United States Department of the Interior

Geological Survey

HEAT FLOW AND SUB-SURFACE TEMPERATURES IN THE GREAT VALLEY, CALIFORNIA

by

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U.S. Geological Survey Open-File Report 82-844

1982

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INTRODUCTION

The Great Valley of California is located between the Coastal Ranges and the Sierra Nevada and geologically is a structural trough with a thick sequence of sediments. Preliminary investigations of heat flow indicates that this region is characterized by a low-to-normal heat flow of 0.6-1.3 HFU.

During recent years, a number of shallow holes for water supply and deep holes for oil and gas exploration have been drilled. Temperature measurements were made in most of these holes. Unfortunately, core and drill cuttings were available from only a few holes for thermal conductivity measurements.

In this report, three new heat-flow values, a gradient map, and an isotherm map of temperatures at 200 meters are presented.

The following symbols and units are used in this report:

T, Temperature, °C

Γ, Temperature gradient, $^{\circ}C\ km^{-1}$

K, Thermal conductivity, 1 TCU = 1 mcal $cm^{-1}\ s^{-1}\ ^{\circ}C^{-1}$
$= 0.4187\ Wm^{-1}\ K^{-1}$

q, Heat flow, 1 HFU = $\mu cal\ cm^{-2}\ s^{-1} = 41.87\ mWm^{-2}$

Acknowledgments: We are grateful to Art Lachenbruch and John Sass for helpful discussions and to Tom Moses, Jack Porter, and Gene Smith, USGS, who assisted in obtaining temperature measurements and to the many land owners, on whose land holes were located, for access to the holes. Personnel from USBR in Fresno and Los Banos and the California State Division of Water Resources in Fresno aided greatly in locating holes. Personnel from the USGS Water Resources Division in Sacramento were especially helpful to us in obtaining core, cuttings, and temperature logs in SV01, SV02, and SV03.

GEOLOGIC SETTING

The Great Valley of California is located between the Coast Ranges on the west and the Sierra Nevada on the east and the Klamath Mountains on the north (Figure 1). The Great Valley is divided into Sacramento Valley on the north and the San Joaquin Valley on the south, named for the major rivers which drain them. The Sierra Nevada and Klamath Mountains supply most of the drainage into the Great Valley. Only intermittent streams drain from the Coast Ranges into the Great Valley.

The Valley is a nearly flat plain with extremes ranging from a meter above sea level to 300 meters. The most prominent topographic feature is the Sutter Buttes north of Sacramento, a Pliocene volcanic plug which rises 600 meters above the surrounding valley floor.

The Great Valley Sequence (GVS), which fills the Great Valley, was accumulated in a forearc basin within an arc-trench gap commencing in the late Mesozoic. The zone where the Pacific plate was being subducted beneath the North American plate was shifted westward into the Coast Ranges. The Sierra Nevada represents the intrusive roots of the magmatic arc.

The steeper, western flank of the Great Valley is underthrust by the Franciscan assemblage while the more gentle eastern flank rests on the eroded rocks of the Sierra Nevada magmatic arc.

The GVS is composed of well-bedded mudstone, siltstone and conglomerate ranging in age from Late Jurassic to latest Cretaceous and derived from igneous and subordinate metamorphic rocks of the Sierra Nevada and Klamath Mountains. The maximum thickness of sediments is in excess of 18 km on the west side of the Sacramento Valley (Figure 2).

