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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.

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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°00' on the south, 43°30' on the north, 118°30' on the east, and 119°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 km^2 (8,100 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.

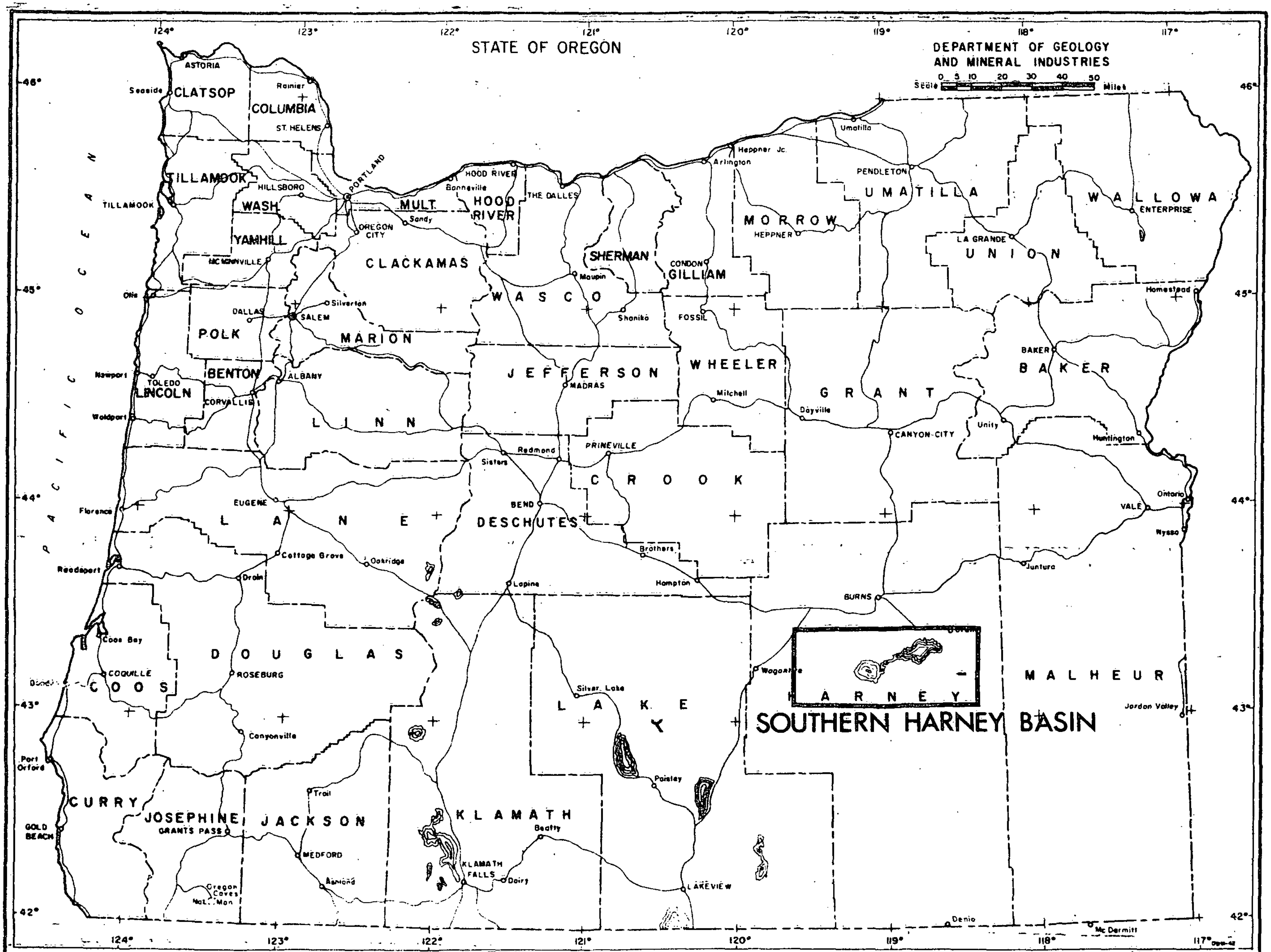


Figure 1: Map showing location of study area.

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 7½-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

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
PA-300	119°04'18" 43°03'06"	Basalt	w8.8±1.4 my	Tmbh
PA-311B	119°22'23" 43°09'03"	Welded tuff	w8.6±0.2 my	Tmtd
PA-146	119°21'11" 43°13'80"	Rhyolite	w8.4±1.3 my	Tmto
PA-119	119°13'30" 43°14'19"	Rhyolite	w8.2±0.12 my	Tmtp
PA-250	119°03'45" 43°02'27"	High Al basalt	w7.9±0.9 my	Tmbh
PA-316D	119°08'45" 43°17'02"	Rhyolite	w7.8±0.5 my	Tmro
PA-243	119°03'45" 43°04'56"	Welded tuff	s7.1±0.10 my	Tmtr
G-165-68	118°34'48" 43°24'48"	Basalt	p6.91±1.09 my	Tmbd
PA-330	119°22'23" 43°09'03"	Welded tuff	w6.7±0.4 my	Tmtr
PA-311G	119°22'23" 43°09'03"	Welded tuff	w6.6±0.2 my	Tmtr
W-2-70	119°18'00" 43°28'48"	Rhyodacite	a6.5±0.3 my b6.1±0.2 my	Tmrp
PA-6-70	119°27'51" 44°46'54	Welded tuff	a6.4±0.2 my	Tmtr
PA-214	119°18'00" 43°30'18"	Rhyolite	w5.6±0.4 my b6.4±0.2 my	Tmrp
PA-160	119°28'00" 43°16'30"	Andesite	w5.8±0.8 my	Tmbi
PA-41	119°06'34" 43°20'24"	Alkali basalt	w2.8±0.2 my	Qtb
PA-158	119°12'00" 43°13'48"	Rhyolite	w2.1±0.24 my b2.7±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

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
PA-14	119°00'23" 43°26'24"	High Al basalt	$^{w}2.6\pm0.3$ my	Qtb
G-32-67	119°00'30" 43°27'00"	Basalt	$^{w}2.38\pm0.07$ my	Qtb
SH-4	118°56'45" 43°2'00"	Andesite	$^{p}16.7\pm0.6$ my	Tmba
SH-12	118°50'22" 43°15'40"	Basalt	$^{w}2.91\pm0.38$ my	Qtb (?)
SH-105	118°30'55" 43°14'45"	Rhyodacite	$^{w}11.3\pm0.5$ my	Tmrd
SH-106	118°30'54" 43°21'53"	Basalt	$^{p}11.1\pm1.3$ my	Tmba
SH-106A	118°30'05" 43°21'45"	Basalt	$^{ps}9.44\pm0.8$ my	Tmba
SH-113	118°53'06" 43°08'13"	Basalt	$^{ps}8.07\pm0.69$ 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.)

Component	*P-159 QTb	P-194 QTmv	P-14 QTb	P-40 QTmv	P-58 QTb	P-181 QTb
SiO_2	48.5	48.6	48.7	48.7	48.9	49.1
TiO_2	3.51	0.87	1.43	1.97	1.47	1.60
Al_2O_3	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_2O	3.8	2.6	2.8	2.4	2.3	3.2
K_2O	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
	P-212 QTb	P-300 Tmbh	P-73-4 Tmbh	P-52 QTb	P-41 QTb	P-250 Tmbh
SiO_2	49.5	49.5	49.5	50.0	50.1	50.2
TiO_2	1.45	1.72	1.93	1.36	1.70	1.38
Al_2O_3	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_2O	3.5	3.1	3.4	2.8	3.0	2.7
K_2O	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
	P-184 QTb	P-199 QTmv	P-193 QTmv	P-44 QTmv	P-206 QTmv	P-185 QTb
SiO_2	50.2	50.4	50.8	51.0	51.2	51.7
TiO_2	3.27	1.52	1.14	0.83	1.17	2.82
Al_2O_3	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_2O	3.9	3.4	3.1	3.0	3.0	3.8
K_2O	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.)

Component	*P-278 Tmbh	P-160 Tmbi	P-197 QTmv	P-245D Tmtd
SiO_2	52.6	57.6	63.7	71.3
TiO_2	1.07	1.25	0.75	0.35
Al_2O_3	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_2O	3.2	4.2	1.9	3.85
K_2O	0.82	2.0	1.9	6.0
Total	100.59	99.55	100.75	101.71

Component	P-146 Tmro	P-119 Tmtp	P-215 Tmrp
SiO_2	73.2	73.8	73.9
TiO_2	0.47	0.13	0.28
Al_2O_3	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_2O	3.9	4.45	3.4
K_2O	4.71	4.5	4.58
Total	100.12	97.93	99.76

Component	P-245L Tmtr	P-214 Tmrp	P-290 Tmtr
SiO_2	75.0	76.0	76.4
TiO_2	0.20	0.08	0.13
Al_2O_3	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_2O	3.12	3.4	4.4
K_2O	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±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°-35°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°C and 67°C for Crane Hot Springs and Harney Lake Hot Springs, respectively, down to 15°-20°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°-120°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. (^{o} 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 HCO_3 X_c as mg/l $CaCO_3$	457_c	416_c	nt	nt	nt
Hardness as mg/l $CaCO_3$	<1	4	<15	<15	205
Total dissolved solids	747	695	452	788	1580
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
HCO_3	nt	nt	nt	nt	nt
PO_4	0.030	0.015	nt	nt	nt
SO_4	25.6	47.0	20	28	92
NO_3	<0.02	<0.02	nt	nt	nt
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.

	Soldier Well	Sage Hen Creek Well	Crane Spring	Crane Spring	Crane Spring
Location	27S/29½E/ 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. (^{o} C)	19.5	23	49	80	78
pH	7.99	7.9	nt	8.3	8.1
Conductance µmhos/cm	270	151	nt	814	810
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	67_c	nt	nt	202_c
Hardness as mg/l $CaCO_3$	70	18	nt	nt	nt
Total dissolved solids	236	125	nt	536	nt
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
HCO_3	nt	nt	173	199	202
PO_4	nt	0.033	nt	nt	0.09
SO_4	15	11.8	80	81	86
NO_3	nt	<0.02	1.4	nt	nt
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.

	Crane Spring	Island Ranch Well	Unnamed Spring	Long Hollow Well	Barnyard Spring
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. (^{o} 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 HCO_3 X_c as mg/l $CaCO_3$	169_c	nt	105_c	105_c	112_c
Hardness as mg/l $CaCO_3$	8	nt	60	115	35
Total dissolved solids	564	957	233	282	237
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
HCO_3	nt	674	nt	nt	nt
PO_4	0.050	nt	0.032	0.084	0.034
SO_4	78	8	11.8	28.2	11.3
NO_3	0.05	0.1	0.72	0.02	0.67
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.

	Warm Spring in Harney Lake	Unnamed Spring	Railroad Well	Harney Lake Hot Spring	Harney Lake Hot Spring
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. (^{o} 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 HCO_3 X_c as mg/l $CaCO_3$	2000_c	103_c	91_c	nt	nt
Hardness as mg/l $CaCO_3$	23	58	27	nt	nt
Total dissolved solids	10615	251	184	nt	nt
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
HCO_3	nt	nt	nt	601	566
PO_4	1.190	0.032	0.027	nt	0.092
SO_4	474	12.9	18.4	140	140
NO_3	0.03	0.75	0.03	0.5	nt
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.

	Harney Lake Hot Spring	OO Station Spring	Adobe Flat Well	Thompson Well	Harney Lake Spit Spring
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. (^{o}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 HCO_3 X_c as mg/l $CaCO_3$	493_c	85_c	120	122	nt
Hardness as mg/l $CaCO_3$	43	44	99	82	30
Total dissolved solids	1777	186	237	341	654
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
HCO_3	nt	nt	nt	nt	nt
PO_4	0.294	0.031	0.029	0.013	nt
SO_4	119.3	6.7	19.9	45	58
NO_3	0.02	0.50	0.51	0.92	nt
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.

	Eagles Nest Spring #1	Eagles Nest Spring #2	Bathtub Spring
Location	27S/29½E/ 25Aad	27S/29½E/ 25Ada	27S/29½E/ 28Cac
Date sampled	10/80	10/80	10/80
Temp (^{o}C)	41.7	28.1	51.1
pH	7.12	9.18	6.87
Conductance µmhos/cm	4750	1150	3900
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt
Hardness as mg/l $CaCO_3$	154	<15	170
Total dissolved solids	3110	632	2096
SiO_2	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_3	nt	nt	nt
PO_4	nt	nt	nt
SO_4	320	23	50
NO_3	nt	nt	nt
NH_3	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_2 conductive °C	148	79	79	83	91	127
SiO_2 adiabatic °C	141	82	83	86	93	124
SiO_2 chalcedony °C	122	47	48	52	60	99
SiO_2 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_2 conductive °C	93	125	127	133	105	106
SiO_2 adiabatic °C	95	123	124	129	106	106
SiO_2 chalcedony °C	62	97	99	106	76	77
SiO_2 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_2 conductive °C	86	130	125	122	112	131
SiO_2 adiabatic °C	89	126	123	120	112	128
SiO_2 chalcedony °C	55	102	97	94	83	104
SiO_2 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	OO 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_2 conductive °C	113	107	133	133	138	117
SiO_2 adiabatic °C	112	107	129	129	134	115
SiO_2 chalcedony °C	84	78	105	105	112	88
SiO_2 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_2 conductive °C	126	127	97
SiO_2 adiabatic °C	123	124	98
SiO_2 chalcedony °C	98	99	67
SiO_2 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^{o}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.

GEOTHERMAL-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: 1×10^{-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}, and 1^{o}C/km = 1 mKm^{-1} = 18.2^{o}F/100 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^{o}C/km and 60-80 mWm^{-2}. Several anomalous

*By D. D. Blackwell, Southern Methodist University, Dallas, Texas.

Table 5. Geothermal-gradient data, south Harney Basin, 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^{-2}	Q HF
24S/33E- 9D	43-30.00	118-39.00	S3	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	43-28.00	118-35.00	S2	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	30.9	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	.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.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^{-2}	Q HF
21D						190.0			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 TMPSON 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.	Bottom Temp. (°C)	Depth Interval (m)	Avg. TC $Wm^{-1}K^{-1}$	# TC	Uncorr. Gradient °C/km	Corr. Gradient °C/km	Corr. HF mWm^{-2}	Q HF
						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	130.3	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	73.1	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	88.4	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
						37.5 50.0			(2.4) 2.1	2.4		C
29S/32E- 6B	43- 5.30	118-49.40	MR-1	1262		56.4 64.0	.92 .07	4	89.0 1.0	89.0 1.0	82 6	A
						40.0 91.0	.92 .07	4	96.0 .6	96.0 .6	88 6	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 2	A
						89.3 92.0	.92 .03	4	83.0 3.0	83.0 3.0	76 3	A
						60.0 100.0	.95 .02	8	74.2 .8	74.2 .8	71 1	A
						.0				87.0	71	A
29S/32E- 34DC	43-[illegible].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.

BIBLIOGRAPHY OF THE HARNEY BASIN

Baldwin, E.M., 1976, Geology of Oregon (revised ed.): Dubuque, Iowa, Kendall/Hunt, 147 p.

Beaulieu, J.D., 1972, Geologic formations of eastern Oregon (east of longitude 121° 30'): Oregon Department of Geology and Mineral Industries Bulletin 73, 80 p.

Beeson, M.H., 1969, Correlation of ash-flows by trace element abundance (abs.): Proceedings of the Oregon Academy of Science, v. 4, p. 23-24.

Berg, J.W., Jr., and Thiruvathukal, J.V., 1967, Regional gravity of Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 29, no. 6, p. 120-126.

Blackwell, D.D., Hull, D.A., Bowen, R.G., and Steele, J.L., 1978, Heat flow of Oregon: Oregon Department of Geology and Mineral Industries Special Paper 4, 42 p.

Blank, H.R., Jr., and Gettings, M.E., 1974, Geophysical evidence of caldera structures in the Harney Basin of central eastern Oregon (abs.): EOS (American Geophysical Union Transactions), v. 55, no. 5, p. 557.

Bodvarsson, G., Couch, R.W., MacFarlane, W.T., Tank, R.W., and Whitsett, R.M., 1974, Telluric current exploration for geothermal anomalies in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 36, no. 6, p. 93-107.

Bowen, R.G., 1972, Geothermal gradient studies in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 34, no. 4, p. 68-71.

______ 1975, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report O-75-3, 133 p.

Bowen, R.G., Blackwell, D.D., and Hull, D.A., 1975, Geothermal studies and exploration in Oregon (draft final report to U.S. Bureau of Mines): Oregon Department of Geology and Mineral Industries Open-File Report O-75-7, 65.

______ 1977, Geothermal exploration studies in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 19, 50 p.

Bowen, R.G., Blackwell, D.D., Hull, D.A., and Peterson, N.V., 1976, Progress report on heat-flow study of the Brothers fault zone, central Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 38, no. 3, p. 39-46.

Bowen, R.G., and Peterson, N.V., compilers, 1970, Thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 14 (map), scale approx. 1:1,000,000.

Bowen, R.G., Peterson, N.V., and Riccio, J.F., compilers, 1978, Low- to intermediate-temperature thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-10, scale approx. 1:1,000,000.

Brooks, H.C., 1963, Quicksilver in Oregon: Oregon Department of Geology and Mineral Industries Bulletin 55, p. 204.

Buwalda, J.P., 1921, Report on oil and gas possibilities of eastern Oregon: Oregon Bureau of Mines and Geology, The mineral resources of Oregon, v. 3, no. 2, p. 28-29.

Campbell, I., Conel, J.E., Rogers, J.J.W., and Whitfield, J.M., 1959, Possible correlation of Rattlesnake and Danforth Formations of eastern Oregon (abs.): Geological Society of America Bulletin, v. 69, no. 12, pt. 2, p. 1678.

Corcoran, R.E., 1956, Sedimentary basins in Oregon: World Oil, v. 143, no. 5, p. 140-142.

Davenport, R.E., 1971, Geology of the Rattlesnake and older ignimbrites in the Paulina Basin and adjacent area, central Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 132 p.

Dole, H.M., and Corcoran, R.E., 1954, Reconnaissance geology along U.S. Highway 20 between Vale and Buchanan, Malheur and Harney Counties, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 16, no. 6, p. 37-39.

Enlows, H.E., and Davenport, R.E., 1971, Tertiary ignimbrites in central Oregon (abs.): Proceedings of the Oregon Academy of Science, v. 7, p. 75.

Enlows, H.E., Parker, D., and Davenport, R.E., 1973, The Rattlesnake ignimbrite tongue (abs.): Geological Society of America Abstracts with Programs, v. 5, no. 1, p. 38-39.

Godwin, L.H., Haigler, L.B., Rioux, R.L., White, D.E., Muffler, L.J.P., and Wayland, R.G., 1971, Classification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geological Survey Circular 647, 18 p.

Greene, R.C., 1970, A crystal-rich ash-flow tuff in southeast Oregon (abs.): Geological Society of America Abstracts with Programs, v. 2, no. 2, p. 97-98.

_____ 1972, Preliminary geologic map of the Burns and West Myrtle Butte 15-minute quadrangles, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-320, scale 1:62,500.

_____ 1973, Petrology of the welded tuff of Devine Canyon, southeastern Oregon: U.S. Geological Survey Professional Paper 797, 26 p.

Greene, R.C., Walker, G.W., and Corcoran, R.E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geological Survey Miscellaneous Geological Investigations Map I-680, scale 1:250,000.

Groh, E.A., 1966, Geothermal energy potential in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 28, no. 7, p. 125-135.

Hull, D.A., Blackwell, D.D., and Black, G.L., 1978, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report O-78-4, 187 p.

Hull, D.A., Blackwell, D.D., Bowen, R.G., and Peterson, N.V., 1977, Heat-flow study of the Brothers fault zone, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-77-3, 43 p.

Hull, D.A., Blackwell, D.D., Bowen, R.G., Peterson, N.V., and Black, G.L., 1977, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report O-77-2, 134 p.

Hull, D.A., Bowen, R.G., Blackwell, D.D., and Peterson, N.V., 1976, Geothermal gradient data, Brothers fault zone, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-76-2, 24 p.

______ 1977, Preliminary heat-flow map and evaluation of Oregon's geothermal energy potential: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 39, no. 7, p. 109-123.

Hull, D.A., and Newton, V.C., Jr., 1977, Geothermal activity in 1976: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 39, no. 1, p. 7-15.

Leonard, A.R., 1970, Ground water resources in Harney Valley, Harney County, Oregon: Oregon State Engineer Ground Water Report 16, 85 p.

Lund, E.H., 1962, Welded tuff in the Danforth Formation (abs.): Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 2, p. 24.

______ 1966, Zoning in an ash flow of the Danforth Formation, Harney County, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 28, no. 9, p. 161-170.

MacLeod, N.S., Walker, G.W., and McKee, E.H., 1975, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeastern Oregon: U.S. Geological Survey Open-File Report 75-348, 22 p.

Maloney, N.J., 1962, Tertiary and Quaternary faulting in southwestern Harney County, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 2, p. 21-22.

Mariner, R.H., Presser, T.S., Rapp, J.B., and Willey, L.M., 1975, The minor and trace elements, gas, and isotope compositions of the principal hot springs of Nevada and Oregon: U.S. Geological Survey open-file report, 27 p.

Mariner, R.H., Rapp, J.B., Willey, L.M., and Presser, T.S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon: U.S. Geological Survey open-file report, 27 p.

Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.

McKee, E.H., MacLeod, N.S., and Walker, G.W., 1976, K/Ar ages of late Cenozoic silicic volcanic rocks, southeast Oregon: Isochron/West, no. 15, p. 37-41.

Merriam, J.C., Stock, C., and Moody, C.L., 1925, The Pliocene Rattlesnake Formation and fauna of eastern Oregon, with notes on the geology of the Rattlesnake and Mascall deposits: Carnegie Institution of Washington Publication 347, p. 43-92.

Muffler, L.J.P., ed., 1979, Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, 163 p.

Newton, V.C., Jr., and Hull, D.A., 1978, Geothermal energy in 1977: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 40, no. 1, p. 8-16.

Parker, D.J., 1974, Petrology of selected volcanic rocks of the Harney Basin, Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 119 p.

Parker, D., and Armstrong, R.L., 1972, K-Ar dates and Sr isotope initial ratios for volcanic rocks in the Harney Basin, Oregon: Isochron/West, no. 5, p. 7-12.

Peterson, N.V., and Groh, E.A., 1964, Diamond Craters, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 26, no. 2, p. 17-34.

Piper, A.M., 1936, Resume of the geologic history of the Harney Basin, Oregon: Geological Society of the Oregon Country Geological News Letter, v. 2, no. 8, p. 9-12.

Piper, A.M., Robinson, T.W., and Park, C.F., Jr., 1939, Geology and ground-water resources of the Harney Basin, Oregon: U.S. Geological Survey Water-Supply Paper 841, 189 p.

Riccio, J.F., compiler, 1979, Preliminary geothermal resource map of Oregon, 1978: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-11, scale 1:500,000.

_____ 1980, Geothermal exploration in Oregon, 1979: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 42, no. 4, p. 59-69.

Riccio, J.F., and Newton, V.C., Jr., 1979, Geothermal exploration in Oregon in 1978: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 41, no. 3, p. 39-46.

Russell, I.C., 1884, A geological reconnaissance in southern Oregon: U.S. Geological Survey 4th Annual Report, 1882-83, p. 431-464.

_____ 1903a, Notes on the geology of southwestern Idaho and southeastern Oregon: U.S. Geological Survey Bulletin 217, p. 36-69.

_____ 1903b, Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: U.S. Geological Survey Water-Supply Paper 78, p. 38-43.

_____ 1905, Preliminary report on the geology and water resources of central Oregon: U.S. Geological Survey Bulletin 252, p. 36-54.

Sass, J.H., Galanis, S.D., Jr., Munroe, R.J., and Urban, T.C., 1976, Heat-flow data from southeastern Oregon: U.S. Geological Survey Open-File Report 76-217, 52 p.

Sass, J.H., Lachenbruch, A.H., Munroe, R.J., Green, G.W., and Moses, T.H., Jr., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, no. 26, p. 6376-6413.

Sass, J.H., and Munroe, R.J., 1973, Temperature gradients in Harney County, Oregon: U.S. Geological Survey Open-File Report 73-247, 3 p., 7 figs.

Stearns, N.D., Stearns, H.T., and Waring, G.A., 1937, Thermal springs in the United States: U.S. Geological Survey Water-Supply Paper 679-B, p. 59-206.

Stone, C.J., 1931, Petroleum reconnaissance report, Harney Basin: Oregon Department of Geology and Mineral Industries, unpublished, 9 p. (geol. map, 1930, 1:125,000).

Thayer, T.P., 1952, The tuff member of the Rattlesnake Formation of eastern Oregon--an ignimbrite (abs.): American Geophysical Union Transactions, v. 33, p. 327.

Thiruvathukal, J.V., 1968, Regional gravity of Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 92 p.

U.S. Geological Survey, 1968, Volcanic rocks and stratigraphy in Washington and Oregon, in Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-A, p. A35-A36 (R.C. Greene and G.W. Walker; D.R. Crandall; D.R. Mullineaux; R.S. Sigafoos and E.L. Hendricks, investigators).

_____ 1972, Aeromagnetic map of the Adel and parts of the Burns, Boise, and Jordan Valley 1° by 2° quadrangles, Oregon: U.S. Geological Survey Open-File Report 72-390, scale 1:250,000.

_____ 1973, Ground-water gradients near Malheur Lake, in Geological Survey research 1973: U.S. Geological Survey Professional Paper 850, p. 186 (L.L. Hubbard and A.R. Leonard, investigators).

U.S. Geological Survey and Oregon Department of Geology and Mineral Industries, 1979, Chemical analyses of thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-79-3, 170 p.

Van Orstrand, C.E., 1938, Temperatures in the lava beds of east-central and south-central Oregon: American Journal of Science, 5th Series, v. 35, no. 205, p. 22-46.

Walker, G.W., 1969a, Possible fissure vent for a Pliocene ash-flow tuff, Buzzard Creek area, Harney County, Oregon, in Geological Survey research 1969: U.S. Geological Survey Professional Paper 650-C, p. C8-C17.

_____ 1969b, Geology of the High Lava Plains province, in Weissenborn, A.E., ed., Mineral and water resources of Oregon: Oregon Department of Geology and Mineral Industries Bulletin 64, p. 77-79.

_____ 1970, Cenozoic ash-flow tuffs of Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 32, no. 6, p. 97-115.

_____ 1974, Some implications of late Cenozoic volcanism to geothermal potential in the High Lava Plains of south-central Oregon: U.S. Geological Survey Open-File Report 74-121, 14 p.

_____ 1977, Geologic map of Oregon east of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Series Map I-902 (prepared in cooperation with the Oregon Department of Geology and Mineral Industries), scale 1:500,000, 2 sheets.

_____ 1979, Revisions to the Cenozoic stratigraphy of Harney Basin, southeastern Oregon: U.S. Geological Survey Bulletin 1475, 35 p.

Walker, G.W., Dalrymple, G.B., and Lanphere, M.A., 1974, Index to potassium-argon ages of Cenozoic volcanic rocks of Oregon: U.S. Geological Survey Misc. Field Studies Map MF-569.

Walker, G.W., and Repenning, C.A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake, Harney, and Malheur Counties, Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-446, scale 1:250,000.

Walker, G.W., and Swanson, D.A., 1968a, Laminar flowage in a Pliocene soda rhyolite ash-flow tuff, Lake and Harney Counties, Oregon, in Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-B, p. B37-B47.

_____ 1968b, Summary report on the geology and mineral resources of the Harney Lake and Malheur Lake areas of the National Wildlife Refuge, north-central Harney County, Oregon: U.S. Geological Survey Bulletin 1260-L, 17 p.

Waring, G.A., 1908, Geology and water resources of a portion of south-central Oregon: U.S. Geological Survey Water-Supply Paper 220, 86 p.

_____ 1909, Geology and water resources of the Harney Basin region, Oregon: U.S. Geological Survey Water-Supply Paper 231, 93 p.

_____ 1965 (revised by Blankenship, R.R., and Bentall, R.), Thermal springs of the United States and other countries of the world--a summary: U.S. Geological Survey Professional Paper 492, 383 p.

Washburne, C.W., 1911, Gas prospects in Harney Valley, Oregon: U.S. Geological Survey Bulletin 431, pt. 2, p. 56-57.

APPENDIX A

Formulas used in calculations

Na:K (revised):

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

Na:K:Ca:

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

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:

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

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.

References cited:

Fournier, R.O., 1979, A revised equation for the Na/K geothermometer, in Geothermal Resources Council Transactions 3, 1979, p. 221-224.

Fournier, R.O., and Potter, R.W., II, 1979, Magnesium correction to the Na:K:Ca chemical geothermometer: Geochimica et Cosmochimica Acta, v. 43, p. 1543-1550.

Fournier, R.O., and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: American Journal of Science, v. 264, p. 685-697.

Fournier, R.O., and Truesdell, A.H., 1973, An empirical Na:K:Ca geothermometer for natural waters: Geochimica et Cosmochimica Acta, v. 37, p. 1255-1275.

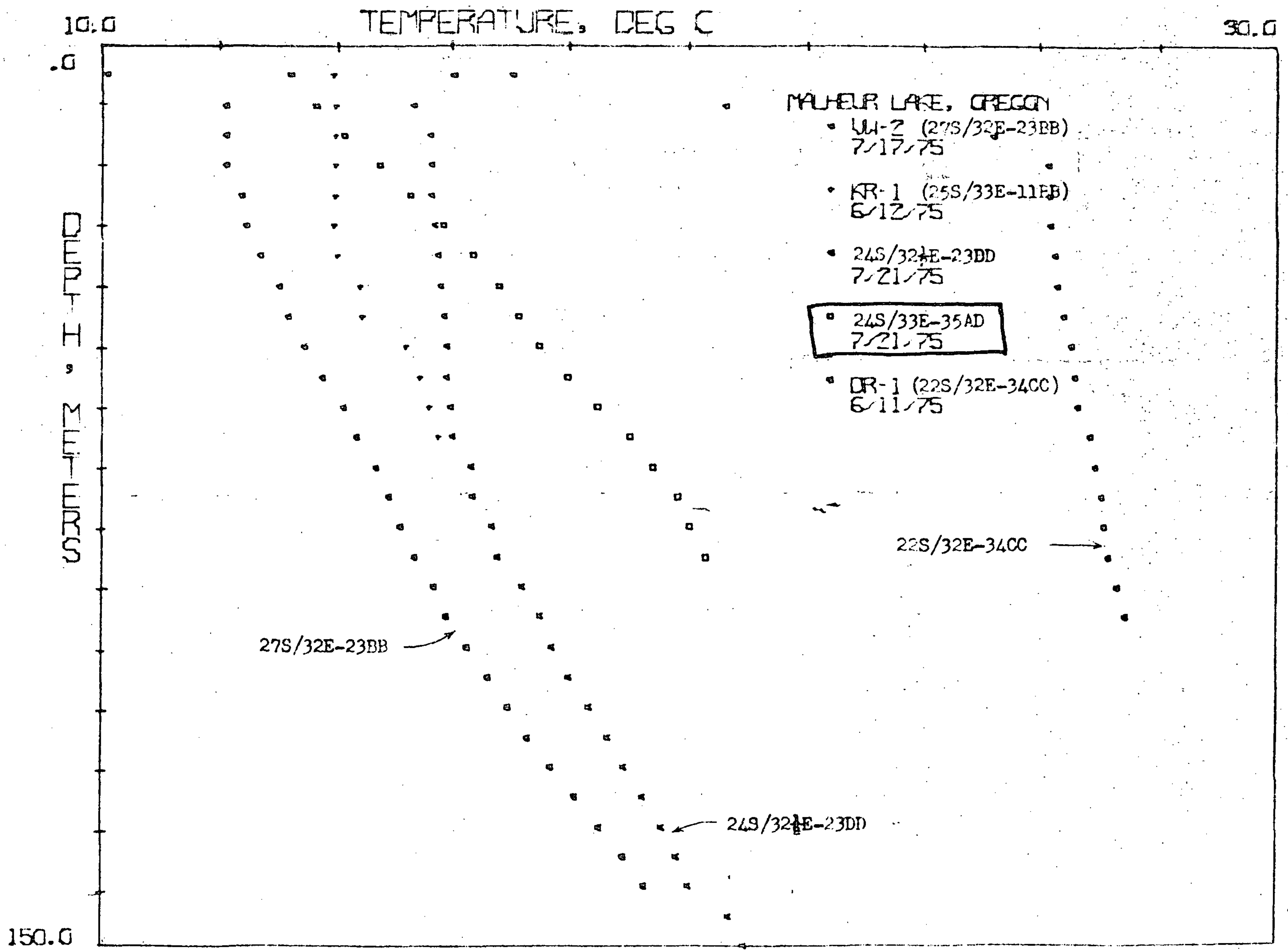
Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.

