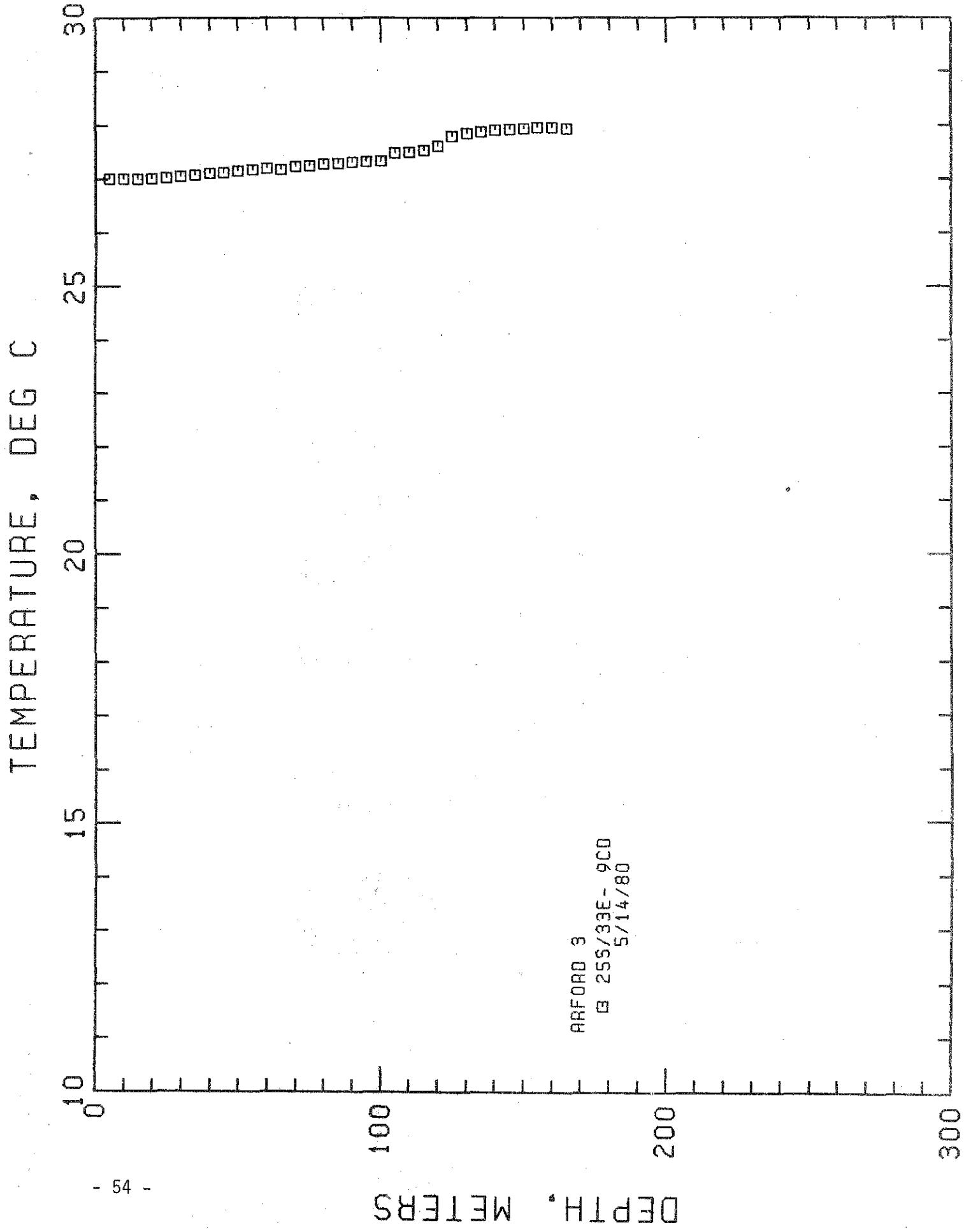
LOCATION: BURNS AMS, OREGON

25S/33E- 9CD

HOLE NAME: ARFORD 3

DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	27.020	80.64	0.0	0.0
10.0	32.8	27.020	80.64	0.0	0.0
15.0	49.2	27.020	80.64	0.0	0.0
20.0	65.6	27.030	80.65	0.1	0.1
25.0	82.0	27.040	80.67	0.1	0.1
30.0	98.4	27.060	80.71	4.0	0.0
35.0	114.8	27.090	80.76	4.0	0.0
40.0	131.2	27.120	80.82	4.0	0.0
45.0	147.6	27.130	80.83	4.0	0.0
50.0	164.0	27.160	80.89	4.0	0.0
55.0	180.4	27.190	80.94	4.0	0.0
60.0	196.8	27.210	80.98	4.0	0.0
65.0	213.2	27.190	80.94	4.0	0.0
70.0	229.6	27.250	81.05	4.0	0.0
75.0	246.0	27.260	81.07	4.0	0.0
80.0	262.4	27.290	81.12	4.0	0.0
85.0	278.8	27.300	81.14	4.0	0.0
90.0	295.2	27.330	81.19	4.0	0.0
95.0	311.6	27.340	81.21	4.0	0.0
100.0	328.0	27.350	81.23	4.0	0.0
105.0	344.4	27.500	81.50	4.0	0.0
110.0	360.8	27.510	81.50	4.0	0.0
115.0	377.2	27.540	81.57	4.0	0.0
120.0	393.6	27.620	81.72	4.0	0.0
125.0	410.0	27.800	82.04	4.0	0.0
130.0	426.4	27.860	82.15	4.0	0.0
135.0	442.8	27.890	82.20	4.0	0.0
140.0	459.2	27.920	82.26	4.0	0.0
145.0	475.6	27.930	82.27	4.0	0.0
150.0	492.0	27.940	82.29	4.0	0.0
155.0	508.4	27.970	82.36	4.0	0.0
160.0	524.8	27.960	82.33	4.0	0.0
165.0	541.2	27.940	82.29	4.0	0.0



LOCATION: BURNS AMS, OREGON

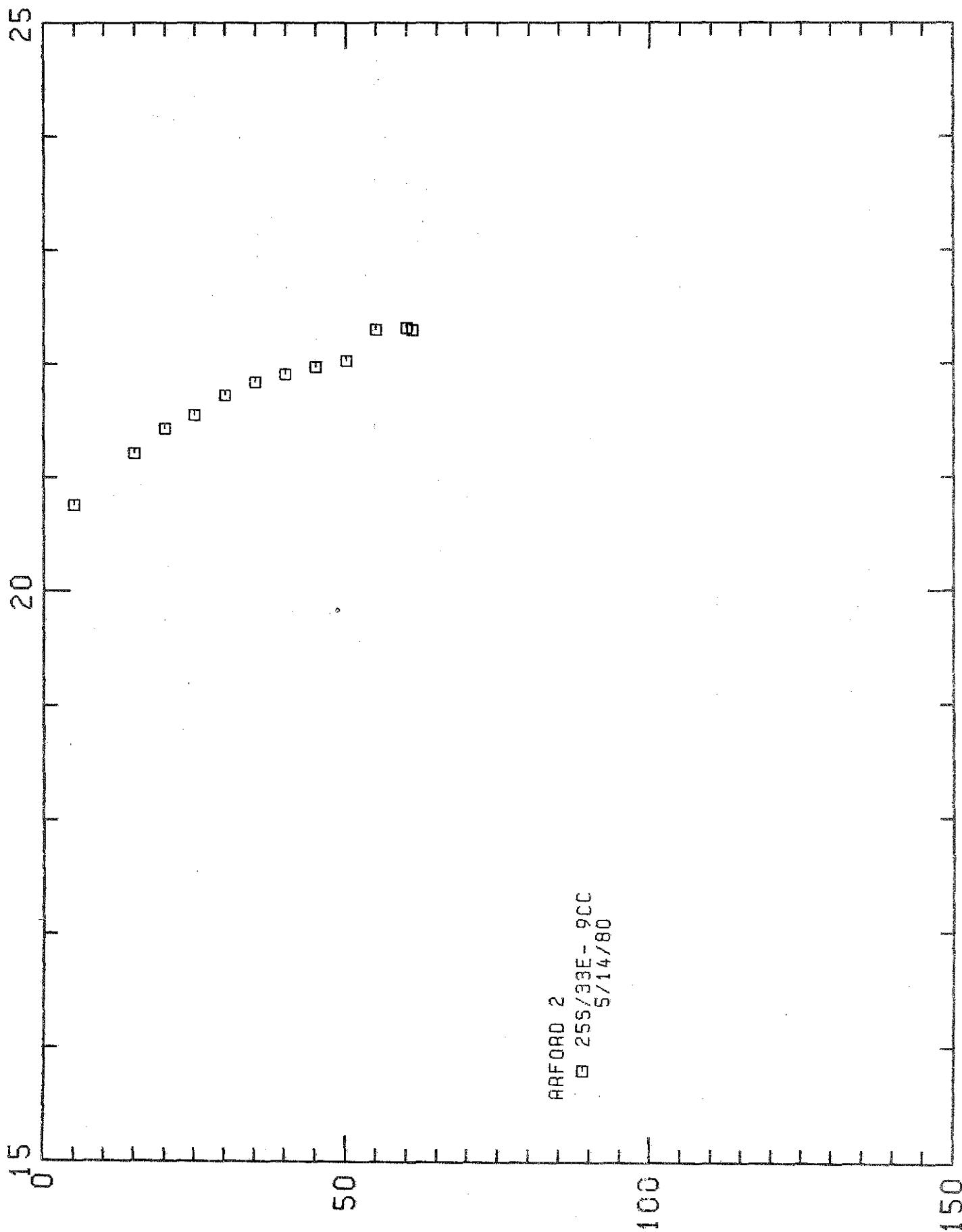
25S/33E- 9CC

HOLE NAME: ARFORD 2

DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
5.0	16.4	20.760	69.37	0.0	0.0
15.0	49.2	21.210	70.18	45.0	2.5
20.0	65.6	21.430	70.57	44.0	2.4
25.0	82.0	21.550	70.79	24.0	1.3
30.0	98.4	21.720	71.10	34.0	1.9
35.0	114.8	21.840	71.31	24.0	1.3
40.0	131.2	21.910	71.44	14.0	0.0
45.0	147.6	21.980	71.56	14.0	0.0
50.0	164.0	22.030	71.65	10.0	0.5
55.0	180.4	22.300	72.14	54.0	3.0
60.0	196.8	22.320	72.18	4.0	0.02
61.0	200.1	22.300	72.14	-20.0	-1.1

