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HEAT-FLOW DATA FROM SOUTHEASTERN OREGON

by

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Contents

Abstract

With the exception of values from two holes drilled within 2 km of Mickey Hot Springs, 17 new heat-flow values in southeastern Oregon are within or somewhat below the range one would normally expect in non-anomalous parts of the North American Cordillera. This is not surprising for a region in which most igneous rocks on the surface are 5 m.y. old or more. There is a suggestion of a thermal anomaly associated with the very young (late Pleistocene or Holocene) Diamond Craters lava field, and the thermal regime on both sides of Steens Mountain seems to be controlled, to some degree, by lateral and vertical movement of water.

INTRODUCTION

A systematic regional study of the geothermal energy potential of the western United States should include heat-flow measurements in both sedimentary basins and the ranges that separate them from one another. Previous regional heat-flow work (Roy and others, 1968; Blackwell, 1969, 1974; Sass and others, 1971b, 1975; Diment and others, 1975) has been focused mainly on the solid rock forming the ranges and pediments because

i) Most drilling for minerals was done in this type of rock, and

ii) Thermal conductivity measurements were most easily made on solid core specimens or chips of relatively nonporous rocks. This type of specimen was most often available from the rotary- or diamond-drilled holes used for mineral exploration.

The part of southeastern Oregon chosen for this study (Figure 1) contained only one preliminary determination of heat flow (Bowen, 1973) of 2.3 HFU in an altered basalt south of Fields (Figure 1) and a few thermal gradient determinations (Bowen, 1972; Sass and Munroe, 1973). Blackwell (1969) estimated a heat flow of 2.0 ± 0.3 HFU in the Burns area based on temperature measurements reported by Spicer (1964). This is presumably Spicer's site OR-4 (reported as V-1 by Sass and Munroe, 1973) even though the geographic coordinates given by Blackwell place the well some 75 km east of Burns.

The present work was planned to

i) Extend the regional heat-flow coverage into this part of the Basin and Range and Columbia Plateau provinces, and

ii) Evaluate the use of relatively shallow holes (∿ 100 m) in sedimentary formations of intermontane valleys as thermal flux plates. This area was chosen, not only because of the scarcity of heat-flow determinations within it, but also because some of the hottest springs in Oregon are found there (Bowen and Peterson, 1970; Mariner and others, 1974). The area includes the southeastern half of the "Brothers Fault Zone" (Walker, 1974; MacLeod and others, 1975), the major structural feature of the high lava plains of eastern Oregon (see also Walker and Repenning, 1965, 1966; Greene and others, 1972). It also contains 5 of the 10 prospective geothermal areas identified by Groh (1966). Despite the many surface geothermal manifestations, the youngest silicic volcanic rocks found on the surface in the study area are about 5 m.y. old and the majority are in the range 7-10 m.y. with some as old as 15 m.y. (MacLeod and others, 1975). There are, however, some younger basaltic volcanic rocks, in particular some very young (∿ 5000 y) flows at Diamond Craters near the southern margin of Harney Basin.

Our original plan for southern Oregon included drilling heat-flow holes in the Lower Klamath Lake and Swan Lake valleys, Warner Valley, Catlow Valley, Mickey Hot Springs, and Diamond Craters areas with some possible additional work in the Harney Basin, Summer Lake Basin and Lakeview region. Some work has been done south of Klamath Falls (Sass and Sammel, 1976), but we have not been able to complete the drilling planned for the Warner Valley and other basins west of it.

Acknowledgments. William Diment and Arthur Lachenbruch helped to plan the overall pattern and spacing of drill sites. Paul Twichell supervised the drilling operation, and Tom Moses gave technical advice on drilling and well completion. Thermal conductivities were measured by Eugene Smith.

HEAT-FLOW DATA

The heat-flow data obtained during this study are shown, together with Bowen's (1973) previously published value near Fields, in Figure 1. For the Catlow Valley - Alvord Valley area, they are shown in more detail in Figure 2. Values shown in parentheses are estimates obtained by combining temperature gradients and regional average thermal conductivities measured on samples from other holes or outcrops thought to be representative of the rocks penetrated by the borehole. All other heat flows were determined by combining least-squares temperature gradients with harmonic mean thermal conductivities from the same hole.

Temperature and thermal conductivity measurements were made using equipment similar to that described by Sass and others (1971a, b). Temperature gradients at Blue Mountain, the Burns area (Harney Basin) and Foster Lake (Figure 1, Table 1) were obtained from holes drilled for other purposes. The remainder of the sites were specially drilled heat-flow observation wells about 100 m deep with at least one cored interval. (Coring runs were made at least twice for each hole, but sometimes no sample was recovered). Upon completion of drilling, observation casing (32 mm steel or PVC pipe) was emplaced to nearly total depth and the annulus between casing and borehole wall was filled with a cement grout.

Table 1 summarizes the principal elements of the heat-flow calculations for the various localities which are listed in alphabetical order.

Individual temperature profiles are given in Figures 3 through 19, and individual conductivities and lithologic descriptions, in Tables 2 through 13.

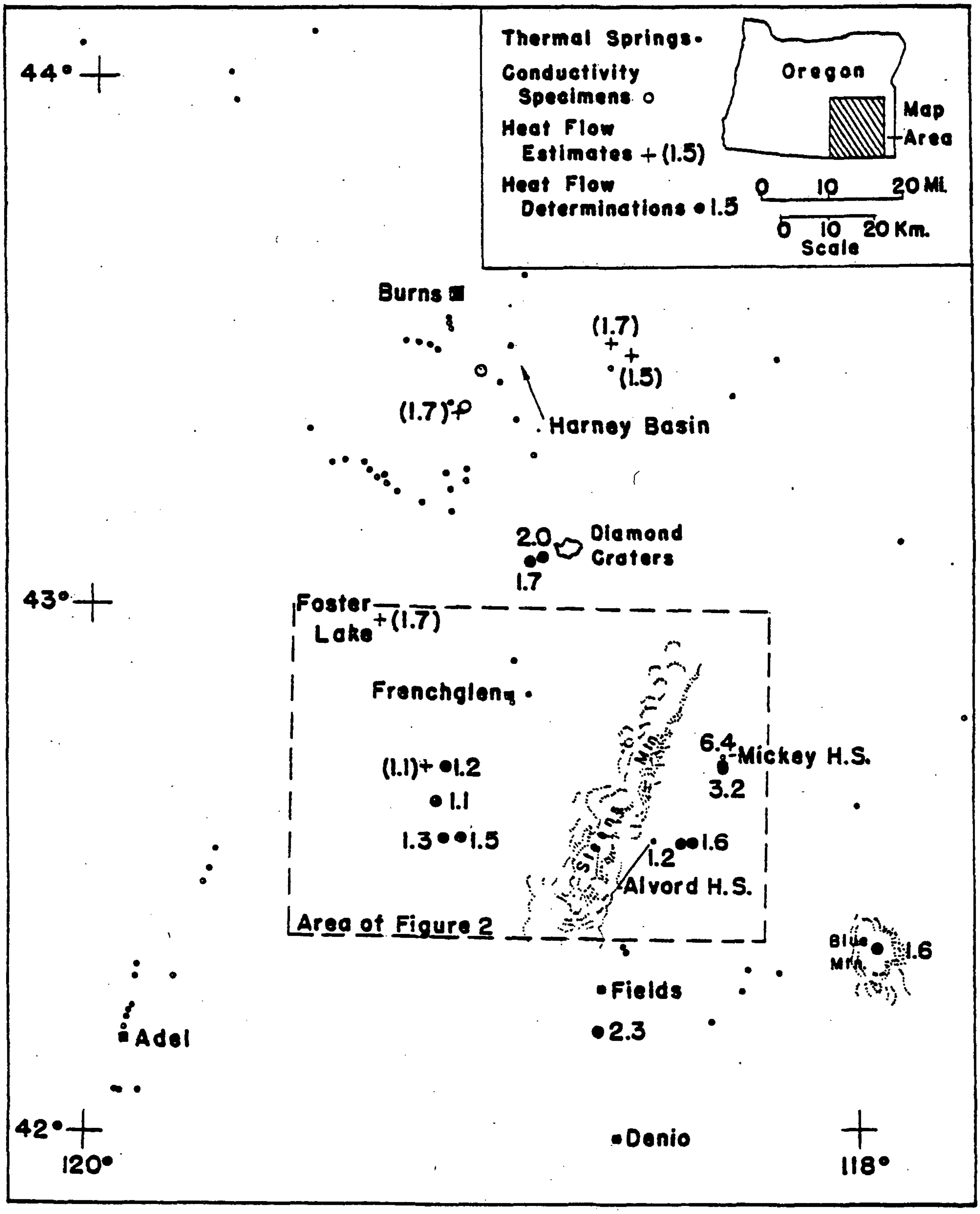

Figure 1. Distribution of thermal springs and heat flow in southeastern Oregon

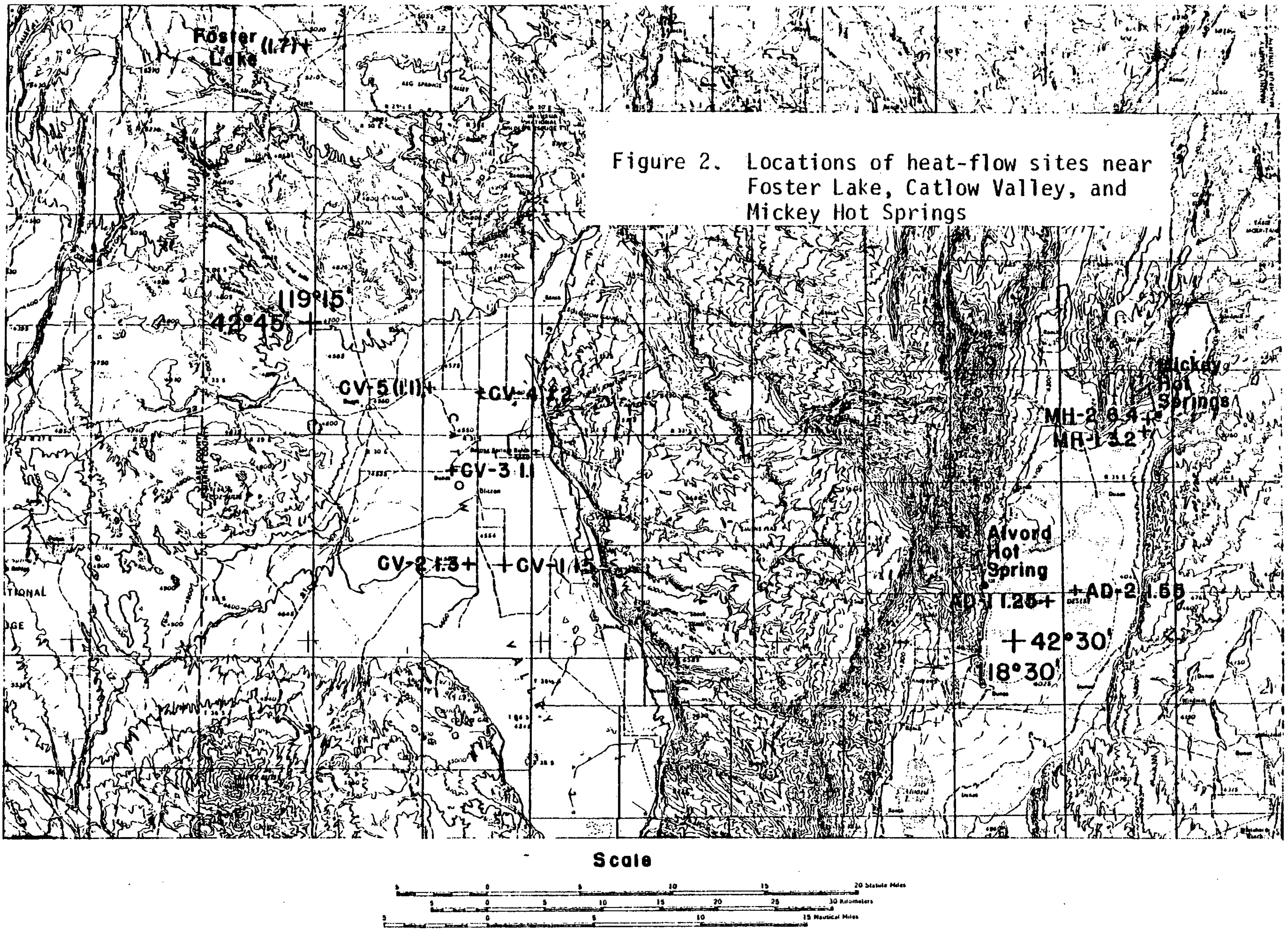

Figure 2. Locations of heat-flow sites near Foster Lake, Catlow Valley, and Mickey Hot Springs