APPENDIX B

Geothermal-gradient data

LOCATION: CRANE, OREGON
24S/33E-35AD
HOLE NUMBER:
DATE MEASURED: 7/21/75

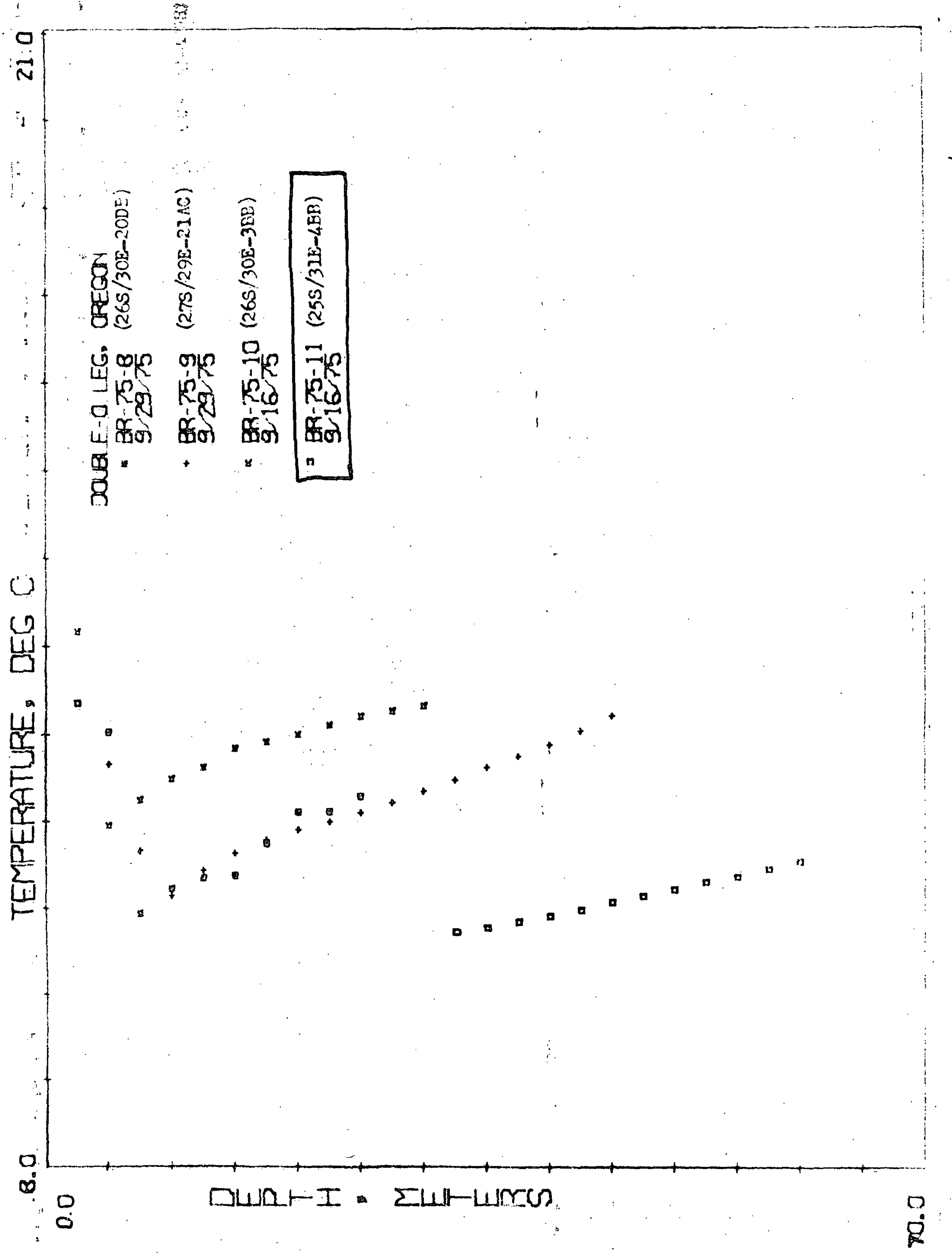
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	13.230	55.81	.0	.0
10.0	32.8	13.640	56.55	82.0	4.5
15.0	49.2	14.140	57.45	100.0	5.5
20.0	65.6	14.750	58.55	122.0	6.7
25.0	82.0	15.290	59.52	108.0	5.9
30.0	98.4	15.870	60.57	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



TEMPERATURE, DEG C
10.0
30.0
.0
150.0
DEPTH, METERS
MALHEUR LAKE, OREGON
WW-2 (27S/32E-23BB)
7/17/75
KR-1 (25S/33E-11BB)
6/12/75
24S/32½E-23DD
7/21/75
24S/33E-35AD
7/21/75
DR-1 (22S/32E-34CC)
6/11/75
22S/32E-34CC
27S/32E-23BB
24S/32½E-23DD

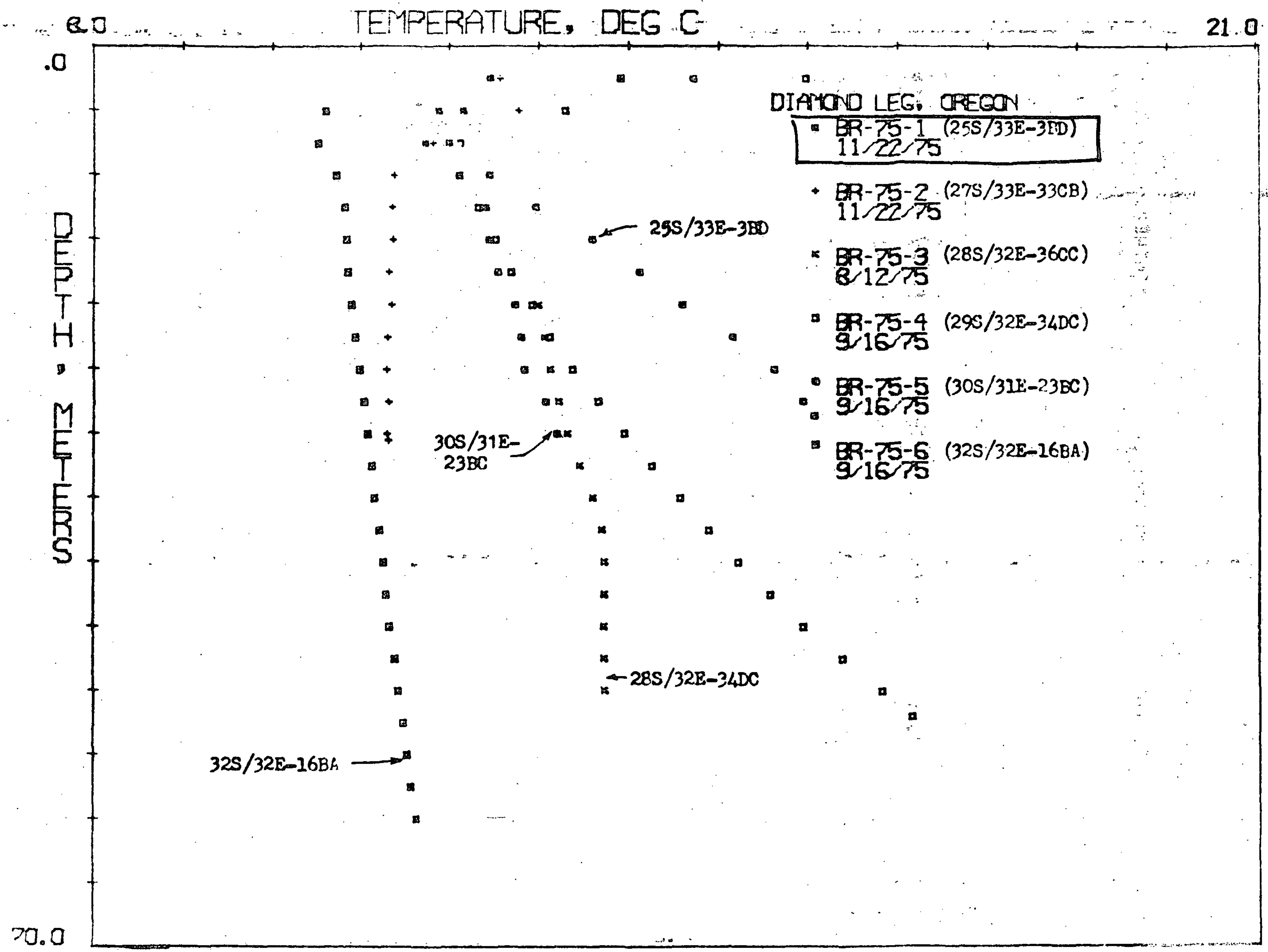
LOCATION: DOUBLE-O LEG, OREGON
25S/31E-4BB
HOLE NUMBER: BR-75-11
DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
2.5	8.2	13.340	56.01	.0	.0
5.0	16.4	10.510	50.92	-1132.0	-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
8.0
21.0
DEPTH, METERS
0.0
70.0
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DE)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

LOCATION: DIAMOND LEG, OREGON
25S/33E-3BD
HOLE NUMBER: BR-75-1
DATE MEASURED: 11/22/75

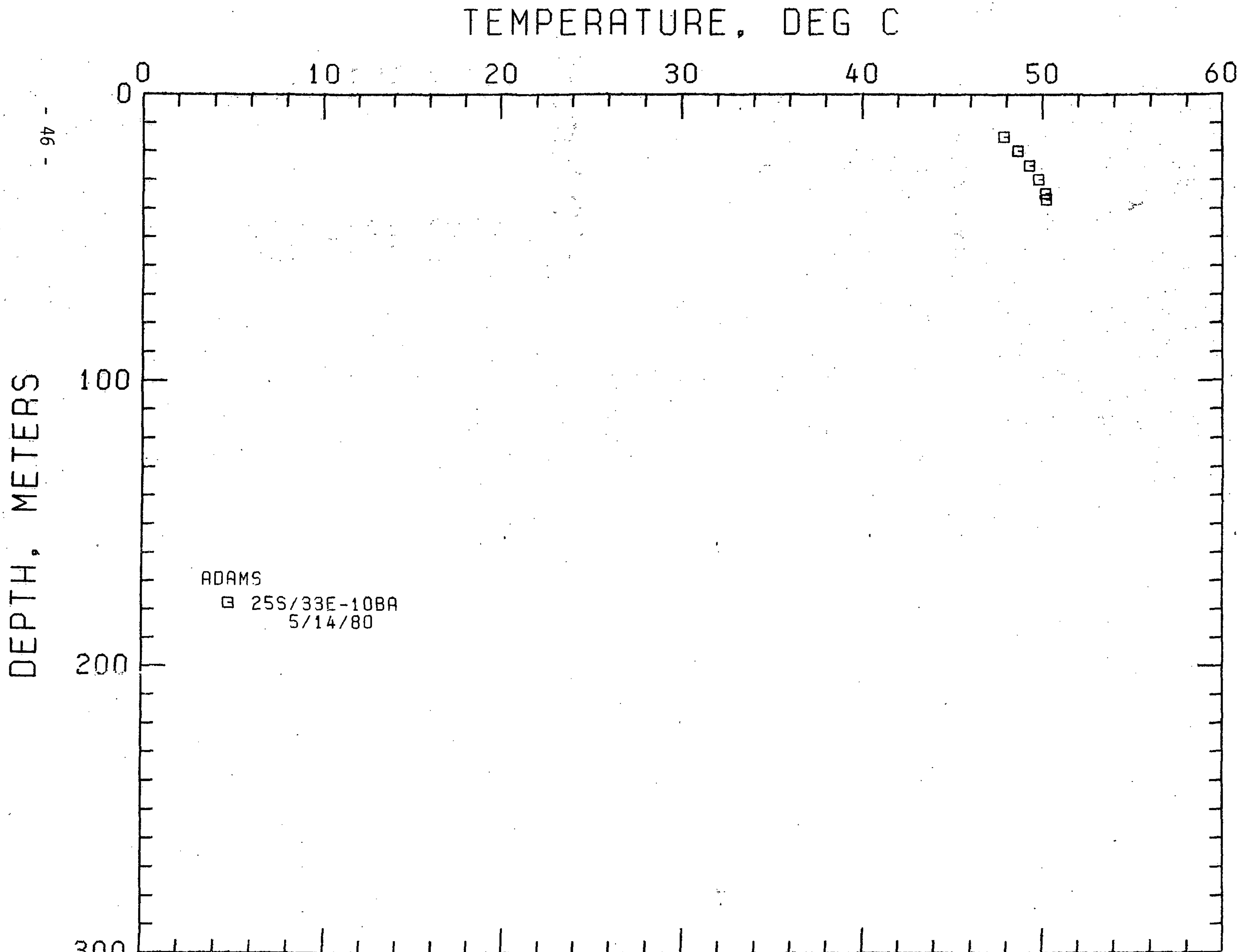
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.450	54.41	.0	.0
5.0	16.4	12.150	53.87	-120.0	-6.6
7.5	24.6	11.980	53.56	-68.0	-3.7
10.0	32.8	12.430	54.37	180.0	9.9
12.5	41.0	12.950	55.31	208.0	11.4
15.0	49.2	13.580	56.44	252.0	13.8
17.5	57.4	14.090	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



6.0
TEMPERATURE, DEG C
21.0
.0
DEPTH, METERS
70.0
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

LOCATION: BURNS AMS, OREGON
25S/33E-10BA
HOLE NAME: ADAMS
DATE MEASURED: 5/14/80

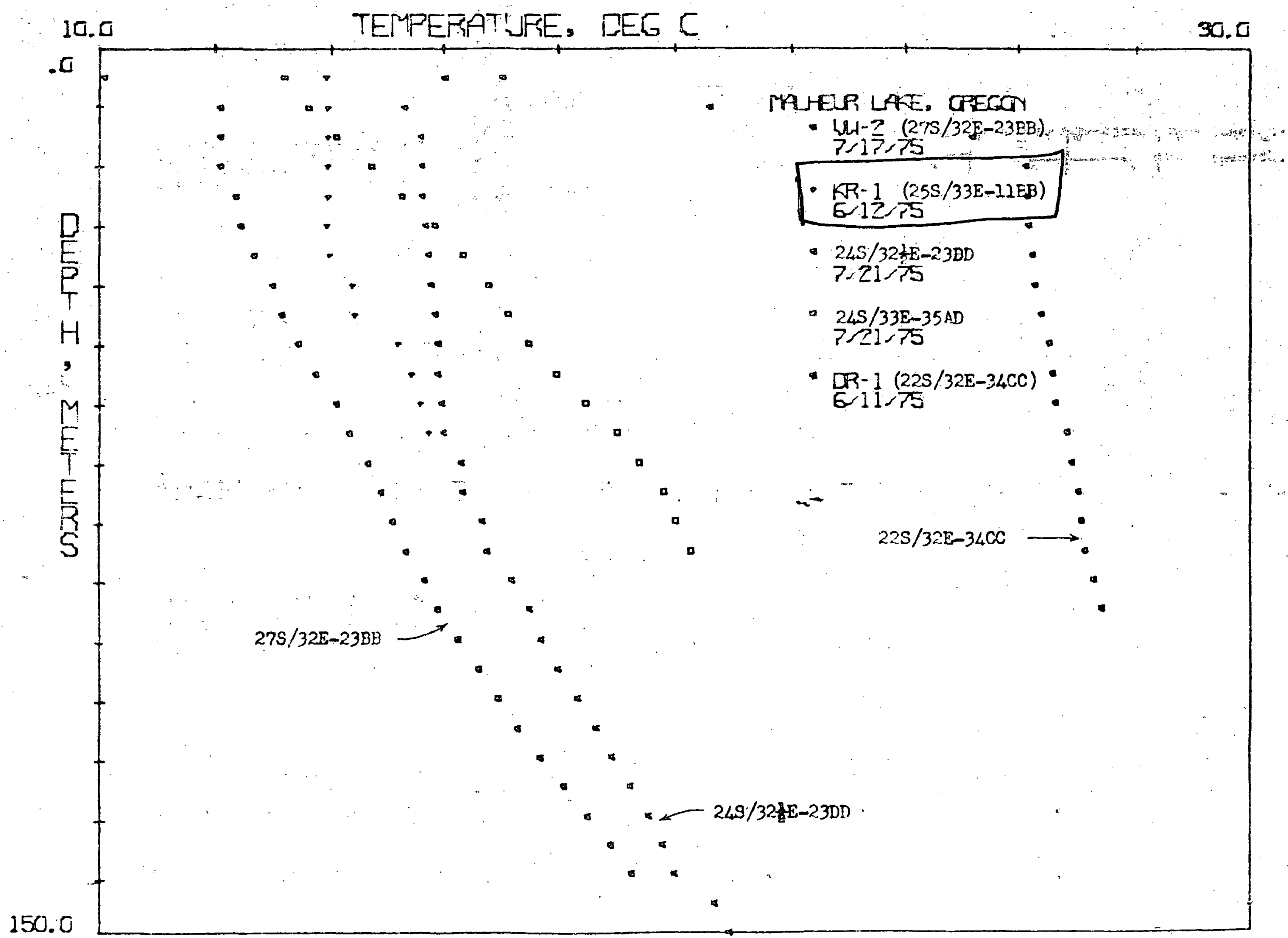
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
15.0	49.2	47.860	118.15	0.0	0.0
20.0	65.6	48.620	119.52	152.0	8.3
25.0	82.0	49.260	120.67	128.0	7.0
30.0	98.4	49.790	121.62	106.0	5.8
35.0	114.8	50.170	122.31	76.0	4.2
37.0	121.4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



TEMPERATURE, DEG C
0
10
20
30
40
50
60
DEPTH, METERS
0
100
200
300
ADAMS
25S/33E-10BA
5/14/80

LOCATION: CRANE, OREGON
25S/33E-11BBB
HOLE NUMBER: KR-1
DATE MEASURED: 6/12/75

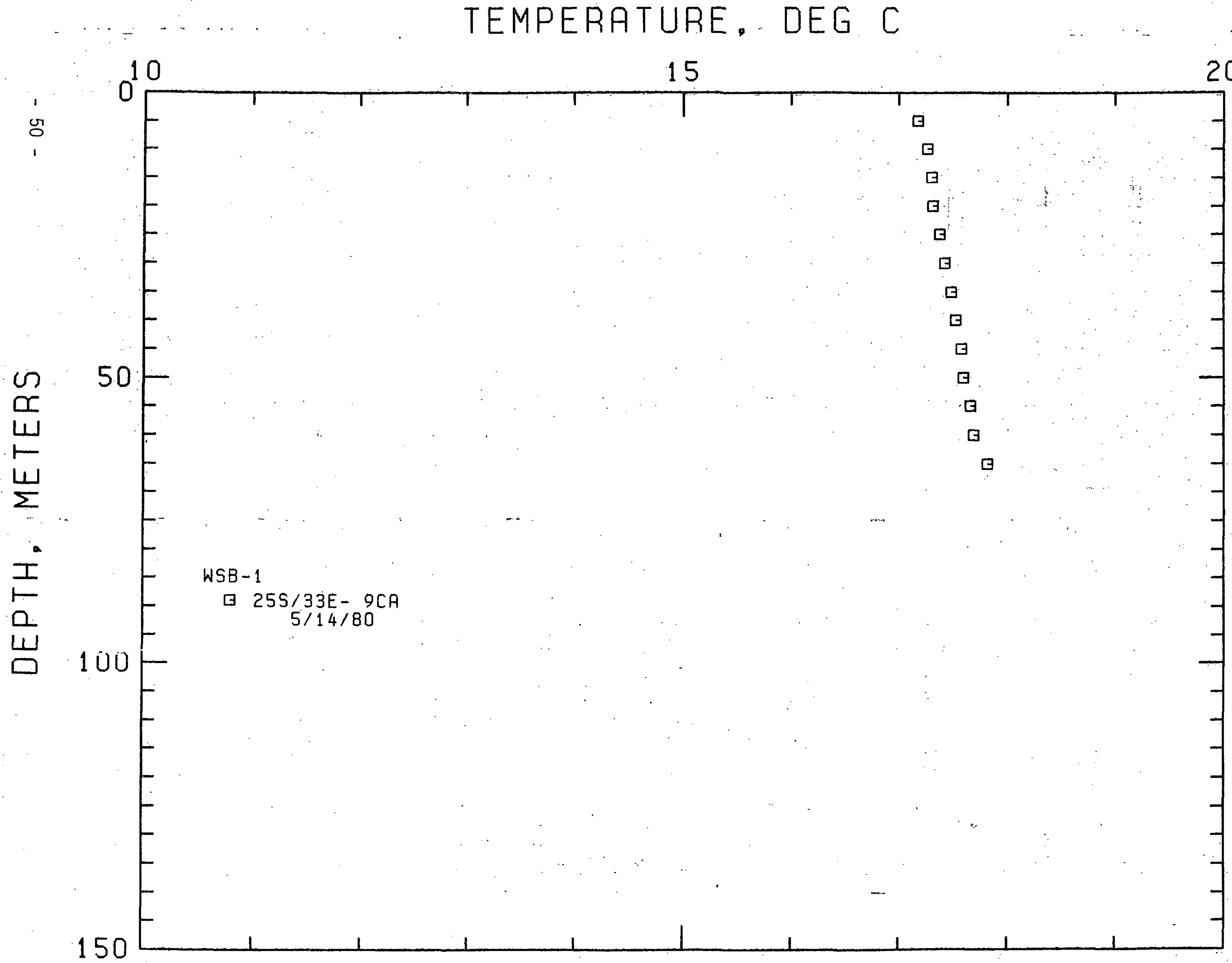
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	13.950	57.11	.0	.0
10.0	32.8	13.970	57.15	4.0	.2
15.0	49.2	13.970	57.15	.0	.0
20.0	65.6	13.970	57.15	.0	.0
25.0	82.0	13.980	57.16	2.0	.1
30.0	98.4	13.960	57.13	-4.0	-.2
35.0	114.8	13.990	57.18	6.0	.3
40.0	131.2	14.390	57.90	80.0	4.4
45.0	147.6	14.440	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



10.0
TEMPERATURE, DEG C
30.0
.0
150.0
DEPTH, METERS
MALHEUR LAKE, OREGON
WW-2 (27S/32E-23BB)
7/17/75
KR-1 (25S/33E-11EB)
6/12/75
24S/32½E-23DD
7/21/75
24S/33E-35AD
7/21/75
DR-1 (22S/32E-34CC)
6/11/75
22S/32E-34CC
27S/32E-23BB
24S/32½E-23DD

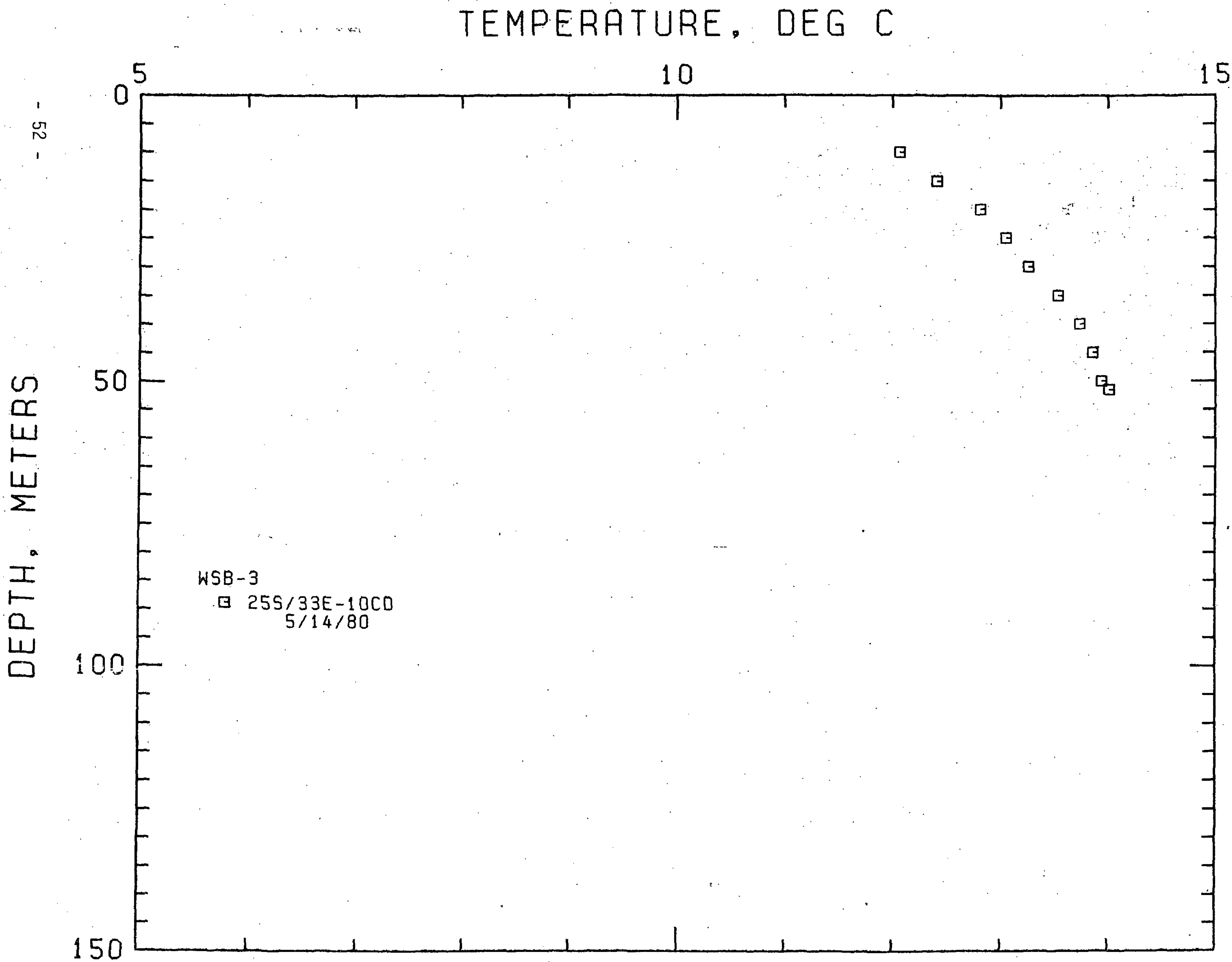
LOCATION: BURNS AMS, OREGON
25S/33E- 9CA
HOLE NAME: WSB-1
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	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	63.68	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
10
15
20
0
50
100
150
DEPTH, METERS
WSB-1
25S/33E- 9CA
5/14/80

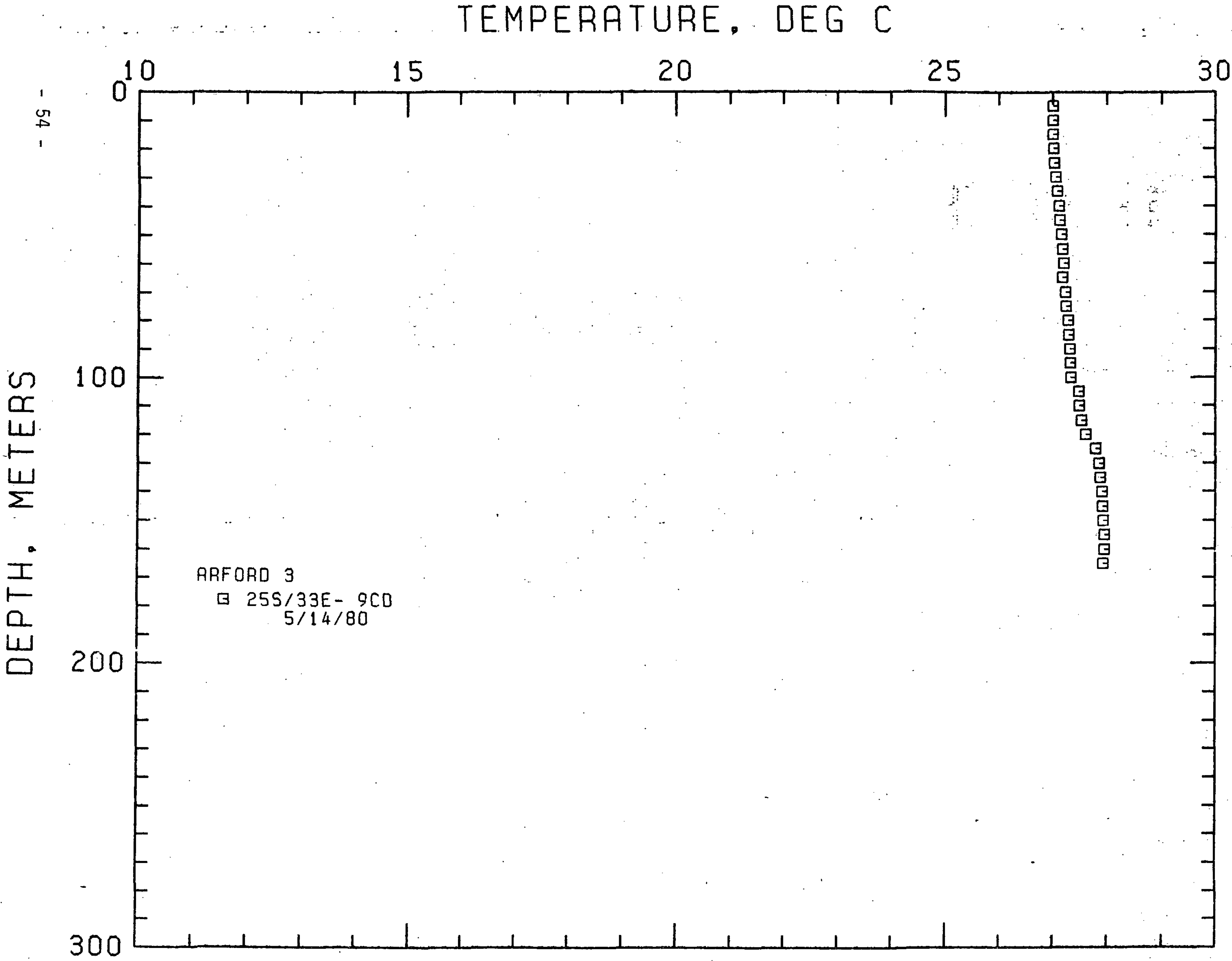
LOCATION: BURNS AMS, OREGON
25S/33E-10CD
HOLE NAME: WSB-3
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT 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
5
10
15
0
50
100
150
DEPTH, METERS
WSB-3
25S/33E-10CD
5/14/80

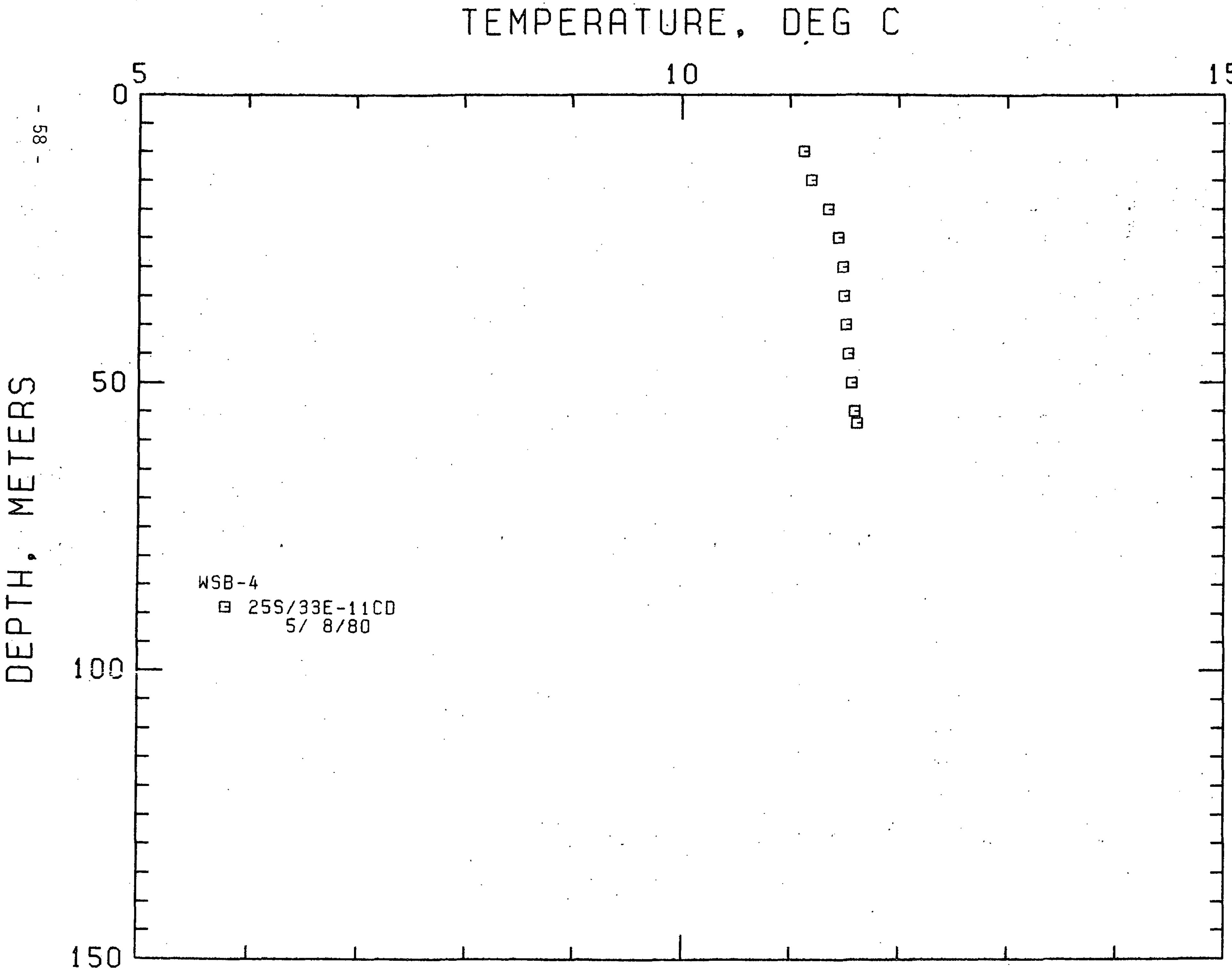
LOCATION: BURNS AMS, OREGON
25S/33E- 9CD
HOLE NAME: ARFORD 3
DATE MEASURED: 5/14/80

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	2.0	0.1
25.0	82.0	27.040	80.67	2.0	0.1
30.0	98.4	27.060	80.71	4.0	0.2
35.0	114.8	27.090	80.76	6.0	0.3
40.0	131.2	27.120	80.82	6.0	0.3
45.0	147.6	27.130	80.83	2.0	0.1
50.0	164.0	27.160	80.89	6.0	0.3
55.0	180.4	27.190	80.94	6.0	0.3
60.0	196.8	27.210	80.98	4.0	0.2
65.0	213.2	27.190	80.94	-4.0	-0.2
70.0	229.6	27.250	81.05	12.0	0.7
75.0	246.0	27.260	81.07	2.0	0.1
80.0	262.4	27.290	81.12	6.0	0.3
85.0	278.8	27.300	81.14	2.0	0.1
90.0	295.2	27.330	81.19	6.0	0.3
95.0	311.6	27.340	81.21	2.0	0.1
100.0	328.0	27.350	81.23	2.0	0.1
105.0	344.4	27.500	81.50	30.0	1.6
110.0	360.8	27.510	81.52	2.0	0.1
115.0	377.2	27.540	81.57	6.0	0.3
120.0	393.6	27.620	81.72	16.0	0.9
125.0	410.0	27.800	82.04	36.0	2.0
130.0	426.4	27.860	82.15	12.0	0.7
135.0	442.8	27.890	82.20	6.0	0.3
140.0	459.2	27.920	82.26	6.0	0.3
145.0	475.6	27.930	82.27	2.0	0.1
150.0	492.0	27.940	82.29	2.0	0.1
155.0	508.4	27.970	82.35	6.0	0.3
160.0	524.8	27.960	82.33	-2.0	-0.1
165.0	541.2	27.940	82.29	-4.0	-0.2


TEMPERATURE, DEG C
10
15
20
25
30
0
100
200
300
DEPTH, METERS
ARFORD 3
25S/33E- 9CD
5/14/80

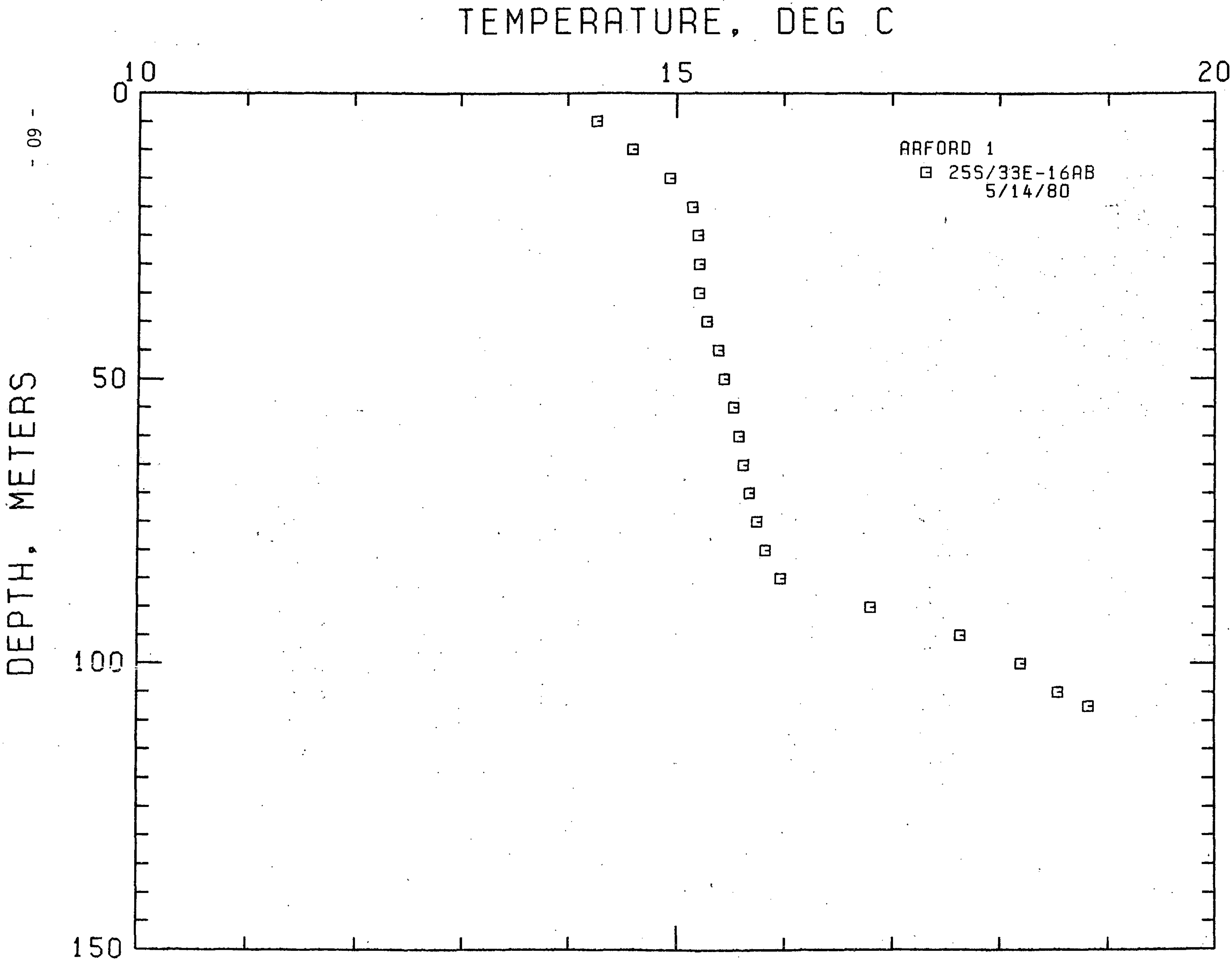
LOCATION: BURNS AMS, OREGON
25S/33E-11CD
HOLE NAME: WSB-4
DATE MEASURED: 5/ 8/80