TEMPERATURE, DEG C



ARFORD 2  
25S/33E - 9C  
5/14/80

DEPTH, METERS

LOCATION: BURNS AMS, OREGON

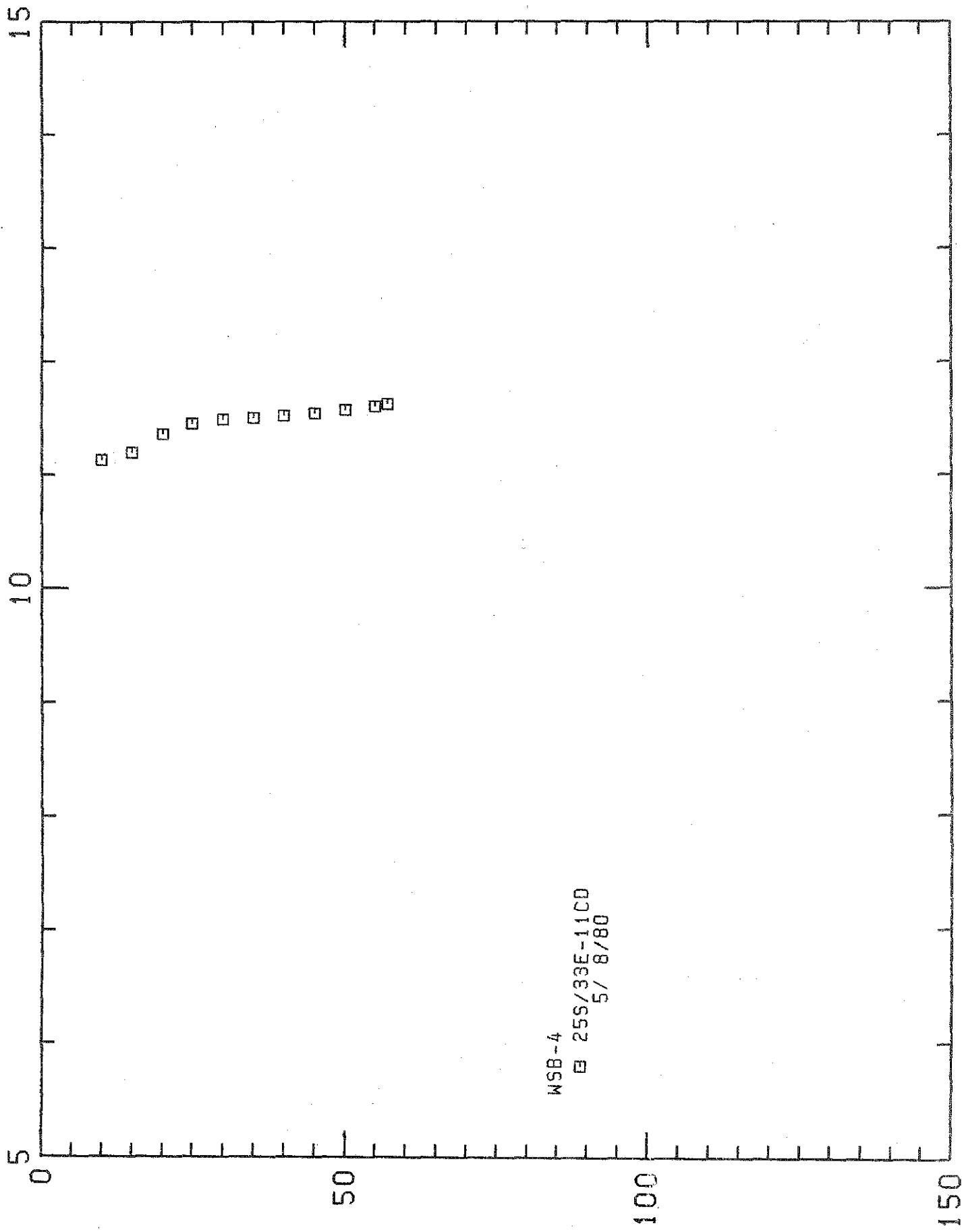
25S/33E-11CD

HOLE NAME: WSB-4

DATE MEASURED: 5/ 8/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	11.130	52.03	0.0	0.0
15.0	49.2	11.200	52.16	14.0	0.8
20.0	65.6	11.360	52.45	32.0	1.6
25.0	82.0	11.450	52.61	48.0	1.0
30.0	98.4	11.490	52.68	8.0	0.4
35.0	114.0	11.500	52.70	2.0	0.1
40.0	131.2	11.520	52.74	4.0	0.08
45.0	147.6	11.540	52.77	4.0	0.08
50.0	164.0	11.570	52.83	6.0	0.13
55.0	180.4	11.600	52.88	6.0	0.13
57.0	187.0	11.620	52.92	10.0	0.5

TEMPERATURE, DEG C



DEPTH, METERS

LOCATION: BURNS AMS, OREGON

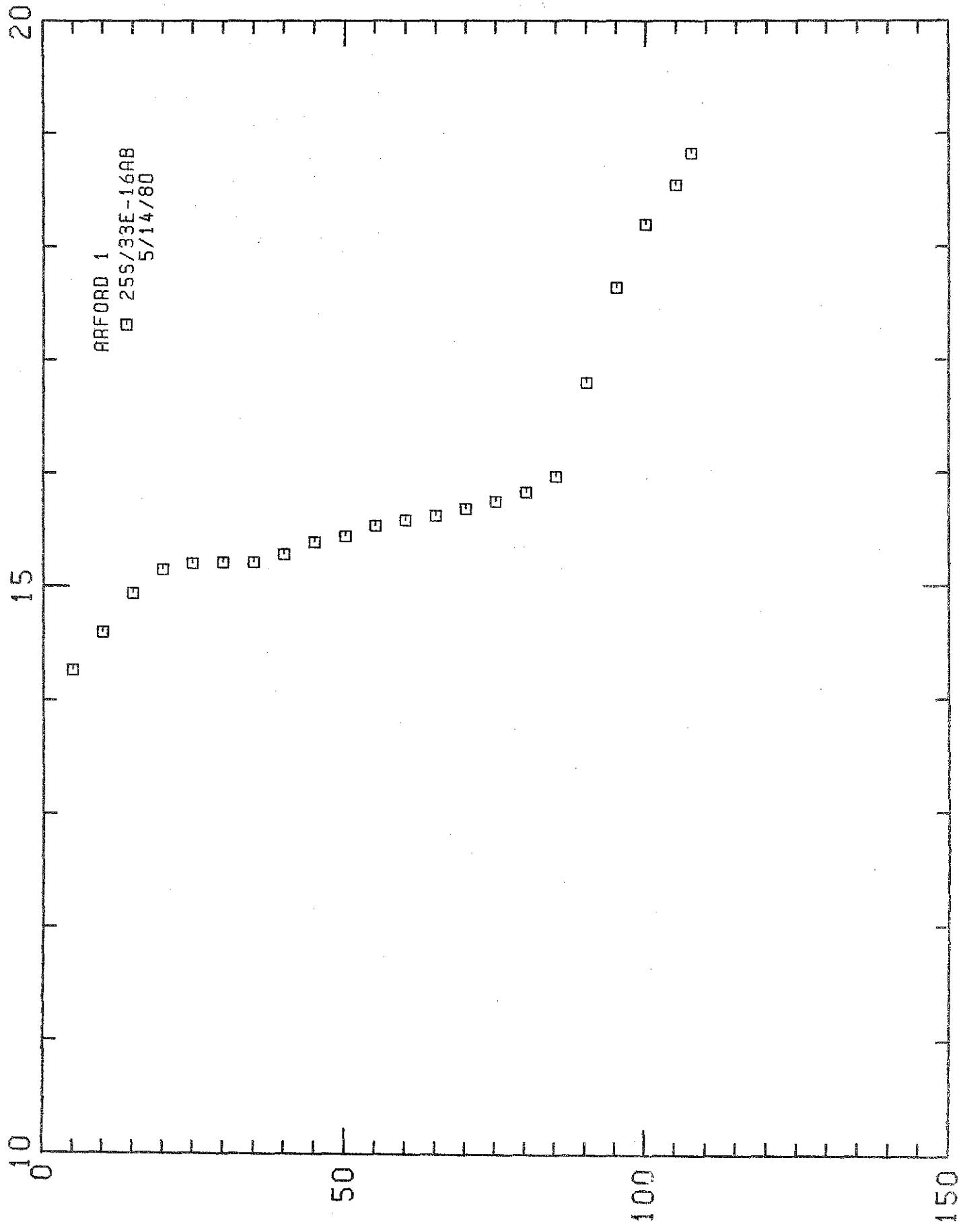
25S/33E-16AB

HOLE NAME: ARFORD 1

DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEO THERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
5.0	16.4	14.270	57.69	0.0	0.0
10.0	32.8	14.600	58.28	66.0	0.0
15.0	49.2	14.940	58.89	68.0	0.0
20.0	65.6	15.150	59.27	42.0	0.0
25.0	82.0	15.200	59.36	10.0	0.0
30.0	98.4	15.210	59.38	2.0	0.1
35.0	114.8	15.210	59.38	0.0	0.0
40.0	131.2	15.280	59.50	14.0	0.0
45.0	147.6	15.390	59.70	22.0	0.1
50.0	164.0	15.440	59.79	10.0	0.0
55.0	180.4	15.530	59.95	18.0	1.0
60.0	196.8	15.580	60.04	10.0	0.5
65.0	213.2	15.620	60.12	10.0	0.4
70.0	229.6	15.680	60.22	10.0	0.7
75.0	246.0	15.750	60.35	14.0	0.0
80.0	262.4	15.830	60.49	16.0	0.0
85.0	278.8	15.970	60.75	28.0	1.0
90.0	295.2	16.800	62.24	166.0	0.1
95.0	311.5	17.640	63.75	168.0	0.0
100.0	328.0	18.200	64.76	112.0	0.1
105.0	344.4	18.550	65.39	70.0	0.0
107.5	352.6	18.830	65.89	112.0	0.1

TEMPERATURE, DEG C



- 60 -  
DEPTH, METERS

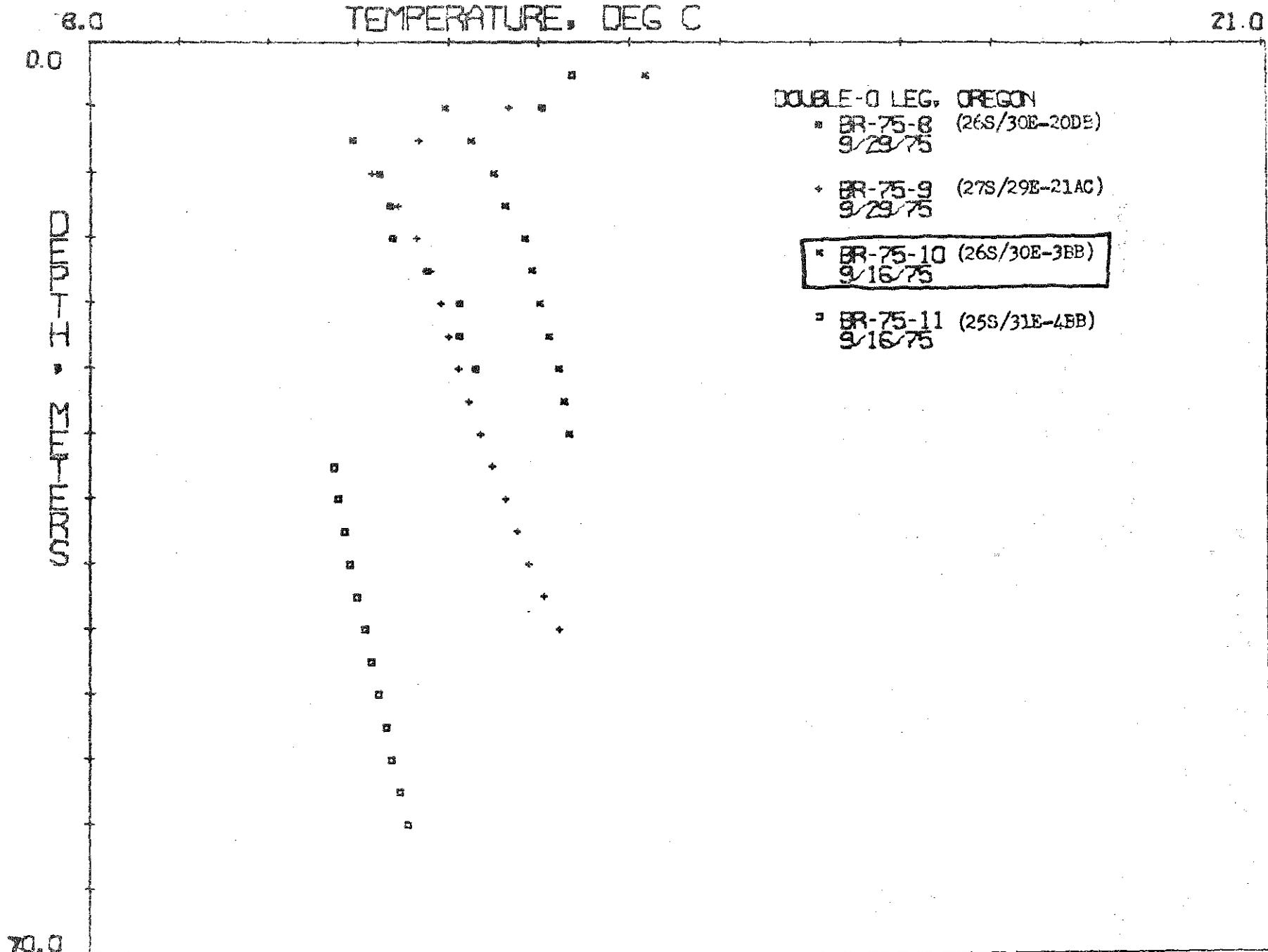
**LOCATION: DOUBLE-O LEG, OREGON**

26S/30E-38B

HOLE NUMBER: BR-75-10

DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
2.0	8.2	14.160	57.49	.0	.0
5.0	16.4	11.940	53.49	-858.0	-43.7
7.5	24.6	12.230	54.01	116.0	5.4
10.0	32.8	12.480	54.46	100.0	5.5
12.5	41.0	12.610	54.70	52.0	2.9
15.0	49.2	12.320	55.08	34.0	4.6
17.5	57.4	12.890	55.20	28.0	1.5
20.0	65.6	12.980	55.36	36.0	2.0
22.5	73.8	13.090	55.56	44.0	2.4
25.0	82.0	13.180	55.72	36.0	2.0
27.5	90.2	13.250	55.85	28.0	1.5
30.0	98.4	13.300	55.94	20.0	1.1