TABLE 1. Temperature gradients and heat flows from Southeastern Oregon

Locality	Well No.	N. Lat.	W. Long.	Elev. (m)	Depth Range (m)	Gradient (°C/km)	N[1]	<K>[2] (mcal/cm sec °C)	q[3] (HFU)
Blue Mountain	FU 1	42° 19'	117° 54'	1704	37 - 100	93 ± 3	20[4]	4.15 ± 0.11[5]	3.9 ± 0.2
					130 - 250	70.1 ± 0.3			2.9 ± 0.1
					250 - 300	58.9 ± 0.8			2.4 ± 0.1
					300 - 350	49.0 ± 0.4			2.0 ± 0.1
					350 - 400	38.1 ± 0.3			1.58 ± 0.04
					400 - 565	40.6 ± 0.2			1.69 ± 0.05
							Adopted value		(1.6)
Burns area	S1[6]	43° 22'	119° 02'	1266	50 - 190	81 ± 1		2.1[7]	(1.7)
	S2[6]	43° 28'	118° 35'	1262	60 - 183	69.5 ± 0.5		2.1[7]	(1.5)
	S3[6]	43° 30'	118° 39'	1255	40 - 203	82 ± 1		2.1[7]	(1.7)
Catlow Valley	1	42° 32'	119° 02'	1390	55.8 - 59.4	74.2 ± 0.6	3	1.97 ± 0.07	1.46 ± 0.05
					89.3 - 92.3	61.6 ± 0.7	3	2.26 ± 0.04	1.39 ± 0.03
					35 - 90	71.4 ± 0.3	6	2.10 ± 0.07	1.50 ± 0.05
							Best value		1.5
	2	42° 32'	119° 05'	1390	50 - 95	60.9 ± 0.2	6	2.08 ± 0.04	1.27 ± 0.02
	3	42° 37'	119° 04'	1390	65 - 93	52.0 ± 0.3	4	2.06 ± 0.13	1.07 ± 0.07
	4	42° 42'	119° 04'	1390	68.0 - 70.7	48.8 ± 0.6	4	2.28 ± 0.08	1.11 ± 0.04
					87.7 - 90.8	51.5 ± 0.4	4	2.43 ± 0.03	1.25 ± 0.02
					65 - 91	50.1 ± 0.1	8	2.35 ± 0.05	1.18 ± 0.03
							Best value		1.2
	5	42° 42'	119° 06'	1390	45 - 90	51	0	2.2[8]	(1.1)
Diamond Craters	MR-1	43° 05'	118° 49'	1262	56.4 - 64.0	89 ± 1	4	2.19 ± 0.17	1.95 ± 0.15
					40 - 91	96.0 ± 0.6	4	2.19 ± 0:17	2.10 ± 0.16
							Best value		2.0
	MR-2	43° 05'	118° 51'	1260	57.9 - 62.5	65 ± 2	4	2.37 ± 0.04	1.54 ± 0.05
					89.3 - 92.0	83 ± 3	4	2.19 ± 0.06	1.82 ± 0.08
					60 - 100	74.2 ± 0.8	8	2.28 ± 0.05	1.69 ± 0.04
							Best value		1.7
Foster Lake	BLM	42° 58'	119° 15'	1530	61 - 107	78 ± 2		2.2[9]	(1.7)

TABLE 1. Temperature gradients and heat flows from Southeastern Oregon (continued)

Locality	Well No.	N. Lat.	W. Long.	Elev. (m)	Depth Range (m)	Gradient (°C/km)	N[1]	<K>[2] (mcal/cm sec °C)	q[3] (HFU)
Alvord Valley (Mickey Hot Springs)	AD-1	42° 32'	118° 28'	1220	54.9 - 61.0	73.9 ± 0.02	7	2.06 ± 0.02	1.52 ± 0.02
					88.4 - 95.7	78.6 ± 0.3	9	2.03 ± 0.02	1.60 ± 0.02
					55 - 96	75.8 ± 0.3	16	2.04 ± 0.02	1.55 ± 0.02
							Best value		1.55
	AD-2[10]	42° 32'	118° 26'	1220	59 - 96	58.5 ± 0.3	19	2.13 ± 0.03	1.25 ± 0.02
	MH-1[12]	42° 40'	118° 22'	1225	40 - 51	146.2 ± 0.6	6	2.21 ± 0.03[11]	3.2 ± 0.1
	MH-2	42° 40'	118° 21'	1235	10 - 30	294.9 ± 0.8			
					30 - 35	255 ± 2			
					10 - 35	289.2 ± 0.8		2.21[13]	6.4

[1] N, number of thermal conductivity determinations.
[2] <K>, harmonic mean thermal conductivity.
[3] q, heat flow = gradient x <K>, 1 HFU = 10^{-6} cal/cm^2 sec = 41.8 mw/m^2.
[4] No systematic variation of conductivity with depth (see Table 2).
[5] Measurements were made on chips; this is the upper limit based on no porosity.
[6] Temperature profiles published by Sass and Munroe, 1973.
[7] Mean of saturated conductivities (Table 3).
[8] No core recovered; <K> is average from other holes in Catlow Valley.
[9] No core from hole; <K> is mean conductivity of tuffaceous sediments in other parts of the region.
[10] 1.8 km SW of Mickey Hot Springs.
[11] Cored interval was below bottom of casing and not accessible for temperature measurements.
[12] ~1 km W of Mickey Hot Springs.
[13] No core recovered; <K> is from MH-1.

STANDARD OIL COMPANY OF CALIFORNIA,
BLUE MOUNTAIN FEDERAL UNIT NO. 1

This well was drilled to a total depth of 2565 m between June 18 and August 4, 1973, whereupon several cement plugs were set between the bottom of the hole and the bottom of the surface casing at 565 m, and the well was turned over to the Oregon Department of Geology and Mineral Industries (DOGAMI) for use as a thermal observation well. DOGAMI later turned the well over to the USGS and we are still making temperature measurements periodically.

Figure 3 shows the most recent temperature profile in the well, and Figure 4, a number of profiles obtained between 10-9-73 and 8-24-75. The first log was made by R. G. Bowen of DOGAMI using lightweight portable equipment that would not penetrate beyond 150 m in the heavy mud. A month later, the USGS using heavier tools could penetrate to only 210 m. A small drilling rig was then brought in and 32 mm i.d. pipe was run to the first cement plug (at 565 m) and filled with water to allow access for subsequent logs.

The drilling records report considerable lost circulation in the depth interval 100 to 150 m and the long lived transient temperature disturbance in this interval indicates that a large amount of cement entered the formation when the casing was grouted in place.

In Table 2 individual thermal conductivity values on composite samples of drill cuttings are listed together with a generalized lithologic description based on examination of the drill cuttings. In the upper 130 or so metres, it is impossible to estimate a value of porosity, but below this level, drilling rates declined and the borehole penetrated a series of massive basalt flows for which we estimate an average porosity of no more than 10%. In view of the very uniform thermal conductivity of the solid component of the rock (Table 2), it seems unlikely that the observed curvature of the temperature profile (Figure 3 and Table 1) involving a halving of the temperature gradient between the top and bottom of the cased section, can be attributed to variations in porosity. Upward water movement in the formation is a more plausible explanation for the curvature between the surface and about 350 m. Below 350 m, the profile is quite linear with a gradient of ∿40°/km which results in heat flows between 1.5 (for 10% porosity) and an upper limit of 1.7 HFU. We adopt a value of 1.6 HFU as the best estimate of heat flux at this site.

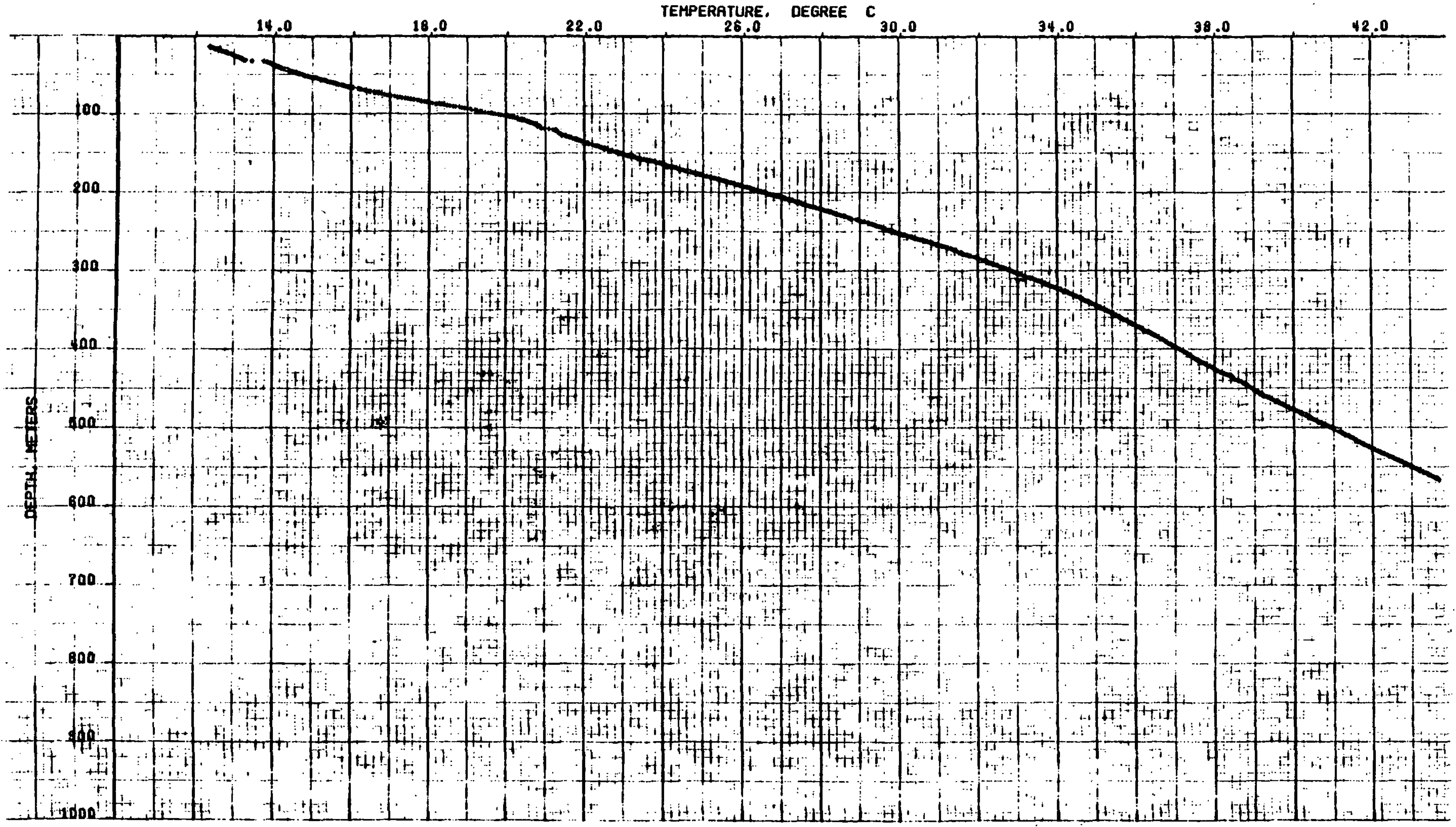

Figure 3. Temperatures in Standard Oil Company of California Blue Mountain Federal Unit #1, 8-24-75

