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Thermal Gradients and Heat Flow at Roosevelt Hot Springs

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Abstract

Thermal gradient and electrical resistivity surveys both outline anomalous zones along the system of faults that control the near surface flow at Roosevelt Hot Springs. The source of both anomalies is the circulation of thermal water, which gives rise to the high heat flow and the lowered resistivity due to the hot brine and the associated hydrothermal alteration.

The nature of the temperature profiles and the asymmetry of the thermal gradient profile across the system are suggestive of a leakage and mixing of thermal water with the regional groundwater flow to the west. This interpretation is consistent with the resisitivty data in which conductive regions to the west of the fault system have been interpreted in terms of brine-saturated sediments.

The maximum conductive heat flow over the anomaly is 40 HFT ($1.7 W/m^2$) and the total conductive heat loss is estimated at 2 MW. Heat flow in the Mineral Mountains, to the east of the near-surface thermal anomaly, is low or near average for the Basin and Range. Recharge may be taking place in this region.

1.0 Introduction

Thermal gradient data from 39 drill holes in the Roosevelt Hot Springs KGRA area are presented in this report. Fifteen of these holes were drilled under subcontract to the University of Utah, permission to log another ten holes was granted by Phillips Petroleum Company and the remaining fourteen holes were provided by other sources. The locations of most of the holes are shown in Figures 1 through 3, along with the locations of test and production holes. These figures also show the contoured average thermal gradient in three depth intervals; shallow (30-60m), intermediate (60-100m) and deep (>100m).

Figure 4 displays a plan view of the interpreted faults in the area. Comparison of Figures 1 and 4 shows that the region of highest thermal gradients is aligned along the Dome Fault and Fault 1. To the south the high thermal gradients are terminated by several east-west trending faults. To the north there is a bending of the contours resulting in a ridge aligned along fault 5, which trends to the north west.

In Figures 1 and 2 there are isolated highs in the north and south that are probably the result of the sparseness of data in the central region. Considerations of the probable thermal gradient in the early steam well (drilled by Dr. E. N. Davie), based on the depth of blowout, and the near surface temperatures in sulfur pits in the bottom of Negro Mag Wash (North of 54-3) would indicate that the 900°C/km should run further to the west in the southern portion and is probably continuous with the high in the north.

Comparison of Figure 1 with the contoured apparent resistivity (Figure 5) shows that the resistivity and thermal gradient patterns are highly correlated. Both exhibit contours aligned along the Dome fault and a bending to the northwest along Fault 5. The obvious cause of the correlation

is the hot water circulation along the faults which gives rise to both high thermal gradients and low resistivities due to the hot brine and the associated hydrothermal alteration.

With increasing depth (Figures 2 and 3) the thermal gradients decrease and the alignment along the faults is less clear. The smearing of the pattern is partly due to the lack of data at greater depths. The acquisition of deep thermal gradient data from small drill holes in regions of very high thermal gradients is hindered by fear of blowouts, among other things.

2.0 Thermal Gradients at Roosevelt Hot Springs

Figures 6 to 20 show the temperature vs depth curves for the holes drilled by the University of Utah. As can be seen in these figures, the thermal gradient in holes drilled in alluvium often decreases with depth, with the depth intervals used in Figures 1 to 3 being somewhat characteristic of the several regions of changing gradient. For example, hole UUTG6 (Figure 20) shows an abrupt change at 30m and hole UUTG3 (Figure 18) displays a more gradual transition with suggested breaks at 35m and 70m. Such changes in the thermal gradients can be caused by changes in thermal conductivity due to changes in the porosity, saturation and lithology among other things.

Gravity measurements over a wash in the alluvium (Crebs and Cook, 1976) indicate a porosity of about 25% in the near surface (25-50m). Some decrease in porosity with depth is to be expected due to the increase in load. A change in the porosity of saturated granite alluvium from 25% to 10% would give rise to a change in thermal conductivity (and gradient) of about 25%. The changes in thermal gradient caused by such variations in porosity are then rather modest.

On the other hand, changes in saturation, from dry to completely saturated, would give rise to changes in thermal conductivity by a factor of 2.0 to 2.5 for porosities in the range from 20 to 30%.

Changes in the thermal conductivity due to lithology changes depends on the thermal conductivity of the components. For example, changing the thermal conductivity of the solid components by a factor of 2 results in a 1.7 change in conductivity at a porosity of 25%. Changes in lithology from a granite alluvium to a quartz rich sand are possible in this area. Measurements made on sands from the Roosevelt KGRA give solid component conductivities in the range from 10 to 11 HCU and samples of granite alluvium give

values in the range from 6 to 7 HCU. Therefore, such changes in lithology can be expected to give rise to rather substantial changes in gradient.

Considering the thermal gradients in hole UUTG6 (Figure 21) we see that the average gradient in the 20-30m interval is about 200°C/km and below this depth it averages about 30°C/km, a factor of about 7 change is slope. Thermal conductivity measurements on samples from this hole average about 4 HCU, at a saturated bulk density of 2.2g/cm^3, with no consistent changes above and below the break in the slope. The water table in a nearby well (2.4km) at about the same elevation is 26m (Mower and Cordova, 1974). This is near the break in the thermal gradient. However, the change in thermal conductivity due to undersaturation would only be a factor of 2 to 2.5 which is well below the observed value.

One possible explanation of the strong change in gradient is a leakage of thermal water into the groundwater flow to the west. Some leakage of thermal water is indicated by the chemical analysis of the seep west of Salt Cove, which has a cool temperature (25°C) but a Na-K-Ca temperature of 241°C (Parry et. al., 1976). For a uniform mixing of thermal water into the groundwater in a region of constant thermal conductivity, the thermal gradient should decrease smoothly with depth in the mixing zone. The two gradient regions in UUTG6 may result from a combination of effects due to the presence of the water table and mixing. On the other hand, the thermal gradient in hole UUTG3 (3km to the south) shows a more gradual change, with no sharp break at the water table (50m). The overall change in slope between the top and bottom of this hole is about a factor of 8, which seems too large to be explained by the effects of saturation alone.

In holes UU751A and UU751B, just to the west of the dome fault, the water tables were located at about 35m and 40m respectively, which are also the locations of the alluvium altered bedrock interface. In both cases the thermal gradients do not show an abrupt change at the water table.

However, there is gradual increase in thermal gradient above these depths (20% to 40%), perhaps due to gradual changes in the saturation.

Figure 21 shows a series of temperature profiles on a west-east line across the southern part of the system (the letter designation runs from West-A to East-I). The thermal gradients and the 10m depth temperatures increase as the Dome Fault is approached from the west (A to G) and the two eastern holes (H & I) show decreasing temperatures and gradients.

The five westernmost holes (AA to D) show a decreasing gradient with depth, as did the western holes to the north(UUTG6 and UUTG3) discussed previously. The two westernmost holes 5(AA) and 12(A) have a thermal gradient in the deeper part near 50°C/km, which is near normal for a thermal gradient in the alluvium. The water table is about 40m in this region (Mower and Cordova, 1974) and both curves show changes in slope (15 to 30%) at this depth, which could be due to changes in saturation. There is a change in slope to a near constant slope region at a depth of about 60m. The change in average gradient above and below this depth is a factor of 1.5 to 3. The lithologic log on a nearby water well notes a change in lithology at this point, from sands containing numerous "igneous" fragments (up to 30%) to sands free of such material. Considering the average abundance of such material, it would be difficult to account for the changes in slope by the change in lithology. Once again a possible explanation for the change in slope could be leakage of thermal waters to the west and mixing with the groundwater. With respect to this, it is interesting to note that the thermal gradients at depth in the westernmost holes are near normal and that the gradient in the easternmost hole is constant with depth although slightly above normal. More conclusive evidence for leakage mixing of thermal waters would be the presence of gradient reversals which have not been observed to date.

3.0 Heat Flow at Roosevelt Hot Springs

Thermal conductivity measurements on a limited number of alluvial samples, indicates an average value of 4 HCU (1 HCU – mcal/cm S°C – 0.418 W/m°k). Maximum conductive heat fluxes are then in the neighborhood of 40 HFU (1 HFU = μ cal/cm^{2}S = 41.8 mW/m^2). The total integrated conductive heat loss over the anomaly (6.5 km in length) is about 10^7cal/S or 2MW.

Figure 22 is a west to east thermal gradient profile for two depth intervals, 30-60m and 60-100m. Based on a *conductive* heat flow model, these profiles indicate an equivalent line source at 1.0 to 1.5km depth. Also shown on the figure, as a dashed line, is the theoretical thermal gradient profile for a line source, scaled to the 30-60m data. From this it is easy to see that the observed curve is asymmetrical, with smaller gradients in the east and larger to the west. This asymmetry is also observed in the deeper (60-100m) gradients. The observed asymmetry is compatable with the leakage of thermal water to the west, as discussed in the previous section, but source configuration in a conductive model could also produce such asymmetry.

Several core holes were also drilled in the granite of the Mineral Range so that samples could be measured for thermal conductivity and heat flow values calculated. Figure 13 shows the temperature profile in one such hole (UU76SC) located in Salt Cove on the west side of the Mineral Range, about 3 km east of the center of the thermal gradient-resistivity anomaly. The thermal gradient is quite uniform at an average value of 29°C/km below a depth of 50m. The average thermal conductivity in this region is 6.6 HCU (16 samples) giving a heat flow of 1.92 HFU.

Another hole (UU76BS) was drilled in the central part of the Mineral Range just to the north of Bearskin Mountain, the temperature profile from the last log (Figure 14) still shows some drilling disturbances, but the

3.0 Heat Flow [illegible] Roosevelt Hot Springs

Thermal [illegible] samples, indicate an average value of 4 HCU [illegible] 18 W/m [illegible] Maximum conductive heat fluxes are [illegible] than in the [illegible] (1 HFU = 1 cal/cm²s = 41.8 mW/m²). The total integrated conductive heat loss over the anomaly ([illegible] km in length) is about $10^{?}$ cal/s or [illegible] MW.

Figure 2 [illegible] west to east thermal gradient profiles [illegible] depth intervals, 30-60m and 60-100m. Based on [illegible], these profiles indicate an equivalent line source [illegible] depth [illegible]. Also shown on the figure, as a dashed line, is the theoretical [illegible] gradient profile for a line source, [illegible] to the [illegible] ments. It is easy to see that the observed curve is asymmetric [illegible] gradients in the east are lower [illegible] the west. [illegible] observed in the deeper (60-100m) gradients [illegible] compatible with the leakage of thermal water [illegible] in the previous section, [illegible] could also produce such asymmetries.

Several core holes were also drilled in the [illegible] Range so that samples could be analyzed for thermal conductivity [illegible] flow values calculated. Figure [illegible] shows the temperature [illegible] hole (UU76SC) located [illegible], about 3 km east of the center of the thermal gradient [illegible] gravity anomaly. The thermal gradient is quite uniform at an average [illegible] of 28°C/km below a depth of 50m. The average thermal conductivity [illegible] is 8.5 HCU (16 samples) giving a heat flow of [illegible] HFU.

Another hole (UU-[illegible]S) was drilled in the central part of the Mineral Range just to the north of [illegible], the temperature profile from the last [illegible] (Figure [illegible]) still shows some drilling disturbances, but the smoothed thermal gradient in the 80 to 150m interval is 17^{o}C/km. The thermal gradient in a Phillips Petroleum Company hole, 1.5 km to the north (Figure 1) is similar (16^{o}C/km) indicating that this is maybe representative of the area. The average thermal conductivity in this hole in the above depth interval is 7.65 HCU (11 samples) giving a heat flow of 1.28 HFU.

Two kilometers to the east of this hole, the hole at Ryans Ranch (UU75RR, Figure 11) has thermal gradient of 19.9^{o}C/km (50 to 80 m) and the average thermal conductivity of several samples is 7.1 HCU, resulting in a heat flux of 1.41 HFU.

Roy et al. (1968) report a heat flow of 2.22 HFU for a location on the west side of Milford valley, just about due west of Roosevelt Hot Springs. None of the above calculated heat flow values are large for the Basin and Range, in fact the measurements in the central part of the range seem somewhat low. However, none of the measurements have been corrected for topographic effects, which should be largest for the locations north of Bearskin and at Ryans Ranch.

If the Mineral Mountains and the area to the east are regions of significant recharge, then the downward movements of cool water may contribute to the low thermal gradient and heat flow.

4.0 Conclusions

Thermal gradients and electrical resistivity data at Roosevelt Hot Springs both outline the same anomalous region along the system of faults which control the near surface circulation. Depending on the circumstances, these techniques may provide complementary or redundant information.

The character of the thermal gradients to the west of the fault system suggest that thermal waters are mixing with the ground water flow to the west. If so, this should be reflected in the water chemistry. Parry et al. (1976) show several anomalous Na-Ca-K temperatures to the northwest of Roosevelt Hot Springs but no data was available from wells in the immediate vicinity of the thermal gradient holes.

Heat flow values in the alluvium reach a maximum of about 40 HFU, and the estimated total conductive heat loss from the shallow part of the system is about 2MW. Heat flow values and thermal gradients in the Mineral Range are not high for the Basin and Range, and in fact several of the values seem low.

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Parry, W. T., N. L. Benson and C. D. Miller, 1976; Geochemistry and hydrothermal alteration at selected Utah hot springs, volume 3, Grant GI-43741 National Science Foundation.

Roy, R. F., E. R. Decker, D. D. Blackwell and F. Birch, 1968; Heat flow in the United States, J. Geophys. Res., 73,5207-5221.

LIST OF FIGURES

APPENDIX A

Temperature Logs

LOCATION: RYANS RANCH
LOCATION: RYAN'S RANCH
27S 8W 4DCD
HOLE NUMBER: UU75
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	9.894	.0
10.o	8.803	-218.2
15.0	9.716	182.6
20.0	9.858	28.4
25.0	9.000	-171.6
30.0	9.007	1.4
35.0	9.170	32.6
40.0	9.280	22.0
45.0	9.370	18.0
50.0	9.391	4.2
55.0	9.492	20.2
60.0	9.569	15.4
65.0	9.681	22.4
70.0	9.781	20.0
75.0	9.886	21.0
80.0	9.987	20.2
85.0	10.116	25.8
90.0	10.292	35.2
95.0	10.381	17.8
100.0	10.492	22.2

LOCATION: BIG CEDAR COVE
27S 9W 14 BDC
HOLE NUMBER: BU 75
DATE MEASURED: 9/22/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	16.769	.0
10.0	12.978	-758.2
15.0	13.421	88.6
20.0	13.543	24.4
25.0	13.873	66.0
30.0	14.427	90.8
35.0	14.693	53.2
40.0	15.073	76.0
45.0	15.526	90.6
50.0	15.957	86.2
55.0	16.437	96.0
60.0	16.754	63.4
65.0	17.132	75.6
70.0	17.481	69.8
75.0	17.908	84.8
80.0	18.280	75.0
85.0	18.579	59.8
90.0	18.858	55.4
95.0	19.153	59.4
100.0	19.937	156.8

LOCATION: ALTERATION 75 1A
27S 9W CBB
HOLE NUMBER: UU 751A
DATE MEASURED: 7/22/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	26.283	.0
15.0	34.349	1613.2
20.0	40.036	1137.4
25.0	44.876	928.0
30.0	49.158	896.4
35.0	53.288	826.0
40.0	57.622	866.8
45.0	61.177	711.0
50.0	63.990	562.6
55.0	67.365	675.0
60.0	70.687	664.4
65.0	74.307	724.0
68.5	76.434	607.7

LOCATION: ALTERATION 75 1B
27S 9W 4DDA
HOLE NUMBER: UU 75 1B
DATE MEASURED: 7/22/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.926	.0
10.0	18.065	627.8
15.0	21.878	762.6
20.0	25.194	663.2
25.0	28.354	632.0
30.0	31.719	673.0
35.0	35.043	664.8
40.0	37.561	503.6
45.0	40.288	545.4
50.0	42.688	480.0
55.0	44.676	397.6
60.0	47.008	466.4
65.0	49.088	416.0

LOCATION: BOYLES 12RKGRA
26S 9W 27BBB
HOLE NUMBER: UU 75 12
DATE MEASURED: 6/11/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	16.072	.0
10.0	19.622	710.0
15.0	21.794	434.4
20.0	24.981	637.4
25.0	28.579	719.6
30.0	29.861	256.4
34.5	30.922	235.8

LOCATION: BOYLES 13 RKGRA
26S 9W 20 AC
HOLE NUMBER: UU 75 13
DATE MEASURED: 11/8/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	19.715	.0
20.0	25.496	578.1
30.0	30.489	499.3
40.0	34.301	381.2
43.0	36.742	813.7

LOCATION: BEARSKIN RKGRA
27S 8W BAB
HOLE NUMBER: UU 75
DATE MEASURED: 8/20/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.088	.0
15.0	9.455	273.4
20.0	9.907	90.4
25.0	9.683	-44.8
30.0	9.074	-121.8
35.0	9.048	-5.2
40.0	8.834	-42.8
45.0	8.867	6.6
50.0	8.942	15.0
55.0	8.998	11.2
60.0	9.077	15.8
65.0	9.084	1.4
70.0	9.217	26.6
75.0	9.331	22.8
80.0	9.351	4.0
85.0	9.462	22.2
90.0	9.496	6.8
95.0	9.629	26.6
100.0	9.797	33.6
110.0	10.137	34.0
115.0	10.176	7.8
120.0	10.113	-12.6
125.0	10.296	36.6
130.0	10.249	-9.4
135.0	10.459	42.0
140.0	10.584	25.0
145.0	10.391	-38.6
150.0	10.459	13.6
155.0	10.823	72.8
156.0	10.999	176.0

LOCATION: ALTERATION 76 1A RKGRA
27S 9W 54CAB
HOLE NUMBER: UU 76 1A
DATE MEASURED: 6/ /76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	30.028	.0
10.0	41.190	2232.8
15.0	57.022	3166.4
20.0	63.642	1324.0
25.0	69.025	1076.6
30.0	77.158	1626.6
35.0	84.082	1384.8
40.0	98.606	953.2
45.0	93.914	1013.2
50.0	97.362	689.6
55.0	101.100	747.6
60.0	105.584	896.8
63.5	107.885	657.4

LOCATION: RKGRA TG-0
26S 9W 16BDC
HOLE NUMBER: UU 76 160
DATE MEASURED: 8/30/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.029	.0
15.0	15.124	219.0
20.0	15.405	56.2
25.0	15.757	70.4
30.0	16.164	81.4
35.0	16.501	67.4
40.0	16.839	67.6
45.0	17.234	79.0
50.0	17.502	53.6
55.0	17.674	34.4
60.0	18.012	67.6
65.0	18.210	39.6
70.0	18.432	44.4
75.0	18.750	63.6
77.5	18.967	86.8

LOCATION: BKGRA TG-1
265 9W 15 CBA
HOLE NUMBER: VU76 TG1
DATE MEASURED: 10/10/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	16.428	.0
15.0	18.095	333.4
20.0	19.382	257.4
25.0	20.549	233.4
30.0	21.506	191.4
35.0	22.476	194.0
40.0	23.231	151.0
45.0	23.893	132.4
50.0	24.521	125.6
55.0	25.071	110.0
60.0	25.582	102.2

LOCATION: BKGRA TG-2
265 9W 5CDB
HOLE NUMBER: UU76 TG2
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	15.877	.0
10.0	14.619	-251.6
15.0	15.169	110.0
20.0	15.567	79.6
25.0	15.902	67.0
30.0	16.259	71.4
35.0	16.679	84.0
40.0	17.066	77.4
45.0	17.389	64.6
50.0	17.690	60.2
55.0	17.955	53.0
60.0	18.195	48.0
65.0	18.426	46.2
67.5	18.580	61.6

LOCATION: BKGRA TG-3
26S 9W 19 DBC
HOLE NUMBER: U476 TG3
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	17.946	.0
10.0	18.391	89.0
15.0	21.383	398.4
20.0	22.441	411.6
25.0	24.223	356.4
30.0	26.143	384.0
35.0	28.078	387.0
40.0	29.447	273.8
45.0	30.770	264.6
50.0	32.031	252.2
55.0	32.994	192.6
60.0	33.887	178.6
65.0	34.691	160.8
70.0	35.305	123.0
75.0	35.601	59.0
80.0	35.883	56.4
85.0	36.121	47.6
90.0	36.243	24.4
95.0	36.544	60.2
100.0	36.405	-27.8

LOCATION: BKGRA T6-5
265 9W 14 DAA
HOLE NUMBER: UU76 TG5
DATE MEASURED: 10/10/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
		.0
10.0	13.204	74.6
15.0	13.577	65.8
20.0	13.906	50.0
25.0	14.156	45.0
30.0	14.381	42.4
35.0	14.593	37.6
40.0	14.781	45.0
45.0	15.006	35.8
50.0	15.195	

LOCATION: BKGRA TG-6
26S 9W 7CAA
HOLE NUMBER: UU76 TG6
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.273	
10.0	14.275	.0
15.0	14.847	.4
20.0	15.436	114.4
25.0	16.913	117.8
30.0	17.828	295.4
35.0	18.108	183.0
40.0	18.224	56.0
45.0	18.458	23.2
50.0	18.692	46.8
55.0	18.721	46.8
60.0	18.835	5.8
65.0	19.004	22.8
70.0	19.149	33.8
75.0	19.255	29.0
80.0	19.348	21.2
85.0	19.489	18.6
90.0	19.712	28.2
95.0	19.952	44.6
97.5	19.983	48.0
		12.4

LOCATION: BKGRA SALT COVE
265 9W 25 DCA
HOLE NUMBER: UU 76
DATE MEASURED: 3/24/77

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	10.908	.0
15.0	10.989	16.2
20.0	11.188	39.8
25.0	11.492	60.8
30.0	11.742	50.0
35.0	11.596	-29.2
40.0	12.156	112.0
45.0	12.335	35.8
50.0	12.504	33.8
55.0	12.658	30.8
60.0	12.807	29.8
65.0	12.942	27.0
70.0	13.071	25.8
75.0	13.196	25.0
80.0	13.337	28.2
85.0	13.476	27.8
90.0	13.617	28.2
95.0	13.761	28.8
100.0	13.908	29.4
105.0	14.052	28.8
110.0	14.201	29.8
115.0	14.352	30.2
120.0	14.505	30.6
125.0	14.653	29.6
130.0	14.836	36.6
135.0	14.993	31.4
140.0	15.145	30.4
145.0	15.298	30.6
150.0	15.404	21.2

LOCATION: RANCH CANYON PPC
27S/9W-35 CAD
HOLE NUMBER: EV 4113
DATE MEASURED: 8/12/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.650	.0
20.0	9.640	99.0
30.0	9.770	13.0
36.0	9.890	20.0

LOCATION: RANCH CANYON PPC
27S/9W-35 DB
HOLE NUMBER: EV 4115
DATE MEASURED: 8/12/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	10.920	.0
20.0	11.240	132.0
30.0	11.700	46.0
40.0	11.820	12.0
50.0	11.910	9.0
60.0	11.980	7.0
70.0	12.140	16.0

LOCATION: MINERAL MTS - RADIO RD PPC
26S/8W-30 CDA
HOLE NUMBER: Crater Knoll #2
DATE MEASURED: 8/15/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.010	.0
20.0	8.660	65.0
30.0	8.690	4.0
40.0	8.750	6.0
50.0	8.850	10.0
60.0	8.870	2.0
70.0	8.890	2.0
80.0	8.990	10.0
90.0	9.080	9.0

LOCATION: MINERAL MTS - PPC
27S/8W-6 AA
HOLE NUMBER: Crater Knoll #3
DATE MEASURED: 8/15/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	9.230	.0
20.0	9.700	47.0
30.0	10.210	51.0
40.0	10.430	22.0
50.0	10.610	18.0
59.0	10.700	10.0

LOCATION: NEGRO MAG WASH PPC
27S/9W-1
HOLE NUMBER: 21

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	13.000	.0
20.0	15.600	260.0
30.0	17.300	170.0
32.0	17.550	125.0

LOCATION: WATER WELL 42
275/10W-12D
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/05/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.500	.0
20.0	17.700	320.0
30.0	20.600	290.0
35.0	21.900	260.0
40.0	23.000	220.0
45.0	23.950	190.0
50.0	24.800	170.0
55.0	25.600	200.0
60.0	26.700	180.0
65.0	27.800	180.0
70.0	28.400	160.0
75.0	29.100	140.0
80.0	29.800	140.0
85.0	30.600	160.0
90.0	31.200	120.0
95.0	31.800	120.0
100.0	32.500	140.0
105.0	33.000	100.0
110.0	33.600	120.0
115.0	33.800	40.0

LOCATION: PHILLIPS WATER WELL #3
26S/10W-25A
HOLE NUMBER: PHILLIPS
DATE MEASURED: 6/30/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.200	.0
15.0	17.100	290.0
20.0	18.400	260.0
25.0	19.500	220.0
30.0	21.000	300.0
35.0	22.400	280.0
40.0	23.600	240.0
45.0	24.600	200.0
50.0	25.600	240.0
55.0	27.200	280.0
60.0	27.900	140.0
65.0	28.900	200.0
70.0	29.400	100.0
75.0	30.000	120.0
80.0	30.600	120.0
85.0	30.600	.0

LOCATION: WATER WELL 44
26S/9W-36C
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/03/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	17.900	.0
10.0	17.200	-140.0
15.0	19.100	380.0
20.0	20.700	320.0
25.0	21.500	160.0
30.0	24.200	540.0
35.0	26.200	400.0
40.0	28.600	480.0
45.0	29.300	140.0
50.0	31.800	500.0
55.0	34.900	620.0

LOCATION: WATER WELL 45
27S/9W-17A
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/02/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	12.900	.0
10.0	15.300	480.0
15.0	17.500	440.0
20.0	19.100	320.0
25.0	20.900	360.0
30.0	22.100	240.0
35.0	23.700	320.0
40.0	25.200	300.0
45.0	26.700	300.0
50.0	28.000	260.0
55.0	29.600	320.0
60.0	31.200	320.0
65.0	32.400	240.0
70.0	33.700	260.0
75.0	35.600	260.0
80.0	36.400	280.0
85.0	37.900	300.0
90.0	39.200	260.0
95.0	40.200	200.0
100.0	41.600	280.0
105.0	43.100	300.0
110.0	44.400	260.0
115.0	45.600	240.0
120.0	47.000	280.0
125.0	48.600	320.0
130.0	49.700	220.0
135.0	51.000	260.0
140.0	52.600	260.0
145.0	53.400	220.0
150.0	54.800	280.0
155.0	56.000	240.0
160.0	58.800	560.0
165.0	59.500	140.0
170.0	60.600	220.0
175.0	61.200	120.0
180.0	61.800	120.0
185.0	61.900	20.0

LOCATION: RHS KGRA
27S/10W-23 CA
HOLE NUMBER: 5
DATE MEASURED: 9/03/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.480	.0
20.0	17.450	297.0
30.0	20.130	268.0
40.0	22.580	245.0
50.0	25.000	242.0
60.0	26.930	193.0
70.0	27.650	72.0
80.0	28.390	74.0
90.0	28.960	57.0
100.0	29.590	63.0
110.0	30.100	51.0
120.0	30.550	45.0
130.0	31.100	55.0
140.0	31.520	42.0
150.0	32.180	66.0
151.5	32.210	20.0

LOCATION: RHS KGRA
275/9W-16 BB
HOLE NUMBER: 7
DATE MEASURED: 8/08/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	16.600	.0
20.0	23.300	670.0
30.0	28.200	490.0
40.0	32.900	470.0
50.0	37.300	440.0
60.0	41.550	425.0
70.0	45.730	418.0
80.0	49.800	407.0
90.0	53.900	410.0
100.0	57.780	388.0
110.0	61.450	367.0
120.0	65.300	385.0
130.0	68.840	354.0
140.0	72.300	346.0
145.0	74.000	340.0

LOCATION: RHS KGRA
27S/9W-16 AD

HOLE NUMBER: 8

DATE MEASURED: 8/11/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	24.620	.0
20.0	37.470	1285.0
30.0	49.320	1185.0
40.0	60.170	1085.0
50.0	69.580	941.0
60.0	78.120	854.0
70.0	84.080	596.0
80.0	89.650	557.0
90.0	95.400	575.0

LOCATION: RHS KGRA
27S/9W-21 DD
HOLE NUMBER: 9
DATE MEASURED: 9/05/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	20.950	.0
20.0	32.810	1186.0
23.0	34.000	396.7

LOCATION: RHS KGRA
27S/9W-15 ABD
HOLE NUMBER: 10
DATE MEASURED: 9/02/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.370	.0
20.0	19.880	451.0
30.0	23.800	392.0
40.0	27.560	376.0
50.0	32.580	502.0
60.0	37.410	483.0
64.3	39.100	393.0

LOCATION: RHS KGRA
27S/10W-10 DDD
HOLE NUMBER: 12
DATE MEASURED: 8/11/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.860	.0
20.0	18.640	378.0
30.0	21.380	274.0
40.0	24.190	281.0
50.0	26.270	208.0
60.0	27.470	120.0
70.0	28.510	104.0
80.0	29.240	73.0
90.0	29.810	57.0
100.0	30.370	56.0
110.0	30.960	59.0
120.0	31.530	57.0
130.0	32.150	62.0
140.0	32.730	58.0
150.0	33.180	45.0
160.0	33.770	59.0
170.0	34.320	55.0
180.0	34.840	52.0
190.0	35.320	48.0
200.0	35.860	54.0
203.0	35.980	40.0

LOCATION: RHS KGRA
27S/9W-7 CC
HOLE NUMBER: 14
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.250	.0
20.0	17.900	265.0
30.0	20.500	260.0
40.0	23.100	260.0
50.0	25.100	200.0
60.0	26.900	180.0
70.0	28.700	180.0
80.0	30.500	180.0
90.0	31.900	140.0
100.0	33.200	130.0
110.0	34.300	110.0
120.0	35.250	95.0
130.0	36.100	85.0
140.0	36.900	80.0
150.0	37.600	70.0
160.0	38.300	70.0
170.0	39.050	75.0
180.0	39.850	80.0
190.0	40.650	80.0
195.0	41.000	70.0

LOCATION: RHS KGRA
27S/9W-7D DD
HOLE NUMBER: 15
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.040	.0
20.0	18.100	306.0
30.0	20.300	220.0
40.0	22.200	190.0
50.0	24.400	220.0
60.0	26.300	190.0
70.0	28.000	170.0
80.0	29.500	150.0
90.0	31.200	170.0
100.0	32.800	160.0
110.0	34.700	190.0
120.0	36.300	160.0
130.0	37.700	140.0
140.0	38.900	120.0
150.0	39.800	90.0
160.0	40.700	90.0
170.0	41.600	90.0
175.0	41.900	60.0

LOCATION: RHS KGRA
27S/9W-4 AD
HOLE NUMBER: 17
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	17.600	.0
20.0	23.600	600.0
30.0	29.700	610.0
40.0	34.700	500.0
50.0	40.000	530.0
60.0	44.100	410.0
63.0	45.000	300.0

LOCATION: RHS KGRA
27S/R9W-2 CAA
HOLE NUMBER: 20
DATE MEASURED: 8/13/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	12.410	.0
20.0	14.690	228.0
30.0	16.570	188.0
40.0	18.310	174.0
50.0	20.300	199.0
60.0	21.160	86.0
70.0	22.400	124.0
80.0	23.440	104.0
90.0	24.290	85.0
100.0	24.990	70.0
105.0	25.350	72.0
105.5		

LOCATION: RHS KGRA
265/9W-32 AA
HOLE NUMBER: 25
DATE MEASURED: 9/05/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.590	.0
20.0	21.160	557.0
30.0	25.030	387.0
40.0	28.080	305.0
50.0	30.960	288.0
60.0	33.590	263.0
70.0	36.200	261.0
80.0	38.550	235.0
90.0	40.510	196.0
100.0	42.600	209.0
110.0	44.790	219.0
120.0	47.090	230.0
130.0	49.330	224.0
140.0	51.260	193.0
144.3	51.360	23.3