LOCATION: BURNS AMS, OREGON

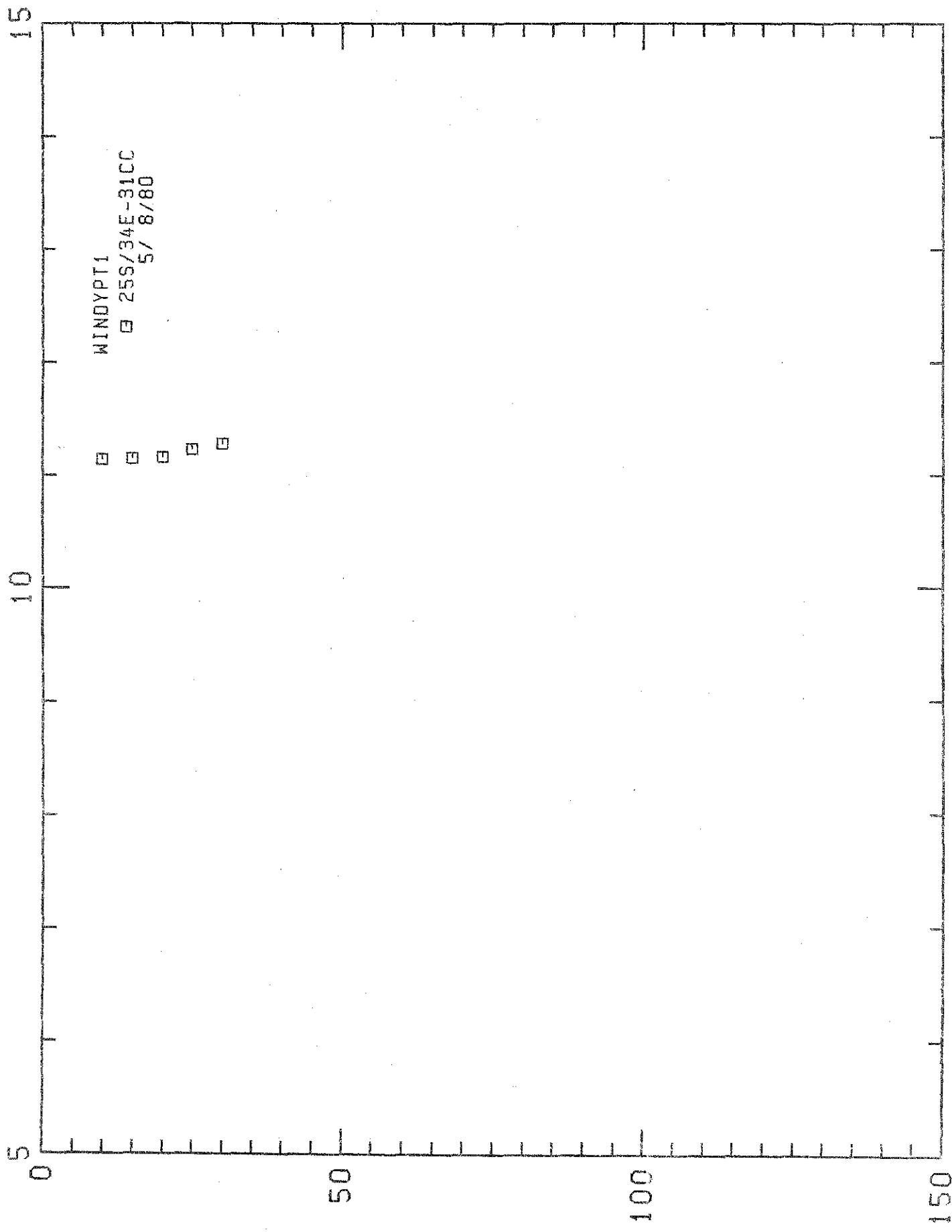
25S/34E-31CC

HOLE NAME: WINDYPT1

DATE MEASURED: 5/ 8/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	11.140	52.05	0.0	0.0
15.0	49.2	11.150	52.07	0.0	0.1
20.0	65.6	11.160	52.09	0.0	0.1
25.0	82.0	11.230	52.21	14.0	0.005
30.0	98.4	11.280	52.30	10.0	0.5

TEMPERATURE, DEG C



LOCATION: BURNS AMS, OREGON

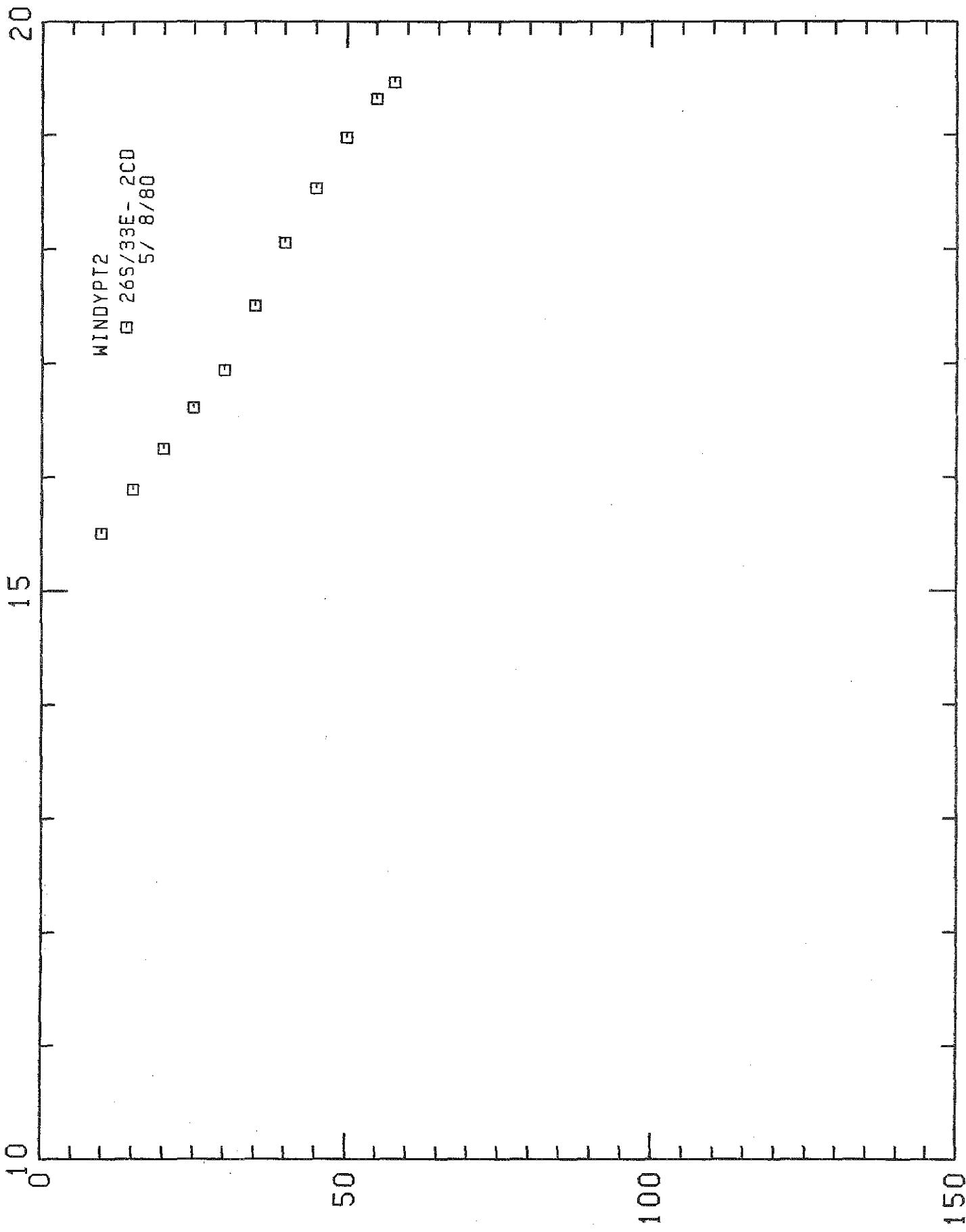
26S/33E- 2CD

HOLE NAME: WINDYPT2

DATE MEASURED: 5/ 8/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEO THERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	15.510	59.92	0.0	0.0
15.0	49.2	15.890	60.60	76.0	4.2
20.0	65.6	16.250	61.25	72.0	4.0
25.0	82.0	16.610	61.90	72.0	4.0
30.0	98.4	16.940	62.49	66.0	3.6
35.0	114.8	17.500	63.50	112.0	6.1
40.0	131.2	18.060	64.51	112.0	6.1
45.0	147.6	18.530	65.35	94.0	5.4
50.0	164.0	18.980	66.16	90.0	4.9
55.0	180.4	19.320	66.78	68.0	3.7
58.0	190.2	19.460	67.03	46.7	2.6

TEMPERATURE, DEG C



LOCATION: BURNS AMS, OREGON

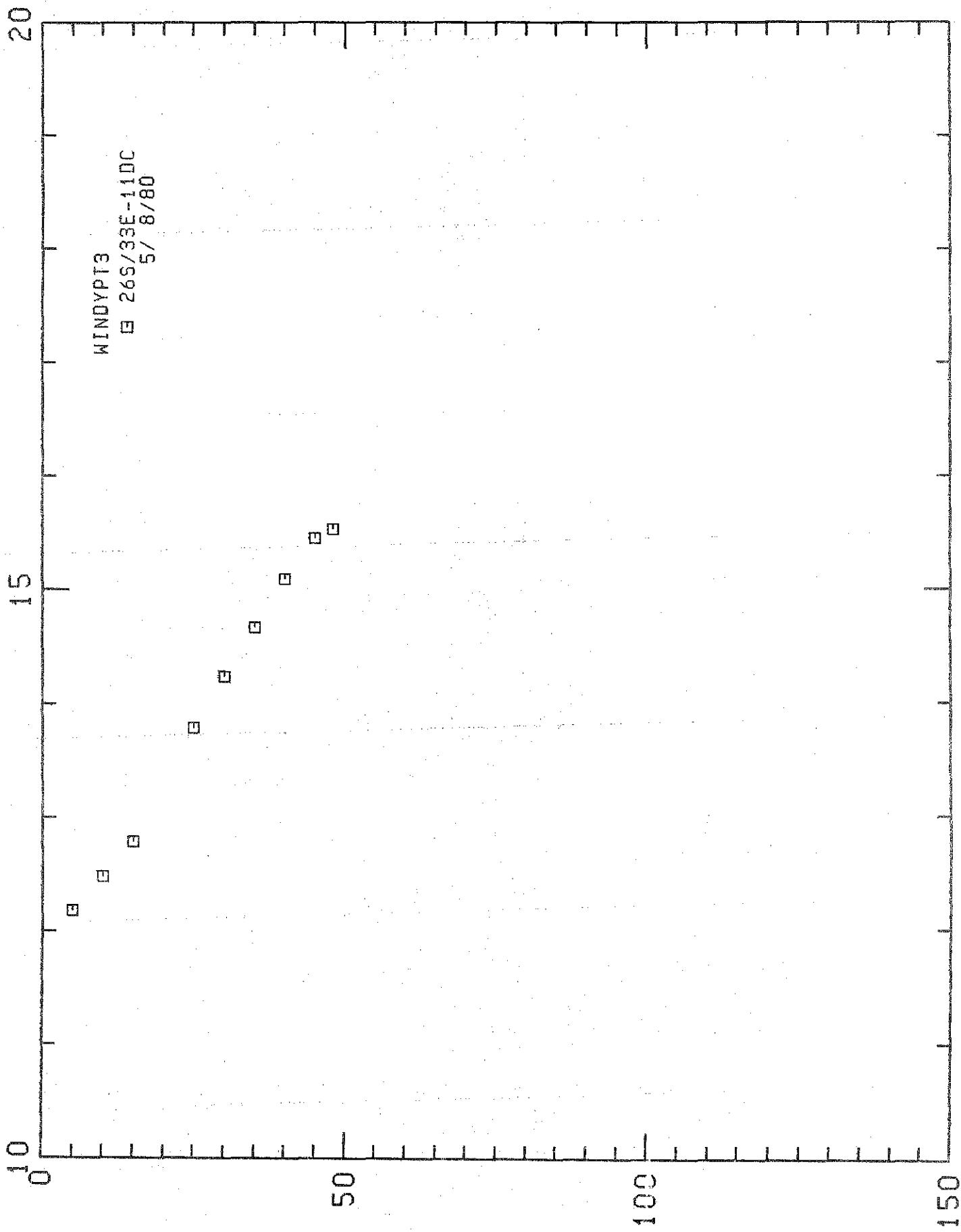
26S/33E-11DC

HOLE NAME: WINDYPT3

DATE MEASURED: 5/ 8/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
5.0	16.4	12.180	53.92	0.0	0.0
10.0	32.8	12.480	54.46	60.0	3.3
15.0	49.2	12.790	55.02	62.0	3.4
25.0	82.0	13.790	56.82	100.0	6.5
30.0	98.4	14.240	57.63	90.0	4.9
35.0	114.8	14.670	58.41	86.0	4.7
40.0	131.2	15.090	59.16	84.0	4.6
45.0	147.6	15.450	59.81	72.0	4.0
48.0	157.4	15.530	59.95	26.7	1.5