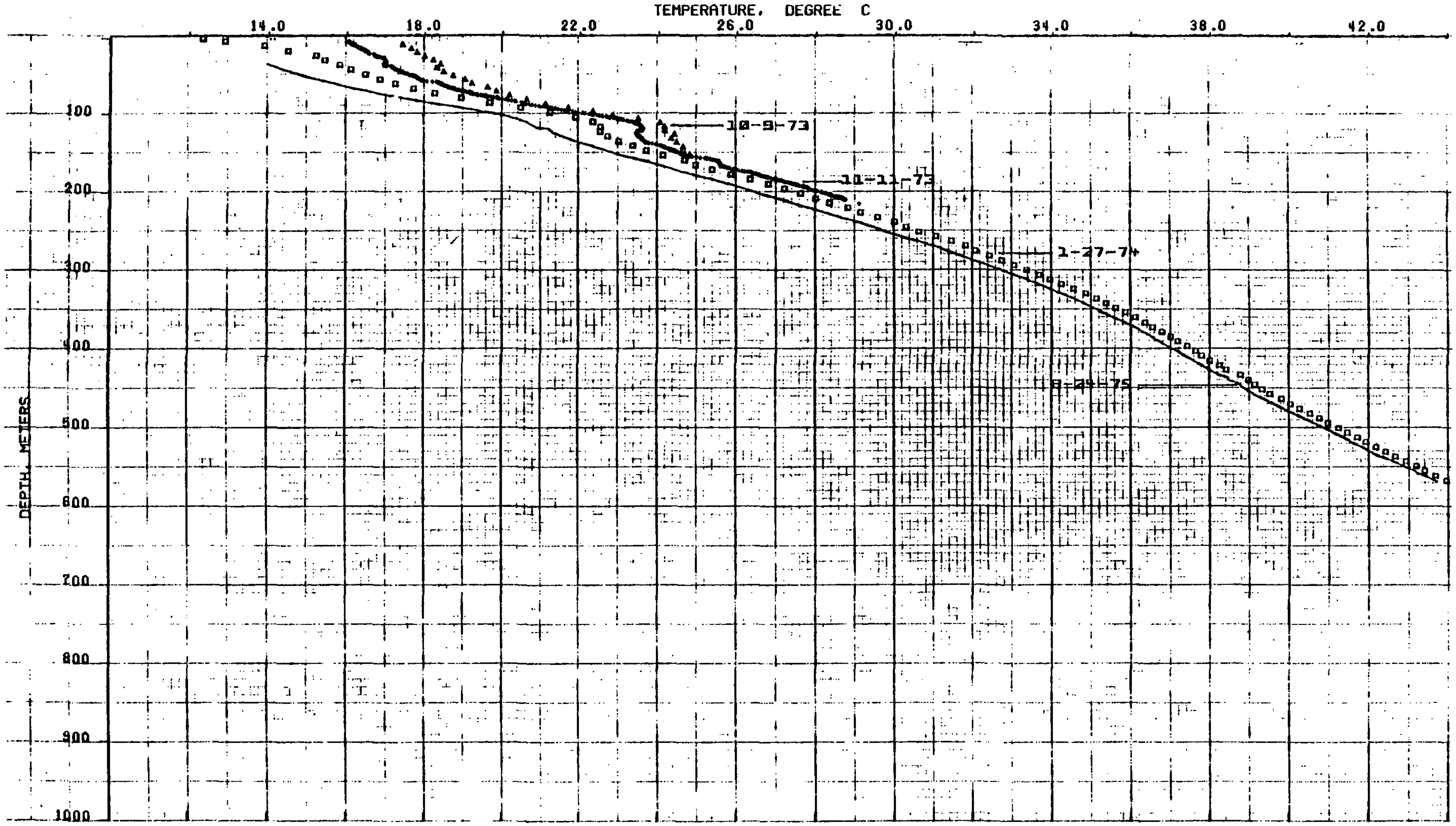

Figure 4. Temperatures at four different times in Standard Blue Mountain #1

TABLE 2. Thermal conductivity measurements on composite samples of drill cuttings and generalized lithologic description for Standard Blue Mountain Federal Unit #1

Depth Range (m)	Description	K* (mcal/cm sec °C)
15 - 40	Basalt (0 to 10% vesicles), tan and gray vitric tuff, black and brown volcanic glass, woody fragments	4.05
52 - 70		4.25
70 - 100	Gray tuffaceous material, black and brown volcanic glass, varying but sometimes abundant amounts of white mica	4.39
113 - 137		6.14
137 - 162	Basalt (0 to 10% vesicles), black and brown volcanic glass, pea-green earthy amygdules, minor woody fragments, varying amounts of white mica, cuttings from the zone 472-613 m have slickensides	4.67
174 - 192		3.83
204 - 222		3.56
235 - 253		3.57
265 - 283		3.46
296 - 314		4.09
326 - 344		3.85
357 - 375		4.31
387 - 405		4.23
411 - 436		4.40
448 - 466		4.30
478 - 497		4.26
509 - 527		4.29
540 - 558		3.85
570 - 588		4.70
594 - 613		4.11
		<K> = 4.15 ± 0.11

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*Conductivity measured on chips assuming zero porosity.

BURNS AREA (HARNEY BASIN)

Temperature gradients reported by Sass and Munroe (1973) for Harney County included quasi-conductive profiles to depths of ∿200 m at three sites within the Harney Basin. Temperature gradients at these sites have been combined with the mean of four conductivity determinations from two outcrops judged to be representative of the rock types in the holes (Table 3). The resulting heat-flow estimates (Table 1, Figure 1) are in the range 1.5 to 1.7 HFU.

TABLE 3. Thermal conductivities of some sedimentary rocks from the Harney Basin

Location	Description	K_D[1]	K_S[2]	K_S/K_D	Apparent porosity[3] (ϕ)
		(mcal/cm sec °C)			
Dog Mountain	Grey palagonitic tuff outcrop 1000' W of SE corner S8, T25S, R31E	0.94	1.98	2.1	0.23
	(Dog Mountain 15' quad) Harney Formation(?)	0.84	1.93	2.3	0.26
Wrights Point	Buff tuffaceous palagonitic sediment from roadcut 1800' W, 250' N of	1.1	2.4	2.2	0.25
	SE corner S34, T24S, R31E (Lawen 15' quad) Harney Formation(?)	0.93	2.2	2.4	0.28

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[1] Conductivity of shelf-dried specimen. Pores in clay minerals, zeolites, etc., probably retain some water.

[2] Conductivity of water-saturated specimen.

[3] Porosity, calculated assuming geometric mean conductivity ($K_R = K_M^{(1-\phi)} \cdot K_F^{\phi}$). ϕ is fractional porosity; K_M is matrix conductivity; K_F is fluid conductivity. Assumption is that K_D represents all pores filled with air; K_S, all pores filled with water; $K_W \sim 1.5$; $K_A \sim 0.063$. From geometric mean, $\phi = \log (K_S/K_D)/\log (K_W/K_A)$.

CATLOW VALLEY

Five holes ~90 m deep were drilled in Catlow Valley (Figures 1 and 2). This valley contains no geothermal manifestations, but there are a number of large (cold) springs on the east side of the valley as well as many irrigation wells. Some irrigation wells had been drilled before the heat-flow holes in the same area; however, production of water from these wells has been small during the study period.

A composite plot of temperatures from all five wells is shown in Figure 5 and profiles obtained at different times for each well are shown in Figures 6 through 10. Lithology and conductivity are listed in Tables 4 through 7. There is some interesting thermal structure in the temperature profiles and we plan further studies of the time-variation of temperature and some pertinent geophysical quantities. At this stage of our interpretation, we recognize a systematic variation in heat flow (Table 1, Figures 1 and 2) with q apparently decreasing to the northwest from the maximum value at CV-1.

