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PRELIMINARY GEOLOGY AND GEOTHERMAL RESOURCE POTENTIAL OF THE NORTHERN 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 northern end of a large, circular topographic depression in the central portion of eastern Oregon known as the Harney Basin (Figure 1). Limits of the study area were arbitrarily set at the boundaries of available U. S. Geological Survey (USGS) topographic maps at latitudes 43° 45' on the north and 43° 30' on the south and at longitudes 119° 15' on the west and 118° 30' on the east. This study, performed under U. S. Department of Energy (USDOE) Contract No. DE FC07-79ET27220, was undertaken to estimate the geothermal potential of the area by 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 5,180-km^2 (200-mi^2) relatively flat, closed drainage basin surrounded by mountainous highlands. Total relief in the basin is less than 9 m (30 ft), and the total relief in the highlands is more than 600 m (2,000 ft). The only major population center is the county seat of Burns with the adjacent community of Hines, both of which are located on the western edge of the basin. The remainder of the northern Harney Basin is comprised of swampy bird habitat, cattle ranches and range land, and scrub forests in the higher elevations. Drainage within the basin is toward the south and east through Sage Hen Creek from the west, Silvies River from the north, and Malheur Slough from the east.

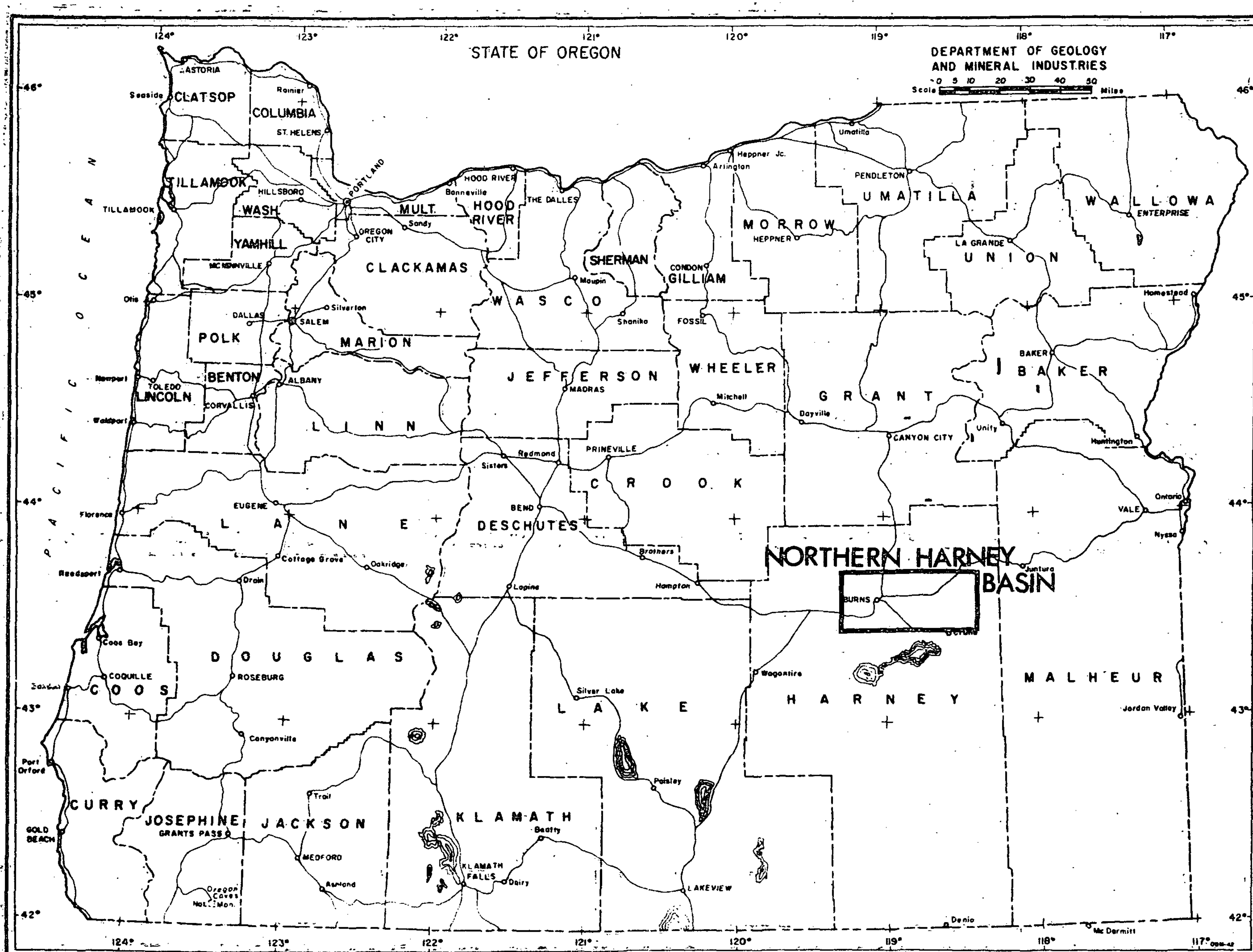

Figure 1: Map showing location of study area.

GEOLOGY

The geologic map (Plate I) of this area is based on (1) a field check of the published map by Greene (1972) of the Burns 15-minute quadrangle, with minor revisions, and (2) an original reconnaissance study, conducted during the fall of 1979 and the spring of 1980, of the Buchanan, Carson Point, Stinkingwater Pass, and Mahon Creek 7½-minute quadrangles and the Harney 15-minute quadrangle. Lithologies and age assignments were based on hand-specimen identification, limited K/Ar ages (Table 1), and bulk chemistry (Table 2). Areal extent of units and other field data were plotted on USGS topographic maps; specific points were located by Brunton compass and pacing. No aerial photographs were used in mapping.

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

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
ML-114-75	118°37'30" 43°38'07"	Silicic dome	[s] 14.74±0.5 my	Tmrd
G-54-5-66	119°08'18" 43°30'48"	Rhyodacite	[a] 7.82±0.26 my	Tmrb
ML-33-75	119°18'12" 43°34'06"	Rhyolite	[n] 7.55±0.10 my	Tmrb
MK-3-79	119°08'12" 43°34'06"	Rhyolite	[o] 7.54±0.10 my	Tmrb
G-257-3-66	119°04'12" 43°37'42"	Welded tuff	[a] 6.82±0.33 my	Tmtr

* References: G - from Greene and others, 1972; ML - from McLeod and others, 1975; MK - from McKee and others, 1976.
**s - sanidine age; a - anorthoclase age; o - obsidian age; n - no method given.

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

Component	*G-9-3 Tmtd	G-9-6 Tmtd	B-0-20-2 Tmtp	G-9-1 Tmtd	B-0-19-2 Tmtr
SiO_2	73.6	74.1	74.27	75.2	75.82
TiO_2	0.26	0.28	0.18	0.21	0.22
Al_2O_3	11.2	12.2	13.73	11.6	12.59
FeO (Total Fe)	2.66	2.96	0.30	3.2	1.48
MgO	0.83	0.24	0.16	0.13	0.04
CaO	0.71	0.34	0.14	0.25	0.29
Na_2O	3.8	4.0	4.02	3.7	3.91
K_2O	4.5	4.6	4.37	4.4	4.18
Total	97.62	98.72	97.17	98.66	98.53

* References: G - from Greene, 1973; B - from Beeson, 1969.

The geology of the northern Harney Basin is comprised of a framework of three flat-lying, extensive, late Miocene ash-flow sheets onlapping a regional unit of early Miocene flood basalts. These ash flows, named in order of increasing age, the Rattlesnake (unit *Tmtr* on the geologic map), Prater Creek (unit *Tmtp*), and Devine Canyon (unit *Tmtd*) Ash-flow Tuffs, are separated by discrete sedimentary units, limited basalt and andesite flows, and silicic intrusions.

Trace element studies (Park and Armstrong, 1972) indicate that the ash-flow tuffs, the silicic intrusives, and the related mafic flows, for the study area as well as for adjacent areas to the south and west, constitute a genetically related bimodal compositional assemblage. Although detailed relationships are unclear at the time of this study, at least one caldera--the source for the Devine Canyon Ash-flow Tuff--is located in the study area near Burns (Walker, 1979). The oldest units recognized in the field were found in the northwest corner of the map area and are the early Miocene basalts (unit *Tmba*) dated in adjacent areas at 12.1 to 20.2 m.y. The youngest bedrock units are mafic vent complexes and associated flows (units *QTmv* and *QTb*) near Burns dated at 2.3 to 2.9 m.y. (Parker, 1974). Complete age relationships of all units are presented in the time-rock chart included on the geologic map (Plate I).

Faulting in the northern basin follows three general trends. The first is the trend of the Brothers fault zone (N.25^{o}-35^{o}W.), which is exhibited most strongly immediately west of Burns in the area of Burns Butte cutting all geologic units present including the aforementioned 2.3- to 2.9-m.y.-old basalts. Motion on these faults appears to be dip-slip; however, several investigators (MacLeod and others, 1975) feel such motion may be the surface manifestation of a right-lateral wrench system at depth. The second trend is the Basin-Range trend (approximately north-south) found throughout the eastern portion of the study area, cutting all lithologies present. Although some of these faults appear to be dip-slip, they may have some strike-slip or oblique-slip component, specifically along Soldier Creek in the north-central portion, where an extensively mineralized north-striking fault zone appears to contain some right-lateral component and may represent a major structural discontinuity for the basin. The third trend (N.40^{o}-50^{o}W.) occurs in the east-central portion of the study area and appears to represent a transitional trend between the Brothers trend and the Basin-Range trend. This transitional trend ends abruptly at the Soldier Creek shear zone.

A lineament study (Plate II) prepared for this report from U-2 and Landsat imagery shows a one-to-one correspondence of structural trends with the mapped fault trends. It also shows a number of lineaments that cross the alluvium-filled basin but which could not be traced through geologic mapping.

Folding of the units is generally in the form of broad, shallowly dipping anticlines and synclines plunging toward the center of the basin. Exceptions are several sharply folded local structures adjacent and probably subsequent to major faults (e.g., the Soldier Creek shear zone). In the past, investigators (Greene, 1972; Greene and others, 1972) have shown the northern highlands to be a homocline dipping into the basin off a core of older rocks to the north. However, the mapping connected with this study shows a large number of discrete fault blocks that dip away from the center of the basin. Downwarping of the basin itself probably began during the middle to late Miocene (Walker, 1979) and may be continuing at present. The probable cause of the downwarping is the loss of material by volcanic eruption from the extensive ash-flow sheets and numerous flood basalts and, to a lesser extent, the loss of volume due to loss of stored heat (Blackwell, 1980, personal communication).

GEOPHYSICS

At the present time, no geophysical surveys are available for the northern Harney Basin. Recommendations for future work in this extremly important area are included in the Conclusions and Recommendations section of this report.

WATER CHEMISTRY

During this study, fifteen wells, springs, and gradient holes were sampled and their waters analyzed. Together with existing published analyses (Leonard, 1970; U. S. Geological Survey and Oregon Department of Geology and Mineral Industries, 1979), a total of 21 analyses are available for evaluation (Table 3). Published reports of the hydrology of the Harney Basin (Piper and others, 1939; Leonard, 1970) show a considerable number of thermal anomalies; however, a large number of the listed springs and wells either could not be located or were not flowing at the time of the study.

Sampling temperatures during field collection ranged from 72°C for the O. J. Thomas well in the north-central portion of the study area to 17°-22°C for artesian wells and springs near the town of Burns. The natural waters of the study area can best be described as generally low in chloride and high in magnesium and bicarbonate. On the basis of preliminary evaluation of the available data, two groups of waters are recognized: (1) The wells near Soldier Creek and directly south, which appear to be relatively high in silica (72-104 mg/l) and show relatively high Na:K atomic ratios (144-260) and high contents of ions such as boron, arsenic, chloride, and fluoride. The estimated minimum reservoir temperatures for these wells are in the moderate range, calculated to be approximately 100°-130°C (Table 4). (2) The springs and wells near Burns, which are lower in silica (37-60 mg/l); lower in Na:K atomic ratios (11-15); lower in relative amounts of boron, arsenic, chloride, and fluoride; and lower in calculated reservoir temperatures (75° -100°C). They are also higher in magnesium, which is generally thought to indicate cooler waters or waters that have traveled a longer distance from their source (Fournier, 1980, personal communication). The cooler waters near Burns may represent a dilute species of the warmer waters found to the east; however,

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

	Cow Creek Spring	Bar Negative Well	Hotchkiss Well	Hotchkiss Well	Hotchkiss Well
Location	22 S/32½E/ 14Ca	23S/32E/ 28Acd	24S/30E/ 1Aca	24S/30E/ 1Aca	24S/30E/ 1Aca
Date sampled	9/31	7/68	10/80	8/31	9/68
Temp. (^{o}C)	22	16	33	27	27
pH	nt	7.6	8.37	nt	8.1
Conductance µmhos/cm	nt	771	220	nt	194
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	nt	30	30	nt	nt
Total dissolved solids	nt	511	166	nt	155
SiO_2	nt	52	45	51	46
Na	nt	172	30	30	31
K	nt	5.6	3	2.4	2.9
Ca	16	5.4	10	9.6	8.8
Mg	nt	3.9	2	1.7	1.4
Cl	1.9	16	7	5.2	5.0
As	nt	nt	<0.680	nt	nt
B	nt	1	0.3	nt	0.06
Li	nt	nt	<0.054	nt	nt
F	nt	0.8	0.5	nt	0.5
Fe (total)	nt	0.34	<0.027	0.01	nt
Al	nt	nt	<0.680	nt	nt
HCO_3	nt	nt	nt	95	93
PO_4	nt	nt	nt	nt	nt
SO_4	4	0.4	12	13	12
NO_3	nt	1.9	nt	1.2	1.1
NH_3	nt	nt	tr	nt	nt

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

	Hines Mill Well #1	Hines Mill Well #1	Hines Mill Well #2	Powerhouse Well	Millpond Spring
Location	23S/30E/ 35Aaa	23S/30E/ 35Aaa	23S/30E/ 26Dac	23S/30E/ 26Add	23S/30E/ 36Aaa
Date sampled	7/68	10/80	11/80	10/80	8/31
Temp. (^{o}C)	25	28.5	27.8	25	26
pH	7.8	7.9	8.18	8.04	nt
Conductance μmhos/cm	222	280	240	225	nt
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	nt	34.2	34	50	nt
Total dissolved solids	180	180	172	210	nt
SiO_2	55	45	42	37	nt
Na	33	29	26	30	nt
K	4	4	4	3	nt
Ca	11	10	9	7	14
Mg	2.0	2	2	1	nt
Cl	7.0	8	9	10	8
As	nt	<0.680	<0.680	<0.680	nt
B	0.38	0.3	0.3	0.3	nt
Li	nt	<0.054	<0.054	<0.054	nt
F	0.5	0.6	0.5	0.4	nt
Fe (total)	0.02	<0.027	<0.027	<0.027	nt
Al	nt	<0.680	<0.680	0.680	nt
HCO_3	105	nt	nt	nt	109
PO_4	nt	nt	nt	nt	nt
SO_4	14	12	10	14	11
NO_3	1.5	nt	nt	nt	1.1
NH_3	nt	<0.1	tr	0.3	nt

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

	Hines City Well	Goodman Spring	O.J. Thomas Well	O.J. Thomas Well	Potters Swamp Well
Location	23S/30E/ 23Cda	23S/30E/ 35Ddd	22S/32E/ 35Bbb	22S/32E/ 35Bbb	24S/30E/ 11Aba
Date sampled	7/68	9/68	9/68	5/80	5/80
Temp. (^{o}C)	17	22	72	72	27
pH	7.8	7.5	9.5	9.6	7.9
Conductance µmhos/cm	289	210	716	622	172
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	193_c	62_c
Hardness as mg/l $CaCO_3$	nt	nt	nt	2	22
Total dissolved solids	221	165	499	523	149
SiO_2	60	46	89	104	54.0
Na	35	35	157	147	28.6
K	6.9	3.2	1.8	1.3	2.3
Ca	15	8.2	1.0	0.3	7.7
Mg	5.7	1.4	0.2	<0.1	1.1
Cl	13	7	38	42	6.5
As	nt	nt	0.06	0.063	0.033
B	0.53	0.23	4.0	6.7	0.38
Li	nt	nt	nt	0.1	<0.1
F	0.5	0.6	2.8	5.1	0.5
Fe (total)	0.05	0.02	0.03	0.20	<0.05
Al	nt	nt	nt	0.41	<0.10
HCO_3	128	92	49	nt	nt
PO_4	nt	nt	nt	0.027	0.021
SO_4	18	16	89	75.9	13.9
NO_3	3.8	2.1	nt	0.03	0.28
NH_3	nt	nt	nt	0.90	0.03

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

	Rest Stop Well	Harney Valley Dev. Co. Oil Well	Harney Valley Dev. Co. Oil Well	Development Well	Fischer Well
Location	23S/30E/ 36Cbb	24S/32E/ 8Dab	24S/32E/ 8Dab	23S/30E/ 35Abd	24S/30E/ 2Dab
Date sampled	5/80	9/68	5/80	10/80	10/80
Temp. (^oC)	26	46	50	26.5	25.5
pH	8.0	9.6	9.9	8.33	8.43
Conductance µmhos/cm	177	602	540	230	210
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	73_c	nt	252_c	nt	nt
Hardness as mg/l $CaCO_3$	28	3	<1	15	30
Total dissolved solids	156	396	416	178	140
SiO_2	59.8	72	92	45	37
Na	28.9	135	119	32	30
K	2.6	1.6	0.8	4	3
Ca	8.9	0.8	0.1	8	7
Mg	1.3	0.2	0.1	2	1
Cl	6.1	11	20.5	8	8
As	0.019	nt	0.015	<0.680	<0.680
B	0.31	4.11	4.93	0.5	0.6
Li	<0.1	nt	<0.1	<0.054	<0.054
F	0.4	12	1.2	0.5	0.6
Fe (total)	<0.05	0.20	<0.05	<0.027	<0.027
Al	<0.10	nt	0.16	<0.680	<0.680
HCO_3	nt	94	nt	nt	nt
PO_4	0.044	nt	0.010	nt	nt
SO_4	13.0	29	9.7	13	15
NO_4	0.24	0.2	0.02	nt	nt
NH_3	0.05	nt	2.77	tr	tr

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

	Trailer Court Well	Soldier Creek Well #1 (50')	Soldier Creek Well #1 (600')	Burns High School Well
Location	23S/31E/ 36Bdc	22S/32E/ 32Aad	22S/32E/ 32Aad	23S/30E/ 13Cbc
Date Sampled	10/80	11/80	11/80	10/80
Temp. (^{o}C)	26.5	15	22	16.2
pH	8.24	8.26	8.23	7.2
Conductance µmhos/cm	210	nt	nt	nt
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	30	nt	nt	51
Total dissolved solids	150	190	206	178
SiO_2	43	43	47	42
Na	28	22	24	12
K	3	3	4	3
Ca	9	16	15	8
Mg	1	2	1	4
Cl	6	6	5	27
As	<0.680	<0.625	<0.625	<0.625
B	0.2	<0.125	<0.125	<0.125
Li	0.054	<0.05	<0.05	<0.05
F	0.5	0.4	0.6	0.3
Fe (total)	<0.027	0.15	<0.025	<0.025
Al	<0.680	<0.625	<0.625	<0.625
HCO_3	nt	nt	nt	nt
PO_4	nt	nt	nt	nt
SO_4	11	14	15	4
NO_3	nt	nt	nt	nt
NH_3	tr	nt	nt	tr

