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Geological Survey[1]

in cooperation with

Lawrence Berkeley Laboratory[2]

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HEAT FLOW NEAR KYLE HOT SPRINGS, BUENA VISTA VALLEY, NEVADA

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by

J. H. Sass[1], H. A. Wollenberg[2], D. E. di Somma[2], and J. P. Ziagos[1]

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INTRODUCTION

Electrical geophysical surveys in the Kyle Hot Springs area, northern Nevada, conducted in 1975-1976 by the Lawrence Berkeley Laboratory and the University of California, Berkeley (description of surveys and results are presently in preparation) indicated the presence of a zone of anomalous self-potential and electrical resistivity in bedrock of the western flank of the East Range, east of Kyle Hot Springs. As part of the ERDA-sponsored program of assessment of geophysical techniques in areas of geothermal potential in northern Nevada, heat-flow measurements were planned near Kyle, to see if the electrical anomalies were indicative of a circulating hydrothermal system, or were reflecting geochemical anomalies in the bedrock. In this area, banded quartzitic and phyllitic rocks of the Valmy Formation, early Paleozoic in age, have been thrust over carbonates of probable Triassic age (Muller and others, 1951). Five heat-flow holes were planned, two in quartzite, one in the carbonate rock, and two in valley alluvium west of the hot springs (only one hole was ultimately drilled in the quartzite). The holes in alluvium would furnish a comparison of heat flow in that material with heat flow in the bedrock.

Inspection of cores and cuttings from hole KY-3, which penetrated $\sim$100 meters of Valmy Formation at Star Point Mine (Figure 1), indicated numerous graphite bands, as well as appreciable sulphide mineralization below a near-surface zone of oxidation $\sim$30-meters thick. Hole KY-1, drilled in the carbonate rock exposed on the south side of Hot Springs Canyon, encountered a ∿1-meter-thick zone of graphite, about 31 meters below the surface and several thinner graphitic bands at other depths.

Temperature profiles obtained in early November (about two months after completion of drilling) are shown in Figure 2. The profiles in KY-1 and KY-3 are quasi-linear and indicate predominantly conductive heat flux in the upper ∿100 m. Convective disturbances are evident in both KY-4 and KY-5. In KY-4, a sharp break in temperature gradient at about 65 meters indicates a separation between what might be a conductive, impermeable cap and a deeper permeable zone in which (from the convex-upward curvature) water appears to be moving upward. Upward water movement is indicated by temperatures in Hole KY-5 above ∿75 m. Below 75 meters the profile is smooth, but there is still some curvature.

Tables 1 and 2 summarize heat-flow calculations in all four holes. In Table 1 heat flows are determined over individual, discrete cored intervals. (This type of calculation was not performed for KY-3 which was continuously cored.) Table 2 presents estimates over depth intervals of constant gradient using conductivities from both cores and chips. For chips the porosities determined from cores were used together with the conductivities of the chips (Ks) to estimate the in situ conductivity (Kr). For all conductivity estimates, we used the geometric mean model (see e.g., Woodside and Messmer, 1961; Sass and others, 1971a), i.e., $Kr = Ks^{(1-\phi)} \cdot Kw^{\phi}$ where ϕ is fractional porosity and Kw is the conductivity of water. Conductivity values over individual depth intervals are summarized in Tables 3-6.

The following symbols and units are used in this report.

q heat flow, 1 heat-flow unit (HFU) = 10^{-6} cal cm^{-2} sec^{-1} = 4.18×10^{-2} w m^{-2}

Γ temperature gradient °C km^{-1}

K thermal conductivity, 1 heat-conductivity unit (HCU) = 10^{-3} cal cm^{-1} sec^{-1} °C^{-1} = 0.418 w m^{-1} °K^{-1}

HEAT FLOW

Holes KY-1, 4, and 5 were drilled with a rotary rig and "spot" cores were obtained at intervals of from 30 to 60 meters. KY-3 was continuously cored, but core recovery was poor because the rock was fractured and weathered throughout the drilled section.

For the holes in which only a few cores were obtained, we combined the temperature gradients over the cored intervals with the harmonic mean thermal conductivities over the same intervals to obtain component heat flows, summarized in Table 1. Because the flux plate represented by the core (∿1.5 m) is short in relation to the wavelength of temperature disturbances caused by local convection, there is considerable uncertainty in the gradient (Γ, Table 1) which is reflected in the heat-flow values (q, Table 1). We present these values notwithstanding the uncertainties, because they were obtained without the additional interpretive step (estimating bulk porosity) followed in determining heat flows over larger depth intervals (Table 2). Despite the considerable scatter in component heat flows listed in Table 1, some tentative conclusions can be drawn from them:

1) Heat flows from KY-1 and the bottom part of KY-5 are typical of others found in this part of the "Battle Mountain High" (cf. Sass and others, 1971b, 1976a, b).