LOCATION BOYLES 12RKGRA
26S 9W 27 BB
HOLE NUMBER UU 75 12
DATE MEASURED 6/11/76

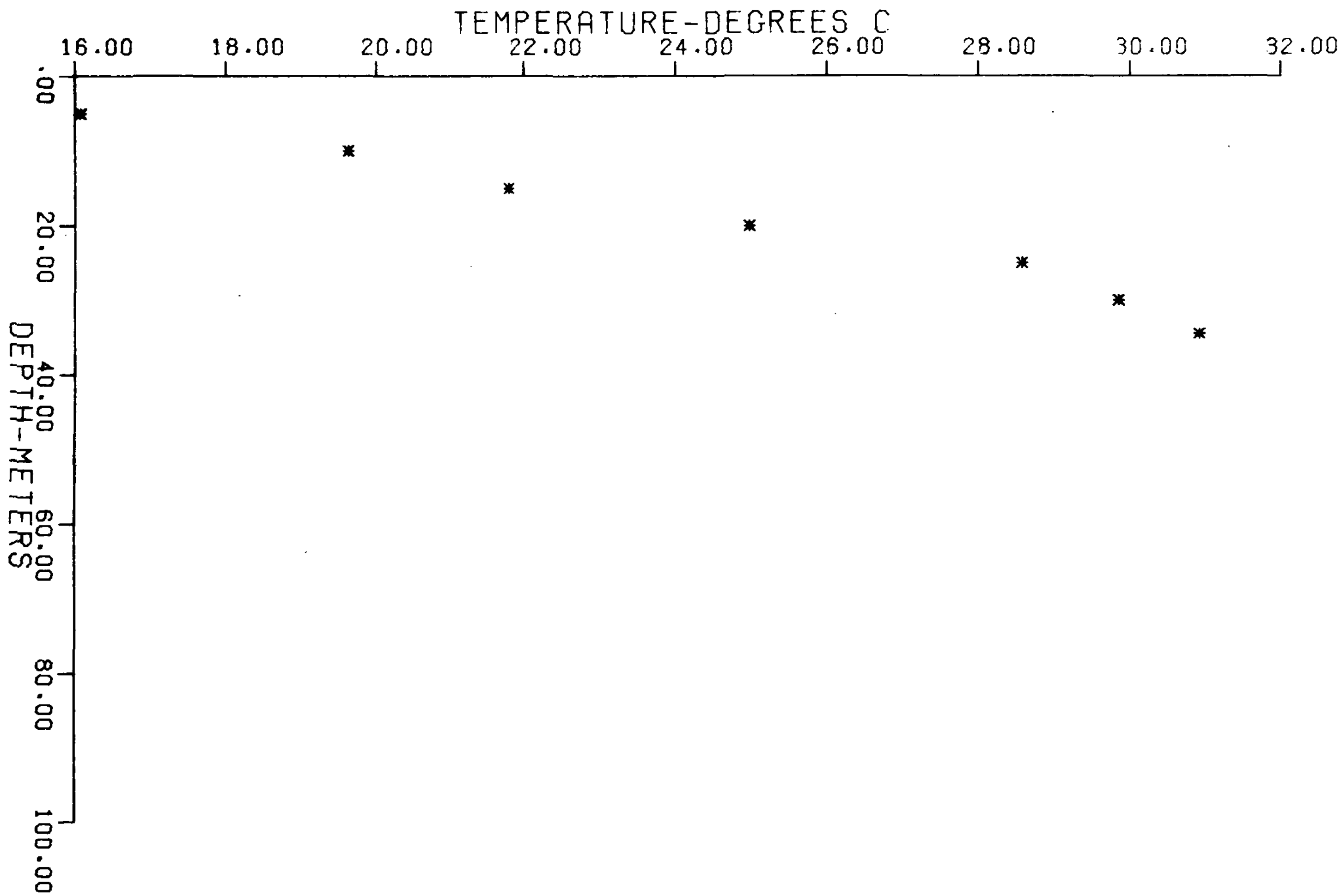


Figure 6

LOCATION BOYLES 13 RKGRA
26S-9W-20 AC
HOLE NUMBER UU-75-13
DATE MEASURED 11/8/75

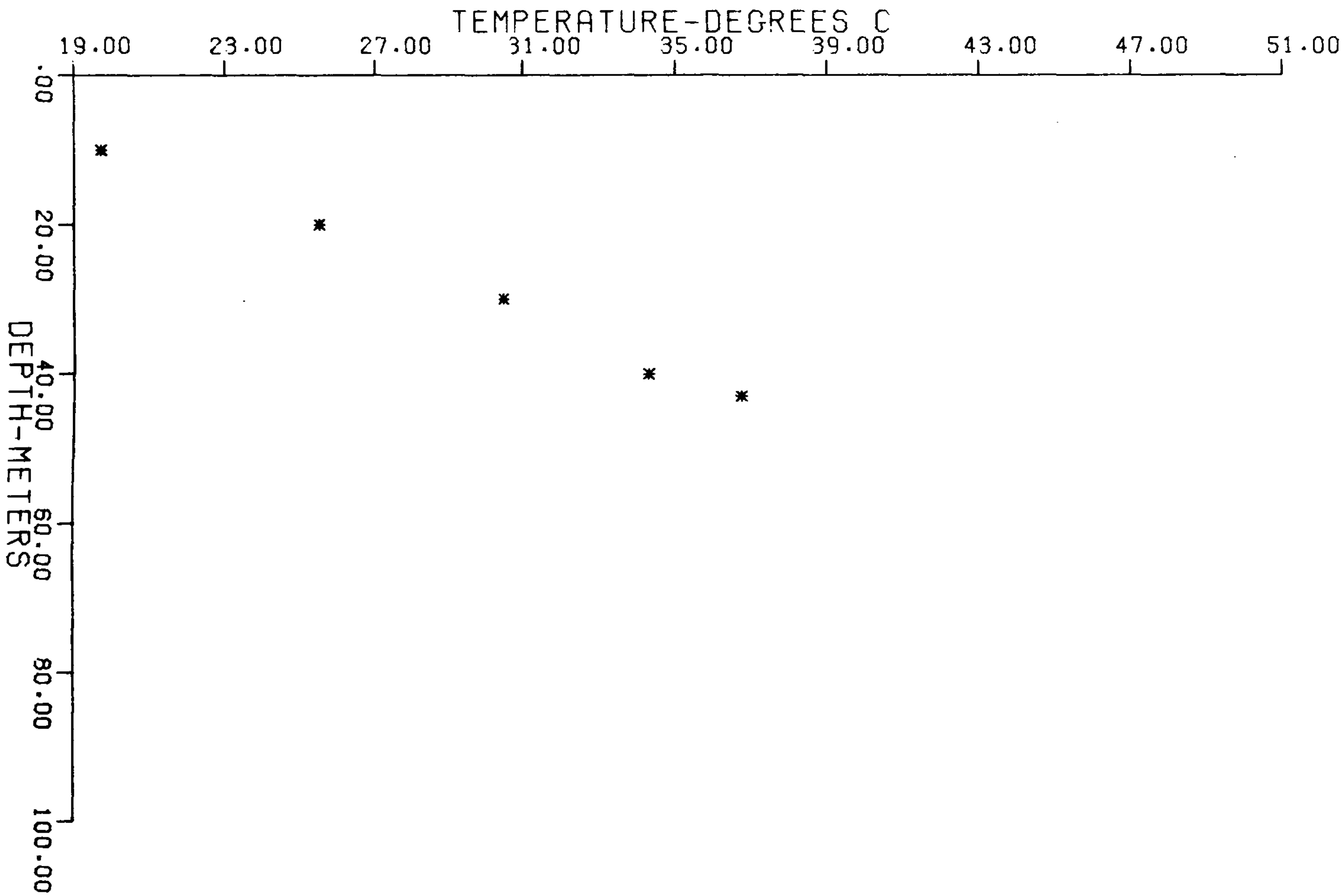


Figure 7

LOCATION ALTERATION 75 1A
275 9W 3CBB
HOLE NUMBER UU 751A
DATE MEASURED 7/22/76

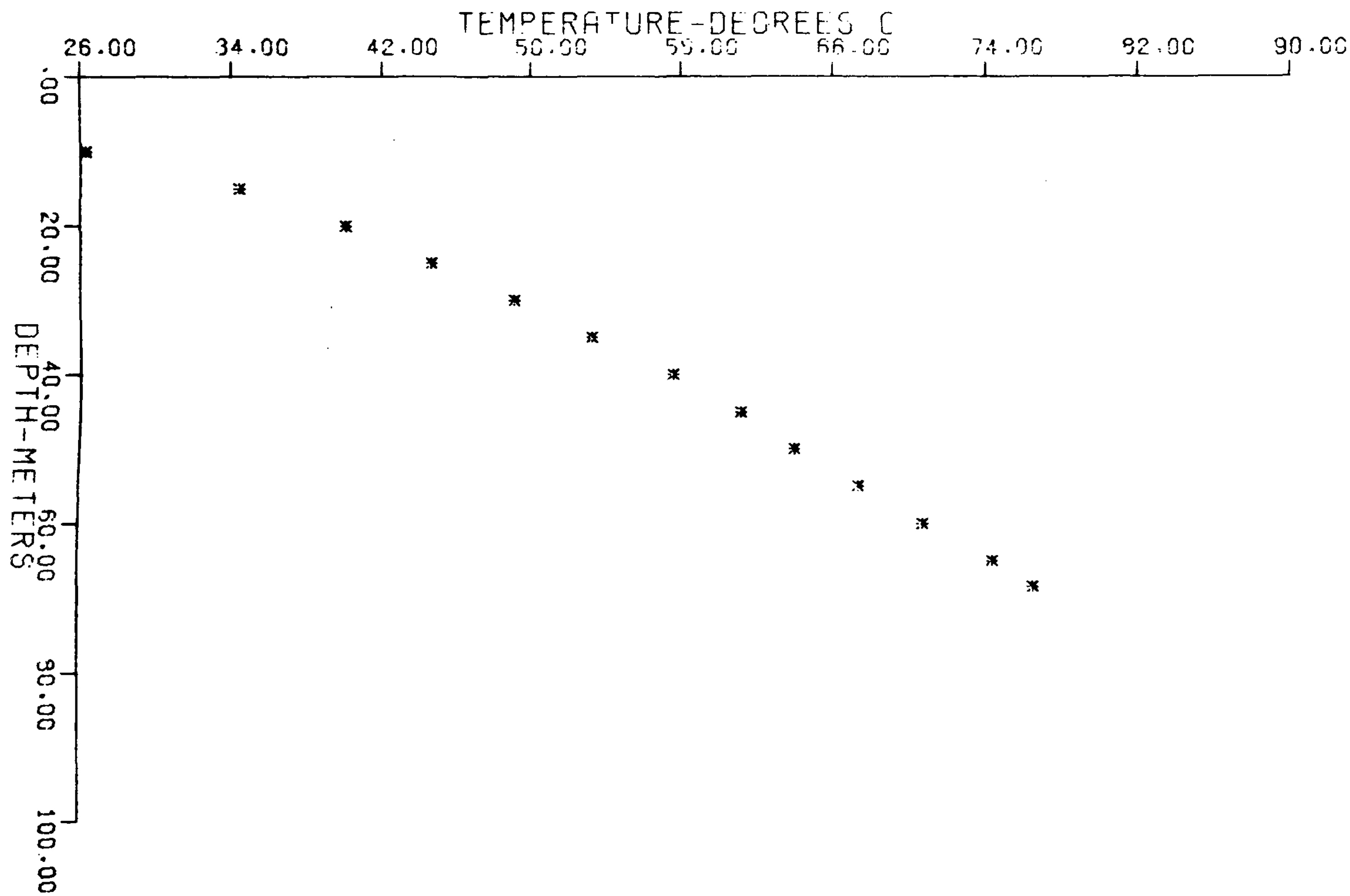


Figure 8

LOCATION ALTERATION 75 1B
27S 9W 4DDA
HOLE NUMBER UU 75 1B
DATE MEASURED 7/22/76

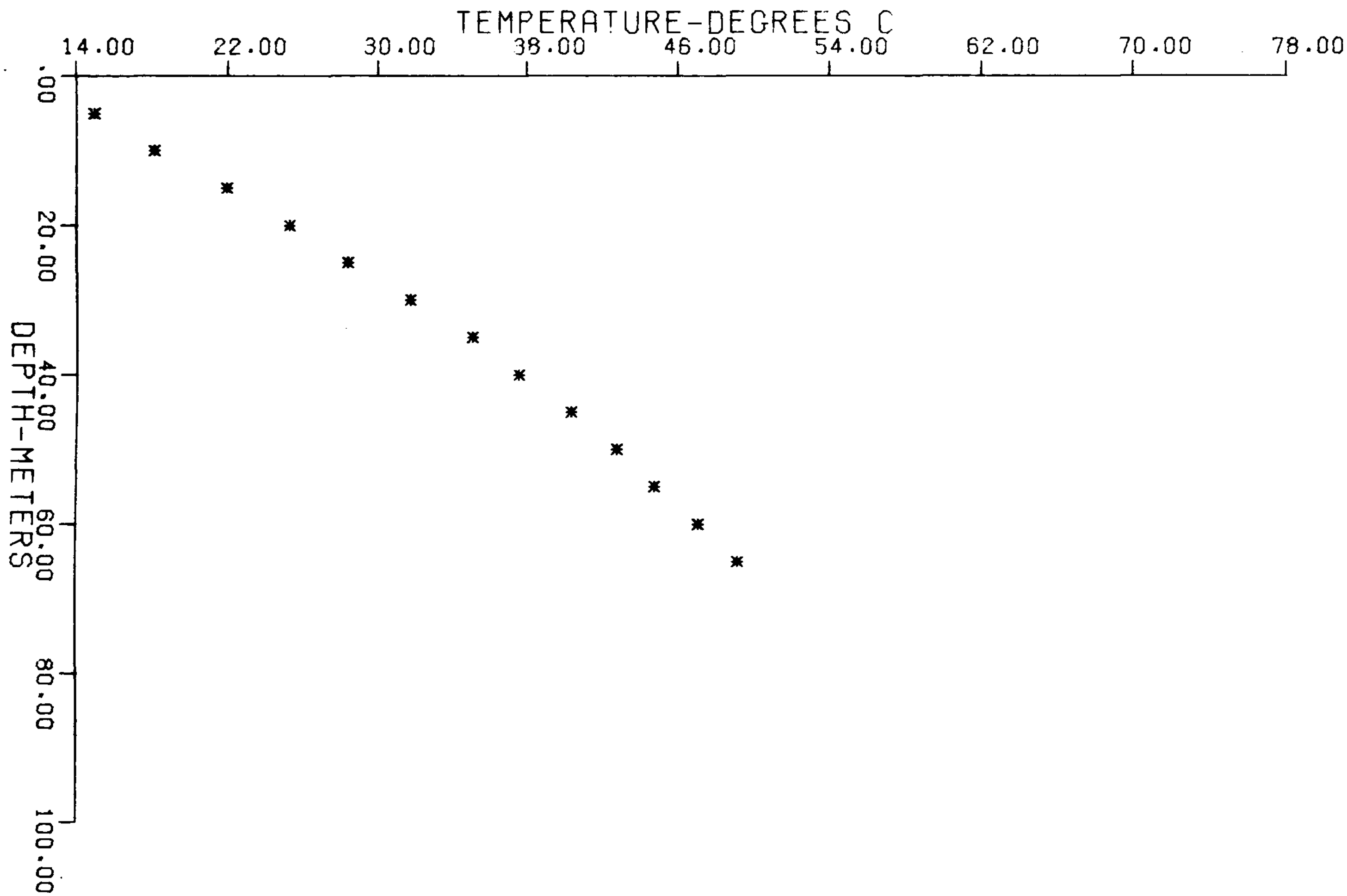


Figure 9

LOCATION BIG CEDAR COVE
27S 9W 14 BD
HOLE NUMBER UU 75 3CC
DATE MEASURED 9/22/75

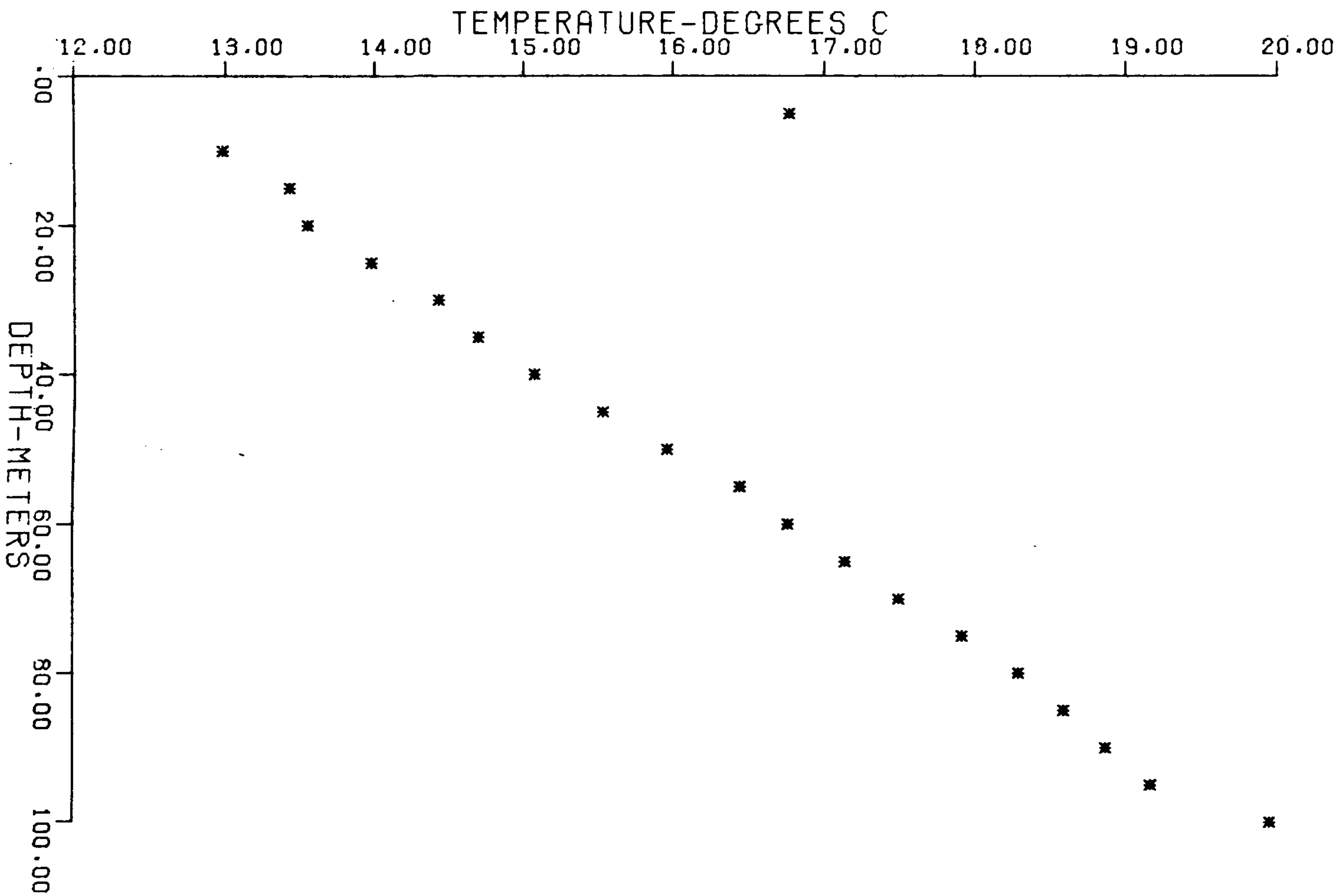


Figure 10

LOCATION RYANS RANCH
27S 8W 4DCD
HOLE NUMBER UU 75 RR
DATE MEASURED 11/6/76

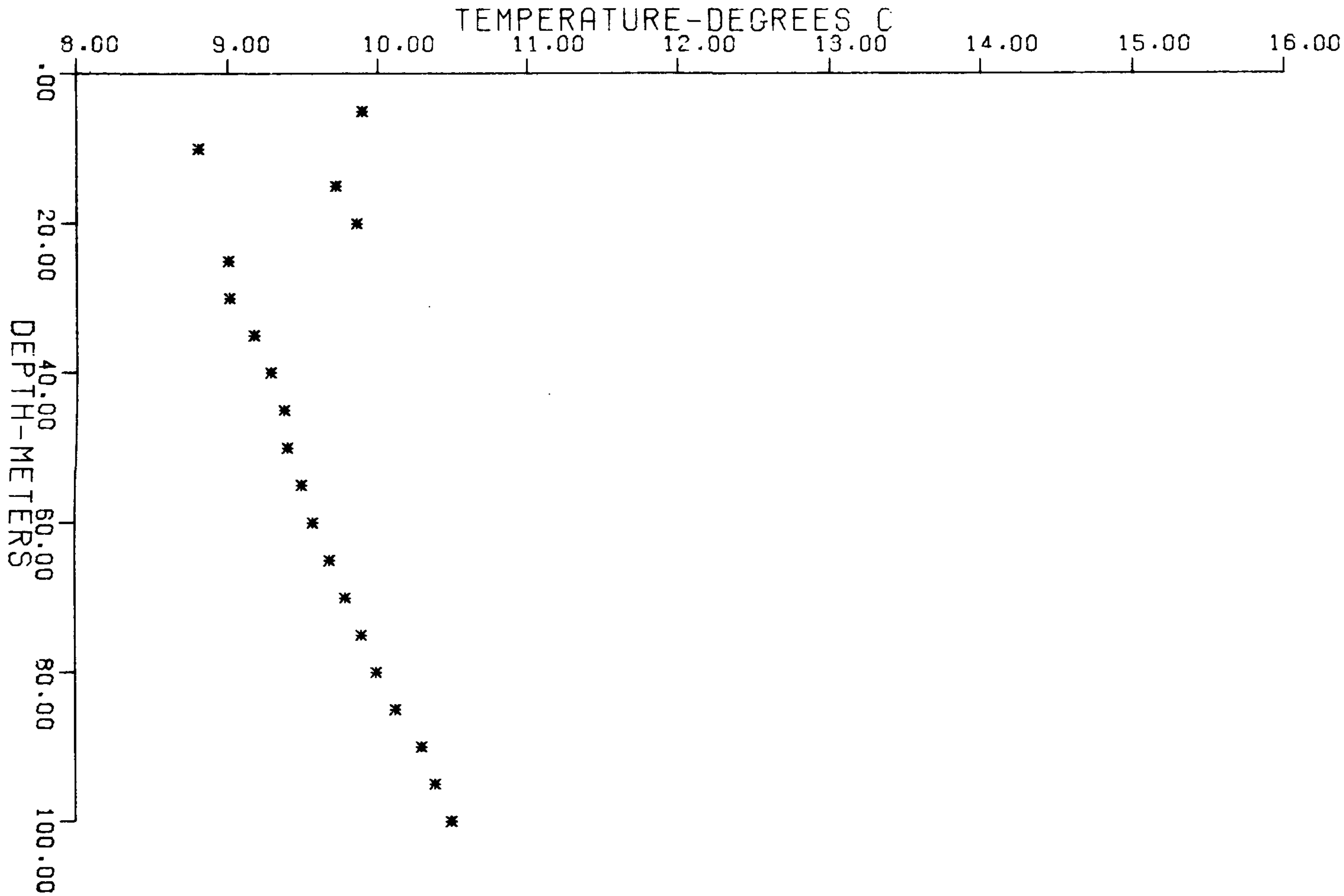


Figure 11

LOCATION ALTERATION 76-1A RKGRA
27S 9W 34 CA
HOLE NUMBER UU 76-1A
DATE MEASURED 8/ /76

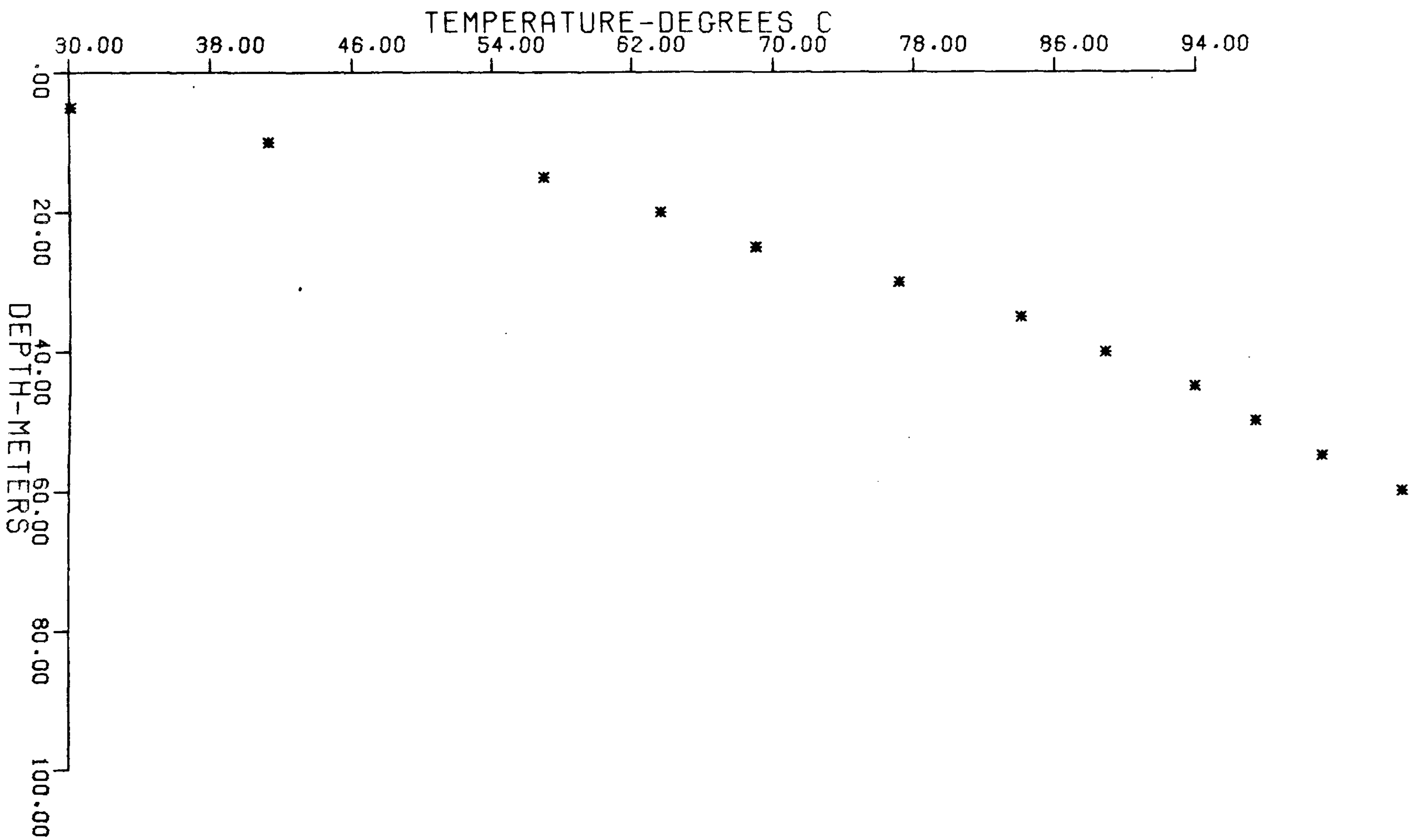


Figure 12

LOCATION RKGRA SALT COVE
26S 9W 25 DC
HOLE NUMBER UU 76 SC
DATE MEASURED 3/24/77

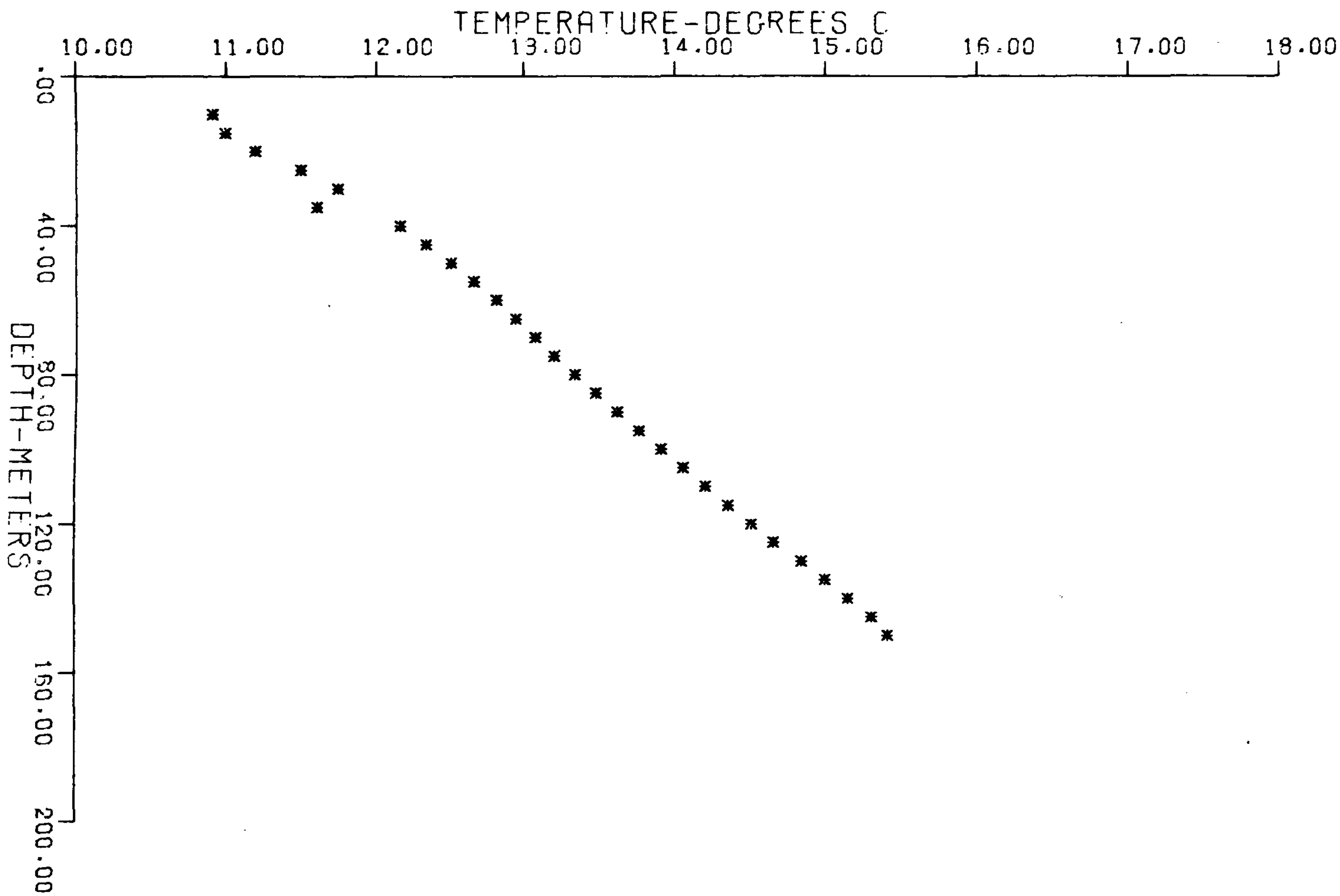


Figure 13

LOCATION BEARSKIN RKGRA
27S 8W 8 BAB
HOLE NUMBER UU 76 BS
DATE MEASURED 8/20/76

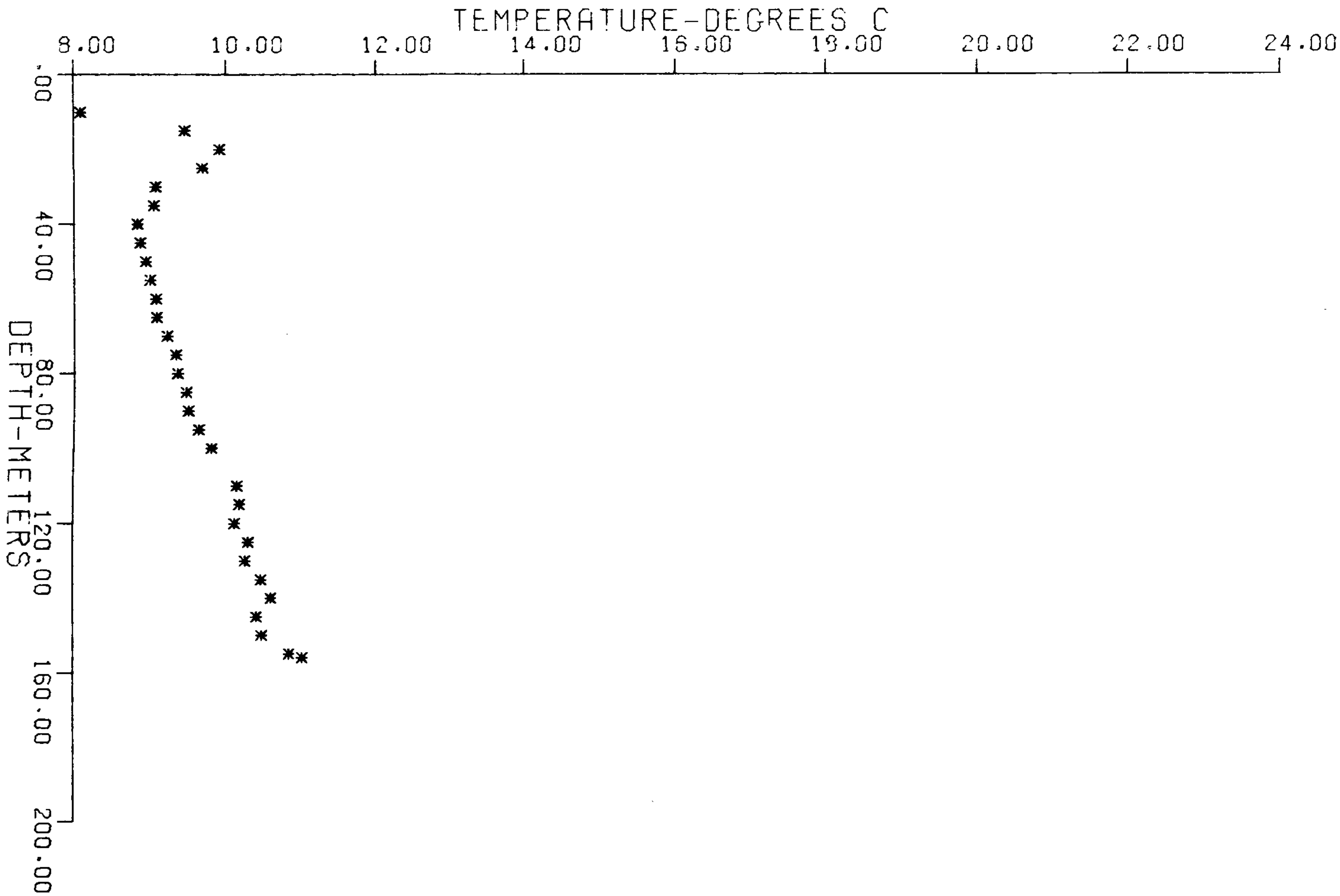


Figure 14

LOCATION RKGRA TG-0
26S 9W 16 BD
HOLE NUMBER UU76 TG0
DATE MEASURED 8/30/76

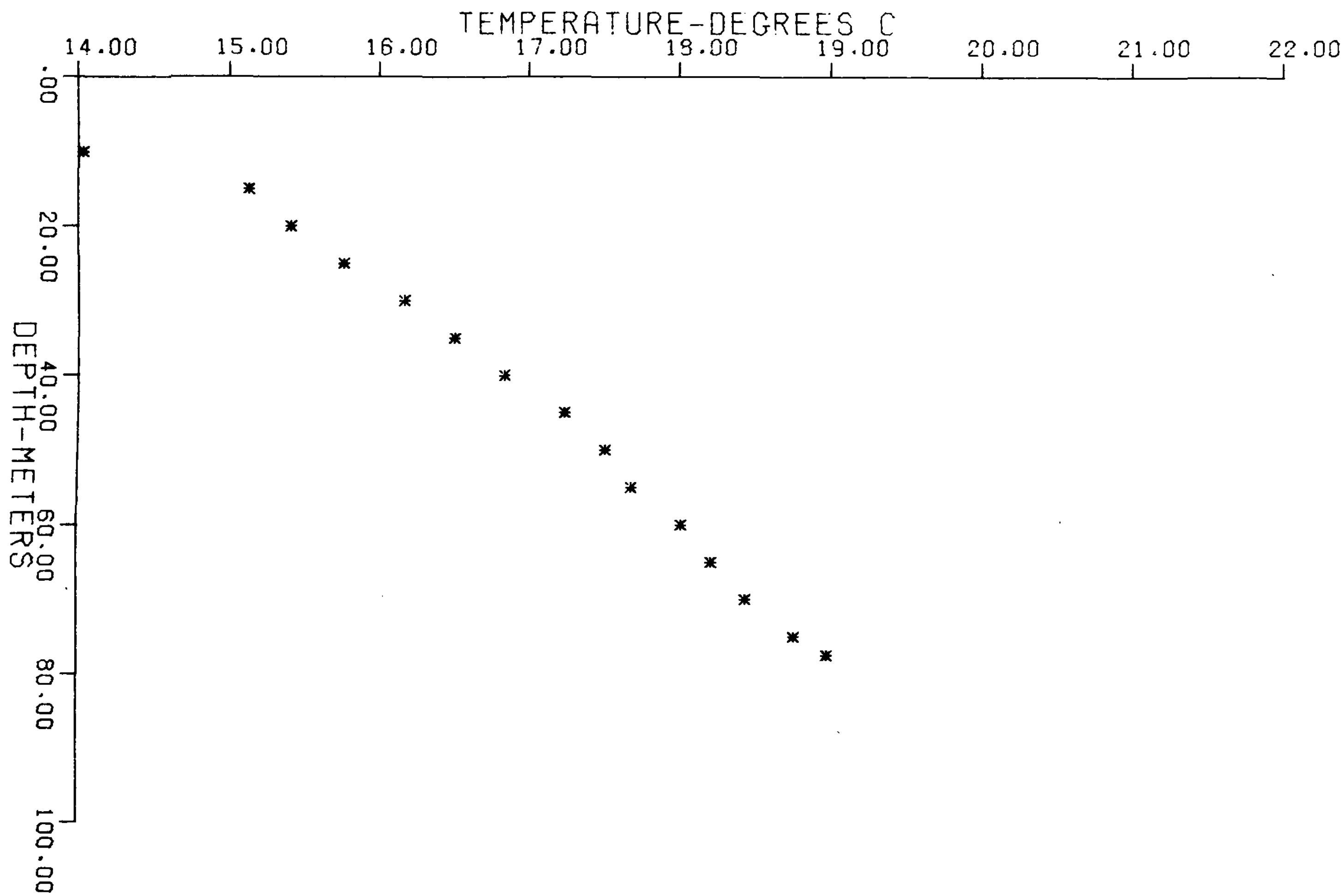


Figure 15

LOCATION RKGRA TG-1
26S 9W 15 CB
HOLE NUMBER UU76 TG1
DATE MEASURED 10/10/76

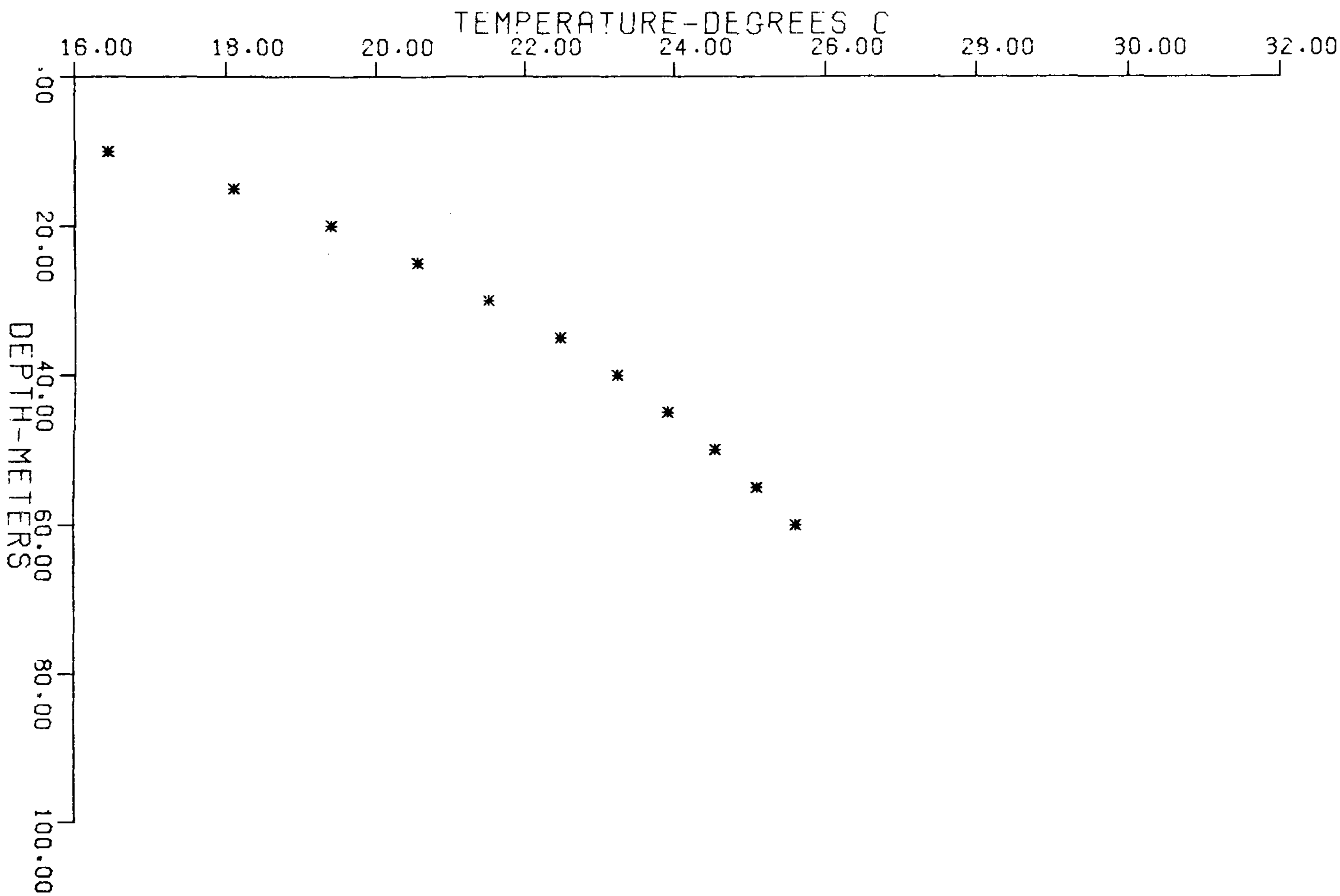


Figure 16

LOCATION RKGRA TG-2
26S 9W 5CDB
HOLE NUMBER UU76 TG2
DATE MEASURED 11/6/76

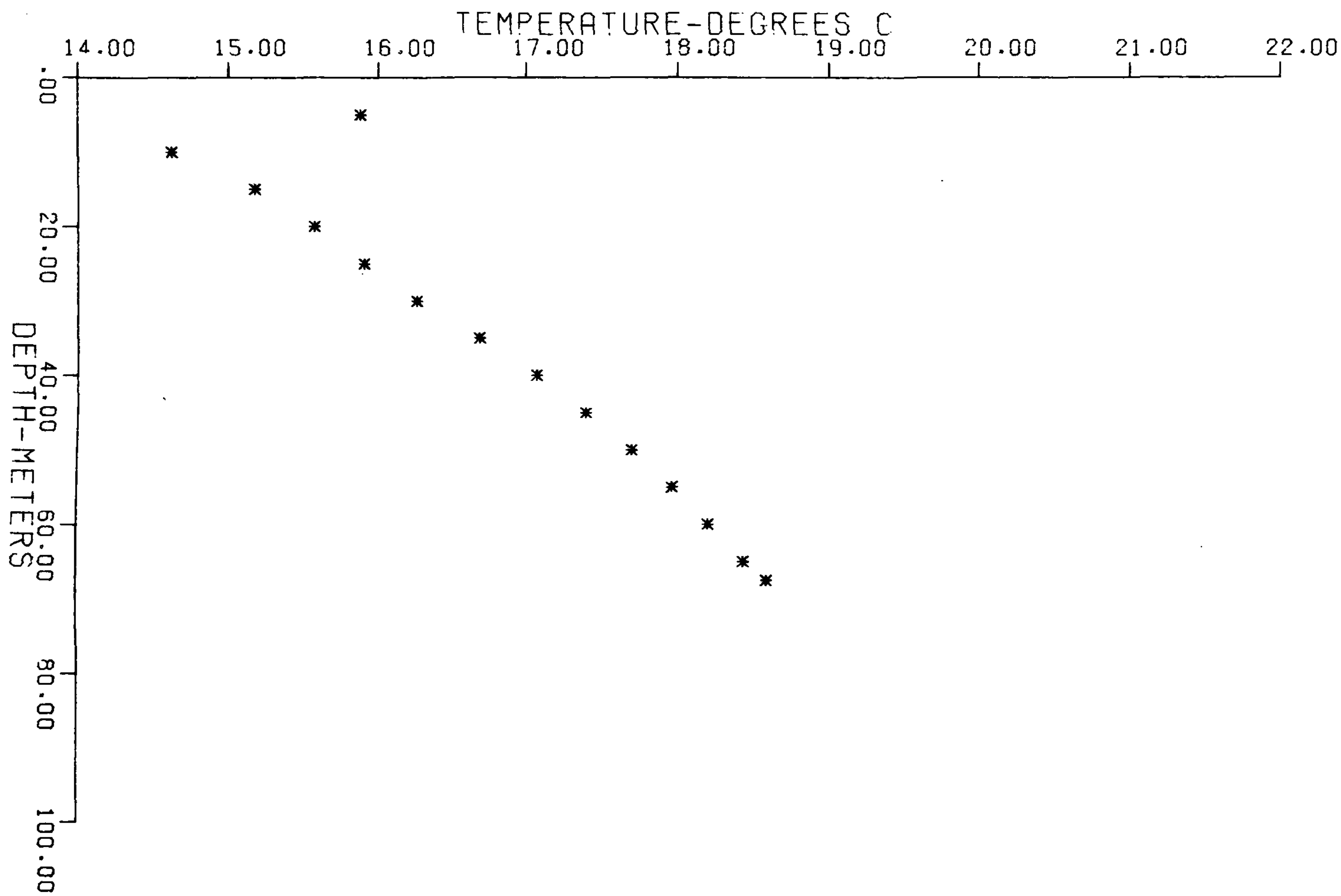


Figure 17

LOCATION RKGRA TG 3
26S 9W 19 DB
HOLE NUMBER UU76 TG3
DATE MEASURED 11/5/76

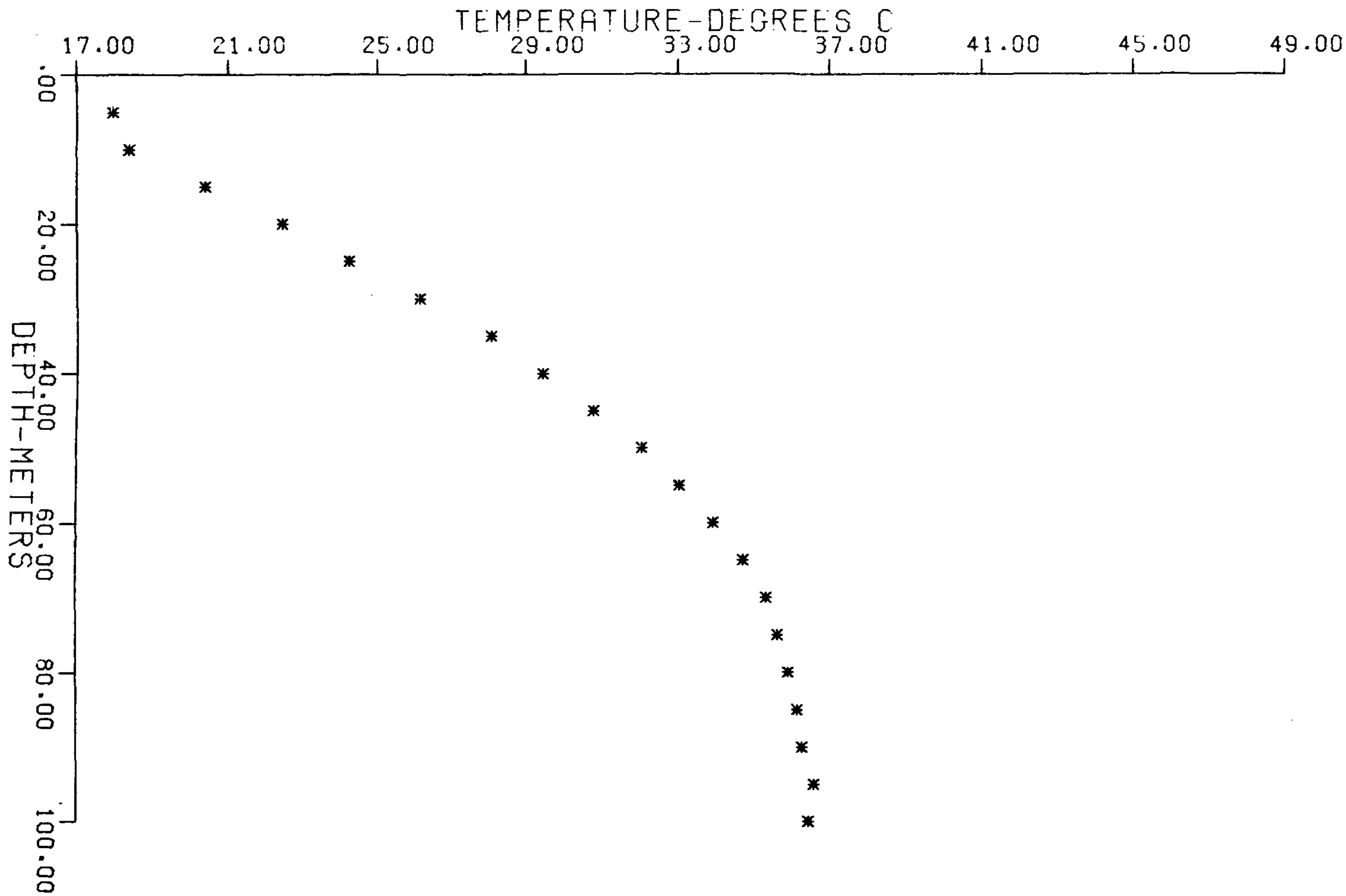
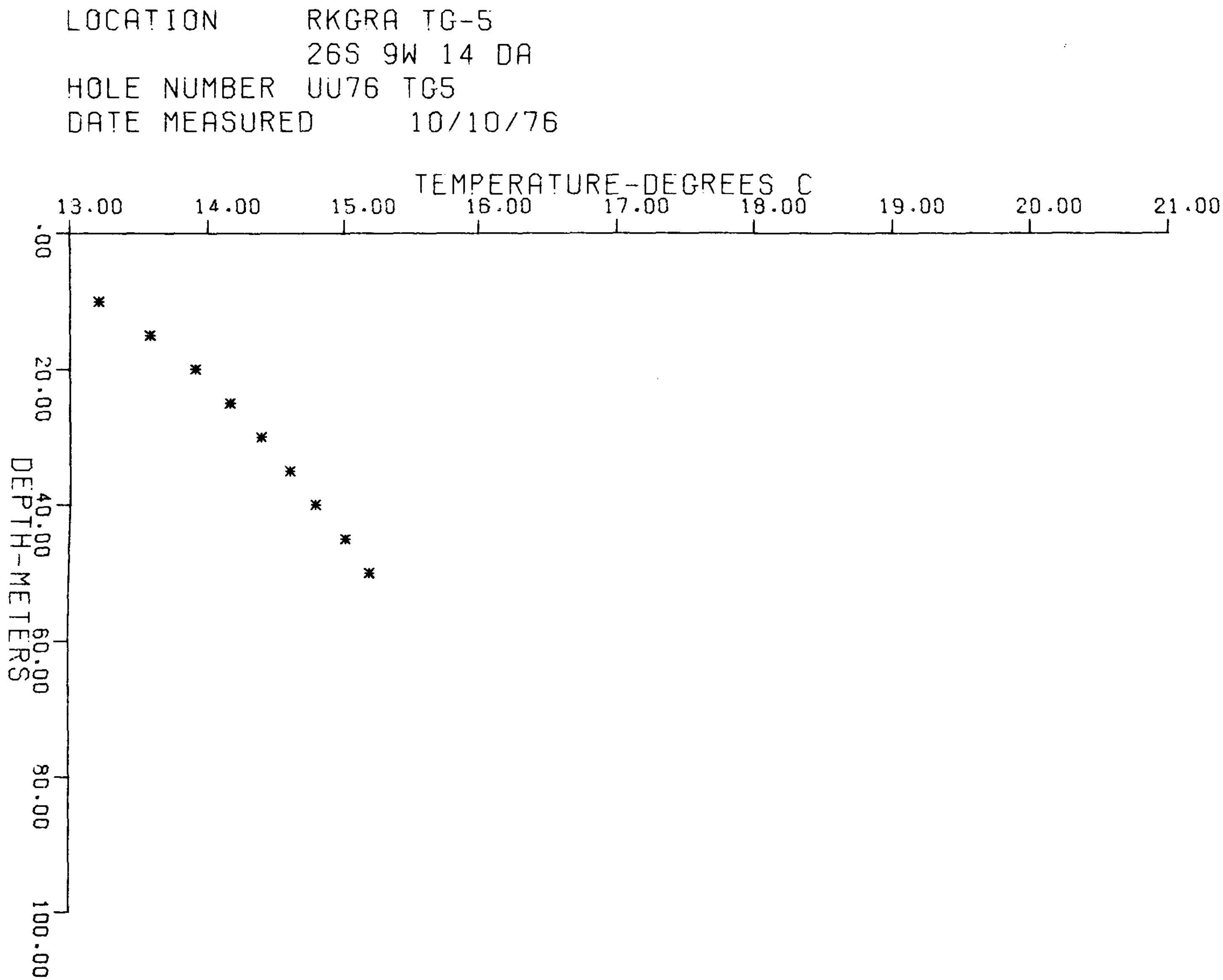
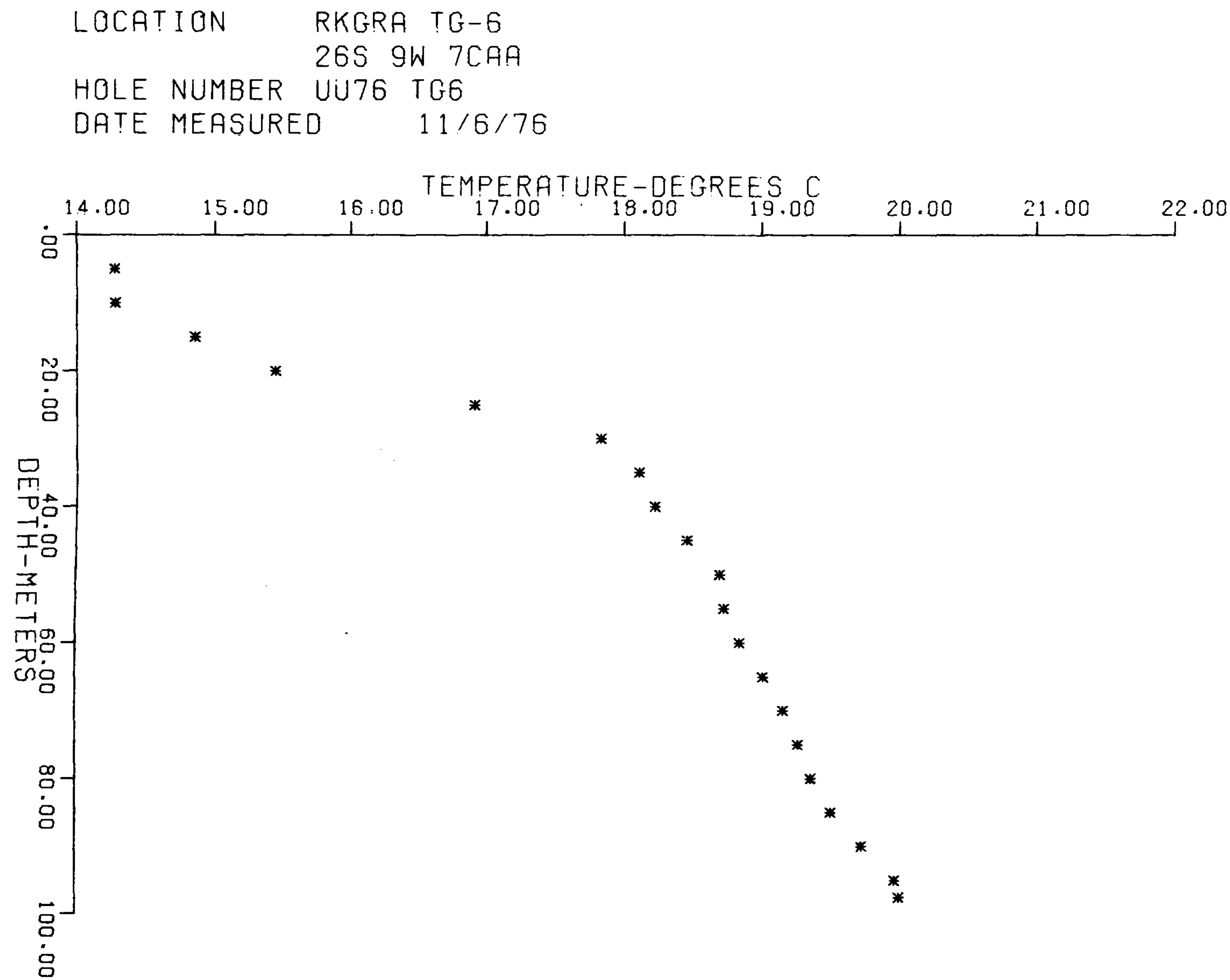


Figure 18



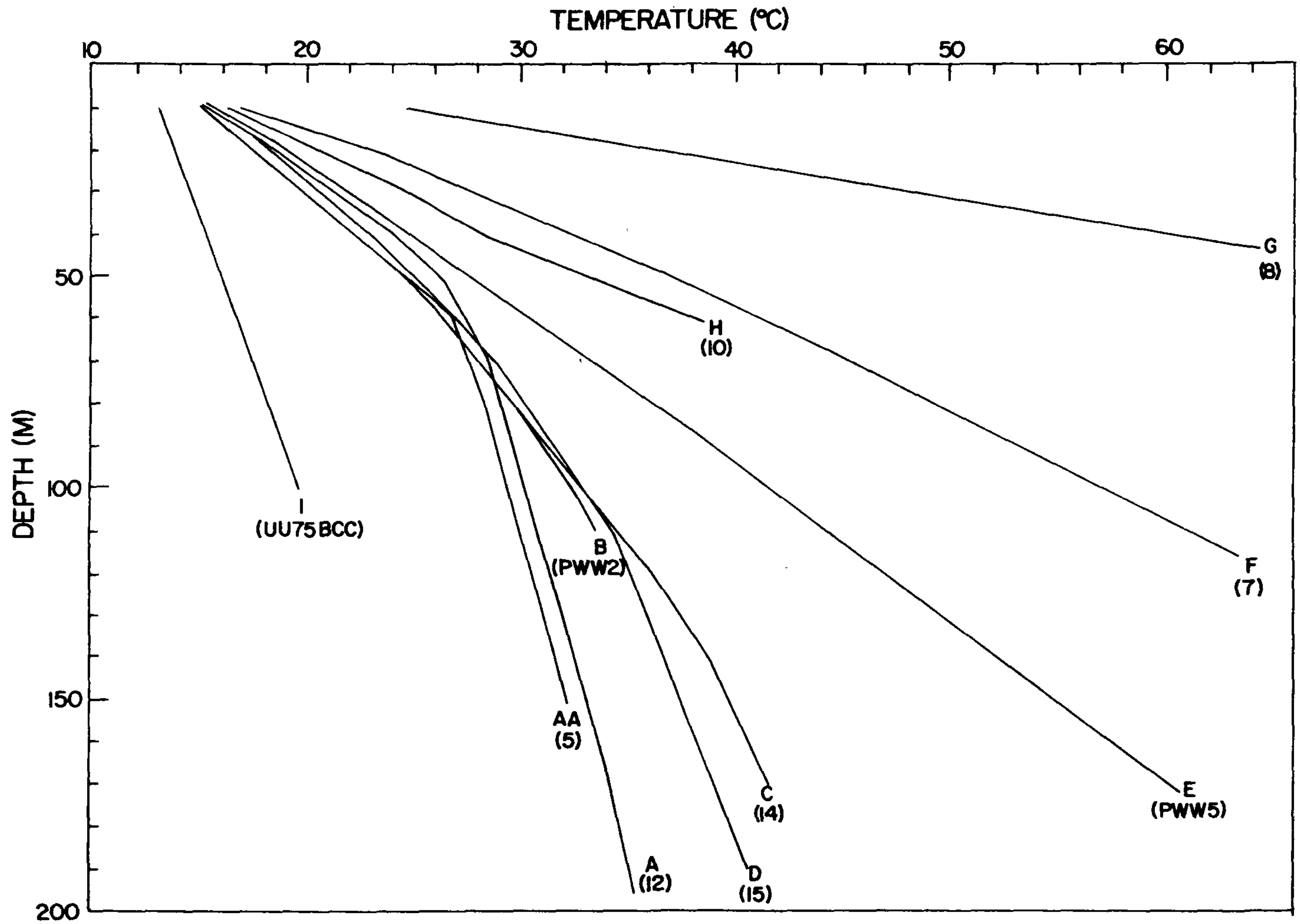
LOCATION RKGRA TG-5
26S 9W 14 DA
HOLE NUMBER UU76 TG5
DATE MEASURED 10/10/76
TEMPERATURE-DEGREES C
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
.00
20.00
40.00
60.00
80.00
100.00
DEPTH-METERS

Figure 19



LOCATION RKGRA TG-6
26S 9W 7CAA
HOLE NUMBER UU76 TG6
DATE MEASURED 11/6/76
TEMPERATURE-DEGREES C
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
DEPTH-METERS
.00
20.00
40.00
60.00
80.00
100.00

Figure 20



TEMPERATURE (°C)
10
20
30
40
50
60
DEPTH (M)
50
100
150
200
G
(8)
H
(10)
F
(7)
I
(UU75BCC)
B
(PWW2)
AA
(5)
C
(14)
E
(PWW5)
A
(12)
D
(15)

Figure 21

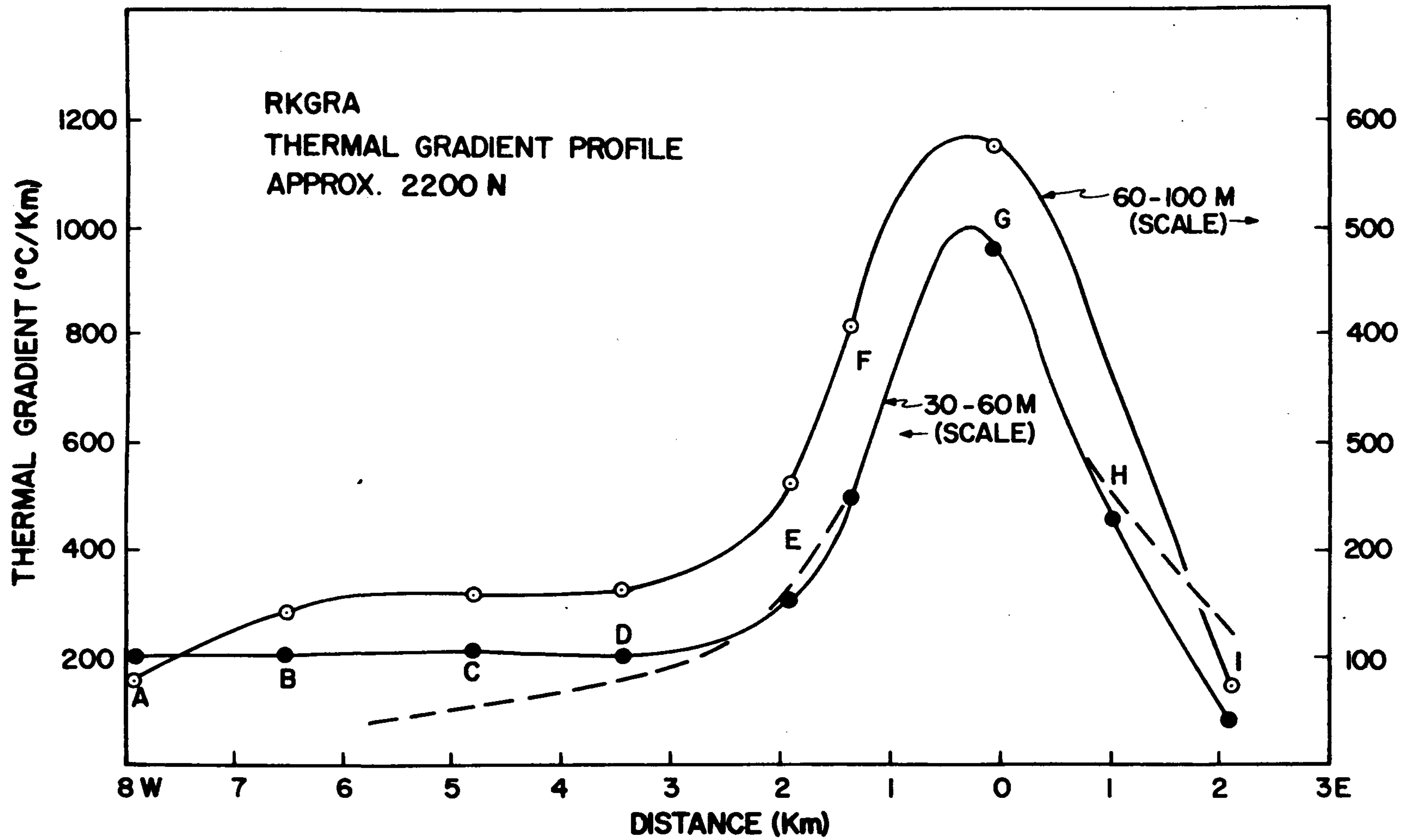

RKGRA
THERMAL GRADIENT PROFILE
APPROX. 2200 N
THERMAL GRADIENT (°C/Km)
1200
1000
800
600
400
200
600
500
400
500
200
100
60-100 M
(SCALE)
30-60 M
(SCALE)
A
B
C
D
E
F
G
H
I
8 W
7
6
5
4
3
2
1
0
1
2
3 E
DISTANCE (Km)

Figure 22

TECHNICAL REPORT: VOLUME 77-3

Thermal Gradients and Heat Flow at Roosevelt Hot Springs

Energy Research and Development Administration

Contract EY-76-S-07-1601

W. R. Sill

J. Bodell

TABLE OF CONTENTS

Abstract

Thermal gradient and electrical resistivity surveys both outline anomalous zones along the system of faults that control the near surface flow at Roosevelt Hot Springs. The source of both anomalies is the circulation of thermal water, which gives rise to the high heat flow and the lowered resistivity due to the hot brine and the associated hydrothermal alteration.

The nature of the temperature profiles and the asymmetry of the thermal gradient profile across the system are suggestive of a leakage and mixing of thermal water with the regional groundwater flow to the west. This interpretation is consistent with the resisitivty data in which conductive regions to the west of the fault system have been interpreted in terms of brine-saturated sediments.

The maximum conductive heat flow over the anomaly is 40 HFT ($1.7 W/m^2$) and the total conductive heat loss is estimated at 2 MW. Heat flow in the Mineral Mountains, to the east of the near-surface thermal anomaly, is low or near average for the Basin and Range. Recharge may be taking place in this region.

1.0 Introduction

Thermal gradient data from 39 drill holes in the Roosevelt Hot Springs KGRA area are presented in this report. Fifteen of these holes were drilled under subcontract to the University of Utah, permission to log another ten holes was granted by Phillips Petroleum Company and the remaining fourteen holes were provided by other sources. The locations of most of the holes are shown in Figures 1 through 3, along with the locations of test and production holes. These figures also show the contoured average thermal gradient in three depth intervals; shallow (30-60m), intermediate (60-100m) and deep (>100m).

Figure 4 displays a plan view of the interpreted faults in the area. Comparison of Figures 1 and 4 shows that the region of highest thermal gradients is aligned along the Dome Fault and Fault 1. To the south the high thermal gradients are terminated by several east-west trending faults. To the north there is a bending of the contours resulting in a ridge aligned along fault 5, which trends to the north west.

In Figures 1 and 2 there are isolated highs in the north and south that are probably the result of the sparseness of data in the central region. Considerations of the probable thermal gradient in the early steam well (drilled by Dr. E. N. Davie), based on the depth of blowout, and the near surface temperatures in sulfur pits in the bottom of Negro Mag Wash (North of 54-3) would indicate that the 900°C/km should run further to the west in the southern portion and is probably continuous with the high in the north.

Comparison of Figure 1 with the contoured apparent resistivity (Figure 5) shows that the resistivity and thermal gradient patterns are highly correlated. Both exhibit contours aligned along the Dome fault and a bending to the northwest along Fault 5. The obvious cause of the correlation

is the hot water circulation along the faults which gives rise to both high thermal gradients and low resistivities due to the hot brine and the associated hydrothermal alteration.

With increasing depth (Figures 2 and 3) the thermal gradients decrease and the alignment along the faults is less clear. The smearing of the pattern is partly due to the lack of data at greater depths. The acquisition of deep thermal gradient data from small drill holes in regions of very high thermal gradients is hindered by fear of blowouts, among other things.

2.0 Thermal Gradients at Roosevelt Hot Springs

Figures 6 to 20 show the temperature vs depth curves for the holes drilled by the University of Utah. As can be seen in these figures, the thermal gradient in holes drilled in alluvium often decreases with depth, with the depth intervals used in Figures 1 to 3 being somewhat characteristic of the several regions of changing gradient. For example, hole UUTG6 (Figure 20) shows an abrupt change at 30m and hole UUTG3 (Figure 18) displays a more gradual transition with suggested breaks at 35m and 70m. Such changes in the thermal gradients can be caused by changes in thermal conductivity due to changes in the porosity, saturation and lithology among other things.

Gravity measurements over a wash in the alluvium (Crebs and Cook, 1976) indicate a porosity of about 25% in the near surface (25-50m). Some decrease in porosity with depth is to be expected due to the increase in load. A change in the porosity of saturated granite alluvium from 25% to 10% would give rise to a change in thermal conductivity (and gradient) of about 25%. The changes in thermal gradient caused by such variations in porosity are then rather modest.

On the other hand, changes in saturation, from dry to completely saturated, would give rise to changes in thermal conductivity by a factor of 2.0 to 2.5 for porosities in the range from 20 to 30%.

Changes in the thermal conductivity due to lithology changes depends on the thermal conductivity of the components. For example, changing the thermal conductivity of the solid components by a factor of 2 results in a 1.7 change in conductivity at a porosity of 25%. Changes in lithology from a granite alluvium to a quartz rich sand are possible in this area. Measurements made on sands from the Roosevelt KGRA give solid component conductivities in the range from 10 to 11 HCU and samples of granite alluvium give