TEMPERATURE, DEG C



LOCATION: BURNS AMS, OREGON

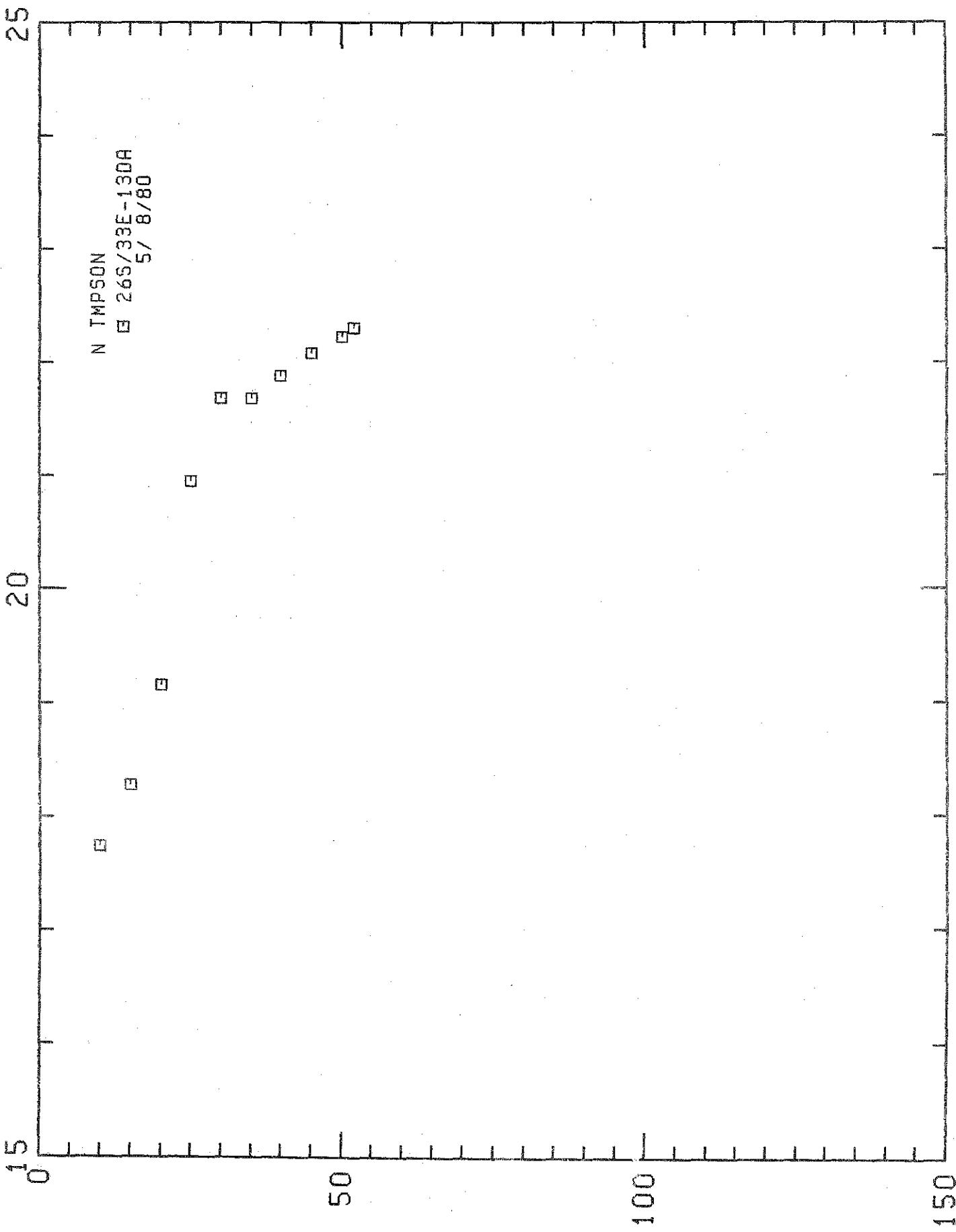
26S/33E-13DA

HOLE NAME: N TIPSON

DATE MEASURED: 5/ 8/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	17.740	63.93	0.0	0.0
15.0	49.2	18.280	64.90	108.0	5.9
20.0	65.6	19.160	66.49	176.0	9.7
25.0	82.0	20.950	69.71	358.0	19.6
30.0	98.4	21.680	71.02	146.0	8.0
35.0	114.8	21.680	71.02	0.0	0.0
40.0	131.2	21.880	71.38	40.0	2.0
45.0	147.6	22.080	71.74	40.0	2.0
50.0	164.0	22.230	72.01	30.0	1.6
52.0	170.6	22.310	72.16	40.0	2.0

TEMPERATURE, DEG C



DEPTH, METERS

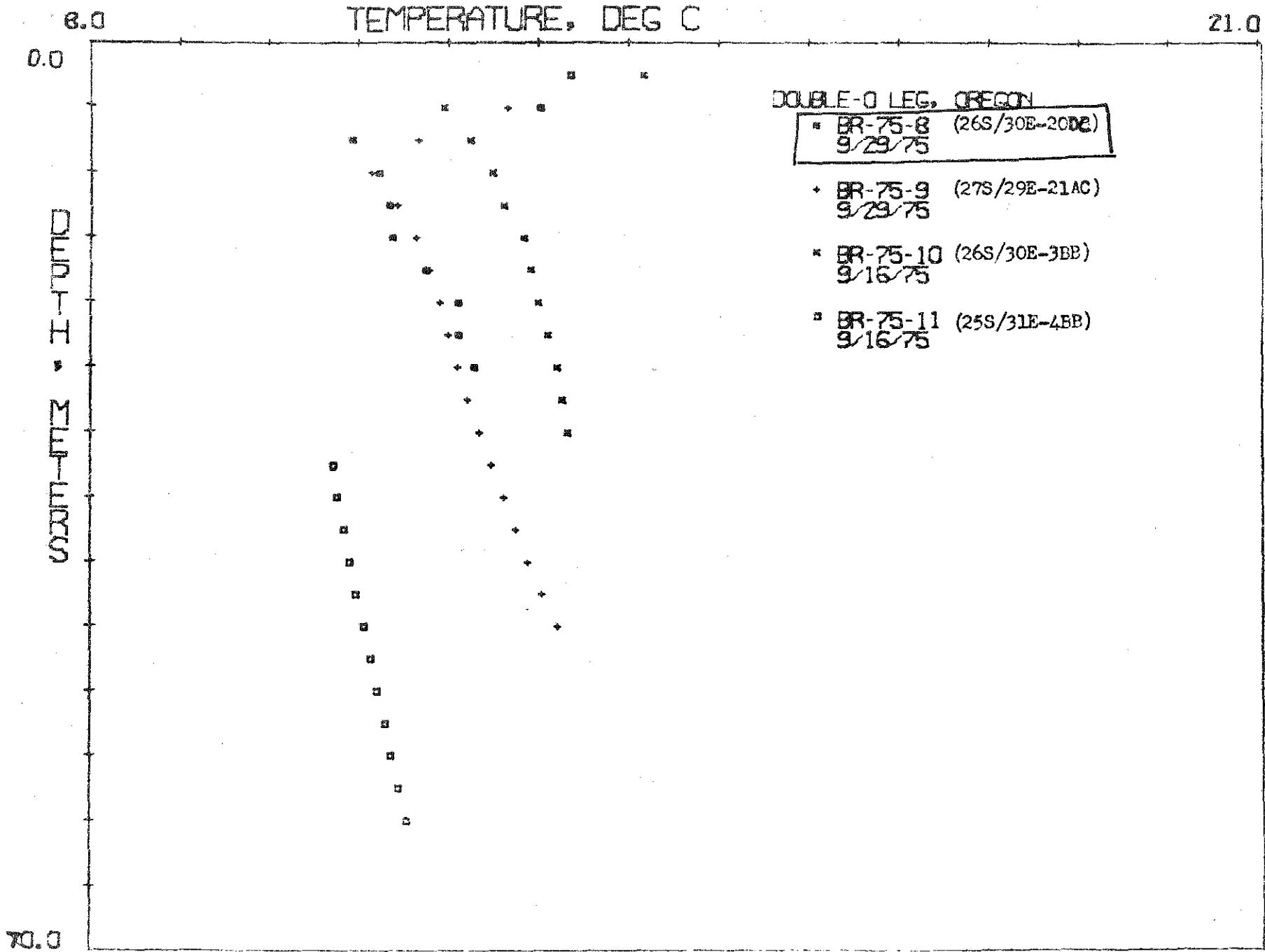
LOCATION: DOUBLE-8 LEG, BREGEN

26S/30E-20DG

HOLE NUMBER: BR-75-8

DATE MEASURED: 9/29/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	13.010	55.42	.0	.0
7.0	24.6	10.935	51.68	-830.0	-45.5
10.0	32.8	11.215	52.19	112.0	6.1
12.5	41.0	11.330	52.39	46.0	2.5
15.0	49.2	11.365	52.46	14.0	.8
17.5	57.4	11.720	53.10	142.0	7.8
20.0	65.6	12.085	53.75	146.0	8.0
22.5	73.8	12.095	53.77	4.0	.2
25.0	82.0	12.260	54.07	56.0	3.6