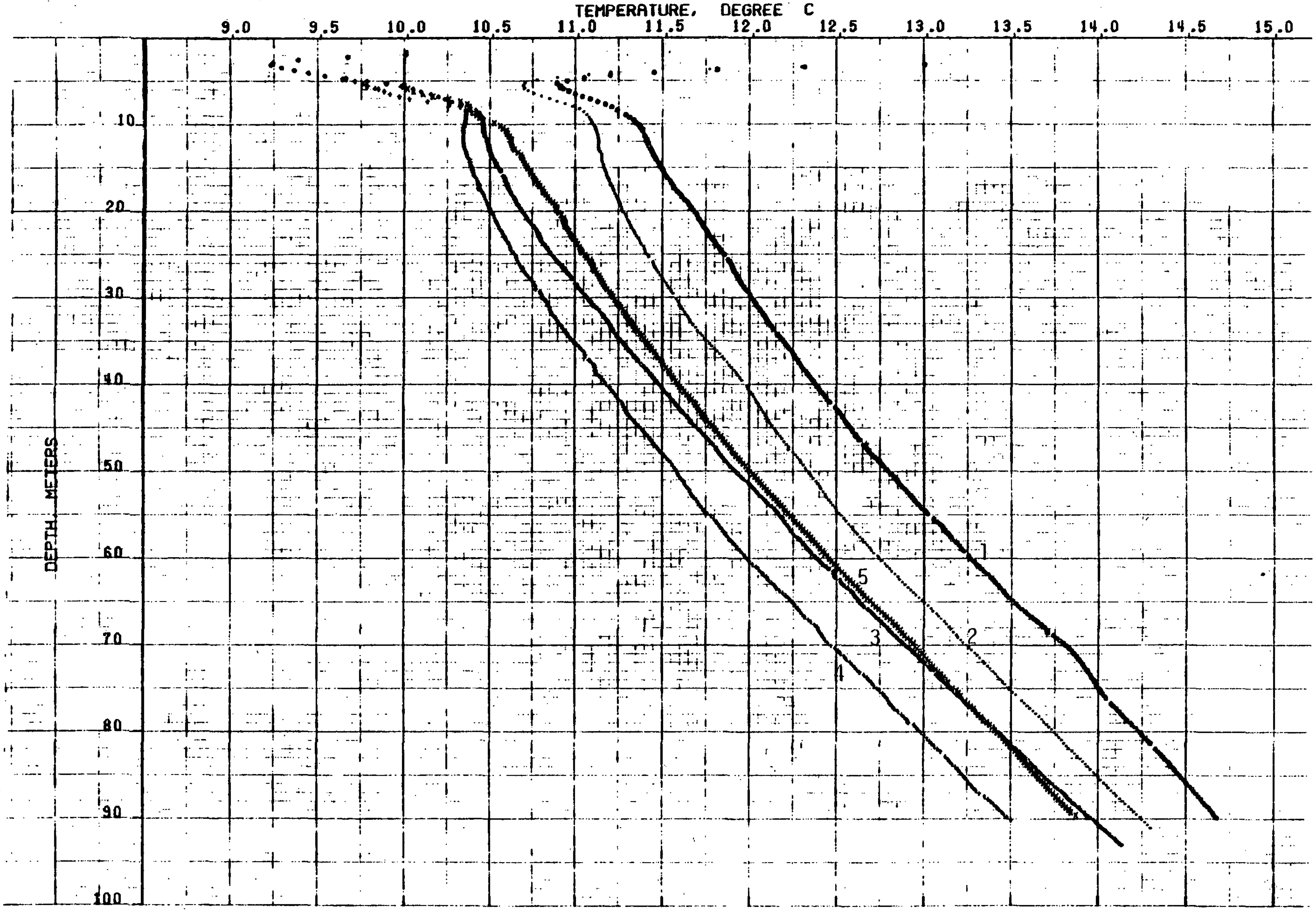


Figure 5. Temperature profiles for Catlow Valley wells

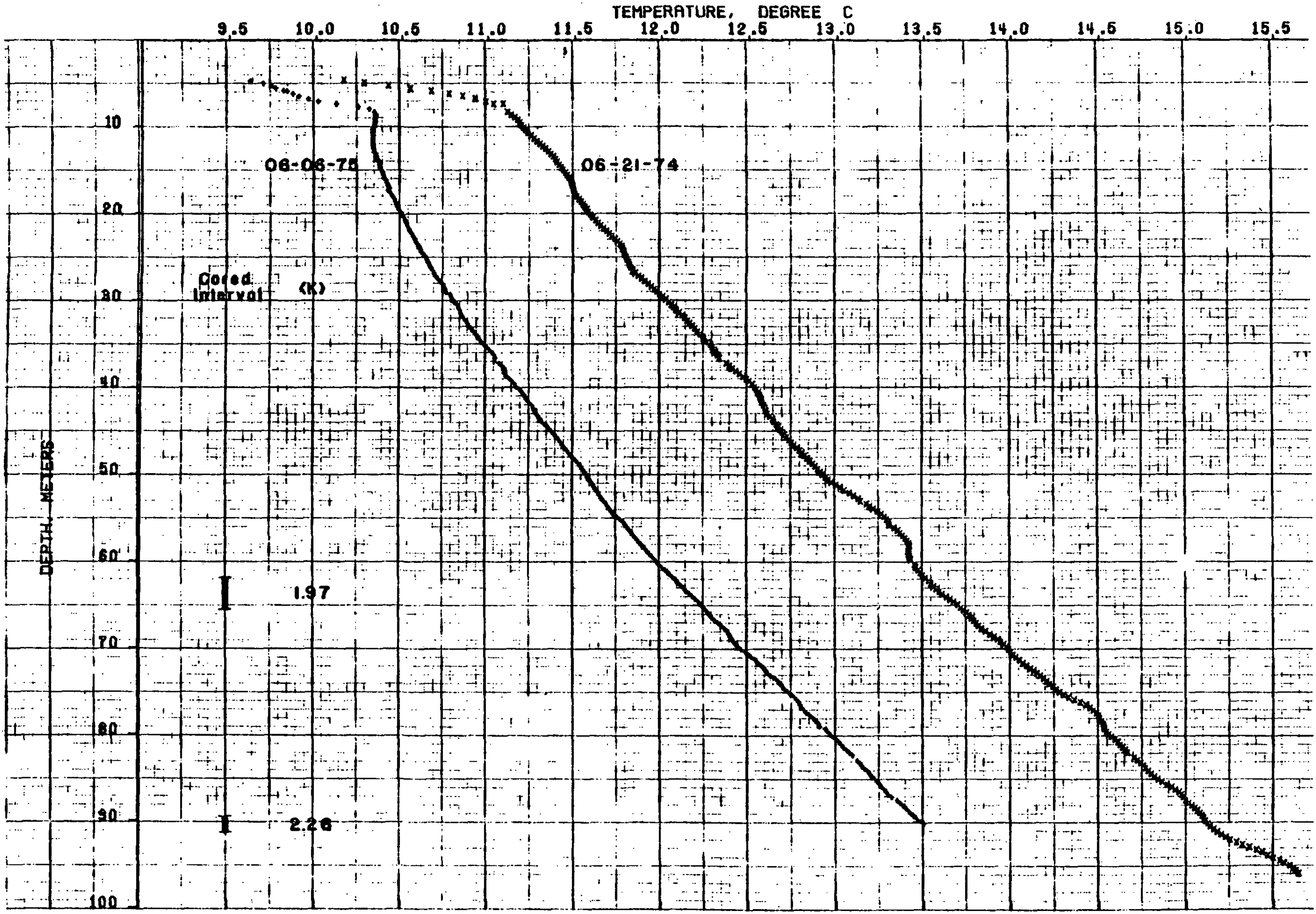


Figure 6. Temperatures in Catlow Valley CV-1

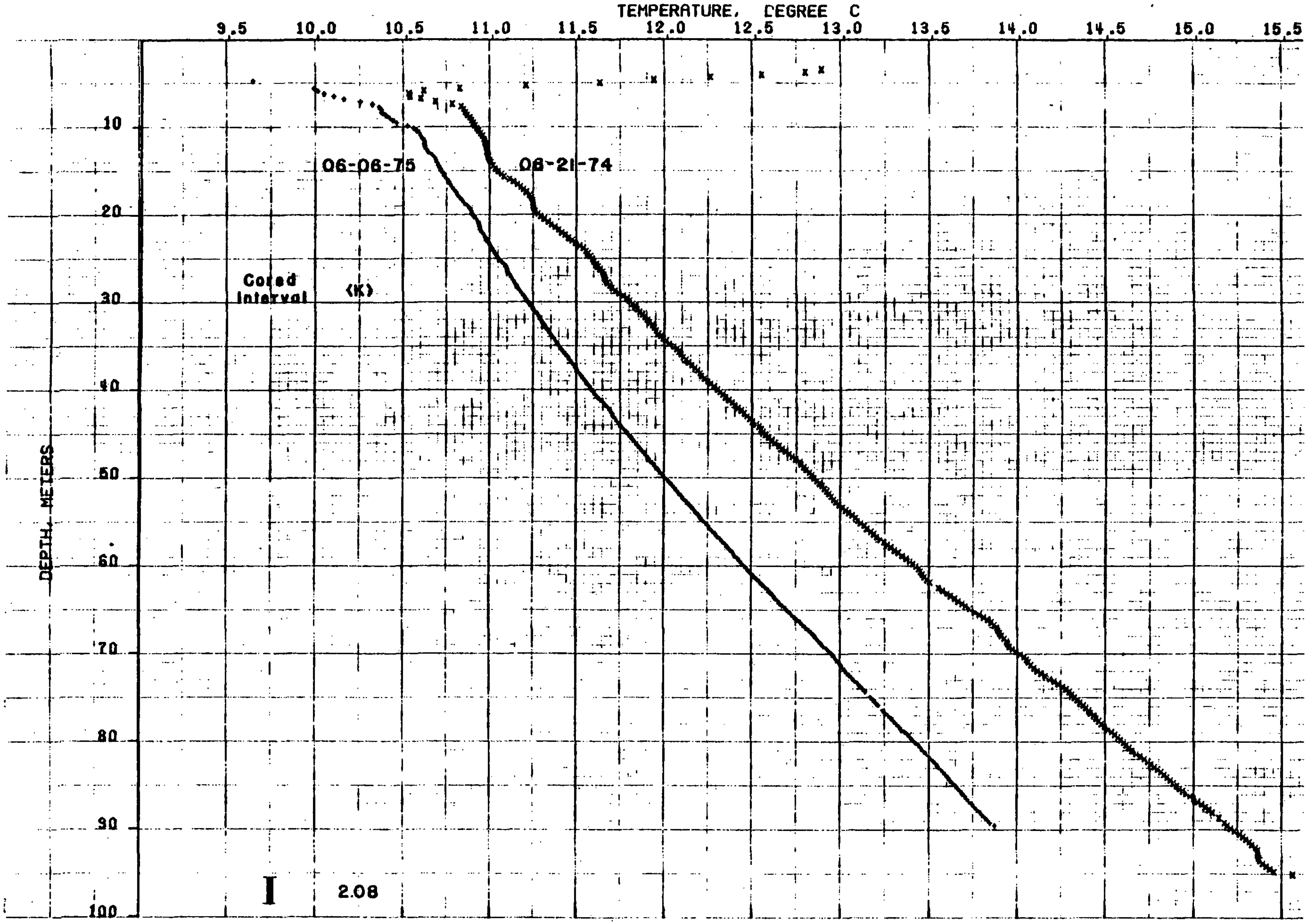


Figure 7. Temperatures in Catlow Valley CV-2

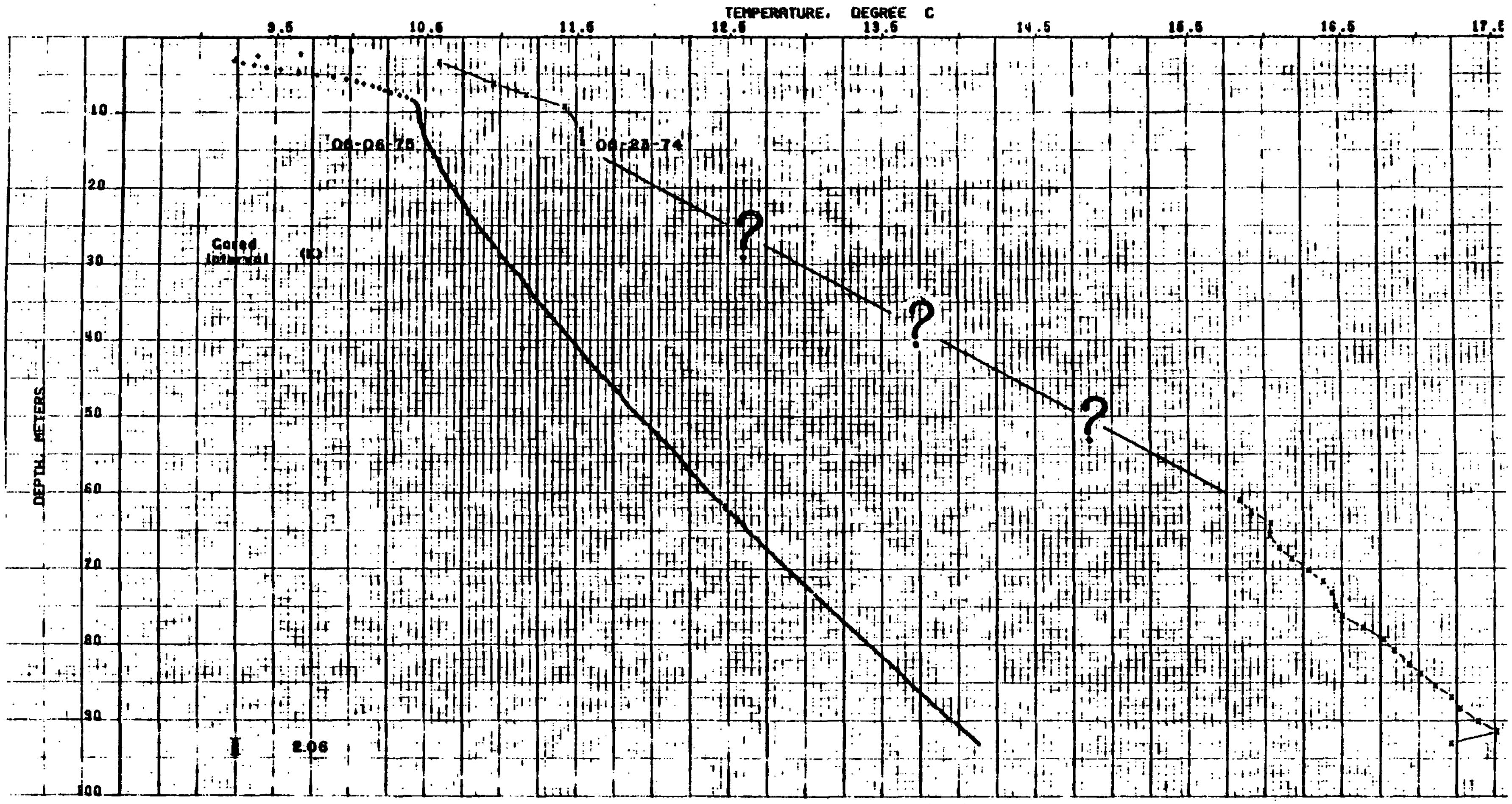


Figure 8. Temperatures in Catlow Valley CV-3

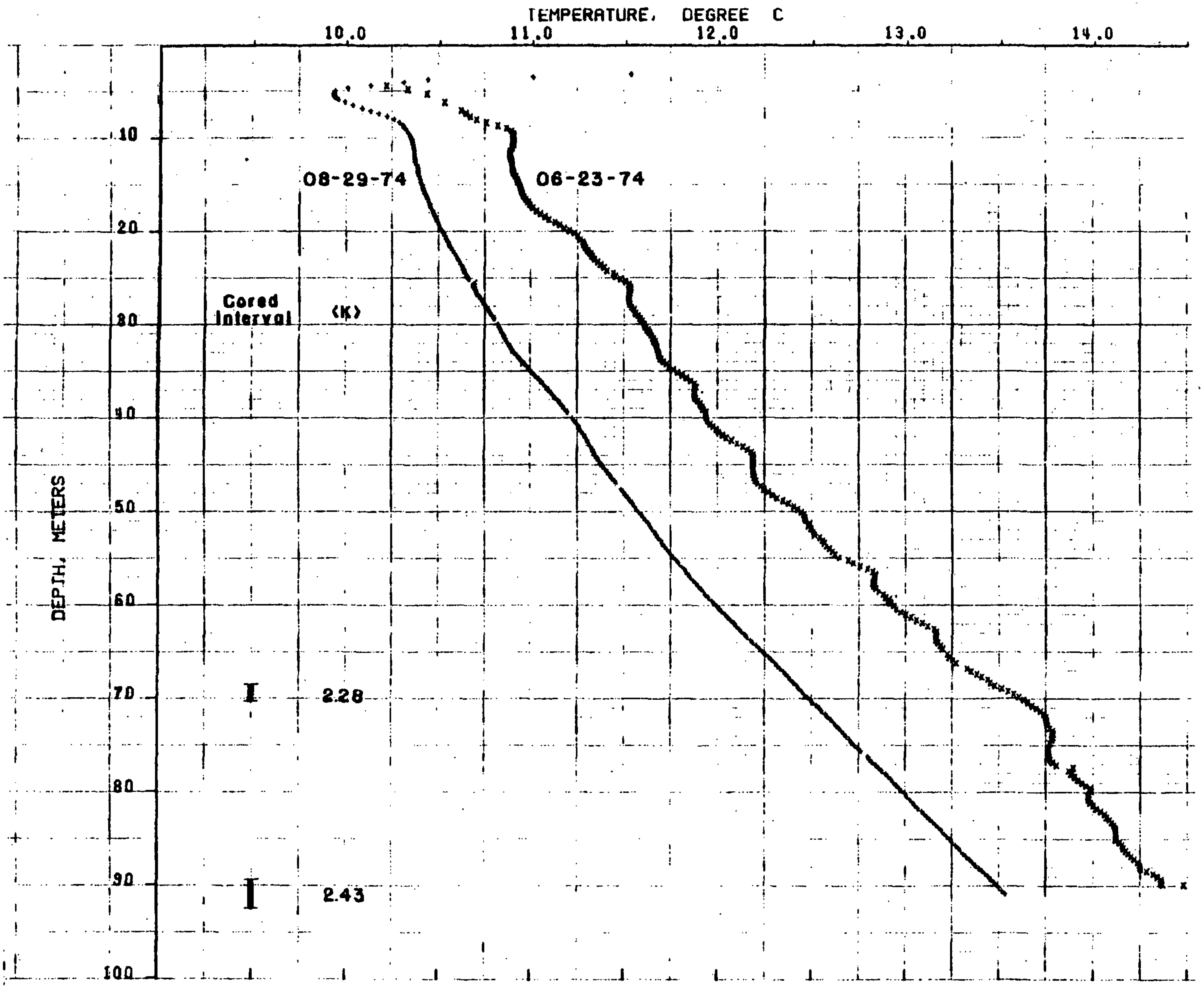


Figure 9. Temperatures in Catlow Valley CV-4

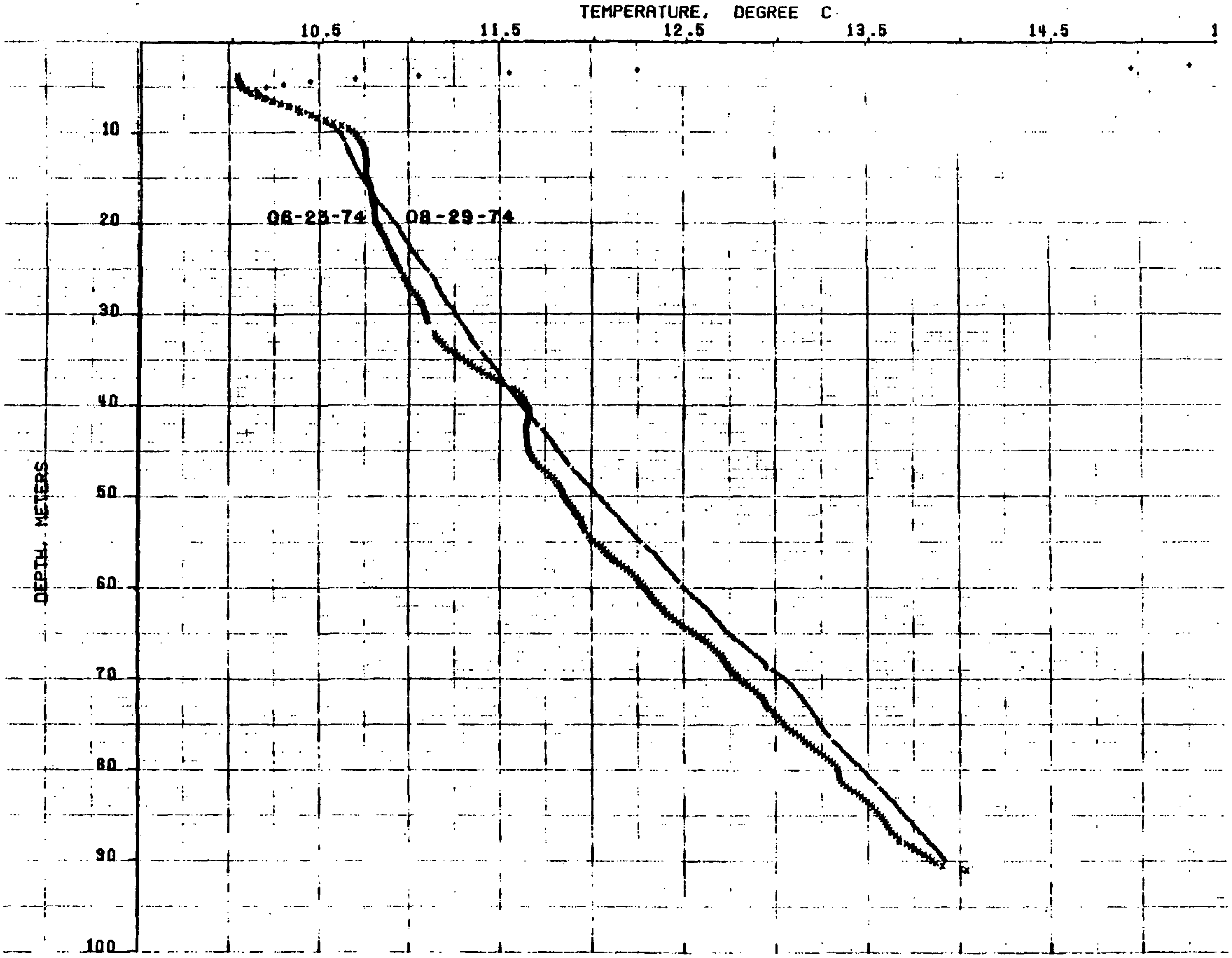


Figure 10. Temperatures in Catlow Valley CV-5

TABLE 4. Lithology from cores and cuttings and thermal conductivity of cores from hole CV-1, Catlow Valley, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0		Clay to very coarse sand, tan		
18.30		Clay and silt, tan, minor clasts (maximum size 20 mm)		
36.60		Clay and silt, tan, minor medium sand		
61.87 65.53	■	Clay and silt, tan, moderate induration, massive bedding, irregularly shaped carbonaceous clots, rare rounded clasts of white, fine grained, siliceous rock (maximum size 3 mm)	62.14 62.42 62.66	1.88 2.11 1.94
		Tan clay and silt		
89.31 89.97	■	Tan clay and silt, moderate induration, massive bedding, molds of plant(?) parts	89.46 89.58 89.68	2.28 2.31 2.18

<K> = 2.10 ± 0.07

TABLE 5. Lithology from cores and cuttings and thermal conductivity of cores from hole CV-2, Catlow Valley, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0		Clay and silt, tan, 3%± clasts (maximum size 7.0 mm)		
27.45		Clay and silt, pale green, 3%± very coarse sand (1.2 mm)		
95.40 98.30	■	Silt and clay, pale green, massive bedding	95.91	1.94
			96.31	2.14
			96.67	2.06
			97.53	2.21
			97.94	2.04
			98.24	2.13

<K> = 2.08 ± 0.04

TABLE 6. Lithology from cores and cuttings and thermal conductivity of cores from hole CV-3, Catlow Valley, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0				
20				
40		Clay and silt to very coarse sand (maximum size 1.8 mm), tan, rare pebble-sized clasts (maximum size 8.0 mm)		
60				
80				
			92.64	2.17
92.35 94.79	■	Clay and silt, tan, 30-40% fine sand, massive bedding	92.94	1.74
			93.26	2.17
			93.52	2.25
100				

<K> = 2.06 ± 0.13

TABLE 7. Lithology from cores and cuttings and thermal conductivity of cores from hole CV-4, Catlow Valley, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0		Clay and silt, tan, 3-30% fine to very coarse sand (maximum size 1.5 mm)		