values in the range from 6 to 7 HCU. Therefore, such changes in lithology can be expected to give rise to rather substantial changes in gradient.

Considering the thermal gradients in hole UUTG6 (Figure 21) we see that the average gradient in the 20-30m interval is about 200°C/km and below this depth it averages about 30°C/km, a factor of about 7 change is slope. Thermal conductivity measurements on samples from this hole average about 4 HCU, at a saturated bulk density of $2.2 g/cm^3$, with no consistent changes above and below the break in the slope. The water table in a nearby well (2.4km) at about the same elevation is 26m (Mower and Cordova, 1974). This is near the break in the thermal gradient. However, the change in thermal conductivity due to undersaturation would only be a factor of 2 to 2.5 which is well below the observed value.

One possible explanation of the strong change in gradient is a leakage of thermal water into the groundwater flow to the west. Some leakage of thermal water is indicated by the chemical analysis of the seep west of Salt Cove, which has a cool temperature (25°C) but a Na-K-Ca temperature of 241°C (Parry et. al., 1976). For a uniform mixing of thermal water into the groundwater in a region of constant thermal conductivity, the thermal gradient should decrease smoothly with depth in the mixing zone. The two gradient regions in UUTG6 may result from a combination of effects due to the presence of the water table and mixing. On the other hand, the thermal gradient in hole UUTG3 (3km to the south) shows a more gradual change, with no sharp break at the water table (50m). The overall change in slope between the top and bottom of this hole is about a factor of 8, which seems too large to be explained by the effects of saturation alone.

In holes UU751A and UU751B, just to the west of the dome fault, the water tables were located at about 35m and 40m respectively, which are also the locations of the alluvium altered bedrock interface. In both cases the thermal gradients do not show an abrupt change at the water table.

However, there is gradual increase in thermal gradient above these depths (20% to 40%), perhaps due to gradual changes in the saturation.

Figure 21 shows a series of temperature profiles on a west-east line across the southern part of the system (the letter designation runs from West-A to East-I). The thermal gradients and the 10m depth temperatures increase as the Dome Fault is approached from the west (A to G) and the two eastern holes (H & I) show decreasing temperatures and gradients.

The five westernmost holes (AA to D) show a decreasing gradient with depth, as did the western holes to the north(UUTG6 and UUTG3) discussed previously. The two westernmost holes 5(AA) and 12(A) have a thermal gradient in the deeper part near 50°C/km, which is near normal for a thermal gradient in the alluvium. The water table is about 40m in this region (Mower and Cordova, 1974) and both curves show changes in slope (15 to 30%) at this depth, which could be due to changes in saturation. There is a change in slope to a near constant slope region at a depth of about 60m. The change in average gradient above and below this depth is a factor of 1.5 to 3. The lithologic log on a nearby water well notes a change in lithology at this point, from sands containing numerous "igneous" fragments (up to 30%) to sands free of such material. Considering the average abundance of such material, it would be difficult to account for the changes in slope by the change in lithology. Once again a possible explanation for the change in slope could be leakage of thermal waters to the west and mixing with the groundwater. With respect to this, it is interesting to note that the thermal gradients at depth in the westernmost holes are near normal and that the gradient in the easternmost hole is constant with depth although slightly above normal. More conclusive evidence for leakage mixing of thermal waters would be the presence of gradient reversals which have not been observed to date.

3.0 Heat Flow at Roosevelt Hot Springs

Thermal conductivity measurements on a limited number of alluvial samples, indicates an average value of 4 HCU (1 HCU – mcal/cm S°C – 0.418 W/m°k). Maximum conductive heat fluxes are then in the neighborhood of 40 HFU (1 HFU = μ cal/cm^{2}S = 41.8 mW/m^2). The total integrated conductive heat loss over the anomaly (6.5 km in length) is about 10^{7}cal/S or 2MW.

Figure 22 is a west to east thermal gradient profile for two depth intervals, 30-60m and 60-100m. Based on a *conductive* heat flow model, these profiles indicate an equivalent line source at 1.0 to 1.5km depth. Also shown on the figure, as a dashed line, is the theoretical thermal gradient profile for a line source, scaled to the 30-60m data. From this it is easy to see that the observed curve is asymmetrical, with smaller gradients in the east and larger to the west. This asymmetry is also observed in the deeper (60-100m) gradients. The observed asymmetry is compatable with the leakage of thermal water to the west, as discussed in the previous section, but source configuration in a conductive model could also produce such asymmetry.

Several core holes were also drilled in the granite of the Mineral Range so that samples could be measured for thermal conductivity and heat flow values calculated. Figure 13 shows the temperature profile in one such hole (UU76SC) located in Salt Cove on the west side of the Mineral Range, about 3 km east of the center of the thermal gradient-resistivity anomaly. The thermal gradient is quite uniform at an average value of 29°C/km below a depth of 50m. The average thermal conductivity in this region is 6.6 HCU (16 samples) giving a heat flow of 1.92 HFU.

Another hole (UU76BS) was drilled in the central part of the Mineral Range just to the north of Bearskin Mountain, the temperature profile from the last log (Figure 14) still shows some drilling disturbances, but the

smoothed thermal gradient in the 80 to 150m interval is 17°C/km. The thermal gradient in a Phillips Petroleum Company hole, 1.5 km to the north (Figure 1) is similar (16°C/km) indicating that this is maybe representative of the area. The average thermal conductivity in this hole in the above depth interval is 7.65 HCU (11 samples) giving a heat flow of 1.28 HFU.

Two kilometers to the east of this hole, the hole at Ryans Ranch (UU75RR, Figure 11) has thermal gradient of 19.9°C/km (50 to 80 m) and the average thermal conductivity of several samples is 7.1 HCU, resulting in a heat flux of 1.41 HFU.

Roy et al. (1968) report a heat flow of 2.22 HFU for a location on the west side of Milford valley, just about due west of Roosevelt Hot Springs. None of the above calculated heat flow values are large for the Basin and Range, in fact the measurements in the central part of the range seem somewhat low. However, none of the measurements have been corrected for topographic effects, which should be largest for the locations north of Bearskin and at Ryans Ranch.

If the Mineral Mountains and the area to the east are regions of significant recharge, then the downward movements of cool water may contribute to the low thermal gradient and heat flow.

4.0 Conclusions

Thermal gradients and electrical resistivity data at Roosevelt Hot Springs both outline the same anomalous region along the system of faults which control the near surface circulation. Depending on the circumstances, these techniques may provide complementary or redundant information.

The character of the thermal gradients to the west of the fault system suggest that thermal waters are mixing with the ground water flow to the west. If so, this should be reflected in the water chemistry. Parry et al. (1976) show several anomalous Na-Ca-K temperatures to the northwest of Roosevelt Hot Springs but no data was available from wells in the immediate vicinity of the thermal gradient holes.