2) Heat flow in KY-4 seems to be above the regional average and the value in the upper ∿60 meters is significantly higher than that below.

These preliminary observations can be refined and strengthened by considering conductivities measured on drill cuttings and reasonable estimates for the porosity of the rocks in situ.

The results of this analysis are shown in Table 2. In this case, least-squares gradients were calculated over major depth intervals for which we could reasonably assign a single temperature gradient. Conductivities were estimated on the basis of the harmonic mean of the solid component <Ks> as determined from chips and on the basis of the mean porosity of the cores. Heat flows from the three rotary-drilled holes compare favorably with the component heat flows shown in Table 1.

For the core hole (KY-3) divided-bar measurements on disks of solid rock are in good agreement with chip measurements (Table 4) and the low porosity measured on disks allows us to ignore porosity in determining the heat flow. The value of 3.8 HFU from KY-3 may be compared with the nearest previously published values of 3.8 and 3.4 from bedrock at Panther Canyon and Adelaide, respectively (Sass and others, 1971b).

For KY-1, low thermal conductivities in porous carbonate rocks in the upper $\sim$35 m are reflected by high temperature gradients. Indeed there is a remarkable, if somewhat fortuitous, agreement between component heat flows over cored intervals at depths of about 30 and 60 meters (Table 1). Between 37 and 96 m if we assume zero porosity, the mean thermal conductivity is about 8.5 HCU (Table 3) and the heat flux is 3.3 HFU (Table 2), also in good agreement with the mean from Table 1 and other regional values in the Battle Mountain High.

For KY-5 as noted above, the upper 75 meters of the temperature profile seems dominated by upward water flow. Below 75 meters, the profile is regular, but slightly concave upward between about 75 and 110 m and slightly concave downward below 110 m. There is no evidence for compensating variation of thermal conductivity; therefore, we assume that a linear temperature profile is slightly perturbed by water movement in the hole. The least-squares gradient when combined with the harmonic mean conductivity (assuming a mean porosity of 0.38, Table 6) yields a heat flow of 3.18, also compatible with the mean from Table 1 and other regional values.

As noted in the discussion of Table 1, heat flow in KY-4 seems higher than the regional background flux and a higher value is found for the upper 65 meters than below. It seems reasonable to identify this thermal anomaly with the convective system responsible for the spring because KY-4 is only 2 km from the spring and is collared about 85 meters lower in elevation. The simplest, most plausible explanation for the shape of the temperature profile (Figure 2) and for the observed variation in heat flow within KY-4 (Tables 1 and 2) is that the high conductive heat flow in the upper 65 meters of the hole is being maintained, in part, by an upward component of water movement in the permeable zone below the 65-meter depth.

CONCLUSION

It is apparent that heat flow in the area of the electrical geophysical anomaly on the western flank of the East Range is not significantly higher than average for the "Battle Mountain High," and is typical of other values measured in bedrock in the region. Therefore it is unlikely that the anomalous zone is indicative of the presence of a hydrothermal system in that area.

References

Muller, S. W., Ferguson, H. G., and Roberts, R. J., 1951, Geology of the Mount Tobin Quadrangle, Nevada: U.S. Geol. Survey Map GQ-7.

Sass, J. H., Lachenbruch, A. H., and Munroe, R. J., 1971a, Thermal conductivity of rocks from measurements on fragments and its application to heat-flow determinations: Jour. Geophys. Research, v. 76, no. 14, p. 3391-3401.

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

Sass, J. H., Diment, W. H., Lachenbruch, A. H., Marshall, B. V., Munroe, R. J., Moses, T. H., Jr., and Urban, T. C., 1976a, A new heat-flow contour map of the conterminous United States: U.S. Geol. Survey Open-File Rept. 76-756, 24 pp.

Sass, J. H., Olmsted, F. H., Sorey, M. L., Wollenberg, H. A., Lachenbruch, A. H., Munroe, R. J., and Galanis, S. P., Jr., 1976b, Geothermal data from test wells drilled in Grass Valley and Buffalo Valley, Nevada: U.S. Geol. Survey Open-File Rept. 76-85.