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	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	1.8
25.0	82.0	11.450	52.61	18.0	1.0
30.0	98.4	11.490	52.68	8.0	0.4
35.0	114.8	11.500	52.70	2.0	0.1
40.0	131.2	11.520	52.74	4.0	0.2
45.0	147.6	11.540	52.77	4.0	0.2
50.0	164.0	11.570	52.83	6.0	0.3
55.0	180.4	11.600	52.88	6.0	0.3
57.0	187.0	11.620	52.92	10.0	0.5


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
WSB-4
25S/33E-11CD
5/ 8/80

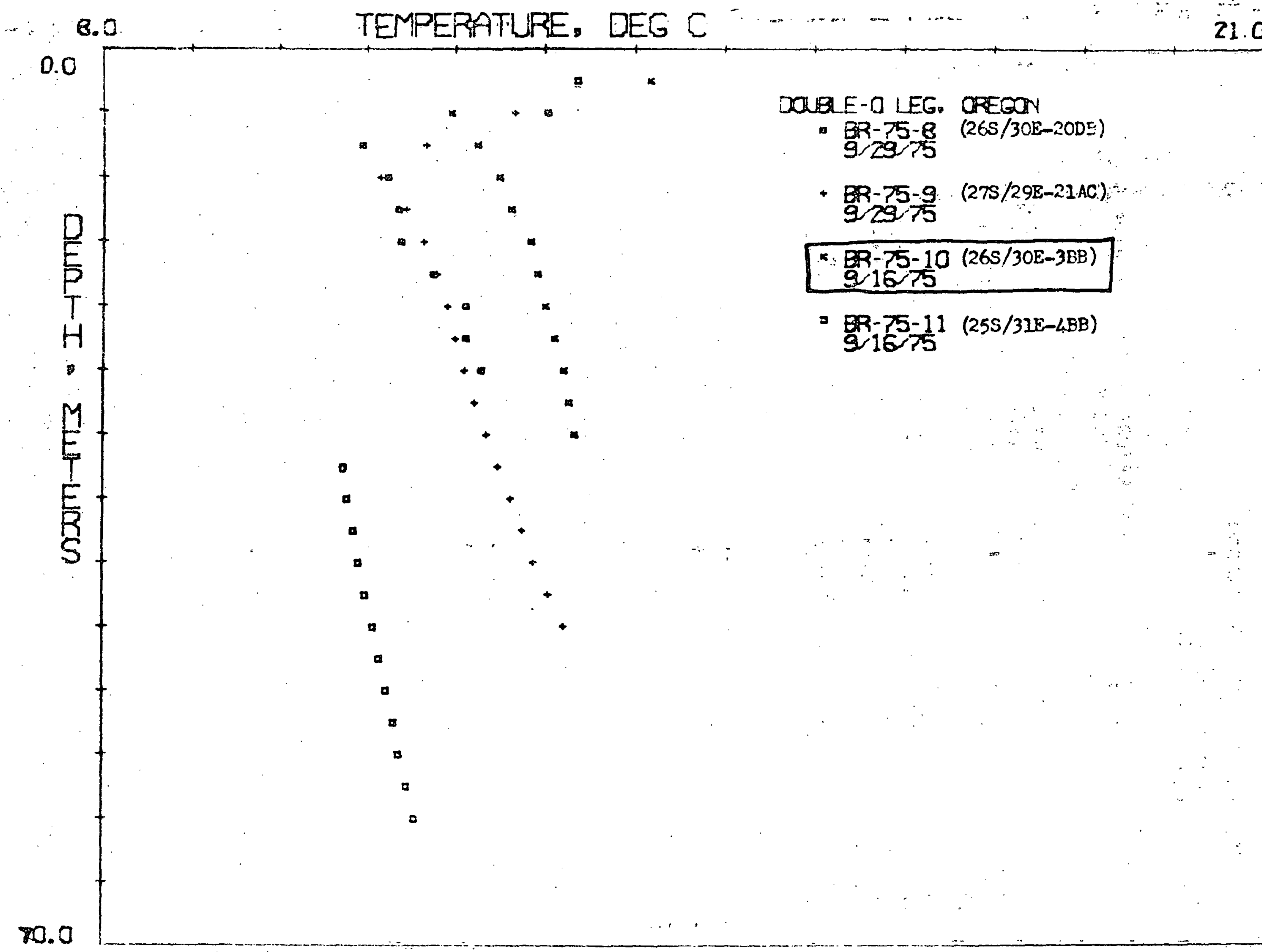
LOCATION: BURNS AMS, OREGON
25S/33E-16AB
HOLE NAME: ARFORD 1
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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	3.6
15.0	49.2	14.940	58.89	68.0	3.7
20.0	65.6	15.150	59.27	42.0	2.3
25.0	82.0	15.200	59.36	10.0	0.5
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	0.8
45.0	147.6	15.390	59.70	22.0	1.2
50.0	164.0	15.440	59.79	10.0	0.5
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	8.0	0.4
70.0	229.6	15.680	60.22	12.0	0.7
75.0	246.0	15.750	60.35	14.0	0.8
80.0	262.4	15.830	60.49	16.0	0.9
85.0	278.8	15.970	60.75	28.0	1.5
90.0	295.2	16.800	62.24	166.0	9.1
95.0	311.6	17.640	63.75	168.0	9.2
100.0	328.0	18.200	64.76	112.0	6.1
105.0	344.4	18.550	65.39	70.0	3.8
107.5	352.6	18.830	65.89	112.0	6.1


TEMPERATURE, DEG C
10
15
20
0
50
100
150
DEPTH, METERS
AAFORD 1
25S/33E-16AB
5/14/80

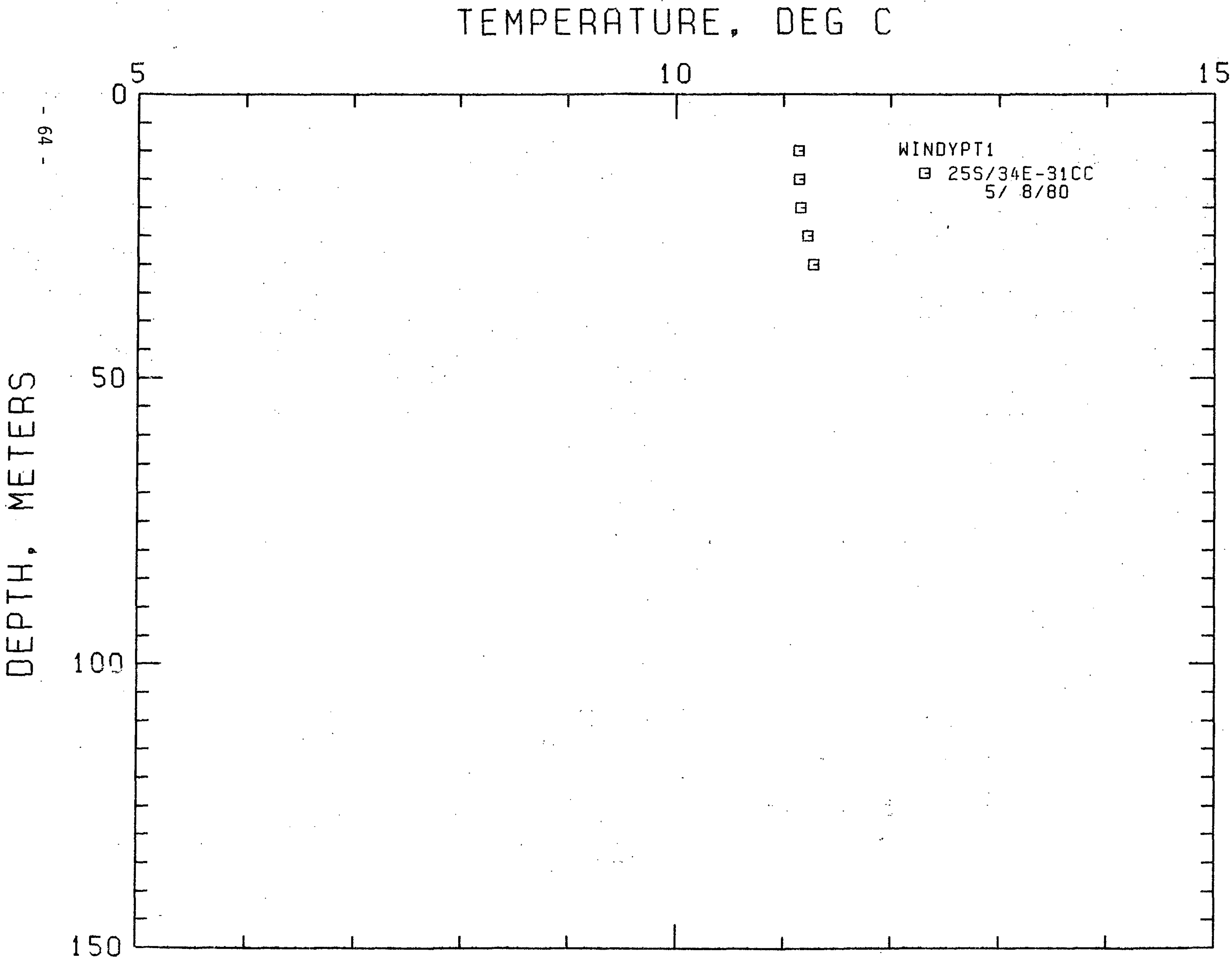
LOCATION: DOUBLE-O LEG, OREGON
26S/30E-3BB
HOLE NUMBER: BR-75-10
DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
2.5	8.2	14.160	57.49	.0	.0
5.0	16.4	11.940	53.49	-888.0	-48.7
7.5	24.6	12.230	54.01	116.0	6.4
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	12.820	55.08	84.0	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


TEMPERATURE, DEG C
8.0
21.0
0.0
70.0
DEPTH, METERS
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DB)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

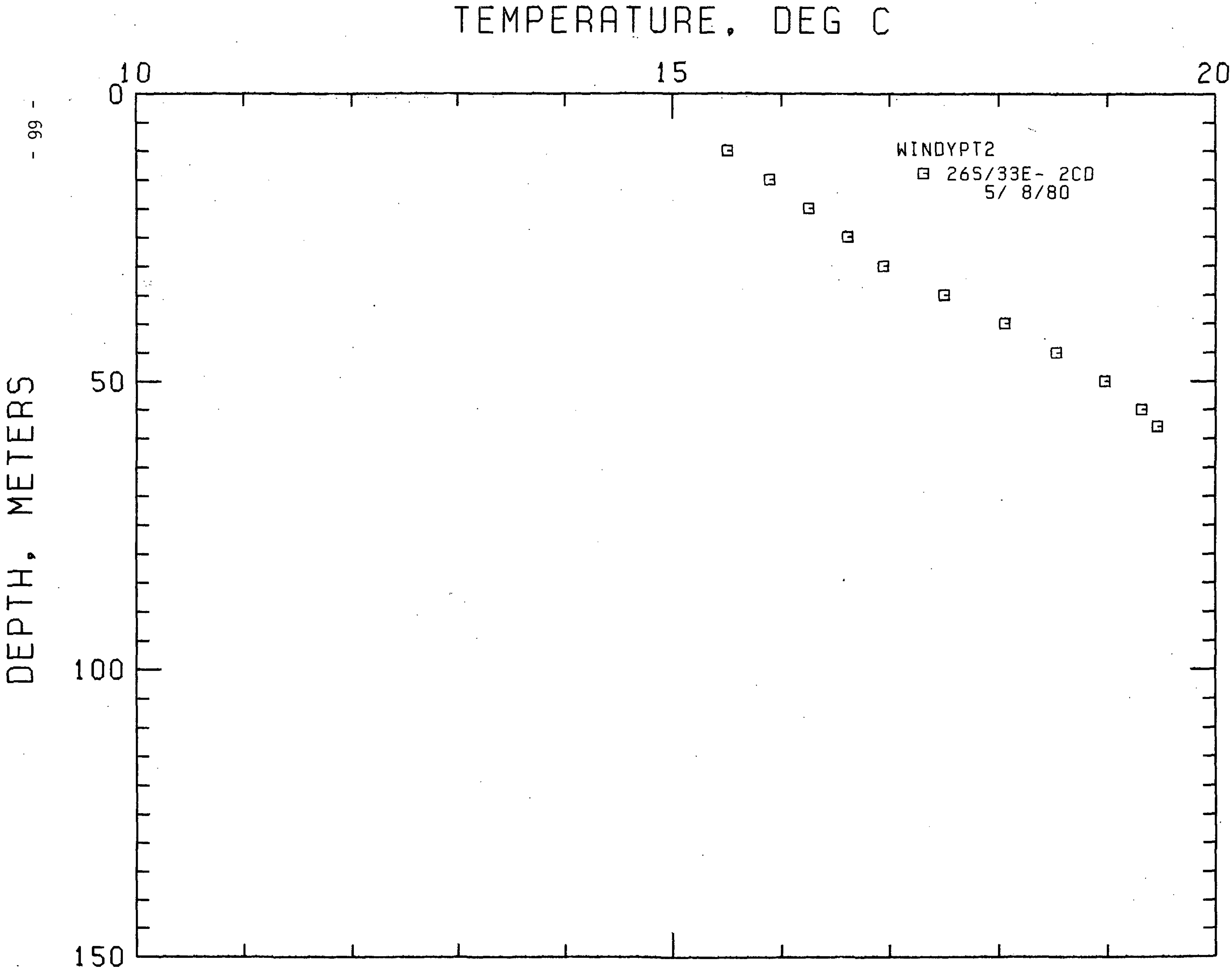
LOCATION: BURNS AMS, OREGON
25S/34E-31CC
HOLE NAME: WINDYPT1
DATE MEASURED: 5/ 8/80

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	11.140	52.05	0.0	0.0
15.0	49.2	11.150	52.07	2.0	0.1
20.0	65.6	11.160	52.09	2.0	0.1
25.0	82.0	11.230	52.21	14.0	0.8
30.0	98.4	11.280	52.30	10.0	0.5


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
WINDYPT1
25S/34E-31CC
5/ 8/80

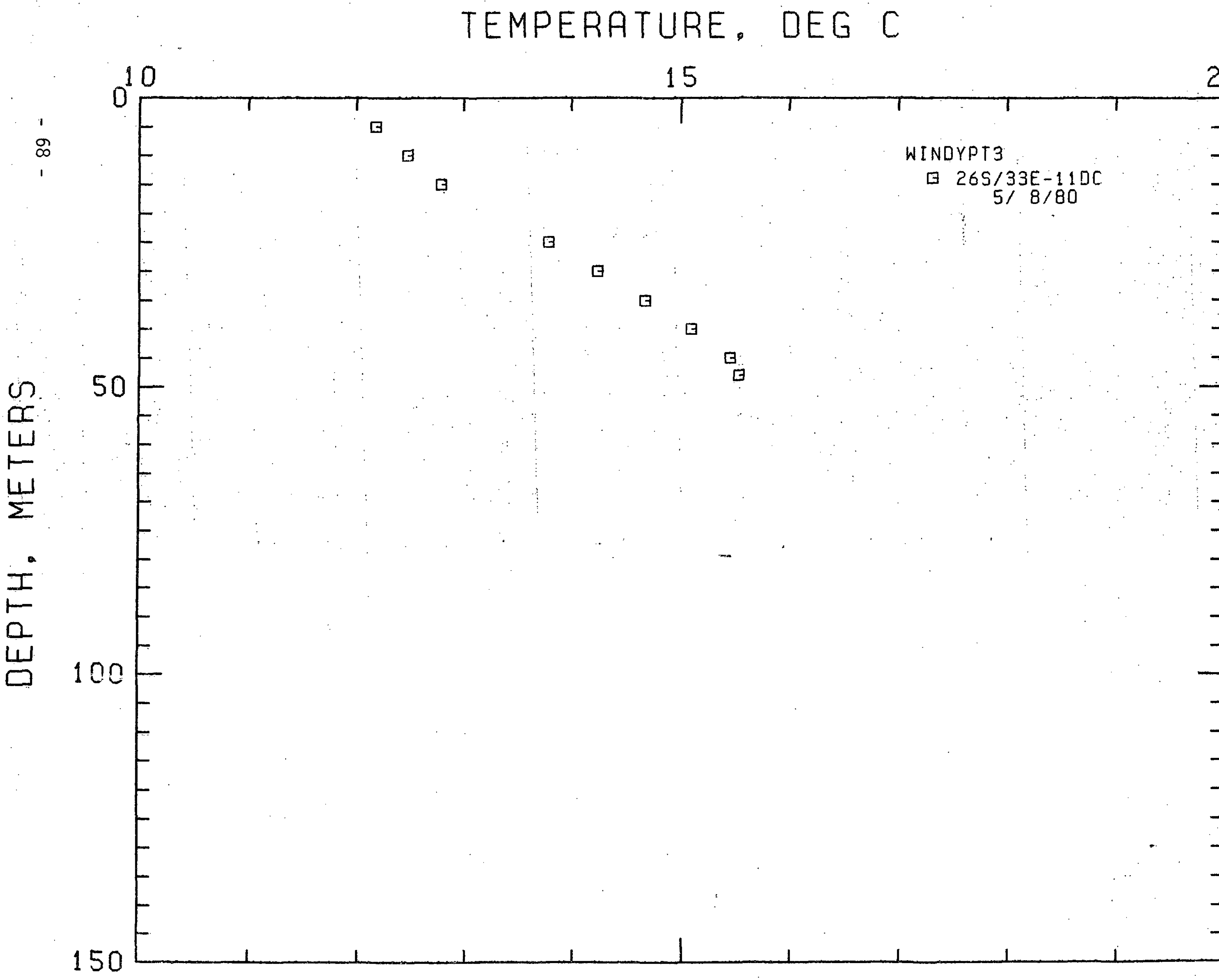
LOCATION: BURNS AMS, OREGON
26S/33E- 2CD
HOLE NAME: WINDYPT2
DATE MEASURED: 5/ 8/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	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	5.2
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
10
15
20
0
50
100
150
DEPTH, METERS
WINDYPT2
26S/33E- 2CD
5/ 8/80

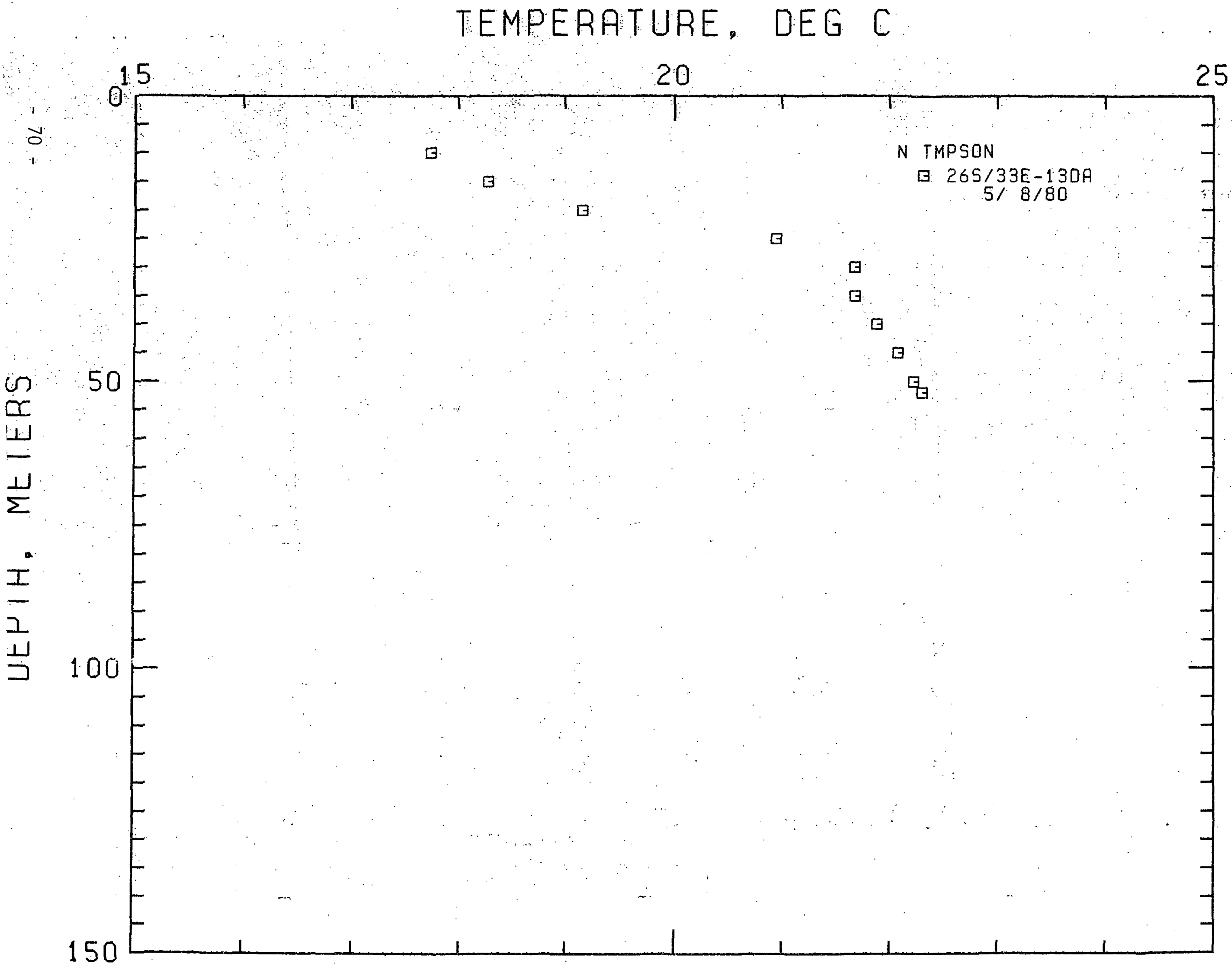
LOCATION: BURNS AMS, OREGON
26S/33E-11DC
HOLE NAME: WINDYPT3
DATE MEASURED: 5/ 8/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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	5.5
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
10
15
20
0
50
100
150
DEPTH, METERS
WINDYPT3
26S/33E-11DC
5/ 8/80

LOCATION: BURNS AMS, OREGON
26S/33E-13DA
HOLE NAME: N TMPSON
DATE MEASURED: 5/ 8/80

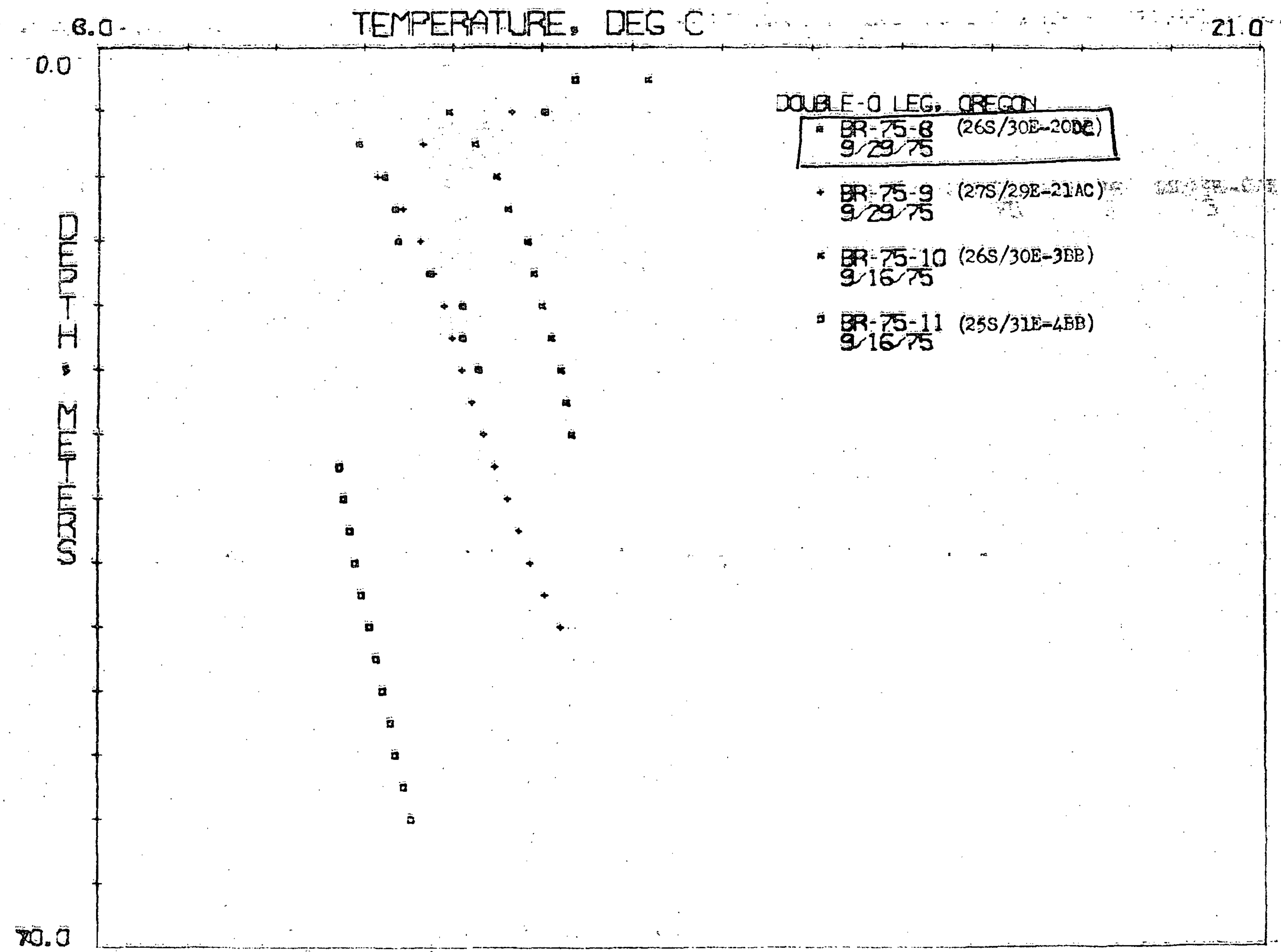
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
10.0	32.8	17.740	63.93	0.0	0.0
15.0	49.2	18.280	64.90	108.0	5.9
20.0	65.6	19.160	66.49	176.0	9.7
25.0	82.0	20.950	69.71	358.0	19.6
30.0	98.4	21.680	71.02	146.0	8.0
35.0	114.8	21.680	71.02	0.0	0.0
40.0	131.2	21.880	71.38	40.0	2.2
45.0	147.6	22.080	71.74	40.0	2.2
50.0	164.0	22.230	72.01	30.0	1.6
52.0	170.6	22.310	72.16	40.0	2.2



TEMPERATURE, DEG C
15
20
25
0
50
100
150
DEPTH, METERS
N TMPSON
26S/33E-13DA
5/ 8/80

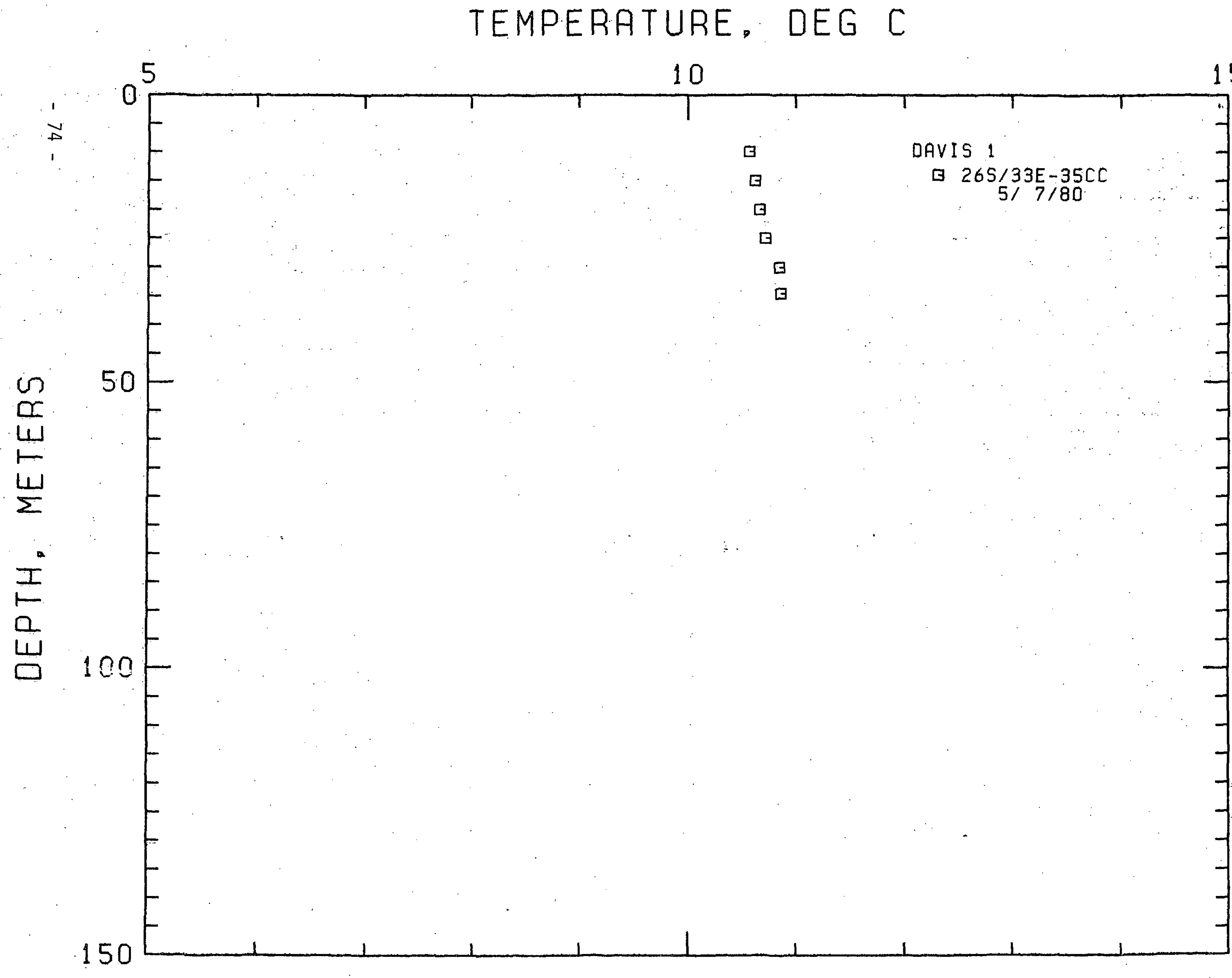
LOCATION: DOUBLE-O LEG, OREGON
26S/30E-20DC
HOLE NUMBER: OR-75-8
DATE MEASURED: 9/29/75

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
7.5	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	66.0	3.6


TEMPERATURE, DEG C
8.0
21.0
DEPTH, METERS
0.0
70.0
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DC)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

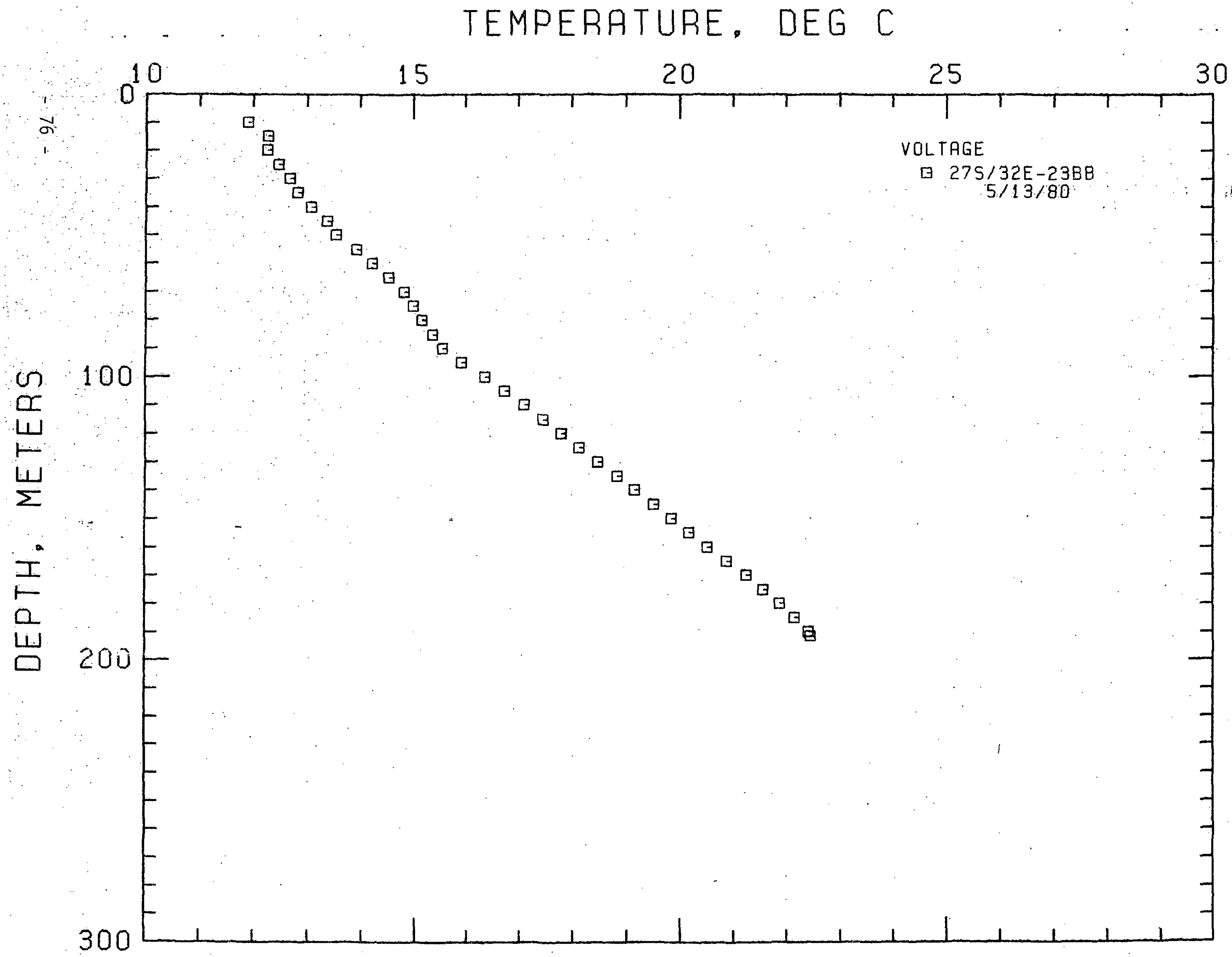
LOCATION: BURNS AMS, OREGON
26S/33E-35CC
HOLE NAME: DAVIS 1
DATE MEASURED: 5/ 7/80