68.58 69.25	■	Clay and silt, tan, 5-10%+ fine to very coarse sand, moderate induration, massive bedding	68.72	2.35
			68.85	2.41
			69.04	2.35
			69.13	2.04
		Clay and silt, tan, 3-30% fine to very coarse sand (1.5 mm)		
82.30		Clay and silt to very coarse sand (1.5 mm), brown		
89.31 90.58	■	Clay and silt, brown, 40-50% fine to very coarse sand, moderate induration, massive bedding	89.86	2.50
			90.01	2.34
			90.32	2.45
			90.52	2.45
100				

<K> = 2.35 ± 0.06

DIAMOND CRATERS

On strictly geological grounds, Diamond Craters should be one of the more promising prospects within our study area inasmuch as the surface rocks are very young (MacLeod and others, 1975; Groh, 1966). According to Groh (1966) there is also evidence for a shallow laccolithic intrusion beneath the lava field. In an attempt to see if heat flow increases systematically in the direction of the surface volcanic rocks, two holes were drilled. A third hole in Diamond Valley, south of the Craters was plugged and abandoned because of excessive and uncontrollable caving after having been drilled to a depth of about 7 m. Hole MR-1 was drilled in valley fill as close as possible to the western edge of the Diamond Craters volcanic field, and hole MR-2 was drilled about 2.2 km west of MR-1 near the center of the Donner und Blitzen Valley. Temperature profiles for the wells are shown in Figures 11 through 13. From Figure 11, we note that both the temperatures and gradients in MR-1, nearer the Craters are higher than those in MR-2. From the curvature in the upper 60 m of MR-2, however, we must infer that systematic downward water flow in the formation is at least partially responsible for the lower temperatures. In both holes, there is structure of the stair-step variety in the temperature profiles (see also Figure 3 curve 6, Blackwell, 1969; and Figure 4, Sass and others, 1974) indicating fairly vigorous convective water movement over relatively permeable intervals a few metres thick. Lithology and individual conductivity values are given in Tables 8 and 9.

The heat-flow value of 1.7 in the lower section of MR-2 is consistent with estimates in the Harney Basin (Figure 1). The heat flow at MR-1 is significantly higher, and while it should not be considered a positive indicator of an economically exploitable thermal anomaly, it should encourage further exploration of the Diamond Craters area.