Heat flow values in the alluvium reach a maximum of about 40 HFU, and the estimated total conductive heat loss from the shallow part of the system is about 2MW. Heat flow values and thermal gradients in the Mineral Range are not high for the Basin and Range, and in fact several of the values seem low.

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Parry, W. T., N. L. Benson and C. D. Miller, 1976; Geochemistry and hydrothermal alteration at selected Utah hot springs, volume 3, Grant GI-43741 National Science Foundation.

Roy, R. F., E. R. Decker, D. D. Blackwell and F. Birch, 1968; Heat flow in the United States, J. Geophys. Res., 73,5207-5221.

LIST OF FIGURES

APPENDIX A

Temperature Logs

LOCATION: RYANS RANCH
LOCATION: RYANS'RANCH
27S 8W 4DCD
HOLE NUMBER: UU 75
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	9.894	.0
10.0	8.803	-218.2
15.0	9.716	182.6
20.0	9.858	28.4
25.0	9.000	-171.6
30.0	9.007	1.4
35.0	9.170	32.6
40.0	9.280	22.0
45.0	9.370	18.0
50.0	9.391	4.2
55.0	9.492	20.2
60.0	9.569	15.4
65.0	9.681	22.4
70.0	9.781	20.0
75.0	9.888	21.0
80.0	9.987	20.2
85.0	10.116	25.8
90.0	10.292	35.2
95.0	10.381	17.8
100.0	10.492	22.2

LOCATION: BIG CEDAR COVE
27S 8W 14 DDC
HOLE NUMBER: UU 75
DATE MEASURED: 9/22/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	16.769	.0
10.0	12.978	-758.2
15.0	13.421	88.6
20.0	13.543	24.4
25.0	13.973	86.0
30.0	14.427	90.8
35.0	14.693	53.2
40.0	15.073	76.0
45.0	15.526	90.6
50.0	15.957	86.2
55.0	16.437	96.0
60.0	16.754	63.4
65.0	17.132	75.6
70.0	17.081	69.8
75.0	17.905	84.8
[illegible]	18.380	75.0
[illegible]	18.579	59.8
[illegible]	18.858	55.4
[illegible]	19.153	59.4
100.0	19.937	156.8

LOCATION: ALTERATION 75 1A
27S 9W 3CLB
HOLE NUMBER: UU 751A
DATE MEASURED: 7/22/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	26.283	.0
15.0	34.349	1613.2
20.0	40.036	1137.4
25.0	44.676	928.0
30.0	49.158	896.4
35.0	53.288	826.0
40.0	57.622	866.8
45.0	61.177	711.0
50.0	63.990	562.6
55.0	67.365	675.0
60.0	70.687	664.4
65.0	74.307	724.0
68.5	76.434	607.7

LOCATION: ALTERATION 75 1B
27S 9W 4DDA
HOLE NUMBER: UU 75 1B
DATE MEASURED: 7/22/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.926	.0
10.0	18.065	627.8
15.0	21.878	762.6
20.0	25.194	663.2
25.0	28.354	632.0
30.0	31.719	673.0
35.0	35.043	664.8
40.0	37.561	503.6
45.0	40.288	545.4
50.0	42.688	480.0
55.0	44.676	397.6
60.0	47.008	466.4
65.0	49.088	416.0

LOCATION: BOYLES 12RKGRA
26S 9W 27 BBB
HOLE NUMBER: UU 75 12
DATE MEASURED: 6/11/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	16.072	.0
10.0	19.622	710.0
15.0	21.794	434.4
20.0	24.981	637.4
25.0	28.579	719.6
30.0	29.861	256.4
34.5	30.922	235.8

LOCATION: BOYLES 13 RKGRA
26S-9W-20 AC
HOLE NUMBER: UU-75-13
DATE MEASURED: 11/8/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	19.715	.0
20.0	25.496	578.1
30.0	30.489	499.3
40.0	34.301	381.2
43.0	36.742	813.7

LOCATION: BEARSKIN RKGRA
27S 8W 8 BAB
HOLE NUMBER: UU 75
DATE MEASURED: 8/20/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.088	.0
15.0	9.455	273.4
20.0	9.907	90.4
25.0	9.683	-44.8
30.0	9.074	-121.8
55.0	9.048	-5.2
40.0	8.834	-42.8
45.0	8.867	6.6
50.0	8.942	15.0
55.0	8.998	11.2
60.0	9.077	15.8
65.0	9.084	1.4
70.0	9.217	26.6
75.0	9.331	22.8
80.0	9.351	4.0
85.0	9.462	22.2
90.0	9.496	6.8
95.0	9.629	26.6
100.0	9.797	33.6
110.0	10.137	34.0
115.0	10.176	7.8
120.0	10.113	-12.6
125.0	10.296	36.6
130.0	10.249	-9.4
135.0	10.459	42.0
140.0	10.584	25.0
145.0	10.391	-38.6
150.0	10.459	13.6
155.0	10.823	72.8
156.0	10.999	176.0

LOCATION: ALTERATION 76-1A RKGRA
275 9W 34 CAB
WELL NUMBER: UU 76-1A
DATE MEASURED: 6/ /76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	30.026	.0
10.0	41.194	2232.6
15.0	57.022	3166.4
20.0	63.642	1324.0
25.0	69.025	1076.6
30.0	77.158	1626.6
35.0	84.082	1384.8
40.0	98.843	953.2
45.0	93.914	1013.2
50.0	97.362	689.6
55.0	101.100	747.6
60.0	105.584	896.8
63.5	107.885	657.4

LOCATION: RKGRA TG-1
26S 9W 15 CBA
HOLE NUMBER: U076 TG1
DATE MEASURED: 10/10/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	16.428	.0
15.0	18.095	333.4
20.0	19.382	257.4
25.0	20.549	233.4
30.0	21.506	191.4
35.0	22.476	194.0
40.0	23.231	151.0
45.0	23.893	132.4
50.0	24.521	125.6
55.0	25.071	110.0
60.0	25.582	102.2

LOCATION: RKGRA TG-O
26S 9W 16 BDC
HOLE NUMBER: UU76 TGO
DATE MEASURED: 8/30/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.029	.0
15.0	15.124	219.0
20.0	15.405	56.2
25.0	15.757	70.4
30.0	16.164	81.4
35.0	16.501	67.4
40.0	16.839	67.6
45.0	17.234	79.0
50.0	17.502	53.6
55.0	17.674	34.4
60.0	18.012	67.6
65.0	18.210	39.6
70.0	18.432	44.4
75.0	18.750	63.6
77.5	18.967	86.8

LOCATION: RKGRA TG-2
26S 9W 5CDB
HOLE NUMBER: UU76 TG2
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	15.877	.0
10.0	14.619	-251.6
15.0	15.169	110.0
20.0	15.567	79.6
25.0	15.902	67.0
30.0	16.259	71.4
35.0	16.679	84.0
40.0	17.068	77.4
45.0	17.389	64.6
50.0	17.690	60.2
55.0	17.955	53.0
60.0	18.195	48.0
65.0	18.426	46.2
67.0	18.580	61.6

LOCATION: RKGRA TG-3
265 9W 19 DGC
HOLE NUMBER: UU76 T63
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	17.946	.0
10.0	15.391	89.0
15.0	20.383	398.4
20.0	28.441	411.6
25.0	24.223	356.4
30.0	26.143	384.0
35.0	28.078	387.0
40.0	29.147	273.8
45.0	38.770	264.6
50.0	32.031	252.2
55.0	32.994	192.6
60.0	33.887	178.6
65.0	34.691	160.8
70.0	35.306	123.0
75.0	35.601	59.0
80.0	35.883	56.4
85.0	36.121	47.6
90.0	36.243	24.4
95.0	36.544	60.2
100.0	36.405	-27.8

LOCATION: RKGRA TG-5
265 9N 14 DAA
HOLE NUMBER: UU76 TG5
DATE MEASURED: 10/15/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	13.204	.0
15.0	13.577	74.6
20.0	13.906	65.8
25.0	14.156	50.0
30.0	14.381	45.0
35.0	14.593	42.4
40.0	14.781	37.6
45.0	15.006	45.0
50.0	15.195	35.8

LOCATION: RKGRA TG-6
265 9W 7CAA
HOLE NUMBER: UU76 TG6
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.273	.0
10.0	14.275	.4
15.0	14.847	114.4
20.0	15.436	117.8
25.0	16.913	295.4
30.0	17.828	183.0
35.0	18.108	56.0
[illegible]	18.924	23.2
[illegible]	18.458	46.8
[illegible]	18.692	46.8
[illegible]	18.721	5.8
[illegible]	15.835	22.8
[illegible]	19.004	33.8
[illegible]	18.149	29.0
[illegible]	19.256	21.2
[illegible]	19.348	18.6
[illegible]	19.449	28.2
[illegible]	19.712	44.6
95.0	19.952	48.0
97.5	19.983	12.4

LOCATION: RKGRA SALT COVE
26S 9W 25 DCA
HOLE NUMBER: UU 76
DATE MEASURED: 6/24/77

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	10.908	.0
15.0	10.689	16.2
20.0	11.188	39.8
25.0	11.492	60.8
30.0	11.742	50.0
35.0	11.596	-29.2
40.0	12.150	112.0
45.0	12.335	35.8
50.0	12.904	33.8
55.0	12.658	30.8
60.0	12.607	29.8
65.0	12.942	27.0
70.0	13.071	25.8
75.0	13.186	25.0
80.0	13.337	28.2
85.0	13.476	27.8
90.0	13.617	28.2
95.0	13.761	28.8
100.0	13.908	29.4
105.0	14.452	28.8
110.0	14.201	29.8
115.0	14.352	30.2
120.0	14.505	30.6
125.0	14.653	29.6
130.0	14.836	36.6
135.0	14.993	31.4
140.0	15.145	30.4
145.0	15.298	30.6
150.0	15.404	21.2

LOCATION: RANCH CANYON PPC
27S/9W-35 CAD
HOLE NUMBER: EV 4113
DATE MEASURED: 8/12/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.650	.0
20.0	9.640	99.0
30.0	9.770	13.0
36.0	9.890	20.0

LOCATION: RANCH CANYON PPC
27S/9W-35 DB
HOLE NUMBER: EV 4115
DATE MEASURED: 8/12/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	10.920	.0
20.0	11.240	132.0
30.0	11.700	46.0
40.0	11.820	12.0
50.0	11.910	9.0
60.0	11.980	7.0
70.0	12.140	16.0

LOCATION: MINERAL MTS - RADIO RD PPC
26S/8W-30 CDA
HOLE NUMBER: Crater Knoll #2
DATE MEASURED: 8/15/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.010	.0
20.0	8.660	65.0
30.0	8.690	4.0
40.0	8.750	6.0
50.0	8.850	10.0
60.0	8.870	2.0
70.0	8.890	2.0
80.0	8.990	10.0
90.0	9.080	9.0

LOCATION: MINERAL MTS - PPC
27S/8W-6 AA
HOLE NUMBER: Crater Knoll #3
DATE MEASURED: 8/15/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	9.230	.0
20.0	9.700	47.0
30.0	10.210	51.0
40.0	10.430	22.0
50.0	10.610	18.0
59.0	10.700	10.0

LOCATION: NEGRO MAG WASH PPC
27S/9W-1
HOLE NUMBER: 21

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	13.000	.0
20.0	15.600	260.0
30.0	17.300	170.0
32.0	17.550	125.0

LOCATION: WATER WELL #2
27S/10W-12B
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/05/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.500	.0
20.0	17.700	320.0
30.0	20.600	290.0
35.0	21.900	260.0
40.0	23.000	220.0
45.0	23.950	190.0
50.0	24.800	170.0
55.0	25.500	200.0
60.0	26.700	180.0
65.0	27.600	180.0
70.0	28.400	160.0
75.0	29.100	140.0
80.0	29.500	140.0
85.0	30.600	160.0
90.0	31.200	120.0
95.0	31.300	120.0
100.0	32.500	140.0
105.0	33.000	100.0
110.0	33.800	120.0
115.0	33.800	40.0

LOCATION: PHILLIPS WATER WELL #3
26S/10W-25A
HOLE NUMBER: PHILLIPS
DATE MEASURED: 6/30/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.800	.0
10.0	17.100	290.0
20.0	18.400	260.0
25.0	19.500	220.0
30.0	21.600	300.0
35.0	22.400	280.0
40.0	23.600	240.0
45.0	24.600	200.0
50.0	25.800	240.0
55.0	27.200	280.0
60.0	27.900	140.0
65.0	28.900	200.0
70.0	29.400	100.0
75.0	30.000	120.0
80.0	30.600	120.0
85.0	30.800	.0

LOCATION: WATER WELL #4
28S/9W-3 C
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/03/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	17.900	.0
10.0	17.200	-140.0
15.0	19.100	380.0
20.0	20.700	320.0
25.0	21.500	160.0
30.0	24.200	540.0
35.0	26.200	400.0
40.0	28.600	480.0
45.0	29.300	140.0
50.0	31.800	500.0
55.0	34.900	620.0

LOCATION: WARER WELL #5
275/9W-17A
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/02/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	12.900	.0
10.0	15.300	480.0
15.0	17.500	440.0
20.0	19.100	320.0
25.0	20.900	360.0
30.0	22.100	240.0
35.0	23.700	320.0
40.0	25.200	300.0
45.0	26.700	300.0
50.0	28.000	260.0
55.0	29.600	320.0
60.0	31.200	320.0
65.0	32.400	240.0
70.0	33.700	260.0
75.0	35.600	260.0
80.0	36.400	280.0
85.0	37.900	300.0
90.0	39.200	260.0
95.0	40.200	200.0
100.0	41.600	280.0
105.0	43.100	300.0
110.0	44.400	260.0
115.0	45.600	240.0
120.0	47.000	280.0
125.0	48.600	320.0
130.0	49.700	220.0
135.0	51.000	260.0
140.0	52.600	260.0
145.0	53.400	220.0
150.0	54.800	280.0
155.0	56.000	240.0
160.0	58.800	560.0
165.0	59.500	140.0
170.0	60.600	220.0
175.0	61.200	120.0
180.0	61.800	120.0
185.0	61.900	20.0

LOCATION: RHS KGRA
27S/10W-23 CA
HOLE NUMBER: 5
DATE MEASURED: 9/03/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.480	.0
20.0	17.450	297.0
30.0	20.130	268.0
40.0	22.580	245.0
50.0	25.000	242.0
60.0	26.930	193.0
70.0	27.650	72.0
80.0	28.390	74.0
90.0	28.960	57.0
100.0	29.590	63.0
110.0	30.100	51.0
120.0	30.550	45.0
130.0	31.100	55.0
140.0	31.520	42.0
150.0	32.180	66.0
151.5	32.210	20.0

LOCATION: RHS KGRA
27S/9W-16 BB
HOLE NUMBER: 7
DATE MEASURED: 3/08/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	16.600	.0
20.0	23.300	670.0
30.0	28.200	490.0
40.0	32.900	470.0
50.0	37.300	440.0
60.0	41.550	425.0
70.0	45.730	418.0
80.0	49.800	407.0
90.0	53.900	410.0
100.0	57.780	388.0
110.0	61.450	367.0
120.0	65.300	385.0
130.0	68.840	354.0
140.0	72.300	346.0
145.0	74.000	340.0

LOCATION: RHS KGRA
27S/9W-16 AD
HOLE NUMBER: 8
DATE MEASURED: 8/11/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	24.620	.0
20.0	37.470	1285.0
30.0	49.320	1185.0
40.0	60.170	1085.0
50.0	69.580	941.0
60.0	78.120	854.0
70.0	84.080	596.0
80.0	89.650	557.0
90.0	95.400	575.0

LOCATION: RHS KGRA
27S/9W-21 DD
HOLE NUMBER: 9
DATE MEASURED: 9/05/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	20.950	.0
20.0	32.810	1186.0
23.0	34.000	396.7

LOCATION: RHS KGRA
27S/9W-15 ABD
HOLE NUMBER: 10
DATE MEASURED: 9/02/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.370	.0
20.0	19.880	451.0
30.0	23.800	392.0
40.0	27.560	376.0
50.0	32.580	502.0
60.0	37.410	483.0
64.3	39.100	393.0

LOCATION: RHS KGRA
27S/10W-10 DDD
HOLE NUMBER: 12
DATE MEASURED: 8/11/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.860	.0
20.0	18.640	378.0
30.0	21.380	274.0
40.0	24.190	281.0
50.0	26.270	208.0
60.0	27.470	120.0
70.0	28.510	104.0
80.0	29.240	73.0
90.0	29.810	57.0
100.0	30.370	56.0
110.0	30.960	59.0
120.0	31.530	57.0
130.0	32.150	62.0
140.0	32.730	58.0
150.0	33.180	45.0
160.0	33.770	59.0
170.0	34.320	55.0
180.0	34.840	52.0
190.0	35.320	48.0
200.0	35.860	54.0
203.0	35.980	40.0

LOCATION: RHS KGRA
27S/9W-7 CC
HOLE NUMBER: 14
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.250	.0
20.0	17.900	265.0
30.0	20.500	260.0
40.0	23.100	260.0
50.0	25.100	200.0
60.0	26.900	180.0
70.0	28.700	180.0
80.0	30.500	180.0
90.0	31.900	140.0
100.0	33.200	130.0
110.0	34.300	110.0
120.0	35.250	95.0
130.0	36.100	85.0
140.0	36.900	80.0
150.0	37.600	70.0
160.0	38.300	70.0
170.0	39.050	75.0
180.0	39.850	80.0
190.0	40.650	80.0
195.0	41.000	70.0

LOCATION: RHS KGRA
27S/9W-7D DD
HOLE NUMBER: 15
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.040	.0
20.0	18.100	306.0
30.0	20.300	220.0
40.0	22.200	190.0
50.0	24.400	220.0
60.0	26.300	190.0
70.0	28.000	170.0
80.0	29.500	150.0
90.0	31.200	170.0
100.0	32.800	160.0
110.0	34.700	190.0
120.0	36.300	160.0
130.0	37.700	140.0
140.0	38.900	120.0
150.0	39.800	90.0
160.0	40.700	90.0
170.0	41.600	90.0
175.0	41.900	60.0

LOCATION: RHS KGRA
27S/9W-4 AD
HOLE NUMBER: 17
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	17.600	.0
20.0	23.600	600.0
30.0	29.700	610.0
40.0	34.700	500.0
50.0	40.000	530.0
60.0	44.100	410.0
63.0	45.000	300.0

LOCATION: RHS KGRA
27S/R9W-2 CAA
HOLE NUMBER: 20
DATE MEASURED: 8/13/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	12.410	.0
20.0	14.690	228.0
30.0	16.570	188.0
40.0	18.310	174.0
50.0	20.300	199.0
60.0	21.160	86.0
70.0	22.400	124.0
80.0	23.440	104.0
90.0	24.290	85.0
100.0	24.990	70.0
105.0	25.350	72.0
105.5		

LOCATION: RHS KGRA
26S/9W-32 AA
HOLE NUMBER: 25
DATE MEASURED: 9/05/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.590	.0
20.0	21.160	557.0
30.0	25.030	387.0
40.0	28.080	305.0
50.0	30.960	288.0
60.0	33.590	263.0
70.0	36.200	261.0
80.0	38.550	235.0
90.0	40.510	196.0
100.0	42.600	209.0
110.0	44.790	219.0
120.0	47.090	230.0
130.0	49.330	224.0
140.0	51.260	193.0
144.3	51.360	23.3