LOCATION: BURNS AMS, OREGON

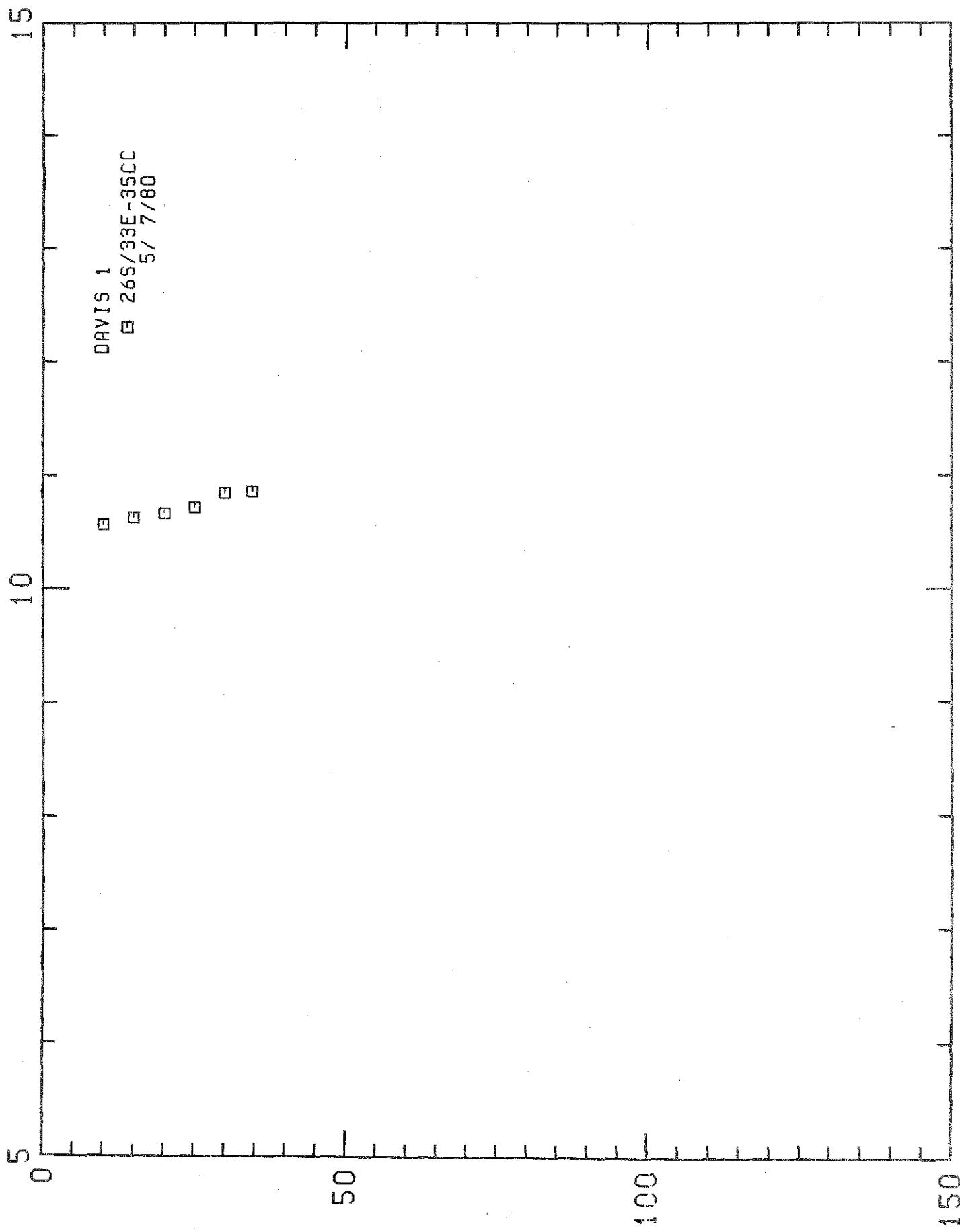
26S/33E-35CC

HOLE NAME: DAVIS 1

DATE MEASURED: 5/ 7/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEO THERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	10.570	51.03	0.0	0.0
15.0	49.2	10.630	51.13	12.0	0.7
20.0	65.6	10.670	51.21	8.0	0.4
25.0	82.0	10.720	51.30	10.0	0.5
30.0	98.4	10.850	51.53	26.0	1.4
34.0	113.2	10.860	51.55	2.2	0.1

TEMPERATURE, DEG C



LOCATION: BURNS AMS, OREGON

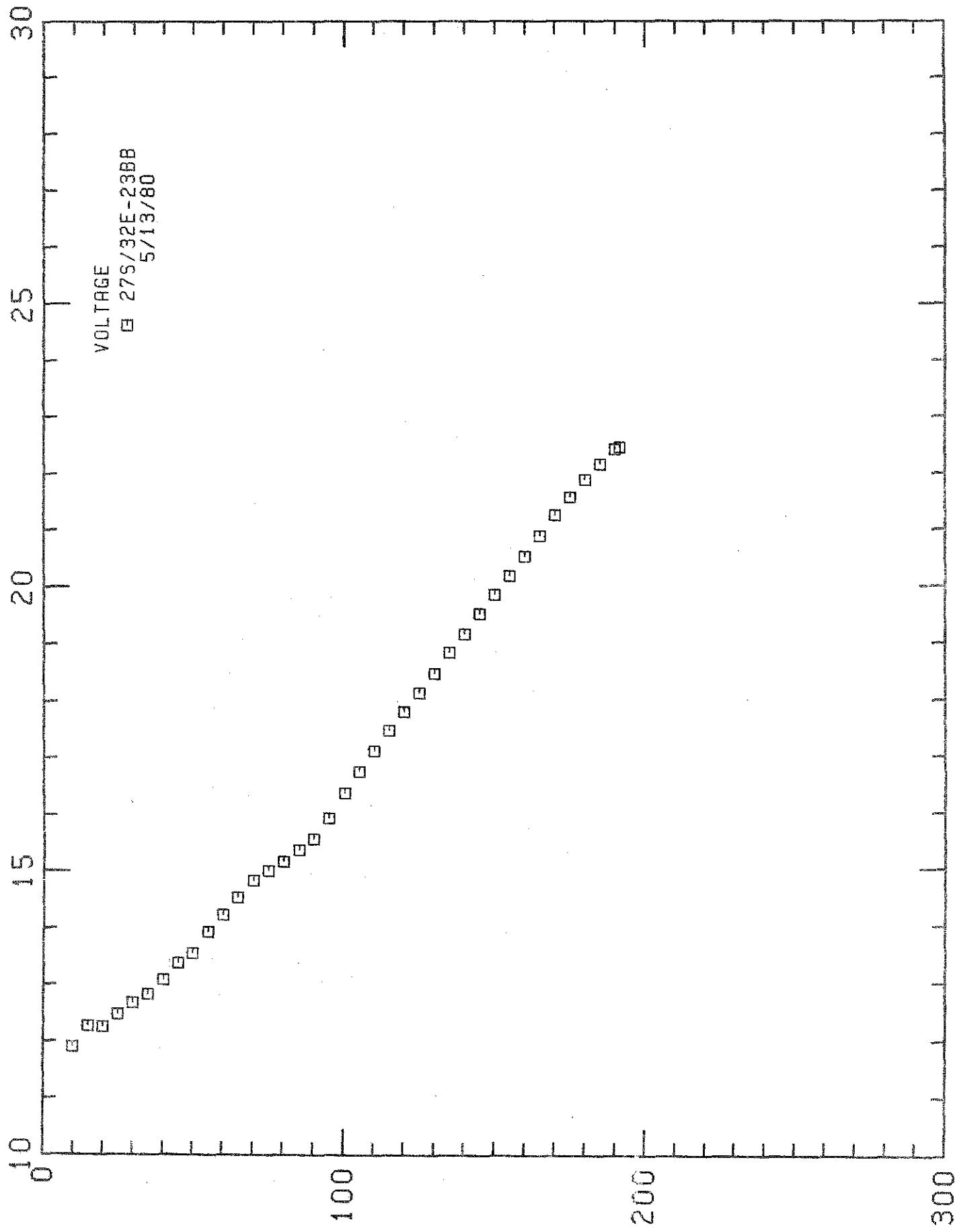
275/32E-23BB

HOLE NAME: VOLTAGE

DATE MEASURED: 5/13/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEOTHERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.0	11.910	53.44	0.0	0.0
15.0	49.2	12.270	54.09	72.0	4.0
20.0	65.6	12.260	54.07	-2.0	-0.1
25.0	82.0	12.480	54.46	44.0	2.4
30.0	98.4	12.690	54.84	42.0	2.3
35.0	114.8	12.830	55.09	28.0	1.15
40.0	131.2	13.090	55.56	52.0	2.0
45.0	147.6	13.380	56.08	58.0	1.9
50.0	164.0	13.550	56.39	34.0	1.8
55.0	180.4	13.930	57.07	76.0	4.0
60.0	196.8	14.230	57.61	60.0	3.03
65.0	213.2	14.540	58.17	62.0	3.4
70.0	229.6	14.830	58.69	58.0	3.09
75.0	246.0	15.000	59.00	34.0	1.09
80.0	262.4	15.170	59.31	34.0	1.12
85.0	278.0	15.370	59.67	40.0	2.1
90.0	295.2	15.560	60.01	38.0	2.1
95.0	311.6	15.930	60.67	74.0	4.1
100.0	328.0	16.380	61.48	90.0	4.9
105.0	344.4	16.760	62.17	76.0	4.2
110.0	360.8	17.120	62.82	72.0	4.0
115.0	377.2	17.470	63.45	70.0	3.8
120.0	393.6	17.800	64.04	66.0	3.6
125.0	410.0	18.140	64.65	68.0	3.7
130.0	426.4	18.480	65.26	68.0	3.1
135.0	442.8	18.850	65.93	74.0	4.1
140.0	459.2	19.170	66.51	64.0	3.55
145.0	475.6	19.520	67.14	70.0	3.68
150.0	492.0	19.850	67.73	66.0	3.6
155.0	508.4	20.180	68.33	66.0	3.6
160.0	524.8	20.530	68.95	70.0	3.0
165.0	541.2	20.890	69.60	72.0	4.0
170.0	557.6	21.260	70.27	74.0	4.1
175.0	574.0	21.580	70.84	64.0	3.5
180.0	590.4	21.890	71.38	60.0	3.0
185.0	606.8	22.160	71.89	56.0	3.1
190.0	623.2	22.420	72.36	52.0	2.0
191.5	628.1	22.460	72.43	26.7	1.5

TEMPERATURE, DEG C



LOCATION: DOUBLE-B LEG, OREGON

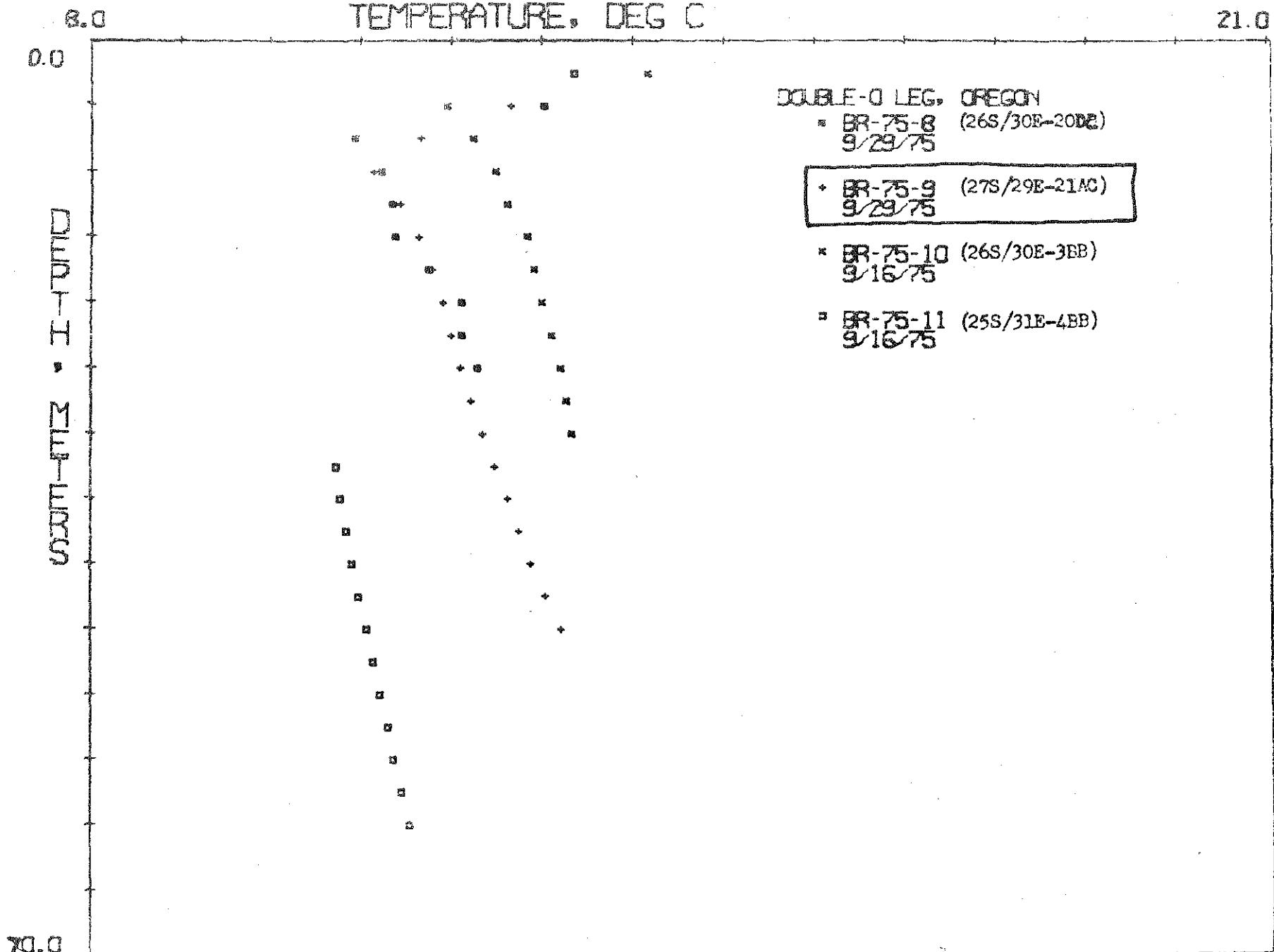
27S/29E-21AC

HOLE NUMBER: BR-75-9

DATE MEASURED: 9/29/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GRADIENT DEG F/100 FT
5.0	16.4	12.650	54.77	.0	.0
7.5	24.6	11.650	52.97	-400.0	-22.0
10.0	32.8	11.140	52.05	-204.0	-11.2
12.5	41.0	11.420	52.56	112.0	6.1
15.0	49.2	11.630	52.93	84.0	4.6
17.5	57.4	11.770	53.19	56.0	3.1
20.0	65.6	11.880	53.38	44.0	2.4
22.5	73.8	11.970	53.55	36.0	2.0
25.0	82.0	12.070	53.73	40.0	2.2
27.5	90.2	12.195	53.95	50.0	2.7
30.0	98.4	12.320	54.18	52.0	2.9
32.5	106.6	12.450	54.41	50.0	2.7
35.0	114.8	12.600	54.58	50.0	3.3
37.5	123.0	12.730	54.91	52.0	2.9
40.0	131.2	12.860	55.15	52.0	2.9
42.5	139.4	13.010	55.42	50.0	3.3
45.0	147.6	13.180	55.72	58.0	3.7