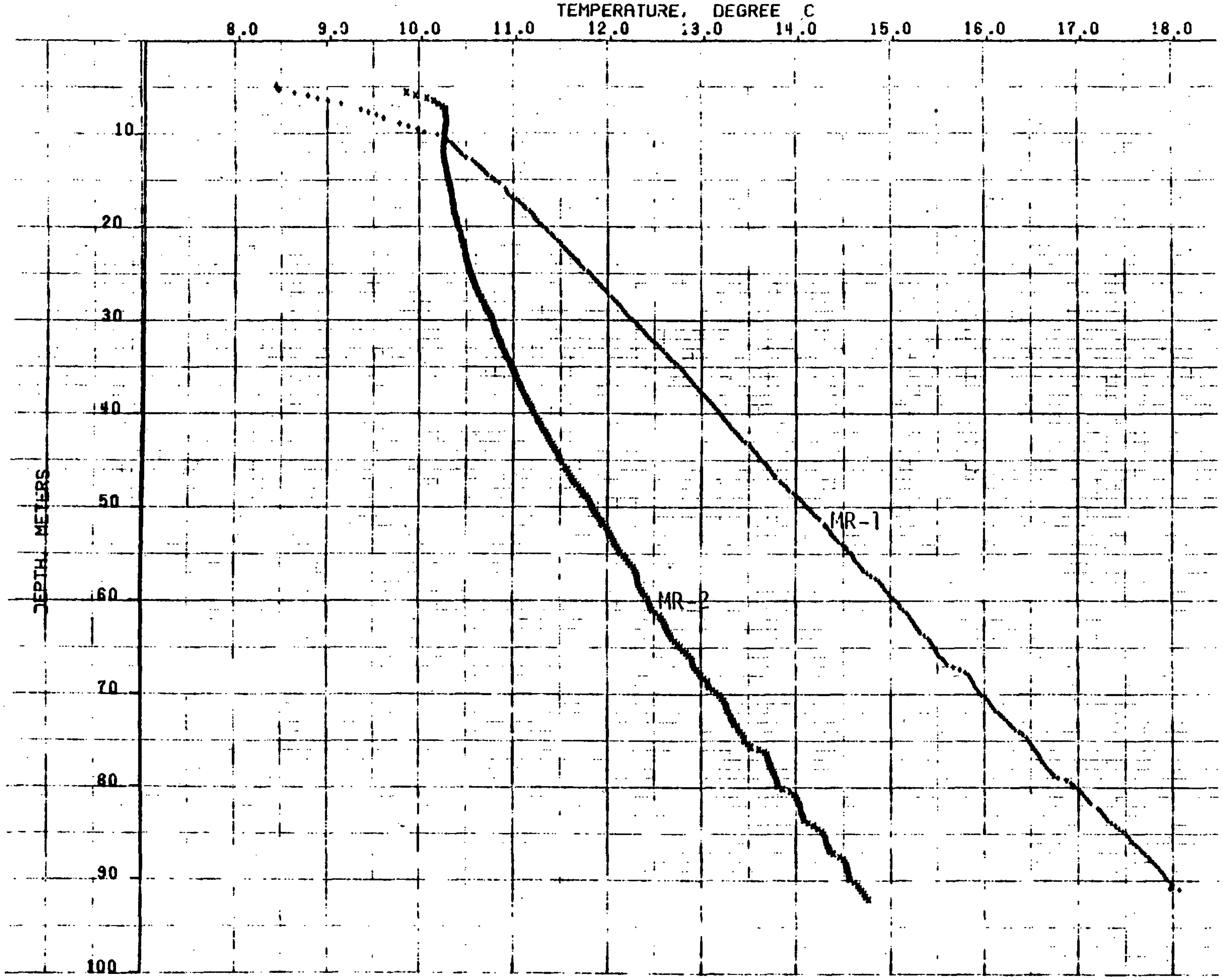


Figure 11. Temperature profiles for two wells near Diamond Craters, Oregon

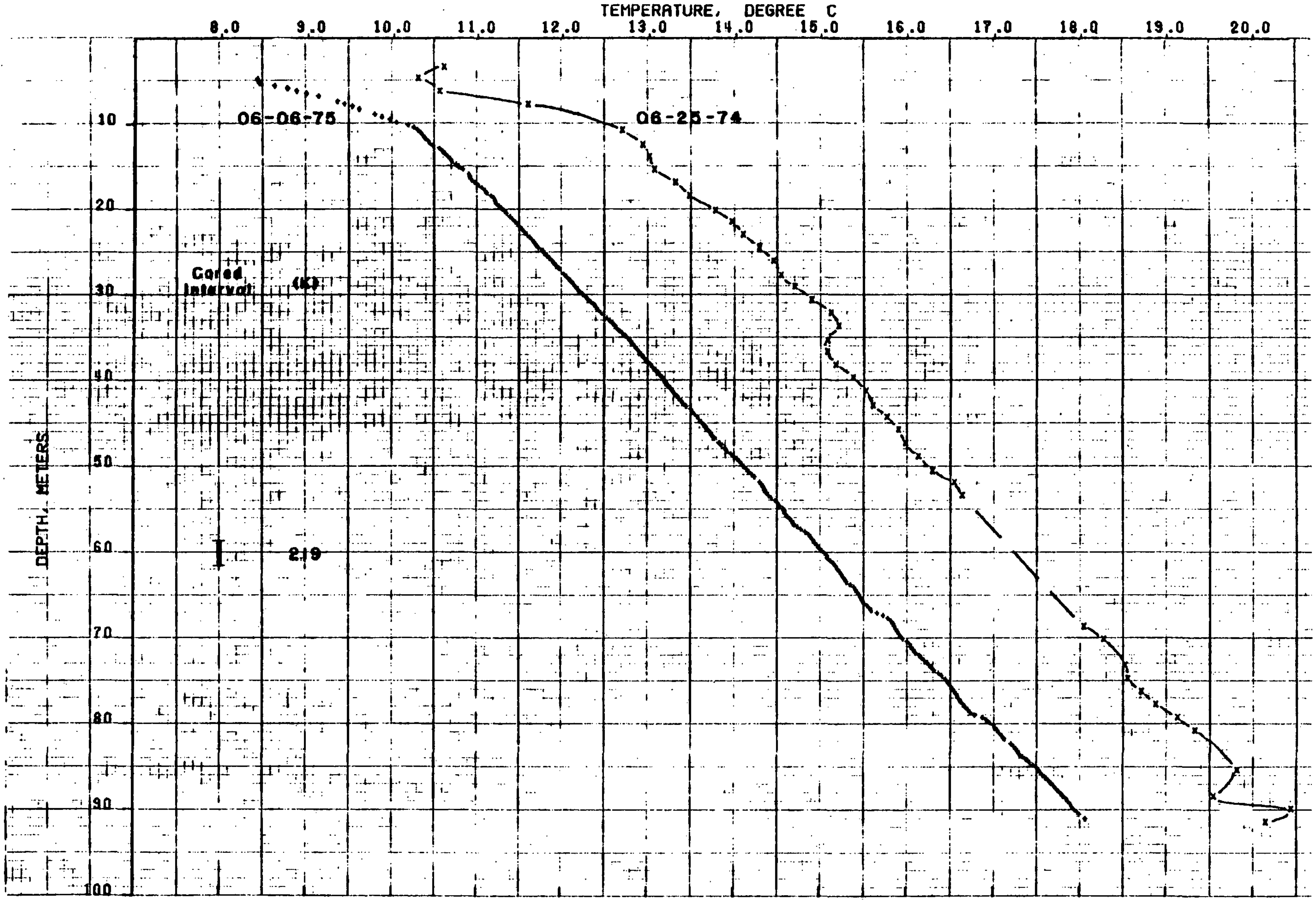


Figure 12. Temperatures in hole MR-1, Diamond Craters area, Oregon

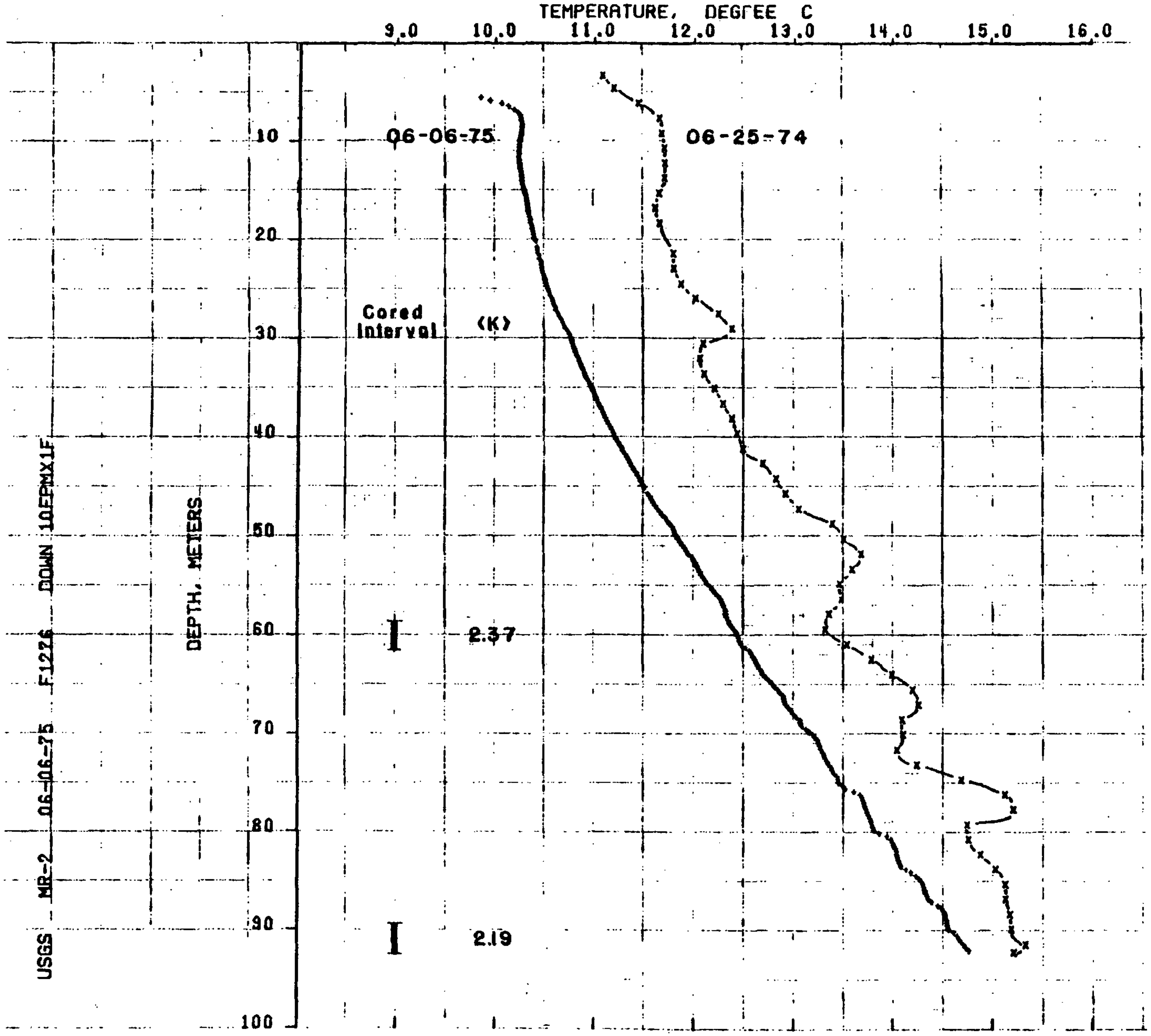


Figure 13. Temperatures in hole MR-2, Diamond Craters area, Oregon

TABLE 8. Lithology from cores and cuttings and thermal conductivity of cores from hole MR-1, Diamond Craters, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0 12.20		Clay and silt, tan, 10% subrounded clasts of basalt (maximum size 2 mm)		
20 40		Silt to medium sand, gray, 10% clasts of basalt (minor porphyritic andesite)		
58.83		58.83 to 59.82 m clay and silt; brown	59.16 59.31	2.05 1.92
60 60.43	■	59.82 to 59.97 m conglomerate; clasts of rounded vesicular basalt, average clast size 10 mm (maximum size 50 mm), 30%± brown clay to fine sand matrix	59.60	2.16
		59.97 to 60.43 m conglomerate; same as above but with 50-60% matrix	60.13	2.80
80		Clay to medium sand, gray, 10% basalt clasts		
87.80 93.00		Conglomerate		
100				

<K> = 2.19 ± 0.17

TABLE 9. Lithology from cores and cuttings and thermal conductivity of cores from hole MR-2, Diamond Craters, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0				
		Clay to medium sand (maximum size .7 mm), tan		
15.24				
20				
		Clay to medium sand, brown, some coarse clasts (maximum size 4 mm)		
40				
			59.25	2.28
58.83	■	Silt, brown, massive bedding, moderate induration	59.55	2.44
60 60.20			59.87	2.44
			60.10	2.33
80				
			89.61	2.30
89.31	■	Silt, brown, massive bedding, moderate induration	89.82	2.26
92.35			90.16	2.03
			90.28	2.18
100				

<K> = 2.28 ± 0.05

FOSTER LAKE

A consistent temperature gradient of 78°/km was obtained from temperature measurements in a dry well abandoned by the Bureau of Land Management near the south end of Foster Lake (Figures 1 and 2). This hole penetrated tuffaceous sediments similar to those encountered in the Harney Basin and Catlow Valley, and our heat-flow estimate is based on the regional mean thermal conductivity (Table 1). Since we did not obtain any samples locally, this heat-flow estimate is probably our least reliable one, subject to the assumption that the rather uniform regional average conductivity (Table 1) is representative of the area.

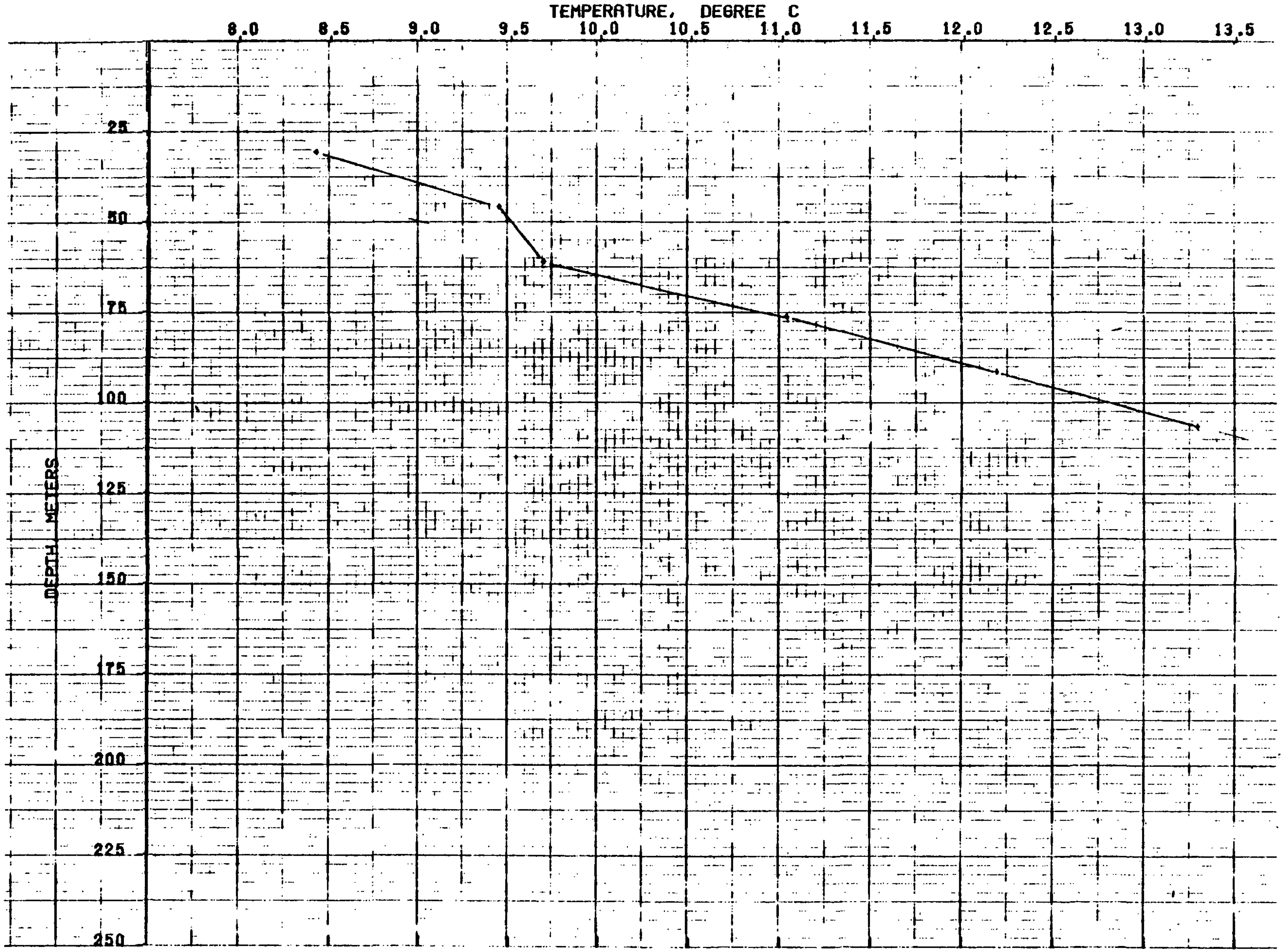


Figure 14. Temperatures in a BLM dry well at Foster Lake, Oregon

ALVORD VALLEY
(MICKEY AND ALVORD HOT SPRINGS)

Mickey spring is one of the hottest (based on reservoir temperatures estimated from silica geothermometry) in the entire state (Bowen and Peterson, 1970; Mariner and others, 1974; Renner and others, 1975). To provide background and to investigate possible anomalies associated with the cooler Alvord Hot Springs, two holes were drilled near the center of the Alvord Desert (Figures 1 and 2). Two additional holes were drilled near Mickey Hot Springs to study the decay of the thermal anomaly as a function of distance from the spring orifice.