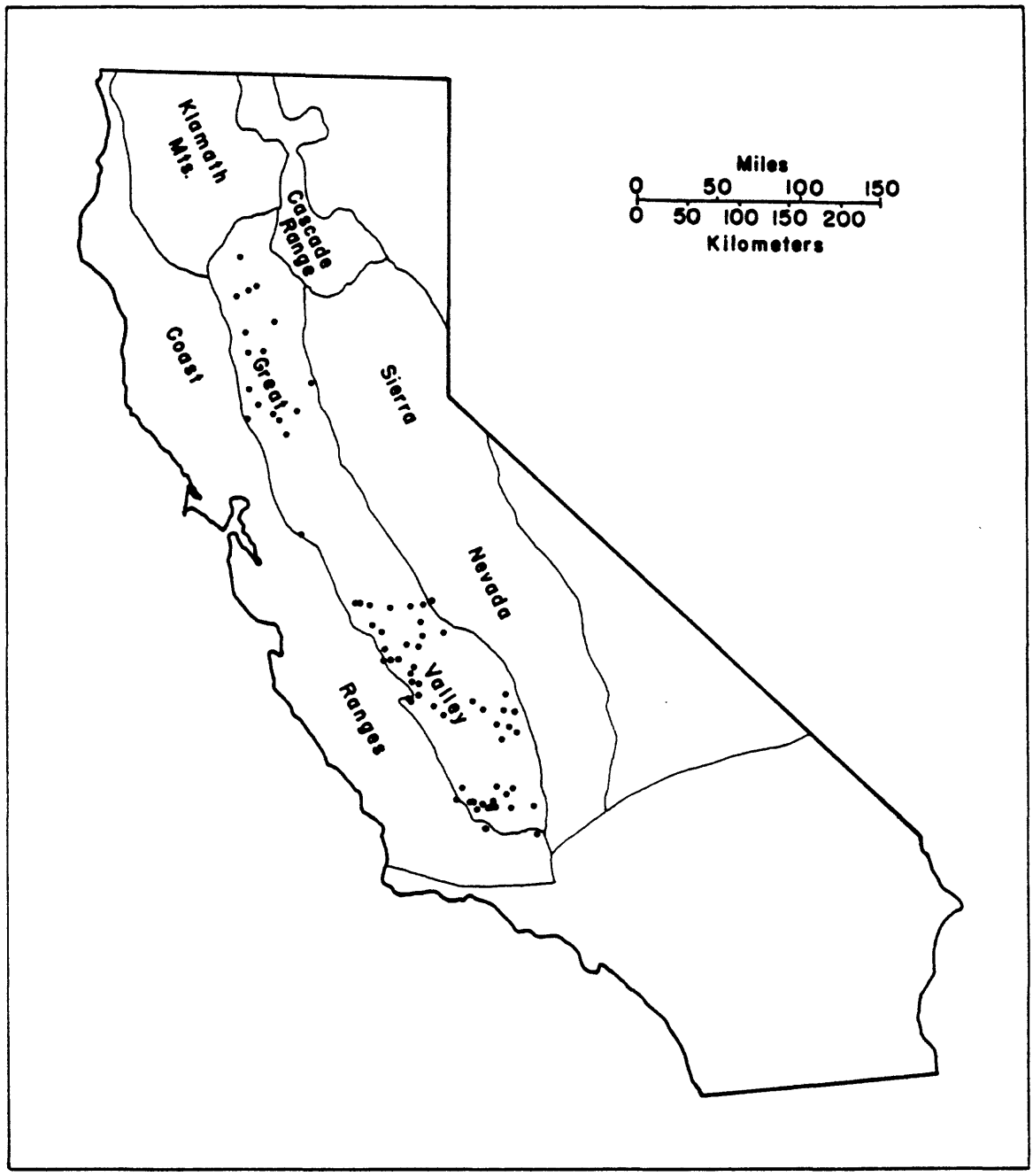

Figure 1. Location of Great Valley, California. Dots indicate hole locations.