LOCATION BOYLES 12RKGRA
26S 9W 27 BB
HOLE NUMBER UU 75 12
DATE MEASURED 6/11/76

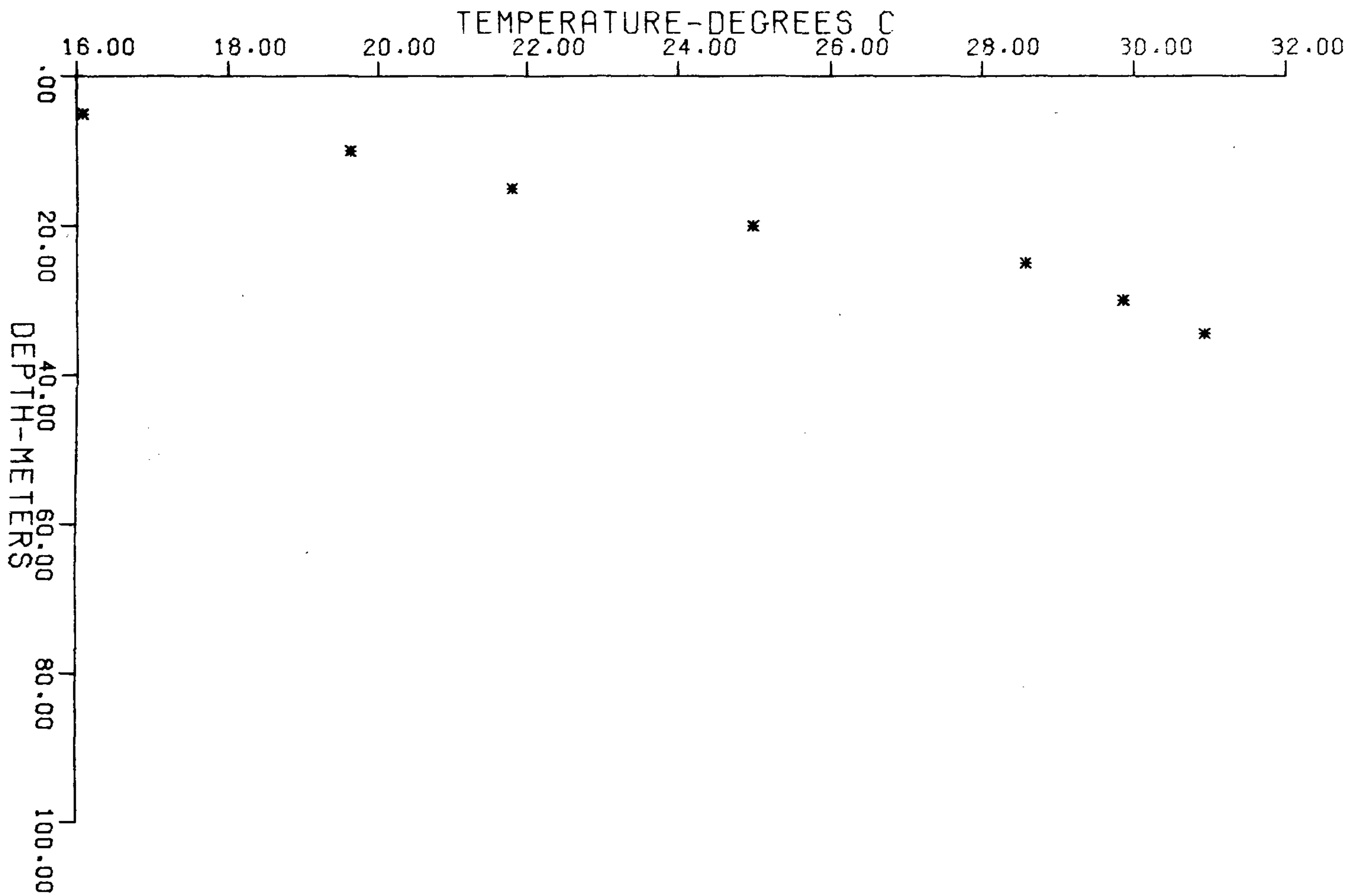


Figure 6

LOCATION BOYLES 13 RKGRA
26S-9W-20 AC
HOLE NUMBER UU-75-13
DATE MEASURED 11/8/75

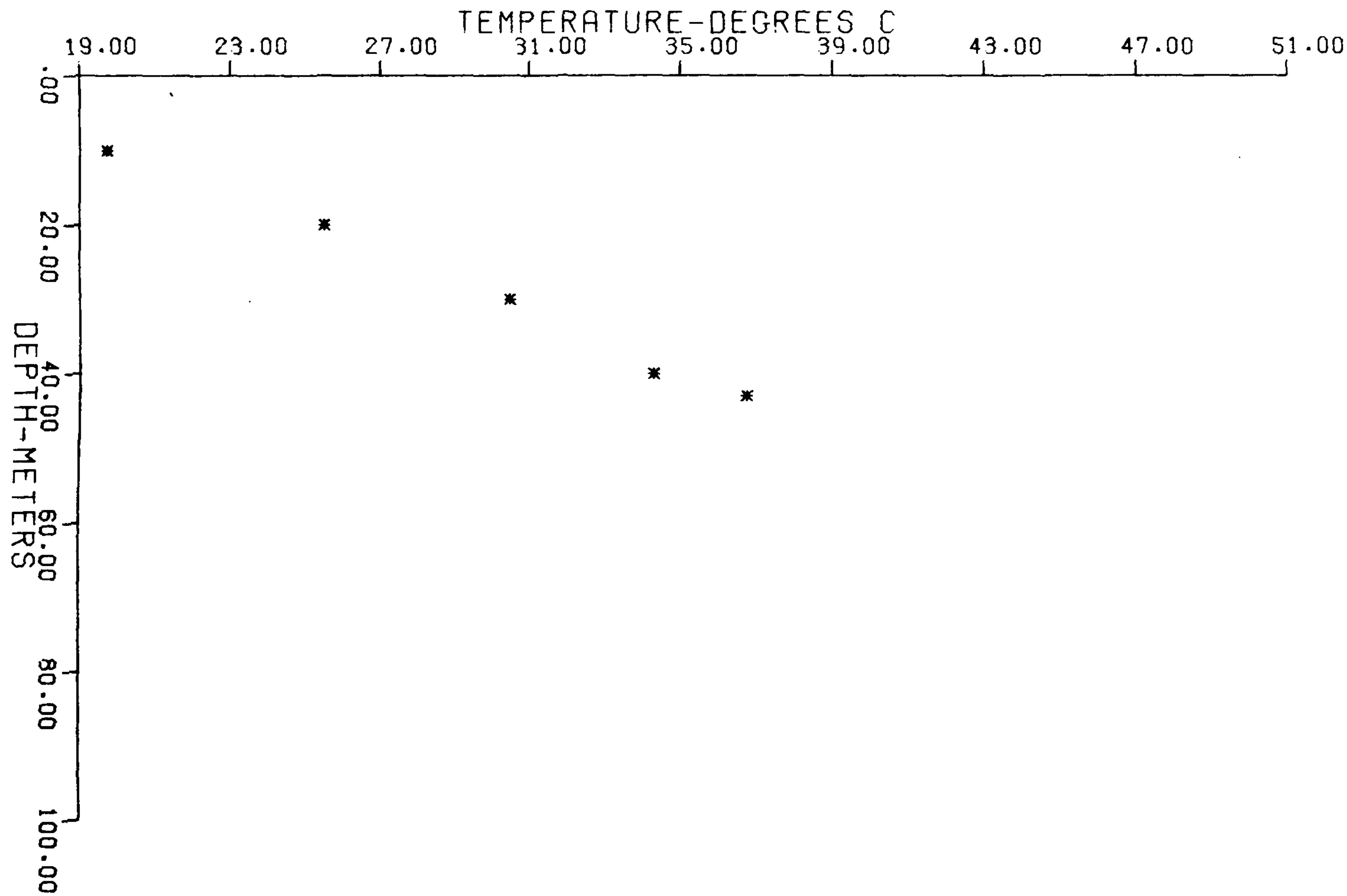


Figure 7

LOCATION ALTERATION 75 1A
275 9W 3CBB
HOLE NUMBER UU 751A
DATE MEASURED 7/22/76

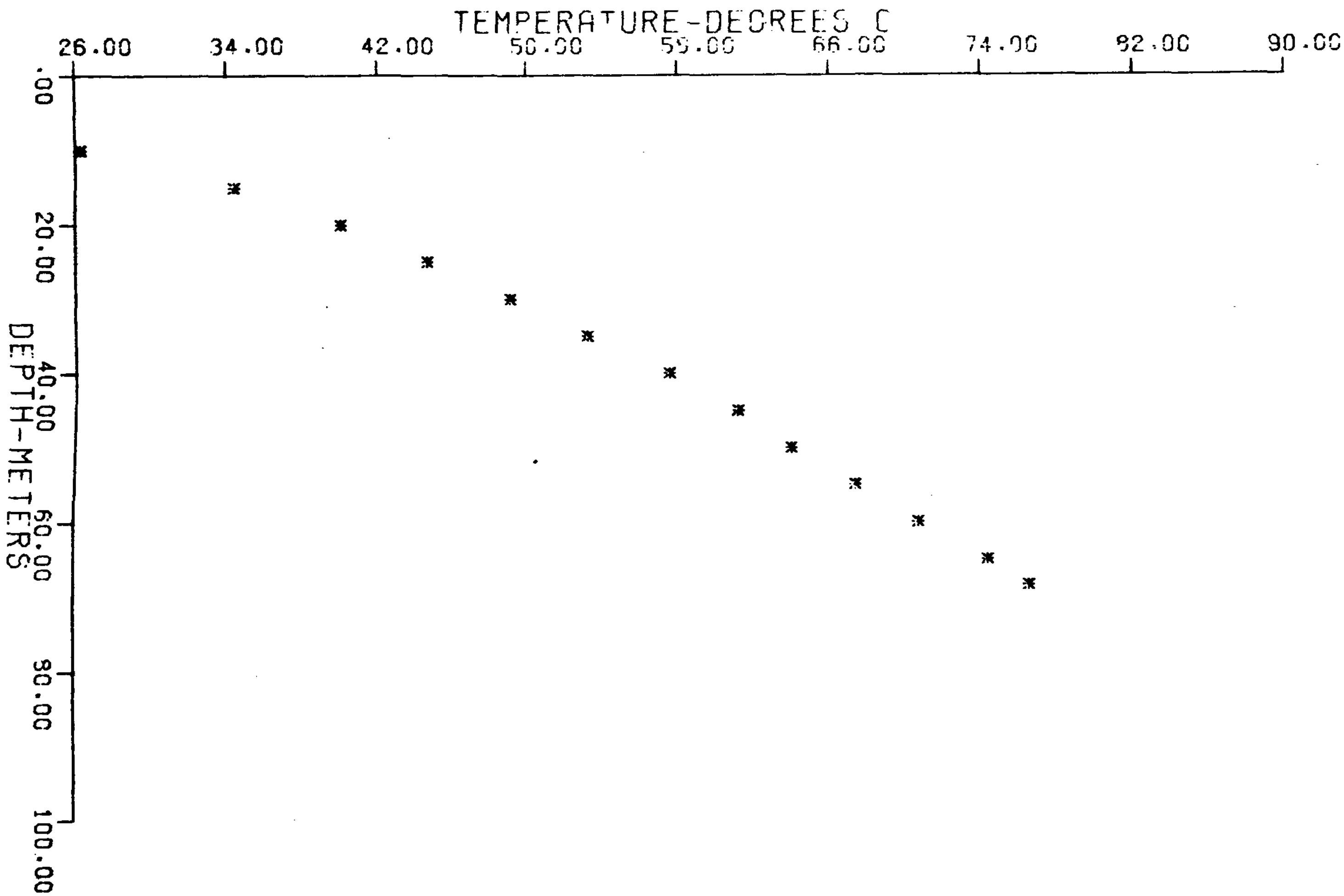


Figure 8

LOCATION ALTERATION 75 1B
27S 9W 4DDA
HOLE NUMBER UU 75 1B
DATE MEASURED 7/22/76

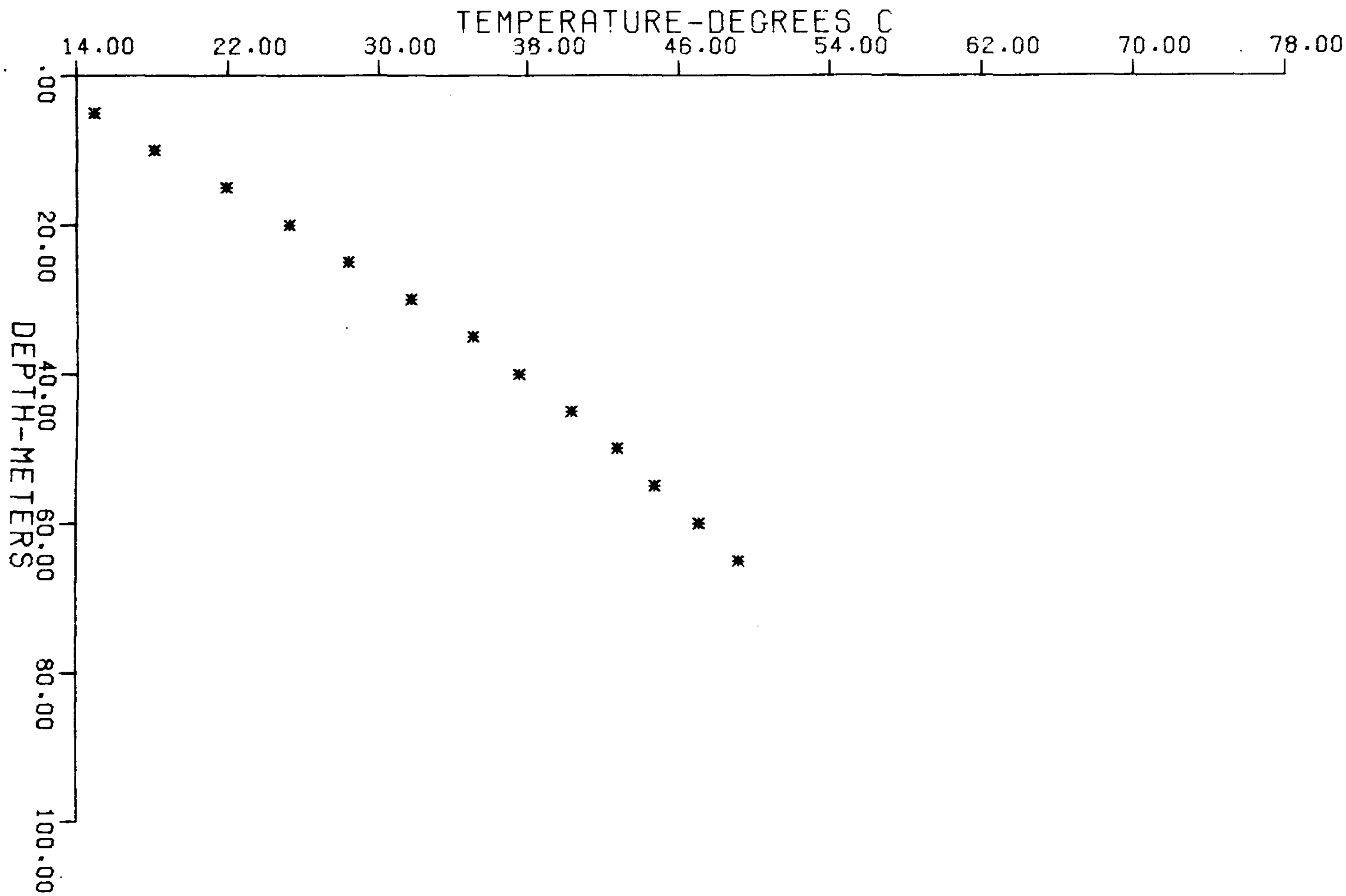


Figure 9

LOCATION BIG CEDAR COVE
27S 9W 14 BD
HOLE NUMBER UU 75 3CC
DATE MEASURED 9/22/75

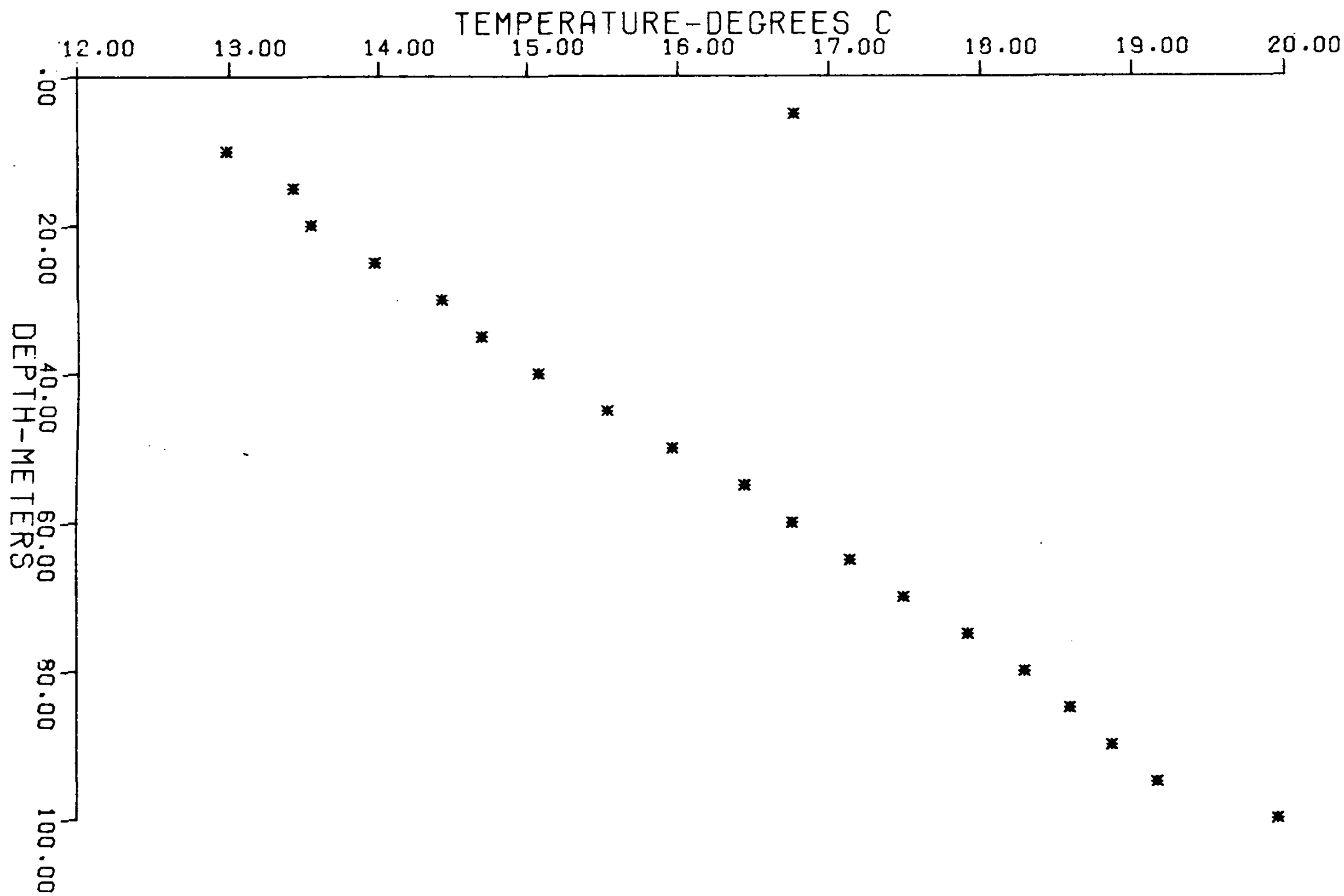


Figure 10

LOCATION RYANS RANCH
27S 8W 4DCD
HOLE NUMBER UU 75 RR
DATE MEASURED 11/6/76

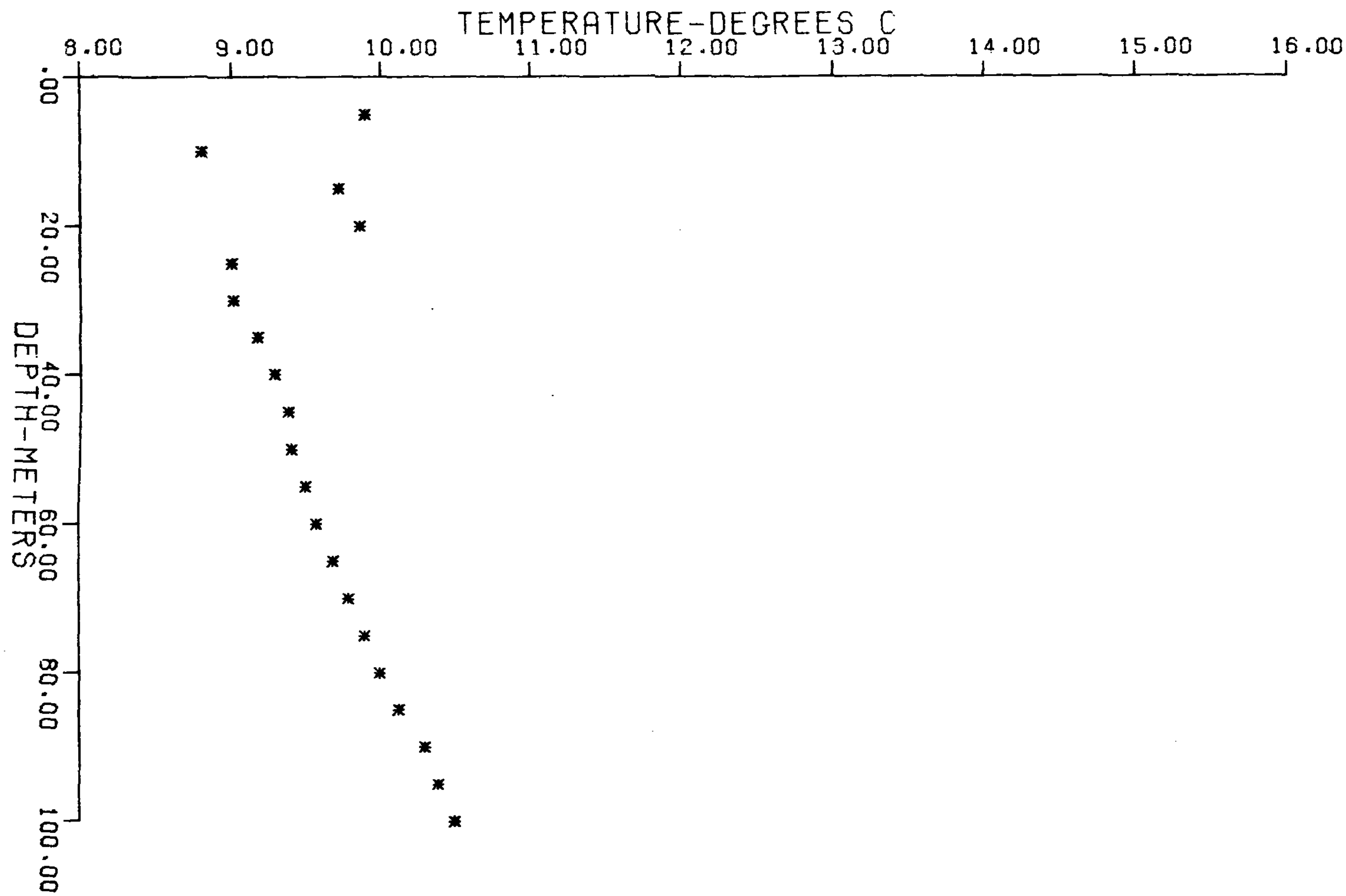


Figure 11

LOCATION ALTERATION 76-1A RKGRA
27S 9W 34 CA
HOLE NUMBER UU 76-1A
DATE MEASURED 8/ /76

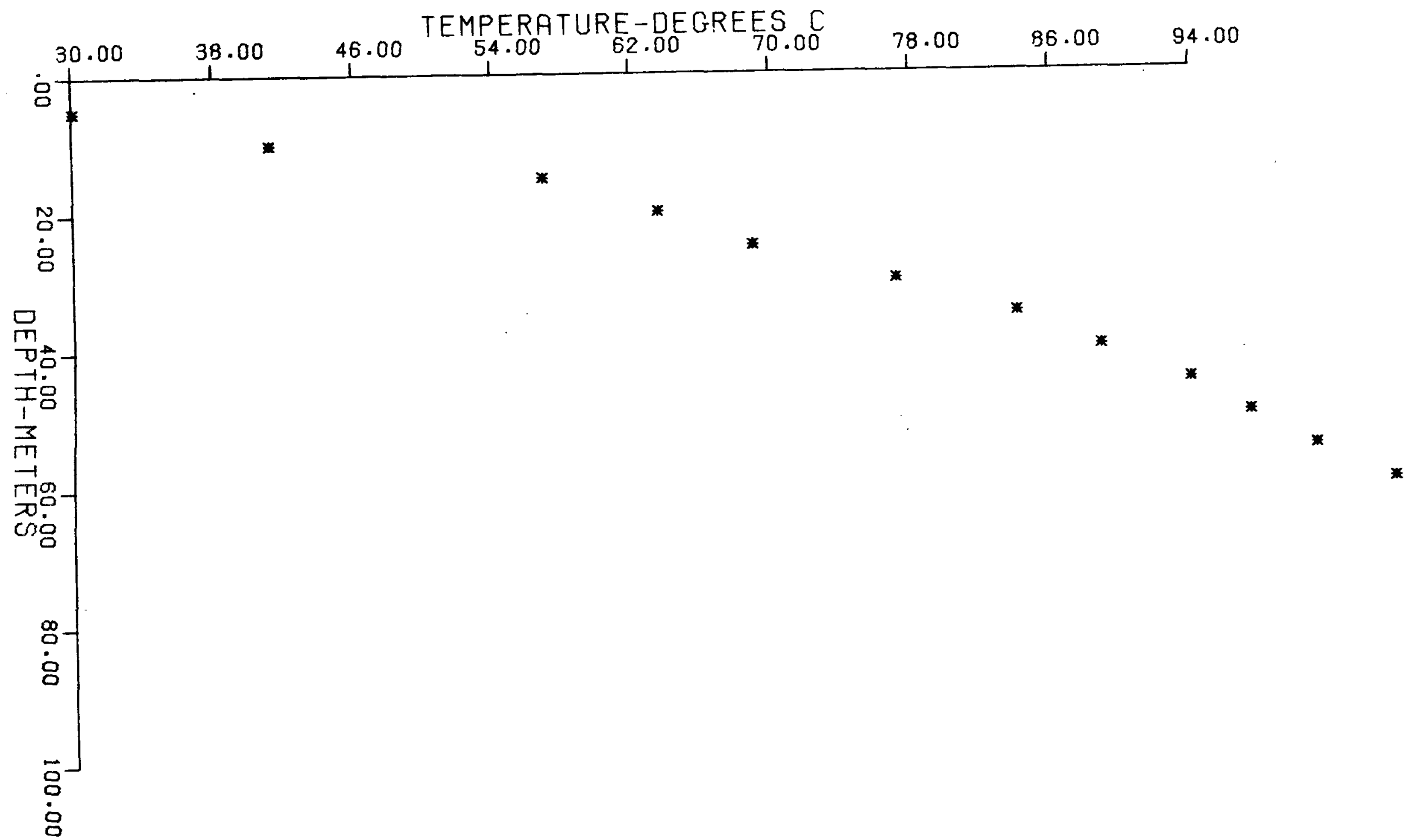


Figure 12

LOCATION RKGRA SALT COVE
26S 9W 25 DC
HOLE NUMBER UU 76 SC
DATE MEASURED 3/24/77

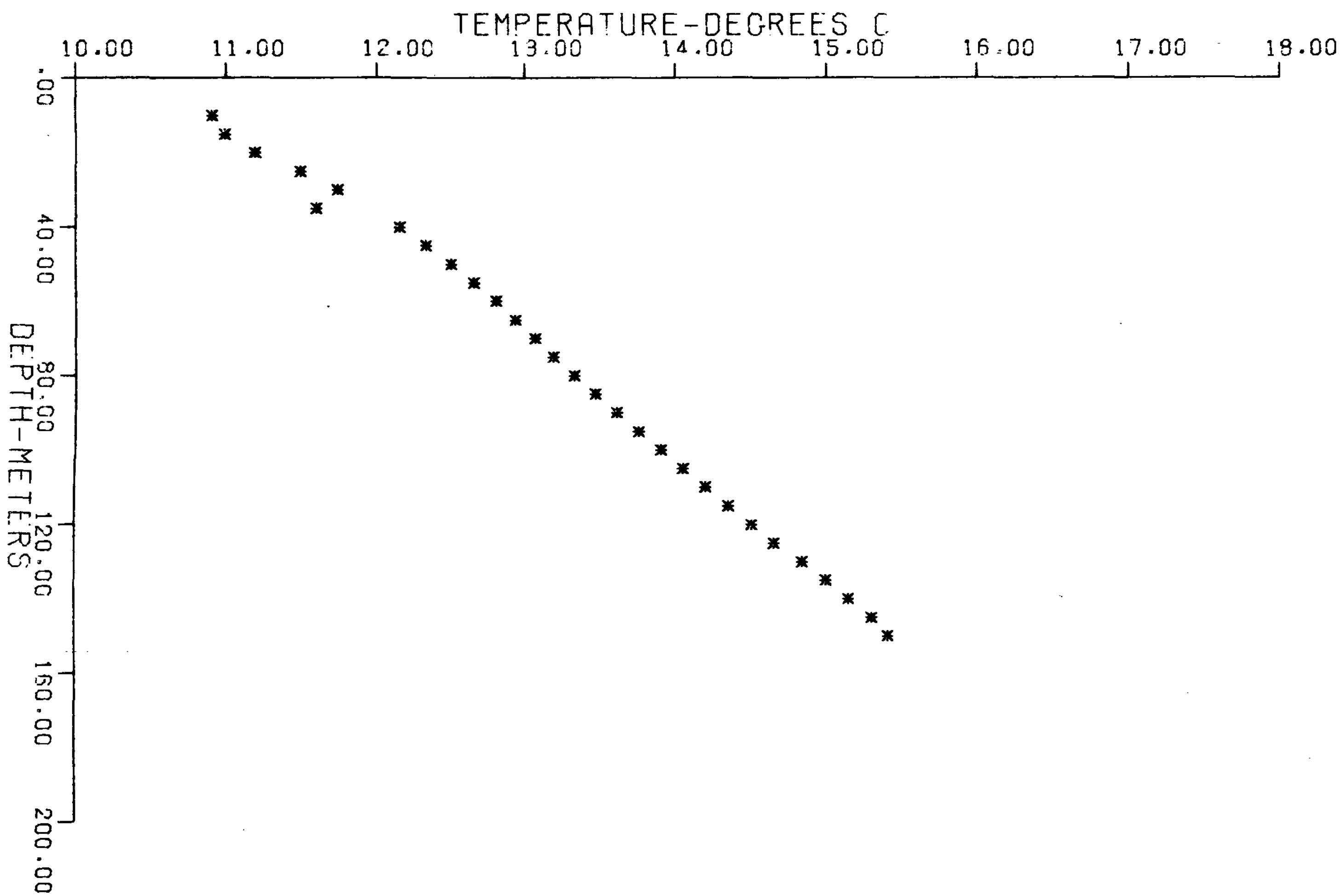


Figure 13

LOCATION BEARSKIN RKGRA
27S 8W 8 BAB
HOLE NUMBER UU 76 8S
DATE MEASURED 8/20/76

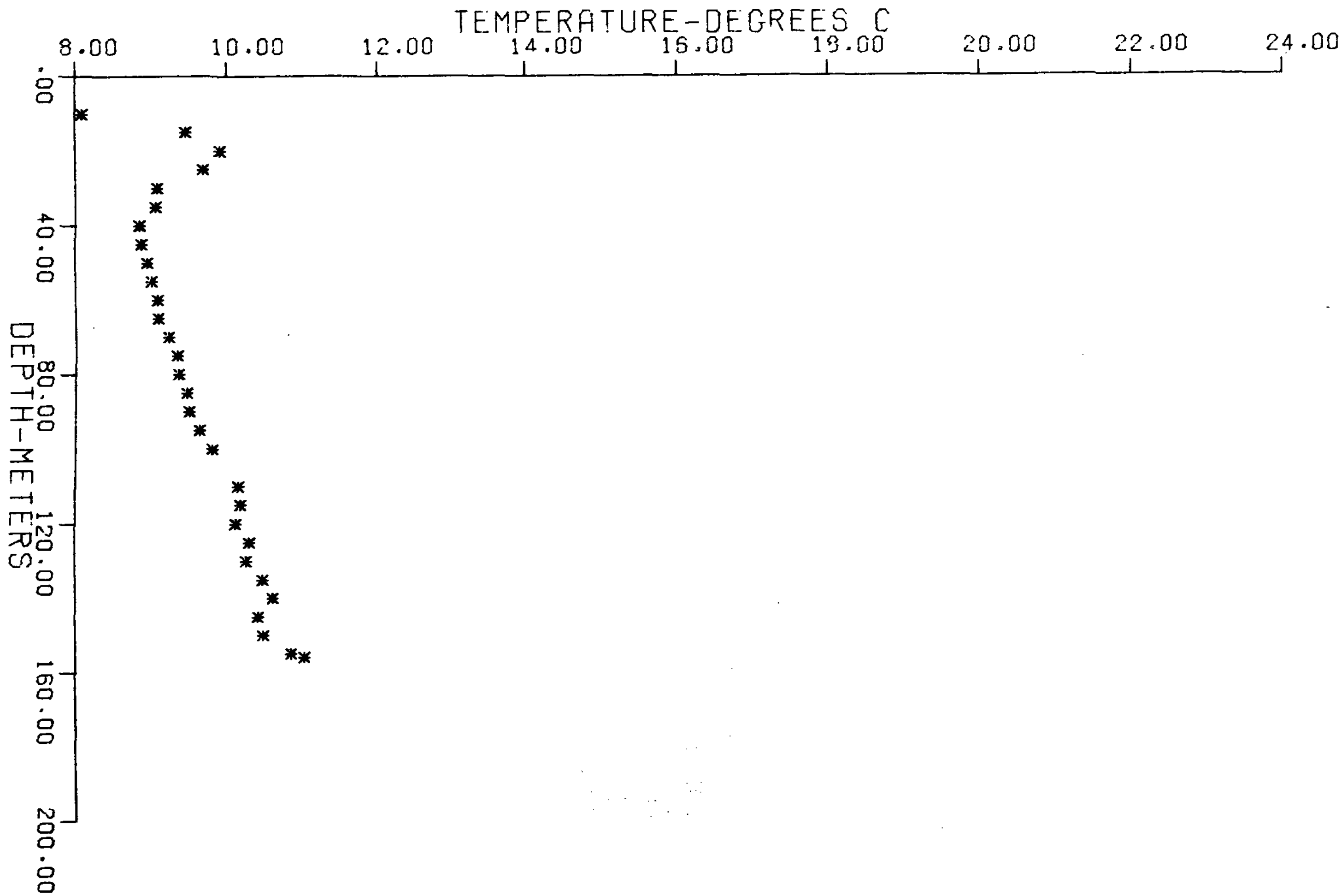


Figure 14

LOCATION RKGRA TG-O
26S 9W 16 BD
HOLE NUMBER UU76 TGO
DATE MEASURED 8/30/76

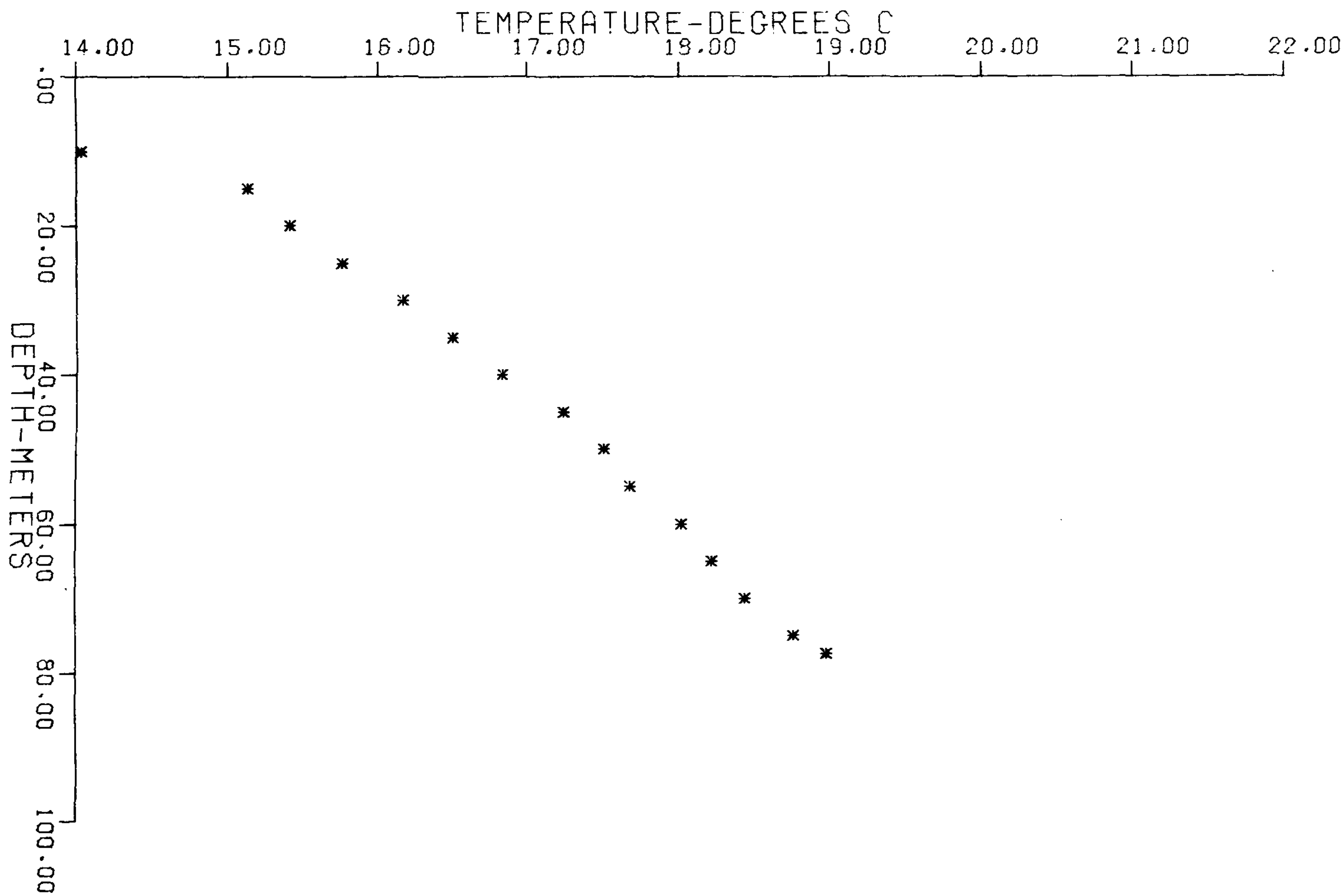


Figure 15

LOCATION RKGRA TG-1
26S 9W 15 CB
HOLE NUMBER UU76 TG1
DATE MEASURED 10/10/76

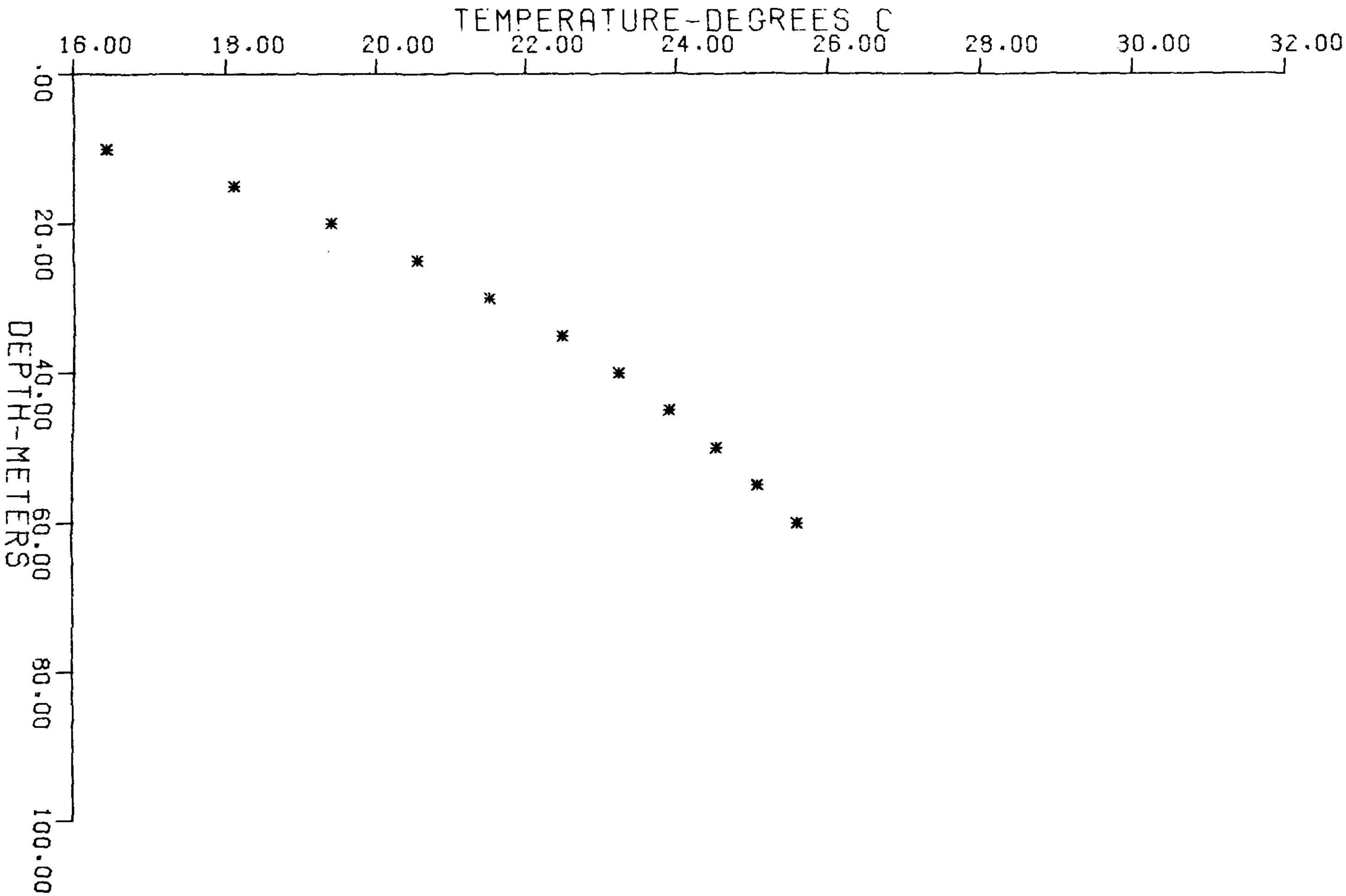


Figure 16

LOCATION RKGRA TG-2
26S 9W 5CDB
HOLE NUMBER UU76 TG2
DATE MEASURED 11/6/76

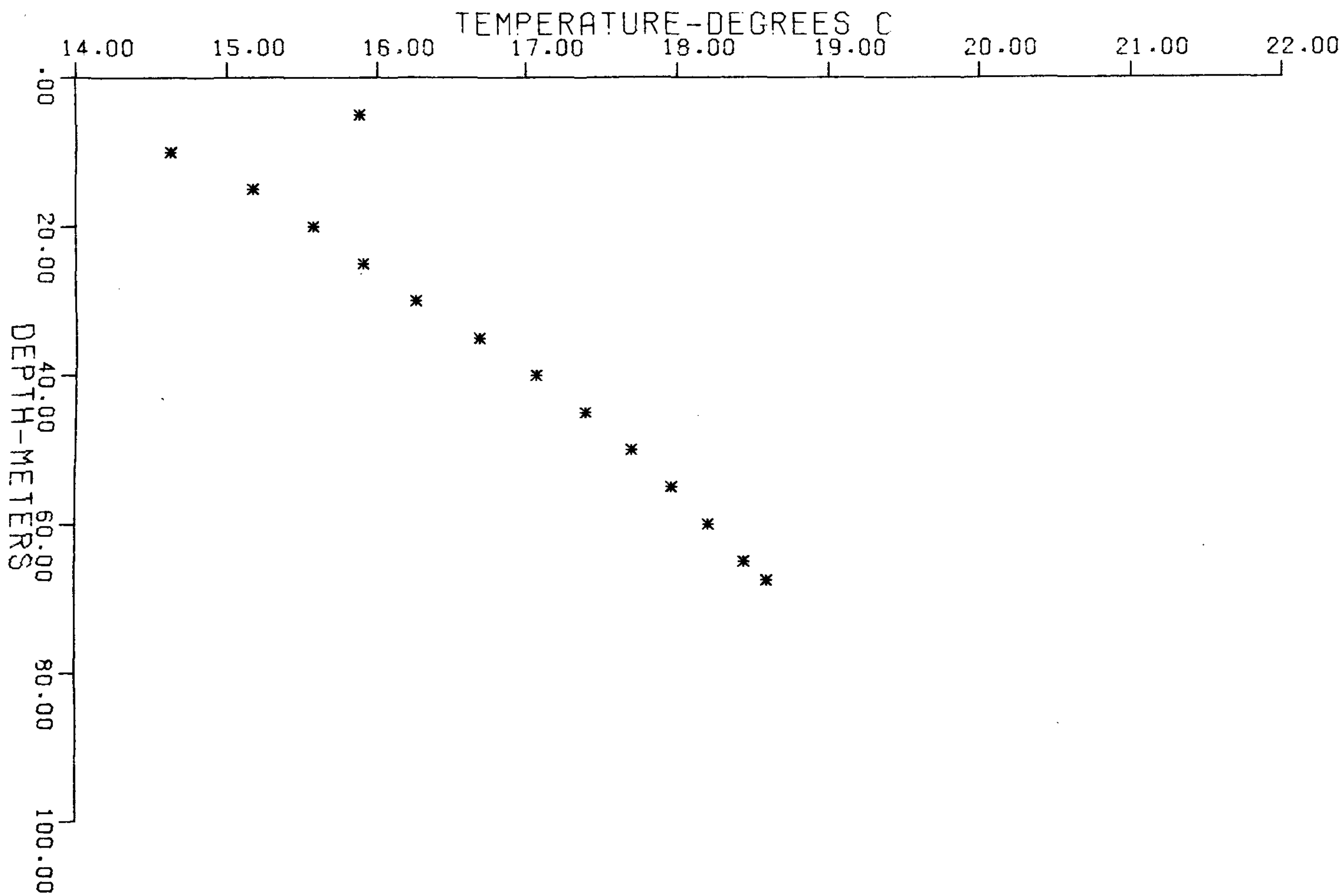


Figure 17

LOCATION RKGRA TG 3
26S 9W 19 DB
HOLE NUMBER UU76 TG3
DATE MEASURED 11/5/76

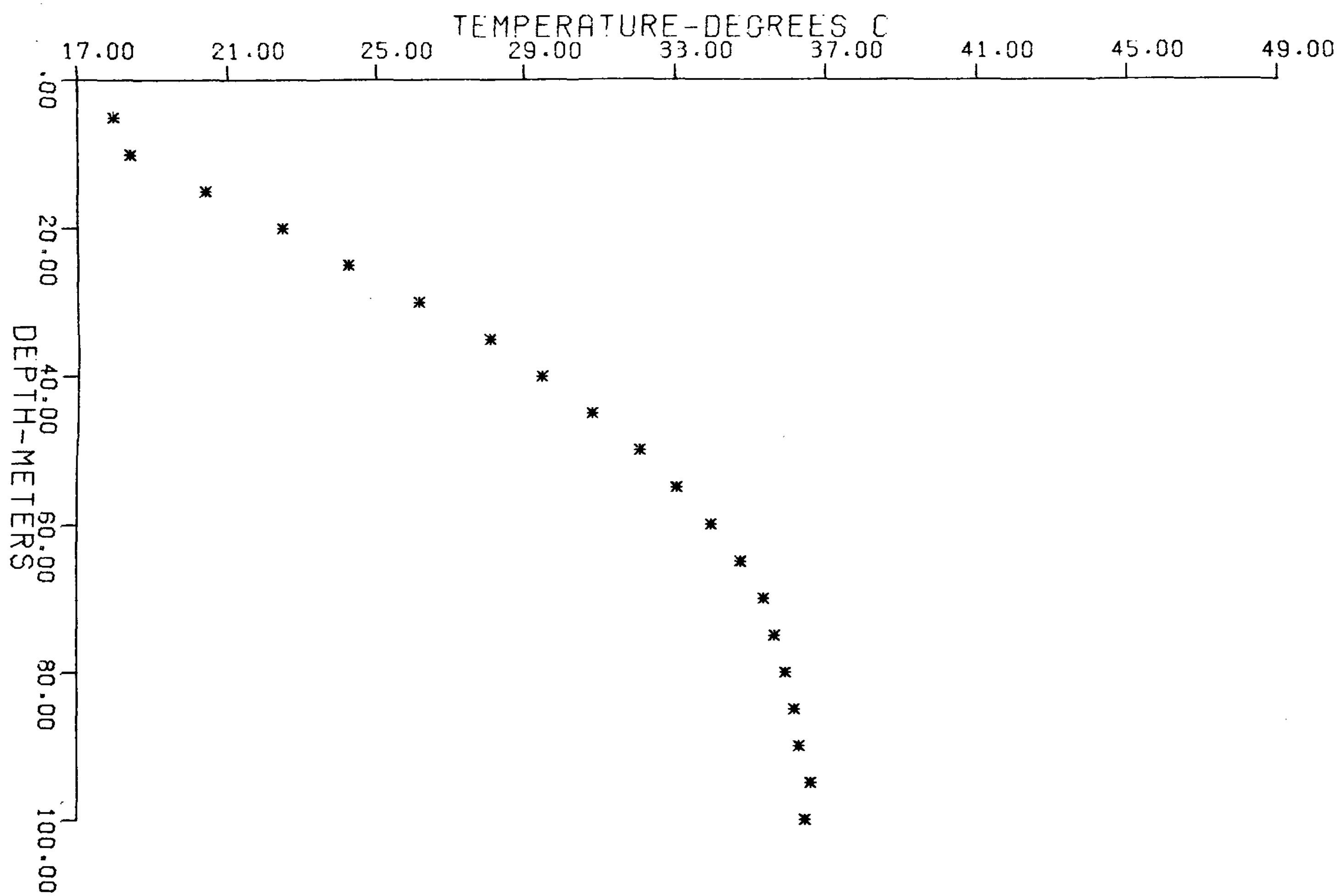


Figure 18

LOCATION RKGRA TG-5
26S 9W 14 DA
HOLE NUMBER UU76 TG5
DATE MEASURED 10/10/76

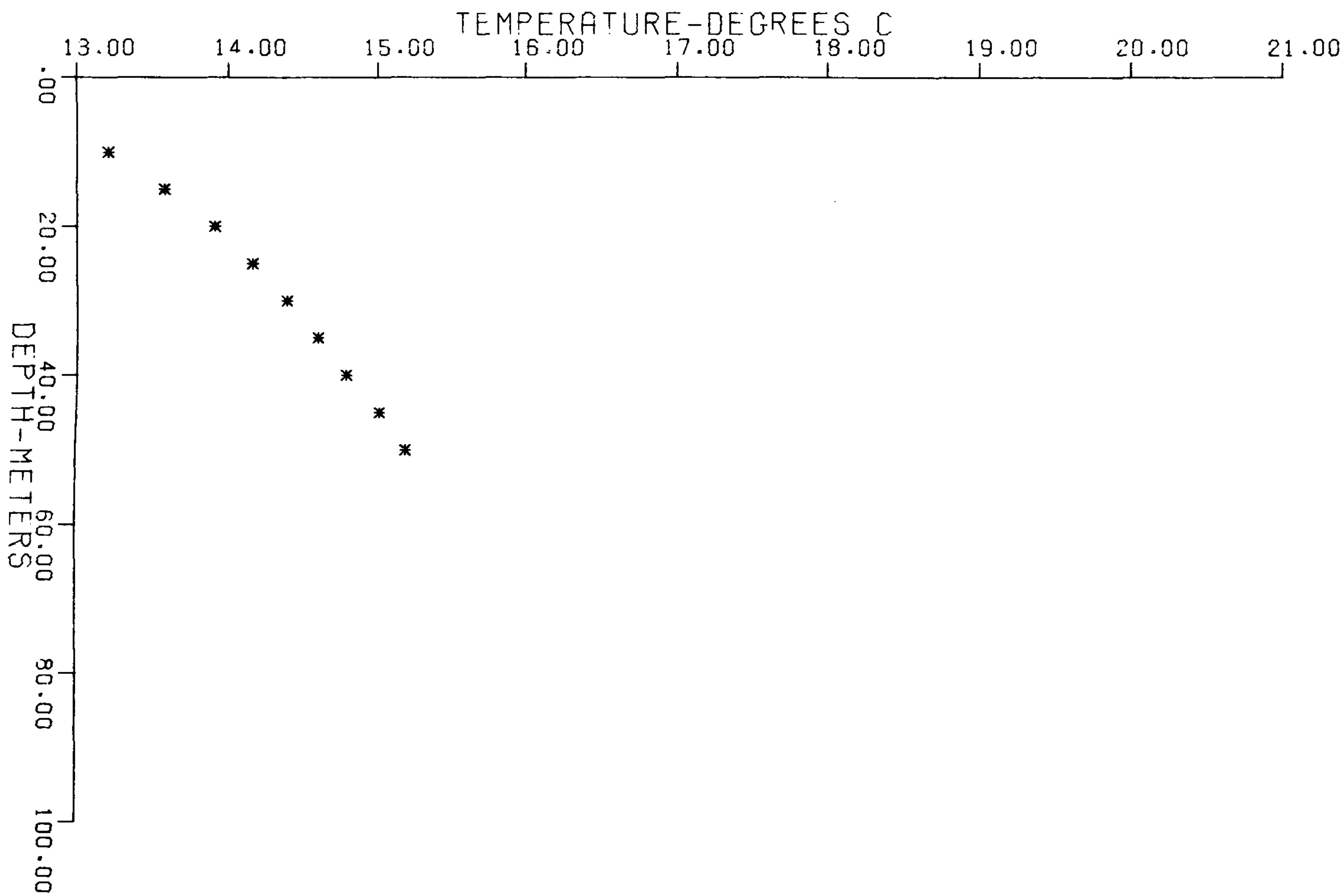


Figure 19

LOCATION RKGRA TG-6
26S 9W 7CAA
HOLE NUMBER UU76 TG6
DATE MEASURED 11/6/76

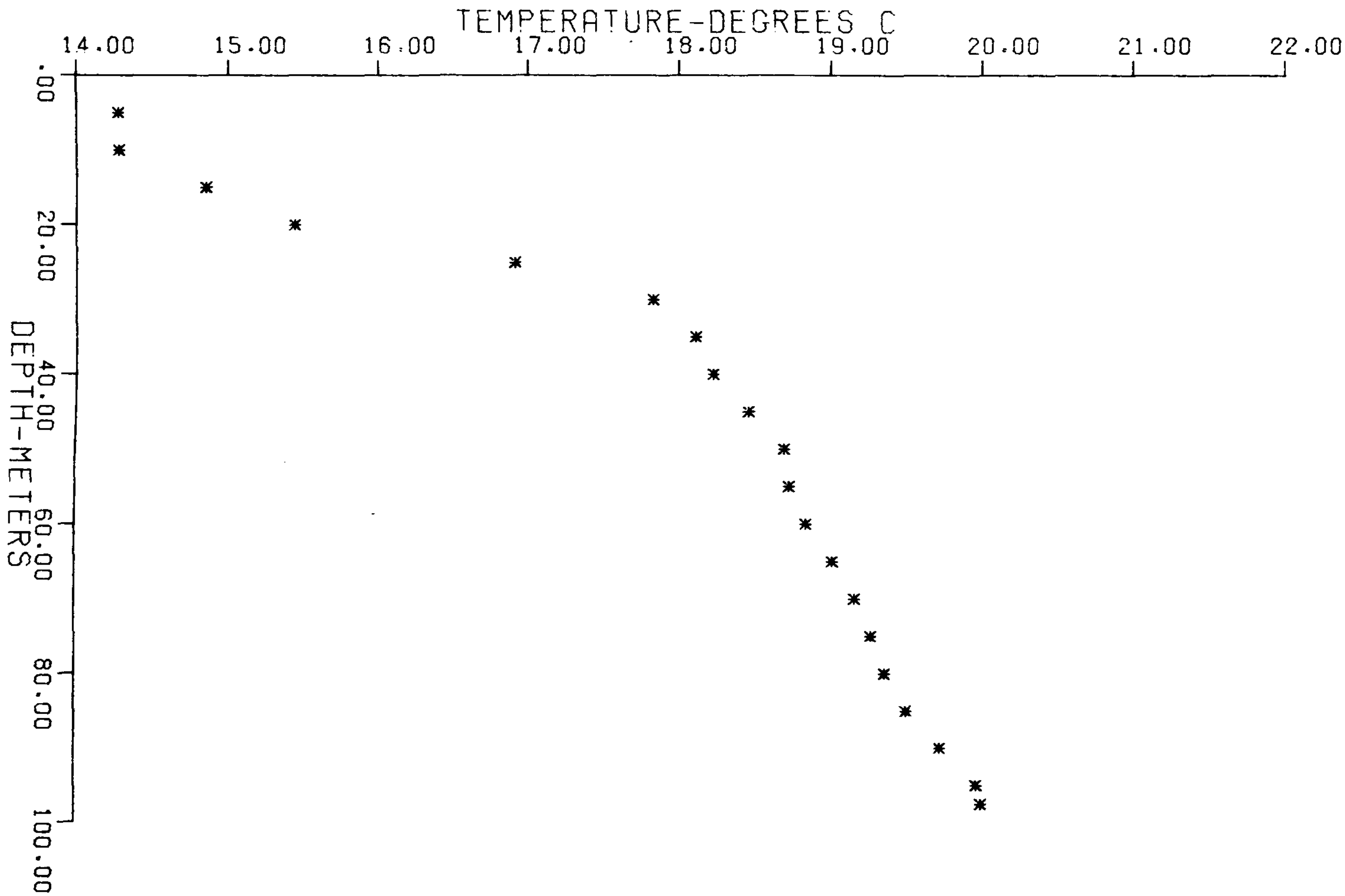
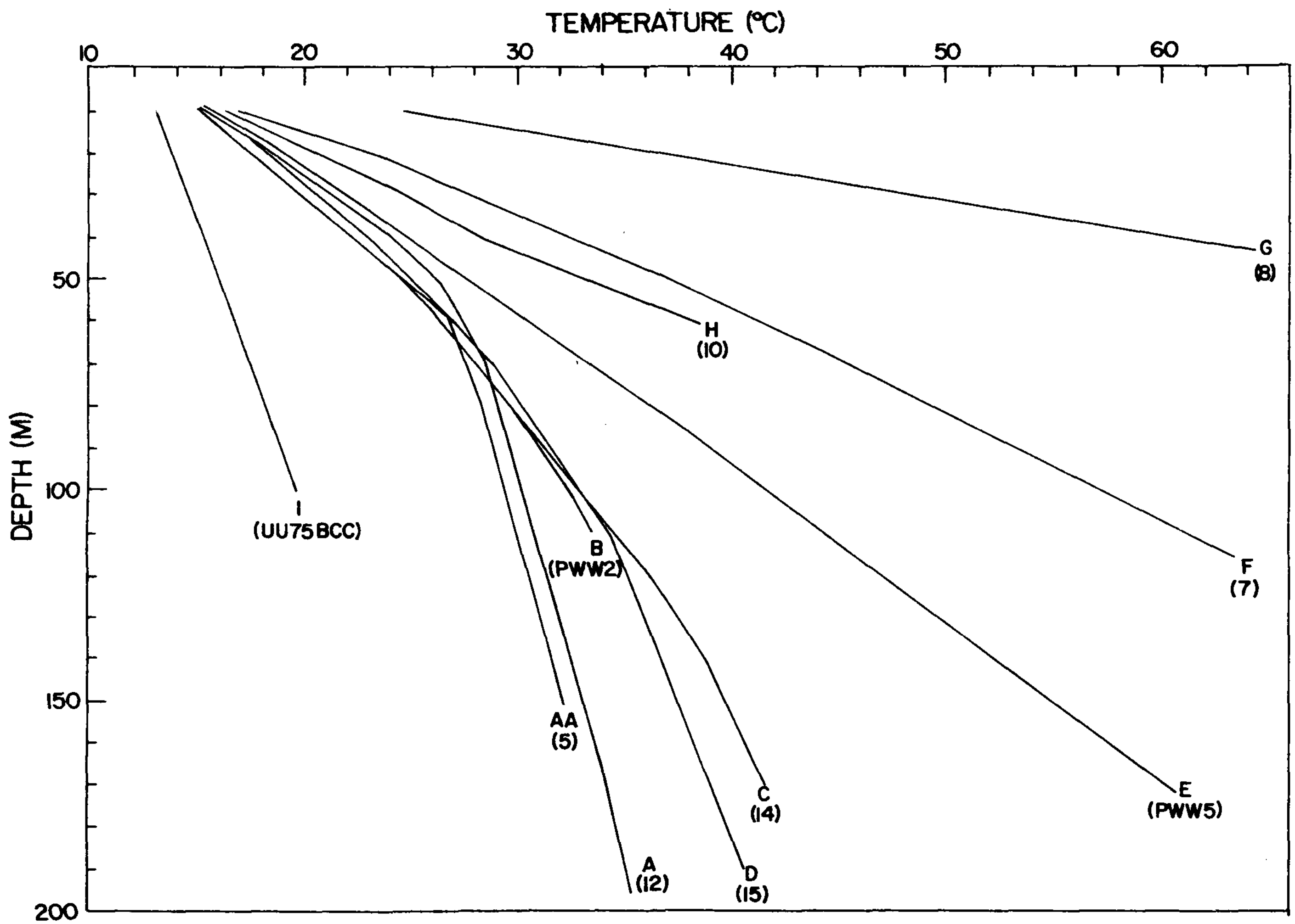
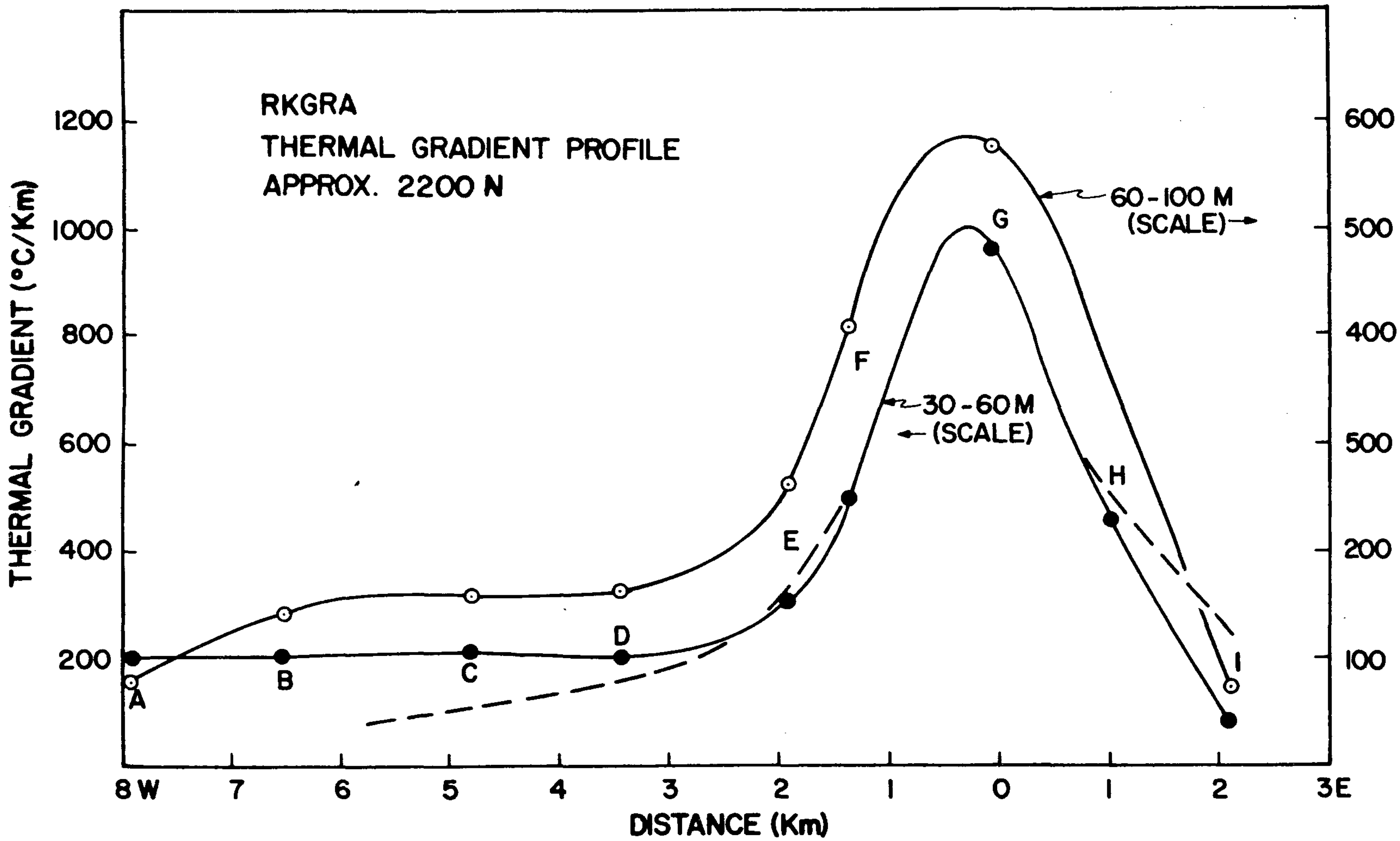


Figure 20



TEMPERATURE (°C)
10
20
30
40
50
60
DEPTH (M)
50
100
150
200
G
(8)
H
(10)
I
(UU75BCC)
B
(PWW2)
F
(7)
AA
(5)
C
(14)
E
(PWW5)
A
(12)
D
(15)

Figure 21



RKGRA
THERMAL GRADIENT PROFILE
APPROX. 2200 N
THERMAL GRADIENT (°C/Km)
1200
1000
800
600
400
200
600
500
400
500
200
100
60-100 M
(SCALE)
30-60 M
(SCALE)
A
B
C
D
E
F
G
H
I
8 W
7
6
5
4
3
2
1
0
1
2
3E
DISTANCE (Km)

Figure 22

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

REPORT: Technical Report: Volume 77-3

CONTRACT: EY-76-S-07-1601

AGENCY: ERDA

TITLE: Thermal Gradients and Heat Flow at Roosevelt Hot Springs

AUTHORS: W. R. Sill, J. Bodell

DATE: July, 1977

UNIVERSITY OF UTAH SALT LAKE CITY, UTAH 84112

TECHNICAL REPORT: VOLUME 77-3

Thermal Gradients and Heat Flow at Roosevelt Hot Springs

Energy Research and Development Administration

Contract EY-76-S-07-1601

W. R. Sill

J. Bodell

TABLE OF CONTENTS

Abstract

Thermal gradient and electrical resistivity surveys both outline anomalous zones along the system of faults that control the near surface flow at Roosevelt Hot Springs. The source of both anomalies is the circulation of thermal water, which gives rise to the high heat flow and the lowered resistivity due to the hot brine and the associated hydrothermal alteration.

The nature of the temperature profiles and the asymmetry of the thermal gradient profile across the system are suggestive of a leakage and mixing of thermal water with the regional groundwater flow to the west. This interpretation is consistent with the resisitivty data in which conductive regions to the west of the fault system have been interpreted in terms of brine-saturated sediments.

The maximum conductive heat flow over the anomaly is 40 HFT ($1.7 W/m^2$) and the total conductive heat loss is estimated at 2 MW. Heat flow in the Mineral Mountains, to the east of the near-surface thermal anomaly, is low or near average for the Basin and Range. Recharge may be taking place in this region.

1.0 Introduction

Thermal gradient data from 39 drill holes in the Roosevelt Hot Springs KGRA area are presented in this report. Fifteen of these holes were drilled under subcontract to the University of Utah, permission to log another ten holes was granted by Phillips Petroleum Company and the remaining fourteen holes were provided by other sources. The locations of most of the holes are shown in Figures 1 through 3, along with the locations of test and production holes. These figures also show the contoured average thermal gradient in three depth intervals; shallow (30-60m), intermediate (60-100m) and deep (>100m).

Figure 4 displays a plan view of the interpreted faults in the area. Comparison of Figures 1 and 4 shows that the region of highest thermal gradients is aligned along the Dome Fault and Fault 1. To the south the high thermal gradients are terminated by several east-west trending faults. To the north there is a bending of the contours resulting in a ridge aligned along fault 5, which trends to the north west.

In Figures 1 and 2 there are isolated highs in the north and south that are probably the result of the sparseness of data in the central region. Considerations of the probable thermal gradient in the early steam well (drilled by Dr. E. N. Davie), based on the depth of blowout, and the near surface temperatures in sulfur pits in the bottom of Negro Mag Wash (North of 54-3) would indicate that the 900°C/km should run further to the west in the southern portion and is probably continuous with the high in the north.

Comparison of Figure 1 with the contoured apparent resistivity (Figure 5) shows that the resistivity and thermal gradient patterns are highly correlated. Both exhibit contours aligned along the Dome fault and a bending to the northwest along Fault 5. The obvious cause of the correlation

is the hot water circulation along the faults which gives rise to both high thermal gradients and low resistivities due to the hot brine and the associated hydrothermal alteration.

With increasing depth (Figures 2 and 3) the thermal gradients decrease and the alignment along the faults is less clear. The smearing of the pattern is partly due to the lack of data at greater depths. The acquisition of deep thermal gradient data from small drill holes in regions of very high thermal gradients is hindered by fear of blowouts, among other things.

2.0 Thermal Gradients at Roosevelt Hot Springs

Figures 6 to 20 show the temperature vs depth curves for the holes drilled by the University of Utah. As can be seen in these figures, the thermal gradient in holes drilled in alluvium often decreases with depth, with the depth intervals used in Figures 1 to 3 being somewhat characteristic of the several regions of changing gradient. For example, hole UUTG6 (Figure 20) shows an abrupt change at 30m and hole UUTG3 (Figure 18) displays a more gradual transition with suggested breaks at 35m and 70m. Such changes in the thermal gradients can be caused by changes in thermal conductivity due to changes in the porosity, saturation and lithology among other things.

Gravity measurements over a wash in the alluvium (Crebs and Cook, 1976) indicate a porosity of about 25% in the near surface (25-50m). Some decrease in porosity with depth is to be expected due to the increase in load. A change in the porosity of saturated granite alluvium from 25% to 10% would give rise to a change in thermal conductivity (and gradient) of about 25%. The changes in thermal gradient caused by such variations in porosity are then rather modest.

On the other hand, changes in saturation, from dry to completely saturated, would give rise to changes in thermal conductivity by a factor of 2.0 to 2.5 for porosities in the range from 20 to 30%.

Changes in the thermal conductivity due to lithology changes depends on the thermal conductivity of the components. For example, changing the thermal conductivity of the solid components by a factor of 2 results in a 1.7 change in conductivity at a porosity of 25%. Changes in lithology from a granite alluvium to a quartz rich sand are possible in this area. Measurements made on sands from the Roosevelt KGRA give solid component conductivities in the range from 10 to 11 HCU and samples of granite alluvium give

values in the range from 6 to 7 HCU. Therefore, such changes in lithology can be expected to give rise to rather substantial changes in gradient.

Considering the thermal gradients in hole UUTG6 (Figure 21) we see that the average gradient in the 20-30m interval is about 200°C/km and below this depth it averages about 30°C/km, a factor of about 7 change is slope. Thermal conductivity measurements on samples from this hole average about 4 HCU, at a saturated bulk density of 2.2g/cm^3, with no consistent changes above and below the break in the slope. The water table in a nearby well (2.4km) at about the same elevation is 26m (Mower and Cordova, 1974). This is near the break in the thermal gradient. However, the change in thermal conductivity due to undersaturation would only be a factor of 2 to 2.5 which is well below the observed value.

One possible explanation of the strong change in gradient is a leakage of thermal water into the groundwater flow to the west. Some leakage of thermal water is indicated by the chemical analysis of the seep west of Salt Cove, which has a cool temperature (25°C) but a Na-K-Ca temperature of 241°C (Parry et. al., 1976). For a uniform mixing of thermal water into the groundwater in a region of constant thermal conductivity, the thermal gradient should decrease smoothly with depth in the mixing zone. The two gradient regions in UUTG6 may result from a combination of effects due to the presence of the water table and mixing. On the other hand, the thermal gradient in hole UUTG3 (3km to the south) shows a more gradual change, with no sharp break at the water table (50m). The overall change in slope between the top and bottom of this hole is about a factor of 8, which seems too large to be explained by the effects of saturation alone.

In holes UU751A and UU751B, just to the west of the dome fault, the water tables were located at about 35m and 40m respectively, which are also the locations of the alluvium altered bedrock interface. In both cases the thermal gradients do not show an abrupt change at the water table.

However, there is gradual increase in thermal gradient above these depths (20% to 40%), perhaps due to gradual changes in the saturation.

Figure 21 shows a series of temperature profiles on a west-east line across the southern part of the system (the letter designation runs from West-A to East-I). The thermal gradients and the 10m depth temperatures increase as the Dome Fault is approached from the west (A to G) and the two eastern holes (H & I) show decreasing temperatures and gradients.

The five westernmost holes (AA to D) show a decreasing gradient with depth, as did the western holes to the north(UUTG6 and UUTG3) discussed previously. The two westernmost holes 5(AA) and 12(A) have a thermal gradient in the deeper part near 50°C/km, which is near normal for a thermal gradient in the alluvium. The water table is about 40m in this region (Mower and Cordova, 1974) and both curves show changes in slope (15 to 30%) at this depth, which could be due to changes in saturation. There is a change in slope to a near constant slope region at a depth of about 60m. The change in average gradient above and below this depth is a factor of 1.5 to 3. The lithologic log on a nearby water well notes a change in lithology at this point, from sands containing numerous "igneous" fragments (up to 30%) to sands free of such material. Considering the average abundance of such material, it would be difficult to account for the changes in slope by the change in lithology. Once again a possible explanation for the change in slope could be leakage of thermal waters to the west and mixing with the groundwater. With respect to this, it is interesting to note that the thermal gradients at depth in the westernmost holes are near normal and that the gradient in the easternmost hole is constant with depth although slightly above normal. More conclusive evidence for leakage mixing of thermal waters would be the presence of gradient reversals which have not been observed to date.