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	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
34.5	113.2	10.860	51.55	2.2	0.1


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
DAVIS 1
26S/33E-35CC
5/ 7/80

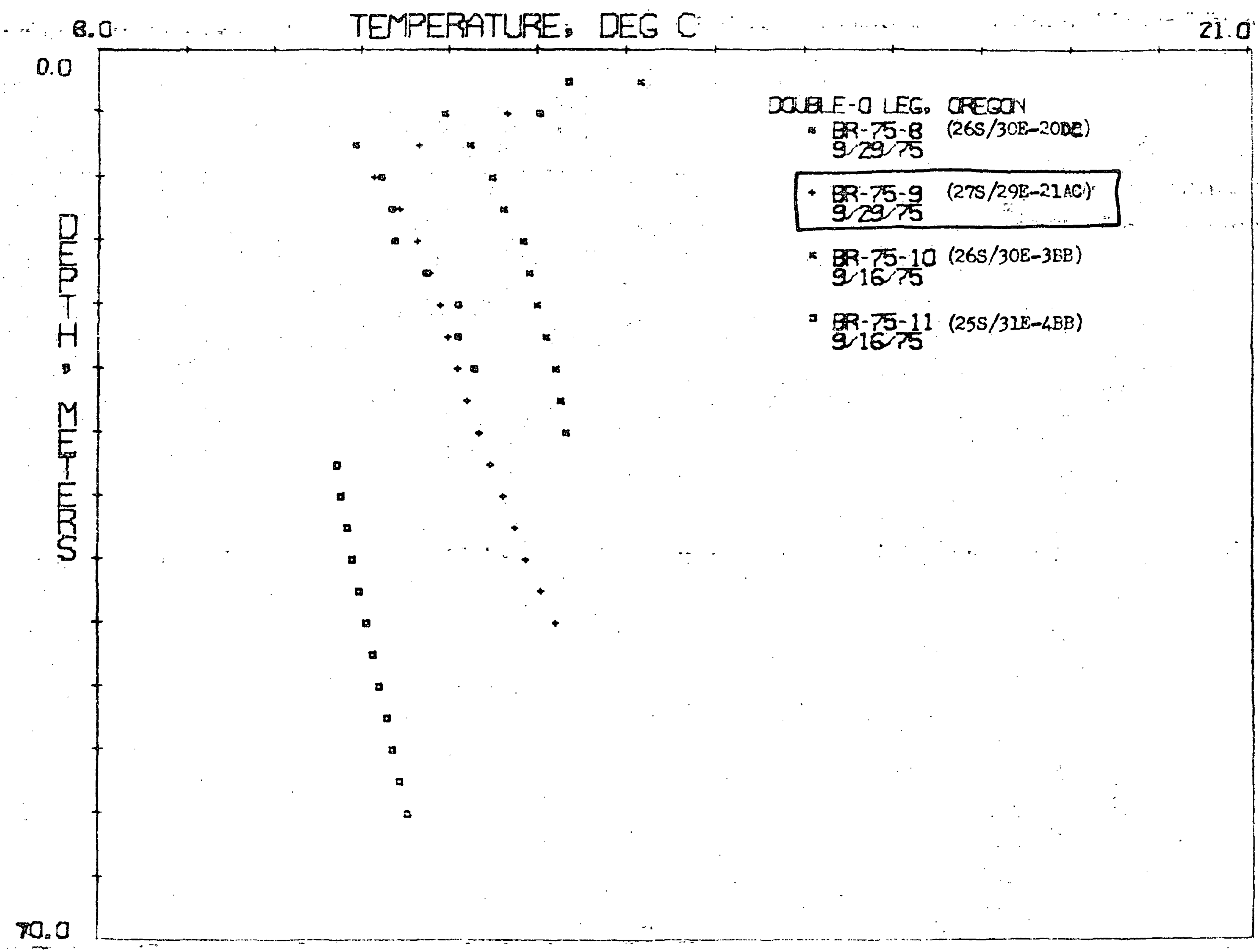
LOCATION: BURNS AMS, OREGON
27S/32E-23BB
HOLE NAME: VOLTAGE
DATE MEASURED: 5/13/80

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	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	1.5
40.0	131.2	13.090	55.56	52.0	2.9
45.0	147.6	13.380	56.08	58.0	3.2
50.0	164.0	13.550	56.39	34.0	1.9
55.0	180.4	13.930	57.07	76.0	4.2
60.0	196.8	14.230	57.61	60.0	3.3
65.0	213.2	14.540	58.17	62.0	3.4
70.0	229.6	14.830	58.69	58.0	3.2
75.0	246.0	15.000	59.00	34.0	1.9
80.0	262.4	15.170	59.31	34.0	1.9
85.0	278.8	15.370	59.67	40.0	2.2
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	3.7
135.0	442.8	18.850	65.93	74.0	4.1
140.0	459.2	19.170	66.51	64.0	3.5
145.0	475.6	19.520	67.14	70.0	3.8
150.0	492.0	19.850	67.73	66.0	3.6
155.0	508.4	20.180	68.32	66.0	3.6
160.0	524.8	20.530	68.95	70.0	3.8
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	21.880	71.38	60.0	3.3
185.0	606.8	22.160	71.89	56.0	3.1
190.0	623.2	22.420	72.36	52.0	2.9
191.5	628.1	22.460	72.43	26.7	1.5


TEMPERATURE, DEG C
10
15
20
25
30
0
100
200
300
DEPTH, METERS
VOLTAGE
27S/32E-23BB
5/13/80

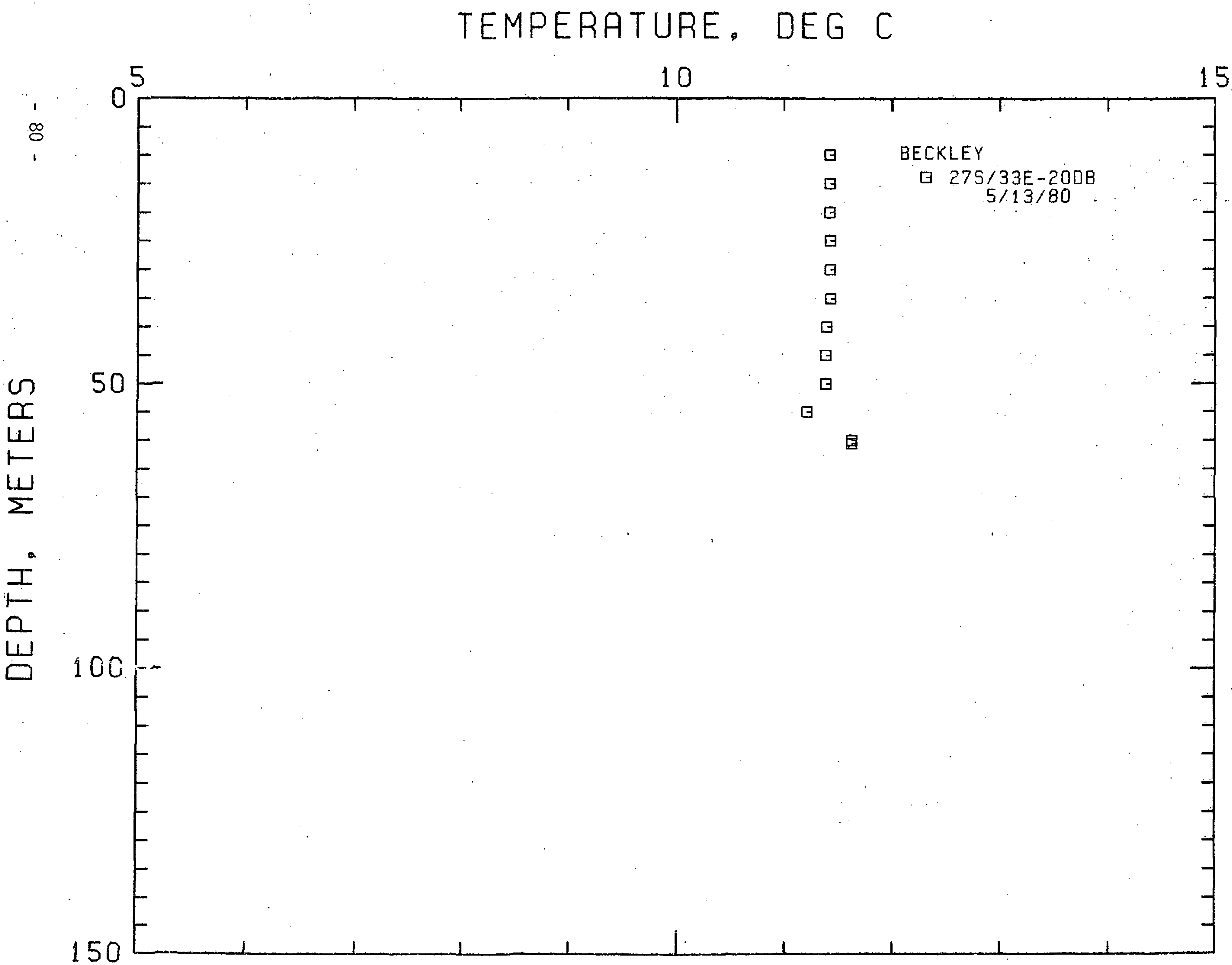
LOCATION: DOUBLE-O LEG, OREGON
27S/29E-21AC
HOLE NUMBER: BR-75-9
DATE MEASURED: 9/29/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	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	12.325	54.18	52.0	2.9
32.5	106.6	12.450	54.41	50.0	2.7
35.0	114.8	12.600	54.68	60.0	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	60.0	3.3
45.0	147.6	13.180	55.72	68.0	3.7


TEMPERATURE, DEG C
8.0
21.0
DEPTH, METERS
0.0
70.0
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DE)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

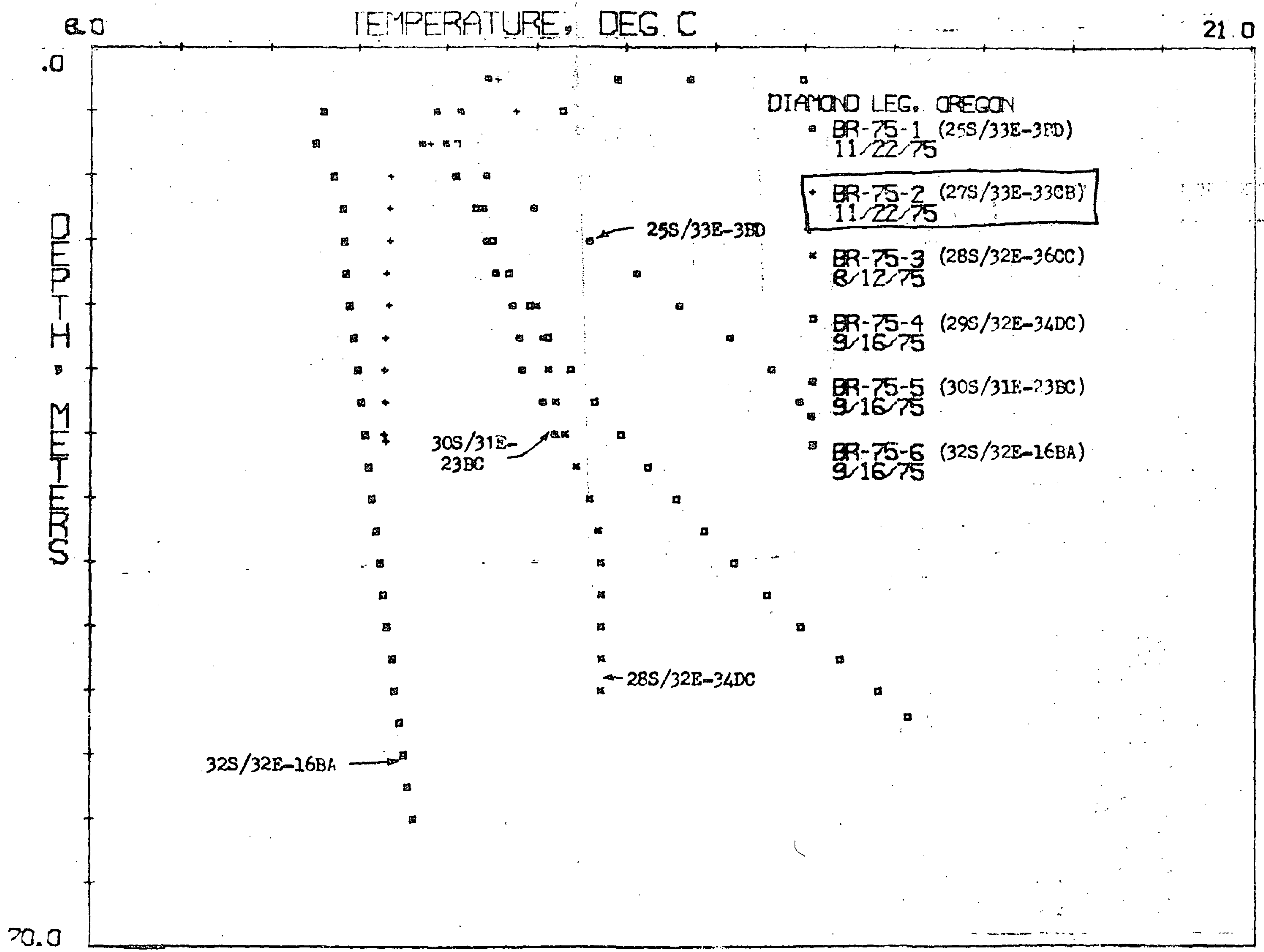
LOCATION: BURNS AMS, OREGON
27S/33E-20DB
HOLE NAME: BECKLEY
DATE MEASURED: 5/13/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	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	2.0	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	-8.0	-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
50.0	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


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
BECKLEY
27S/33E-20DB
5/13/80

LOCATION: DIAMOND LEG, OREGON
27S/33E-33CB
HOLE NUMBER: BR-75-2
DATE MEASURED: 11/22/75

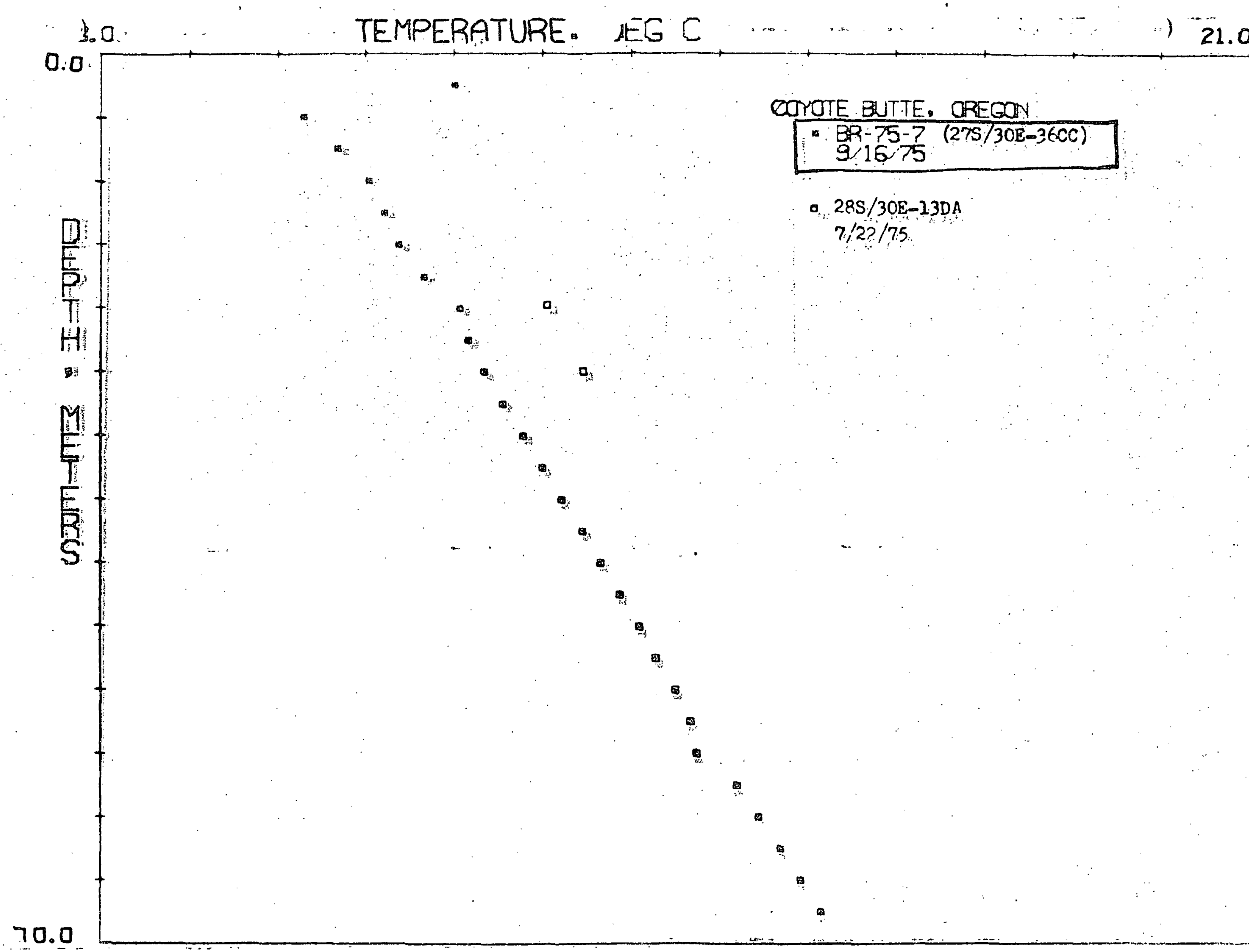
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C		GEOTHERMAL GRADIENT DEG C/KM	
		DEG C	DEG F	DEG C/KM	DEG F/100 FT
2.5	8.2	12.570	54.63	.0	.0
5.0	16.4	12.760	54.97	76.0	4.2
7.5	24.6	11.810	53.26	-380.0	-20.9
10.0	32.8	11.360	52.45	-180.0	-9.9
12.5	41.0	11.350	52.43	-4.0	-.2
15.0	49.2	11.350	52.43	.0	.0
17.5	57.4	11.310	52.36	-16.0	-.9
20.0	65.6	11.330	52.39	8.0	.4
22.5	73.8	11.290	52.32	-16.0	-.9
25.0	82.0	11.280	52.30	-4.0	-.2
27.5	90.2	11.290	52.32	4.0	.2
30.0	98.4	11.280	52.30	-4.0	-.2
30.5	100.0	11.290	52.32	20.0	1.1



TEMPERATURE, DEG C
8.0
21.0
DEPTH, METERS
.0
70.0
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

LOCATION: COYOTE BUTTE, OREGON
27S/30E-36CC
HOLE NUMBER: BR-75-7
DATE MEASURED: 9/16/75

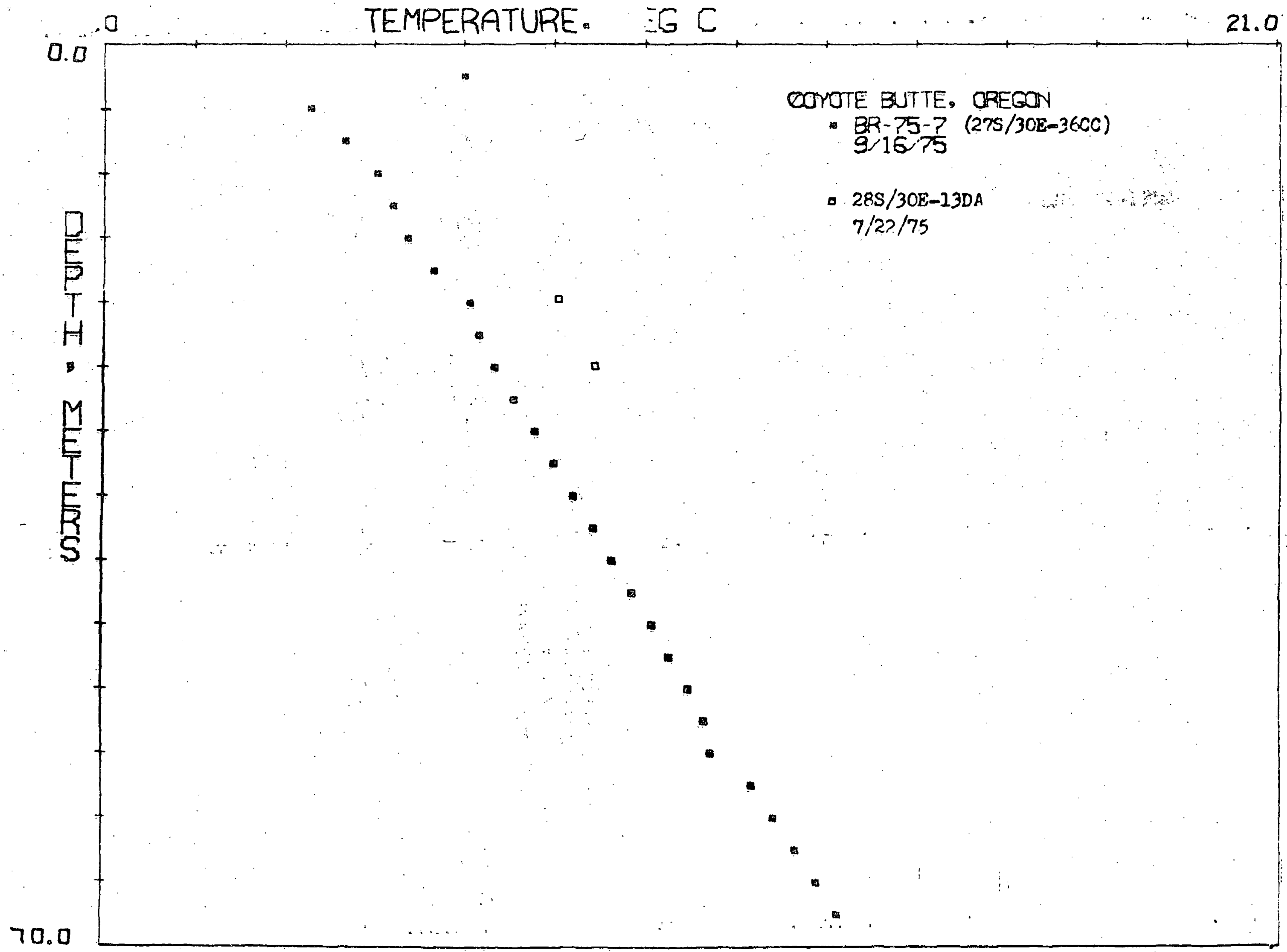
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
2.5	8.2	12.000	53.60	.0	.0
5.0	16.4	10.280	50.50	-688.0	-37.8
7.5	24.6	10.670	51.21	156.0	8.6
10.0	32.8	11.040	51.87	148.0	8.1
12.5	41.0	11.200	52.16	64.0	3.5
15.0	49.2	11.360	52.45	64.0	3.5
17.5	57.4	11.650	52.97	116.0	6.4
20.0	65.6	12.060	53.71	164.0	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



TEMPERATURE, DEG C
21.0
0.0
70.0
DEPTH, METERS
COYOTE BUTTE, OREGON
BR-75-7 (27S/30E-36CC)
9/16/75
28S/30E-13DA
7/22/75

LOCATION: COYOTE BUTTES, OREGON
28S/30E-13DA
HOLE NUMBER: HP-12
DATE MEASURED: 7/22/75

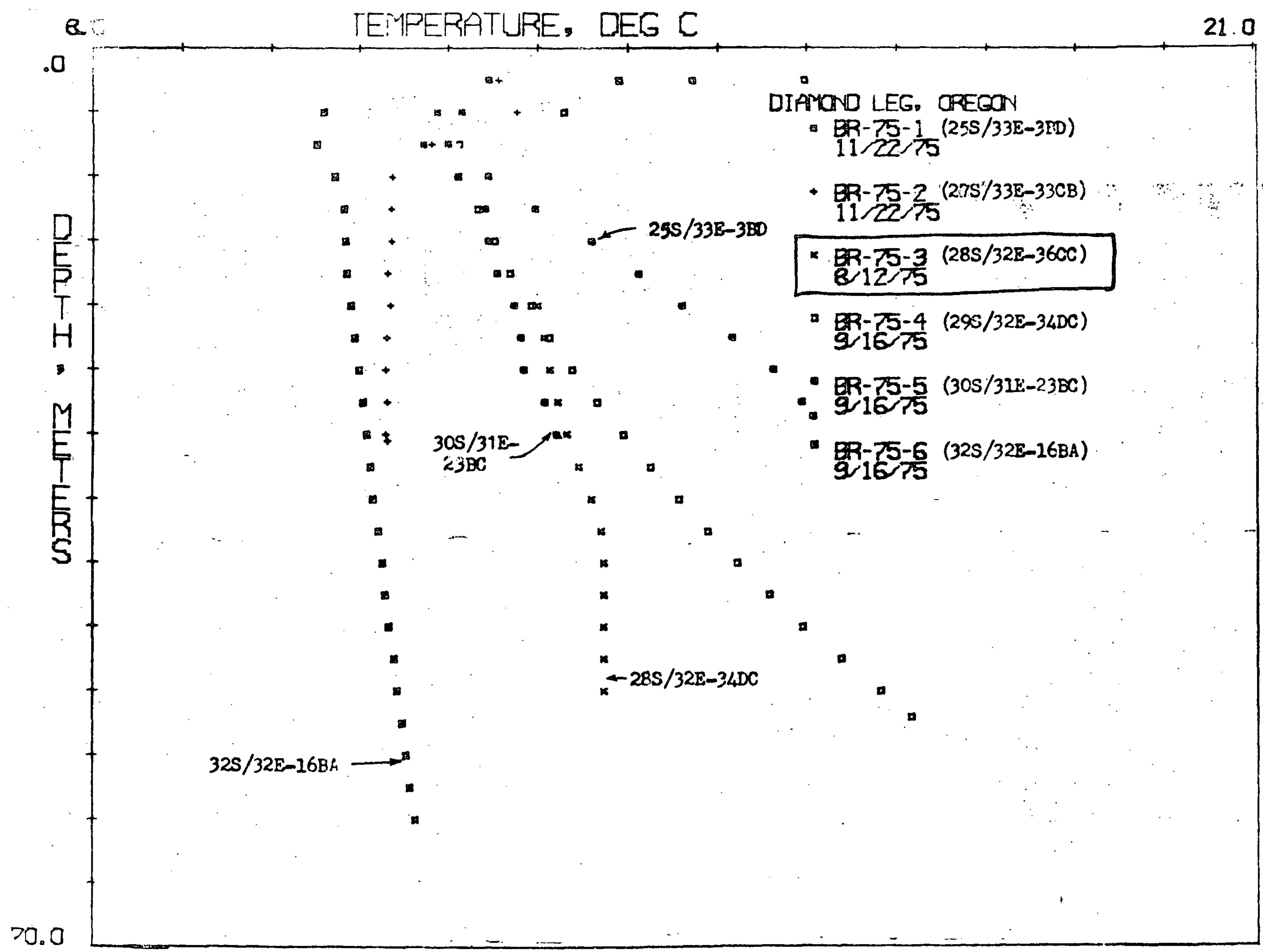
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100
20.0	65.6	13.040	55.47	.0	.0
25.0	82.0	13.450	56.21	82.0	4.5



TEMPERATURE, DEG C
21.0
0.0
70.0
DEPTH, METERS
COYOTE BUTTE, OREGON
BR-75-7 (27S/30E-36CC)
9/16/75
28S/30E-13DA
7/22/75

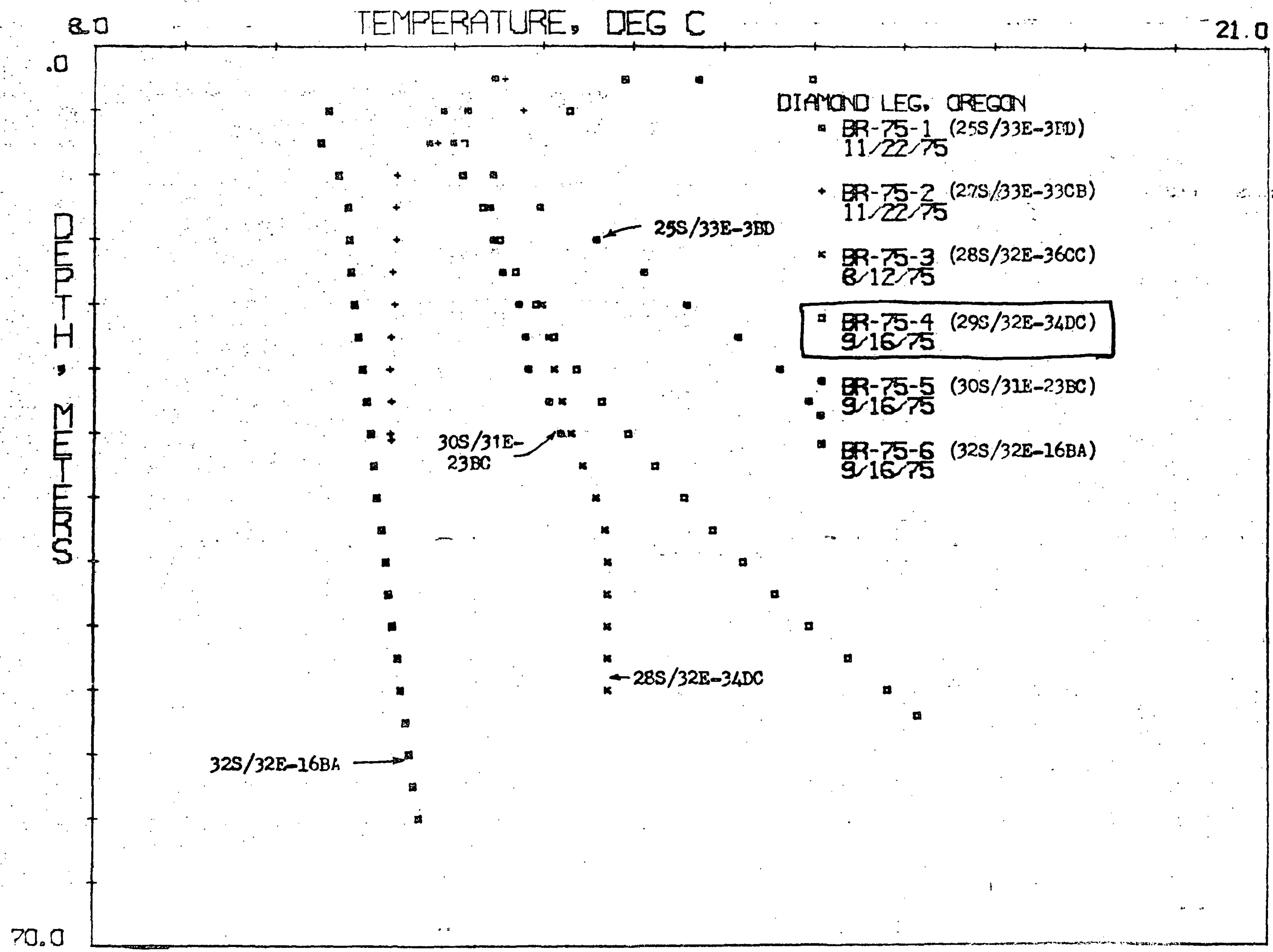
LOCATION: DIAMOND LEG, OREGON
28S/32E-36CC
HOLE NUMBER: BR-75-3
DATE MEASURED: 8/12/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	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


8.0
TEMPERATURE, DEG C
21.0
.0
DEPTH, METERS
70.0
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

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

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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	-468.0	-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



TEMPERATURE, DEG C
8.0
21.0
DEPTH, METERS
.0
70.0
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

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1005 State Office Building
Portland, Oregon 97201

OPEN-FILE REPORT 0-80-7

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

by

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G. L. Black

Under the direction of J. F. Riccio

Study completed under U. S. Department of Energy
Cooperative Agreement No. DE-FC07-79ET27220

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.

CONTENTS

ILLUSTRATIONS

FIGURES

TABLES

MAPS (folded, in envelope)

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°00' on the south, 43°30' on the north, 118°30' on the east, and 119°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 km^2 (8,100 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.

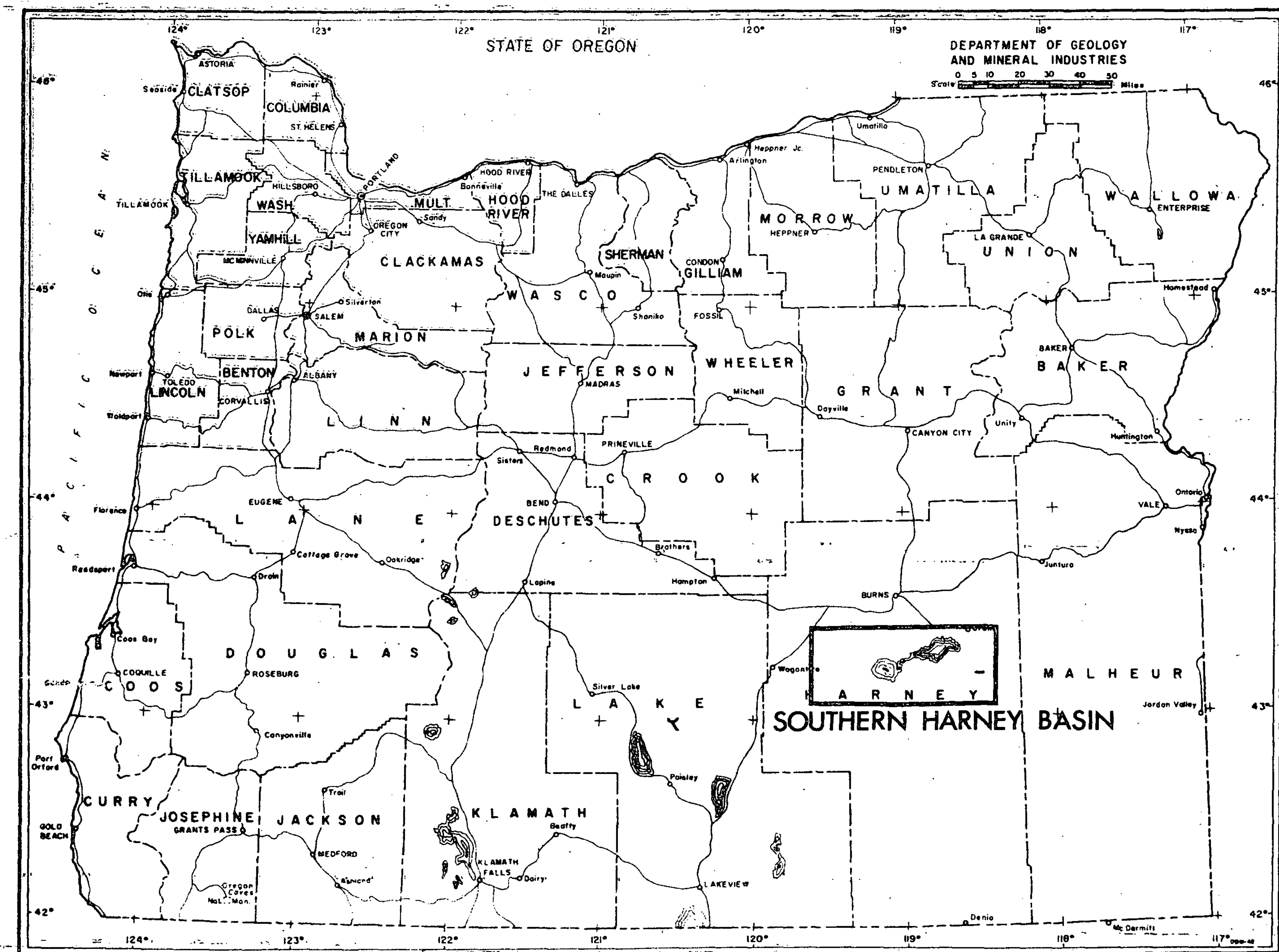


Figure 1: Map showing location of study area.