Wollenberg, H. A., Asaro, F., Bowman, H., McEvilly, T., Morrison, F., and Witherspoon, P., 1975, Geothermal energy resource assessment: Lawrence Berkeley Laboratory Rept. UCID 3762.

Woodside, W., and Messmer, J. H., 1961, Thermal conductivity of porous media: Jour. Appl. Physics, v. 32, p. 1688.

TABLE 1. Temperature gradients (Γ), harmonic mean conductivities (<K>), and component heat flows (q) over individual cored intervals for Kyle holes

Hole	Depth interval (m)	Γ °C/km	N*	<K> HCU	q HFU
KY-1	30.5 - 32.0	60.7 ± 8.0	7	4.62 ± 0.2	2.8 ± 0.4
	61.0 - 62.5	37.7 ± 3.1	2	8.38 ± 1.1	3.2 ± 0.5
			Mean		3.0
KY-4	30.5 - 32.0	148 ± 16	15	4.60 ± 0.20	6.8 ± 0.8
	102.1 - 103.6	86.5 ± 7.0	16	5.22 ± 0.29	4.5 ± 0.4
	137.2 - 138.7	73.6 ± 6.6	16	6.53 ± 0.38	4.8 ± 0.5
KY-5	79.2 - 80.8	72.4 ± 4.1	16	3.32 ± 0.01	2.40 ± 0.14
	115.8 - 117.3	97.4 ± 5.2	16	4.13 ± 0.42	4.02 ± 0.46
			Mean		3.2

*N is number of conductivity determinations.

TABLE 2. Heat flows over quasi-linear sections of temperature profiles for Kyle holes

Hole	Depth interval m	Γ °C/km	N*	<K> HCU	q HFU
KY-1	37 - 96	38.70 ± 0.05	9	8.53 ± 0.25	3.30 ± 0.10
KY-3	18 - 100	34.77 ± 0.10	24	10.95 ± 0.44	3.81 ± 0.15
KY-4	23 - 67	136.7 ± 0.2	16	4.98 ± 0.15	6.8 ± 0.2
	75 - 137	84.2 ± 0.1	27	5.87 ± 0.19	4.95 ± 0.16
KY-5	75 - 152	87.69 ± 0.05	29	3.63 ± 0.09	3.18 ± 0.08

*N is number of thermal conductivity determinations.

TABLE 3. Thermal conductivities for Hole KY-1

Depth (m)	Kr	Ks[††]	Porosity (%)
6.1		8.09	
12.2		8.25	
32.0	4.62 ± .20*(7)	8.97	35.7
48.8		8.69	
54.9		7.62	
62.0	8.38[†]	8.83	1.5
65.5		9.53	
85.3		8.32	
91.4		8.49	
93.0		8.80	

*Needle-probe measurements on core, number of determinations in parentheses.

[†]Divided-bar measurements on solid disks.

[††]Conductivity of solid component using chips.

TABLE 4. Thermal conductivities for Hole KY-3

Depth (m)	Kr[†]	Ks[††]	Porosity (%)
4.6		15.86	
9.1		11.86	
13.7		15.61	
18.3		8.03	
22.9		9.72	
24.1	9.47		4
27.4		10.36	
32.0		11.53	
36.6		9.36	
41.1		11.43	
42.1	13.44		1
45.7		11.53	
50.3		11.46	
54.9		10.12	
55.8	11.01		1
59.4		9.28	
64.0		10.06	
68.6		9.50	
69.5	13.38		1
73.2		9.70	
77.7		15.71	
82.3		9.48	
86.9	10.05	12.61	1
91.4		15.49	
96.0		9.98	
100.6		13.22	
101.5	14.50		1
105.2		10.53	

[†]Divided-bar measurements on solid disks.
[††]Conductivity of solid component using chips.

TABLE 5. Thermal conductivities for Hole KY-4

Depth (m)	Kr*	Ks††	Porosity (%)
6.1		7.99	
12.2		10.06	
18.3		9.76	
24.4		9.92	
30.5	4.60 ± .20(7)	8.86	35.5
36.6		7.50	
42.7		9.15	
48.8		8.06	
54.9		9.35	
61.0		9.76	
67.1		10.63	
79.2		8.33	
85.3		9.24	
91.4		8.10	
97.5		9.74	
103.6	5.22 ± .29(7)	9.24	30.3
109.7		8.78	
115.8		9.76	
121.9		10.52	
128.0		9.70	
134.1		9.96	
140.2	6.53 ± .38(8)	10.47	23.5
146.3		10.94	

*Needle-probe measurements on core, number of determinations in parentheses.