3.0 Heat Flow at Roosevelt Hot Springs

Thermal conductivity measurements on a limited number of alluvial samples, indicates an average value of 4 HCU (1 HCU — mcal/cm S°C — 0.418 W/m°k). Maximum conductive heat fluxes are then in the neighborhood of 40 HFU (1 HFU = μ cal/cm^{2}S = 41.8 mW/m^2). The total integrated conductive heat loss over the anomaly (6.5 km in length) is about 10^{7}cal/S or 2MW.

Figure 22 is a west to east thermal gradient profile for two depth intervals, 30-60m and 60-100m. Based on a *conductive* heat flow model, these profiles indicate an equivalent line source at 1.0 to 1.5km depth. Also shown on the figure, as a dashed line, is the theoretical thermal gradient profile for a line source, scaled to the 30-60m data. From this it is easy to see that the observed curve is asymmetrical, with smaller gradients in the east and larger to the west. This asymmetry is also observed in the deeper (60-100m) gradients. The observed asymmetry is compatable with the leakage of thermal water to the west, as discussed in the previous section, but source configuration in a conductive model could also produce such asymmetry.

Several core holes were also drilled in the granite of the Mineral Range so that samples could be measured for thermal conductivity and heat flow values calculated. Figure 13 shows the temperature profile in one such hole (UU76SC) located in Salt Cove on the west side of the Mineral Range, about 3 km east of the center of the thermal gradient-resistivity anomaly. The thermal gradient is quite uniform at an average value of 29°C/km below a depth of 50m. The average thermal conductivity in this region is 6.6 HCU (16 samples) giving a heat flow of 1.92 HFU.

Another hole (UU76BS) was drilled in the central part of the Mineral Range just to the north of Bearskin Mountain, the temperature profile from the last log (Figure 14) still shows some drilling disturbances, but the

smoothed thermal gradient in the 80 to 150m interval is 17^{0}C/km. The thermal gradient in a Phillips Petroleum Company hole, 1.5 km to the north (Figure 1) is similar (16^{0}C/km) indicating that this is maybe representative of the area. The average thermal conductivity in this hole in the above depth interval is 7.65 HCU (11 samples) giving a heat flow of 1.28 HFU.

Two kilometers to the east of this hole, the hole at Ryans Ranch *(UU75RR, Figure 11) has thermal gradient of 19.9^{0}C/km (50 to 80 m) and* the average thermal conductivity of several samples is 7.1 HCU, resulting in a heat flux of 1.41 HFU.

Roy et al. (1968) report a heat flow of 2.22 HFU for a location on the west side of Milford valley, just about due west of Roosevelt Hot Springs. None of the above calculated heat flow values are large for the Basin and Range, in fact the measurements in the central part of the range seem somewhat low. However, none of the measurements have been corrected for topographic effects, which should be largest for the locations north of Bearskin and at Ryans Ranch.

If the Mineral Mountains and the area to the east are regions of significant recharge, then the downward movements of cool water may contribute to the low thermal gradient and heat flow.

4.0 Conclusions

Thermal gradients and electrical resistivity data at Roosevelt Hot Springs both outline the same anomalous region along the system of faults which control the near surface circulation. Depending on the circumstances, these techniques may provide complementary or redundant information.

The character of the thermal gradients to the west of the fault system suggest that thermal waters are mixing with the ground water flow to the west. If so, this should be reflected in the water chemistry. Parry et al. (1976) show several anomalous Na-Ca-K temperatures to the northwest of Roosevelt Hot Springs but no data was available from wells in the immediate vicinity of the thermal gradient holes.

Heat flow values in the alluvium reach a maximum of about 40 HFU, and the estimated total conductive heat loss from the shallow part of the system is about 2MW. Heat flow values and thermal gradients in the Mineral Range are not high for the Basin and Range, and in fact several of the values seem low.

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LIST OF FIGURES

APPENDIX A

Temperature Logs

LOCATION: RYANS RANCH
LOCATION: RYANS'RANCH
27S 8W 4DCD
HOLE NUMBER: UU 75
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	9.894	.0
10.0	8.803	-218.2
15.0	9.716	182.6
20.0	9.858	28.4
25.0	9.000	-171.6
30.0	9.007	1.4
35.0	9.170	32.6
40.0	9.280	22.0
45.0	9.370	18.0
50.0	9.391	4.2
55.0	9.492	20.2
60.0	9.569	15.4
65.0	9.681	22.4
70.0	9.781	20.0
75.0	9.888	21.0
80.0	9.987	20.2
85.0	10.116	25.8
90.0	10.292	35.2
95.0	10.381	17.8
100.0	10.492	22.2

LOCATION: BIG CEDAR COVE
27S 8W 14 DDC
HOLE NUMBER: UU 75
DATE MEASURED: 9/22/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	16.769	.0
10.0	12.978	-758.2
15.0	13.421	88.6
20.0	13.543	24.4
25.0	13.973	86.0
30.0	14.427	90.8
35.0	14.693	53.2
40.0	15.073	76.0
45.0	15.526	90.6
50.0	15.957	86.2
55.0	16.437	96.0
60.0	16.754	63.4
65.0	17.132	75.6
70.0	17.081	69.8
75.0	17.905	84.8
80.0	18.380	75.0
85.0	18.579	59.8
90.0	18.858	55.4
95.0	19.153	59.4
100.0	19.937	156.8

LOCATION: ALTERATION 75 1A
27S 9W 3CLB
HOLE NUMBER: UU 751A
DATE MEASURED: 7/22/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	26.283	.0
15.0	34.349	1613.2
20.0	40.036	1137.4
25.0	44.676	928.0
30.0	49.158	896.4
35.0	53.288	826.0
40.0	57.622	866.8
45.0	61.177	711.0
50.0	63.990	562.6
55.0	67.365	675.0
60.0	70.687	664.4
65.0	74.307	724.0
68.5	76.434	607.7

LOCATION: ALTERATION 75 1B
27S 9W 4DDA
HOLE NUMBER: UU 75 1B
DATE MEASURED: 7/22/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.926	.0
10.0	18.065	627.8
15.0	21.878	762.6
20.0	25.194	663.2
25.0	28.354	632.0
30.0	31.719	673.0
35.0	35.043	664.8
40.0	37.561	503.6
45.0	40.288	545.4
50.0	42.688	480.0
55.0	44.676	397.6
60.0	47.008	466.4
65.0	49.088	416.0

LOCATION: BOYLES 12RKGRA
265 9W 27 BBB
HOLE NUMBER: UU 75 12
DATE MEASURED: 6/11/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	16.072	.0
10.0	19.622	710.0
15.0	21.794	434.4
20.0	24.981	637.4
25.0	28.579	719.6
30.0	29.861	256.4
34.5	30.922	235.8

LOCATION: BOYLES 13 RKGRA
26S-9W-20 AC
HOLE NUMBER: UU-75-13
DATE MEASURED: 11/8/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	19.715	.0
20.0	25.496	578.1
30.0	30.489	499.3
40.0	34.301	381.2
43.0	36.742	813.7

LOCATION: BEARSKIN RKGRA
275 8W 8 BAB
HOLE NUMBER: UU 75
DATE MEASURED: 8/20/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.088	.0
15.0	9.455	273.4
20.0	9.907	90.4
25.0	9.683	-44.8
30.0	9.074	-121.8
55.0	9.048	-5.2
40.0	8.834	-42.8
45.0	8.867	6.6
50.0	8.942	15.0
55.0	8.998	11.2
60.0	9.077	15.8
65.0	9.084	1.4
70.0	9.217	26.6
75.0	9.331	22.8
80.0	9.351	4.0
85.0	9.462	22.2
90.0	9.496	6.8
95.0	9.629	26.6
100.0	9.797	33.6
110.0	10.137	34.0
115.0	10.176	7.8
120.0	10.113	-12.6
125.0	10.296	36.6
130.0	10.249	-9.4
135.0	10.459	42.0
140.0	10.584	25.0
145.0	10.391	-38.6
150.0	10.459	13.6
155.0	10.823	72.8
156.0	10.999	176.0

LOCATION: ALTERATION 76-1A RKGRA
275 9W 34 CAB
WELL NUMBER: UU 76-1A
DATE MEASURED: 6/ /76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	30.026	.0
10.0	41.194	2232.6
15.0	57.022	3166.4
20.0	63.642	1324.0
25.0	69.025	1076.6
30.0	77.158	1626.6
35.0	84.082	1384.8
40.0	98.843	953.2
45.0	93.914	1013.2
50.0	97.362	689.6
55.0	101.100	747.6
60.0	105.584	896.8
63.5	107.885	657.4

LOCATION: RKGRA TG-1
26S 9W 15 CBA
HOLE NUMBER: UU76 TG1
DATE MEASURED: 10/10/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	16.428	.0
15.0	18.095	333.4
20.0	19.382	257.4
25.0	20.549	233.4
30.0	21.506	191.4
35.0	22.476	194.0
40.0	23.231	151.0
45.0	23.893	132.4
50.0	24.521	125.6
55.0	25.071	110.0
60.0	25.582	102.2

LOCATION: RKGRA TG-2
26S 9W 5CDB
HOLE NUMBER: UU76 TG2
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	15.877	.0
10.0	14.619	-251.6
15.0	15.169	110.0
20.0	15.567	79.6
25.0	15.902	67.0
30.0	16.259	71.4
35.0	16.679	84.0
40.0	17.068	77.4
45.0	17.389	64.6
50.0	17.690	60.2
55.0	17.955	53.0
60.0	18.195	48.0
65.0	18.426	46.2
67.0	18.580	61.6

LOCATION: RKGRA TG-3
265 9W 19 DGC
HOLE NUMBER: UU76 T63
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DLG C	GRADIENT DEG C/KM
5.0	17.946	.0
10.0	15.391	89.0
15.0	20.383	398.4
20.0	28.441	411.6
25.0	24.223	356.4
30.0	26.143	384.0
35.0	28.078	387.0
40.0	29.147	273.8
45.0	38.770	264.6
50.0	32.031	252.2
55.0	32.994	192.6
60.0	33.887	178.6
65.0	34.691	160.8
70.0	35.306	123.0
75.0	35.601	59.0
80.0	35.883	56.4
85.0	36.121	47.6
90.0	36.243	24.4
95.0	36.544	60.2
100.0	36.405	-27.8

LOCATION: RKGRA TG-5
265 9N 14 DAA
HOLE NUMBER: UU76 TG5
DATE MEASURED: 10/15/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	13.204	.0
15.0	13.577	74.6
20.0	13.906	65.8
25.0	14.156	50.0
30.0	14.381	45.0
35.0	14.593	42.4
40.0	14.781	37.6
45.0	15.006	45.0
50.0	15.195	35.8

LOCATION: RKGRA TG-6
265 9W 7CAA
HOLE NUMBER: UU76 TG6
DATE MEASURED: 11/6/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.273	.0
10.0	14.275	.4
15.0	14.847	114.4
20.0	15.436	117.8
25.0	16.913	295.4
30.0	17.828	183.0
35.0	18.108	56.0
[illegible]	18.924	23.2
[illegible]	18.458	46.8
[illegible]	18.692	46.8
[illegible]	18.721	5.8
[illegible]	15.835	22.8
[illegible]	19.004	33.8
[illegible]	18.149	29.0
[illegible]	19.256	21.2
[illegible]	19.348	18.6
[illegible]	19.449	28.2
[illegible]	19.712	44.6
95.0	19.952	48.0
97.5	19.983	12.4

LOCATION: RKGRA SALT COVE
265 9W 25 DCA
HOLE NUMBER: UU 76
DATE MEASURED: 6/24/77

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	10.908	.0
15.0	10.689	16.2
20.0	11.188	39.8
25.0	11.492	60.8
30.0	11.742	50.0
35.0	11.596	-29.2
40.0	12.150	112.0
45.0	12.335	35.8
50.0	12.904	33.8
55.0	12.658	30.8
60.0	12.607	29.8
65.0	12.942	27.0
70.0	13.071	25.8
75.0	13.186	25.0
80.0	13.337	28.2
85.0	13.476	27.8
90.0	13.617	28.2
95.0	13.761	28.8
100.0	13.908	29.4
105.0	14.452	28.8
110.0	14.201	29.8
115.0	14.352	30.2
120.0	14.505	30.6
125.0	14.653	29.6
130.0	14.836	36.6
135.0	14.993	31.4
140.0	15.145	30.4
145.0	15.298	30.6
150.0	15.404	21.2

LOCATION: RANCH CANYON PPC
27S/9W-35 CAD
HOLE NUMBER: EV 4113
DATE MEASURED: 8/12/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.650	.0
20.0	9.640	99.0
30.0	9.770	13.0
36.0	9.890	20.0

LOCATION: RANCH CANYON PPC
27S/9W-35 DB
HOLE NUMBER: EV 4115
DATE MEASURED: 8/12/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	10.920	.0
20.0	11.240	132.0
30.0	11.700	46.0
40.0	11.820	12.0
50.0	11.910	9.0
60.0	11.980	7.0
70.0	12.140	16.0

LOCATION: MINERAL MTS - RADIO RD PPC
26S/8W-30 CDA
HOLE NUMBER: Crater Knoll #2
DATE MEASURED: 8/15/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	8.010	.0
20.0	8.660	65.0
30.0	8.690	4.0
40.0	8.750	6.0
50.0	8.850	10.0
60.0	8.870	2.0
70.0	8.890	2.0
80.0	8.990	10.0
90.0	9.080	9.0

LOCATION: MINERAL MTS - PPC
27S/8W-6 AA
HOLE NUMBER: Crater Knoll #3
DATE MEASURED: 8/15/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	9.230	.0
20.0	9.700	47.0
30.0	10.210	51.0
40.0	10.430	22.0
50.0	10.610	18.0
59.0	10.700	10.0

LOCATION: NEGRO MAG WASH PPC
27S/9W-1
HOLE NUMBER: 21

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	13.000	.0
20.0	15.600	260.0
30.0	17.300	170.0
32.0	17.550	125.0

LOCATION: WATER WELL #2
27S/10W-12B
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/05/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.500	.0
20.0	17.700	320.0
30.0	20.600	290.0
35.0	21.900	260.0
40.0	23.000	220.0
45.0	23.950	190.0
50.0	24.800	170.0
55.0	25.500	200.0
60.0	26.700	180.0
65.0	27.600	180.0
70.0	28.400	160.0
75.0	29.100	140.0
80.0	29.500	140.0
85.0	30.600	160.0
90.0	31.200	120.0
95.0	31.300	120.0
100.0	32.500	140.0
105.0	33.000	100.0
110.0	33.800	120.0
115.0	33.800	40.0

LOCATION: PHILLIPS WATER WELL #3
26S/10W-25A
HOLE NUMBER: PHILLIPS
DATE MEASURED: 6/30/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	14.800	.0
10.0	17.100	290.0
20.0	18.400	260.0
25.0	19.500	220.0
30.0	21.600	300.0
35.0	22.400	280.0
40.0	23.600	240.0
45.0	24.600	200.0
50.0	25.800	240.0
55.0	27.200	280.0
60.0	27.900	140.0
65.0	28.900	200.0
70.0	29.400	100.0
75.0	30.000	120.0
80.0	30.600	120.0
85.0	30.800	.0

LOCATION: WATER WELL #4
28S/9W-3 C
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/03/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	17.900	.0
10.0	17.200	-140.0
15.0	19.100	380.0
20.0	20.700	320.0
25.0	21.500	160.0
30.0	24.200	540.0
35.0	26.200	400.0
40.0	28.600	480.0
45.0	29.300	140.0
50.0	31.800	500.0
55.0	34.900	620.0