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

	Bar Negative Well	Hotchkiss Well	Hotchkiss Well	Hotchkiss Well	Hines Lumber Co. Well #1
Flow rate liters/min.	100+	20	2271	2271	6624
Measured temperature °C	16	33	27	27	25
Na:K °C	107	175	160	170	190
Na:K:Ca 1/3 β °C	136	157	146	155	167
Na:K:Ca 4/3 β °C	118	62	56	64	70
Na:K:Ca Mg corrected °C	28	83	87	86	86
SiO_2 conductive °C	104	97	103	98	106
SiO_2 adiabatic °C	104	98	103	99	106
SiO_2 chalcedony °C	74	67	73	68	77
SiO_2 opal °C	-12	-18	-13	-17	-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 northern Harney Basin -- Continued

	City of Hines Well	Goodman Spring (Hotchkiss)	Hines Mill Well #1	Hines Mill Well #2	Powerhouse Well
Flow rate liters/min.	2555	79	pumped	pumped	pumped
Measured temperature °C	17	22	28.5	27.8	25
Na:K °C	230	169	199	208	175
Na:K:Ca 1/3 β °C	192	156	172	177	159
Na:K:Ca 4/3 β °C	81	69	70	71	69
Na:K:Ca Mg corrected °C	57	81	90	89	106
SiO_2 conductive °C	111	98	97	94	88
SiO_2 adiabatic °C	110	99	98	96	91
SiO_2 chalcedony °C	81	68	67	63	57
SiO_2 opal °C	-7	-17	-18	-21	-25

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

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

	O.J. Thomas Well	O.J. Thomas Well	Potters Swamp Well	Rest Stop Well	Harney Valley Dev. Co. Oil Test Well
Flow rate liters/min.	1000+	1000+	100+	pumped	100+
Measured temperature °C	72	72	27	26	46
Na:K °C	60	50	160	168	61
Na:K:Ca 1/3 β °C	104	101	147	152	105
Na:K:Ca 4/3 β °C	116	135	59	60	115
Na:K:Ca Mg corrected °C	99	NC	102	71	96
SiO_2 conductive °C	131	139	105	110	120
SiO_2 adiabatic °C	127	135	106	110	118
SiO_2 chalcedony °C	103	113	76	81	91
SiO_2 opal °C	11	19	-11	7	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 northern Harney Basin -- Continued

	Harney Valley Dev. Co. Oil Test Well	Development Well	Fischer Well	Trailer Court Well
Flow rate liters/min.	100+	pumped	pumped	pumped
Measured temperature °C	50	26.5	25.5	26.5
Na:K °C	40	192	175	180
Na:K:Ca 1/3 β °C	126	171	159	160
Na:K:Ca 4/3 β °C	143	76	69	63
Na:K:Ca Mg corrected °C	71	71	101	115
SiO_2 conductive °C	133	97	88	95
SiO_2 adiabatic °C	129	98	91	97
SiO_2 chalcedony °C	105	67	57	64
SiO_2 opal °C	13	-18	-25	-20

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

the limited data of this reconnaissance study are inconclusive on this point. Therefore, before detailed analyses of fluid provenance and movement can be made, a detailed sampling program including oxygen-, hydrogen-, and sulfate-isotope analyses must be undertaken.

GEOTHERMAL-GRADIENT AND HEAT-FLOW DATA*

The temperature-gradient and heat-flow results for the north 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 Plate I. 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 north Harney Basin have been obtained in holes drilled as water wells, so most thermal-conductivity values are estimated (parenthesis) or based on one or two cutting samples from surface spoil piles. Several of the holes are artesian, and gradients are estimated based on the bottom hole temperature and the assumed surface temperature. These gradients are maximum values, because some

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Table 5. Geothermal-gradient data, north 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
22S/32E- 27BA	43-38.53	118-52.35	TILLER 2 5/22/80	1277	19.00	20.0 57.0	(.96)		72.1 4.7	71.0	68	C
22S/32E- 26BB	43-38.35	118-51.62	TURDY 5/21/80	1279	12.95	10.0 40.0	(.96)		68.1 3.6	68.1	66	C
22S/32E- 27AC	43-38.30	118-54.17	TILLER 3 5/22/80	1286	20.12	10.0 25.0			226.0 12.7	226.0		
						25.0 96.0	(.96)		72.4 3.5	72.4	70	C
22S/32E- 27CB	43-38.08	118-52.75	TILLER 1 5/22/80	1265	16.48	5.0 100.0	(.96)		78.6 2.4	78.6	76	B
22S/33E- 27CD	43-37.62	118-38.50	TEMPLE 5/20/80	1268	15.84	.0 138.0			> 48.0			X
22S/32E- 31DB	43-37.20	118-55.67	BLCKBURN 5/22/80	1269	12.79	15.0 48.0	(.96)		53.5 2.2	53.5	51	C
22S/32E- 34CC	43-36.90	118-52.60	RICE 6/11/75	1260	27.39	.0 95.0	(.96)		<140.0	<140.0	< 134	C
22S/32E- 34DD	43-36.87	118-51.88	HWY 20 5/20/80	1261	29.19	10.0 35.0			573.8 15.2	573.7		C
						35.0 60.0			181.7 .3	181.7		C
						10.0 62.0	(.96)		355.0 70.2	354.9	341	B
23S/32E- 6CB	43-36.32	118-49.17	*HANSON 5/22/80	1259	13.69	5.0 51.0	(.96)		74.6 1.7	74.5	72	B
24S/32E- 1AD	43-31.33	118-49.32	NINEMILE 5/16/80	1257	38.45	10.0 35.0			273.5 3.8	273.5		C
						35.0 60.0			189.5 .2	189.5		C
						60.0 130.0			155.8 1.7	155.7		C
						130.0 160.0			97.8 .1	97.8		C

Table 5. Geothermal-gradient data, north 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
						10.0 160.0	(.96)		165.8 14.1	165.8	159	C
24S/32E-8DA	43-30.23	118-54.27	STEVENS 5/15/80	1256	54.82	.0 176.0	(.96)			<284.0		C

portion of the flow may come from deeper than the maximum depth actually logged. Also, some of the holes show large variation in geothermal gradient with depth, indicating some nonconductive effect on the data. Complete interpretation of the data set will require detailed understanding of the hydrologic and geologic conditions.

CONCLUSIONS AND RECOMMENDATIONS

The reconnaissance study performed for the northern Harney Basin has tentatively defined two low-temperature resource areas within piping distance of Burns which merit further investigation. They are (1) the area near the Soldier Creek shear zone (Plate I) and (2) the area immediately south, west, and east of the city of Burns. Site-specific analyses of these two areas should be carried out under one field program and include the following:

1. Detailed (scale of 1:24,000 or less) geologic and photogeologic mapping of Burns and Harney 15-minute quadrangles -- to identify and evaluate active and/or thermal structures.
2. Detailed spring and well sampling and analyses, including isotope analyses -- to determine fluid flow directions and provenance.
3. Closely spaced complete Bouguer and residual gravity anomaly studies and aeromagnetic studies -- to delineate possible active thermal structures below the basin fill.
4. Several resistivity traverses (either dipole-dipole, roving dipole, or telluric) in an east-west direction -- in order to further define the thermal regime.
5. A microearthquake/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 the geothermal system.
6. A program of twenty to thirty 500-ft gradient/stratigraphy holes, followed by a program of five to ten 2,000-ft gradient holes -- to model heat flow and directly test geothermal aquifers.

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APPENDIX A

Formulas used in calculations

Na:K (revised):

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

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.

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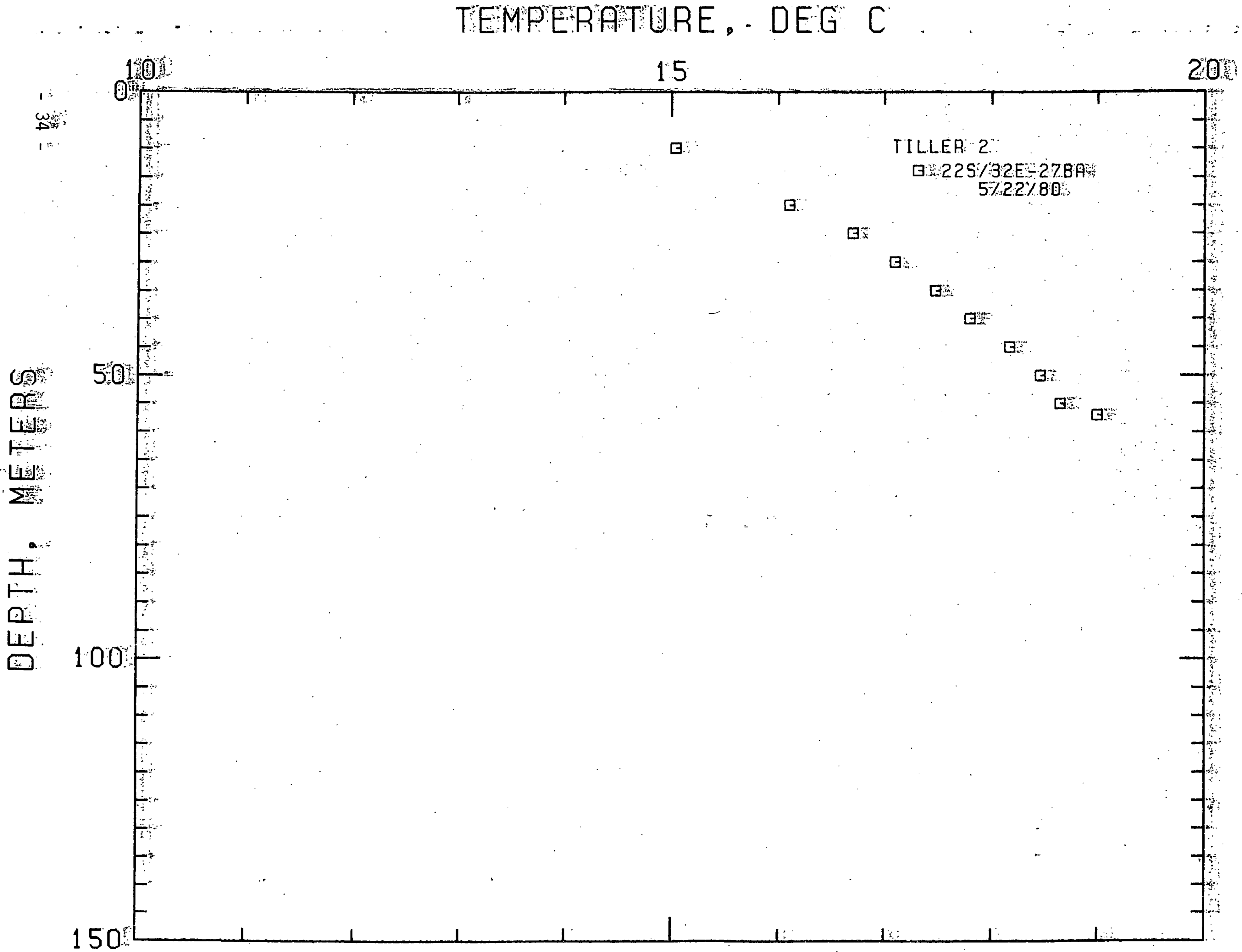
APPENDIX B

Geothermal-gradient data

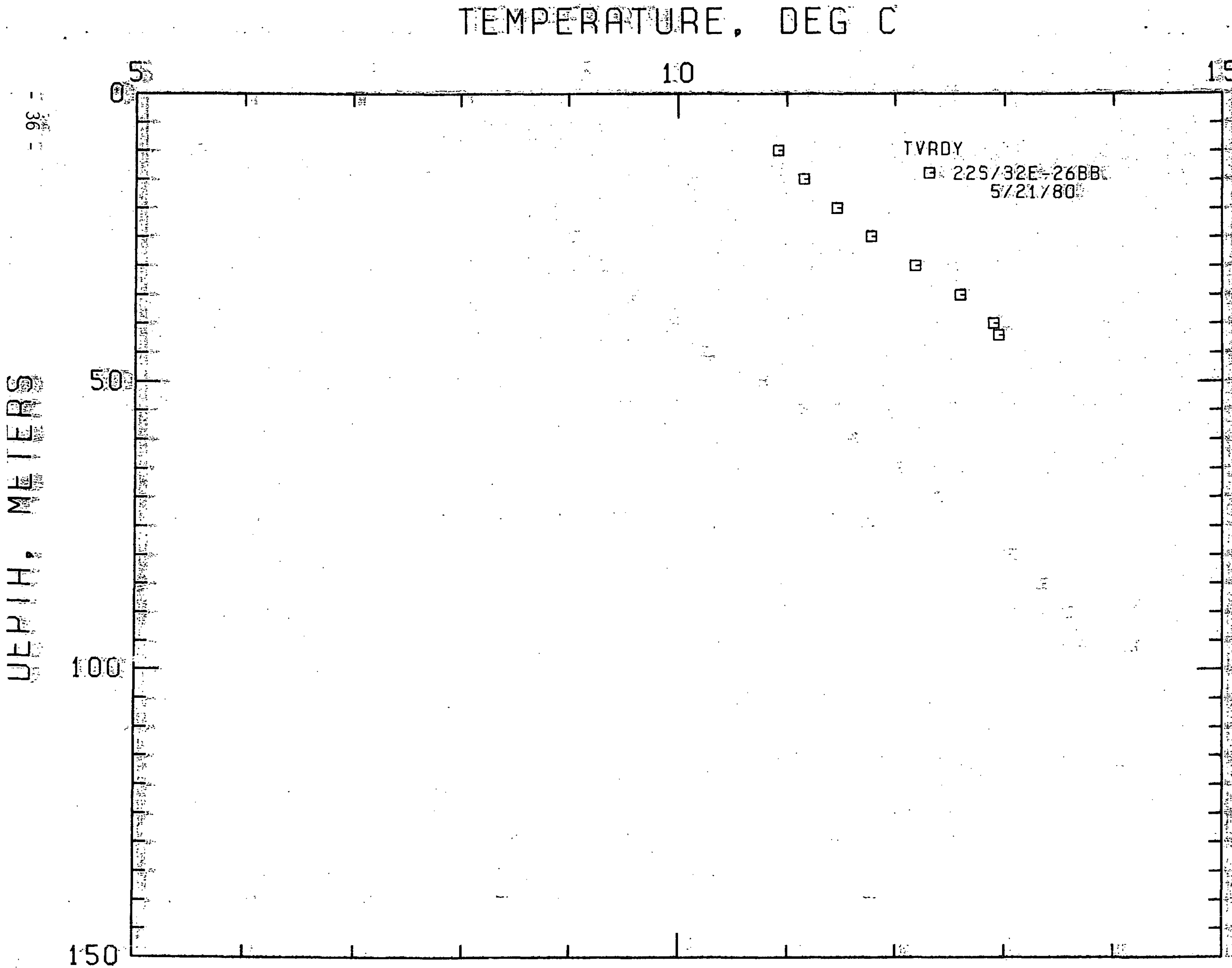
LOCATION: BURNS AMS, OREGON
22S/32E-27BA
HOLE NAME: TILLER 2
DATE MEASURED: 5/22/80

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	15.040	59.07	0.0	0.0
20.0	65.6	16.110	61.00	107.0	5.9
25.0	82.0	16.710	62.08	120.0	6.6
30.0	98.4	17.100	62.78	78.0	4.3
35.0	114.8	17.480	63.46	76.0	4.2
40.0	131.2	17.800	64.04	64.0	3.5
45.0	147.6	18.170	64.71	74.0	4.1
50.0	164.0	18.460	65.23	58.0	3.2
55.0	180.4	18.650	65.57	38.0	2.1
57.0	187.0	19.000	66.20	175.0	9.6


TEMPERATURE, DEG C
10
15
20
0
50
100
150
DEPTH, METERS
TILLER 2
22S/32E-27BA
5/22/80

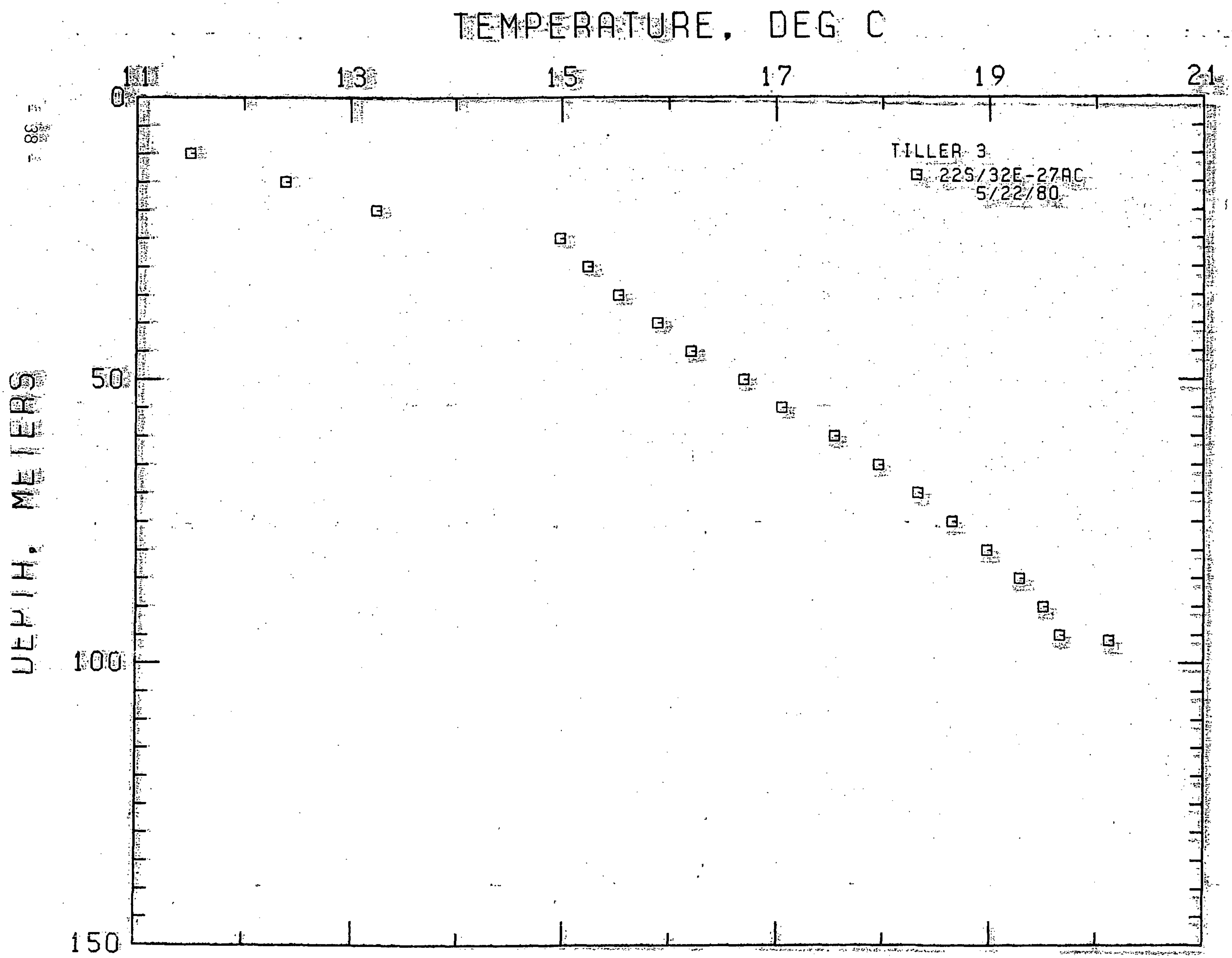
LOCATION: BURNS AMS, OREGON
22S/32E-26BB
HOLE NAME: TVRDY
DATE MEASURED: 5/21/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	10.920	51.66	0.0	0.0
15.0	49.2	11.160	52.09	48.0	2.6
20.0	65.6	11.470	52.65	62.0	3.4
25.0	82.0	11.780	53.20	62.0	3.4
30.0	98.4	12.190	53.94	82.0	4.5
35.0	114.8	12.600	54.68	82.0	4.5
40.0	131.2	12.900	55.22	60.0	3.3
42.0	137.8	12.950	55.31	25.0	1.4