††Conductivity of solid component using chips.

TABLE 6. Thermal conductivities for Hole KY-5

Depth (m)	Kr*	Ks††	Porosity (%)
6.1		5.03	
12.2		6.06	
18.3		7.55	
24.4		6.03	
30.5	3.86 ± .24(7)	6.64	34.8
36.6		5.33	
42.7		6.58	
48.8		5.65	
54.9		5.65	
56.4		3.81	
61.0		6.00	
67.1		4.73	
73.2		5.94	
79.3		6.20	
85.3	4.13 ± .42(5)	6.68	30.8
91.4		5.53	
97.5		4.35	
103.6		6.56	
109.7		7.11	
115.8		6.84	
121.9	3.28 ± .07(11)	7.18	47.9
128.0		6.75	
134.1		7.76	
140.2		6.86	
146.3		6.58	
152.4		7.22	

*Needle-probe measurements on core, number of determinations in parentheses.

††Conductivity of solid component using chips.

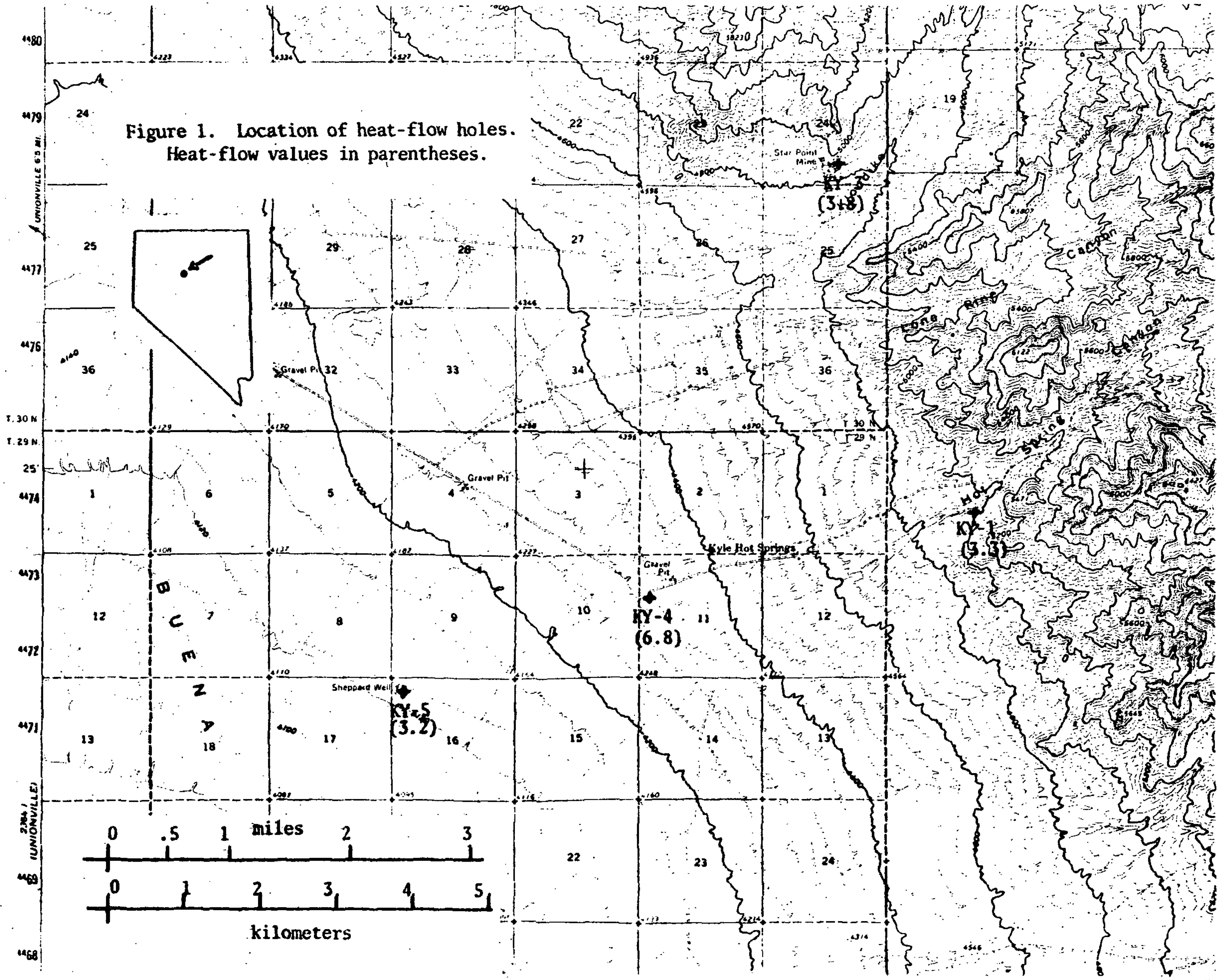

Figure 1. Location of heat-flow holes. Heat-flow values in parentheses.