LOCATION: WARER WELL #5
27S/9W-17A
HOLE NUMBER: PHILLIPS
DATE MEASURED: 7/02/76

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
5.0	12.900	.0
10.0	15.300	480.0
15.0	17.500	440.0
20.0	19.100	320.0
25.0	20.900	360.0
30.0	22.100	240.0
35.0	23.700	320.0
40.0	25.200	300.0
45.0	26.700	300.0
50.0	28.000	260.0
55.0	29.600	320.0
60.0	31.200	320.0
65.0	32.400	240.0
70.0	33.700	260.0
75.0	35.600	260.0
80.0	36.400	280.0
85.0	37.900	300.0
90.0	39.200	260.0
95.0	40.200	200.0
100.0	41.600	280.0
105.0	43.100	300.0
110.0	44.400	260.0
115.0	45.600	240.0
120.0	47.000	280.0
125.0	48.600	320.0
130.0	49.700	220.0
135.0	51.000	260.0
140.0	52.600	260.0
145.0	53.400	220.0
150.0	54.800	280.0
155.0	56.000	240.0
160.0	58.800	560.0
165.0	59.500	140.0
170.0	60.600	220.0
175.0	61.200	120.0
180.0	61.800	120.0
185.0	61.900	20.0

LOCATION: RHS KGRA
27S/10W-23 CA
HOLE NUMBER: 5
DATE MEASURED: 9/03/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.480	.0
20.0	17.450	297.0
30.0	20.130	268.0
40.0	22.580	245.0
50.0	25.000	242.0
60.0	26.930	193.0
70.0	27.650	72.0
80.0	28.390	74.0
90.0	28.960	57.0
100.0	29.590	63.0
110.0	30.100	51.0
120.0	30.550	45.0
130.0	31.100	55.0
140.0	31.520	42.0
150.0	32.180	66.0
151.5	32.210	20.0

LOCATION: RHS KGRA
27S/9W-16 BB
HOLE NUMBER: 7
DATE MEASURED: 8/08/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	16.600	.0
20.0	23.300	670.0
30.0	28.200	490.0
40.0	32.900	470.0
50.0	37.300	440.0
60.0	41.550	425.0
70.0	45.730	418.0
80.0	49.800	407.0
90.0	53.900	410.0
100.0	57.780	388.0
110.0	61.450	367.0
120.0	65.300	385.0
130.0	68.840	354.0
140.0	72.300	346.0
145.0	74.000	340.0

LOCATION: RHS KGRA
27S/9W-16 AD
HOLE NUMBER: 8
DATE MEASURED: 8/11/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	24.620	.0
20.0	37.470	1285.0
30.0	49.320	1185.0
40.0	60.170	1085.0
50.0	69.580	941.0
60.0	78.120	854.0
70.0	84.080	596.0
80.0	89.650	557.0
90.0	95.400	575.0

LOCATION: RHS KGRA
27S/9W-21 DD
HOLE NUMBER: 9
DATE MEASURED: 9/05/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	20.950	.0
20.0	32.810	1186.0
23.0	34.000	396.7

LOCATION: RHS KGRA
27S/9W-15 ABD
HOLE NUMBER: 10
DATE MEASURED: 9/02/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.370	.0
20.0	19.880	451.0
30.0	23.800	392.0
40.0	27.560	376.0
50.0	32.580	502.0
60.0	37.410	483.0
64.3	39.100	393.0

LOCATION: RHS KGRA
27S/10W-10 DDD
HOLE NUMBER: 12
DATE MEASURED: 8/11/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	14.860	.0
20.0	18.640	378.0
30.0	21.380	274.0
40.0	24.190	281.0
50.0	26.270	208.0
60.0	27.470	120.0
70.0	28.510	104.0
80.0	29.240	73.0
90.0	29.810	57.0
100.0	30.370	56.0
110.0	30.960	59.0
120.0	31.530	57.0
130.0	32.150	62.0
140.0	32.730	58.0
150.0	33.180	45.0
160.0	33.770	59.0
170.0	34.320	55.0
180.0	34.840	52.0
190.0	35.320	48.0
200.0	35.860	54.0
203.0	35.980	40.0

LOCATION: RHS KGRA
27S/9W-7 CC
HOLE NUMBER: 14
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.250	.0
20.0	17.900	265.0
30.0	20.500	260.0
40.0	23.100	260.0
50.0	25.100	200.0
60.0	26.900	180.0
70.0	28.700	180.0
80.0	30.500	180.0
90.0	31.900	140.0
100.0	33.200	130.0
110.0	34.300	110.0
120.0	35.250	95.0
130.0	36.100	85.0
140.0	36.900	80.0
150.0	37.600	70.0
160.0	38.300	70.0
170.0	39.050	75.0
180.0	39.850	80.0
190.0	40.650	80.0
195.0	41.000	70.0

LOCATION: RHS KGRA
27S/9W-7D DD
HOLE NUMBER: 15
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.040	.0
20.0	18.100	306.0
30.0	20.300	220.0
40.0	22.200	190.0
50.0	24.400	220.0
60.0	26.300	190.0
70.0	28.000	170.0
80.0	29.500	150.0
90.0	31.200	170.0
100.0	32.800	160.0
110.0	34.700	190.0
120.0	36.300	160.0
130.0	37.700	140.0
140.0	38.900	120.0
150.0	39.800	90.0
160.0	40.700	90.0
170.0	41.600	90.0
175.0	41.900	60.0

LOCATION: RHS KGRA
27S/9W-4 AD
HOLE NUMBER: 17
DATE MEASURED: NO DATE

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	17.600	.0
20.0	23.600	600.0
30.0	29.700	610.0
40.0	34.700	500.0
50.0	40.000	530.0
60.0	44.100	410.0
63.0	45.000	300.0

LOCATION: RHS KGRA
27S/R9W-2 CAA
HOLE NUMBER: 20
DATE MEASURED: 8/13/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	12.410	.0
20.0	14.690	228.0
30.0	16.570	188.0
40.0	18.310	174.0
50.0	20.300	199.0
60.0	21.160	86.0
70.0	22.400	124.0
80.0	23.440	104.0
90.0	24.290	85.0
100.0	24.990	70.0
105.0	25.350	72.0
105.5		

LOCATION: RHS KGRA
26S/9W-32 AA
HOLE NUMBER: 25
DATE MEASURED: 9/05/75

DEPTH METERS	TEMPERATURE DEG C	GRADIENT DEG C/KM
10.0	15.590	.0
20.0	21.160	557.0
30.0	25.030	387.0
40.0	28.080	305.0
50.0	30.960	288.0
60.0	33.590	263.0
70.0	36.200	261.0
80.0	38.550	235.0
90.0	40.510	196.0
100.0	42.600	209.0
110.0	44.790	219.0
120.0	47.090	230.0
130.0	49.330	224.0
140.0	51.260	193.0
144.3	51.360	23.3

LOCATION BOYLES 12RKGRA
26S 9W 27 BB
HOLE NUMBER UU 75 12
DATE MEASURED 6/11/76

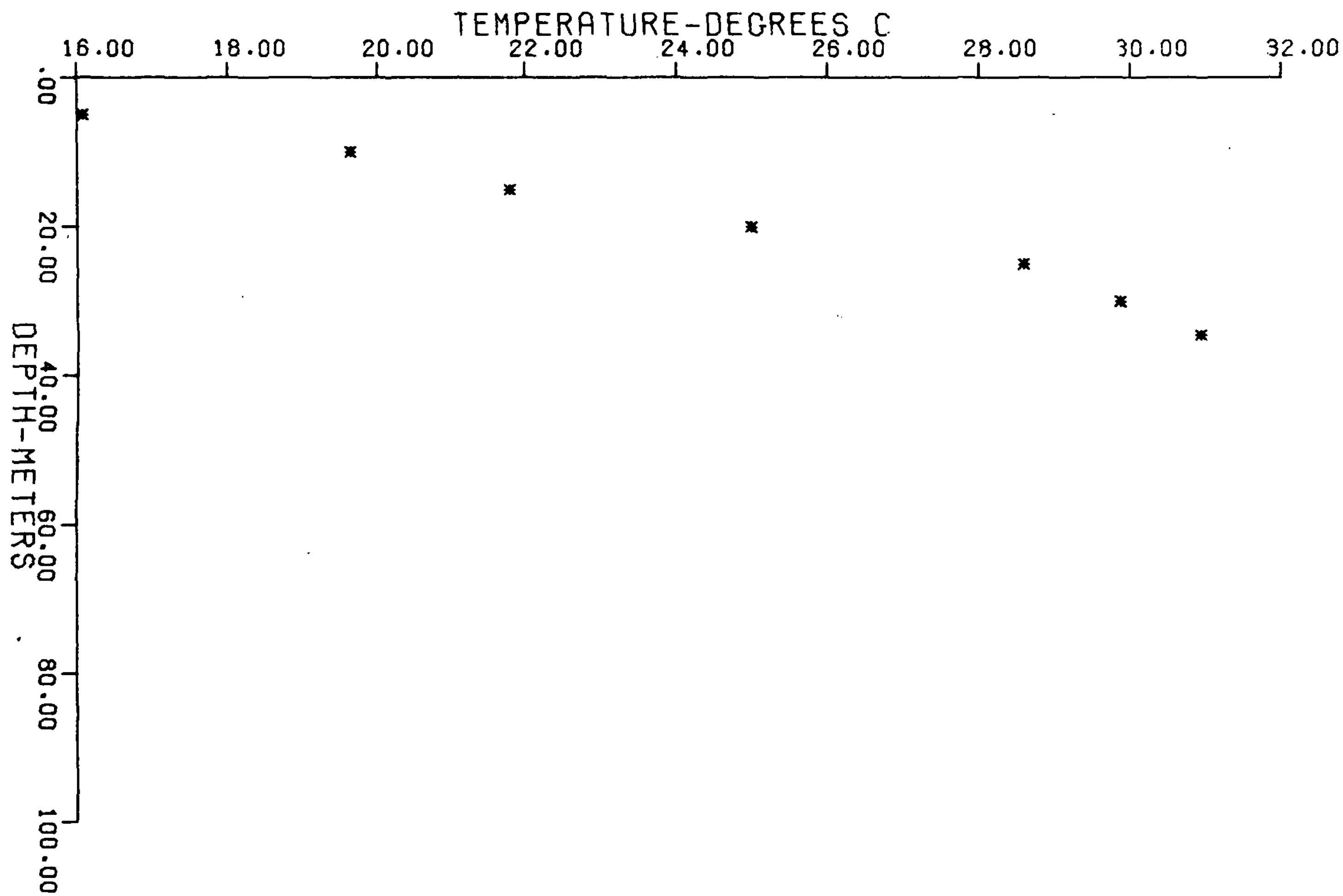

Figure 6

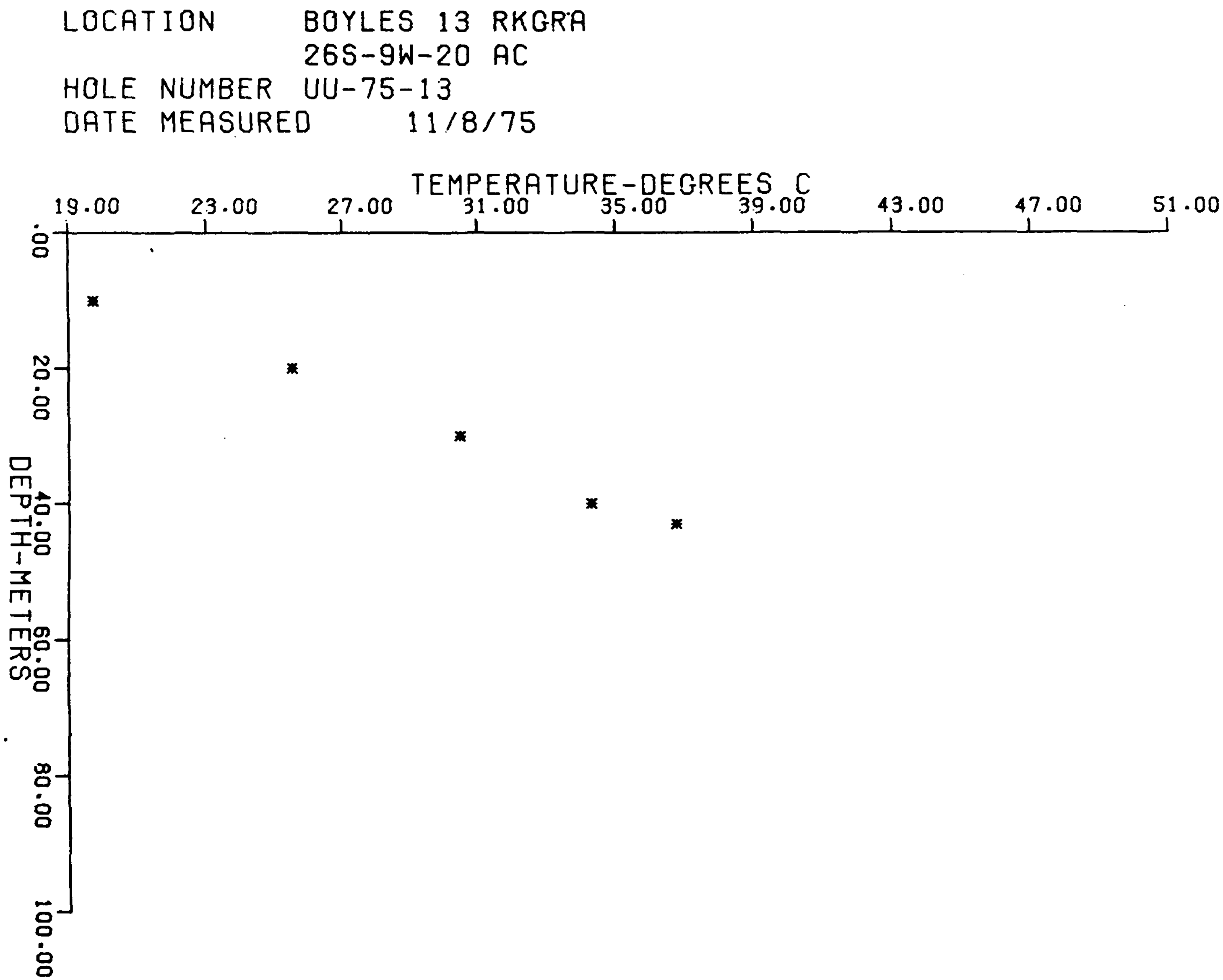
LOCATION BOYLES 13 RKGRA
26S-9W-20 AC
HOLE NUMBER UU-75-13
DATE MEASURED 11/8/75
TEMPERATURE-DEGREES C
19.00
23.00
27.00
31.00
35.00
39.00
43.00
47.00
51.00
DEPTH-METERS
.00
20.00
40.00
60.00
80.00
100.00

Figure 7

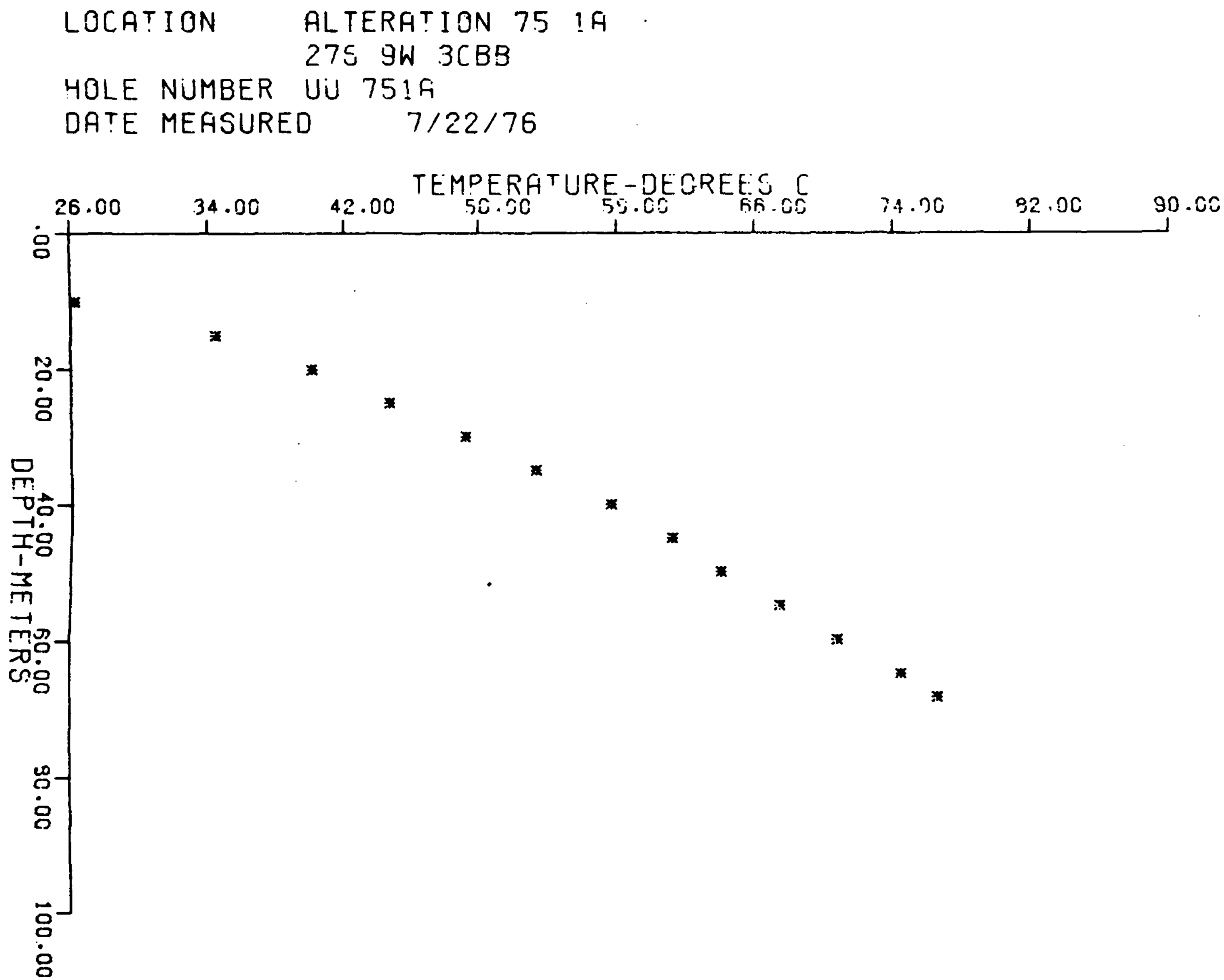
LOCATION ALTERATION 75 1A
27S 9W 3CBB
HOLE NUMBER UU 751A
DATE MEASURED 7/22/76
TEMPERATURE-DEGREES C
26.00
34.00
42.00
50.00
58.00
66.00
74.00
82.00
90.00
DEPTH-METERS
.00
20.00
40.00
60.00
80.00
100.00