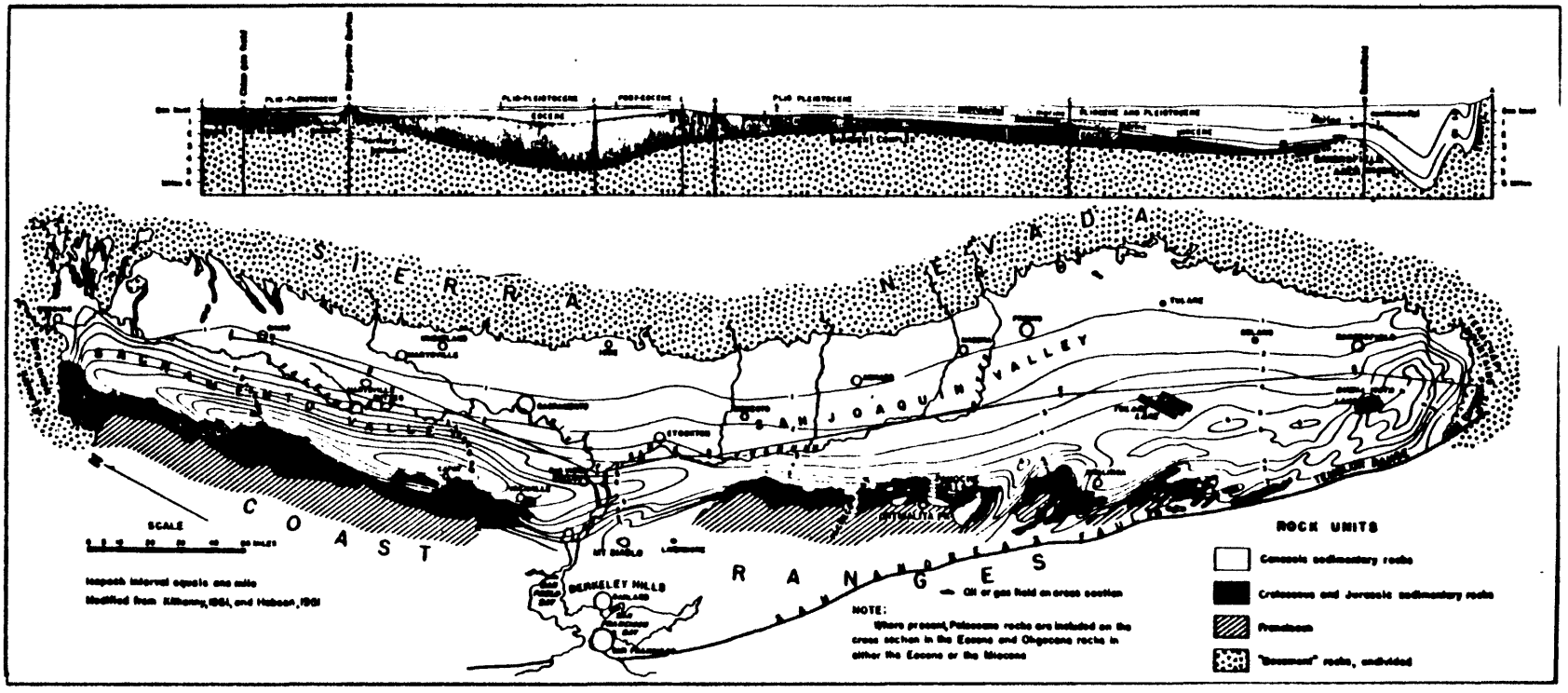

Figure 2. Map of central California showing thickness of sedimentary rocks in the Great Valley, (Hackel, 1966).

HEAT-FLOW DETERMINATIONS

Three holes (SV01, Zamora; SV02, Butte City; SV03, Nicolaus) were drilled in 1979-1980 in the Sacramento Valley by Water Resources Division of the U.S. Geological Survey. Temperature measurements were made on January 29, 1980, in SV01 and SV02 and on February 3, 1981, in SV03. The temperature-depth curves for these holes are presented in Figures 3, 4, and 5, respectively. The curve for SV01 appears undisturbed by water movement but the upper 100 meters of SV02 is apparently influenced by lateral water flow and all of SV03 by upward water flow.

For heat-flow determinations, the least disturbed interval of the temperature-depth profile was selected for each hole. Linear least-squares gradients were calculated for these intervals.

All three holes were cored at intervals, and cuttings were collected. Thermal conductivity measurements were made on both the core, using the needle probe technique (Von Herzen and Maxwell, 1959) and on the cuttings using the chip method (Sass and others, 1971a). Harmonic mean conductivities were calculated for all the measurements. Gradients, thermal conductivities and heat flows are summarized in Table 1. The individual thermal conductivities for SV01, SV02, and SV03 appear in Table 2, Appendix 1.

The heat flows for the three sites are low (0.64-0.78 HFU). Since the topography is essentially flat, no correction for terrain has been made, and although the Great Valley has a thick accumulation of sediments, no correction for sedimentation has been made on the heat-flow values, which may be as high as 0.2 HFU. These new heat-flow values agree with previously determined heat flows in Sacramento Valley (Lachenbruch and Sass, 1980) and are similar to heat flows in the San Joaquin Valley (Benfield, 1947; Sass and others, 1971b). The previously determined heat flows are summarized in Table 3.