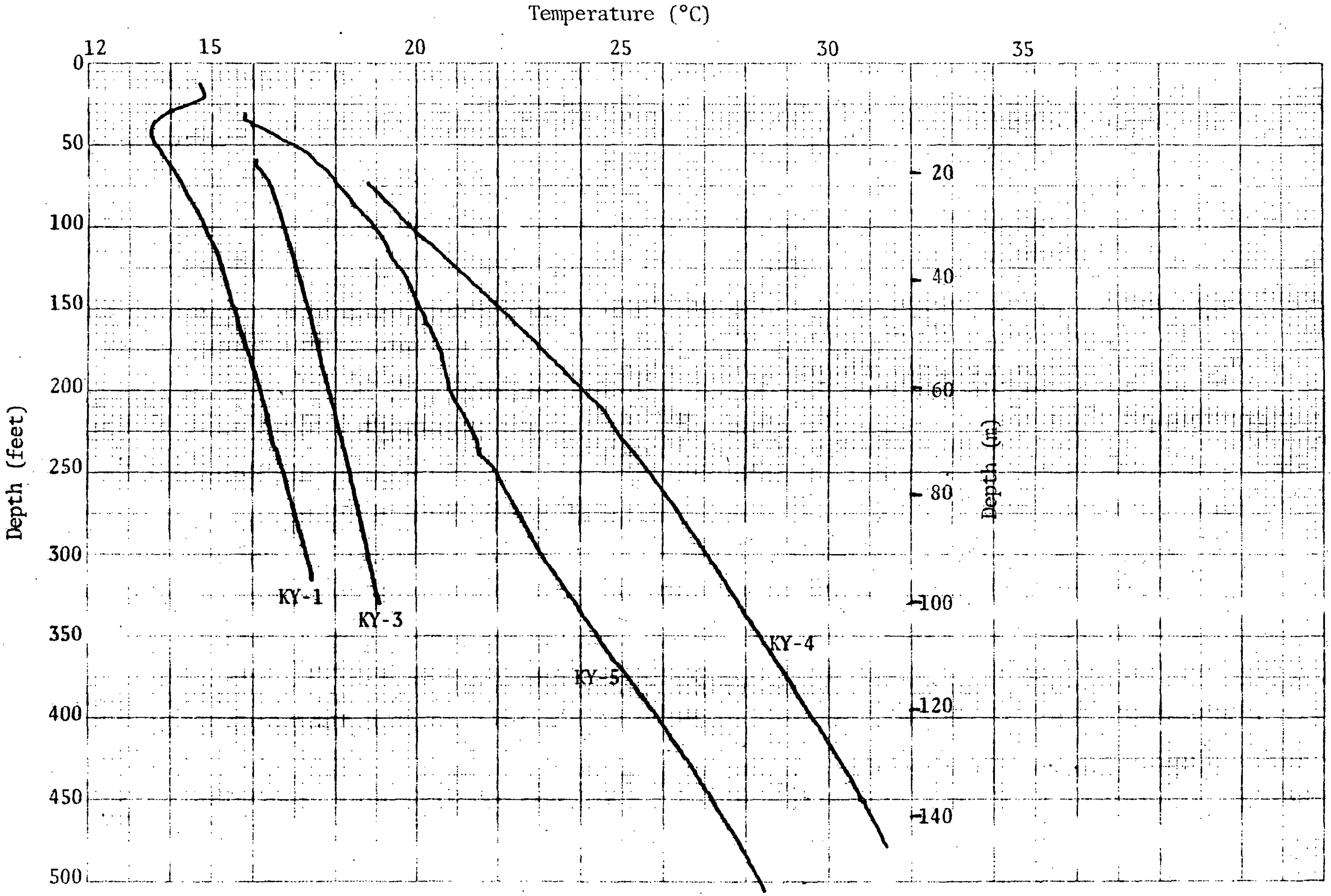

Figure 2. Temperature profiles from holes near Kyle Hot Springs, Nevada.