TEMPERATURE, DEG C



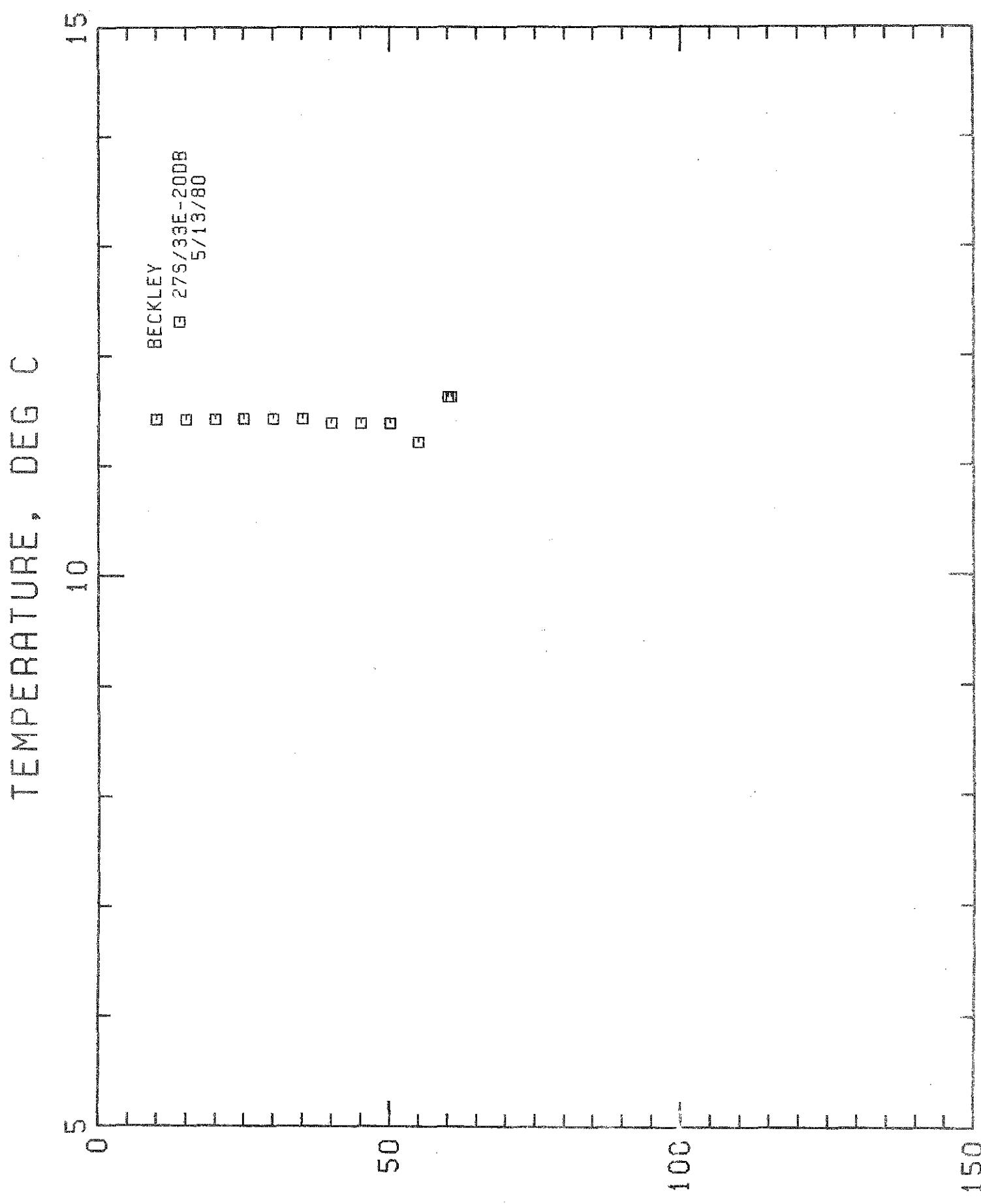
LOCATION: BURNS AMS, OREGON

27S/33E-20DB

HOLE NAME: BECKLEY

DATE MEASURED: 5/13/80

DEPTH METERS	DEPTH FEET	TEMPERATURE		GEO THERMAL GRADIENT	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	11.420	52.56	0.0	0.0
15.0	49.2	11.420	52.56	0.0	0.0
20.0	65.6	11.420	52.56	0.0	0.0
25.0	82.0	11.430	52.57	0.0	0.1
30.0	98.4	11.430	52.57	0.0	0.0
35.0	114.8	11.430	52.57	0.0	0.0
40.0	131.2	11.390	52.50	-0.0	-0.4
45.0	147.6	11.380	52.48	-2.0	-0.1
50.0	164.0	11.380	52.48	0.0	0.0
55.0	164.0	11.380	52.48	0.0	-0.0
55.0	180.4	11.210	52.18	-34.0	-1.9
60.0	196.8	11.620	52.92	82.0	4.5
60.5	198.4	11.620	52.92	0.0	0.0



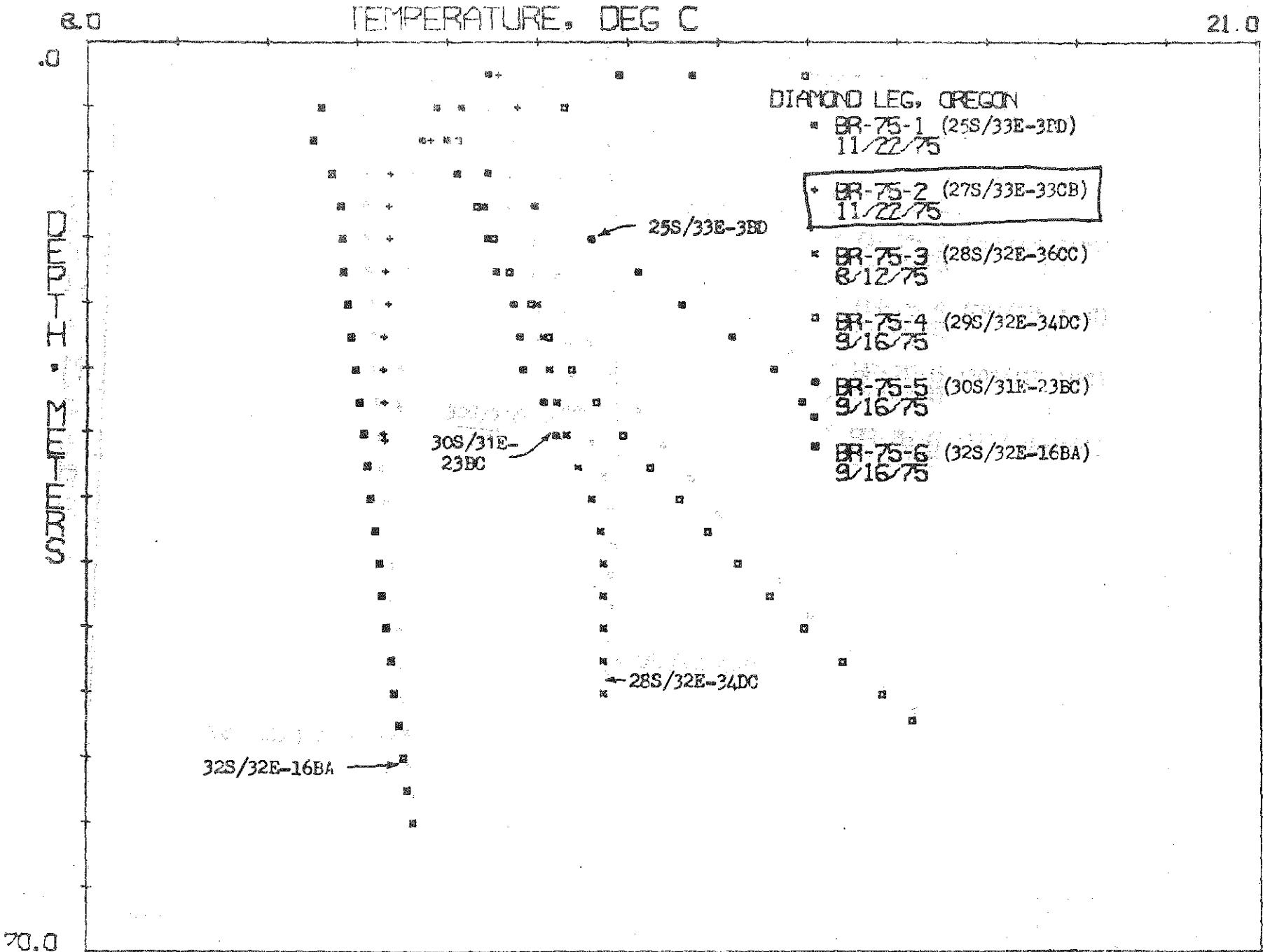
LOCATION: DIAMOND LEGS, OREGON

27S/33E-33CB

HOLE NUMBER: BR-75-2

DATE MEASURED: 11/22/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOThERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.570	54.63	.0	.0
5.0	16.4	12.760	54.97	76.0	4.2
7.5	24.6	11.810	53.26	-380.0	-20.9
10.0	32.8	11.360	52.45	-180.0	-9.9
12.5	41.0	11.350	52.43	-4.00	-.2
15.0	49.2	11.350	52.43	.0	.0
17.5	57.4	11.310	52.36	-16.00	-.9
20.0	65.6	11.330	52.39	8.00	.4
22.5	73.8	11.290	52.32	-16.00	-.9
25.0	82.0	11.280	52.30	-4.00	-.2
27.5	90.2	11.290	52.32	4.00	.2
30.0	98.4	11.280	52.30	-4.00	-.2
30.5	100.0	11.290	52.32	20.0	1.1