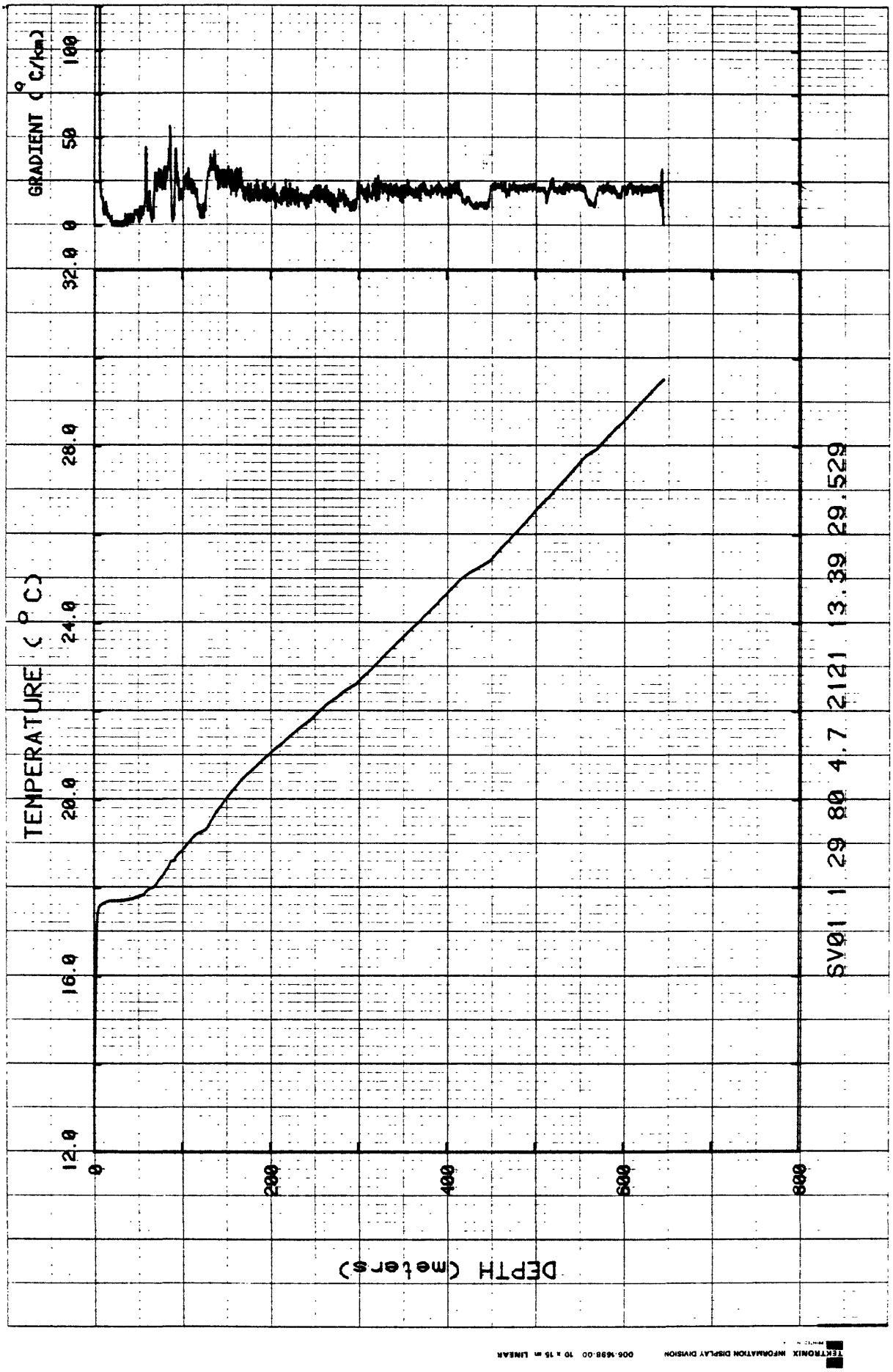

Figure 3. Temperatures and gradients for hole SV01.