Figures 15 through 19 show temperature profiles and harmonic mean conductivities. Individual conductivities and lithologic descriptions are given in Table 12 and 13.

Temperature profiles near Mickey Hot Springs indicate a conductive thermal regime (to depths of ∿50 m at least) with heat flows of the same magnitude as those measured within a radius of ∿2 km of other hot springs (Combs, 1975; Lachenbruch and others, 1976; Sass and Sammel, 1976; Sass and others, 1976; Urban and others, 1976). Heat flows in the Alvord Desert probably represent regional background flux with a component resulting from the lateral and vertical water movement associated with the hydrothermal convection system responsible for Alvord Hot Springs.

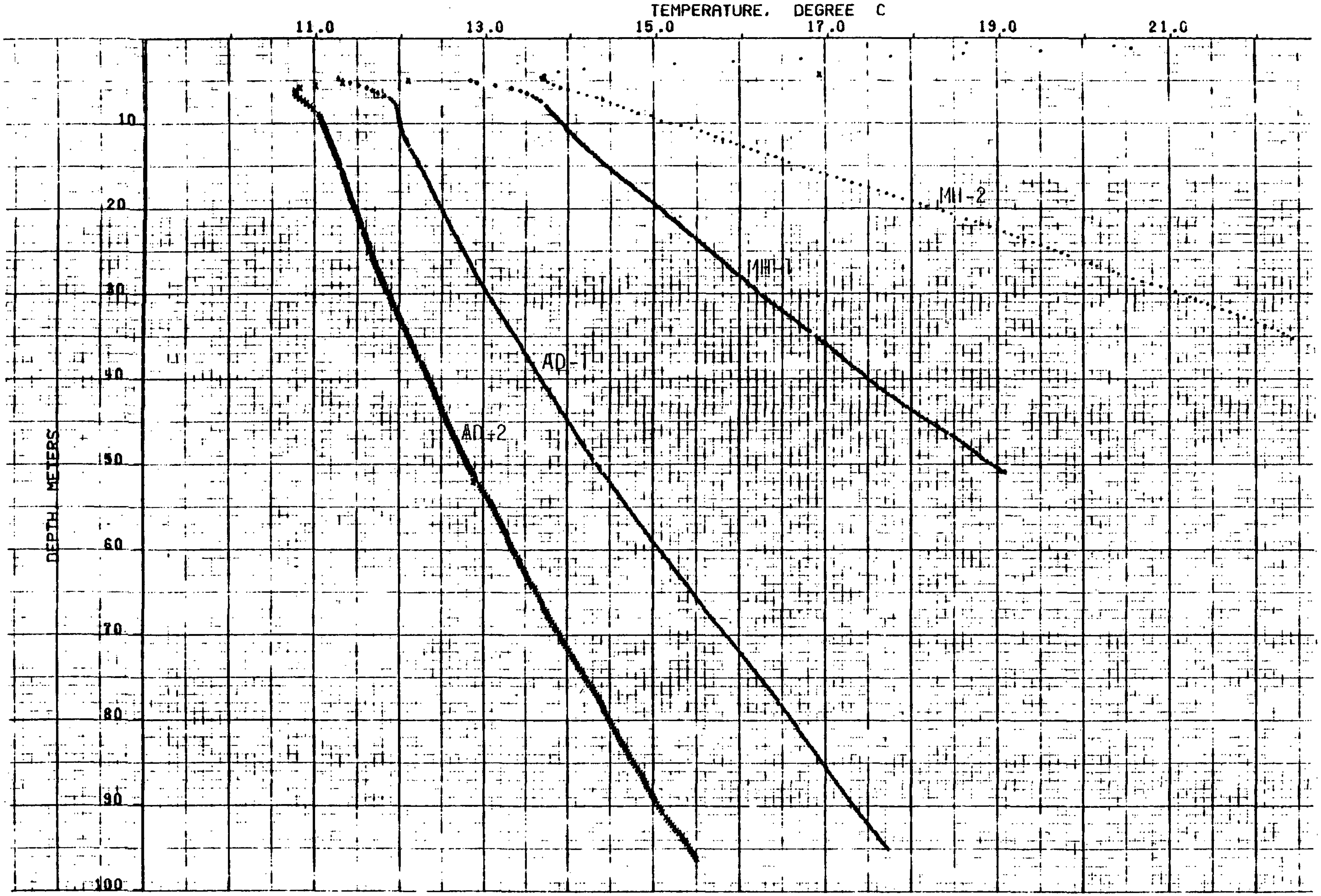


Figure 15. Temperature profiles in the Alvord Valley near Mickey Hot Springs, Oregon