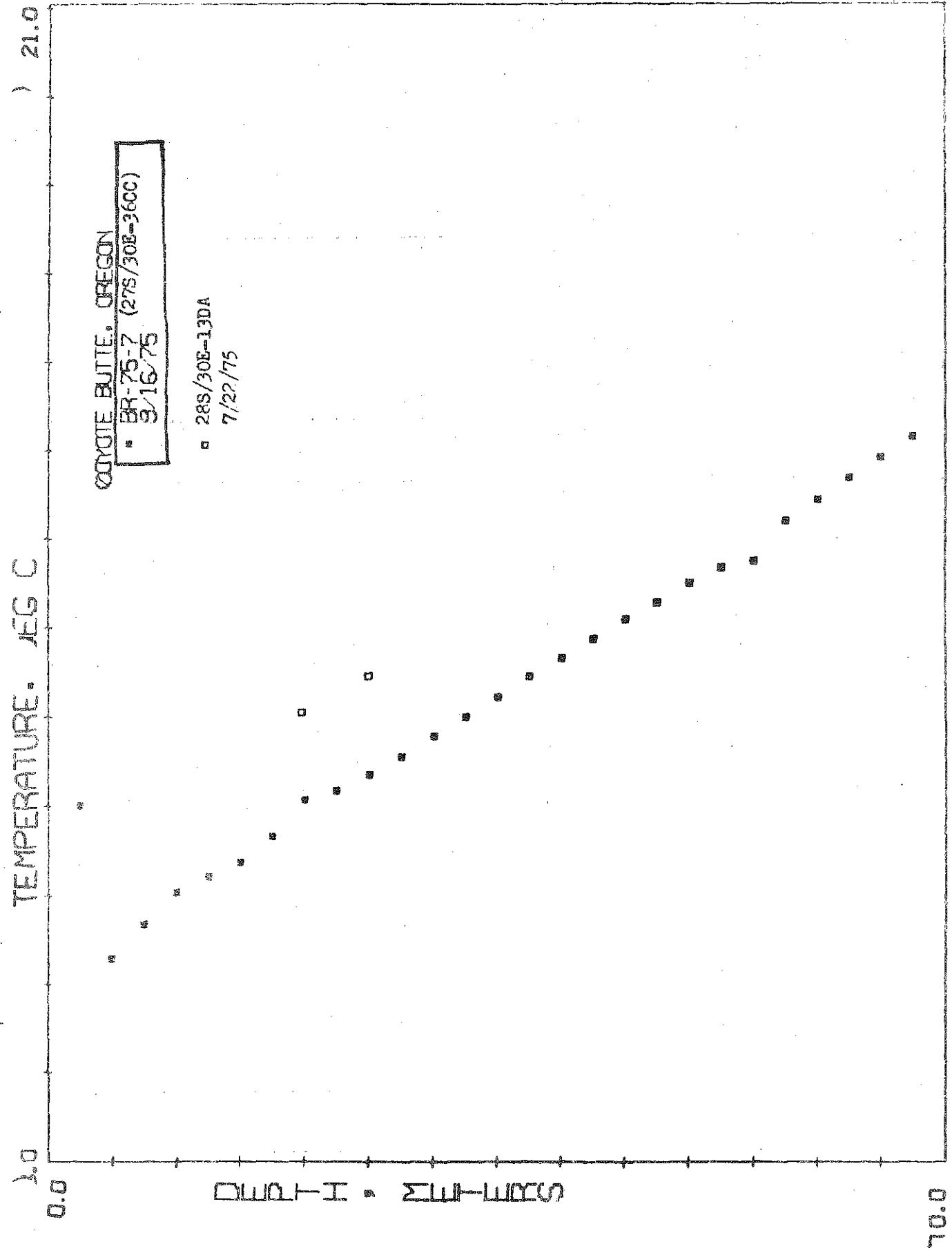
LOCATION: COYOTE BUTTE, OREGON

27S/30E=36CC

HOLE NUMBER: BR-75-7

DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEO THERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.000	53.60	.0	.0
5.0	16.4	10.280	50.50	-688.0	-37.8
7.5	24.6	10.670	51.21	156.0	8.6
10.0	32.8	11.040	51.87	148.0	8.1
12.5	41.0	11.200	52.16	64.0	3.5
15.0	49.2	11.360	52.45	64.0	3.5
17.5	57.4	11.650	52.97	116.0	6.4
20.0	65.6	12.060	53.71	154.0	9.0
22.5	73.8	12.160	53.89	40.0	2.2
25.0	82.0	12.340	54.21	72.0	4.0
27.5	90.2	12.530	54.55	76.0	4.2
30.0	98.4	12.770	54.99	96.0	5.3
32.5	106.6	12.980	55.36	84.0	4.6
35.0	114.8	13.200	55.76	88.0	4.8
37.5	123.0	13.430	56.17	92.0	5.0
40.0	131.2	13.640	56.55	84.0	4.6
42.5	139.4	13.850	56.93	84.0	4.6
45.0	147.6	14.070	57.33	88.0	4.8
47.5	155.8	14.260	57.67	76.0	4.2
50.0	164.0	14.470	58.05	84.0	4.6
52.5	172.2	14.640	58.35	68.0	3.7
55.0	180.4	14.710	58.48	28.0	1.5
57.5	188.6	15.160	59.29	180.0	9.9
60.0	196.8	15.410	59.74	100.0	5.5
62.5	205.0	15.650	60.17	96.0	5.3
65.0	213.2	15.890	60.60	96.0	5.3
67.5	221.4	16.120	61.02	92.0	5.0



LOCATION: COYOTE BUTTES, OREGON

28S/30E-13DA

HOLE NUMBER: HP-12

DATE MEASURED: 7/22/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOThermal GRADIENT DEG C/KM	DEG F/100
20.0	65.6	13.040	55.47	.0	.0
25.0	82.0	13.450	56.21	82.0	4.5

TEMPERATURE. EG C

21.0

COYOTE BUTTE, OREGON  
• BR-75-7 (27S/30E-3600)  
9/16/75

□ 28S/30E-13DA  
7/22/75

DEPT - H - 220-1000

70.0

LOCATION: DIAMOND LEG, OREGON  
28S/32E-36CC

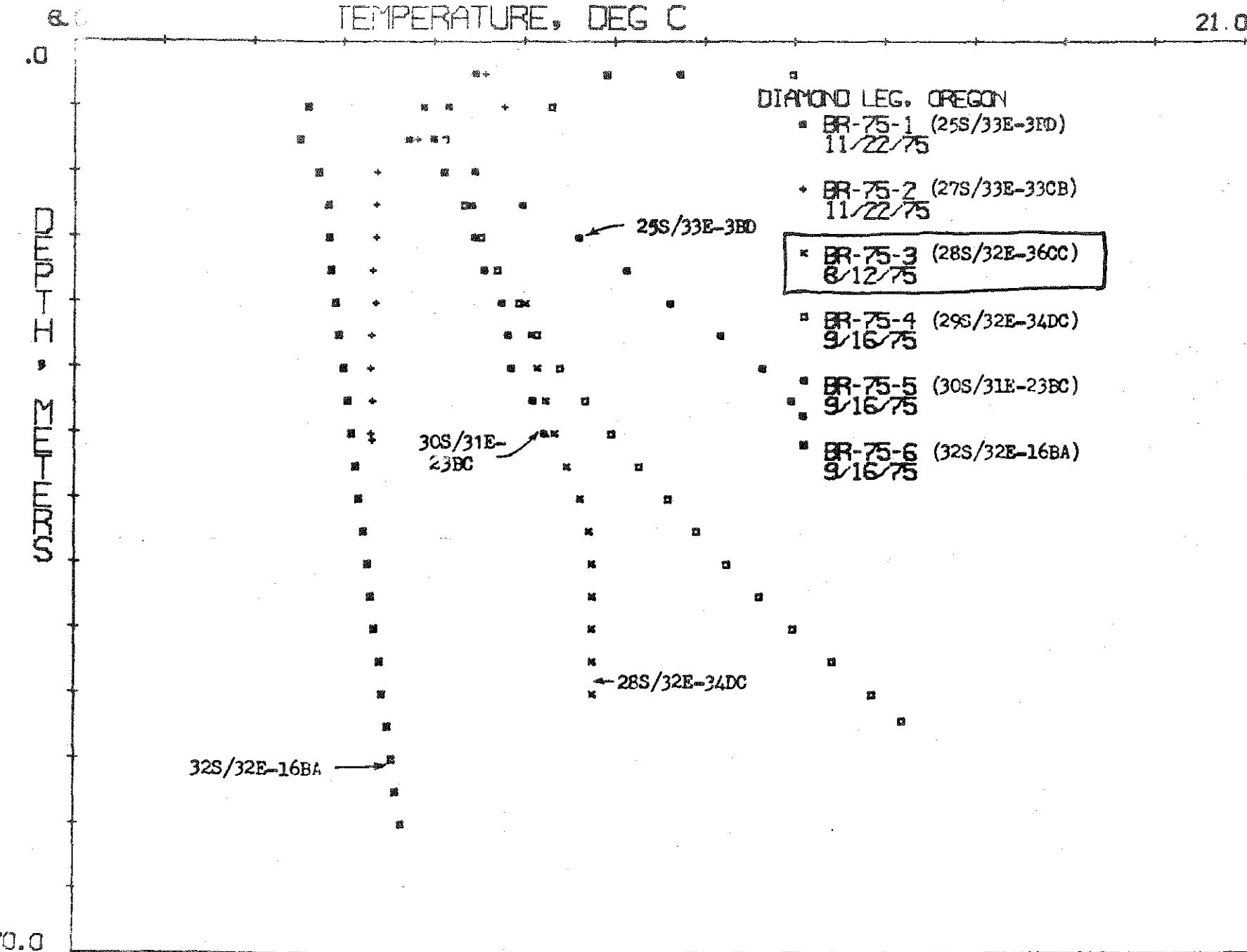
HOLE NUMBER: BR-75-3

DATE MEASURED: 8/12/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GRADIENT DEG F/100 FT
20.0	65.6	12.990	55.38	.0	.0
22.5	73.8	13.050	55.49	24.0	1.3
25.0	82.0	13.120	55.62	28.0	1.5
27.5	90.2	13.200	55.76	32.0	1.8
30.0	98.4	13.300	55.94	40.0	2.2
32.5	106.6	13.430	56.17	52.0	2.9
35.0	114.8	13.570	56.43	56.0	3.1
37.5	123.0	13.680	56.62	44.0	2.4
40.0	131.2	13.700	56.66	8.0	.4
42.5	139.4	13.700	56.66	.0	.0
45.0	147.6	13.700	56.66	.0	.0
47.5	155.8	13.710	56.68	4.0	.2
50.0	164.0	13.710	56.68	.0	.0

21.0

## TEMPERATURE, DEG C



LOCATION: DIAMOND LEG, OREGON  
 29S/32E-34DC  
 HOLE NUMBER: BR-75-4  
 DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOThermal GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	15.960	60.73	.0	.0
5.0	16.4	13.290	55.92	-1068.0	-58.6
7.5	24.6	12.120	53.82	-458.0	-25.7
10.0	32.8	12.100	53.78	-8.0	-4
12.5	41.0	12.320	54.18	88.0	4.8
15.0	49.2	12.500	54.50	72.0	4.0
17.5	57.4	12.680	54.82	72.0	4.0
20.0	65.6	12.910	55.24	92.0	5.0
22.5	73.8	13.120	55.62	84.0	4.6
25.0	82.0	13.360	56.05	96.0	5.3
27.5	90.2	13.630	56.53	108.0	5.9
30.0	98.4	13.920	57.06	116.0	6.4
32.5	106.6	14.220	57.60	120.0	6.6
35.0	114.8	14.540	58.17	128.0	7.0
37.5	123.0	14.860	58.75	128.0	7.0
40.0	131.2	15.200	59.36	136.0	7.5
42.5	139.4	15.550	59.99	140.0	7.7
45.0	147.6	15.930	60.67	152.0	8.3
47.5	155.8	16.360	61.45	172.0	9.4
50.0	164.0	16.790	62.22	172.0	9.4
52.0	170.6	17.130	62.83	170.0	9.3

8.0

## TEMPERATURE, DEG C

21.0

0

DEPT-H.  
FEET-WATER

20.0

## DIAMOND LEG, OREGON

▪ BR-75-1 (25S/33E-3BD)  
11/22/75• BR-75-2 (27S/33E-33CB)  
11/22/75\* BR-75-3 (28S/32E-36CC)  
8/12/75□ BR-75-4 (29S/32E-34DC)  
9/16/75▪ BR-75-5 (30S/31E-23BC)  
9/16/75▪ BR-75-6 (32S/32E-16BA)  
9/16/75