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
TVRDY
22S/32E-26BB
5/21/80

LOCATION: BURNS AMS, OREGON
22S/32E-27AC
HOLE NAME: TILLER 3
DATE MEASURED: 5/22/80

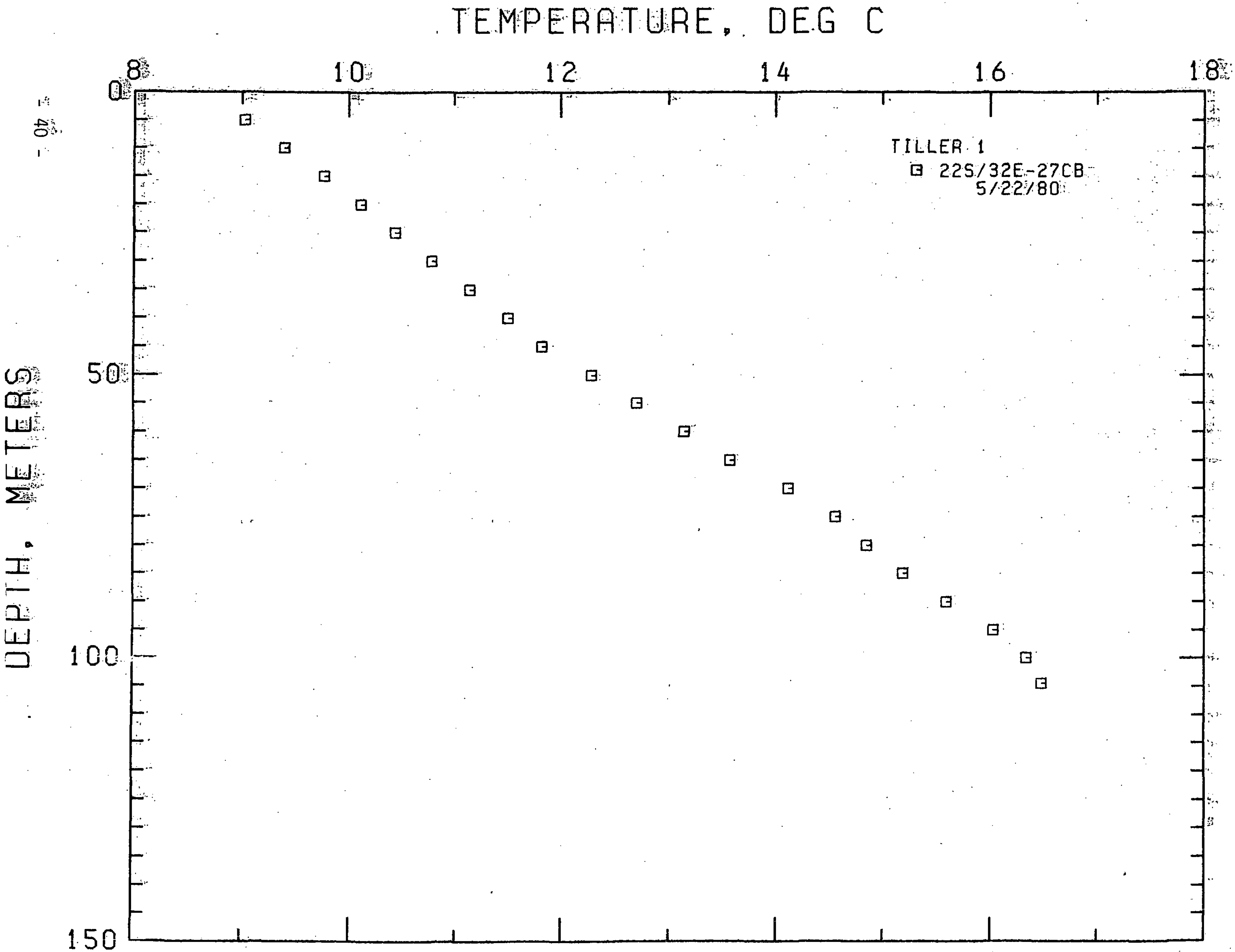
DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	11.500	52.70	0.0	0.0
15.0	49.2	12.380	54.28	176.0	9.7
20.0	65.6	13.240	55.83	172.0	9.4
25.0	82.0	14.980	58.96	348.0	19.1
30.0	98.4	15.240	59.43	52.0	2.9
35.0	114.8	15.530	59.95	58.0	3.2
40.0	131.2	15.890	60.60	72.0	4.0
45.0	147.6	16.200	61.16	62.0	3.4
50.0	164.0	16.700	62.06	100.0	5.5
55.0	180.4	17.050	62.69	70.0	3.8
60.0	196.8	17.550	63.59	100.0	5.5
65.0	213.2	17.960	64.33	82.0	4.5
70.0	229.6	18.330	64.99	74.0	4.1
75.0	246.0	18.650	65.57	64.0	3.5
80.0	262.4	18.970	66.15	64.0	3.5
85.0	278.8	19.280	66.70	62.0	3.4
90.0	295.2	19.500	67.10	44.0	2.4
95.0	311.6	19.660	67.39	32.0	1.8
96.0	314.9	20.120	68.22	460.0	25.2



TEMPERATURE, DEG C
11
13
15
17
19
21
0
50
100
150
DEPTH, METERS
TILLER 3
22S/32E-27AC
5/22/80

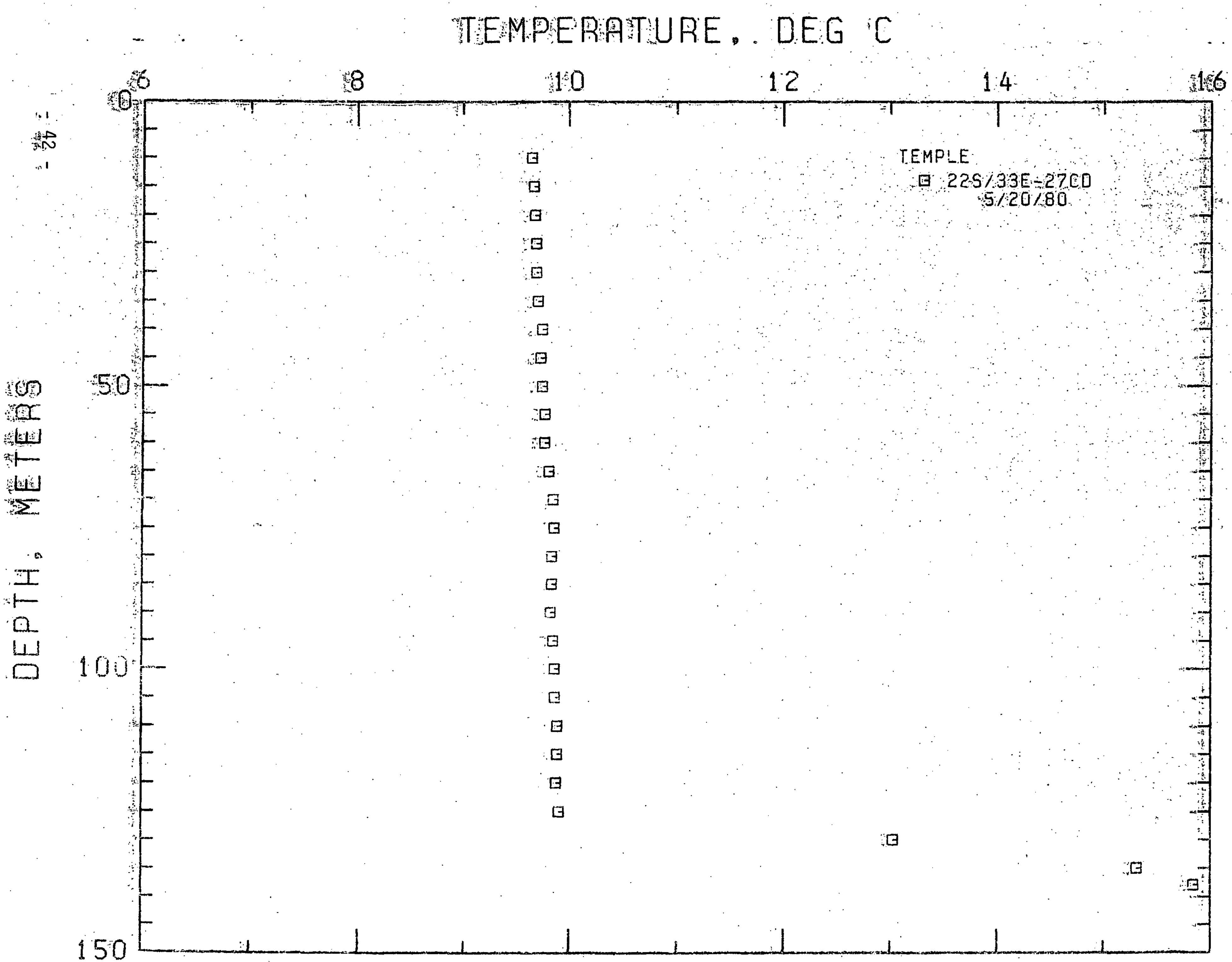
LOCATION: BURNS AMS, OREGON
22S/32E-27CB
HOLE NAME: TILLER 1
DATE MEASURED: 5/22/80

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	9.030	48.25	0.0	0.0
10.0	32.8	9.400	48.92	74.0	4.1
15.0	49.2	9.770	49.59	74.0	4.1
20.0	65.6	10.120	50.22	70.0	3.8
25.0	82.0	10.440	50.79	64.0	3.5
30.0	98.4	10.790	51.42	70.0	3.8
35.0	114.8	11.150	52.07	72.0	4.0
40.0	131.2	11.510	52.72	72.0	4.0
45.0	147.6	11.830	53.29	64.0	3.5
50.0	164.0	12.290	54.12	92.0	5.0
55.0	180.4	12.710	54.88	84.0	4.6
60.0	196.8	13.140	55.65	86.0	4.7
65.0	213.2	13.570	56.43	86.0	4.7
70.0	229.6	14.120	57.42	110.0	6.0
75.0	246.0	14.560	58.21	88.0	4.8
80.0	262.4	14.850	58.73	58.0	3.2
85.0	278.8	15.190	59.34	68.0	3.7
90.0	295.2	15.590	60.06	80.0	4.4
95.0	311.6	16.030	60.85	88.0	4.8
100.0	328.0	16.340	61.41	62.0	3.4
104.5	342.8	16.480	61.66	31.1	1.7


TEMPERATURE, DEG C
8
10
12
14
16
18
0
50
100
150
DEPTH, METERS
TILLER 1
22S/32E-27CB
5/22/80

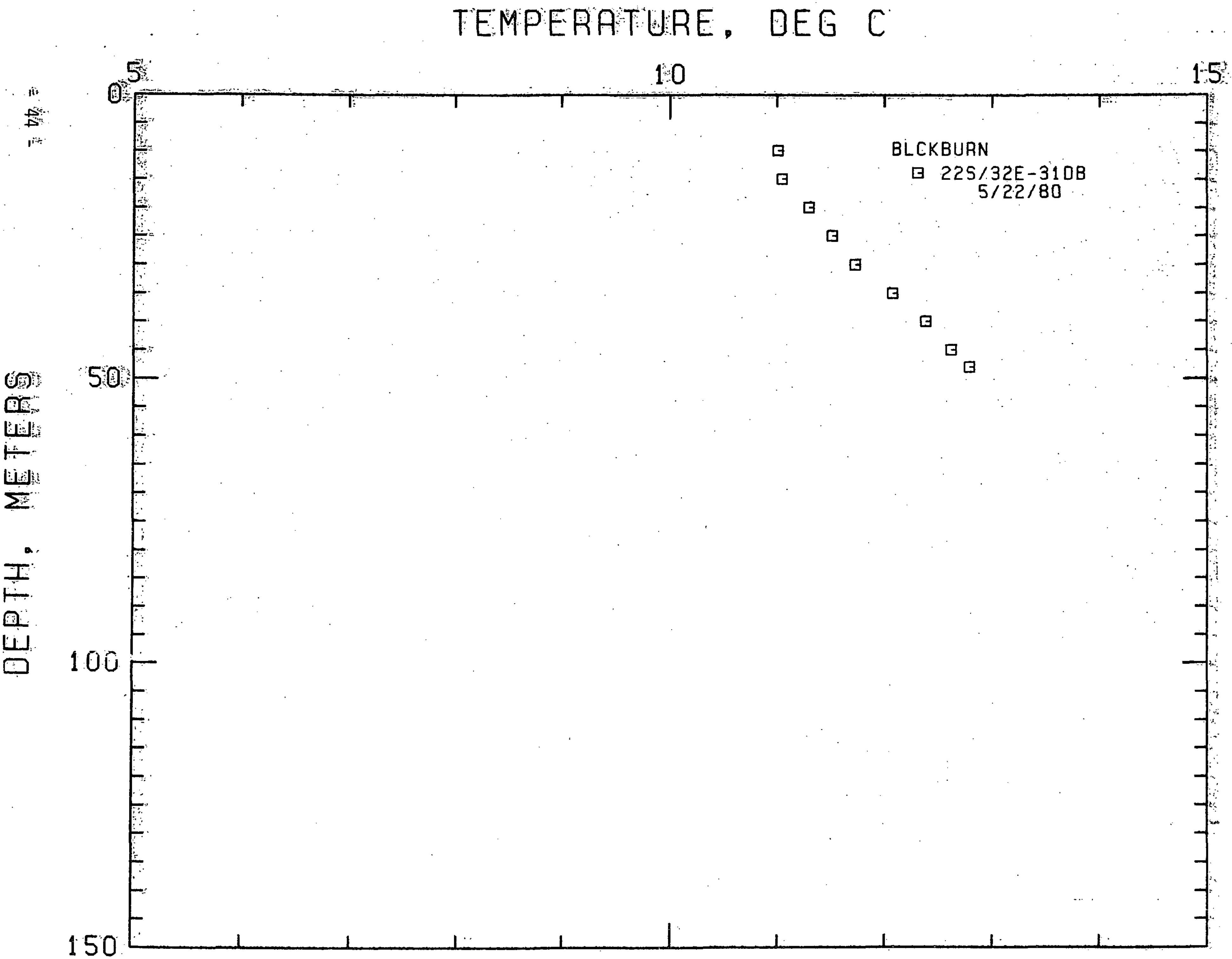
LOCATION: BURNS AMS, OREGON
22S/33E-27CD
HOLE NAME: TEMPLE
DATE MEASURED: 5/20/80

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	9.650	49.37	0.0	0.0
15.0	49.2	9.670	49.41	4.0	0.2
20.0	65.6	9.680	49.42	2.0	0.1
25.0	82.0	9.690	49.44	2.0	0.1
30.0	98.4	9.690	49.44	0.0	0.0
35.0	114.8	9.710	49.48	4.0	0.2
40.0	131.2	9.750	49.55	8.0	0.4
45.0	147.6	9.730	49.51	-4.0	-0.2
50.0	164.0	9.750	49.55	4.0	0.2
55.0	180.4	9.770	49.59	4.0	0.2
60.0	196.8	9.770	49.59	0.0	0.0
65.0	213.2	9.810	49.66	8.0	0.4
70.0	229.6	9.850	49.73	8.0	0.4
75.0	246.0	9.860	49.75	2.0	0.1
80.0	262.4	9.840	49.71	-4.0	-0.2
85.0	278.8	9.840	49.71	0.0	0.0
90.0	295.2	9.830	49.69	-2.0	-0.1
95.0	311.6	9.850	49.73	4.0	0.2
100.0	328.0	9.870	49.77	4.0	0.2
105.0	344.4	9.870	49.77	0.0	0.0
110.0	360.8	9.890	49.80	4.0	0.2
115.0	377.2	9.890	49.80	0.0	0.0
120.0	393.6	9.880	49.78	-2.0	-0.1
125.0	410.0	9.910	49.84	6.0	0.3
130.0	426.4	13.030	55.45	624.0	34.2
135.0	442.8	15.310	59.56	456.0	25.0
138.0	452.6	15.840	60.51	176.7	9.7


TEMPERATURE, DEG C
6
8
10
12
14
16
DEPTH, METERS
0
50
100
150
TEMPLE
22S/33E-27CD
5/20/80

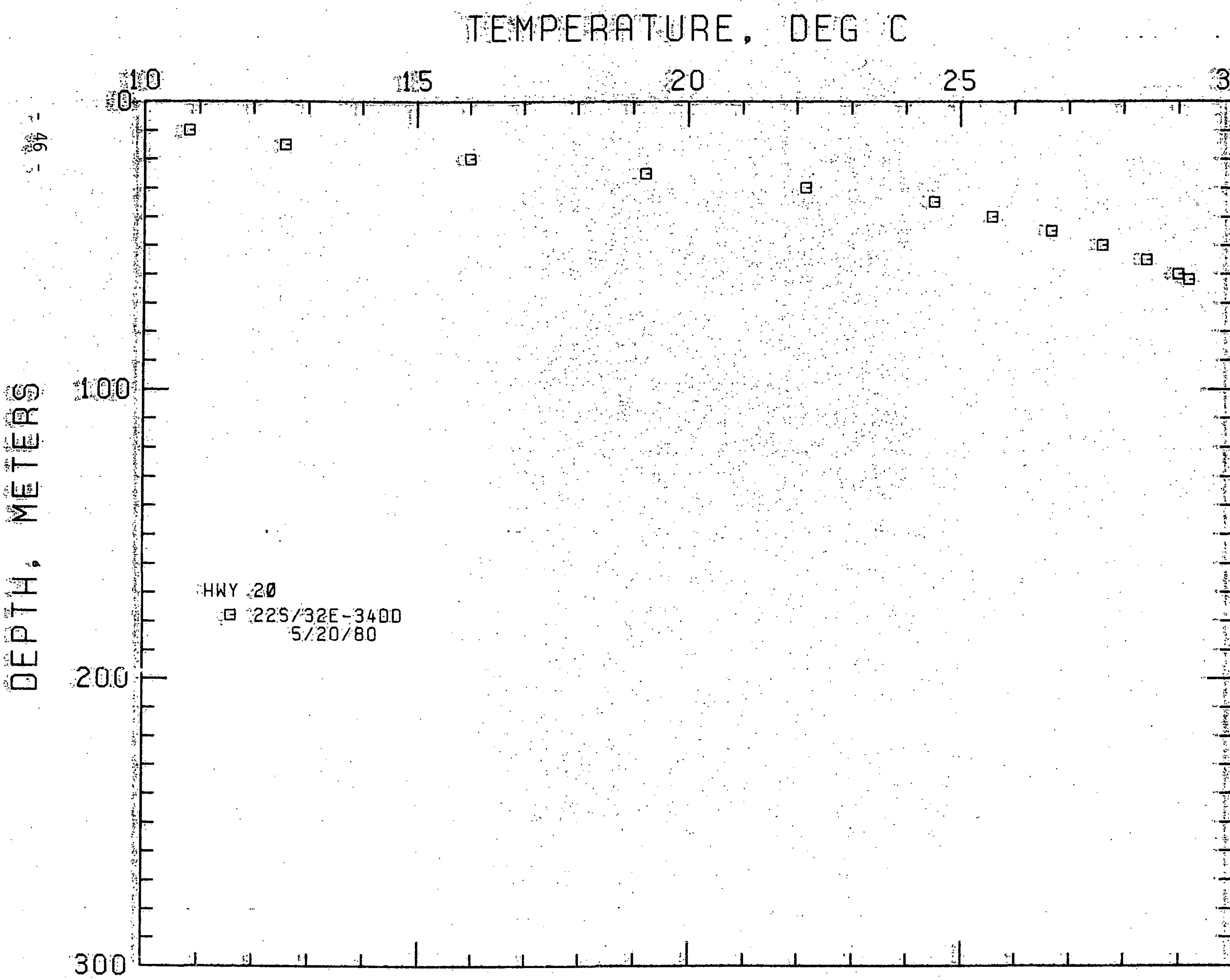
LOCATION: BURNS AMS, OREGON
22S/32E-31DB
HOLE NAME: BLCKBURN
DATE MEASURED: 5/22/80