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 7½-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

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
PA-300	119°04'18" 43°03'06"	Basalt	$^{w}8.8\pm1.4$ my	Tmbh
PA-311B	119°22'23" 43°09'03"	Welded tuff	$^{w}8.6\pm0.2$ my	Tmtd
PA-146	119°21'11" 43°13'80"	Rhyolite	$^{w}8.4\pm1.3$ my	Tmto
PA-119	119°13'30" 43°14'19"	Rhyolite	$^{w}8.2\pm0.12$ my	Tmtp
PA-250	119°03'45" 43°02'27"	High Al basalt	$^{w}7.9\pm0.9$ my	Tmbh
PA-316D	119°08'45" 43°17'02"	Rhyolite	$^{w}7.8\pm0.5$ my	Tmro
PA-243	119°03'45" 43°04'56"	Welded tuff	$^{s}7.1\pm0.10$ my	Tmtr
G-165-68	118°34'48" 43°24'48"	Basalt	$^{p}6.91\pm1.09$ my	Tmbd
PA-330	119°22'23" 43°09'03"	Welded tuff	$^{w}6.7\pm0.4$ my	Tmtr
PA-311G	119°22'23" 43°09'03"	Welded tuff	$^{w}6.6\pm0.2$ my	Tmtr
W-2-70	119°18'00" 43°28'48"	Rhyodacite	$^{a}6.5\pm0.3$ my $^{b}6.1\pm0.2$ my	Tmrp
PA-6-70	119°27'51" 44°46'54	Welded tuff	$^{a}6.4\pm0.2$ my	Tmtr
PA-214	119°18'00" 43°30'18"	Rhyolite	$^{w}5.6\pm0.4$ my $^{b}6.4\pm0.2$ my	Tmrp
PA-160	119°28'00" 43°16'30"	Andesite	$^{w}5.8\pm0.8$ my	Tmbi
PA-41	119°06'34" 43°20'24"	Alkali basalt	$^{w}2.8\pm0.2$ my	Qtb
PA-158	119°12'00" 43°13'48"	Rhyolite	$^{w}2.1\pm0.24$ my $^{b}2.7\pm0.4$ 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

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
PA-14	119°00'23" 43°26'24"	High Al basalt	$^{w}2.6\pm0.3$ my	Qtb
G-32-67	119°00'30" 43°27'00"	Basalt	$^{w}2.38\pm0.07$ my	Qtb
SH-4	118°56'45" 43°2'00"	Andesite	$^{p}16.7\pm0.6$ my	Tmba
SH-12	118°50'22" 43°15'40"	Basalt	$^{w}2.91\pm0.38$ my	Qtb (?)
SH-105	118°30'55" 43°14'45"	Rhyodacite	$^{w}11.3\pm0.5$ my	Tmrd
SH-106	118°30'54" 43°21'53"	Basalt	$^{p}11.1\pm1.3$ my	Tmba
SH-106A	118°30'05" 43°21'45"	Basalt	$^{ps}9.44\pm0.8$ my	Tmba
SH-113	118°53'06" 43°08'13"	Basalt	$^{ps}8.07\pm0.69$ 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.)

Component	*P-159 QTb	P-194 QTmv	P-14 QTb	P-40 QTmv	P-58 QTb	P-181 QTb
SiO_2	48.5	48.6	48.7	48.7	48.9	49.1
TiO_2	3.51	0.87	1.43	1.97	1.47	1.60
Al_2O_3	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_2O	3.8	2.6	2.8	2.4	2.3	3.2
K_2O	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
	P-212 QTb	P-300 Tmbh	P-73-4 Tmbh	P-52 QTb	P-41 QTb	P-250 Tmbh
SiO_2	49.5	49.5	49.5	50.0	50.1	50.2
TiO_2	1.45	1.72	1.93	1.36	1.70	1.38
Al_2O_3	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_2O	3.5	3.1	3.4	2.8	3.0	2.7
K_2O	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
	P-184 QTb	P-199 QTmv	P-193 QTmv	P-44 QTmv	P-206 QTmv	P-185 QTb
SiO_2	50.2	50.4	50.8	51.0	51.2	51.7
TiO_2	3.27	1.52	1.14	0.83	1.17	2.82
Al_2O_3	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_2O	3.9	3.4	3.1	3.0	3.0	3.8
K_2O	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.)

Component	*P-278 Tmbh	P-160 Tmbi	P-197 QTmv	P-245D Tmtd
SiO_2	52.6	57.6	63.7	71.3
TiO_2	1.07	1.25	0.75	0.35
Al_2O_3	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_2O	3.2	4.2	1.9	3.85
K_2O	0.82	2.0	1.9	6.0
Total	100.59	99.55	100.75	101.71

Component	P-146 Tmro	P-119 Tmtp	P-215 Tmrp
SiO_2	73.2	73.8	73.9
TiO_2	0.47	0.13	0.28
Al_2O_3	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_2O	3.9	4.45	3.4
K_2O	4.71	4.5	4.58
Total	100.12	97.93	99.76

Component	P-245L Tmtr	P-214 Tmrp	P-290 Tmtr
SiO_2	75.0	76.0	76.4
TiO_2	0.20	0.08	0.13
Al_2O_3	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_2O	3.12	3.4	4.4
K_2O	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±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^{o}-35^{o}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°C and 67°C for Crane Hot Springs and Harney Lake Hot Springs, respectively, down to 15°-20°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°-120°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. (^{o} 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 HCO_3 X_c as mg/l $CaCO_3$	457_c	416_c	nt	nt	nt
Hardness as mg/l $CaCO_3$	<1	4	<15	<15	205
Total dissolved solids	747	695	452	788	1580
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
HCO_3	nt	nt	nt	nt	nt
PO_4	0.030	0.015	nt	nt	nt
SO_4	25.6	47.0	20	28	92
NO_3	<0.02	<0.02	nt	nt	nt
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.

	Soldier Well	Sage Hen Creek Well	Crane Spring	Crane Spring	Crane Spring
Location	27S/29½E/ 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. (^{o} C)	19.5	23	49	80	78
pH	7.99	7.9	nt	8.3	8.1
Conductance µmhos/cm	270	151	nt	814	810
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	67_c	nt	nt	202_c
Hardness as mg/l $CaCO_3$	70	18	nt	nt	nt
Total dissolved solids	236	125	nt	536	nt
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
HCO_3	nt	nt	173	199	202
PO_4	nt	0.033	nt	nt	0.09
SO_4	15	11.8	80	81	86
NO_3	nt	<0.02	1.4	nt	nt
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.

	Crane Spring	Island Ranch Well	Unnamed Spring	Long Hollow Well	Barnyard Spring
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. (^{o} 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 HCO_3 X_c as mg/l $CaCO_3$	169_c	nt	105_c	105_c	112_c
Hardness as mg/l $CaCO_3$	8	nt	60	115	35
Total dissolved solids	564	957	233	282	237
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
HCO_3	nt	674	nt	nt	nt
PO_4	0.050	nt	0.032	0.084	0.034
SO_4	78	8	11.8	28.2	11.3
NO_3	0.05	0.1	0.72	0.02	0.67
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.

	Warm Spring in Harney Lake	Unnamed Spring	Railroad Well	Harney Lake Hot Spring	Harney Lake Hot Spring
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. (^{o} 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 HCO_3 X_c as mg/l $CaCO_3$	2000_c	103_c	91_c	nt	nt
Hardness as mg/l $CaCO_3$	23	58	27	nt	nt
Total dissolved solids	10615	251	184	nt	nt
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
HCO_3	nt	nt	nt	601	566
PO_4	1.190	0.032	0.027	nt	0.092
SO_4	474	12.9	18.4	140	140
NO_3	0.03	0.75	0.03	0.5	nt
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.

	Harney Lake Hot Spring	OO Station Spring	Adobe Flat Well	Thompson Well	Harney Lake Spit Spring
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. (^{o}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 HCO_3 X_c as mg/l $CaCO_3$	493_c	85_c	120	122	nt
Hardness as mg/l $CaCO_3$	43	44	99	82	30
Total dissolved solids	1777	186	237	341	654
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
HCO_3	nt	nt	nt	nt	nt
PO_4	0.294	0.031	0.029	0.013	nt
SO_4	119.3	6.7	19.9	45	58
NO_3	0.02	0.50	0.51	0.92	nt
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.

	Eagles Nest Spring #1	Eagles Nest Spring #2	Bathtub Spring
Location	27S/29½E/ 25Aad	27S/29½E/ 25Ada	27S/29½E/ 28Cac
Date sampled	10/80	10/80	10/80
Temp (^{o}C)	41.7	28.1	51.1
pH	7.12	9.18	6.87
Conductance µmhos/cm	4750	1150	3900
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt
Hardness as mg/l $CaCO_3$	154	<15	170
Total dissolved solids	3110	632	2096
SiO_2	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_3	nt	nt	nt
PO_4	nt	nt	nt
SO_4	320	23	50
NO_3	nt	nt	nt
NH_3	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_2 conductive °C	148	79	79	83	91	127
SiO_2 adiabatic °C	141	82	83	86	93	124
SiO_2 chalcedony °C	122	47	48	52	60	99
SiO_2 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_2 conductive °C	93	125	127	133	105	106
SiO_2 adiabatic °C	95	123	124	129	106	106
SiO_2 chalcedony °C	62	97	99	106	76	77
SiO_2 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_2 conductive °C	86	130	125	122	112	131
SiO_2 adiabatic °C	89	126	123	120	112	128
SiO_2 chalcedony °C	55	102	97	94	83	104
SiO_2 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	OO 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_2 conductive °C	113	107	133	133	138	117
SiO_2 adiabatic °C	112	107	129	129	134	115
SiO_2 chalcedony °C	84	78	105	105	112	88
SiO_2 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 ^oC	17	24	14.5
Na:K ^oC	242	194	122
Na:K:Ca 1/3 β ^oC	268	176	119
Na:K:Ca 4/3 β ^oC	311	87	37
Na:K:Ca Mg corrected ^oC	148	68	61
SiO_2 conductive ^oC	126	127	97
SiO_2 adiabatic ^oC	123	124	98
SiO_2 chalcedony ^oC	98	99	67
SiO_2 opal ^oC	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^{o}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.

GEOTHERMAL-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: 1×10^{-6} cal/cm^{2}sec (HFU) = 41.84 mWm^{-2}, 1×10^{-3} cal/cm sec$^{\circ}$C (TCU) = 0.4184 Wm^{-1}K^{-1}, and 1°C/km = 1 mKm^{-1} = 18.2°F/100 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°C/km and 60-80 mWm^{-2}. Several anomalous

*By D. D. Blackwell, Southern Methodist University, Dallas, Texas.

Table 5. Geothermal-gradient data, south Harney Basin, 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^{-2}	Q HF
24S/33E-9D	43-30.00	118-39.00	S3	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	43-28.00	118-35.00	S2	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	30.9	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	.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.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^{-2}	Q HF
21D						190.0			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 TMPSON 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.	Bottom Temp. (°C)	Depth Interval (m)	Avg. TC $Wm^{-1}K^{-1}$	# TC	Uncorr. Gradient °C/km	Corr. Gradient °C/km	Corr. HF mWm^{-2}	Q HF
						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	130.3	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	73.1	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	88.4	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
						37.5 50.0			(2.4) 2.1	2.4		C
29S/32E- 6B	43- 5.30	118-49.40	MR-1	1262		56.4 64.0	.92 .07	4	89.0 1.0	89.0 1.0	82 6	A
						40.0 91.0	.92 .07	4	96.0 .6	96.0 .6	88 6	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 2	A
						89.3 92.0	.92 .03	4	83.0 3.0	83.0 3.0	76 3	A
						60.0 100.0	.95 .02	8	74.2 .8	74.2 .8	71 1	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^{0}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.

BIBLIOGRAPHY OF THE HARNEY BASIN

Baldwin, E.M., 1976, Geology of Oregon (revised ed.): Dubuque, Iowa, Kendall/Hunt, 147 p.

Beaulieu, J.D., 1972, Geologic formations of eastern Oregon (east of longitude 121° 30'): Oregon Department of Geology and Mineral Industries Bulletin 73, 80 p.

Beeson, M.H., 1969, Correlation of ash-flows by trace element abundance (abs.): Proceedings of the Oregon Academy of Science, v. 4, p. 23-24.

Berg, J.W., Jr., and Thiruvathukal, J.V., 1967, Regional gravity of Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 29, no. 6, p. 120-126.

Blackwell, D.D., Hull, D.A., Bowen, R.G., and Steele, J.L., 1978, Heat flow of Oregon: Oregon Department of Geology and Mineral Industries Special Paper 4, 42 p.

Blank, H.R., Jr., and Gettings, M.E., 1974, Geophysical evidence of caldera structures in the Harney Basin of central eastern Oregon (abs.): EOS (American Geophysical Union Transactions), v. 55, no. 5, p. 557.

Bodvarsson, G., Couch, R.W., MacFarlane, W.T., Tank, R.W., and Whitsett, R.M., 1974, Telluric current exploration for geothermal anomalies in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 36, no. 6, p. 93-107.

Bowen, R.G., 1972, Geothermal gradient studies in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 34, no. 4, p. 68-71.

_____ 1975, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report 0-75-3, 133 p.

Bowen, R.G., Blackwell, D.D., and Hull, D.A., 1975, Geothermal studies and exploration in Oregon (draft final report to U.S. Bureau of Mines): Oregon Department of Geology and Mineral Industries Open-File Report 0-75-7, 65.

_____ 1977, Geothermal exploration studies in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 19, 50 p.

Bowen, R.G., Blackwell, D.D., Hull, D.A., and Peterson, N.V., 1976, Progress report on heat-flow study of the Brothers fault zone, central Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 38, no. 3, p. 39-46.

Bowen, R.G., and Peterson, N.V., compilers, 1970, Thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Miscellaneous Paper 14 (map), scale approx. 1:1,000,000.

Bowen, R.G., Peterson, N.V., and Riccio, J.F., compilers, 1978, Low- to intermediate-temperature thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-10, scale approx. 1:1,000,000.

Brooks, H.C., 1963, Quicksilver in Oregon: Oregon Department of Geology and Mineral Industries Bulletin 55, p. 204.

Buwalda, J.P., 1921, Report on oil and gas possibilities of eastern Oregon: Oregon Bureau of Mines and Geology, The mineral resources of Oregon, v. 3, no. 2, p. 28-29.

Campbell, I., Conel, J.E., Rogers, J.J.W., and Whitfield, J.M., 1959, Possible correlation of Rattlesnake and Danforth Formations of eastern Oregon (abs.): Geological Society of America Bulletin, v. 69, no. 12, pt. 2, p. 1678.

Corcoran, R.E., 1956, Sedimentary basins in Oregon: World Oil, v. 143, no. 5, p. 140-142.

Davenport, R.E., 1971, Geology of the Rattlesnake and older ignimbrites in the Paulina Basin and adjacent area, central Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 132 p.

Dole, H.M., and Corcoran, R.E., 1954, Reconnaissance geology along U.S. Highway 20 between Vale and Buchanan, Malheur and Harney Counties, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 16, no. 6, p. 37-39.

Enlows, H.E., and Davenport, R.E., 1971, Tertiary ignimbrites in central Oregon (abs.): Proceedings of the Oregon Academy of Science, v. 7, p. 75.

Enlows, H.E., Parker, D., and Davenport, R.E., 1973, The Rattlesnake ignimbrite tongue (abs.): Geological Society of America Abstracts with Programs, v. 5, no. 1, p. 38-39.

Godwin, L.H., Haigler, L.B., Rioux, R.L., White, D.E., Muffler, L.J.P., and Wayland, R.G., 1971, Classification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geological Survey Circular 647, 18 p.

Greene, R.C., 1970, A crystal-rich ash-flow tuff in southeast Oregon (abs.): Geological Society of America Abstracts with Programs, v. 2, no. 2, p. 97-98.

_____ 1972, Preliminary geologic map of the Burns and West Myrtle Butte 15-minute quadrangles, Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-320, scale 1:62,500.

_____ 1973, Petrology of the welded tuff of Devine Canyon, southeastern Oregon: U.S. Geological Survey Professional Paper 797, 26 p.

Greene, R.C., Walker, G.W., and Corcoran, R.E., 1972, Geologic map of the Burns quadrangle, Oregon: U.S. Geological Survey Miscellaneous Geological Investigations Map I-680, scale 1:250,000.

Groh, E.A., 1966, Geothermal energy potential in Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 28, no. 7, p. 125-135.

Hull, D.A., Blackwell, D.D., and Black, G.L., 1978, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report 0-78-4, 187 p.

Hull, D.A., Blackwell, D.D., Bowen, R.G., and Peterson, N.V., 1977, Heat-flow study of the Brothers fault zone, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report 0-77-3, 43 p.

Hull, D.A., Blackwell, D.D., Bowen, R.G., Peterson, N.V., and Black, G.L., 1977, Geothermal gradient data: Oregon Department of Geology and Mineral Industries Open-File Report 0-77-2, 134 p.

Hull, D.A., Bowen, R.G., Blackwell, D.D., and Peterson, N.V., 1976, Geothermal gradient data, Brothers fault zone, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report 0-76-2, 24 p.

_____ 1977, Preliminary heat-flow map and evaluation of Oregon's geothermal energy potential: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 39, no. 7, p. 109-123.

Hull, D.A., and Newton, V.C., Jr., 1977, Geothermal activity in 1976: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 39, no. 1, p. 7-15.

Leonard, A.R., 1970, Ground water resources in Harney Valley, Harney County, Oregon: Oregon State Engineer Ground Water Report 16, 85 p.

Lund, E.H., 1962, Welded tuff in the Danforth Formation (abs.): Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 2, p. 24.

_____ 1966, Zoning in an ash flow of the Danforth Formation, Harney County, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 28, no. 9, p. 161-170.

MacLeod, N.S., Walker, G.W., and McKee, E.H., 1975, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeastern Oregon: U.S. Geological Survey Open-File Report 75-348, 22 p.

Maloney, N.J., 1962, Tertiary and Quaternary faulting in southwestern Harney County, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 2, p. 21-22.

Mariner, R.H., Presser, T.S., Rapp, J.B., and Willey, L.M., 1975, The minor and trace elements, gas, and isotope compositions of the principal hot springs of Nevada and Oregon: U.S. Geological Survey open-file report, 27 p.

Mariner, R.H., Rapp, J.B., Willey, L.M., and Presser, T.S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon: U.S. Geological Survey open-file report, 27 p.

Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.

McKee, E.H., MacLeod, N.S., and Walker, G.W., 1976, K/Ar ages of late Cenozoic silicic volcanic rocks, southeast Oregon: Isochron/West, no. 15, p. 37-41.

Merriam, J.C., Stock, C., and Moody, C.L., 1925, The Pliocene Rattlesnake Formation and fauna of eastern Oregon, with notes on the geology of the Rattlesnake and Mascall deposits: Carnegie Institution of Washington Publication 347, p. 43-92.

Muffler, L.J.P., ed., 1979, Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790, 163 p.

Newton, V.C., Jr., and Hull, D.A., 1978, Geothermal energy in 1977: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 40, no. 1, p. 8-16.

Parker, D.J., 1974, Petrology of selected volcanic rocks of the Harney Basin, Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 119 p.

Parker, D., and Armstrong, R.L., 1972, K-Ar dates and Sr isotope initial ratios for volcanic rocks in the Harney Basin, Oregon: Isochron/West, no. 5, p. 7-12.

Peterson, N.V., and Groh, E.A., 1964, Diamond Craters, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 26, no. 2, p. 17-34.

Piper, A.M., 1936, Resume of the geologic history of the Harney Basin, Oregon: Geological Society of the Oregon Country Geological News Letter, v. 2, no. 8, p. 9-12.

Piper, A.M., Robinson, T.W., and Park, C.F., Jr., 1939, Geology and groundwater resources of the Harney Basin, Oregon: U.S. Geological Survey Water-Supply Paper 841, 189 p.

Riccio, J.F., compiler, 1979, Preliminary geothermal resource map of Oregon, 1978: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-11, scale 1:500,000.

______ 1980, Geothermal exploration in Oregon, 1979: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 42, no. 4, p. 59-69.

Riccio, J.F., and Newton, V.C., Jr., 1979, Geothermal exploration in Oregon in 1978: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 41, no. 3, p. 39-46.

Russell, I.C., 1884, A geological reconnaissance in southern Oregon: U.S. Geological Survey 4th Annual Report, 1882-83, p. 431-464.

_____1903a, Notes on the geology of southwestern Idaho and southeastern Oregon: U.S. Geological Survey Bulletin 217, p. 36-69.

_____1903b, Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: U.S. Geological Survey Water-Supply Paper 78, p. 38-43.

_____1905, Preliminary report on the geology and water resources of central Oregon: U.S. Geological Survey Bulletin 252, p. 36-54.

Sass, J.H., Galanis, S.D., Jr., Munroe, R.J., and Urban, T.C., 1976, Heat-flow data from southeastern Oregon: U.S. Geological Survey Open-File Report 76-217, 52 p.

Sass, J.H., Lachenbruch, A.H., Munroe, R.J., Green, G.W., and Moses, T.H., Jr., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, no. 26, p. 6376-6413.

Sass, J.H., and Munroe, R.J., 1973, Temperature gradients in Harney County, Oregon: U.S. Geological Survey Open-File Report 73-247, 3 p., 7 figs.

Stearns, N.D., Stearns, H.T., and Waring, G.A., 1937, Thermal springs in the United States: U.S. Geological Survey Water-Supply Paper 679-B, p. 59-206.

Stone, C.J., 1931, Petroleum reconnaissance report, Harney Basin: Oregon Department of Geology and Mineral Industries, unpublished, 9 p. (geol. map, 1930, 1:125,000).

Thayer, T.P., 1952, The tuff member of the Rattlesnake Formation of eastern Oregon--an ignimbrite (abs.): American Geophysical Union Transactions, v. 33, p. 327.

Thiruvathukal, J.V., 1968, Regional gravity of Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 92 p.

U.S. Geological Survey, 1968, Volcanic rocks and stratigraphy in Washington and Oregon, <u>in</u> Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-A, p. A35-A36 (R.C. Greene and G.W. Walker; D.R. Crandall; D.R. Mullineaux; R.S. Sigafoos and E.L. Hendricks, investigators).

_____1972, Aeromagnetic map of the Adel and parts of the Burns, Boise, and Jordan Valley 1° by 2° quadrangles, Oregon: U.S. Geological Survey Open-File Report 72-390, scale 1:250,000.

_____1973, Ground-water gradients near Malheur Lake, <u>in</u> Geological Survey research 1973: U.S. Geological Survey Professional Paper 850, p. 186 (L.L. Hubbard and A.R. Leonard, investigators).

U.S. Geological Survey and Oregon Department of Geology and Mineral Industries, 1979, Chemical analyses of thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries Open-File Report 0-79-3, 170 p.

Van Orstrand, C.E., 1938, Temperatures in the lava beds of east-central and south-central Oregon: American Journal of Science, 5th Series, v. 35, no. 205, p. 22-46.

Walker, G.W., 1969a, Possible fissure vent for a Pliocene ash-flow tuff, Buzzard Creek area, Harney County, Oregon, in Geological Survey research 1969: U.S. Geological Survey Professional Paper 650-C, p. C8-C17.

_____ 1969b, Geology of the High Lava Plains province, in Weissenborn, A.E., ed., Mineral and water resources of Oregon: Oregon Department of Geology and Mineral Industries Bulletin 64, p. 77-79.

_____ 1970, Cenozoic ash-flow tuffs of Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 32, no. 6, p. 97-115.

_____ 1974, Some implications of late Cenozoic volcanism to geothermal potential in the High Lava Plains of south-central Oregon: U.S. Geological Survey Open-File Report 74-121, 14 p.

_____ 1977, Geologic map of Oregon east of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Series Map I-902 (prepared in cooperation with the Oregon Department of Geology and Mineral Industries), scale 1:500,000, 2 sheets.

_____ 1979, Revisions to the Cenozoic stratigraphy of Harney Basin, southeastern Oregon: U.S. Geological Survey Bulletin 1475, 35 p.

Walker, G.W., Dalrymple, G.B., and Lanphere, M.A., 1974, Index to potassium-argon ages of Cenozoic volcanic rocks of Oregon: U.S. Geological Survey Misc. Field Studies Map MF-569.

Walker, G.W., and Repenning, C.A., 1965, Reconnaissance geologic map of the Adel quadrangle, Lake, Harney, and Malheur Counties, Oregon: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-446, scale 1:250,000.

Walker, G.W., and Swanson, D.A., 1968a, Laminar flowage in a Pliocene soda rhyolite ash-flow tuff, Lake and Harney Counties, Oregon, in Geological Survey research 1968: U.S. Geological Survey Professional Paper 600-B, p. B37-B47.

_____ 1968b, Summary report on the geology and mineral resources of the Harney Lake and Malheur Lake areas of the National Wildlife Refuge, north-central Harney County, Oregon: U.S. Geological Survey Bulletin 1260-L, 17 p.

Waring, G.A., 1908, Geology and water resources of a portion of south-central Oregon: U.S. Geological Survey Water-Supply Paper 220, 86 p.

_____ 1909, Geology and water resources of the Harney Basin region, Oregon: U.S. Geological Survey Water-Supply Paper 231, 93 p.

_____ 1965 (revised by Blankenship, R.R., and Bentall, R.), Thermal springs of the United States and other countries of the world--a summary: U.S. Geological Survey Professional Paper 492, 383 p.

Washburne, C.W., 1911, Gas prospects in Harney Valley, Oregon: U.S. Geological Survey Bulletin 431, pt. 2, p. 56-57.

APPENDIX A

Formulas used in calculations

Na:K (revised):

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

Na:K:Ca:

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

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

References cited:

Fournier, R.O., 1979, A revised equation for the Na/K geothermometer, in Geothermal Resources Council Transactions 3, 1979, p. 221-224.

Fournier, R.O., and Potter, R.W., II, 1979, Magnesium correction to the Na:K:Ca chemical geothermometer: Geochimica et Cosmochimica Acta, v. 43, p. 1543-1550.

Fournier, R.O., and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: American Journal of Science, v. 264, p. 685-697.

Fournier, R.O., and Truesdell, A.H., 1973, An empirical Na:K:Ca geothermometer for natural waters: Geochimica et Cosmochimica Acta, v. 37, p. 1255-1275.

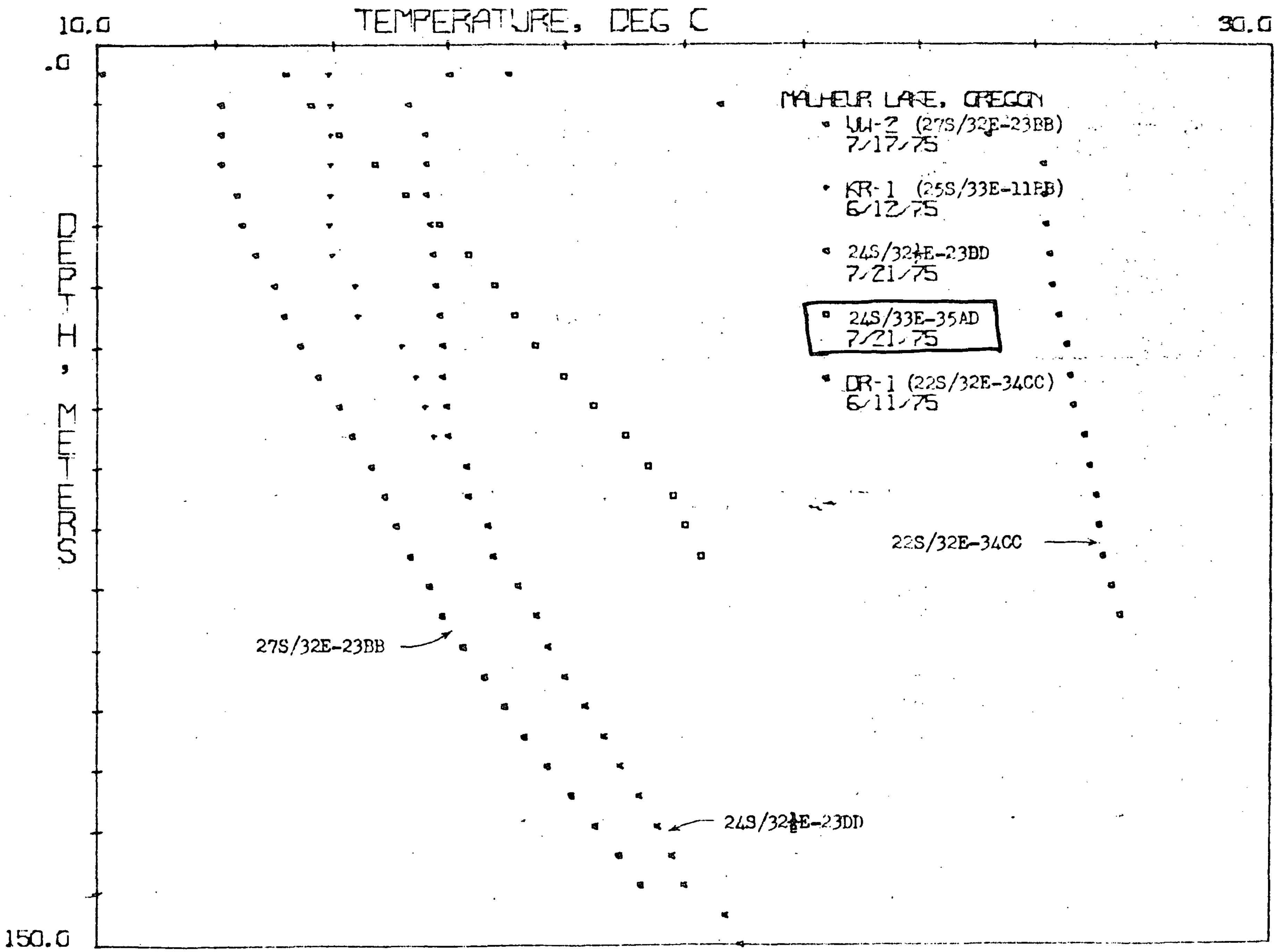
Mariner, R.H., Swanson, J.R., Orris, G.J., Presser, T.S., and Evans, W.C., 1980, Chemical and isotopic data for water from thermal springs and wells of Oregon: U.S. Geological Survey Open-File Report 80-737, 50 p.