25S/33E-3BD

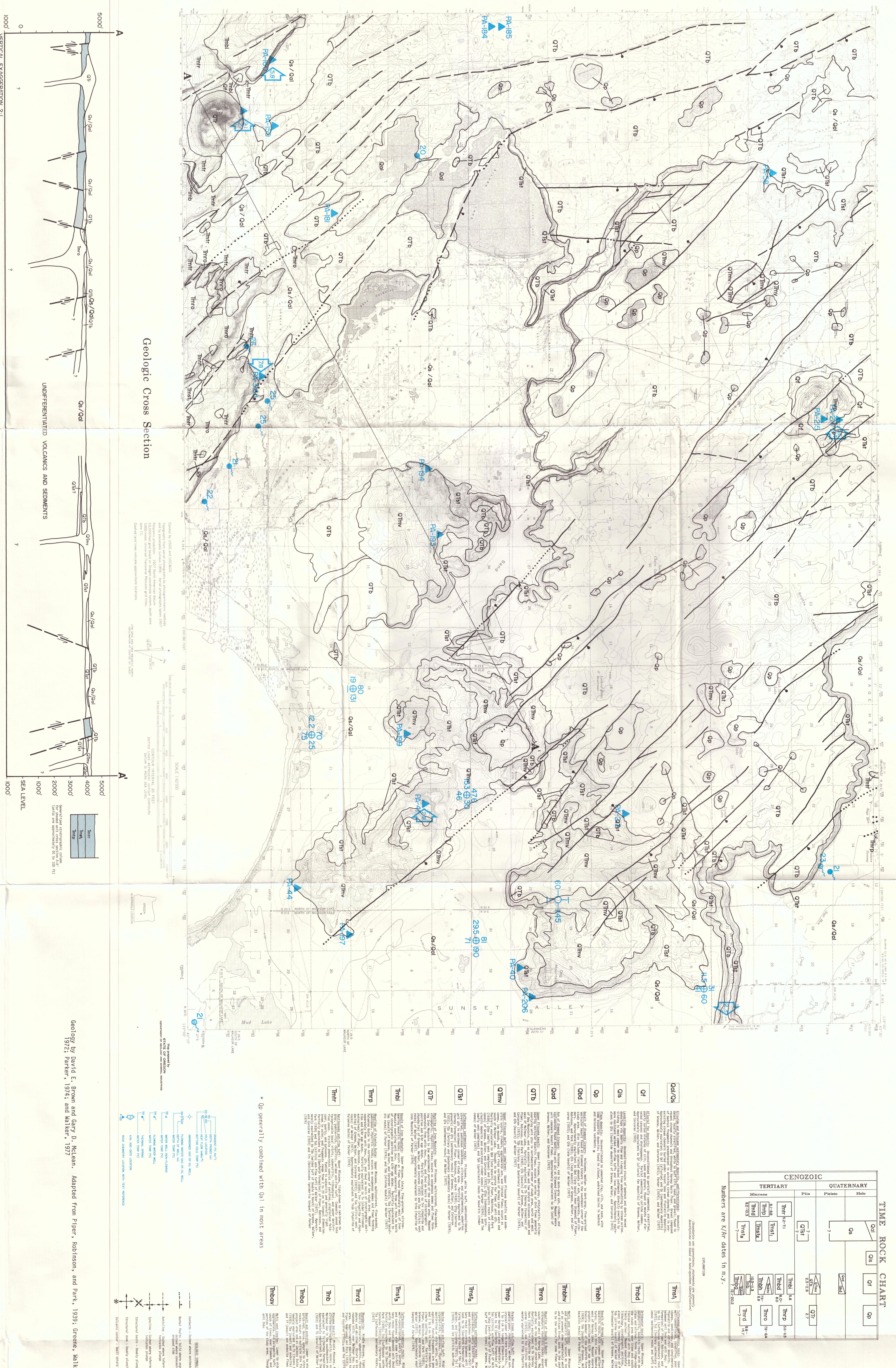
30S/31E-  
23BC

28S/32E-34DC

32S/32E-16BA

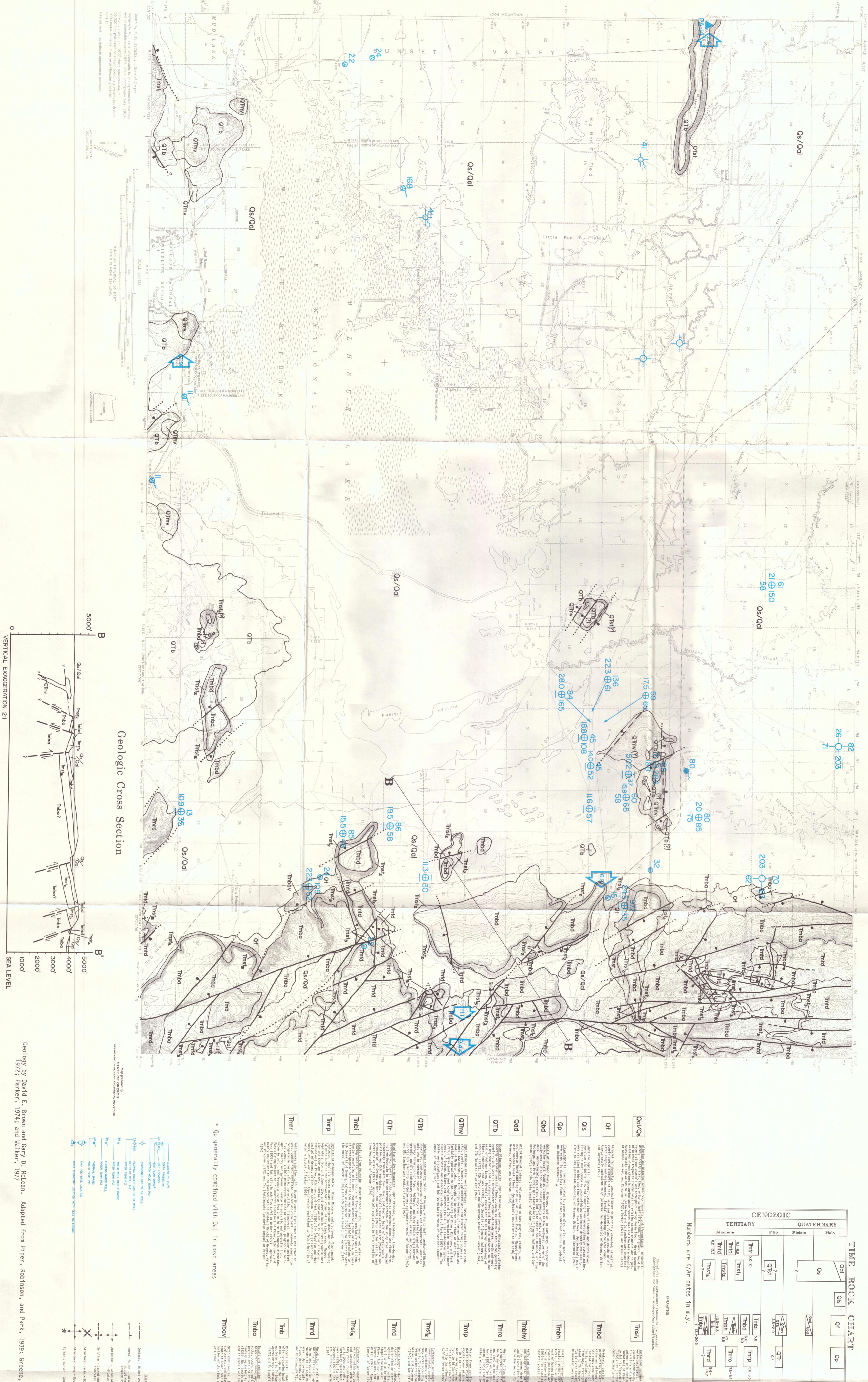
# GEOLIC MAP OF THE SOUTHERN HARNEY BASIN, OREGON

SOUTHERN F



# GEOLOGIC MAP OF THE SOUTHERN HARNEY BASIN, OREGON

SOUTHERN H



Geology by David E. Brown and Gary D. McLean. Adapted from Piper, Robinson, and Park, 1939; Greene, Walker, and Corcoran 1972; Parker 1974; and Walker 1977.

# GEOLOGIC MAP OF THE SOUTHERN HARNEY BASIN, OREGON

OPEN FILE REPORT #0-80-7

OPEN FILE REPORT #0-80-  
ACTIVITY



\* Qp generally combined with Qal in most areas

# GEOLOGIC MAP OF THE SOUTHERN HARNEY BASIN, OREGON

SOUTHERN F

PLATE IV



Lineament study by D.E. Brown, taken from 1:500,000 LANDSAT and 1:120,000 U-2 imagery

# LINEAMENT STUDY of the HARNEY BASIN, OREGON

**PLATE V**  
STATE OF OREGON  
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRY  
DONALD A. HULL, STATE GEOLOGIST

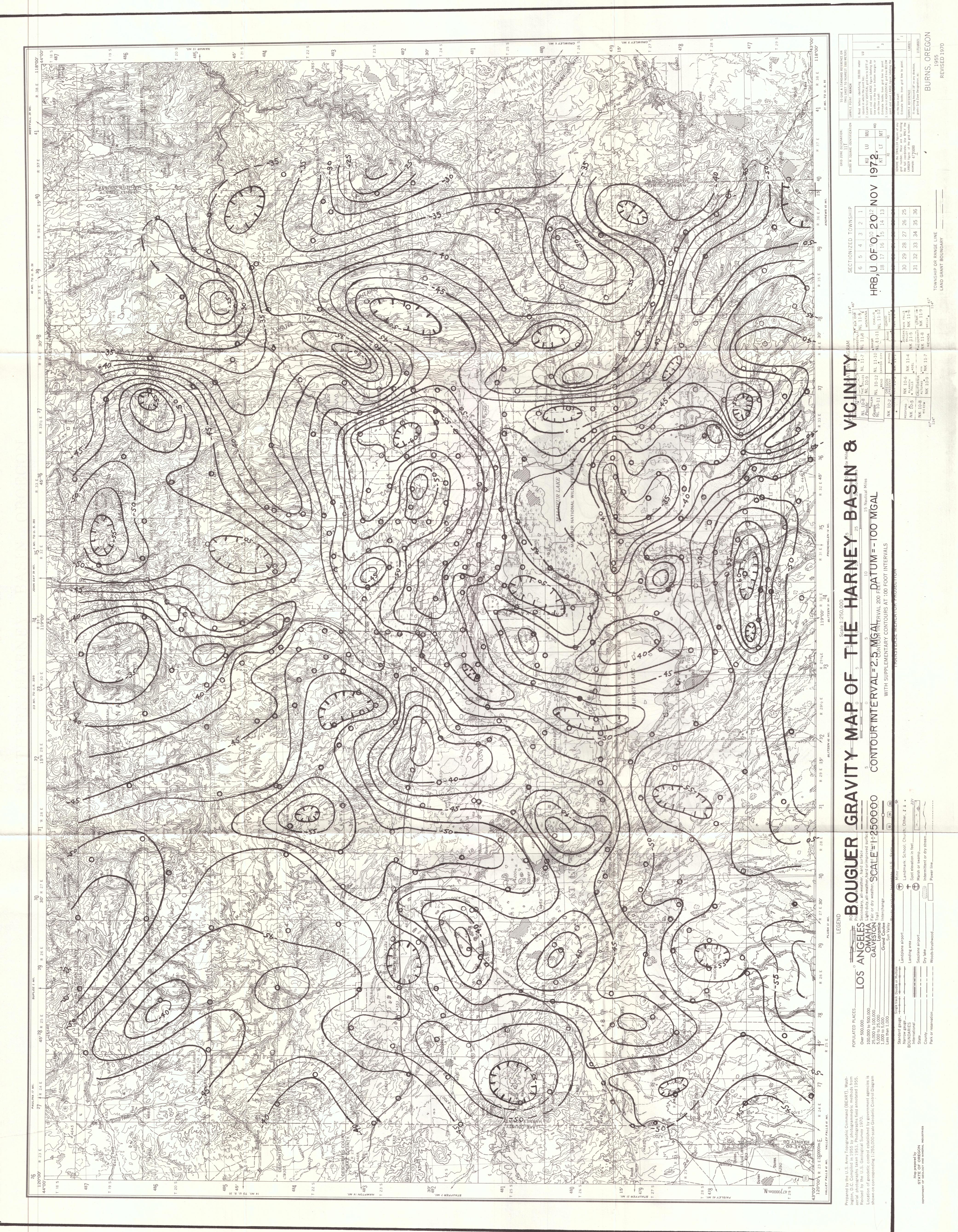


PLATE VI

# TOTAL FIELD AEROMAGNETIC MAP

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





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

# AEROMAGNETIC MAP OF THE HARNEY BASIN & VICINITY

SCALE 1:250000 CONTOUR INTERVAL = 1000' DATUM = 540000.7

HRB U. OF O. 20 NOV 1972.

VALUES IN X 10<sup>-4</sup>

FLIGHT ELEVATION = 6000 FT BAR.

HRB U. OF O. 20 NOV 1972.

VALUES IN X 10<sup>-4</sup>

FLIGHT ELEVATION = 6000 FT BAR.

HRB U. OF O. 20 NOV 1972.

VALUES IN X 10<sup>-4</sup>

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VALUES IN X 10<sup>-4</sup>

FLIGHT ELEVATION = 6000 FT BAR.

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