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	11.010	51.82	0.0	0.0
15.0	49.2	11.050	51.89	8.0	0.4
20.0	65.6	11.300	52.34	50.0	2.7
25.0	82.0	11.520	52.74	44.0	2.4
30.0	98.4	11.730	53.11	42.0	2.3
35.0	114.8	12.080	53.74	70.0	3.8
40.0	131.2	12.390	54.30	62.0	3.4
45.0	147.6	12.620	54.72	46.0	2.5
48.0	157.4	12.790	55.02	56.7	3.1


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
BLCKBURN
22S/32E-31DB
5/22/80

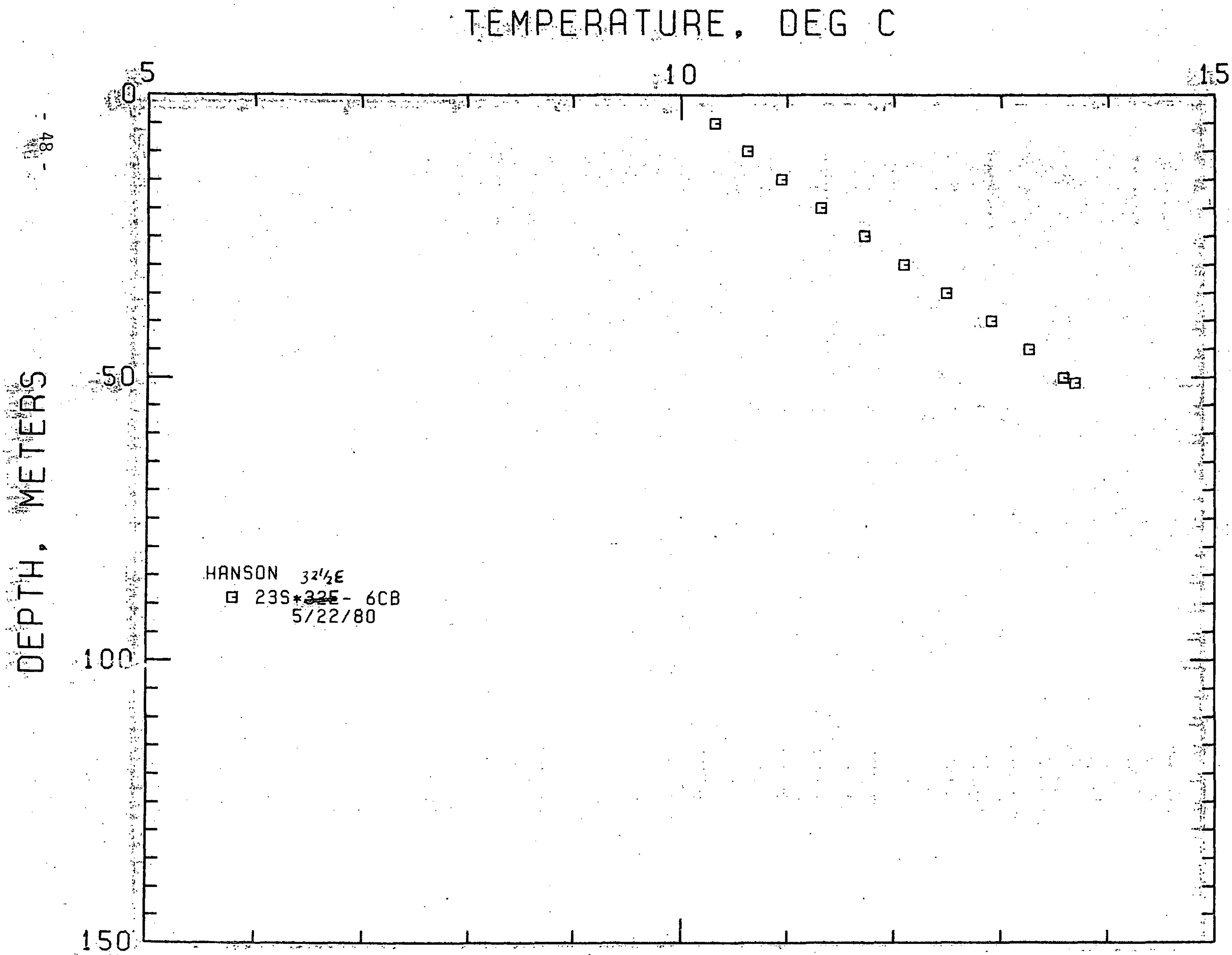
LOCATION: BURNS AMS, OREGON
22S/32E-34DD
HOLE NAME: HWY 20
DATE MEASURED: 5/20/80

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	10.820	51.48	0.0	0.0
15.0	49.2	12.580	54.64	352.0	19.3
20.0	65.6	16.000	60.80	684.0	37.5
25.0	82.0	19.220	66.60	644.0	35.3
30.0	98.4	22.160	71.89	588.0	32.3
35.0	114.8	24.510	76.12	470.0	25.8
40.0	131.2	25.590	78.06	216.0	11.9
45.0	147.6	26.670	80.01	216.0	11.9
50.0	164.0	27.610	81.70	188.0	10.3
55.0	180.4	28.410	83.14	160.0	8.8
60.0	196.8	28.990	84.18	116.0	6.4
62.0	203.4	29.190	84.54	100.0	5.5


TEMPERATURE, DEG C
10
15
20
25
30
0
100
200
300
DEPTH, METERS
HWY 20
22S/32E-34DD
5/20/80

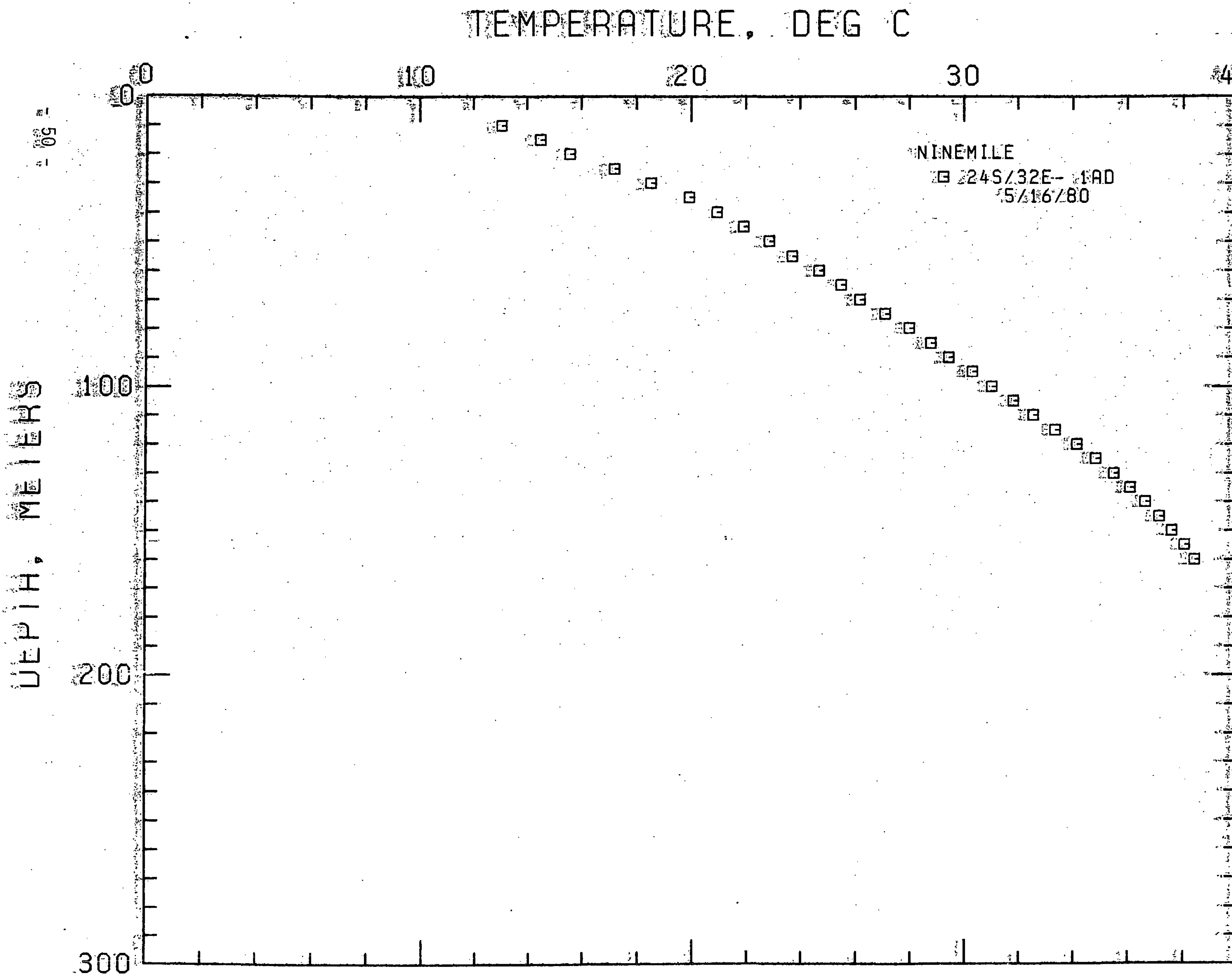
LOCATION: BURNS AMS, OREGON
23S*~~32E~~- 6CB 32½ E
HOLE NAME: HANSON
DATE MEASURED: 5/22/80

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	10.320	50.58	0.0	0.0
10.0	32.8	10.630	51.13	62.0	3.4
15.0	49.2	10.950	51.71	64.0	3.5
20.0	65.6	11.320	52.38	74.0	4.1
25.0	82.0	11.720	53.10	80.0	4.4
30.0	98.4	12.090	53.76	74.0	4.1
35.0	114.8	12.490	54.48	80.0	4.4
40.0	131.2	12.910	55.24	84.0	4.6
45.0	147.6	13.260	55.87	70.0	3.8
50.0	164.0	13.580	56.44	64.0	3.5
51.0	167.3	13.690	56.64	110.0	6.0


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
HANSON 32½E
23S*32E- 6CB
5/22/80

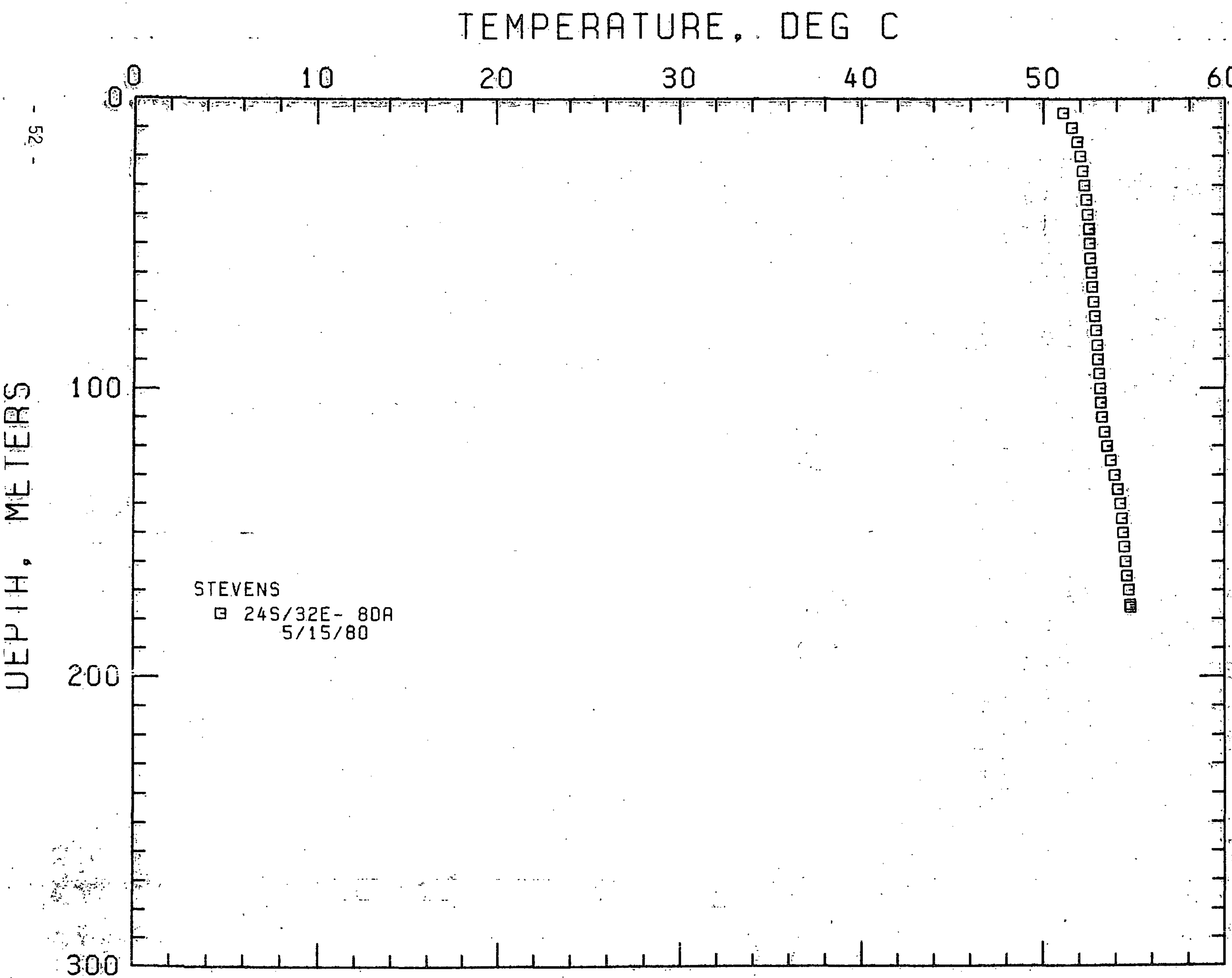
LOCATION: BURNS AMS, OREGON
24S/32E- 1AD
HOLE NAME: NINEMILE
DATE MEASURED: 5/16/80

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	13.080	55.54	0.0	0.0
15.0	49.2	14.510	58.12	286.0	15.7
20.0	65.6	15.590	60.06	216.0	11.9
25.0	82.0	17.200	62.96	322.0	17.7
30.0	98.4	18.530	65.35	266.0	14.6
35.0	114.8	19.920	67.86	278.0	15.3
40.0	131.2	20.970	69.75	210.0	11.5
45.0	147.6	21.940	71.49	194.0	10.6
50.0	164.0	22.880	73.18	188.0	10.3
55.0	180.4	23.730	74.71	170.0	9.3
60.0	196.8	24.710	76.48	196.0	10.8
65.0	213.2	25.500	77.90	158.0	8.7
70.0	229.6	26.190	79.14	138.0	7.6
75.0	246.0	27.110	80.80	184.0	10.1
80.0	262.4	27.990	82.38	176.0	9.7
85.0	278.8	28.790	83.82	160.0	8.8
90.0	295.2	29.470	85.05	136.0	7.5
95.0	311.6	30.320	86.58	170.0	9.3
100.0	328.0	31.040	87.87	144.0	7.9
105.0	344.4	31.850	89.33	162.0	8.9
110.0	360.8	32.560	90.61	142.0	7.8
115.0	377.2	33.360	92.05	160.0	8.8
120.0	393.6	34.180	93.52	164.0	9.0
125.0	410.0	34.860	94.75	136.0	7.5
130.0	426.4	35.510	95.92	130.0	7.1
135.0	442.8	36.120	97.02	122.0	6.7
140.0	459.2	36.660	97.99	108.0	5.9
145.0	475.6	37.170	98.91	102.0	5.6
150.0	492.0	37.620	99.72	90.0	4.9
155.0	508.4	38.080	100.54	92.0	5.0
160.0	524.8	38.450	101.21	74.0	4.1


TEMPERATURE, DEG C
0
10
20
30
40
0
100
200
300
DEPTH, METERS
NINEMILE
24S/32E- 1AD
5/16/80

LOCATION: BURNS AMS, OREGON
24S/32E- 8DA
HOLE NAME: STEVENS
DATE MEASURED: 5/15/80

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	51.080	123.94	0.0	0.0
10.0	32.8	51.580	124.84	100.0	5.5
15.0	49.2	51.880	125.38	60.0	3.3
20.0	65.6	52.050	125.69	34.0	1.9
25.0	82.0	52.180	125.92	26.0	1.4
30.0	98.4	52.300	126.14	24.0	1.3
35.0	114.8	52.390	126.30	18.0	1.0
40.0	131.2	52.470	126.45	16.0	0.9
45.0	147.6	52.530	126.55	12.0	0.7
50.0	164.0	52.560	126.61	6.0	0.3
55.0	180.4	52.610	126.70	10.0	0.5
60.0	196.8	52.660	126.79	10.0	0.5
65.0	213.2	52.700	126.86	8.0	0.4
70.0	229.6	52.770	126.99	14.0	0.8
75.0	246.0	52.830	127.09	12.0	0.7
80.0	262.4	52.890	127.20	12.0	0.7
85.0	278.8	52.960	127.33	14.0	0.8
90.0	295.2	53.010	127.42	10.0	0.5
95.0	311.6	53.080	127.54	14.0	0.8
100.0	328.0	53.150	127.67	14.0	0.8
105.0	344.4	53.190	127.74	8.0	0.4
110.0	360.8	53.260	127.87	14.0	0.8
115.0	377.2	53.380	128.08	24.0	1.3
120.0	393.6	53.520	128.34	28.0	1.5
125.0	410.0	53.730	128.71	42.0	2.3
130.0	426.4	53.940	129.09	42.0	2.3
135.0	442.8	54.110	129.40	34.0	1.9
140.0	459.2	54.230	129.61	24.0	1.3
145.0	475.6	54.330	129.79	20.0	1.1
150.0	492.0	54.410	129.94	16.0	0.9
155.0	508.4	54.480	130.06	14.0	0.8
160.0	524.8	54.560	130.21	16.0	0.9
165.0	541.2	54.630	130.33	14.0	0.8
170.0	557.6	54.720	130.50	18.0	1.0
175.0	574.0	54.800	130.64	16.0	0.9
176.0	577.3	54.820	130.68	20.0	1.1


TEMPERATURE, DEG C
0
10
20
30
40
50
60
DEPTH, METERS
0
100
200
300
STEVENS
24S/32E- 8DA
5/15/80

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

OPEN-FILE REPORT 0-80-6

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

by

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G. D. McLean, and

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 northern end of a large, circular topographic depression in the central portion of eastern Oregon known as the Harney Basin (Figure 1). Limits of the study area were arbitrarily set at the boundaries of available U. S. Geological Survey (USGS) topographic maps at latitudes 43° 45' on the north and 43° 30' on the south and at longitudes 119° 15' on the west and 118° 30' on the east. This study, performed under U. S. Department of Energy (USDOE) Contract No. DE FC07-79ET27220, was undertaken to estimate the geothermal potential of the area by 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 5,180-km^2 (200-mi^2) relatively flat, closed drainage basin surrounded by mountainous highlands. Total relief in the basin is less than 9 m (30 ft), and the total relief in the highlands is more than 600 m (2,000 ft). The only major population center is the county seat of Burns with the adjacent community of Hines, both of which are located on the western edge of the basin. The remainder of the northern Harney Basin is comprised of swampy bird habitat, cattle ranches and range land, and scrub forests in the higher elevations. Drainage within the basin is toward the south and east through Sage Hen Creek from the west, Silvies River from the north, and Malheur Slough from the east.