Figure 8

LOCATION ALTERATION 75 1B
27S 9W 4DDA
HOLE NUMBER UU 75 1B
DATE MEASURED 7/22/76

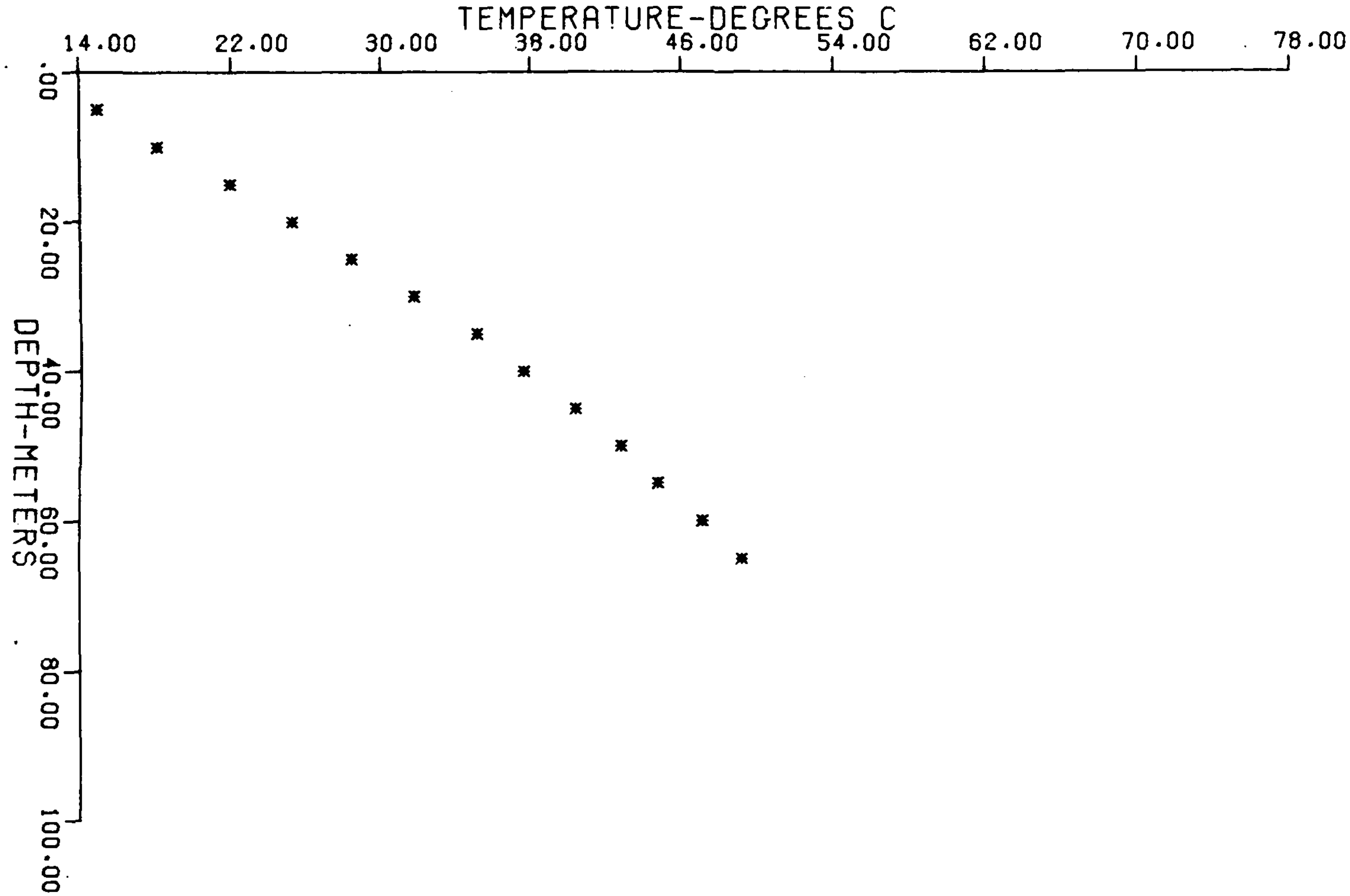

Figure 9

LOCATION BIG CEDAR COVE
27S 9W 14 BD
HOLE NUMBER UU 75 BCC
DATE MEASURED 9/22/75

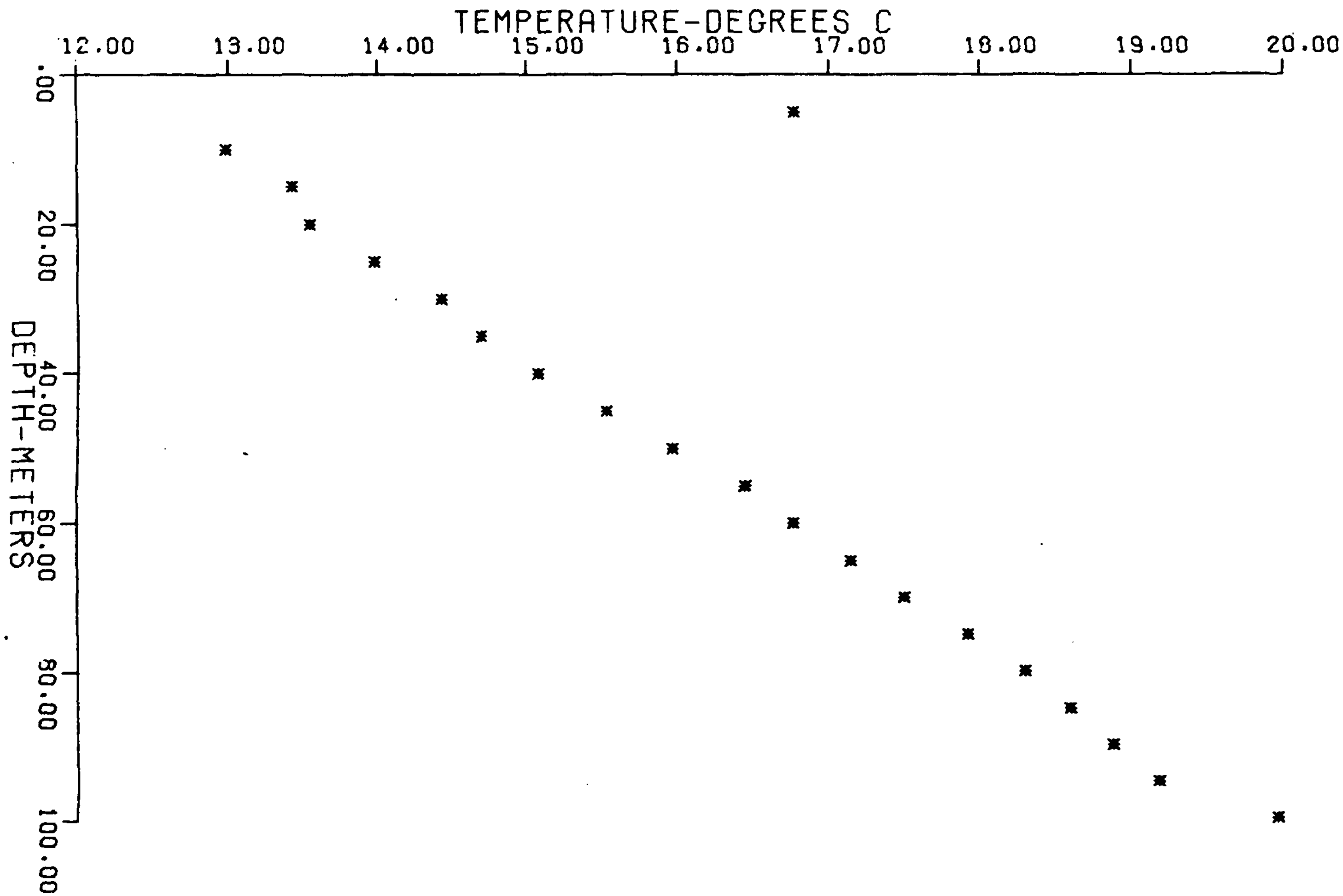

Figure 10

LOCATION RYANS RANCH
27S 8W 4DCD
HOLE NUMBER UU 75 RR
DATE MEASURED 11/6/76

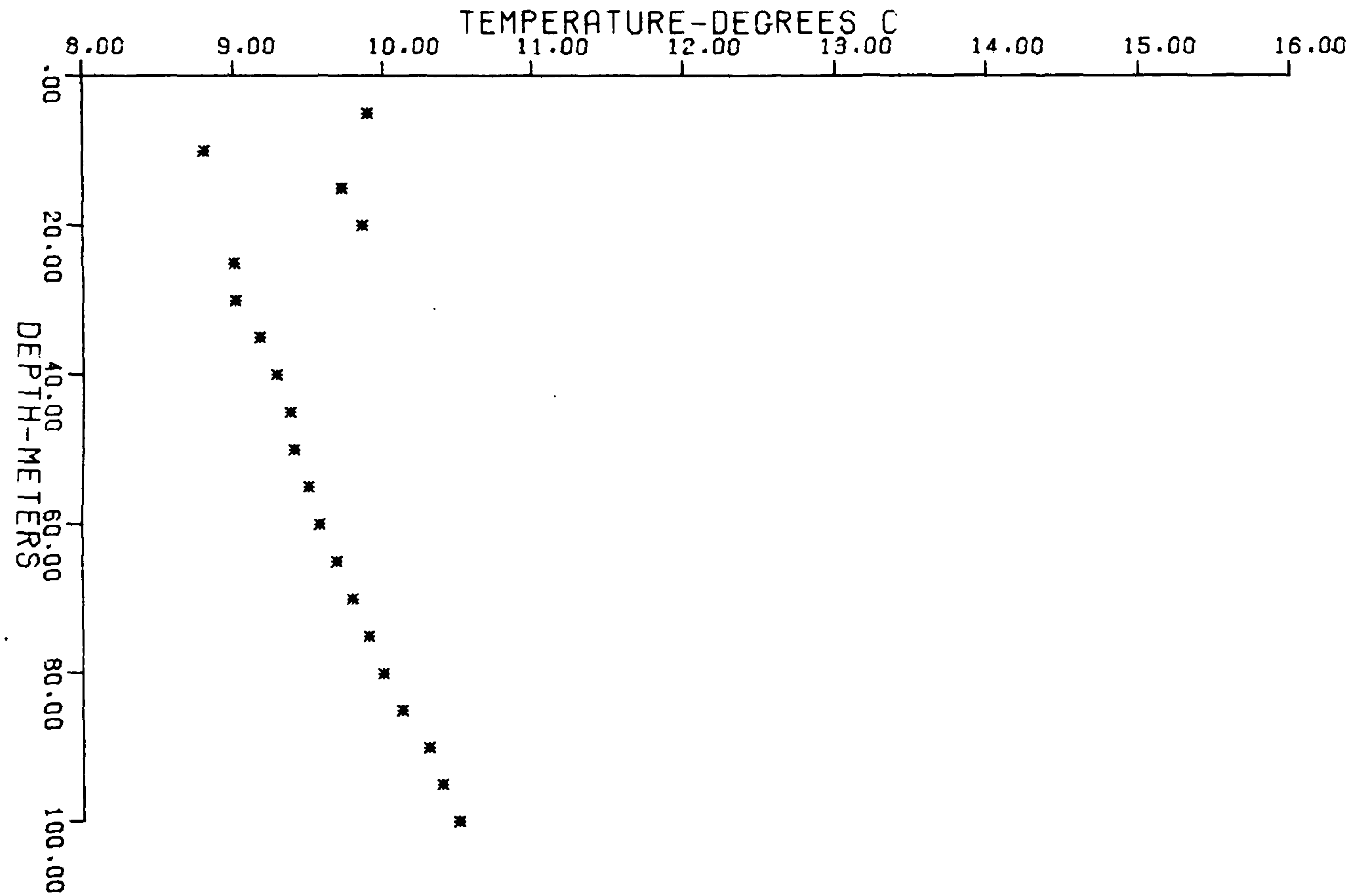

Figure 11

LOCATION ALTERATION 76-1A RKGRA
27S 9W 34 CA
HOLE NUMBER UU 76-1A
DATE MEASURED 8/ /76

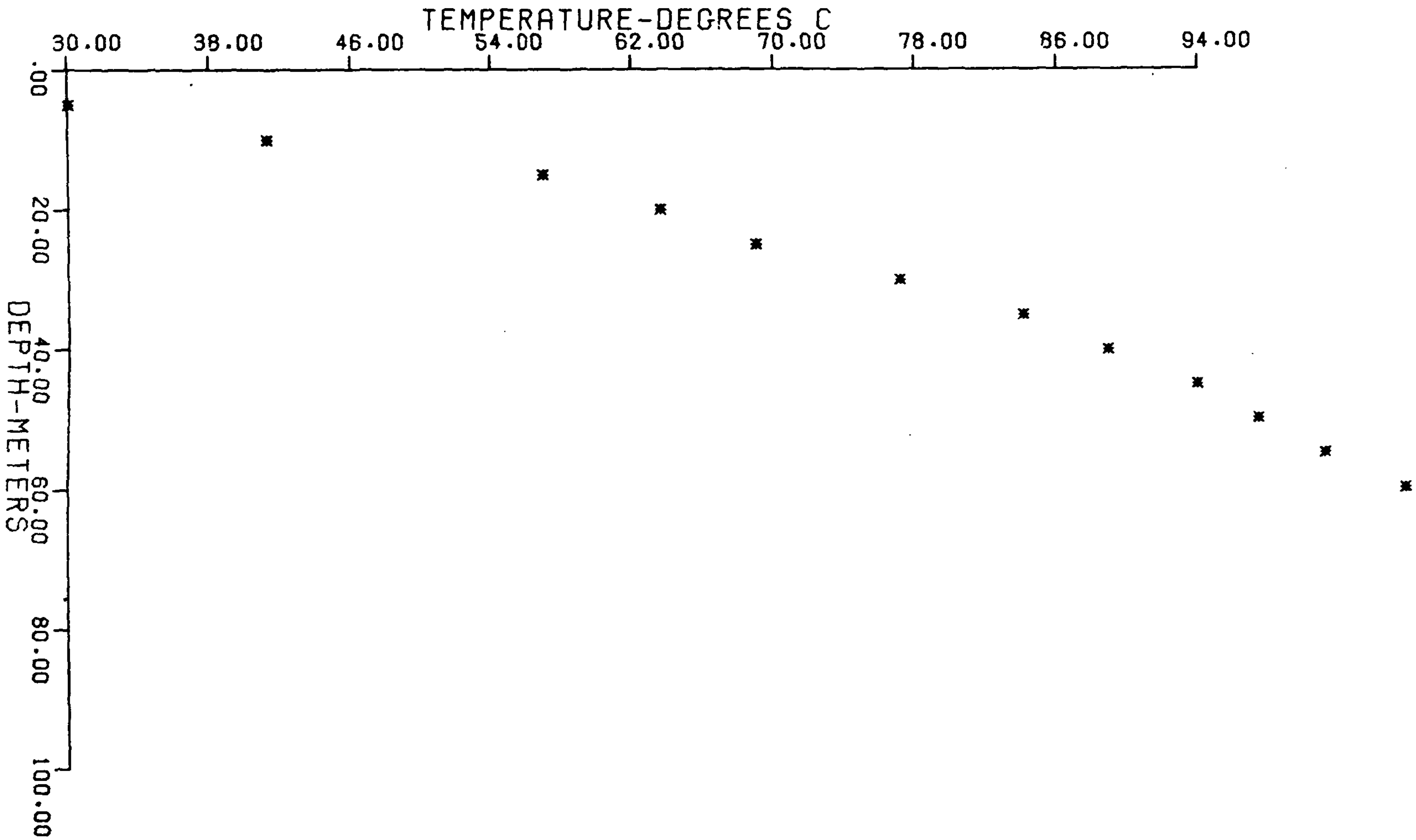

Figure 12

LOCATION RKGRA SALT COVE
26S 9W 25 DC
HOLE NUMBER UU 76 SC
DATE MEASURED 3/24/77

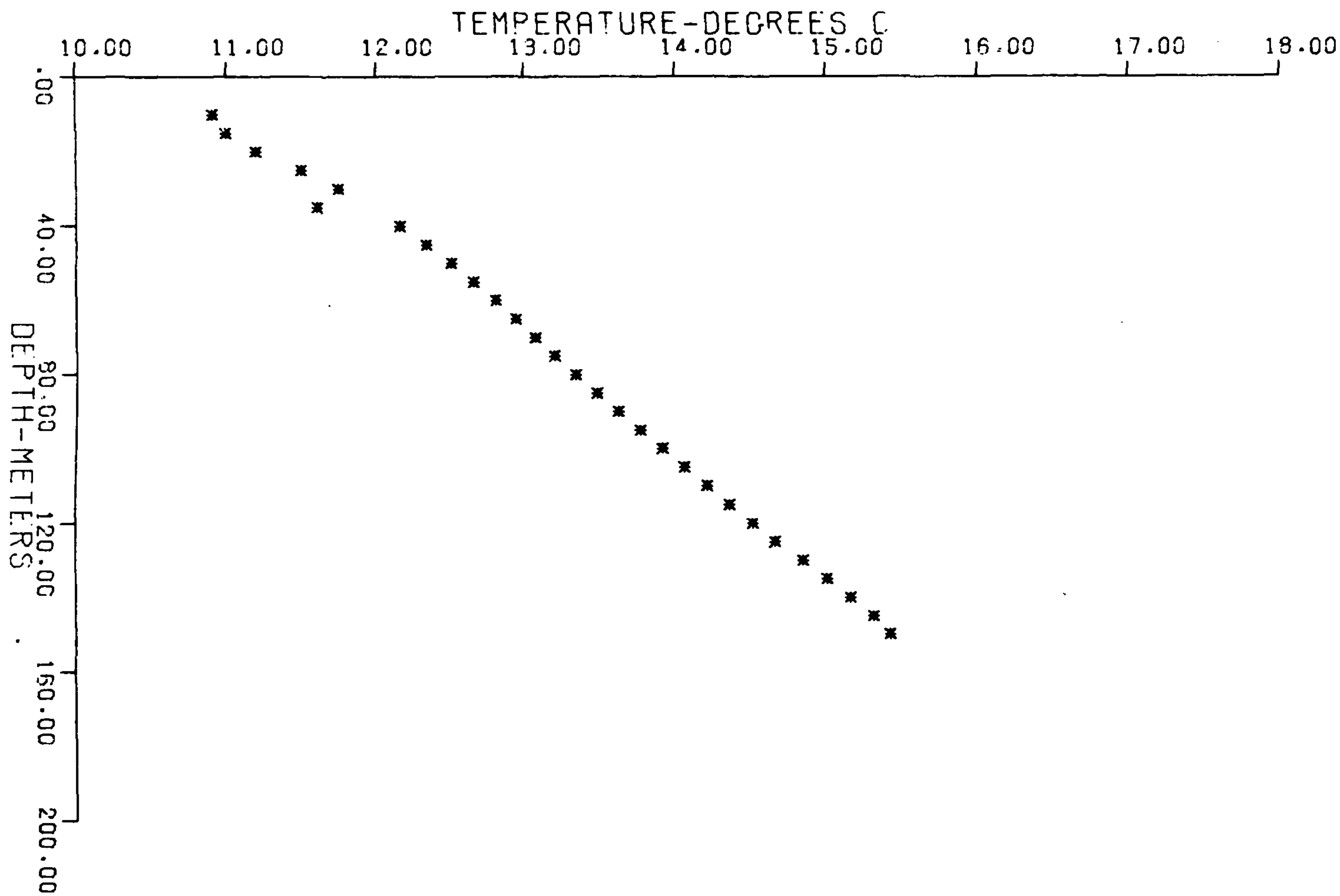

Figure 13

LOCATION BEARSKIN RKGRA
27S 8W 8 BAB
HOLE NUMBER UU 76 BS
DATE MEASURED 8/20/76

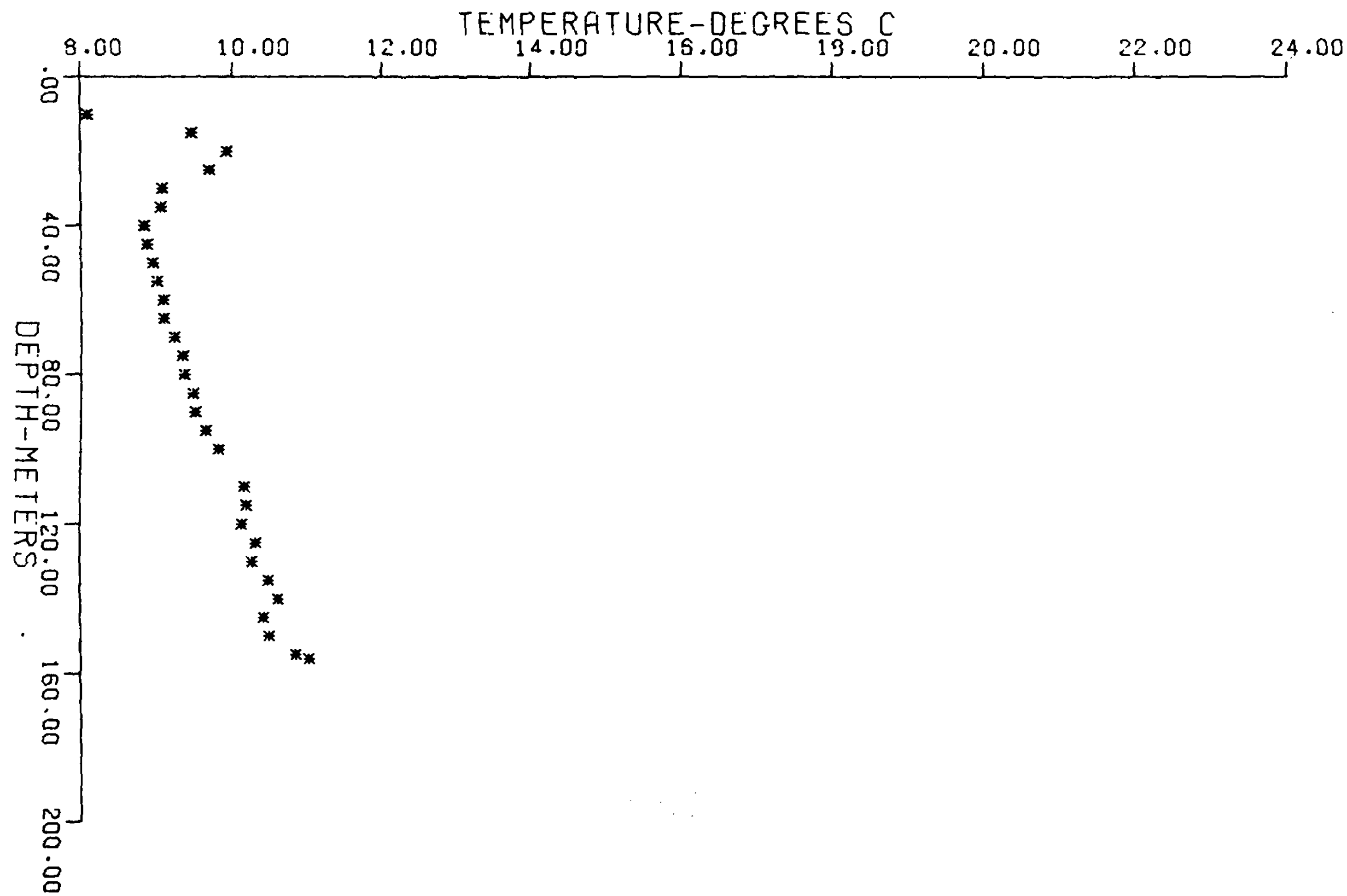

Figure 14

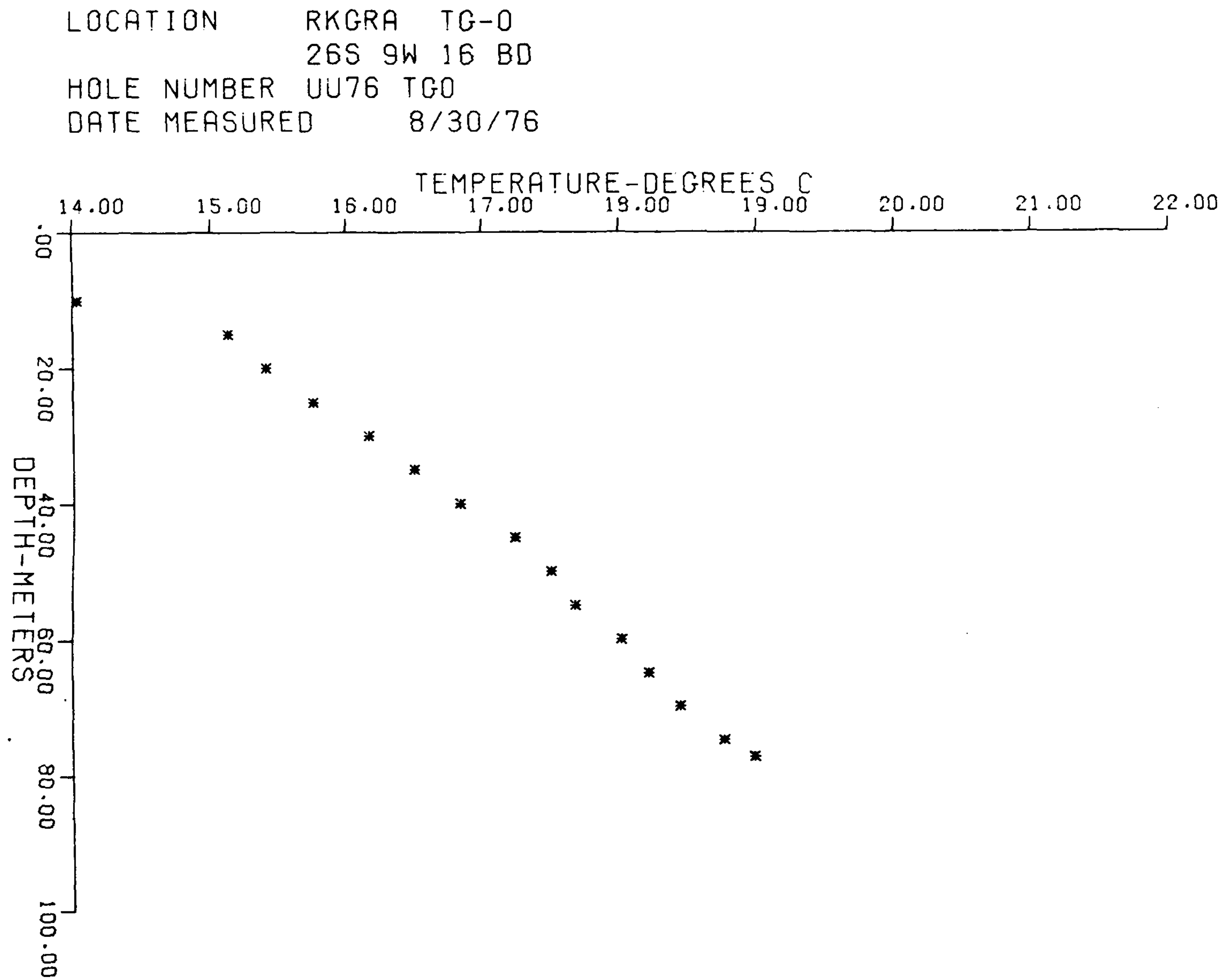
LOCATION RKGRA TG-0
26S 9W 16 BD
HOLE NUMBER UU76 TG0
DATE MEASURED 8/30/76
TEMPERATURE-DEGREES C
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
DEPTH-METERS
.00
20.00
40.00
60.00
80.00
100.00

Figure 15

LOCATION RKGRA TG-1
26S 9W 15 CB
HOLE NUMBER UU76 TG1
DATE MEASURED 10/10/76

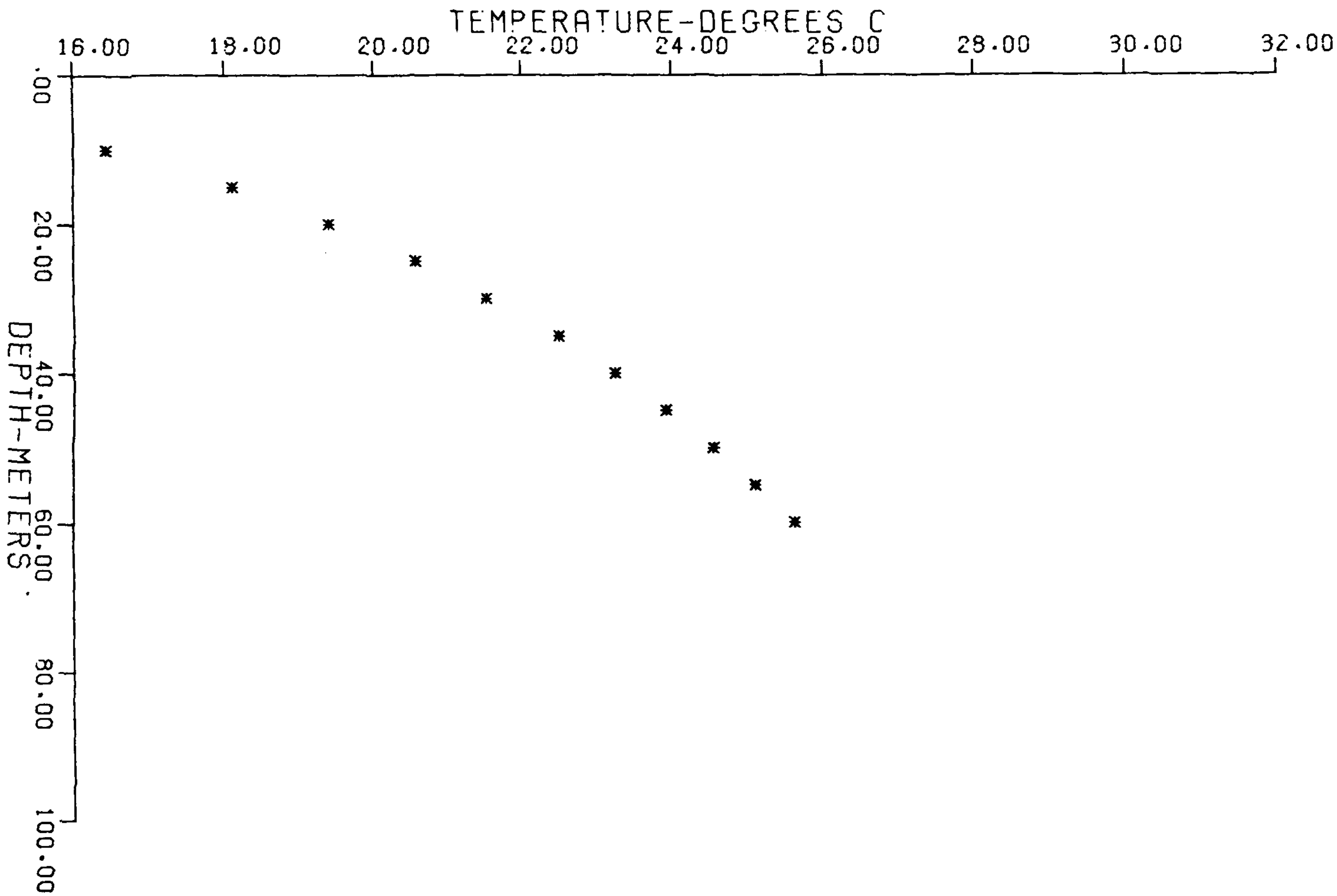

Figure 16

LOCATION RKGRA TG-2
26S 9W 5CDB
HOLE NUMBER UU76 TG2
DATE MEASURED 11/6/76

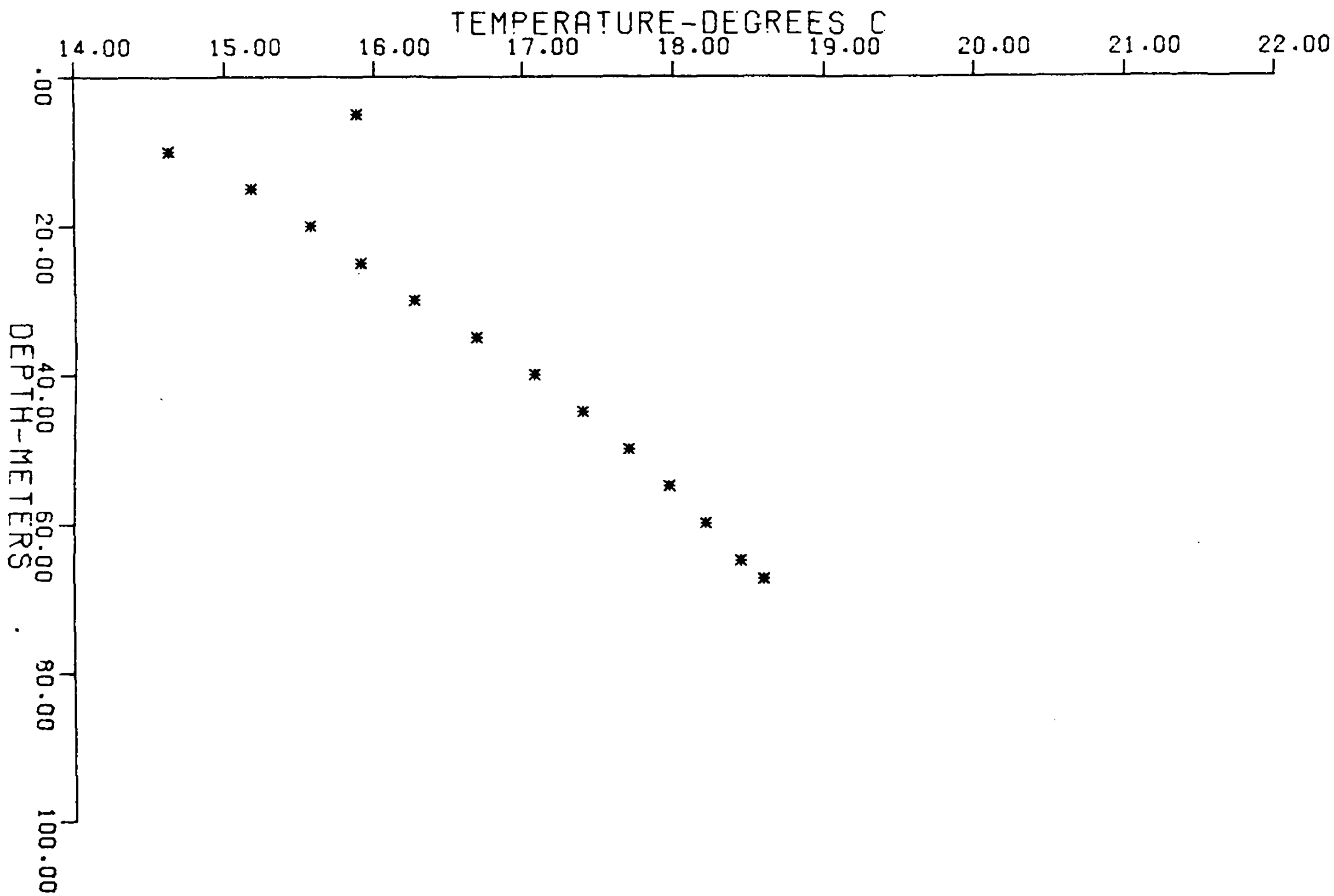

Figure 17

LOCATION RKGRA TG 3
26S 9W 19 DB
HOLE NUMBER UU76 TG3
DATE MEASURED 11/5/76

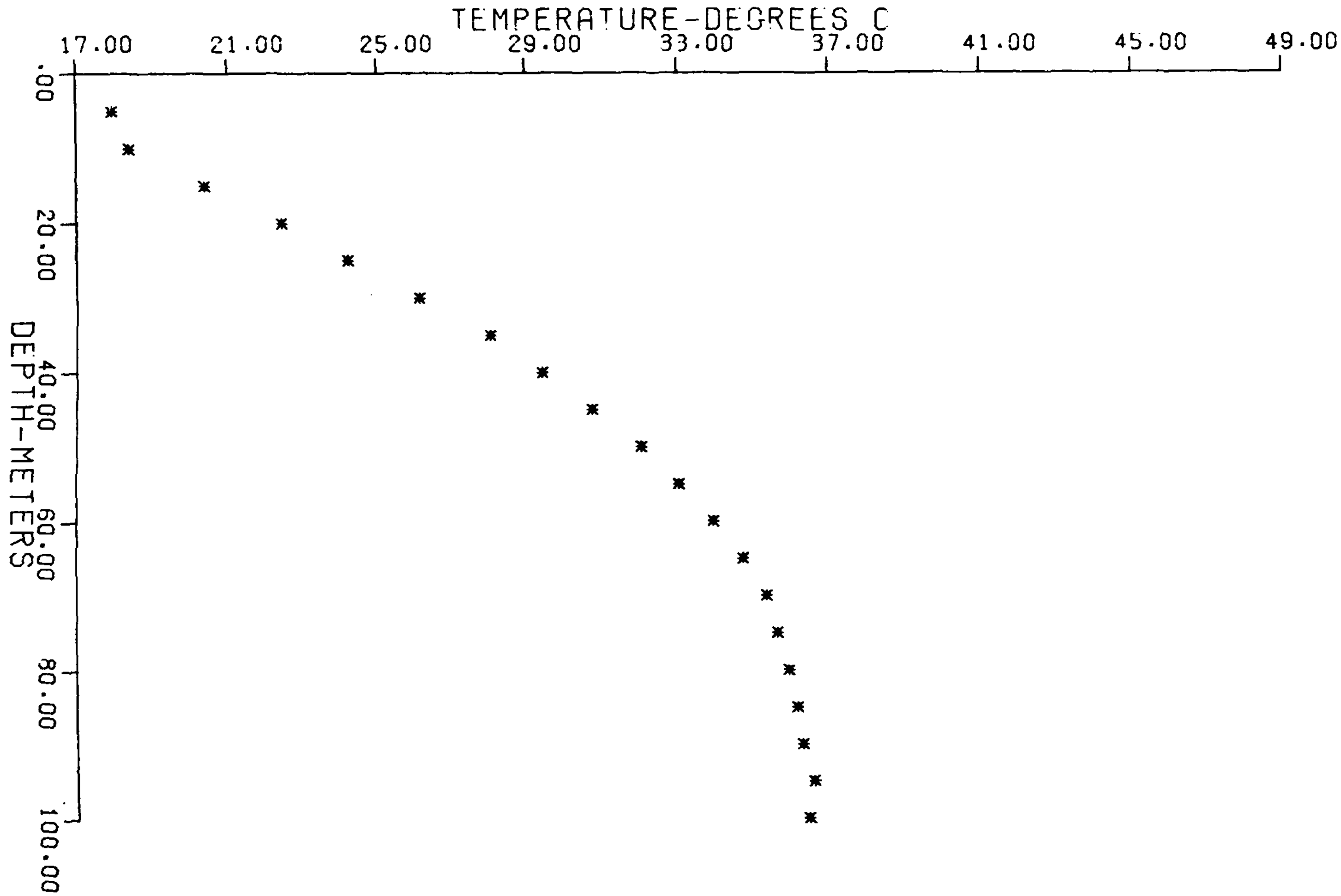

Figure 18

LOCATION RKGRA TG-5
26S 9W 14 DA
HOLE NUMBER UU76 TG5
DATE MEASURED 10/10/76

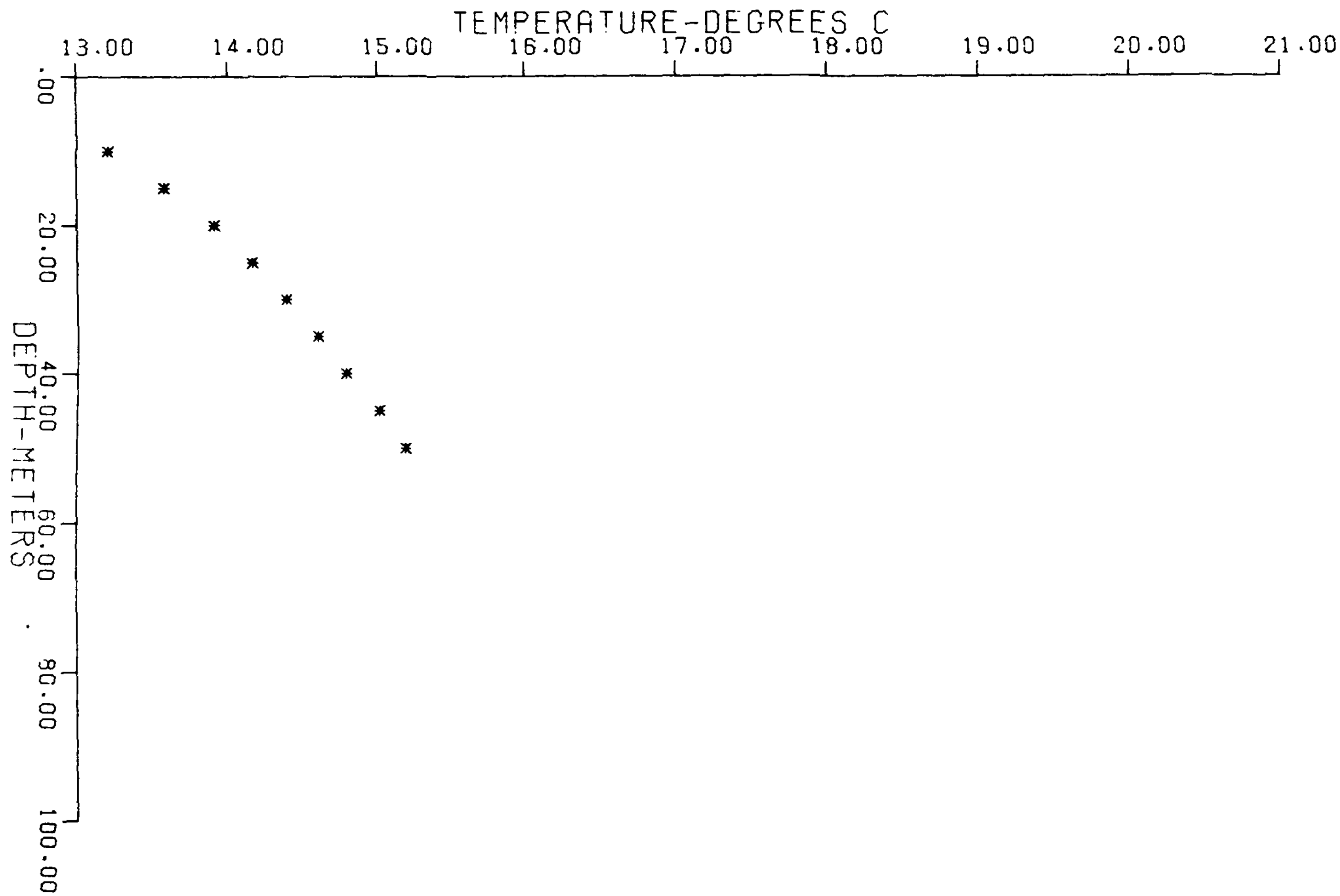

Figure 19

LOCATION RKGRA TG-6
26S 9W 7CAA
HOLE NUMBER UU76 TG6
DATE MEASURED 11/6/76

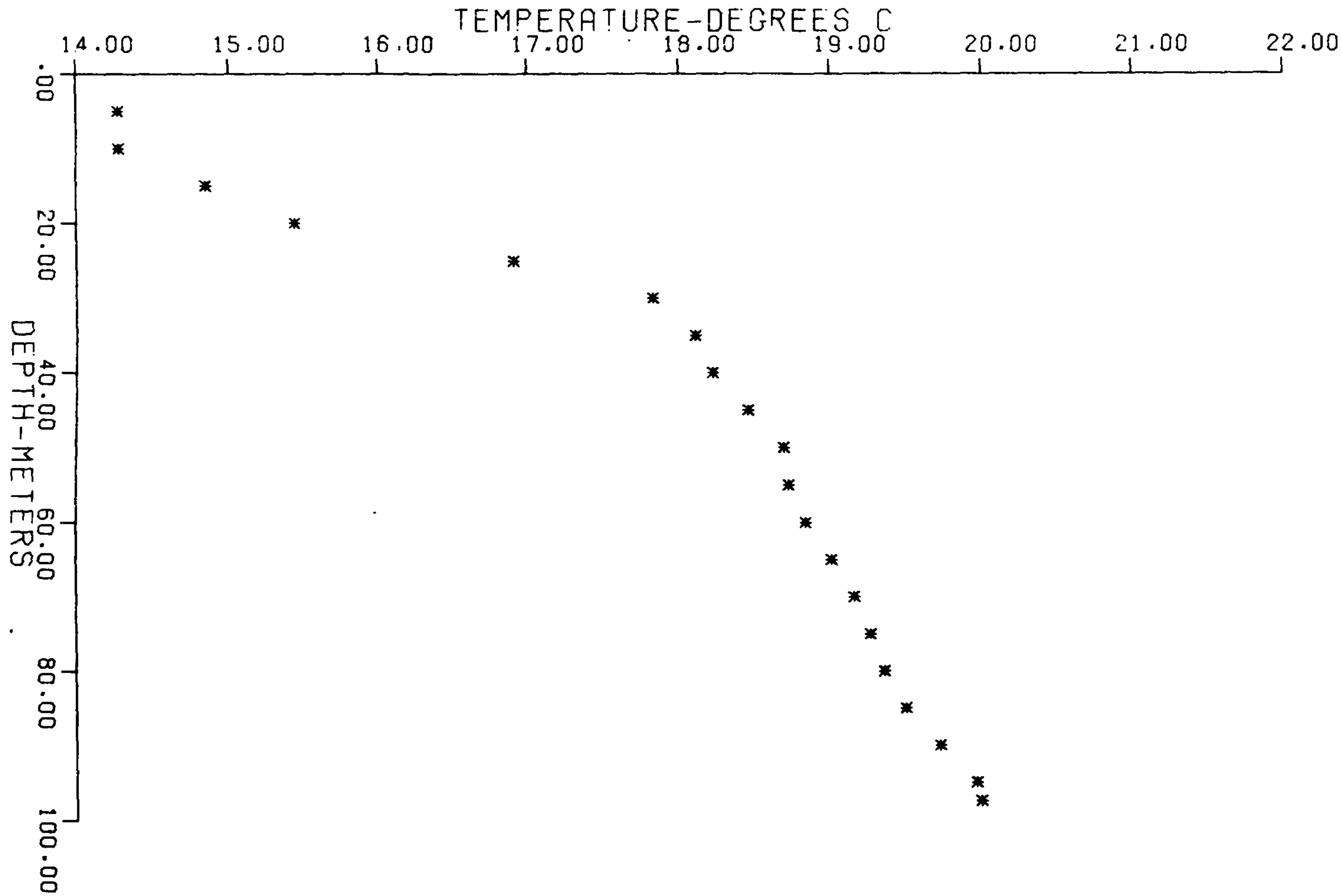

Figure 20

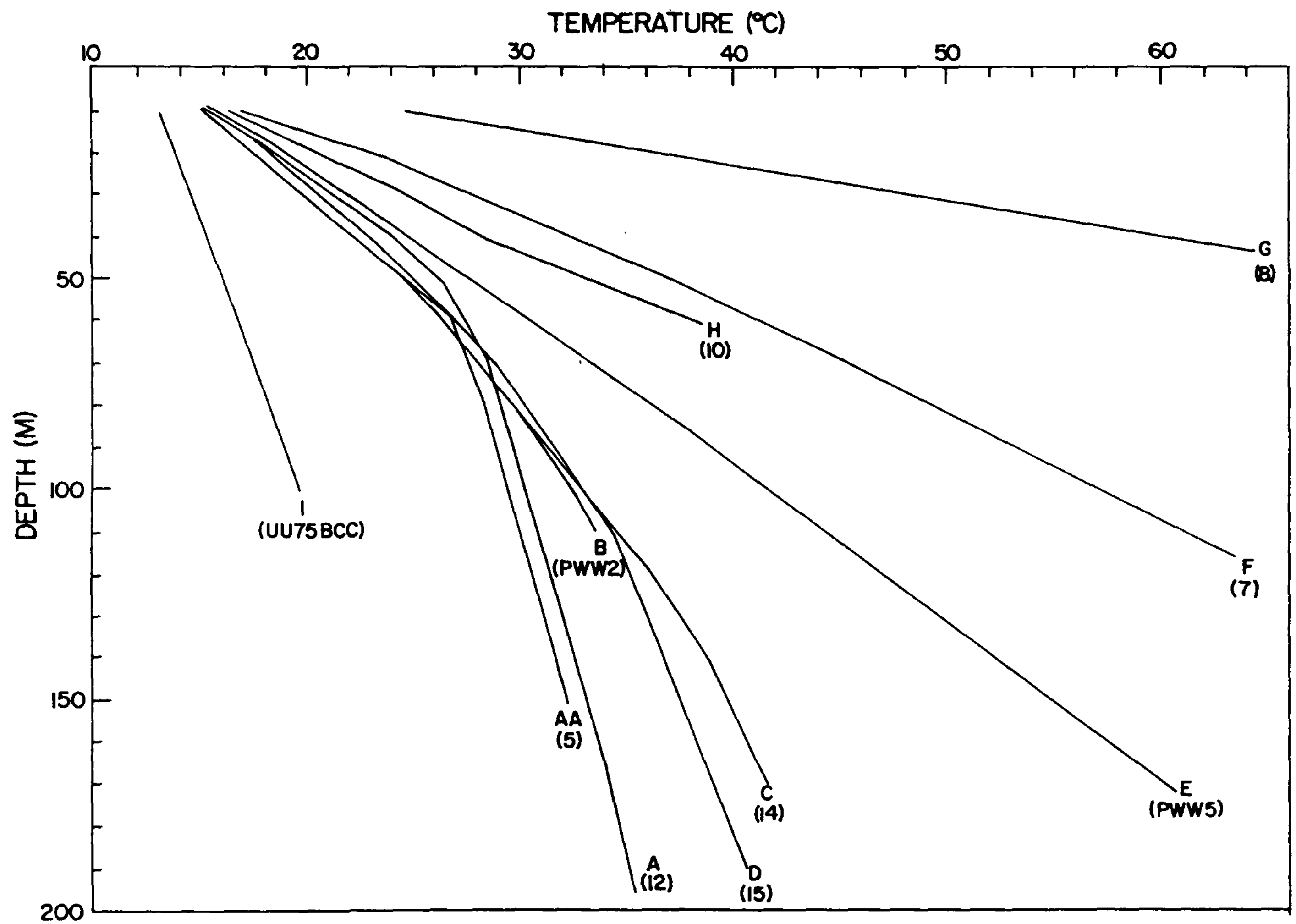
TEMPERATURE (°C)
10
20
30
40
50
60
DEPTH (M)
50
100
150
200
G
(8)
H
(10)
F
(7)
I
(UU75BCC)
B
(PWW2)
AA
(5)
C
(14)
E
(PWW5)
A
(12)
D
(15)

Figure 21

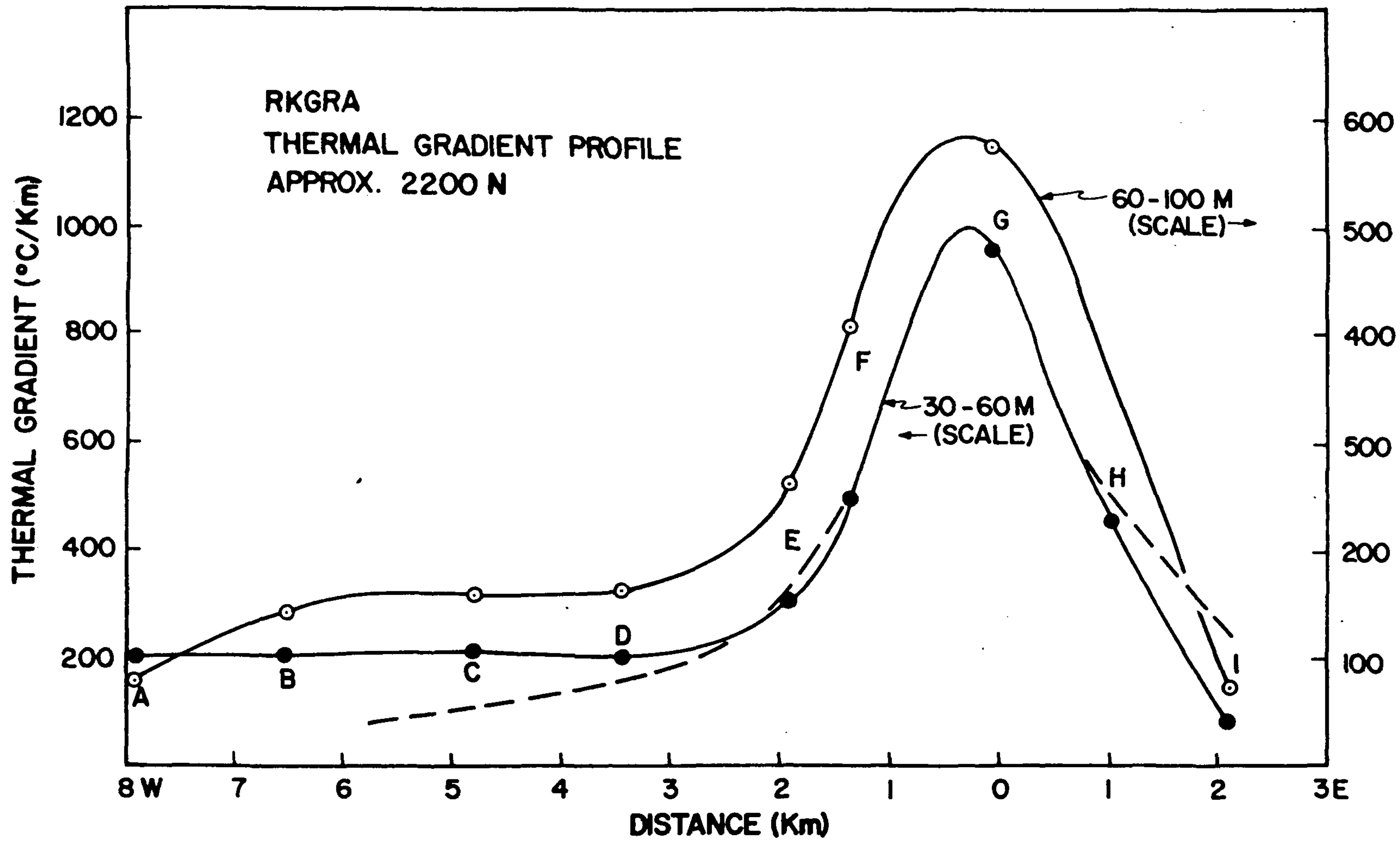
RKGRA
THERMAL GRADIENT PROFILE
APPROX. 2200 N
THERMAL GRADIENT (°C/Km)
1200
1000
800
600
400
200
600
500
400
500
200
100
60-100 M
(SCALE)
30-60 M
(SCALE)
A
B
C
D
E
F
G
H
I
8 W
7
6
5
4
3
2
1
0
1
2
3 E
DISTANCE (Km)

Figure 22