APPENDIX B

Geothermal-gradient data

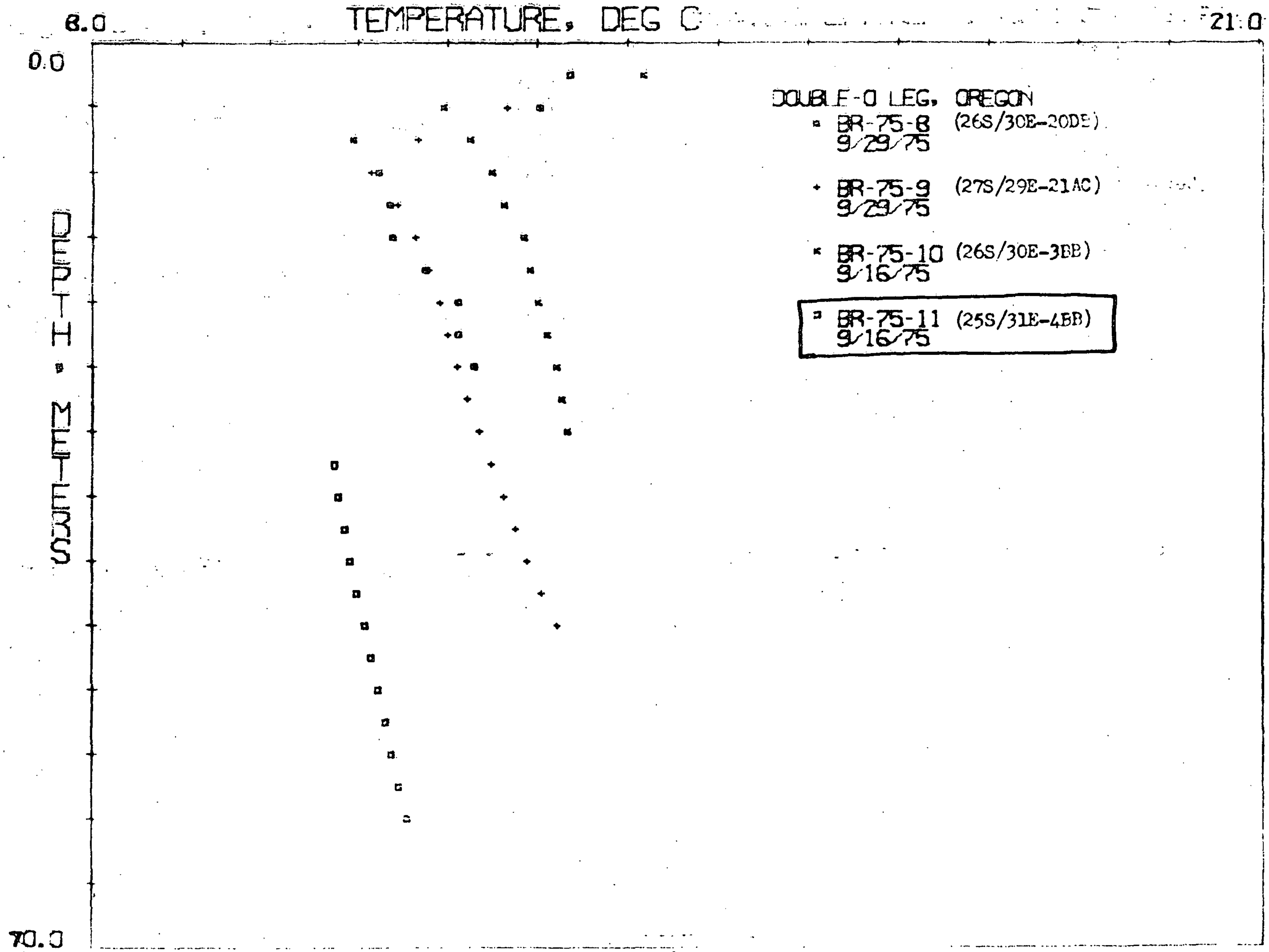
LOCATION: CRANE, OREGON
24S/33E-35AD
HOLE NUMBER:
DATE MEASURED: 7/21/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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


10.0
TEMPERATURE, DEG C
30.0
.0
DEPTH, METERS
150.0
MALHEUR LAKE, OREGON
WW-2 (27S/32E-23BB) 7/17/75
KR-1 (25S/33E-11BB) 6/12/75
24S/32½E-23DD 7/21/75
24S/33E-35AD 7/21/75
DR-1 (22S/32E-34CC) 6/11/75
22S/32E-34CC
27S/32E-23BB
24S/32½E-23DD

LOCATION: DOUBLE-O LEG, OREGON
25S/31E-4BB
HOLE NUMBER: BR-75-11
DATE MEASURED: 9/16/75

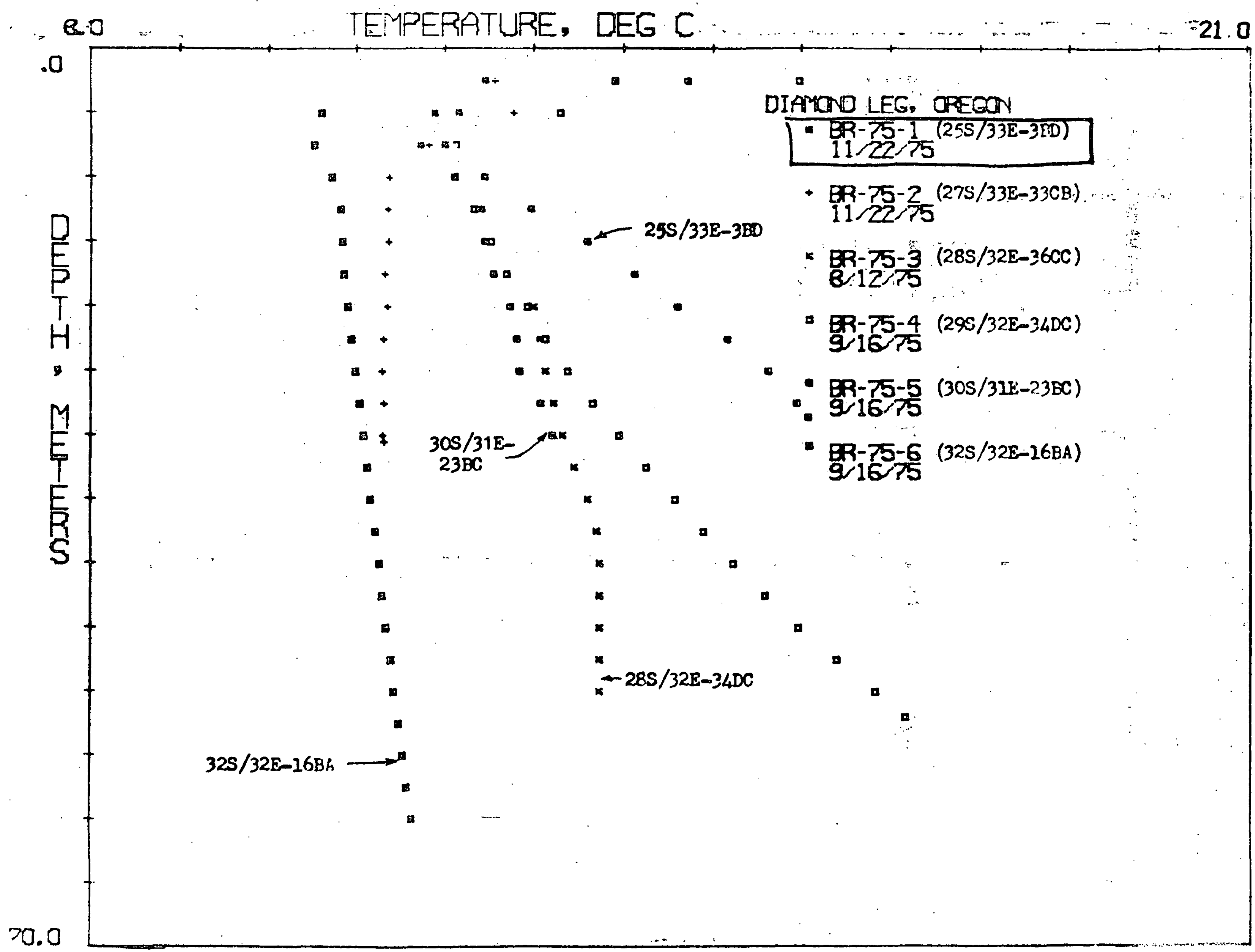
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	13.340	56.01	.0	.0
5.0	16.4	10.510	50.92	-1132.0	-62.1
7.5	24.6	10.240	50.43	-108.0	-5.9
10.0	32.8	10.460	50.83	88.0	4.8
12.5	41.0	10.480	50.86	8.0	.4
15.0	49.2	10.490	50.88	4.0	.2
17.5	57.4	10.490	50.88	.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
8.0
21.0
0.0
70.0
DEPTH, METERS
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DE)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

LOCATION: DIAMOND LEG, OREGON
25S/33E-3BD
HOLE NUMBER: OR-75-1
DATE MEASURED: 11/22/75

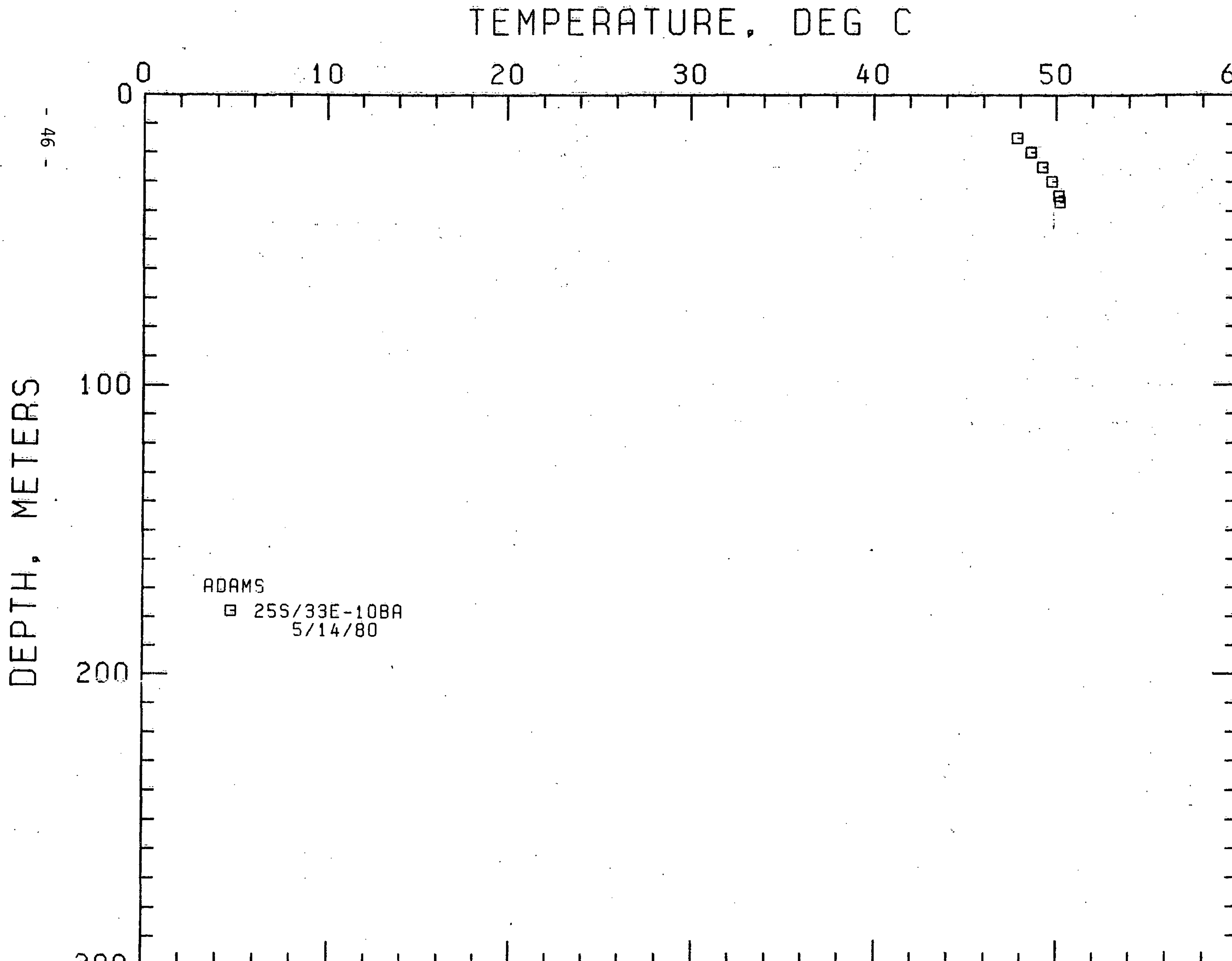
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.450	54.41	.0	.0
5.0	16.4	12.150	53.87	-120.0	-6.6
7.5	24.6	11.980	53.56	-68.0	-3.7
10.0	32.8	12.430	54.37	180.0	9.9
12.5	41.0	12.950	55.31	208.0	11.4
15.0	49.2	13.580	56.44	252.0	13.8
17.5	57.4	14.090	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



8.0
TEMPERATURE, DEG C
21.0
.0
DEPTH, METERS
70.0
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

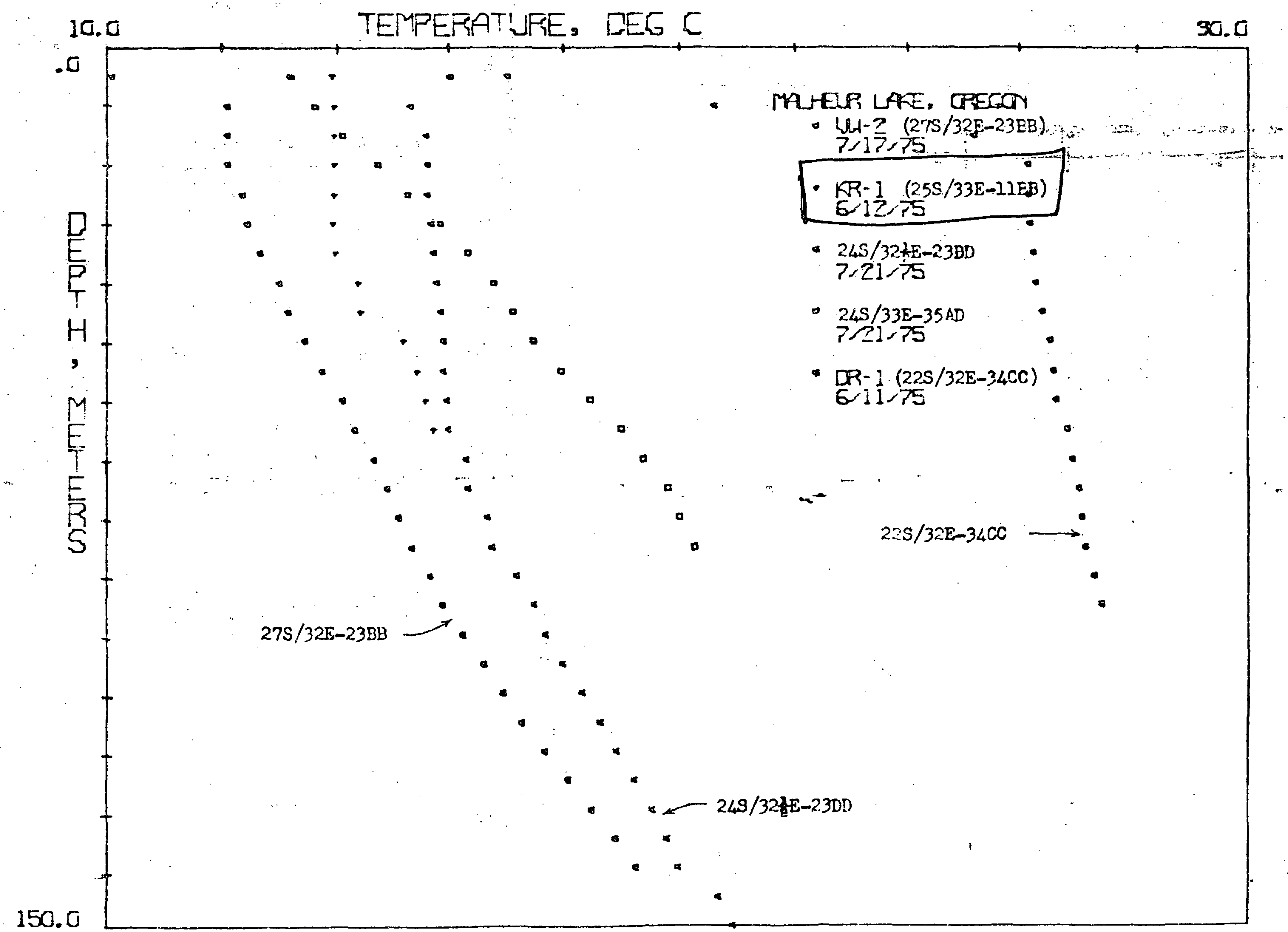
LOCATION: BURNS AMS, OREGON
25S/33E-10BA
HOLE NAME: ADAMS
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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


TEMPERATURE, DEG C
0
10
20
30
40
50
60
DEPTH, METERS
0
100
200
300
ADAMS
25S/33E-10BA
5/14/80

LOCATION: CRANE, OREGON
25S/33E-11BBB
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	14.390	57.90	80.0	4.4
45.0	147.6	14.440	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



10.0
TEMPERATURE, DEG C
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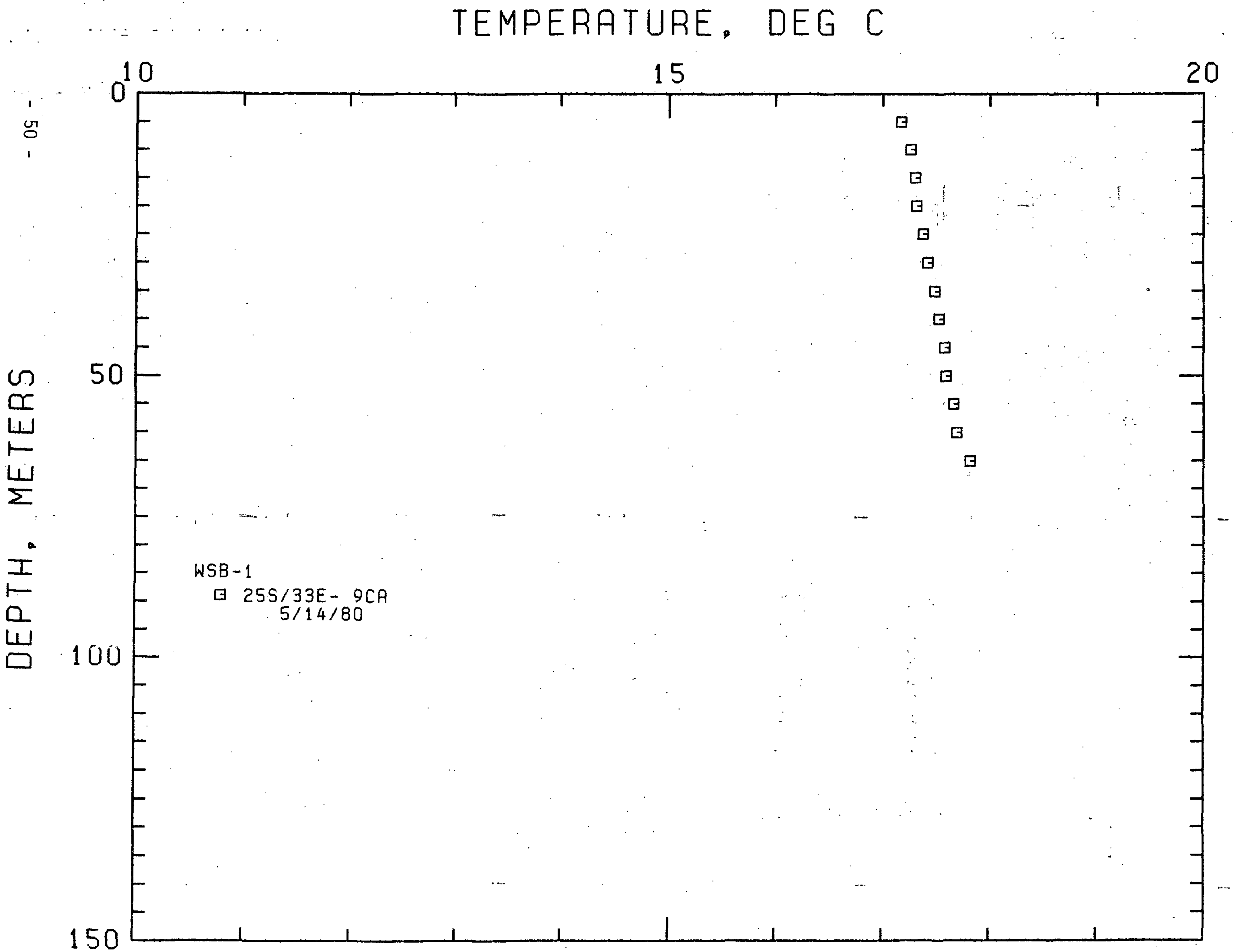
DEPTH, METERS
150.0
MALHEUR LAKE, OREGON
UW-2 (27S/32E-23BB)
7/17/75
KR-1 (25S/33E-11BB)
6/12/75
24S/32½E-23DD
7/21/75
24S/33E-35AD
7/21/75
DR-1 (22S/32E-34CC)
6/11/75
22S/32E-34CC
27S/32E-23BB
24S/32½E-23DD

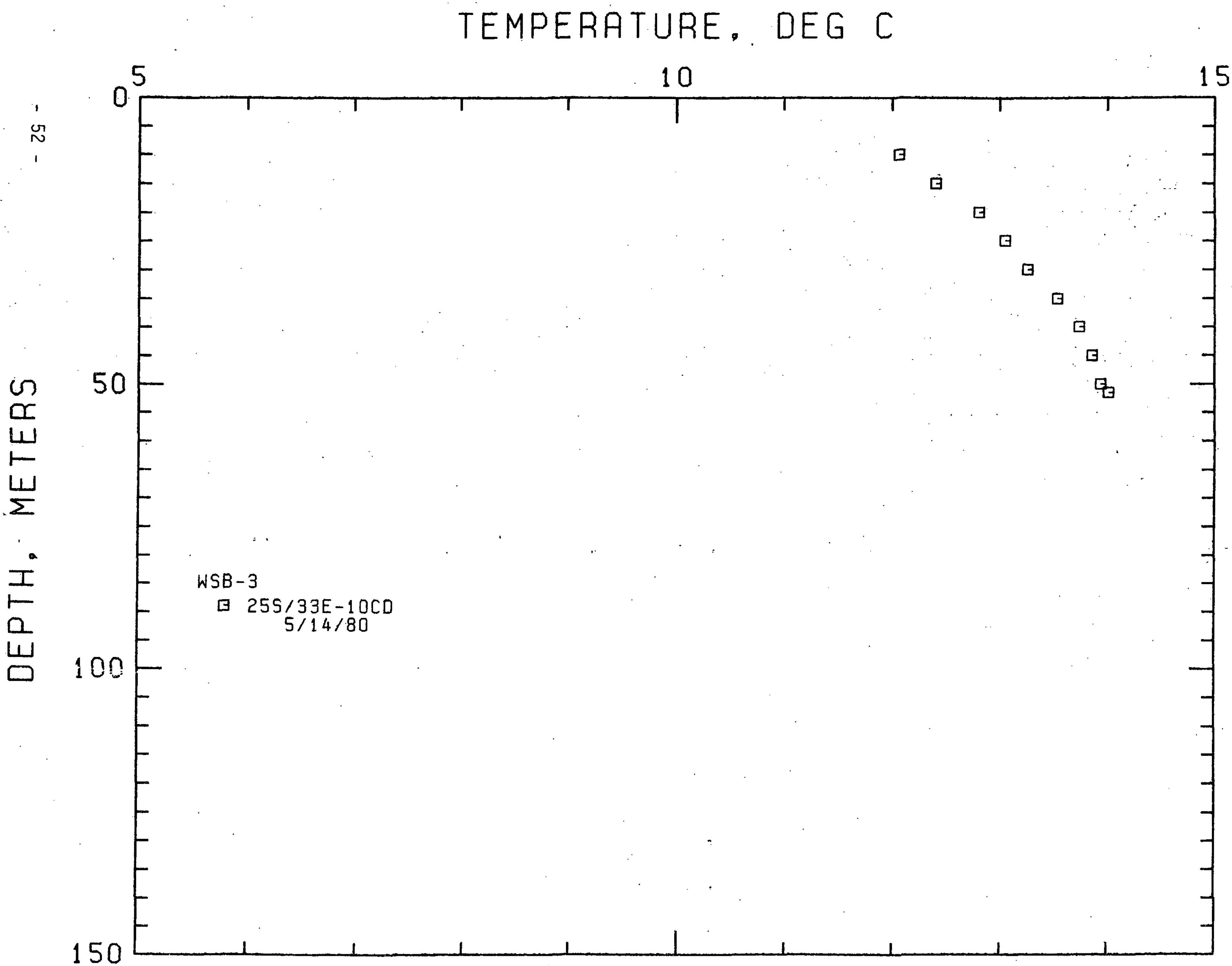
LOCATION: BURNS AMS, OREGON
25S/33E- 9CA
HOLE NAME: WSB-1
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	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	63.68	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
10
15
20
0
50
100
150
DEPTH, METERS
WSB-1
25S/33E- 9CA
5/14/80

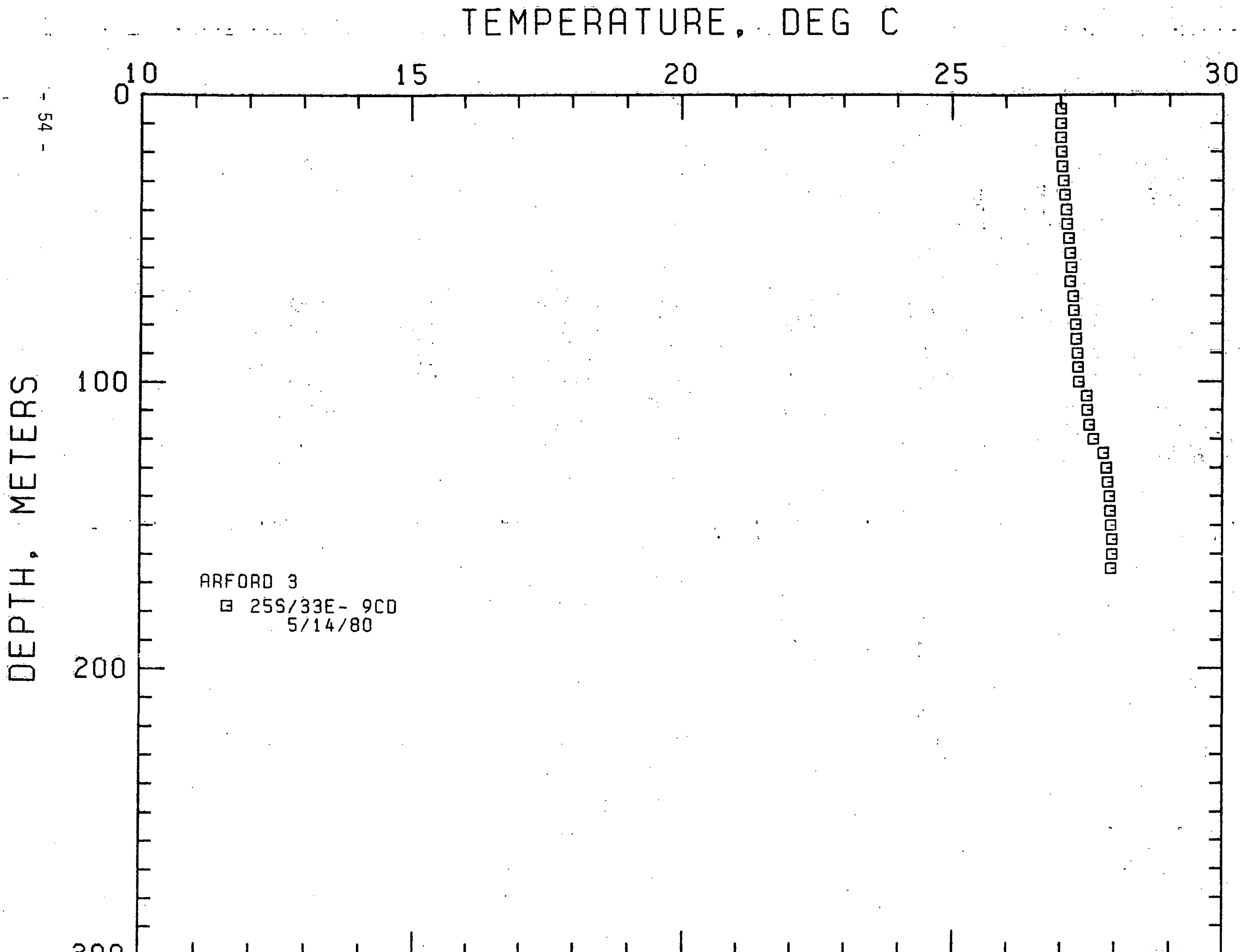
LOCATION: BURNS AMS, OREGON
25S/33E-10CD
HOLE NAME: WSB-3
DATE MEASURED: 5/14/80

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	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
5
10
15
0
50
100
150
DEPTH, METERS
WSB-3
25S/33E-10CD
5/14/80

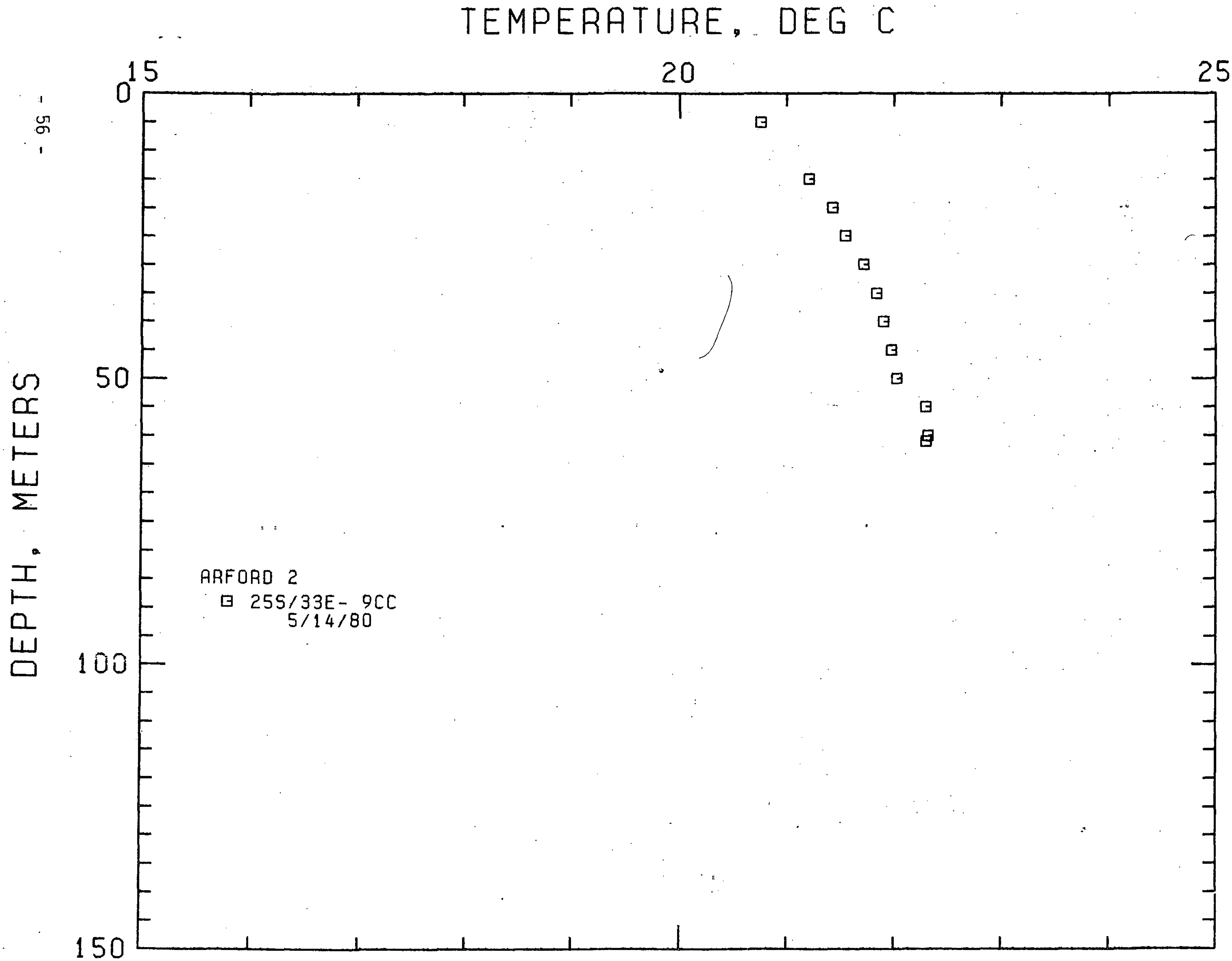
LOCATION: BURNS AMS, OREGON
25S/33E- 9CD
HOLE NAME: ARFORD 3
DATE MEASURED: 5/14/80

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	2.0	0.1
25.0	82.0	27.040	80.67	2.0	0.1
30.0	98.4	27.060	80.71	4.0	0.2
35.0	114.8	27.090	80.76	6.0	0.3
40.0	131.2	27.120	80.82	6.0	0.3
45.0	147.6	27.130	80.83	2.0	0.1
50.0	164.0	27.160	80.89	6.0	0.3
55.0	180.4	27.190	80.94	6.0	0.3
60.0	196.8	27.210	80.98	4.0	0.2
65.0	213.2	27.190	80.94	-4.0	-0.2
70.0	229.6	27.250	81.05	12.0	0.7
75.0	246.0	27.260	81.07	2.0	0.1
80.0	262.4	27.290	81.12	6.0	0.3
85.0	278.8	27.300	81.14	2.0	0.1
90.0	295.2	27.330	81.19	6.0	0.3
95.0	311.6	27.340	81.21	2.0	0.1
100.0	328.0	27.350	81.23	2.0	0.1
105.0	344.4	27.500	81.50	30.0	1.6
110.0	360.8	27.510	81.52	2.0	0.1
115.0	377.2	27.540	81.57	6.0	0.3
120.0	393.6	27.620	81.72	16.0	0.9
125.0	410.0	27.800	82.04	36.0	2.0
130.0	426.4	27.860	82.15	12.0	0.7
135.0	442.8	27.890	82.20	6.0	0.3
140.0	459.2	27.920	82.26	6.0	0.3
145.0	475.6	27.930	82.27	2.0	0.1
150.0	492.0	27.940	82.29	2.0	0.1
155.0	508.4	27.970	82.35	6.0	0.3
160.0	524.8	27.960	82.33	-2.0	-0.1
165.0	541.2	27.940	82.29	-4.0	-0.2


TEMPERATURE, DEG C
10
15
20
25
30
0
100
200
300
DEPTH, METERS
ARFORD 3
25S/33E- 9CD
5/14/80

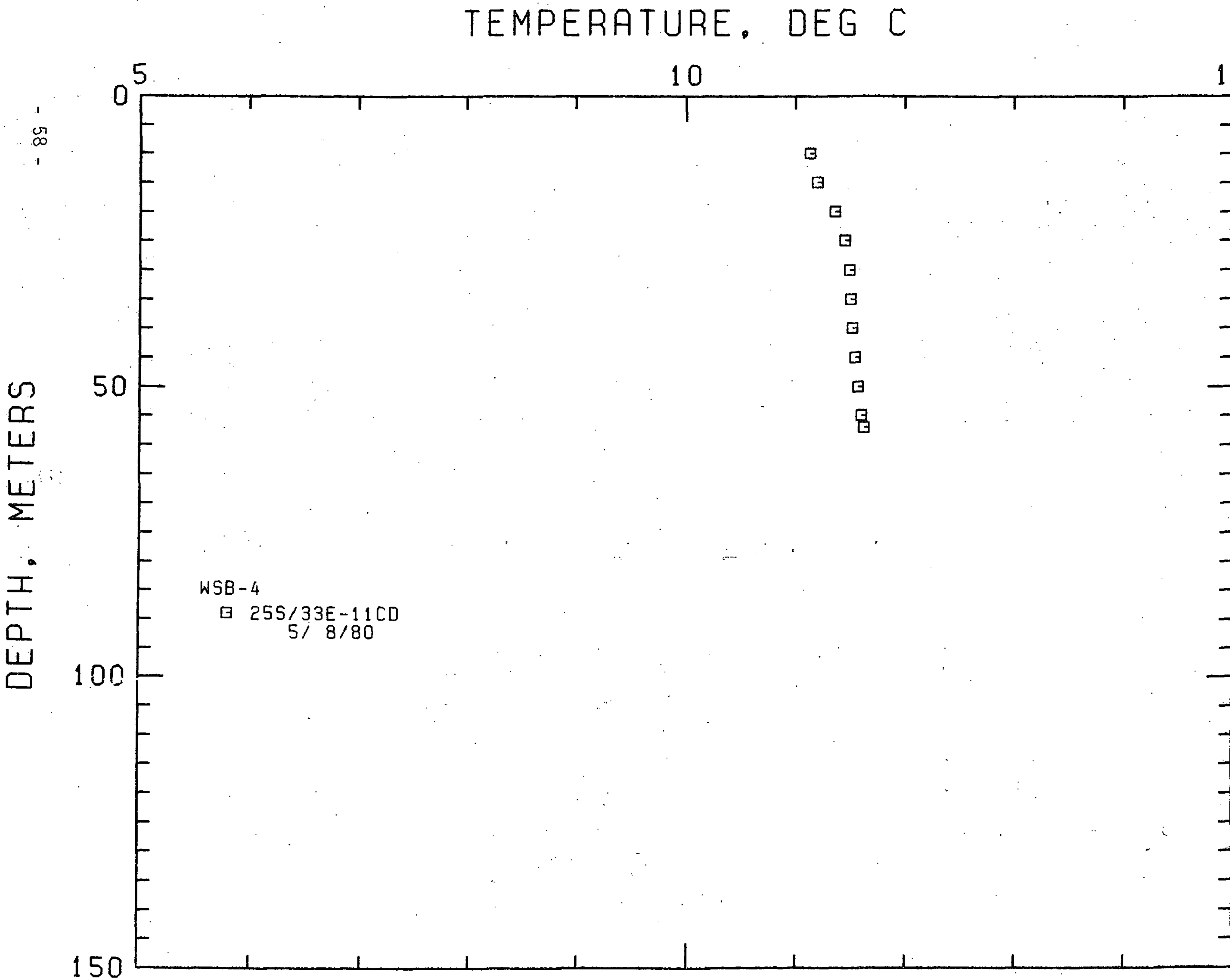
LOCATION: BURNS AMS, OREGON
25S/33E- 9CC
HOLE NAME: ARFORD 2
DATE MEASURED: 5/14/80