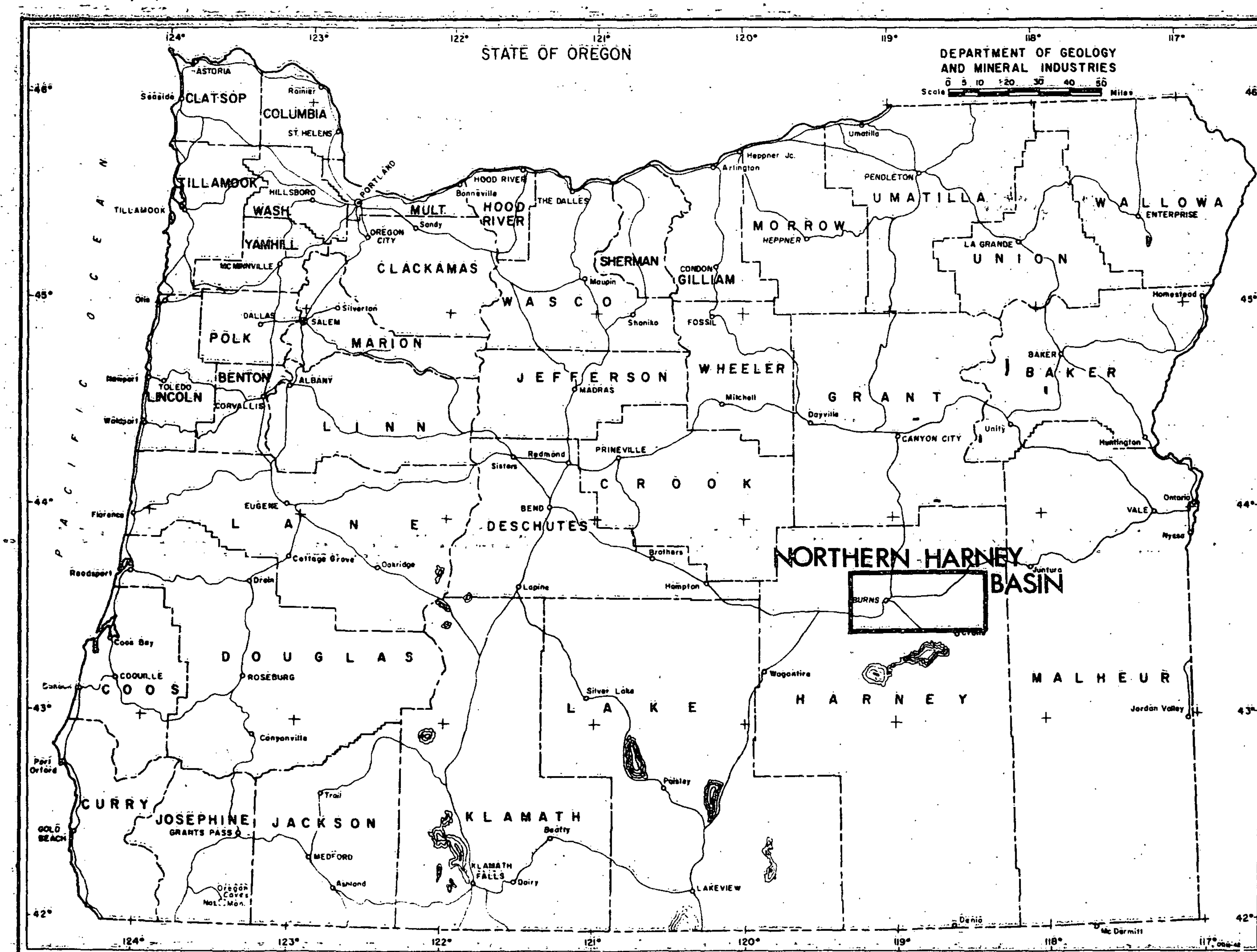

Figure 1: Map showing location of study area.

GEOLOGY

The geologic map (Plate I) of this area is based on (1) a field check of the published map by Greene (1972) of the Burns 15-minute quadrangle, with minor revisions, and (2) an original reconnaissance study, conducted during the fall of 1979 and the spring of 1980, of the Buchanan, Carson Point, Stinkingwater Pass, and Mahon Creek 7½-minute quadrangles and the Harney 15-minute quadrangle. Lithologies and age assignments were based on hand-specimen identification, limited K/Ar ages (Table 1), and bulk chemistry (Table 2). Areal extent of units and other field data were plotted on USGS topographic maps; specific points were located by Brunton compass and pacing. No aerial photographs were used in mapping.

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

Sample no.*	Location	Rock type	Age**	Stratigraphic unit
ML-114-75	118°37'30" 43°38'07"	Silicic dome	^{s}14.74±0.5 my	Tmrd
G-54-5-66	119°08'18" 43°30'48"	Rhyodacite	^{a}7.82±0.26 my	Tmrb
ML-33-75	119°18'12" 43°34'06"	Rhyolite	^{n}7.55±0.10 my	Tmrb
MK-3-79	119°08'12" 43°34'06"	Rhyolite	^{o}7.54±0.10 my	Tmrb
G-257-3-66	119°04'12" 43°37'42"	Welded tuff	^{a}6.82±0.33 my	Tmtr

* References: G - from Greene and others, 1972; ML - from McLeod and others, 1975; MK - from McKee and others, 1976.
**s - sanidine age; a - anorthoclase age; o - obsidian age; n - no method given.

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

Component	*G-9-3 Tmtd	G-9-6 Tmtd	B-0-20-2 Tmtp	G-9-1 Tmtd	B-0-19-2 Tmtr
SiO_2	73.6	74.1	74.27	75.2	75.82
TiO_2	0.26	0.28	0.18	0.21	0.22
Al_2O_3	11.2	12.2	13.73	11.6	12.59
FeO (Total Fe)	2.66	2.96	0.30	3.2	1.48
MgO	0.83	0.24	0.16	0.13	0.04
CaO	0.71	0.34	0.14	0.25	0.29
Na_2O	3.8	4.0	4.02	3.7	3.91
K_2O	4.5	4.6	4.37	4.4	4.18
Total	97.62	98.72	97.17	98.66	98.53

* References: G - from Greene, 1973; B - from Beeson, 1969.

The geology of the northern Harney Basin is comprised of a framework of three flat-lying, extensive, late Miocene ash-flow sheets onlapping a regional unit of early Miocene flood basalts. These ash flows, named in order of increasing age, the Rattlesnake (unit *Tmtr* on the geologic map), Prater Creek (unit *Tmtp*), and Devine Canyon (unit *Tmtd*) Ash-flow Tuffs, are separated by discrete sedimentary units, limited basalt and andesite flows, and silicic intrusions.

Trace element studies (Park and Armstrong, 1972) indicate that the ash-flow tuffs, the silicic intrusives, and the related mafic flows, for the study area as well as for adjacent areas to the south and west, constitute a genetically related bimodal compositional assemblage. Although detailed relationships are unclear at the time of this study, at least one caldera--the source for the Devine Canyon Ash-flow Tuff--is located in the study area near Burns (Walker, 1979). The oldest units recognized in the field were found in the northwest corner of the map area and are the early Miocene basalts (unit *Tmba*) dated in adjacent areas at 12.1 to 20.2 m.y. The youngest bedrock units are mafic vent complexes and associated flows (units *QTmv* and *QTb*) near Burns dated at 2.3 to 2.9 m.y. (Parker, 1974). Complete age relationships of all units are presented in the time-rock chart included on the geologic map (Plate I).

Faulting in the northern basin follows three general trends. The first is the trend of the Brothers fault zone (N.25°-35°W.), which is exhibited most strongly immediately west of Burns in the area of Burns Butte cutting all geologic units present including the aforementioned 2.3- to 2.9-m.y.-old basalts. Motion on these faults appears to be dip-slip; however, several investigators (MacLeod and others, 1975) feel such motion may be the surface manifestation of a right-lateral wrench system at depth. The second trend is the Basin-Range trend (approximately north-south) found throughout the eastern portion of the study area, cutting all lithologies present. Although some of these faults appear to be dip-slip, they may have some strike-slip or oblique-slip component, specifically along Soldier Creek in the north-central portion, where an extensively mineralized north-striking fault zone appears to contain some right-lateral component and may represent a major structural discontinuity for the basin. The third trend (N.40°-50°W.) occurs in the east-central portion of the study area and appears to represent a transitional trend between the Brothers trend and the Basin-Range trend. This transitional trend ends abruptly at the Soldier Creek shear zone.

A lineament study (Plate II) prepared for this report from U-2 and Landsat imagery shows a one-to-one correspondence of structural trends with the mapped fault trends. It also shows a number of lineaments that cross the alluvium-filled basin but which could not be traced through geologic mapping.

Folding of the units is generally in the form of broad, shallowly dipping anticlines and synclines plunging toward the center of the basin. Exceptions are several sharply folded local structures adjacent and probably subsequent to major faults (e.g., the Soldier Creek shear zone). In the past, investigators (Greene, 1972; Greene and others, 1972) have shown the northern highlands to be a homocline dipping into the basin off a core of older rocks to the north. However, the mapping connected with this study shows a large number of discrete fault blocks that dip away from the center of the basin. Downwarping of the basin itself probably began during the middle to late Miocene (Walker, 1979) and may be continuing at present. The probable cause of the downwarping is the loss of material by volcanic eruption from the extensive ash-flow sheets and numerous flood basalts and, to a lesser extent, the loss of volume due to loss of stored heat (Blackwell, 1980, personal communication).

GEOPHYSICS

At the present time, no geophysical surveys are available for the northern Harney Basin. Recommendations for future work in this extremly important area are included in the Conclusions and Recommendations section of this report.

WATER CHEMISTRY

During this study, fifteen wells, springs, and gradient holes were sampled and their waters analyzed. Together with existing published analyses (Leonard, 1970; U. S. Geological Survey and Oregon Department of Geology and Mineral Industries, 1979), a total of 21 analyses are available for evaluation (Table 3). Published reports of the hydrology of the Harney Basin (Piper and others, 1939; Leonard, 1970) show a considerable number of thermal anomalies; however, a large number of the listed springs and wells either could not be located or were not flowing at the time of the study.

Sampling temperatures during field collection ranged from 72°C for the O. J. Thomas well in the north-central portion of the study area to 17°-22°C for artesian wells and springs near the town of Burns. The natural waters of the study area can best be described as generally low in chloride and high in magnesium and bicarbonate. On the basis of preliminary evaluation of the available data, two groups of waters are recognized: (1) The wells near Soldier Creek and directly south, which appear to be relatively high in silica (72-104 mg/l) and show relatively high Na:K atomic ratios (144-260) and high contents of ions such as boron, arsenic, chloride, and fluoride. The estimated minimum reservoir temperatures for these wells are in the moderate range, calculated to be approximately 100°-130°C (Table 4). (2) The springs and wells near Burns, which are lower in silica (37-60 mg/l); lower in Na:K atomic ratios (11-15); lower in relative amounts of boron, arsenic, chloride, and fluoride; and lower in calculated reservoir temperatures (75° -100°C). They are also higher in magnesium, which is generally thought to indicate cooler waters or waters that have traveled a longer distance from their source (Fournier, 1980, personal communication). The cooler waters near Burns may represent a dilute species of the warmer waters found to the east; however,

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

	Cow Creek Spring	Bar Negative Well	Hotchkiss Well	Hotchkiss Well	Hotchkiss Well
Location	22 S/32½E/ 14Ca	23S/32E/ 28Acd	24S/30E/ 1Aca	24S/30E/ 1Aca	24S/30E/ 1Aca
Date sampled	9/31	7/68	10/80	8/31	9/68
Temp. (^{o}C)	22	16	33	27	27
pH	nt	7.6	8.37	nt	8.1
Conductance µmhos/cm	nt	771	220	nt	194
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	nt	30	30	nt	nt
Total dissolved solids	nt	511	166	nt	155
SiO_2	nt	52	45	51	46
Na	nt	172	30	30	31
K	nt	5.6	3	2.4	2.9
Ca	16	5.4	10	9.6	8.8
Mg	nt	3.9	2	1.7	1.4
Cl	1.9	16	7	5.2	5.0
As	nt	nt	<0.680	nt	nt
B	nt	1	0.3	nt	0.06
Li	nt	nt	<0.054	nt	nt
F	nt	0.8	0.5	nt	0.5
Fe (total)	nt	0.34	<0.027	0.01	nt
Al	nt	nt	<0.680	nt	nt
HCO_3	nt	nt	nt	95	93
PO_4	nt	nt	nt	nt	nt
SO_4	4	0.4	12	13	12
NO_3	nt	1.9	nt	1.2	1.1
NH_3	nt	nt	tr	nt	nt

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

	Hines Mill Well #1	Hines Mill Well #1	Hines Mill Well #2	Powerhouse Well	Millpond Spring
Location	23S/30E/ 35Aaa	23S/30E/ 35Aaa	23S/30E/ 26Dac	23S/30E/ 26Add	23S/30E/ 36Aaa
Date sampled	7/68	10/80	11/80	10/80	8/31
Temp. (^{o}C)	25	28.5	27.8	25	26
pH	7.8	7.9	8.18	8.04	nt
Conductance µmhos/cm	222	280	240	225	nt
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	nt	34.2	34	50	nt
Total dissolved solids	180	180	172	210	nt
SiO_2	55	45	42	37	nt
Na	33	29	26	30	nt
K	4	4	4	3	nt
Ca	11	10	9	7	14
Mg	2.0	2	2	1	nt
Cl	7.0	8	9	10	8
As	nt	<0.680	<0.680	<0.680	nt
B	0.38	0.3	0.3	0.3	nt
Li	nt	<0.054	<0.054	<0.054	nt
F	0.5	0.6	0.5	0.4	nt
Fe (total)	0.02	<0.027	<0.027	<0.027	nt
Al	nt	<0.680	<0.680	0.680	nt
HCO_3	105	nt	nt	nt	109
PO_4	nt	nt	nt	nt	nt
SO_4	14	12	10	14	11
NO_3	1.5	nt	nt	nt	1.1
NH_3	nt	<0.1	tr	0.3	nt

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

	Hines City Well	Goodman Spring	O.J. Thomas Well	O.J. Thomas Well	Potters Swamp Well
Location	23S/30E/ 23Cda	23S/30E/ 35Ddd	22S/32E/ 35Bbb	22S/32E/ 35Bbb	24S/30E/ 11Aba
Date sampled	7/68	9/68	9/68	5/80	5/80
Temp. (^{o}C)	17	22	72	72	27
pH	7.8	7.5	9.5	9.6	7.9
Conductance µmhos/cm	289	210	716	622	172
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	193_c	62_c
Hardness as mg/l $CaCO_3$	nt	nt	nt	2	22
Total dissolved solids	221	165	499	523	149
SiO_2	60	46	89	104	54.0
Na	35	35	157	147	28.6
K	6.9	3.2	1.8	1.3	2.3
Ca	15	8.2	1.0	0.3	7.7
Mg	5.7	1.4	0.2	<0.1	1.1
Cl	13	7	38	42	6.5
As	nt	nt	0.06	0.063	0.033
B	0.53	0.23	4.0	6.7	0.38
Li	nt	nt	nt	0.1	<0.1
F	0.5	0.6	2.8	5.1	0.5
Fe (total)	0.05	0.02	0.03	0.20	<0.05
Al	nt	nt	nt	0.41	<0.10
HCO_3	128	92	49	nt	nt
PO_4	nt	nt	nt	0.027	0.021
SO_4	18	16	89	75.9	13.9
NO_3	3.8	2.1	nt	0.03	0.28
NH_3	nt	nt	nt	0.90	0.03

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

	Rest Stop Well	Harney Valley Dev. Co. Oil Well	Harney Valley Dev. Co. Oil Well	Development Well	Fischer Well
Location	23S/30E/ 36Cbb	24S/32E/ 8Dab	24S/32E/ 8Dab	23S/30E/ 35Abd	24S/30E/ 2Dab
Date sampled	5/80	9/68	5/80	10/80	10/80
Temp. (^{o}C)	26	46	50	26.5	25.5
pH	8.0	9.6	9.9	8.33	8.43
Conductance μmhos/cm	177	602	540	230	210
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	73_c	nt	252_c	nt	nt
Hardness as mg/l $CaCO_3$	28	3	<1	15	30
Total dissolved solids	156	396	416	178	140
SiO_2	59.8	72	92	45	37
Na	28.9	135	119	32	30
K	2.6	1.6	0.8	4	3
Ca	8.9	0.8	0.1	8	7
Mg	1.3	0.2	0.1	2	1
Cl	6.1	11	20.5	8	8
As	0.019	nt	0.015	<0.680	<0.680
B	0.31	4.11	4.93	0.5	0.6
Li	<0.1	nt	<0.1	<0.054	<0.054
F	0.4	12	1.2	0.5	0.6
Fe (total)	<0.05	0.20	<0.05	<0.027	<0.027
Al	<0.10	nt	0.16	<0.680	<0.680
HCO_3	nt	94	nt	nt	nt
PO_4	0.044	nt	0.010	nt	nt
SO_4	13.0	29	9.7	13	15
NO_4	0.24	0.2	0.02	nt	nt
NH_3	0.05	nt	2.77	tr	tr

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

	Trailer Court Well	Soldier Creek Well #1 (50')	Soldier Creek Well #1 (600')	Burns High School Well
Location	23S/31E/ 36Bdc	22S/32E/ 32Aad	22S/32E/ 32Aad	23S/30E/ 13Cbc
Date Sampled	10/80	11/80	11/80	10/80
Temp. (^{o}C)	26.5	15	22	16.2
pH	8.24	8.26	8.23	7.2
Conductance µmhos/cm	210	nt	nt	nt
Alkalinity X_h as mg/l HCO_3 X_c as mg/l $CaCO_3$	nt	nt	nt	nt
Hardness as mg/l $CaCO_3$	30	nt	nt	51
Total dissolved solids	150	190	206	178
SiO_2	43	43	47	42
Na	28	22	24	12
K	3	3	4	3
Ca	9	16	15	8
Mg	1	2	1	4
Cl	6	6	5	27
As	<0.680	<0.625	<0.625	<0.625
B	0.2	<0.125	<0.125	<0.125
Li	0.054	<0.05	<0.05	<0.05
F	0.5	0.4	0.6	0.3
Fe (total)	<0.027	0.15	<0.025	<0.025
Al	<0.680	<0.625	<0.625	<0.625
HCO_3	nt	nt	nt	nt
PO_4	nt	nt	nt	nt
SO_4	11	14	15	4
NO_3	nt	nt	nt	nt
NH_3	tr	nt	nt	tr

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

	Bar Negative Well	Hotchkiss Well	Hotchkiss Well	Hotchkiss Well	Hines Lumber Co. Well #1
Flow rate liters/min.	100+	20	2271	2271	6624
Measured temperature °C	16	33	27	27	25
Na:K °C	107	175	160	170	190
Na:K:Ca 1/3 β °C	136	157	146	155	167
Na:K:Ca 4/3 β °C	118	62	56	64	70
Na:K:Ca Mg corrected °C	28	83	87	86	86
SiO_2 conductive °C	104	97	103	98	106
SiO_2 adiabatic °C	104	98	103	99	106
SiO_2 chalcedony °C	74	67	73	68	77
SiO_2 opal °C	-12	-18	-13	-17	-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 northern Harney Basin -- Continued

	City of Hines Well	Goodman Spring (Hotchkiss)	Hines Mill Well #1	Hines Mill Well #2	Powerhouse Well
Flow rate liters/min.	2555	79	pumped	pumped	pumped
Measured temperature °C	17	22	28.5	27.8	25
Na:K °C	230	169	199	208	175
Na:K:Ca 1/3 β °C	192	156	172	177	159
Na:K:Ca 4/3 β °C	81	69	70	71	69
Na:K:Ca Mg corrected °C	57	81	90	89	106
SiO_2 conductive °C	111	98	97	94	88
SiO_2 adiabatic °C	110	99	98	96	91
SiO_2 chalcedony °C	81	68	67	63	57
SiO_2 opal °C	-7	-17	-18	-21	-25

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

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

	O.J. Thomas Well	O.J. Thomas Well	Potters Swamp Well	Rest Stop Well	Harney Valley Dev. Co. Oil Test Well
Flow rate liters/min.	1000+	1000+	100+	pumped	100+
Measured temperature °C	72	72	27	26	46
Na:K °C	60	50	160	168	61
Na:K:Ca 1/3 β °C	104	101	147	152	105
Na:K:Ca 4/3 β °C	116	135	59	60	115
Na:K:Ca Mg corrected °C	99	NC	102	71	96
SiO_2 conductive °C	131	139	105	110	120
SiO_2 adiabatic °C	127	135	106	110	118
SiO_2 chalcedony °C	103	113	76	81	91
SiO_2 opal °C	11	19	-11	-7	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 northern Harney Basin -- Continued

	Harney Valley Dev. Co. Oil Test Well	Development Well	Fischer Well	Trailer Court Well
Flow rate liters/min.	100+	pumped	pumped	pumped
Measured temperature °C	50	26.5	25.5	26.5
Na:K °C	40	192	175	180
Na:K:Ca 1/3 β °C	126	171	159	160
Na:K:Ca 4/3 β °C	143	76	69	63
Na:K:Ca Mg corrected °C	71	71	101	115
SiO_2 conductive °C	133	97	88	95
SiO_2 adiabatic °C	129	98	91	97
SiO_2 chalcedony °C	105	67	57	64
SiO_2 opal °C	13	-18	-25	-20

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

the limited data of this reconnaissance study are inconclusive on this point. Therefore, before detailed analyses of fluid provenance and movement can be made, a detailed sampling program including oxygen-, hydrogen-, and sulfate-isotope analyses must be undertaken.