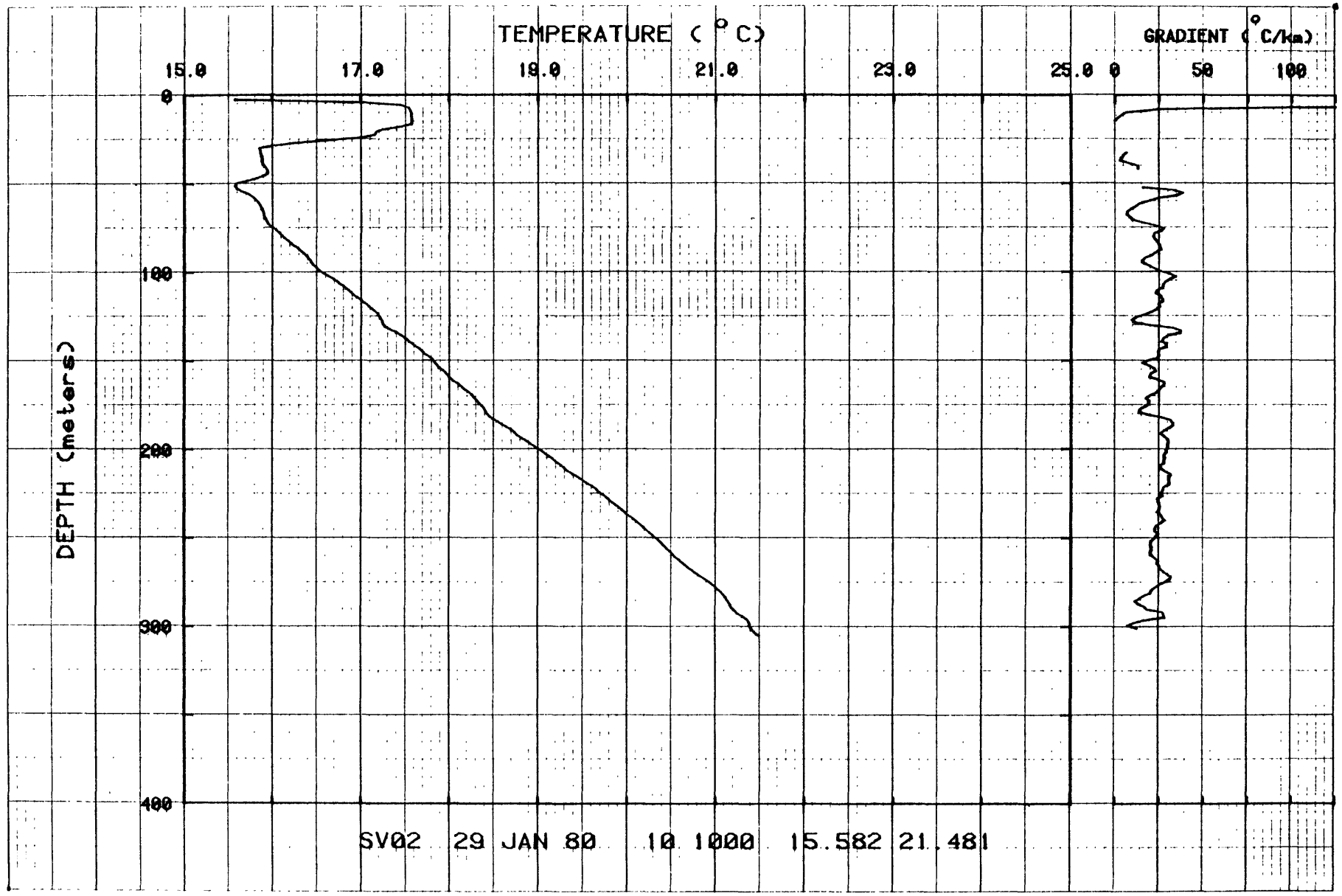

Figure 4. Temperatures and gradients for hole SV02.