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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	0.8
45.0	147.6	21.980	71.56	14.0	0.8
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	0.2
61.0	200.1	22.300	72.14	-20.0	-1.1


TEMPERATURE, DEG C
15
20
25
0
50
100
150
DEPTH, METERS
ARFORD 2
25S/33E- 9CC
5/14/80

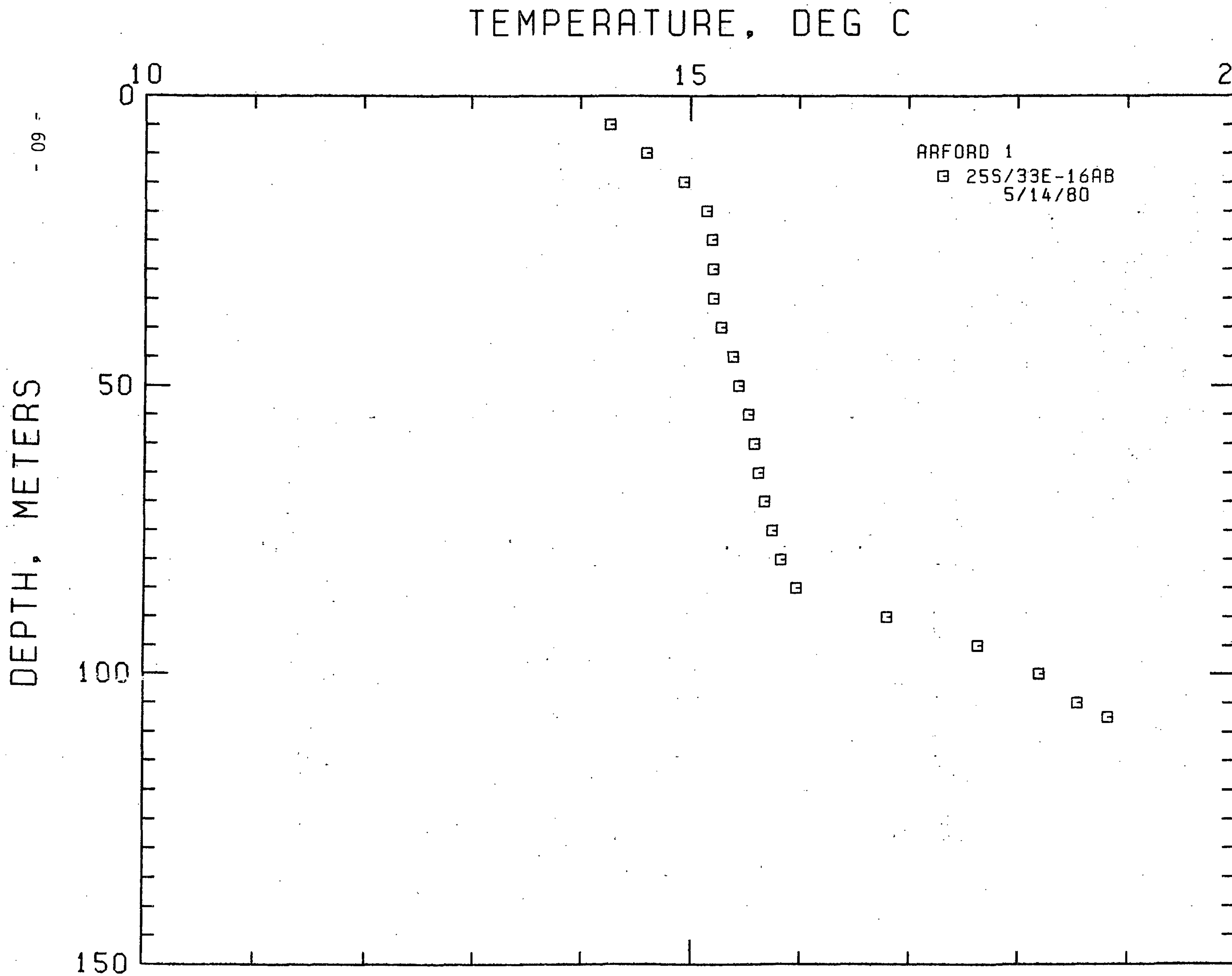
LOCATION: BURNS AMS, OREGON
25S/33E-11CD
HOLE NAME: WSB-4
DATE MEASURED: 5/ 8/80

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	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	1.8
25.0	82.0	11.450	52.61	18.0	1.0
30.0	98.4	11.490	52.68	8.0	0.4
35.0	114.8	11.500	52.70	2.0	0.1
40.0	131.2	11.520	52.74	4.0	0.2
45.0	147.6	11.540	52.77	4.0	0.2
50.0	164.0	11.570	52.83	6.0	0.3
55.0	180.4	11.600	52.88	6.0	0.3
57.0	187.0	11.620	52.92	10.0	0.5


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
WSB-4
25S/33E-11CD
5/ 8/80

LOCATION: BURNS AMS, OREGON
25S/33E-16AB
HOLE NAME: ARFORD 1
DATE MEASURED: 5/14/80

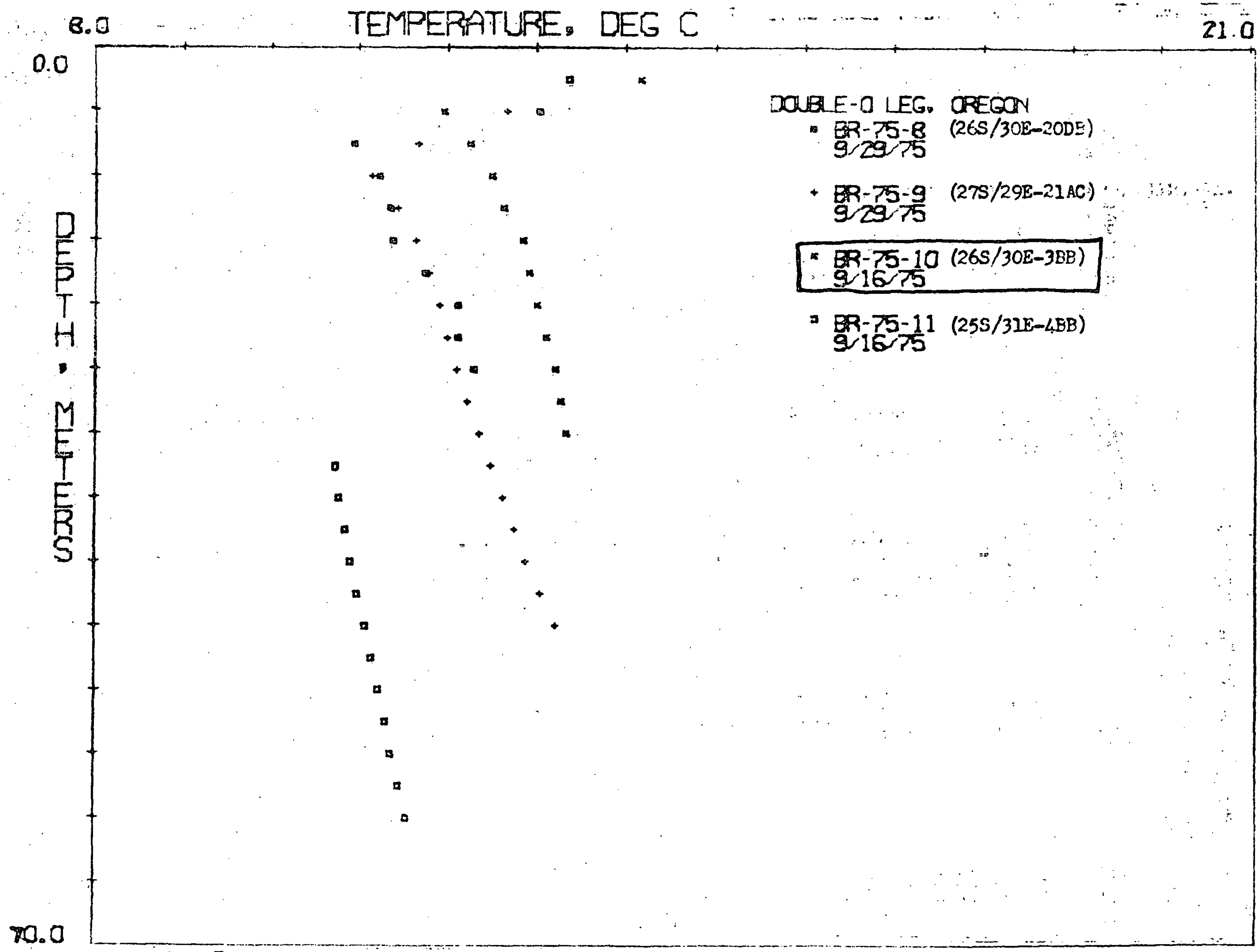
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	14.270	57.69	0.0	0.0
10.0	32.8	14.600	58.28	66.0	3.6
15.0	49.2	14.940	58.89	68.0	3.7
20.0	65.6	15.150	59.27	42.0	2.3
25.0	82.0	15.200	59.36	10.0	0.5
30.0	98.4	15.210	59.38	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	0.8
45.0	147.6	15.390	59.70	22.0	1.2
50.0	164.0	15.440	59.79	10.0	0.5
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	8.0	0.4
70.0	229.6	15.680	60.22	12.0	0.7
75.0	246.0	15.750	60.35	14.0	0.8
80.0	262.4	15.830	60.49	16.0	0.9
85.0	278.8	15.970	60.75	28.0	1.5
90.0	295.2	16.800	62.24	166.0	9.1
95.0	311.6	17.640	63.75	168.0	9.2
100.0	328.0	18.200	64.76	112.0	6.1
105.0	344.4	18.550	65.39	70.0	3.8
107.5	352.6	18.830	65.89	112.0	6.1



TEMPERATURE, DEG C
10
15
20
0
50
100
150
DEPTH, METERS
AAFORD 1
25S/33E-16AB
5/14/80

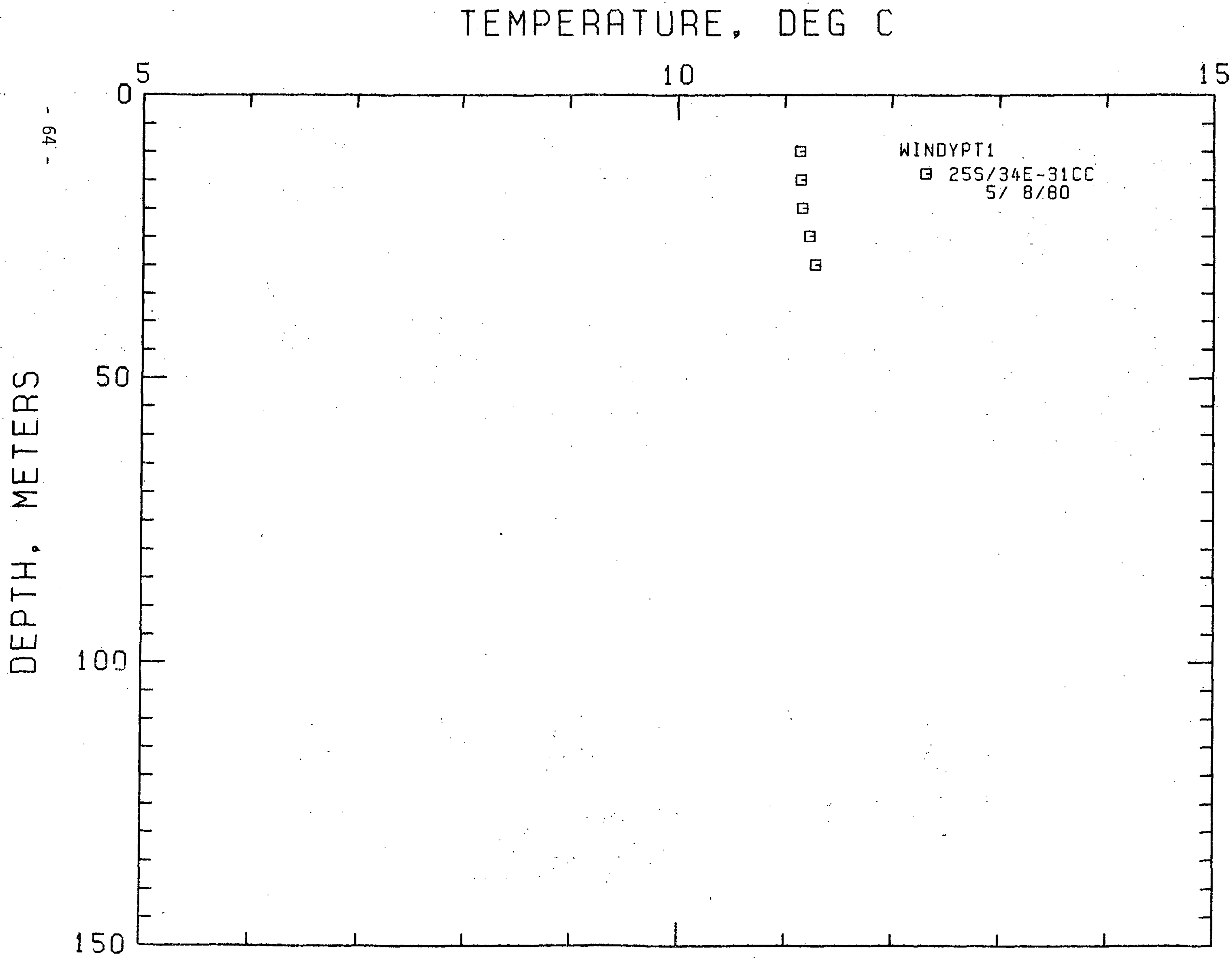
LOCATION: DOUBLE-O LEG, OREGON
26S/30E-3BB
HOLE NUMBER: BR-75-10
DATE MEASURED: 9/16/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
2.5	8.2	14.160	57.49	.0	.0
5.0	16.4	11.940	53.49	-858.0	-48.7
7.5	24.6	12.230	54.01	116.0	6.4
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	12.820	55.08	84.0	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


TEMPERATURE, DEG C
8.0
21.0
0.0
70.0
DEPTH, METERS
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DB)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

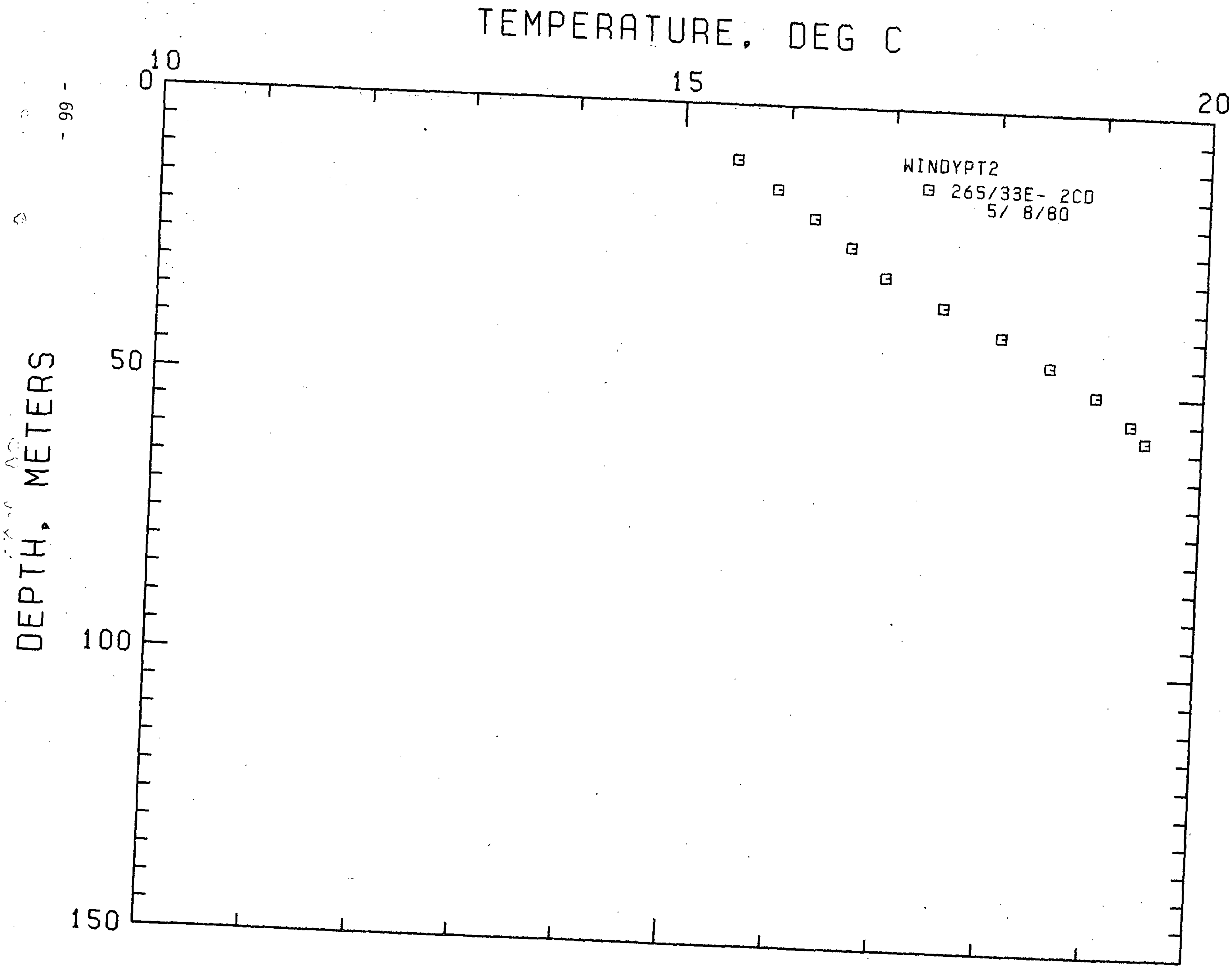
LOCATION: BURNS AMS, OREGON
25S/34E-31CC
HOLE NAME: WINDYPT1
DATE MEASURED: 5/ 8/80

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	11.140	52.05	0.0	0.0
15.0	49.2	11.150	52.07	2.0	0.1
20.0	65.6	11.160	52.09	2.0	0.1
25.0	82.0	11.230	52.21	14.0	0.8
30.0	98.4	11.280	52.30	10.0	0.5


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
WINDYPT1
25S/34E-31CC
5/ 8/80

LOCATION: BURNS AMS, OREGON
26S/33E- 2CD
HOLE NAME: WINDYPT2
DATE MEASURED: 5/ 8/80

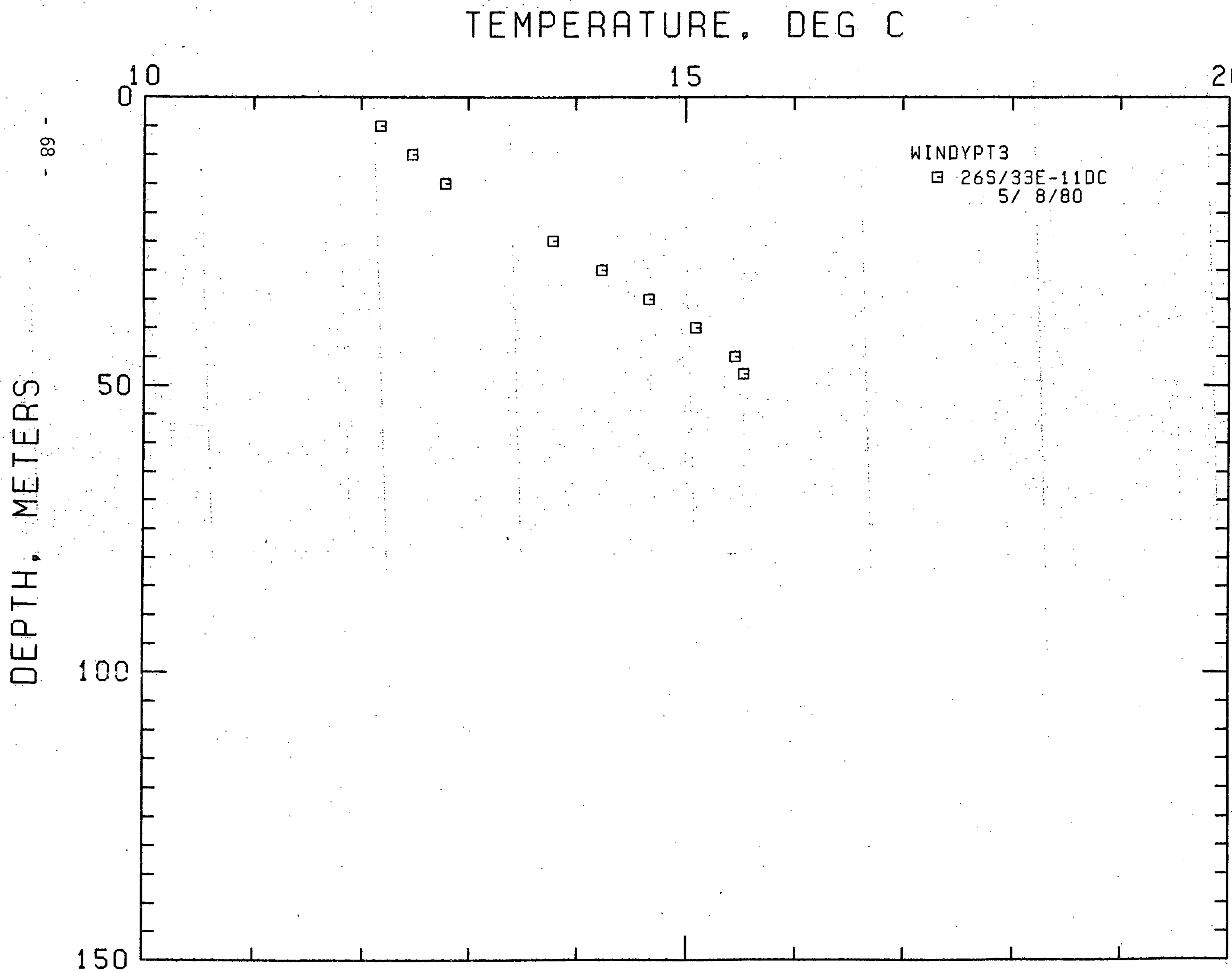
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
10.0	32.8	15.510	59.92	0.0	0.0
15.0	49.2	15.890	60.60	76.0	4.2
20.0	65.6	16.250	61.25	72.0	4.0
25.0	82.0	16.610	61.90	72.0	4.0
30.0	98.4	16.940	62.49	66.0	3.6
35.0	114.8	17.500	63.50	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	5.2
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
10
15
20
0
50
100
150
DEPTH, METERS
WINDYPT2
26S/33E- 2CD
5/ 8/80

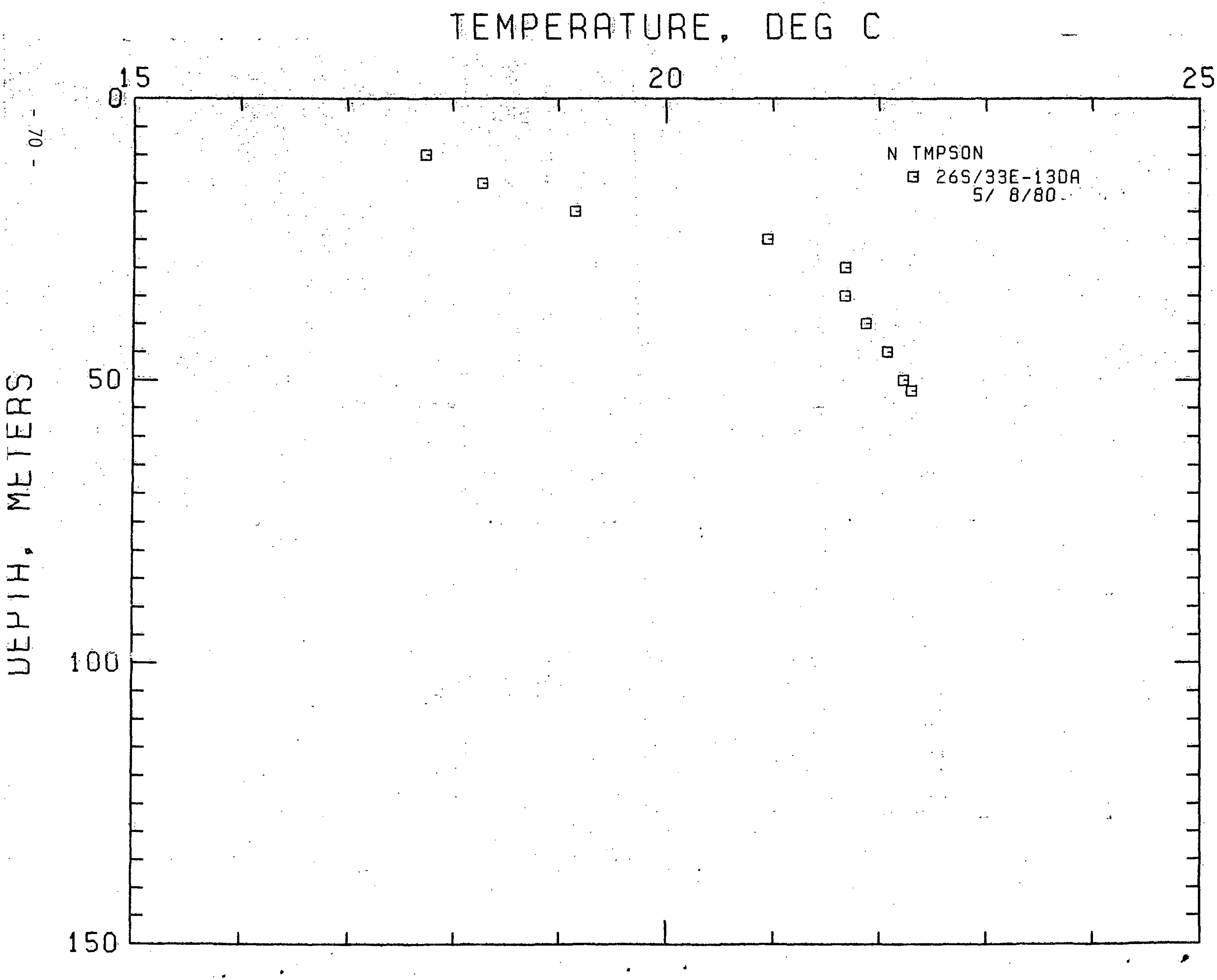
LOCATION: BURNS AMS, OREGON
26S/33E-11DC
HOLE NAME: WINDYPT3
DATE MEASURED: 5/ 8/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	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	5.5
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
10
15
20
DEPTH, METERS
0
50
100
150
WINDYPT3
26S/33E-11DC
5/ 8/80

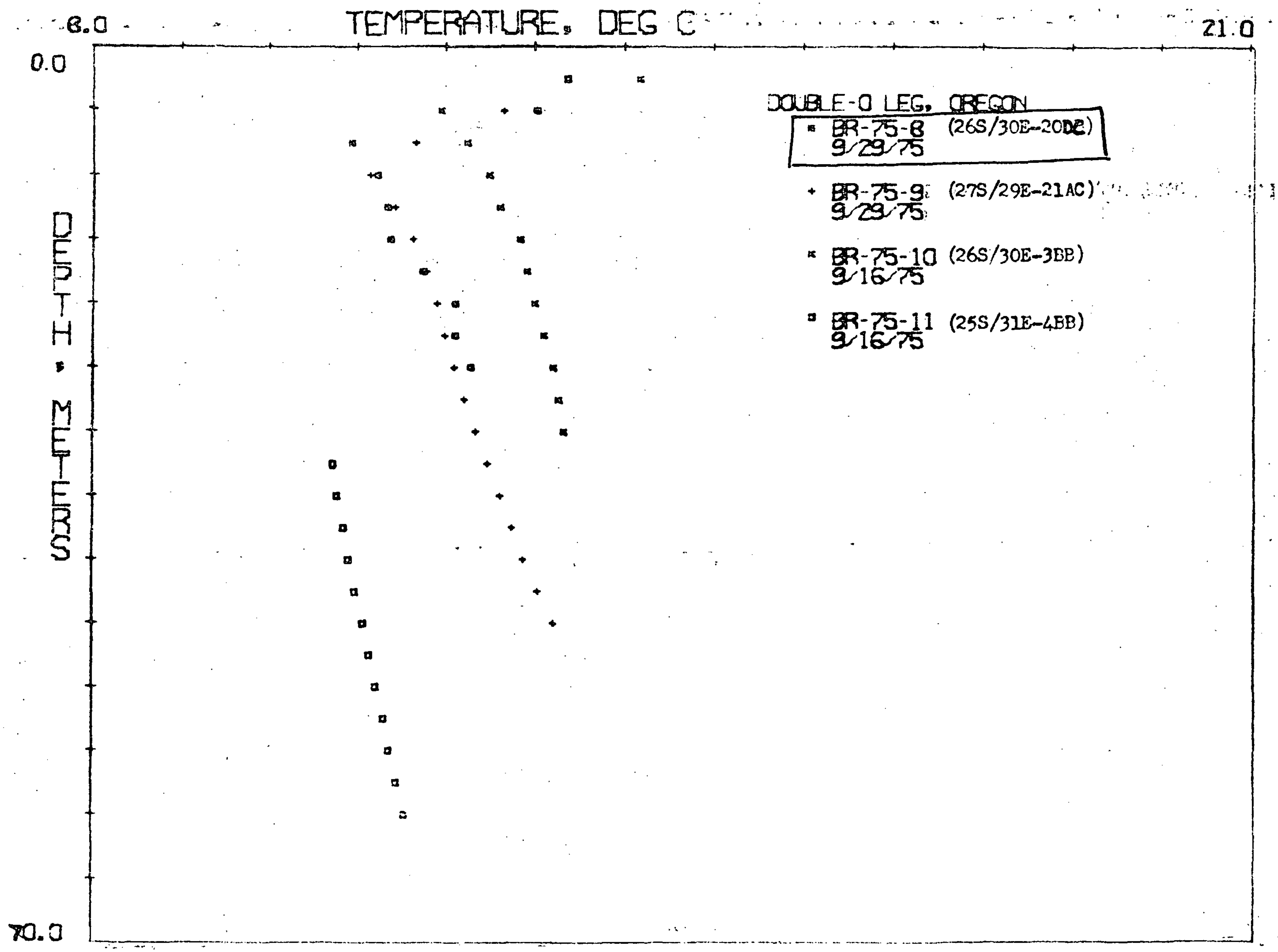
LOCATION: BURNS AMS, OREGON
26S/33E-13DA
HOLE NAME: N TMPSON
DATE MEASURED: 5/ 8/80

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	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	2.2
45.0	147.6	22.080	71.74	40.0	2.2
50.0	164.0	22.230	72.01	30.0	1.6
52.0	170.6	22.310	72.16	40.0	2.2


TEMPERATURE, DEG C
15
20
25
0
50
100
150
DEPTH, METERS
N TMPSON
26S/33E-13DA
5/ 8/80

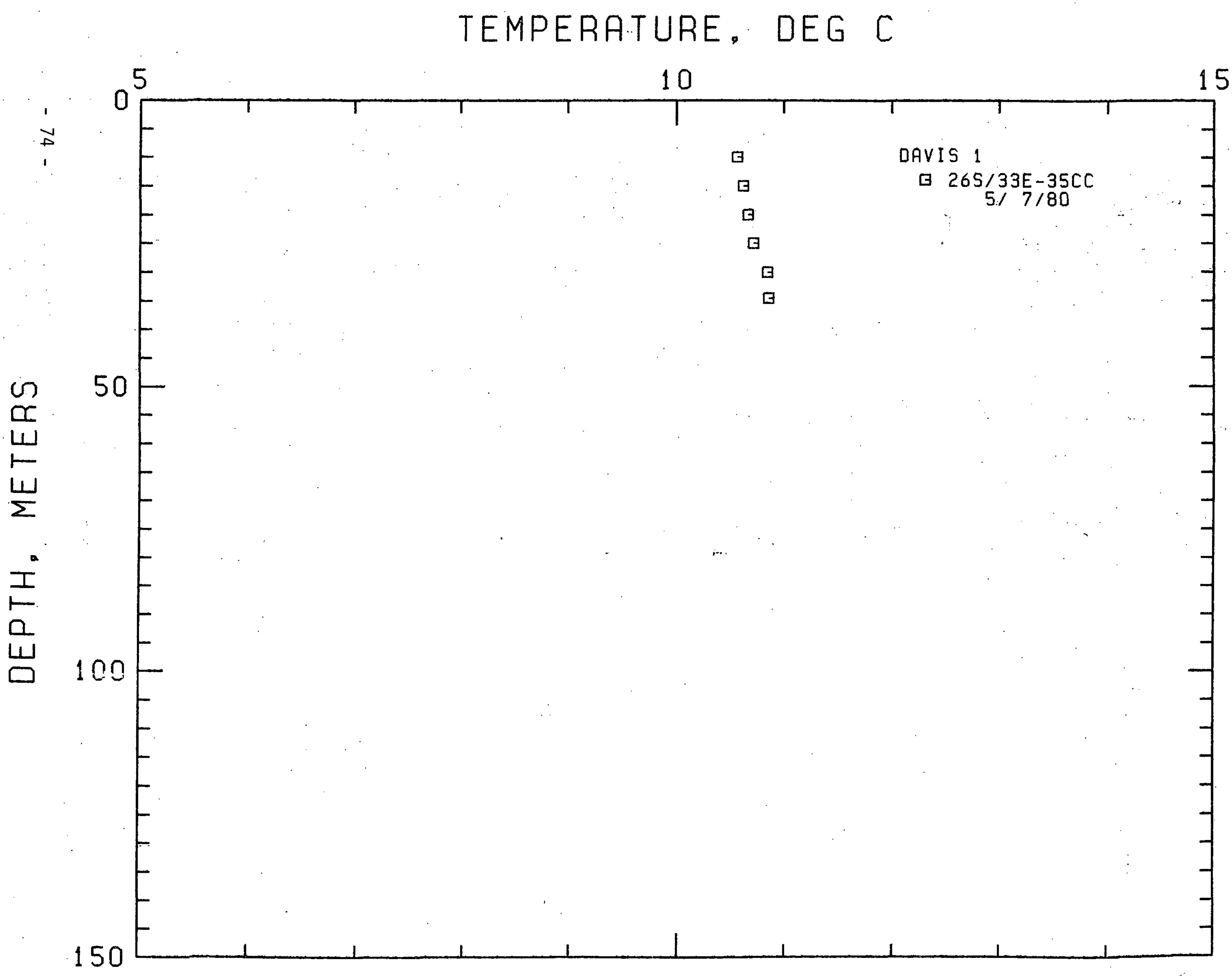
LOCATION: DOUBLE-O LEG, OREGON
26S/30E-20DC
HOLE NUMBER: BR-75-8
DATE MEASURED: 9/29/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
5.0	16.4	13.010	55.42	.0	.0
7.5	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	66.0	3.6


TEMPERATURE, DEG C
8.0
21.0
0.0
70.0
DEPTH, METERS
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DB)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