GEOTHERMAL-GRADIENT AND HEAT-FLOW DATA*

The temperature-gradient and heat-flow results for the north 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 Plate I. 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^oC (TCU) = 0.4184 $Wm^{-1}K^{-1}$, and $1^oC/Km$ = 1 mKm^{-1} =18.2^oF/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 north Harney Basin have been obtained in holes drilled as water wells, so most thermal-conductivity values are estimated (parenthesis) or based on one or two cutting samples from surface spoil piles. Several of the holes are artesian, and gradients are estimated based on the bottom hole temperature and the assumed surface temperature. These gradients are maximum values, because some

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Table 5. Geothermal-gradient data, north 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
22S/32E-27BA	43-38.53	118-52.35	TILLER 2 5/22/80	1277	19.00	20.0 57.0	(.96)		72.1 4.7	71.0	68	C
22S/32E-26BB	43-38.35	118-51.62	TVRDY 5/21/80	1279	12.95	10.0 40.0	(.96)		68.1 3.6	68.1	66	C
22S/32E-27AC	43-38.30	118-54.17	TILLER 3 5/22/80	1286	20.12	10.0 25.0			226.0 12.7	226.0		
						25.0 96.0	(.96)		72.4 3.5	72.4	70	C
22S/32E-27CB	43-38.08	118-52.75	TILLER 1 5/22/80	1265	16.48	5.0 100.0	(.96)		78.6 2.4	78.6	76	B
22S/33E-27CD	43-37.62	118-38.50	TEMPLE 5/20/80	1268	15.84	.0 138.0			> 48.0			X
22S/32E-31DB	43-37.20	118-55.67	BLCKBURN 5/22/80	1269	12.79	15.0 48.0	(.96)		53.5 2.2	53.5	51	C
22S/32E-34CC	43-36.90	118-52.60	RICE 6/11/75	1260	27.39	.0 95.0	(.96)		<140.0	<140.0	< 134	C
22S/32E-34DD	43-36.87	118-51.88	HWY 20 5/20/80	1261	29.19	10.0 35.0			573.8 15.2	573.7		C
						35.0 60.0			181.7 .3	181.7		C
						10.0 62.0	(.96)		355.0 70.2	354.9	341	B
23S/32E-6CB	43-36.32	118-49.17	*HANSON 5/22/80	1259	13.69	5.0 51.0	(.96)		74.6 1.7	74.5	72	B
24S/32E-1AD	43-31.33	118-49.32	NINEMILE 5/16/80	1257	38.45	10.0 35.0			273.5 3.8	273.5		C
						35.0 60.0			189.5 .2	189.5		C
						60.0 130.0			155.8 1.7	155.7		C
						130.0 160.0			97.8 .1	97.8		C

Table 5. Geothermal-gradient data, north 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
						10.0 160.0	(.96)		165.8 14.1	165.8	159	C
24S/32E- 8DA	43-30.23	118-54.27	STEVENS 5/15/80	1256	54.82	.0 176.0	(.96)			<284.0		C

portion of the flow may come from deeper than the maximum depth actually logged. Also, some of the holes show large variation in geothermal gradient with depth, indicating some nonconductive effect on the data. Complete interpretation of the data set will require detailed understanding of the hydrologic and geologic conditions.

CONCLUSIONS AND RECOMMENDATIONS

The reconnaissance study performed for the northern Harney Basin has tentatively defined two low-temperature resource areas within piping distance of Burns which merit further investigation. They are (1) the area near the Soldier Creek shear zone (Plate I) and (2) the area immediately south, west, and east of the city of Burns. Site-specific analyses of these two areas should be carried out under one field program and include the following:

1. Detailed (scale of 1:24,000 or less) geologic and photogeologic mapping of Burns and Harney 15-minute quadrangles -- to identify and evaluate active and/or thermal structures.
2. Detailed spring and well sampling and analyses, including isotope analyses -- to determine fluid flow directions and provenance.
3. Closely spaced complete Bouguer and residual gravity anomaly studies and aeromagnetic studies -- to delineate possible active thermal structures below the basin fill.
4. Several resistivity traverses (either dipole-dipole, roving dipole, or telluric) in an east-west direction -- in order to further define the thermal regime.
5. A microearthquake/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 the geothermal system.
6. A program of twenty to thirty 500-ft gradient/stratigraphy holes, followed by a program of five to ten 2,000-ft gradient holes -- to model heat flow and directly test geothermal aquifers.

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APPENDIX A

Formulas used in calculations

Na:K (revised):

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

Na:K:Ca:

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

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^oC = calculated reservoir temperature,

and concentrations are expressed in molality.

Magnesium correction ratio:

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

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

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

where R = magnesium correction ratio expressed in equivalents,

Δt_{Mg} = the temperature correction that is subtracted from the Na:K:Ca 1/3 β calculated temperature,

T = Na:K:Ca 1/3 β calculated temperature in ^{o}K.

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

SiO_2 temperature calculations (Fournier and Rowe, 1966):

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

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

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

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

where SiO_2 is expressed in mg/l.

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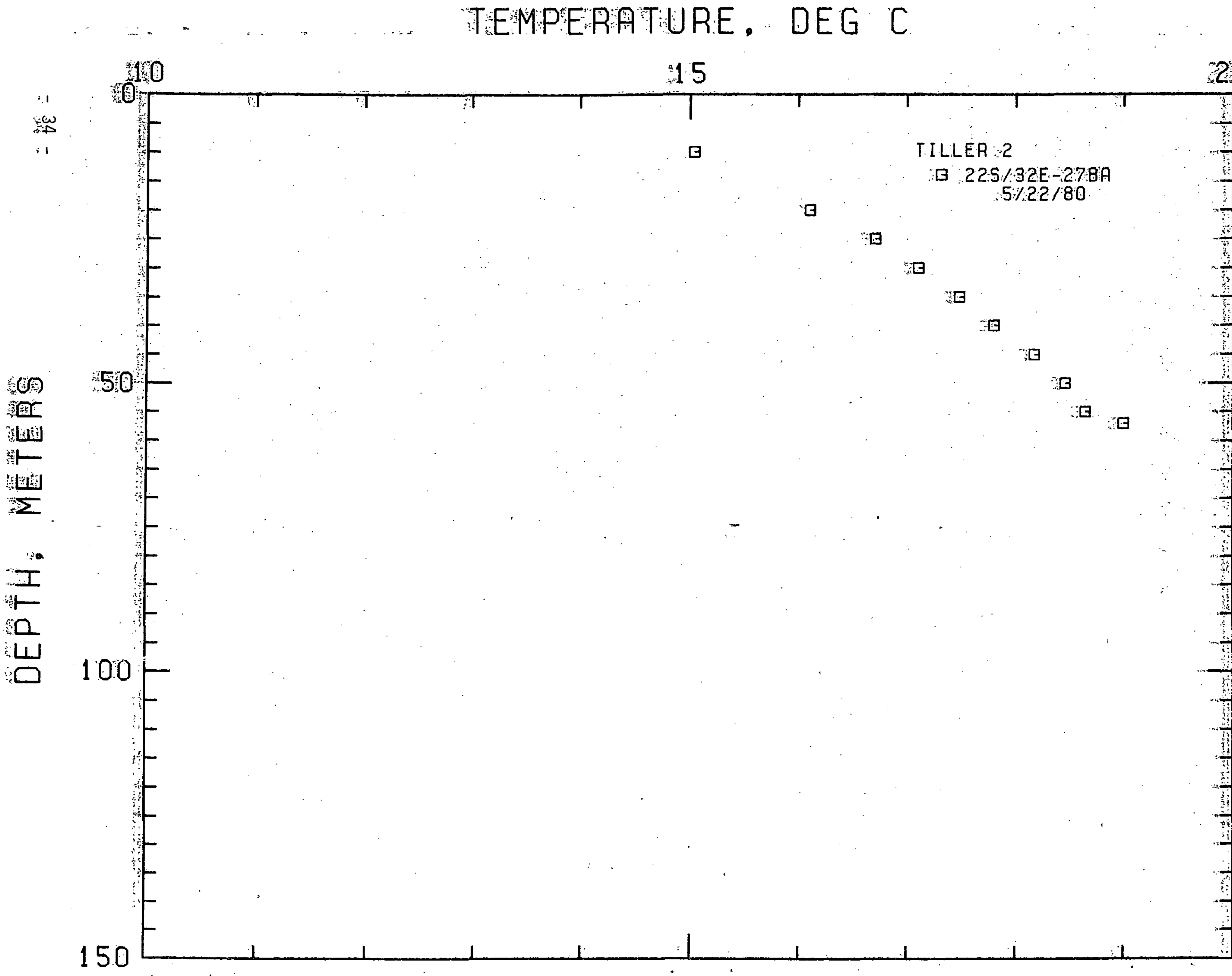
APPENDIX B

Geothermal-gradient data

LOCATION: BURNS AMS, OREGON
22S/32E-27BA
HOLE NAME: TILLER 2
DATE MEASURED: 5/22/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	DEG C	DEG F	DEG C/KM	DEG F/100 FT
10.0	32.8	15.040	59.07	0.0	0.0
20.0	65.6	16.110	61.00	107.0	5.9
25.0	82.0	16.710	62.08	120.0	6.6
30.0	98.4	17.100	62.78	78.0	4.3
35.0	114.8	17.480	63.46	76.0	4.2
40.0	131.2	17.800	64.04	64.0	3.5
45.0	147.6	18.170	64.71	74.0	4.1
50.0	164.0	18.460	65.23	58.0	3.2
55.0	180.4	18.650	65.57	38.0	2.1
57.0	187.0	19.000	66.20	175.0	9.6


TEMPERATURE, DEG C
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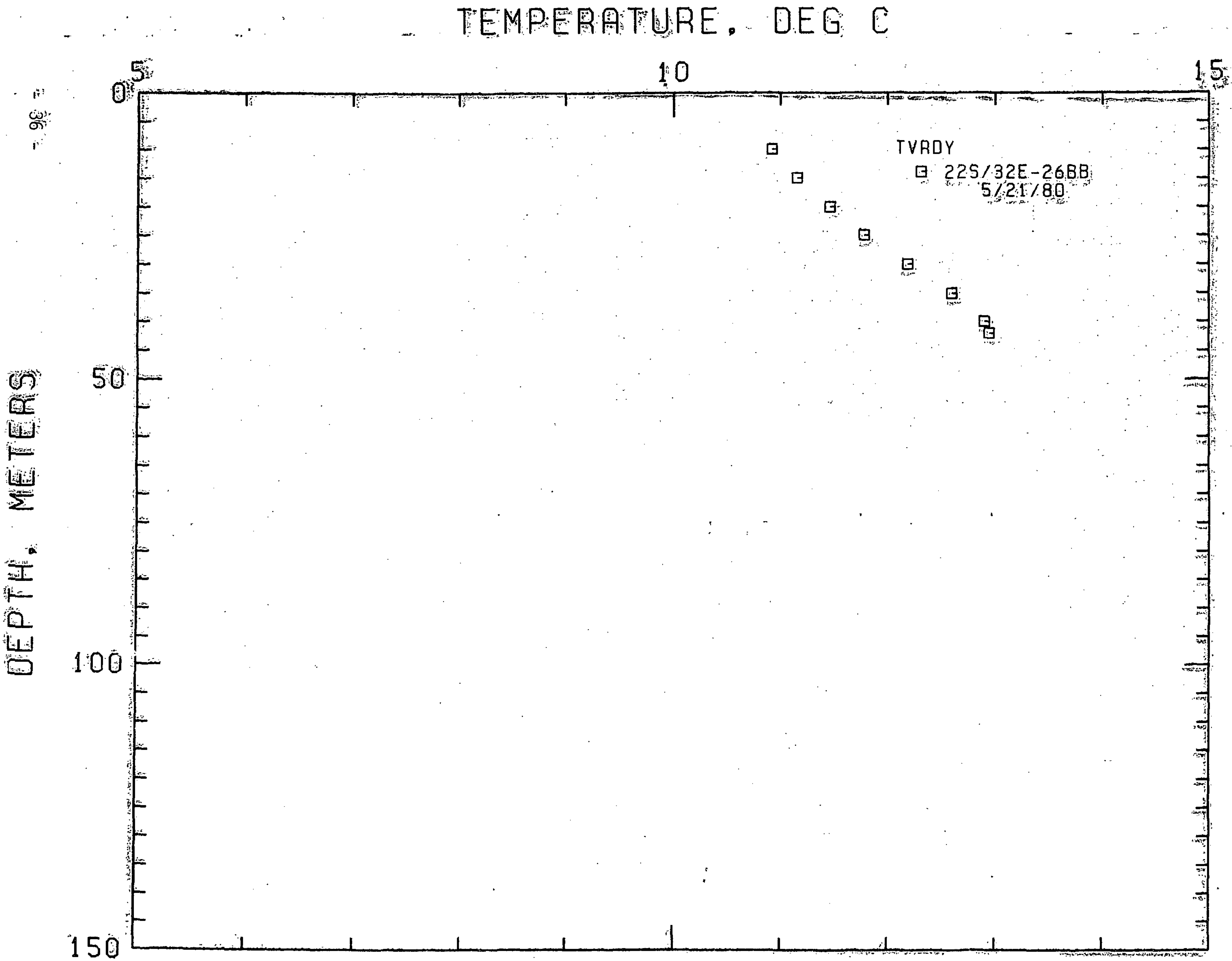
DEPTH, METERS
TILLER 2
22S/32E-27BA
5/22/80

LOCATION: BURNS AMS, OREGON
22S/32E-26BB
HOLE NAME: TVRDY
DATE MEASURED: 5/21/80

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	10.920	51.66	0.0	0.0
15.0	49.2	11.160	52.09	48.0	2.6
20.0	65.6	11.470	52.65	62.0	3.4
25.0	82.0	11.780	53.20	62.0	3.4
30.0	98.4	12.190	53.94	82.0	4.5
35.0	114.8	12.600	54.68	82.0	4.5
40.0	131.2	12.900	55.22	60.0	3.3
42.0	137.8	12.950	55.31	25.0	1.4


TEMPERATURE, DEG C
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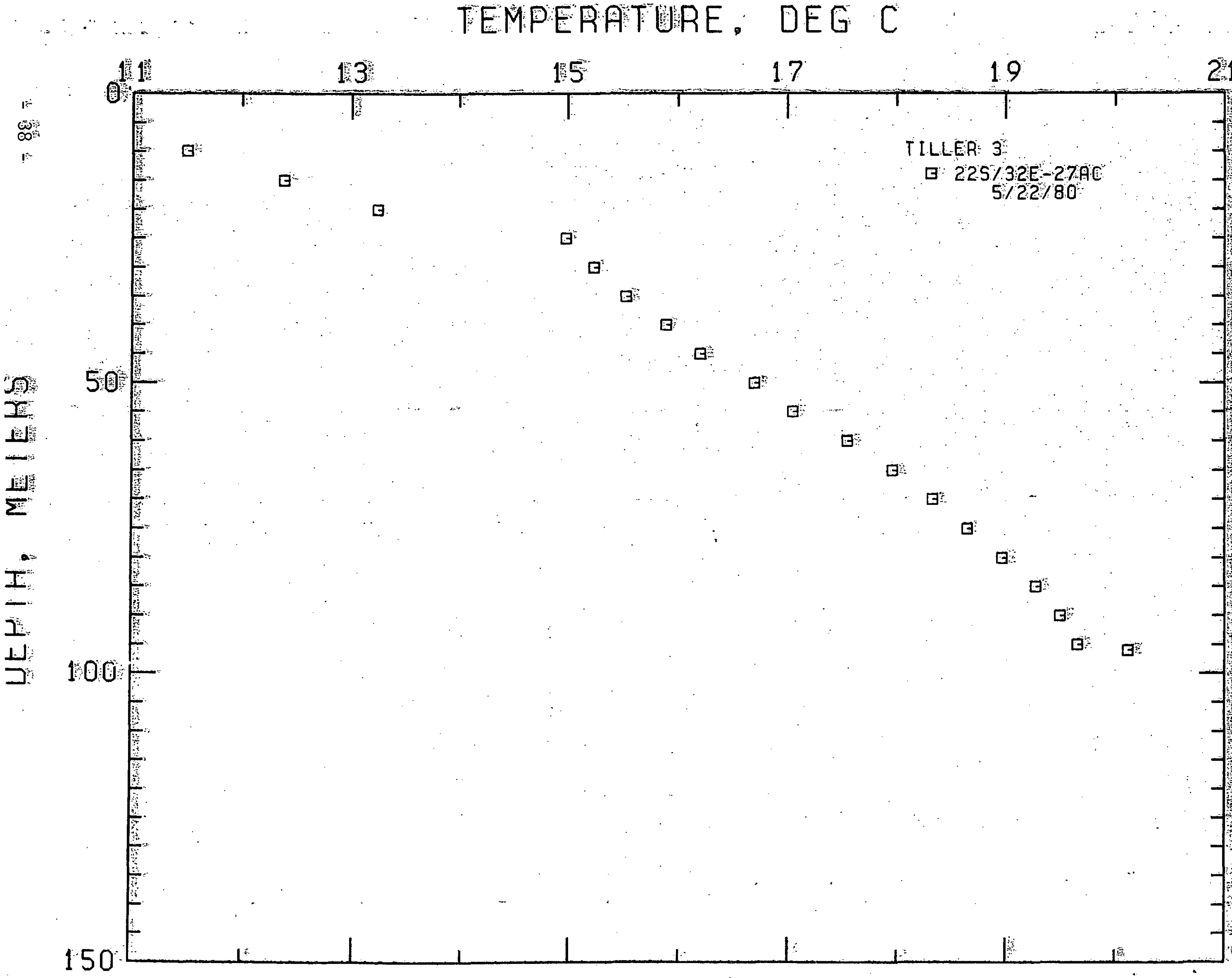
DEPTH, METERS
TVRDY
22S/32E-26BB
5/21/80