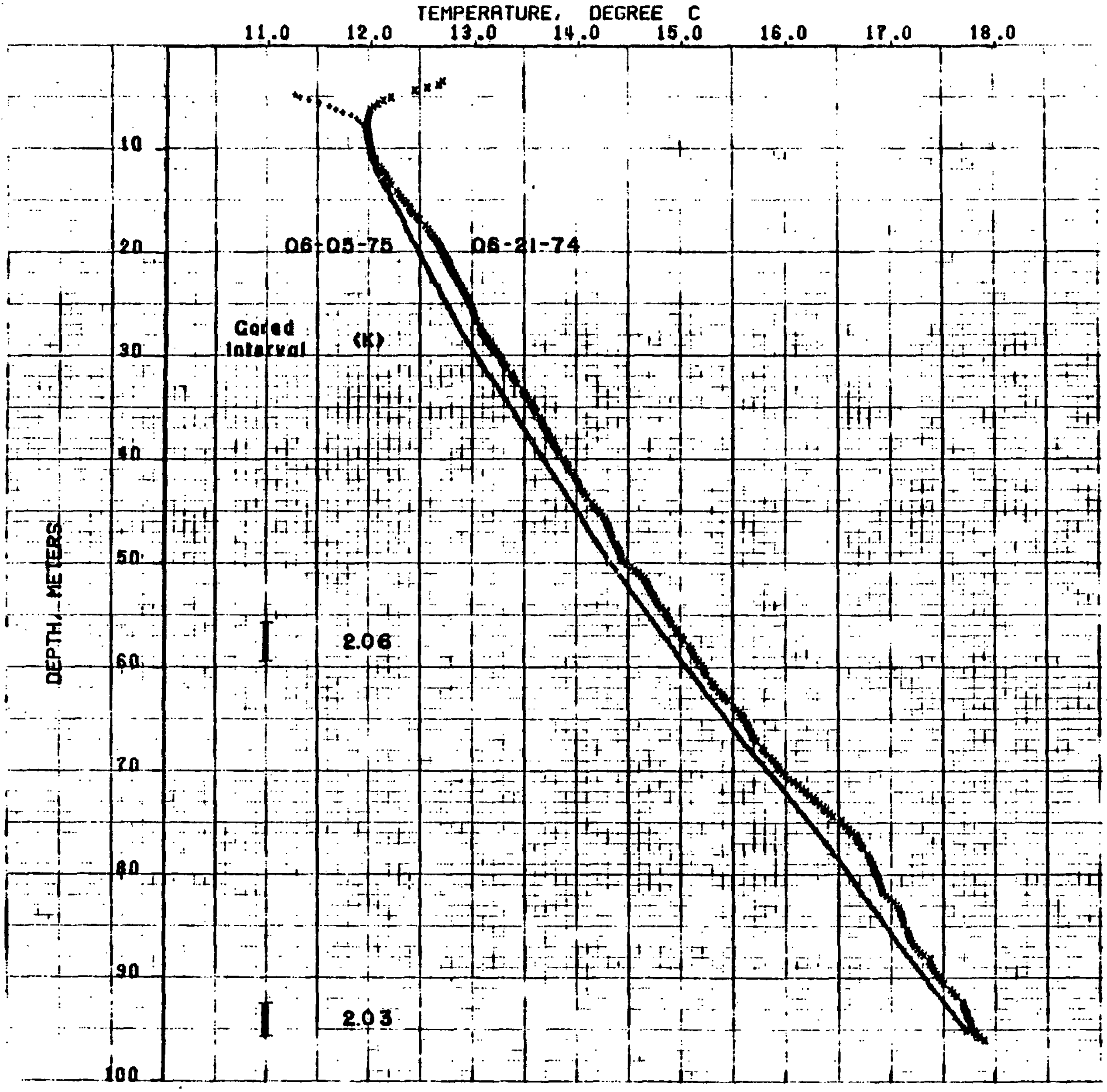


Figure 16. Temperatures in hole AD-1, Alvord Valley, Oregon

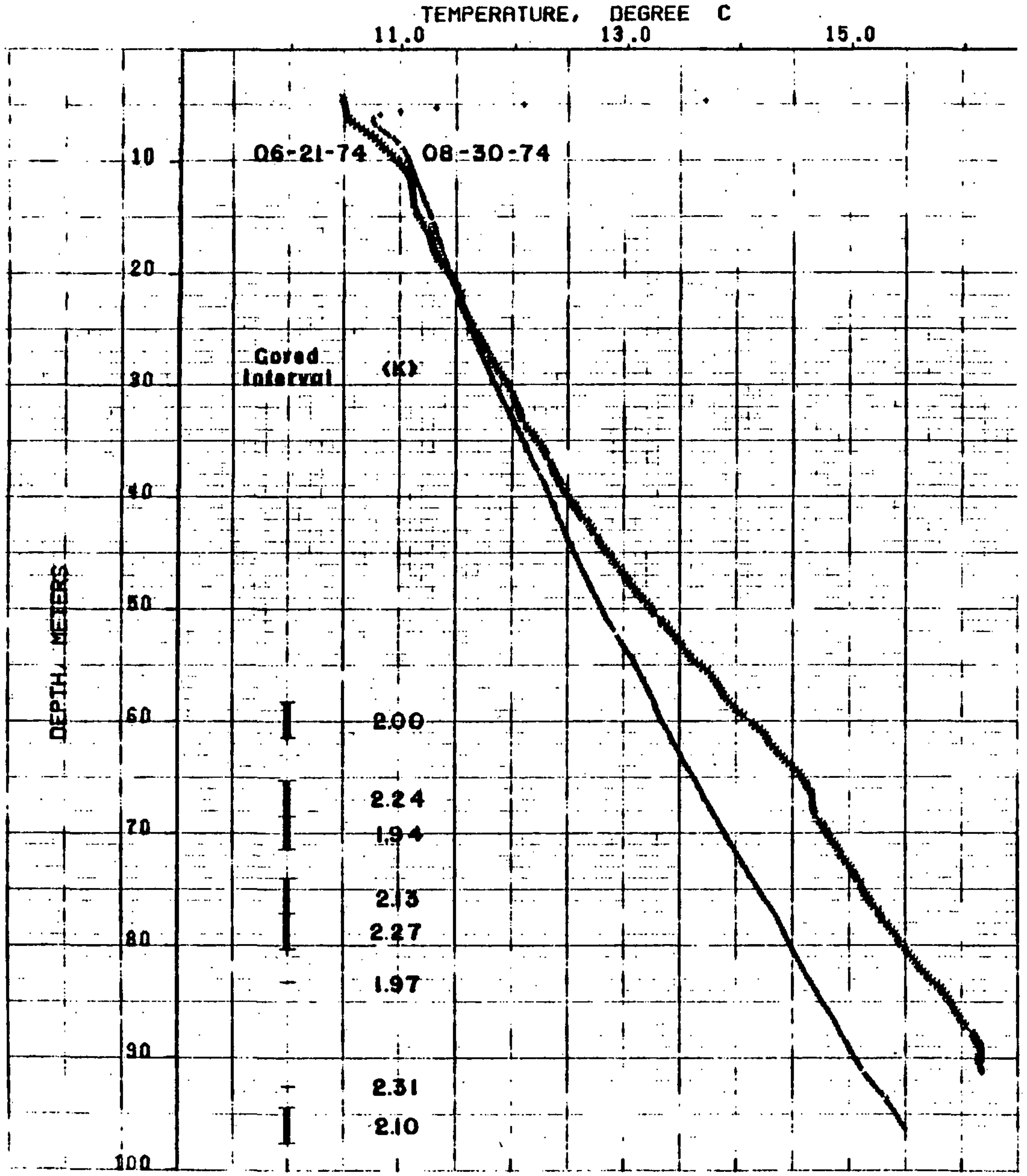


Figure 17. Temperatures in AD-2, Alvord Valley, Oregon

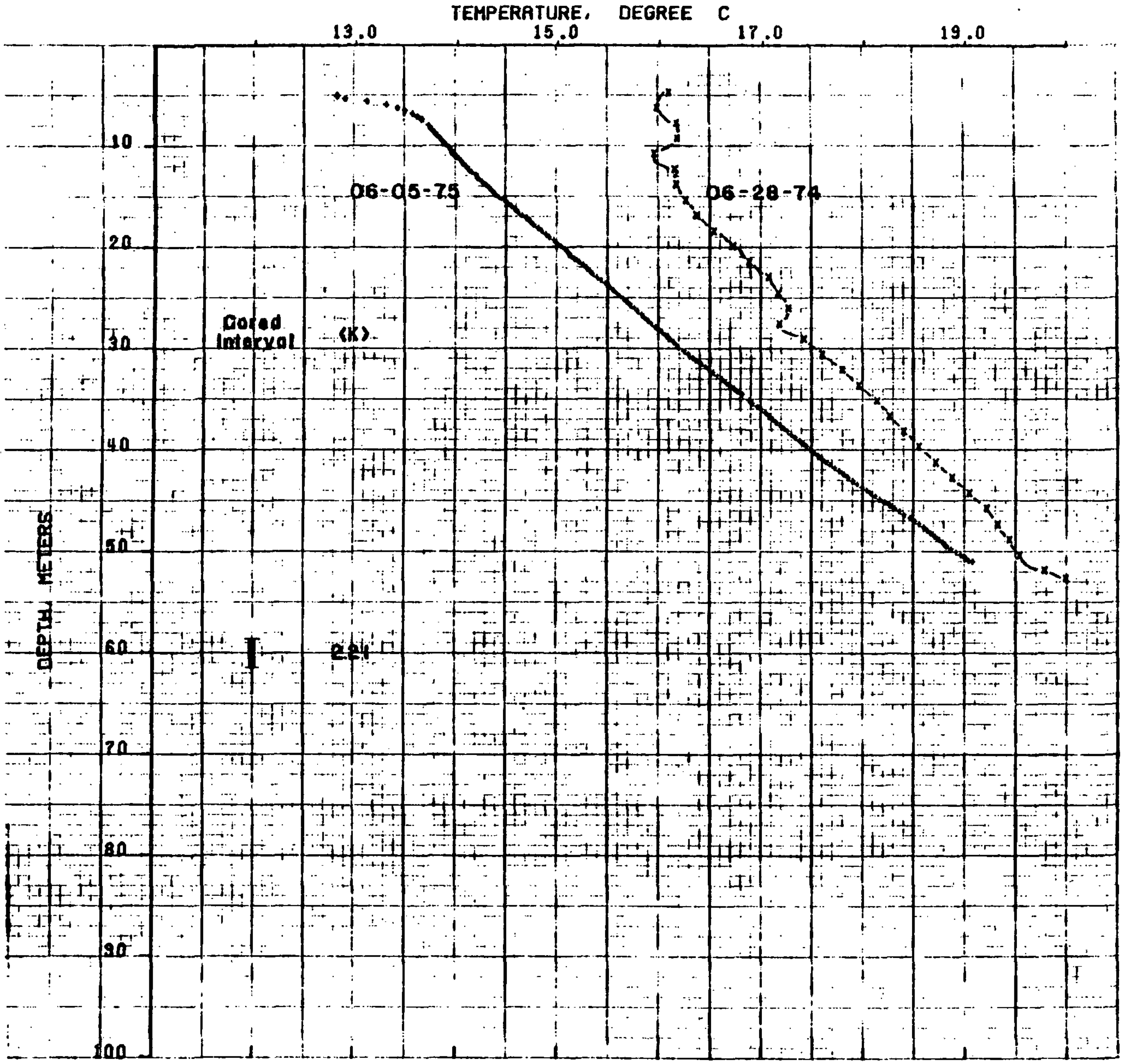


Figure 18. Temperatures in MH-1, ~1.8 km SW of Mickey Hot Springs

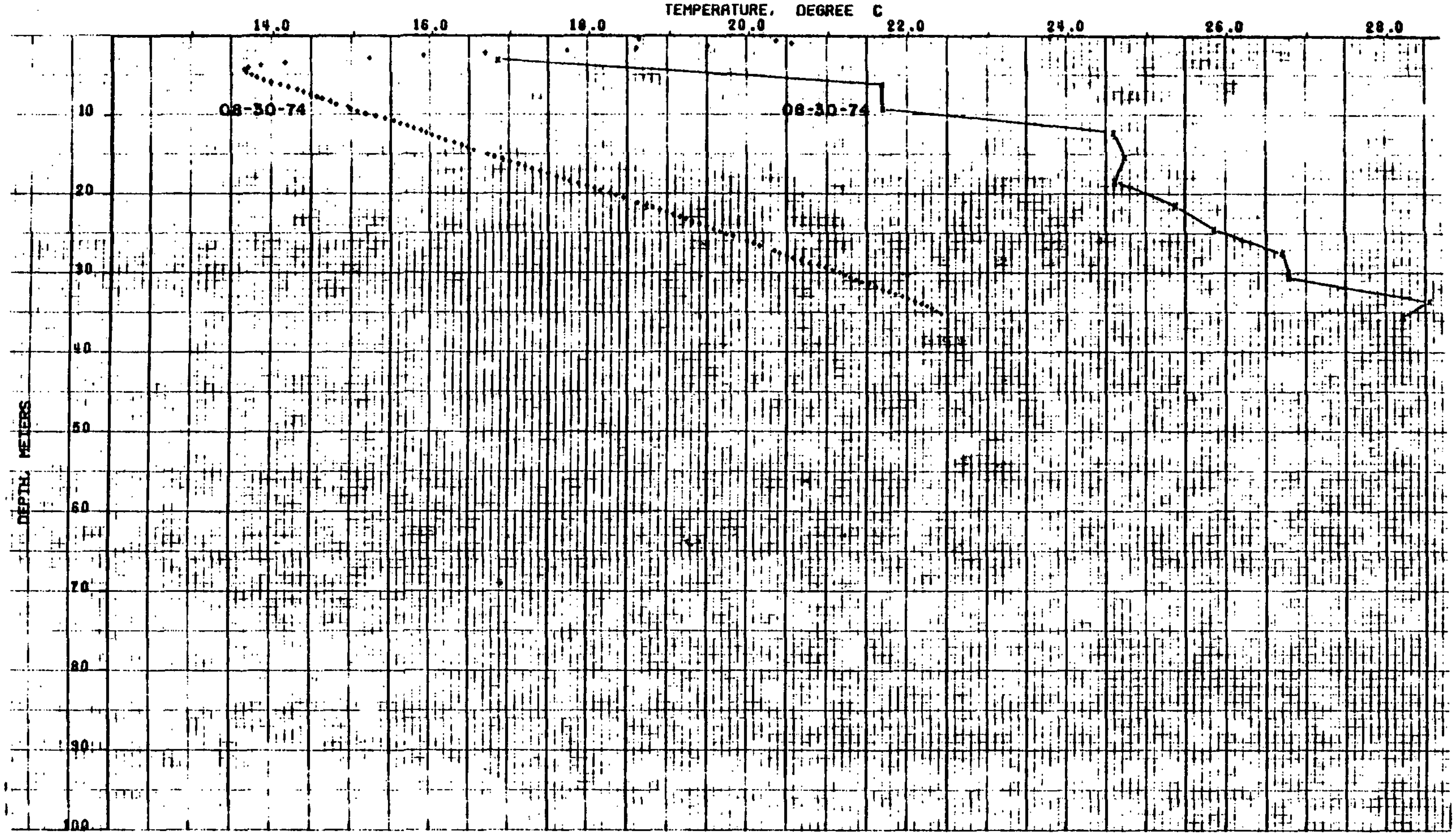


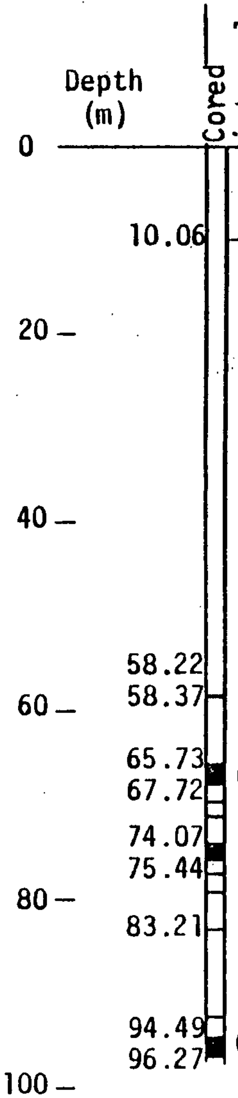
Figure 19. Temperatures in MH-2, ~1 km west of Mickey Hot Springs

TABLE 10. Lithology from cores and cuttings and thermal conductivity of cores from hole AD-1, south of Mickey Hot Springs, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0		Clay and silt, tan, 5% medium sand		
11.89		Clay and silt, pale green with black layers, 0-3% medium sand		
55.78 57.46	■	Clay and silt, pale green, minor iron oxide stain massive bedding	56.28	2.01
			56.45	2.02
			56.76	2.09
			56.91	2.02
			57.16	2.04
			57.32	2.08
			57.50	2.19
92.66 95.71	■	Clay and silt, pale green, 3% iron oxide stain, massive bedding	92.81	2.04
			93.12	2.02
			93.52	2.01
			93.83	2.18
			94.30	2.00
			94.63	1.97
			94.86	2.05
			95.15	2.01
			95.56	1.98

<K> = 2.04 ± 0.02

TABLE 11. Lithology from cores and cuttings and thermal conductivity of cores from hole AD-2, south of Mickey Hot Springs, Oregon



Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0 10.06		Clay and silt, tan, 5%± medium sand (0.3 mm)		
58.22 58.37 65.73 67.72 74.07 75.44 83.21		Clay and silt, pale green, 3% irregular patches of iron oxide stain, massive bedding	58.30 65.64 66.08 66.46 67.07 69.90 71.40 74.23 74.67 75.06 75.33 77.15 79.25 83.21 92.66	2.00 2.19 2.27 2.25 2.25 1.96 1.93 2.24 2.26 2.09 2.03 2.24 2.30 1.97 2.31
94.49 96.27		Clay and silt, pale green, minor iron oxide stain, massive bedding	94.64 95.06 95.71 96.17	1.99 2.04 2.16 2.22

<K> = 2.13 ± 0.03

TABLE 12. Lithology from cores and cuttings and thermal conductivity of cores from hole MH-1, Mickey Hot Springs, Oregon

Depth (m)	Cored interval	Lithology	K sample depth (m)	K (mcal/cm sec °C)
0		Clay and silt, tan		
6.10		Clay and silt, gray		
15.24		Clay and fine sand, pale green, 5% clasts (average size 1-3 mm)		
21.34		Clay and fine sand, pale green, 10-15% clasts of subangular to subrounded basalt, andesite tuffaceous sediment, and volcanic glass (average size 1-3 mm)		
54.86		Clay and silt, pale green, massive bedding, moderate induration	59.28	2.27
58.83	■		59.48	2.38
61.57			59.82	2.16
			60.03	2.13
			60.25	2.14
			60.41	2.23

<K> = 2.21 ± 0.04

TABLE 13. Lithology (based on examination of drill cuttings) of hole MH-2, Mickey Hot Springs, Oregon

Depth (m)	Cored interval	Lithology
0		Clay and silt, tan
4.60		Clay and sand, pale green and black
20		
27.40		Clay and sand, 20-90% sand-sized volcanic clasts
36.90		Basalt?
40		

SUMMARY AND CONCLUSIONS

Excluding the holes very near Mickey Hot Springs, heat-flow values at 15 sites within the area of Figure 1 range from 1.1 to 2.3 HFU with a mean of 1.55 ± 0.09 HFU. This average is consistent with that from the Columbia Plateau province in Washington (Blackwell, 1974; Diment and others, 1975). It is also the heat flow we would expect in a part of the cordillera characterized (as is this one) by surface rocks older than 5 m.y. (MacLeod and others, 1975) and with low-to-moderate crustal radioactivity.

Heat flow on either side of Steens Mountain (Figures 1 and 2) appears to be influenced by hydrothermal convection in a manner that we hope to learn more about with further studies of the hydrology, structure and geophysics of the region.

On the basis of what we have learned to date, further drilling is tentatively planned for the Alvord - Mickey Hot Springs area and for the Diamond Craters area. Details and timing of these plans are subject to modification depending upon available funding and coordination with the Department of Geology and Mineral Industries (DOGAMI). Additional heat-flow work by DOGAMI is presently under way (supported in part by the USGS extramural program) with 28 shallow (30 - 60 m) temperature-gradient holes having been drilled as of November 1975 (Donald A. Hull, verbal communication).

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