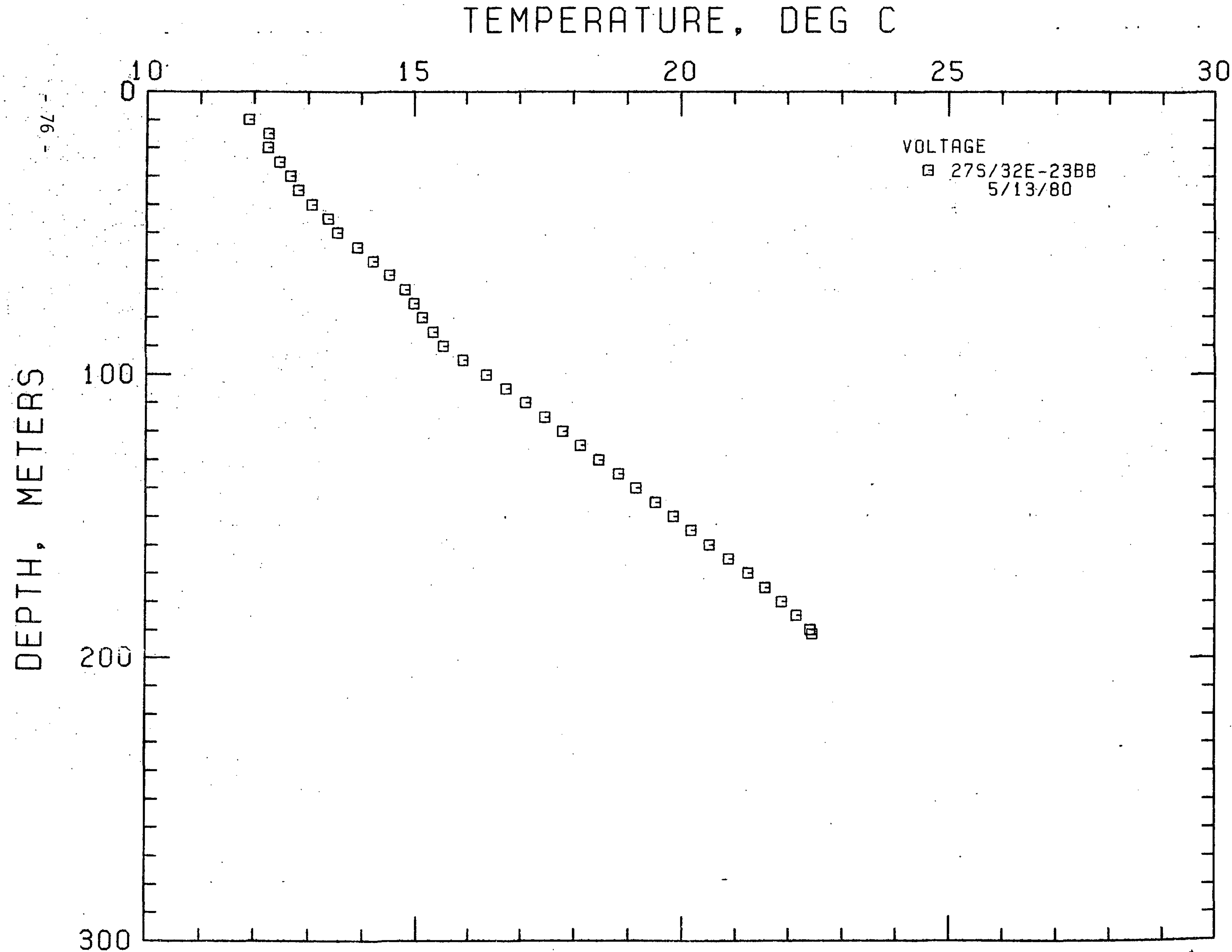
LOCATION: BURNS AMS, OREGON
26S/33E-35CC
HOLE NAME: DAVIS 1
DATE MEASURED: 5/ 7/80

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	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
34.5	113.2	10.860	51.55	2.2	0.1


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
DAVIS 1
26S/33E-35CC
5/ 7/80

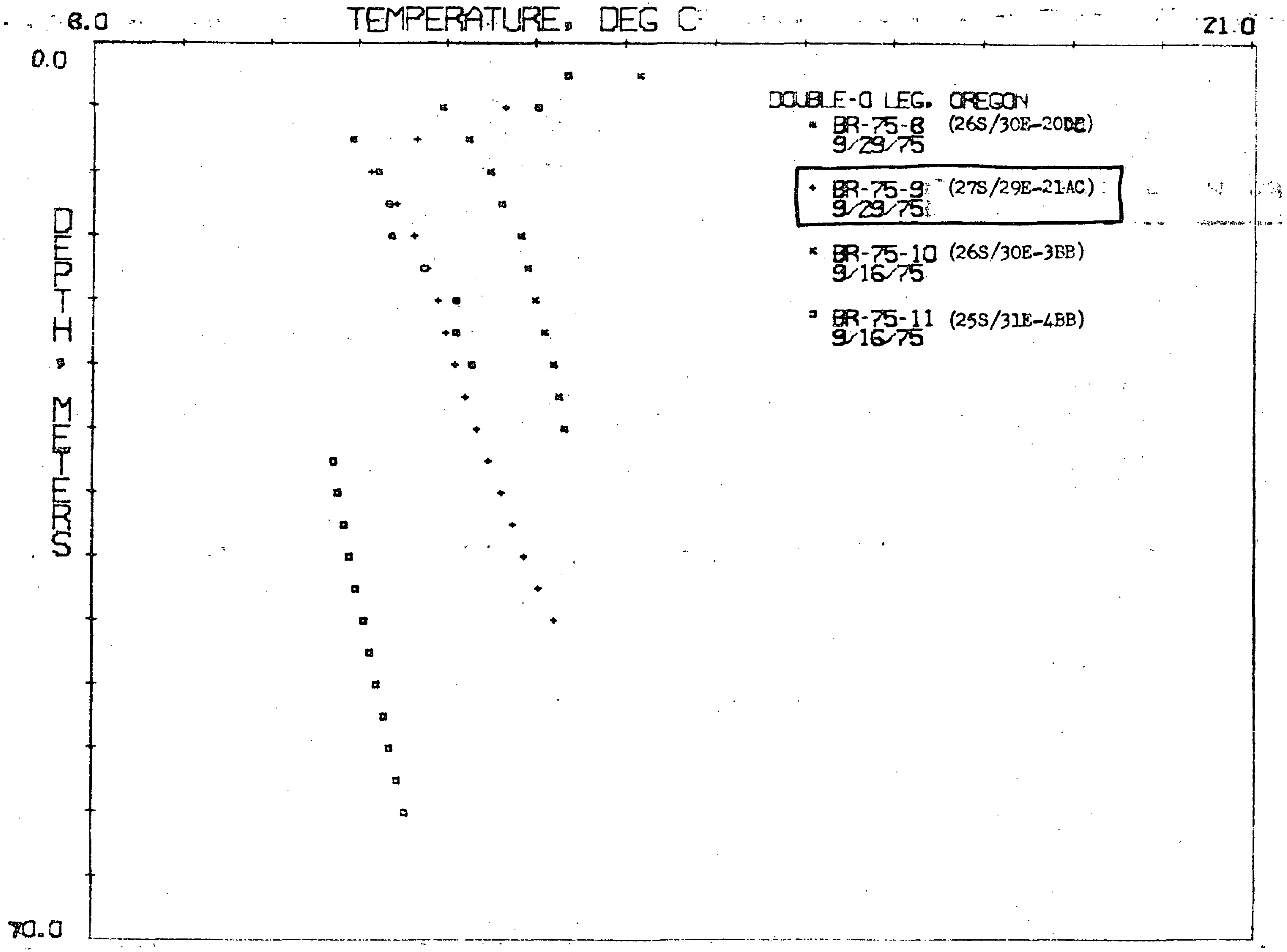
LOCATION: BURNS AMS, OREGON
27S/32E-23BB
HOLE NAME: VOLTAGE
DATE MEASURED: 5/13/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	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	1.5
40.0	131.2	13.090	55.56	52.0	2.9
45.0	147.6	13.380	56.08	58.0	3.2
50.0	164.0	13.550	56.39	34.0	1.9
55.0	180.4	13.930	57.07	76.0	4.2
60.0	196.8	14.230	57.61	60.0	3.3
65.0	213.2	14.540	58.17	62.0	3.4
70.0	229.6	14.830	58.69	58.0	3.2
75.0	246.0	15.000	59.00	34.0	1.9
80.0	262.4	15.170	59.31	34.0	1.9
85.0	278.8	15.370	59.67	40.0	2.2
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	3.7
135.0	442.8	18.850	65.93	74.0	4.1
140.0	459.2	19.170	66.51	64.0	3.5
145.0	475.6	19.520	67.14	70.0	3.8
150.0	492.0	19.850	67.73	66.0	3.6
155.0	508.4	20.180	68.32	66.0	3.6
160.0	524.8	20.530	68.95	70.0	3.8
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	21.880	71.38	60.0	3.3
185.0	606.8	22.160	71.89	56.0	3.1
190.0	623.2	22.420	72.36	52.0	2.9
191.5	628.1	22.460	72.43	26.7	1.5


TEMPERATURE, DEG C
10
15
20
25
30
0
100
200
300
DEPTH, METERS
VOLTAGE
27S/32E-23BB
5/13/80

LOCATION: DOUBLE-O LEG, OREGON
27S/29E-21AC
HOLE NUMBER: BR-75-9
DATE MEASURED: 9/29/75

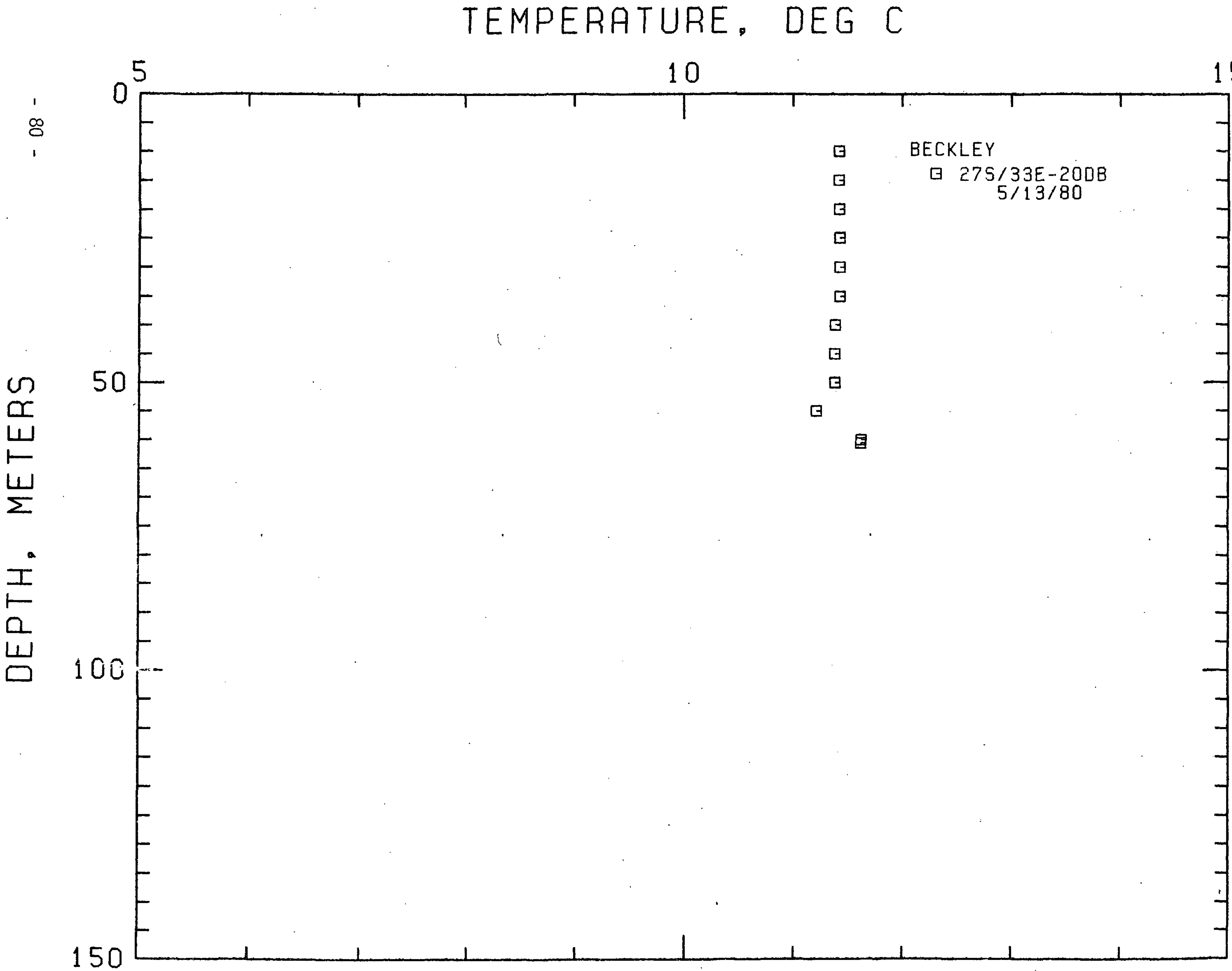
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
5.0	16.4	12.650	54.77	.0	.0
7.5	24.6	11.650	52.97	-400.0	-22.0
10.0	32.8	11.140	52.05	-204.0	-11.2
12.5	41.0	11.420	52.56	112.0	6.1
15.0	49.2	11.630	52.93	84.0	4.6
17.5	57.4	11.770	53.19	56.0	3.1
20.0	65.6	11.880	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	12.325	54.18	52.0	2.9
32.5	106.6	12.450	54.41	50.0	2.7
35.0	114.8	12.600	54.68	60.0	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	60.0	3.3
45.0	147.6	13.180	55.72	68.0	3.7



TEMPERATURE, DEG C
8.0
21.0
0.0
70.0
DEPTH, METERS
DOUBLE-O LEG, OREGON
BR-75-8 (26S/30E-20DE)
9/29/75
BR-75-9 (27S/29E-21AC)
9/29/75
BR-75-10 (26S/30E-3BB)
9/16/75
BR-75-11 (25S/31E-4BB)
9/16/75

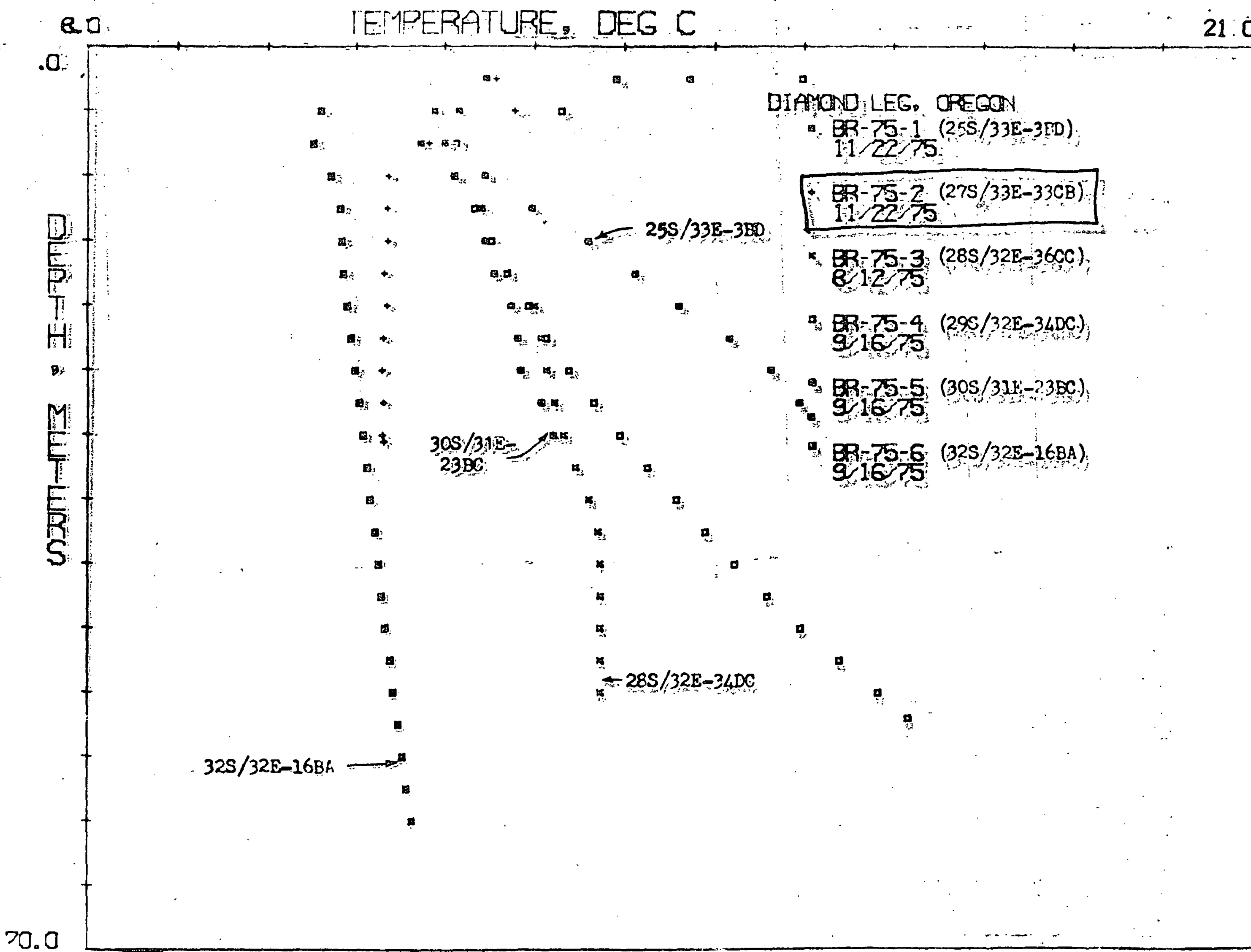
LOCATION: BURNS AMS, OREGON
27S/33E-20DB
HOLE NAME: BECKLEY
DATE MEASURED: 5/13/80

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	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	2.0	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	-8.0	-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
50.0	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


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
BECKLEY
27S/33E-20DB
5/13/80

LOCATION: DIAMOND LEG, OREGON
27S/33E-33CB
HOLE NUMBER: BR-75-2
DATE MEASURED: 11/22/75

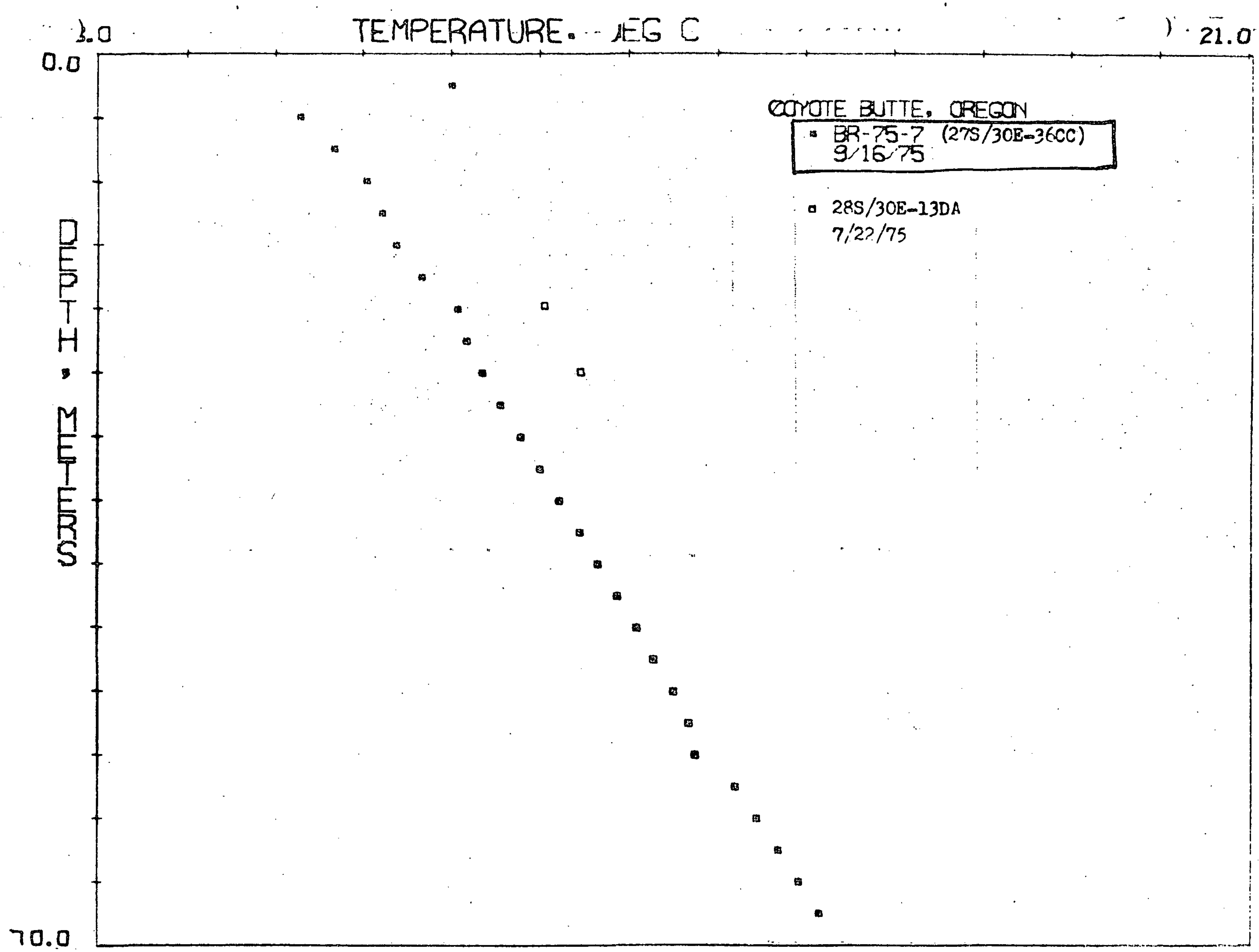
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.570	54.63	.0	.0
5.0	16.4	12.760	54.97	76.0	4.2
7.5	24.6	11.810	53.26	-380.0	-20.9
10.0	32.8	11.360	52.45	-180.0	-9.9
12.5	41.0	11.350	52.43	-4.0	-.2
15.0	49.2	11.350	52.43	.0	.0
17.5	57.4	11.310	52.36	-16.0	-.9
20.0	65.6	11.330	52.39	8.0	.4
22.5	73.8	11.290	52.32	-16.0	-.9
25.0	82.0	11.280	52.30	-4.0	-.2
27.5	90.2	11.290	52.32	4.0	.2
30.0	98.4	11.280	52.30	-4.0	-.2
30.5	100.0	11.290	52.32	20.0	1.1



TEMPERATURE, DEG C
8.0
21.0
.0
70.0
DEPTH, METERS
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

LOCATION: COYOTE BUTTE, OREGON
27S/30E-36CC
HOLE NUMBER: BR-75-7
DATE MEASURED: 9/16/75

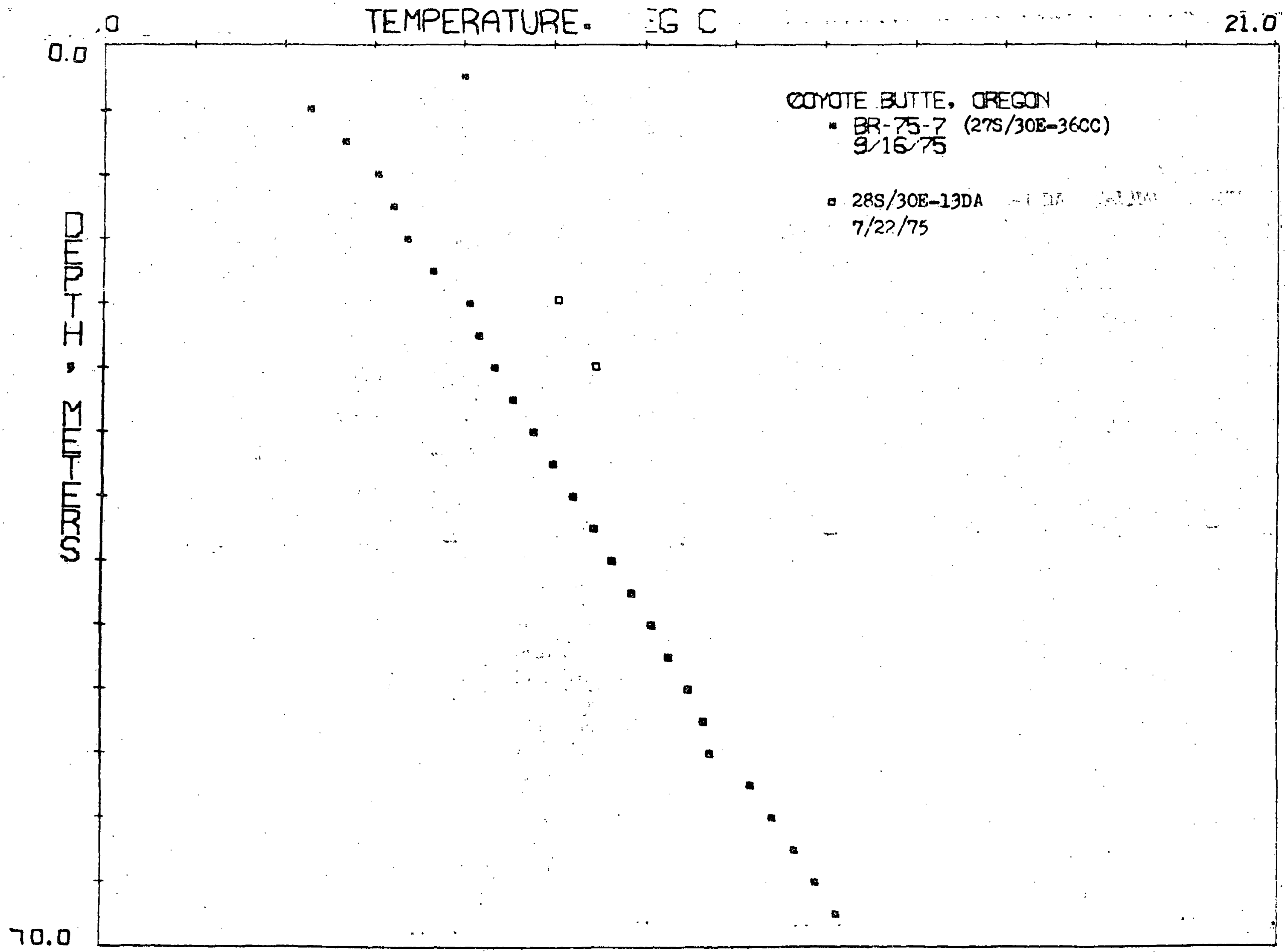
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	DEG F/100 FT
2.5	8.2	12.000	53.60	.0	.0
5.0	16.4	10.280	50.50	-688.0	-37.8
7.5	24.6	10.670	51.21	156.0	8.6
10.0	32.8	11.040	51.87	148.0	8.1
12.5	41.0	11.200	52.16	64.0	3.5
15.0	49.2	11.360	52.45	64.0	3.5
17.5	57.4	11.650	52.97	116.0	6.4
20.0	65.6	12.060	53.71	164.0	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



TEMPERATURE, DEG C
21.0
0.0
70.0
DEPTH, METERS
COYOTE BUTTE, OREGON
BR-75-7 (27S/30E-36CC)
9/16/75
28S/30E-13DA
7/22/75

LOCATION: COYOTE BUTTES, OREGON
28S/30E-13DA
HOLE NUMBER: HP-12
DATE MEASURED: 7/22/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT 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, DEG C
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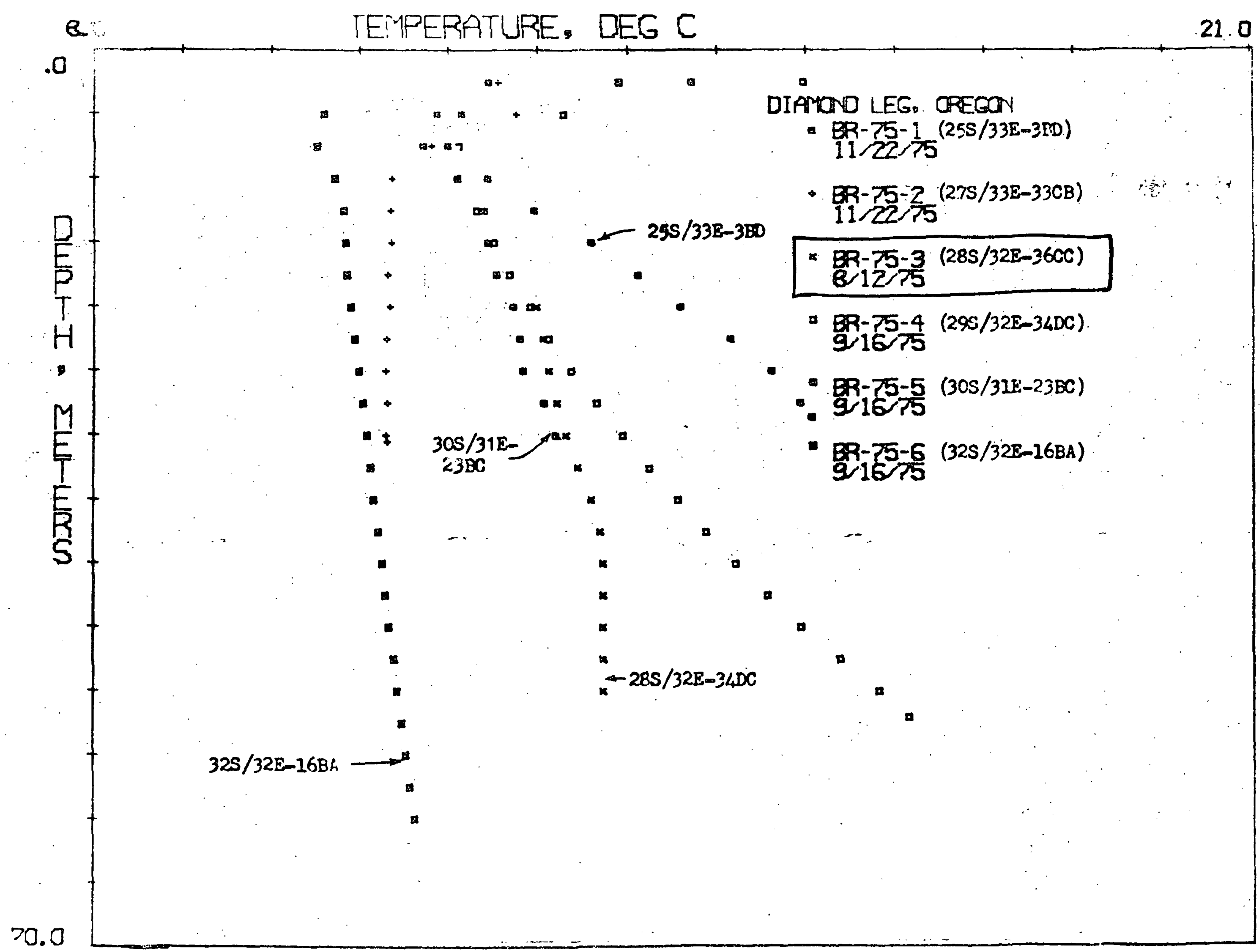
21.0
0.0
70.0
DEPTH, METERS
COYOTE BUTTE, OREGON
BR-75-7 (27S/30E-36CC)
9/16/75
28S/30E-13DA
7/22/75

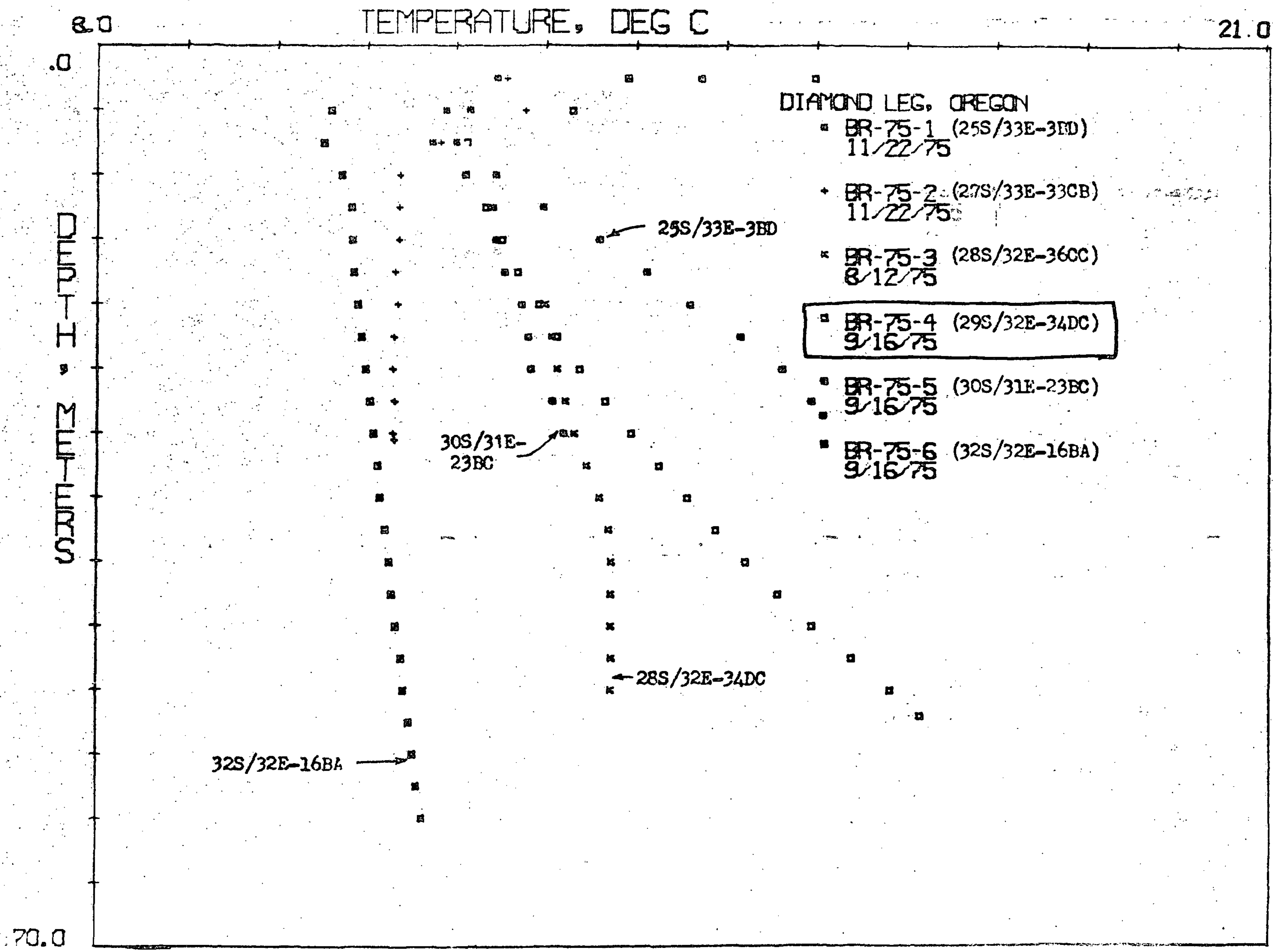
LOCATION: DIAMOND LEG, OREGON
28S/32E-36CC
HOLE NUMBER: BR-75-3
DATE MEASURED: 8/12/75

DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	DEG F	GEOTHERMAL GRADIENT DEG C/KM	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


8.
TEMPERATURE, DEG C
21.0
.0
DEPTH, METERS
70.0
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

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	-468.0	-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


TEMPERATURE, DEG C
8.0
21.0
.0
70.0
DEPTH, METERS
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