- 36 -

LOCATION: BURNS AMS, OREGON
22S/32E-27AC
HOLE NAME: TILLER 3
DATE MEASURED: 5/22/80

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	11.500	52.70	0.0	0.0
15.0	49.2	12.380	54.28	176.0	9.7
20.0	65.6	13.240	55.83	172.0	9.4
25.0	82.0	14.980	58.96	348.0	19.1
30.0	98.4	15.240	59.43	52.0	2.9
35.0	114.8	15.530	59.95	58.0	3.2
40.0	131.2	15.890	60.60	72.0	4.0
45.0	147.6	16.200	61.16	62.0	3.4
50.0	164.0	16.700	62.06	100.0	5.5
55.0	180.4	17.050	62.69	70.0	3.8
60.0	196.8	17.550	63.59	100.0	5.5
65.0	213.2	17.960	64.33	82.0	4.5
70.0	229.6	18.330	64.99	74.0	4.1
75.0	246.0	18.650	65.57	64.0	3.5
80.0	262.4	18.970	66.15	64.0	3.5
85.0	278.8	19.280	66.70	62.0	3.4
90.0	295.2	19.500	67.10	44.0	2.4
95.0	311.6	19.660	67.39	32.0	1.8
96.0	314.9	20.120	68.22	460.0	25.2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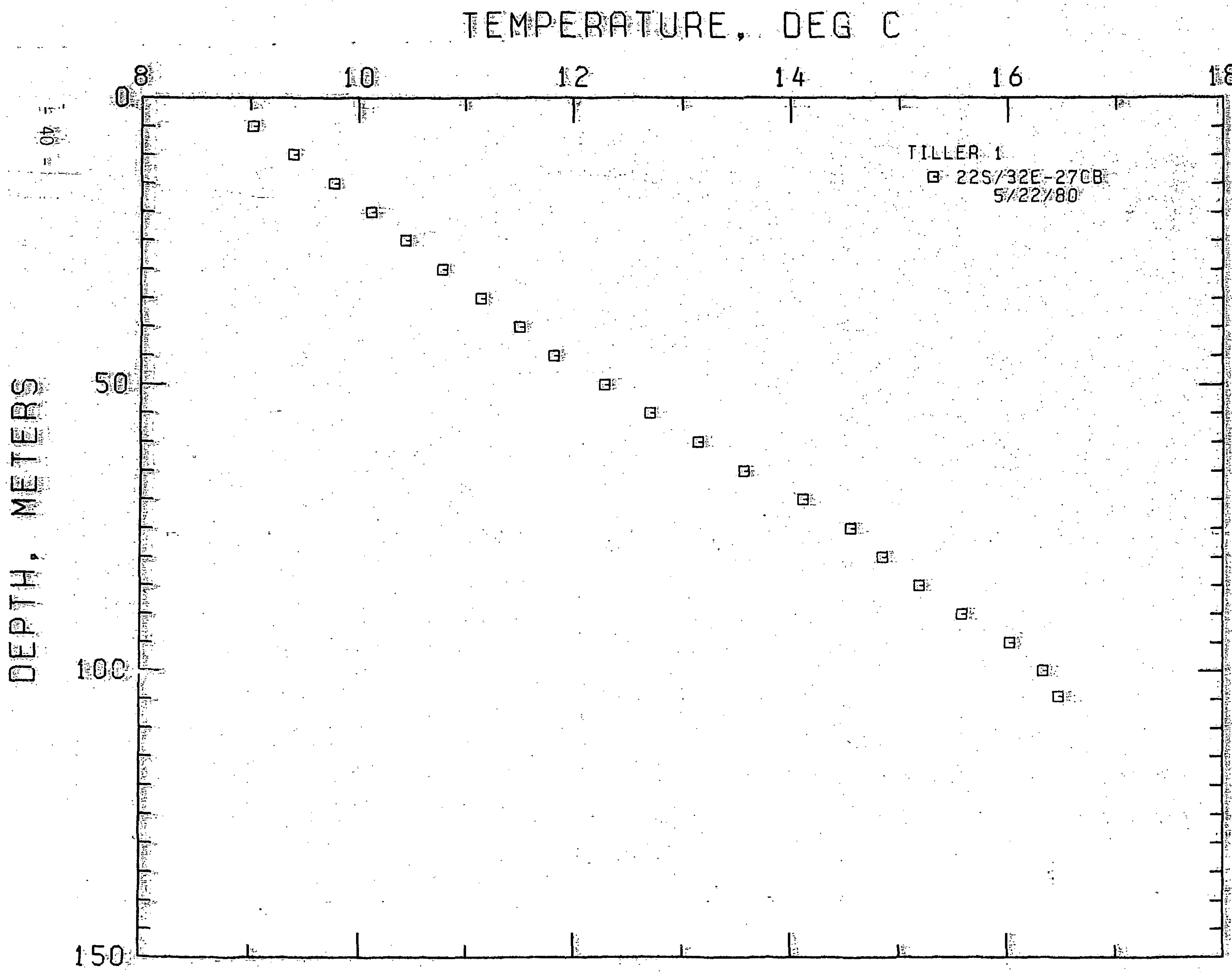
DEPTH, METERS
TILLER 3
22S/32E-27AC
5/22/80

LOCATION: BURNS AMS, OREGON
22S/32E-27CB
HOLE NAME: TILLER 1
DATE MEASURED: 5/22/80

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	9.030	48.25	0.0	0.0
10.0	32.8	9.400	48.92	74.0	4.1
15.0	49.2	9.770	49.59	74.0	4.1
20.0	65.6	10.120	50.22	70.0	3.8
25.0	82.0	10.440	50.79	64.0	3.5
30.0	98.4	10.790	51.42	70.0	3.8
35.0	114.8	11.150	52.07	72.0	4.0
40.0	131.2	11.510	52.72	72.0	4.0
45.0	147.6	11.830	53.29	64.0	3.5
50.0	164.0	12.290	54.12	92.0	5.0
55.0	180.4	12.710	54.88	84.0	4.6
60.0	196.8	13.140	55.65	86.0	4.7
65.0	213.2	13.570	56.43	86.0	4.7
70.0	229.6	14.120	57.42	110.0	6.0
75.0	246.0	14.560	58.21	88.0	4.8
80.0	262.4	14.850	58.73	58.0	3.2
85.0	278.8	15.190	59.34	68.0	3.7
90.0	295.2	15.590	60.06	80.0	4.4
95.0	311.6	16.030	60.85	88.0	4.8
100.0	328.0	16.340	61.41	62.0	3.4
104.5	342.8	16.480	61.66	31.1	1.7



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DEPTH, METERS
TILLER 1
22S/32E-27CB
5/22/80

LOCATION: BURNS AMS, OREGON
22S/33E-27CD
HOLE NAME: TEMPLE
DATE MEASURED: 5/20/80

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	9.650	49.37	0.0	0.0
15.0	49.2	9.670	49.41	4.0	0.2
20.0	65.6	9.680	49.42	2.0	0.1
25.0	82.0	9.690	49.44	2.0	0.1
30.0	98.4	9.690	49.44	0.0	0.0
35.0	114.8	9.710	49.48	4.0	0.2
40.0	131.2	9.750	49.55	8.0	0.4
45.0	147.6	9.730	49.51	-4.0	-0.2
50.0	164.0	9.750	49.55	4.0	0.2
55.0	180.4	9.770	49.59	4.0	0.2
60.0	196.8	9.770	49.59	0.0	0.0
65.0	213.2	9.810	49.66	8.0	0.4
70.0	229.6	9.850	49.73	8.0	0.4
75.0	246.0	9.860	49.75	2.0	0.1
80.0	262.4	9.840	49.71	-4.0	-0.2
85.0	278.8	9.840	49.71	0.0	0.0
90.0	295.2	9.830	49.69	-2.0	-0.1
95.0	311.6	9.850	49.73	4.0	0.2
100.0	328.0	9.870	49.77	4.0	0.2
105.0	344.4	9.870	49.77	0.0	0.0
110.0	360.8	9.890	49.80	4.0	0.2
115.0	377.2	9.890	49.80	0.0	0.0
120.0	393.6	9.880	49.78	-2.0	-0.1
125.0	410.0	9.910	49.84	6.0	0.3
130.0	426.4	13.030	55.45	624.0	34.2
135.0	442.8	15.310	59.56	456.0	25.0
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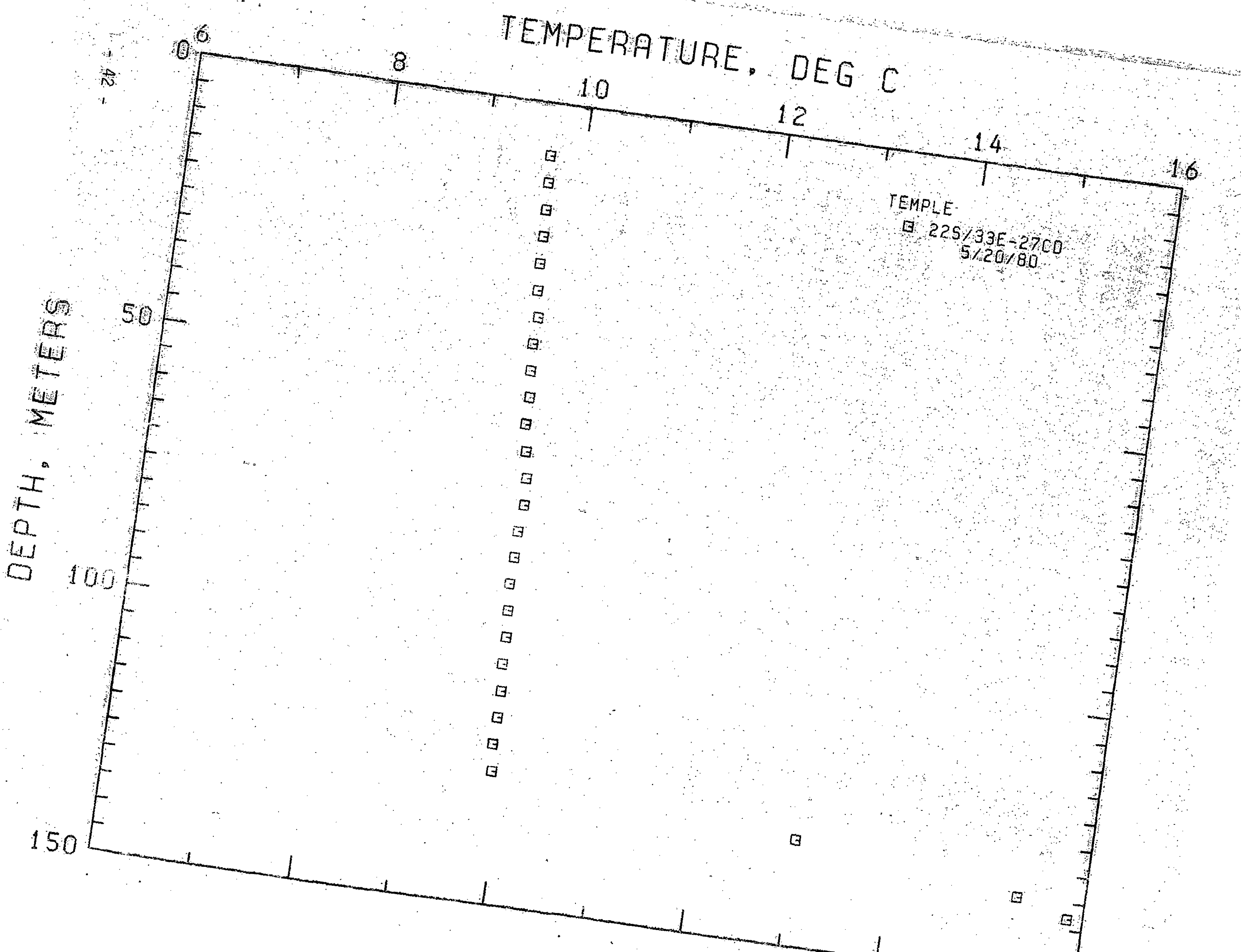

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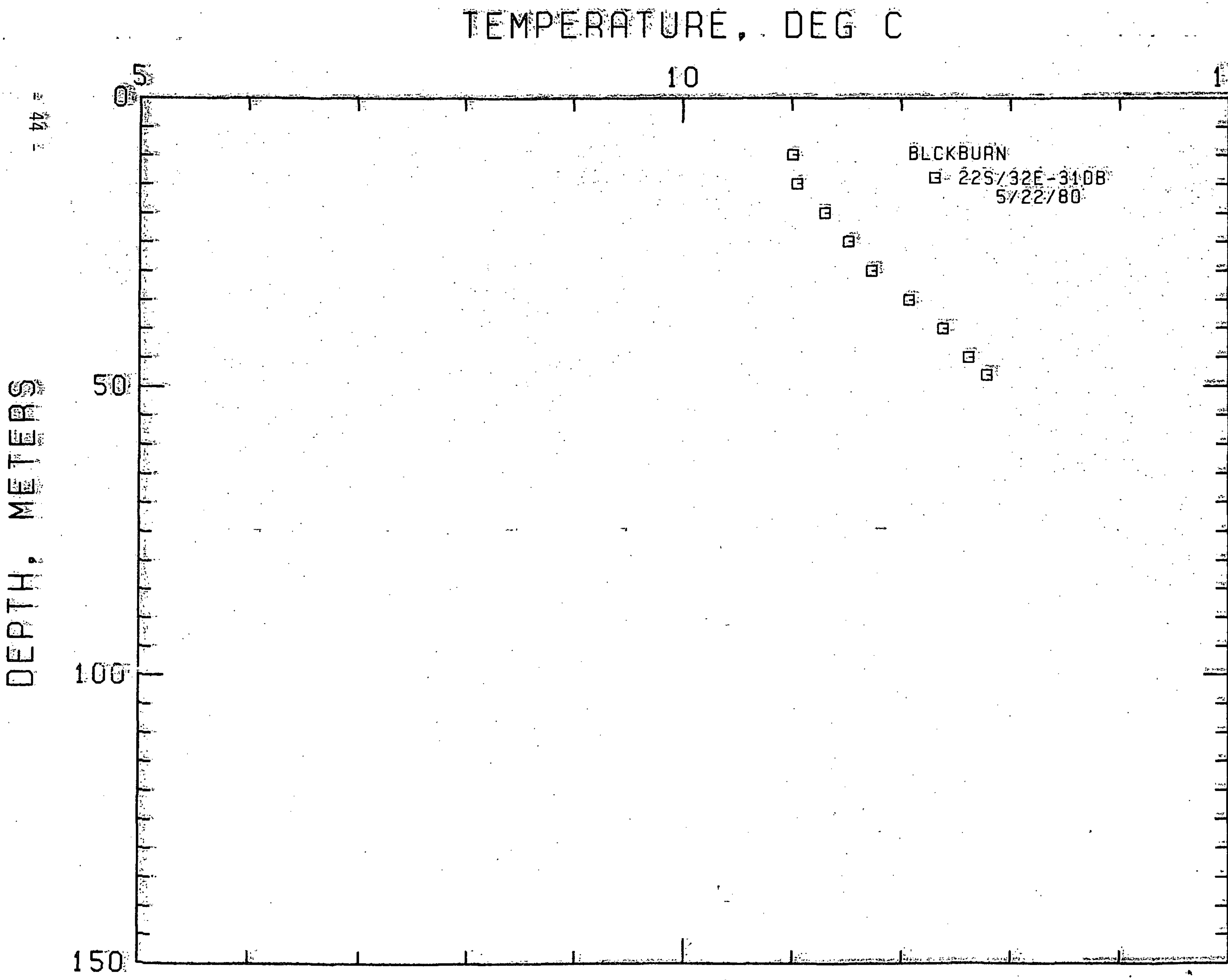
22S/33E-27CD
5/20/80

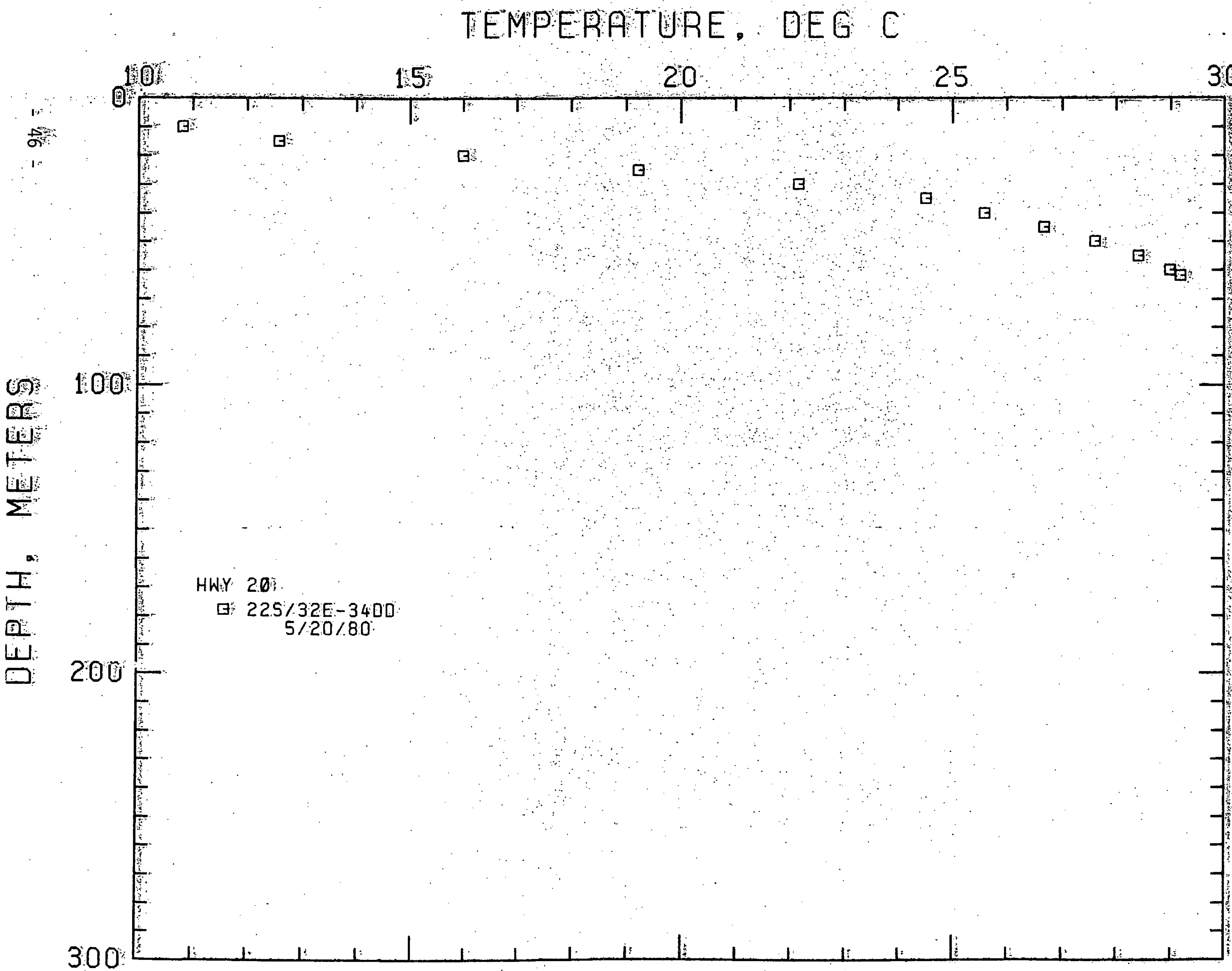
LOCATION: BURNS AMS, OREGON
22S/32E-31DB
HOLE NAME: BLCKBURN
DATE MEASURED: 5/22/80

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	11.010	51.82	0.0	0.0
15.0	49.2	11.050	51.89	8.0	0.4
20.0	65.6	11.300	52.34	50.0	2.7
25.0	82.0	11.520	52.74	44.0	2.4
30.0	98.4	11.730	53.11	42.0	2.3
35.0	114.8	12.080	53.74	70.0	3.8
40.0	131.2	12.390	54.30	62.0	3.4
45.0	147.6	12.620	54.72	46.0	2.5
48.0	157.4	12.790	55.02	56.7	3.1


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
BLCKBURN
22S/32E-310B
5/22/80

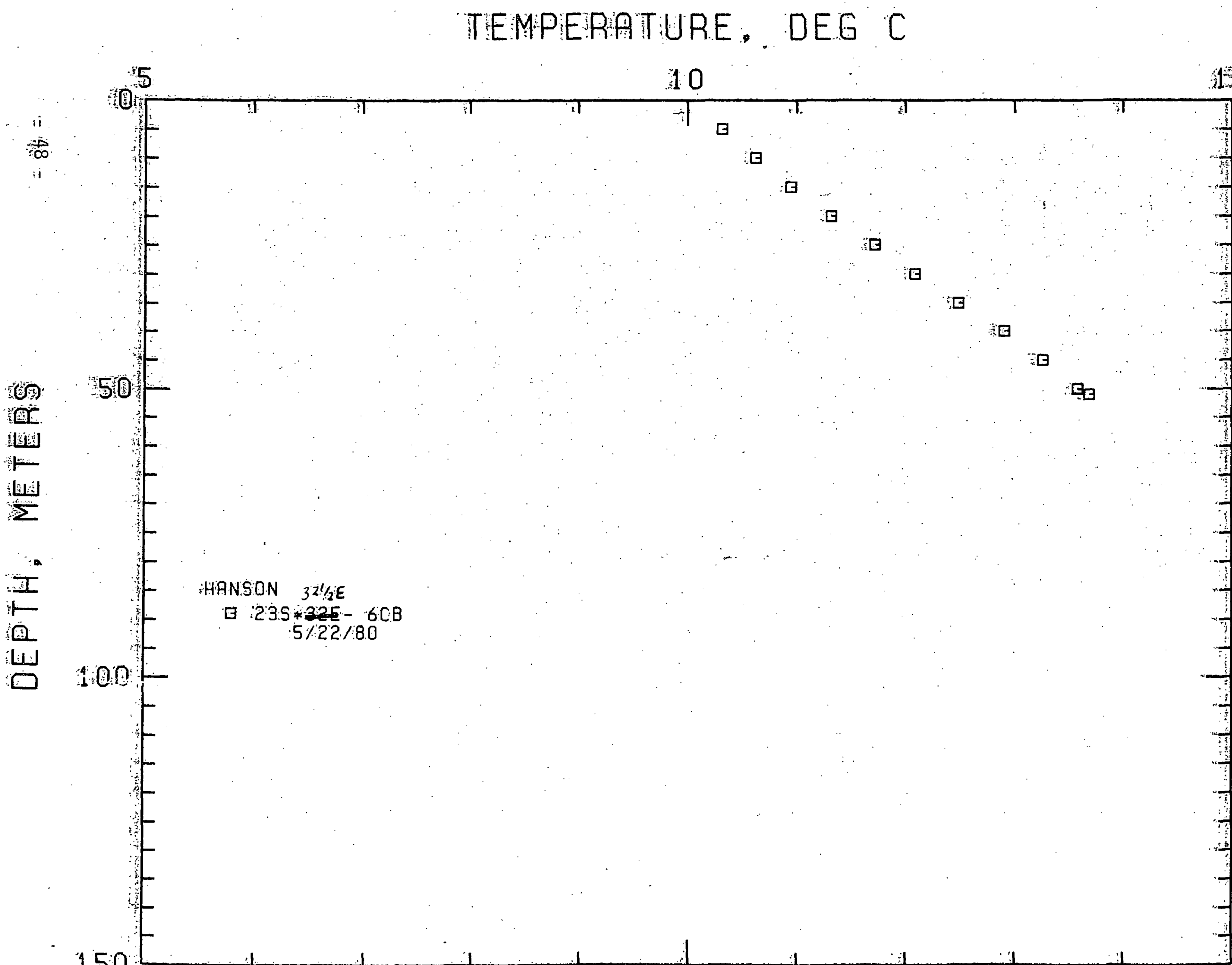
LOCATION: BURNS AMS, OREGON
22S/32E-34DD
HOLE NAME: HWY 20
DATE MEASURED: 5/20/80

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	10.820	51.48	0.0	0.0
15.0	49.2	12.580	54.64	352.0	19.3
20.0	65.6	16.000	60.80	684.0	37.5
25.0	82.0	19.220	66.60	644.0	35.3
30.0	98.4	22.160	71.89	588.0	32.3
35.0	114.8	24.510	76.12	470.0	25.8
40.0	131.2	25.590	78.06	216.0	11.9
45.0	147.6	26.670	80.01	216.0	11.9
50.0	164.0	27.610	81.70	188.0	10.3
55.0	180.4	28.410	83.14	160.0	8.8
60.0	196.8	28.990	84.18	116.0	6.4
62.0	203.4	29.190	84.54	100.0	5.5


TEMPERATURE, DEG C
10
15
20
25
30
0
100
200
300
DEPTH, METERS
HWY 2Ø
22S/32E-3400
5/20/80

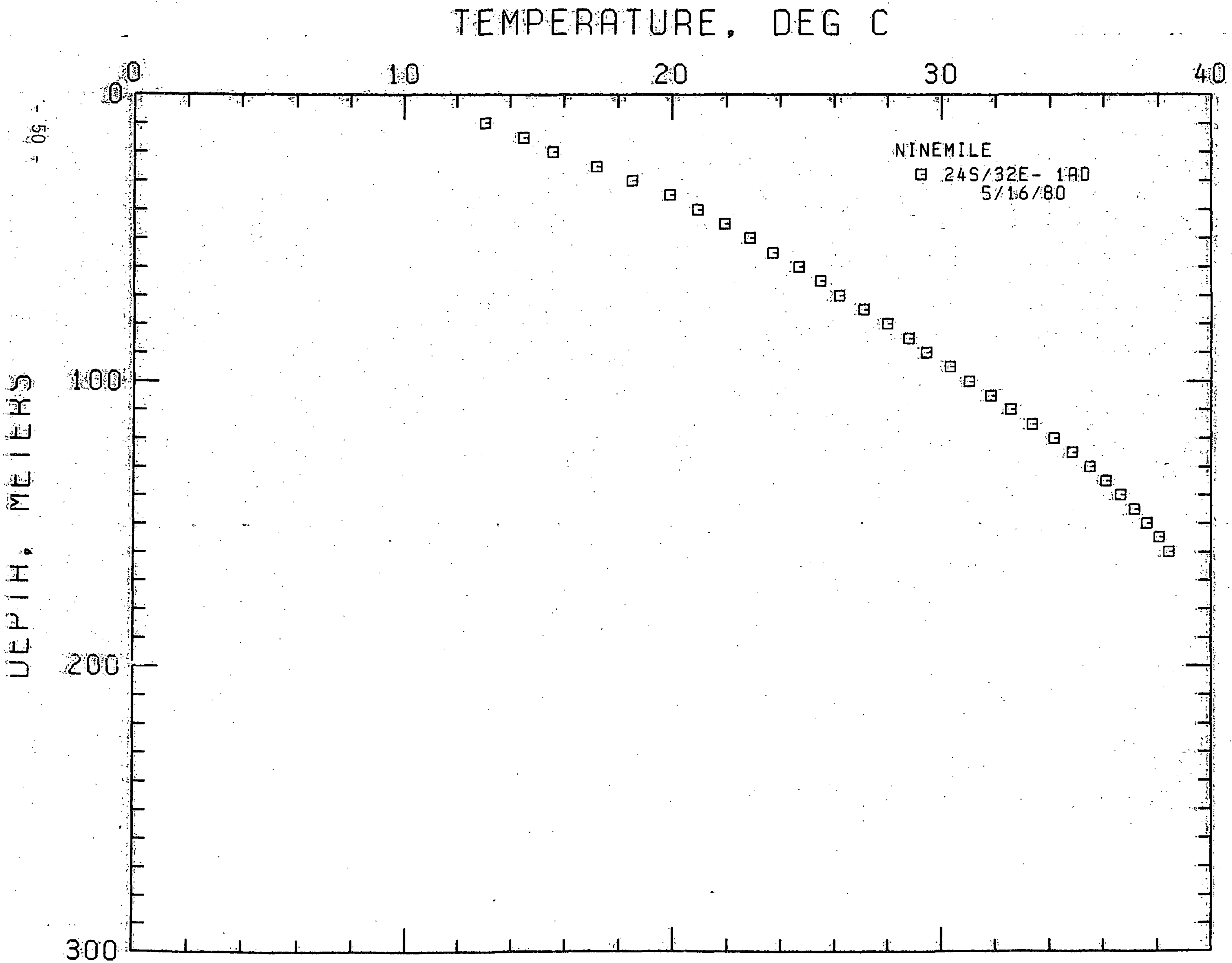
LOCATION: BURNS AMS, OREGON
23S*~~32E~~- 6CB 32½ E
HOLE NAME: HANSON
DATE MEASURED: 5/22/80

DEPTH	DEPTH	TEMPERATURE		GEOTHERMAL GRADIENT	
METERS	FEET	DEG C	DEG F	DEG C/KM	DEG F/100 FT
5.0	16.4	10.320	50.58	0.0	0.0
10.0	32.8	10.630	51.13	62.0	3.4
15.0	49.2	10.950	51.71	64.0	3.5
20.0	65.6	11.320	52.38	74.0	4.1
25.0	82.0	11.720	53.10	80.0	4.4
30.0	98.4	12.090	53.76	74.0	4.1
35.0	114.8	12.490	54.48	80.0	4.4
40.0	131.2	12.910	55.24	84.0	4.6
45.0	147.6	13.260	55.87	70.0	3.8
50.0	164.0	13.580	56.44	64.0	3.5
51.0	167.3	13.690	56.64	110.0	6.0


TEMPERATURE, DEG C
5
10
15
0
50
100
150
DEPTH, METERS
HANSON 32½E
23S*32E- 6CB
5/22/80

LOCATION: BURNS AMS, OREGON
24S/32E- 1AD
HOLE NAME: NINEMILE
DATE MEASURED: 5/16/80

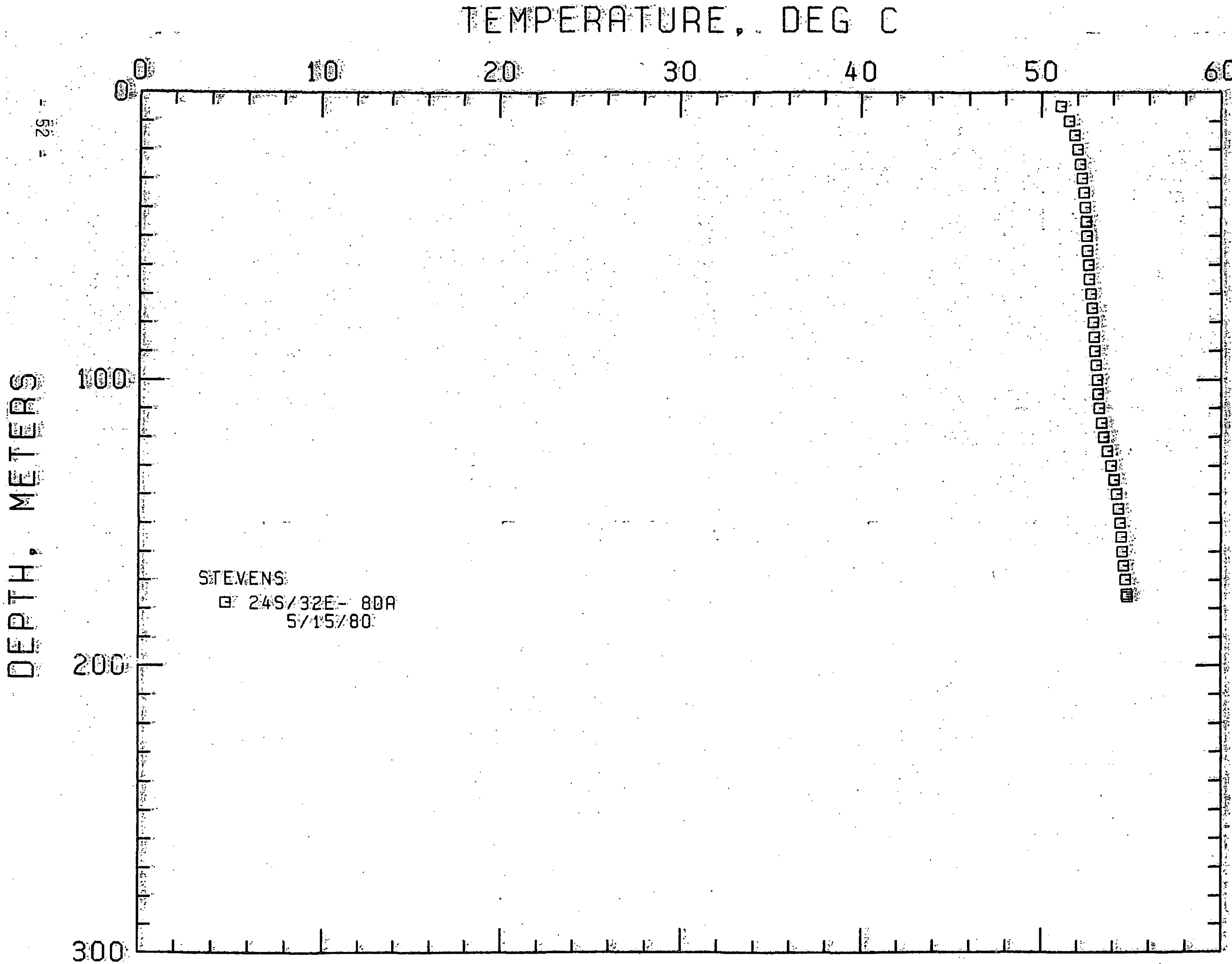
DEPTH METERS	DEPTH FEET	TEMPERATURE DEG C	TEMPERATURE DEG F	GEOTHERMAL GRADIENT DEG C/KM	GEOTHERMAL GRADIENT DEG F/100 FT
10.0	32.8	13.080	55.54	0.0	0.0
15.0	49.2	14.510	58.12	286.0	15.7
20.0	65.6	15.590	60.06	216.0	11.9
25.0	82.0	17.200	62.96	322.0	17.7
30.0	98.4	18.530	65.35	266.0	14.6
35.0	114.8	19.920	67.86	278.0	15.3
40.0	131.2	20.970	69.75	210.0	11.5
45.0	147.6	21.940	71.49	194.0	10.6
50.0	164.0	22.880	73.18	188.0	10.3
55.0	180.4	23.730	74.71	170.0	9.3
60.0	196.8	24.710	76.48	196.0	10.8
65.0	213.2	25.500	77.90	158.0	8.7
70.0	229.6	26.190	79.14	138.0	7.6
75.0	246.0	27.110	80.80	184.0	10.1
80.0	262.4	27.990	82.38	176.0	9.7
85.0	278.8	28.790	83.82	160.0	8.8
90.0	295.2	29.470	85.05	136.0	7.5
95.0	311.6	30.320	86.58	170.0	9.3
100.0	328.0	31.040	87.87	144.0	7.9
105.0	344.4	31.850	89.33	162.0	8.9
110.0	360.8	32.560	90.61	142.0	7.8
115.0	377.2	33.360	92.05	160.0	8.8
120.0	393.6	34.180	93.52	164.0	9.0
125.0	410.0	34.860	94.75	136.0	7.5
130.0	426.4	35.510	95.92	130.0	7.1
135.0	442.8	36.120	97.02	122.0	6.7
140.0	459.2	36.660	97.99	108.0	5.9
145.0	475.6	37.170	98.91	102.0	5.6
150.0	492.0	37.620	99.72	90.0	4.9
155.0	508.4	38.080	100.54	92.0	5.0
160.0	524.8	38.450	101.21	74.0	4.1



TEMPERATURE, DEG C
0
10
20
30
40
0
100
200
300
DEPTH, METERS
NINEMILE
24S/32E- 1AD
5/16/80

LOCATION: BURNS AMS, OREGON
24S/32E- 8DA
HOLE NAME: STEVENS
DATE MEASURED: 5/15/80

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	51.080	123.94	0.0	0.0
10.0	32.8	51.580	124.84	100.0	5.5
15.0	49.2	51.880	125.38	60.0	3.3
20.0	65.6	52.050	125.69	34.0	1.9
25.0	82.0	52.180	125.92	26.0	1.4
30.0	98.4	52.300	126.14	24.0	1.3
35.0	114.8	52.390	126.30	18.0	1.0
40.0	131.2	52.470	126.45	16.0	0.9
45.0	147.6	52.530	126.55	12.0	0.7
50.0	164.0	52.560	126.61	6.0	0.3
55.0	180.4	52.610	126.70	10.0	0.5
60.0	196.8	52.660	126.79	10.0	0.5
65.0	213.2	52.700	126.86	8.0	0.4
70.0	229.6	52.770	126.99	14.0	0.8
75.0	246.0	52.830	127.09	12.0	0.7
80.0	262.4	52.890	127.20	12.0	0.7
85.0	278.8	52.960	127.33	14.0	0.8
90.0	295.2	53.010	127.42	10.0	0.5
95.0	311.6	53.080	127.54	14.0	0.8
100.0	328.0	53.150	127.67	14.0	0.8
105.0	344.4	53.190	127.74	8.0	0.4
110.0	360.8	53.260	127.87	14.0	0.8
115.0	377.2	53.380	128.08	24.0	1.3
120.0	393.6	53.520	128.34	28.0	1.5
125.0	410.0	53.730	128.71	42.0	2.3
130.0	426.4	53.940	129.09	42.0	2.3
135.0	442.8	54.110	129.40	34.0	1.9
140.0	459.2	54.230	129.61	24.0	1.3
145.0	475.6	54.330	129.79	20.0	1.1
150.0	492.0	54.410	129.94	16.0	0.9
155.0	508.4	54.480	130.06	14.0	0.8
160.0	524.8	54.560	130.21	16.0	0.9
165.0	541.2	54.630	130.33	14.0	0.8
170.0	557.6	54.720	130.50	18.0	1.0
175.0	574.0	54.800	130.64	16.0	0.9
176.0	577.3	54.820	130.68	20.0	1.1


TEMPERATURE, DEG C
0
10
20
30
40
50
60
DEPTH, METERS
0
100
200
300
STEVENS
24S/32E- 80A
5/15/80