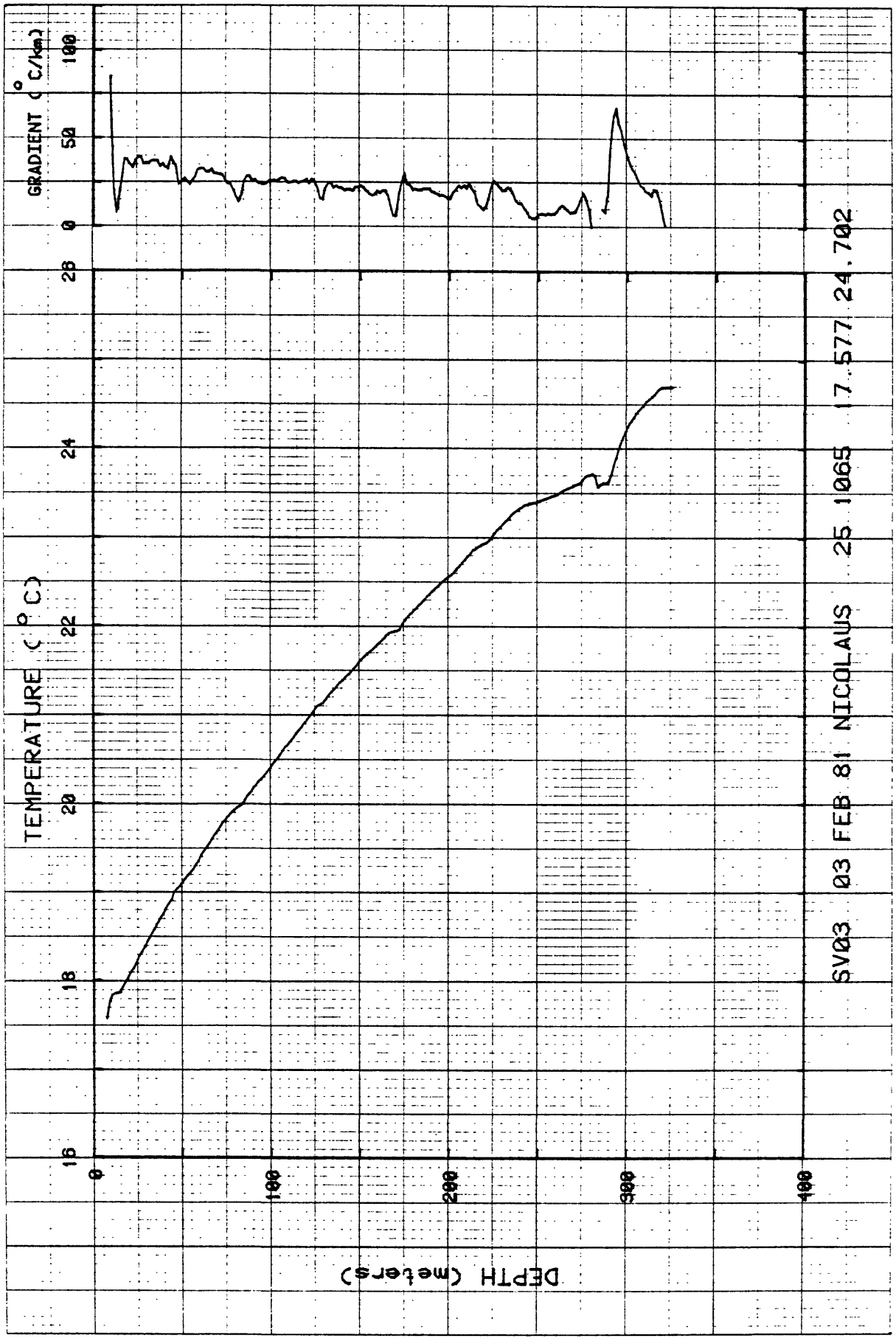

Figure 5. Temperatures and gradients for hole SV03.

TABLE 1. Summary of heat-flow data from holes SV01, SV02, and SV03

Hole	N. Lat.	W. Long.	Elev. (m)	Depth range (m)	Γ (°C/km)	K		Heat flow	
						mcal cm^{-1} s^{-1} $°C^{-1}$	Wm^{-1} K^{-1}	μcal cm^{-2} sec^{-1}	mWm^{-2}
SV01 (Zamora)	38°-50.4'	121°-50.6'	7	61-646	19.18±0.016	3.32±0.12	1.39±0.05	0.64±0.02	27±0.8
SV02 (Butte City)	39°-27.4'	121°-59.5'	27	122-305	24.75±0.091	3.14±0.14	1.31±0.06	0.78±0.04	33±1.7
SV03 (Nicolaus)	38°-55.0'	121°-36.3'	10	114-206	20.30±0.108	3.38±0.058	1.42±0.02	0.69±0.02	29±0.8

TABLE 3. Summary of existing heat-flow data from the Great Valley, California

Hole	N. Lat.	W. Long.	Heat flow		References[1]
			μcal cm^{-2} sec^{-1}	mWm^{-2}	
ML1 (Maricopa)	35°-04.2'	119°-26.3'	1.93	81	4
EH1 (Elk Hills 382-3G)	35°-16. '	119°-23. '	1.26	53	5
EH2 (Elk Hills 343-4G)	35°-16. '	119°-24. '	1.12	47	5
EH3 (Elk Hills 344-35S)	35°-17. '	119°-22. '	1.20	50	5
EH4 (Elk Hills 372-35R)	35°-17. '	119°-28. '	1.30	54	5
EH5 (Elk Hills 326-28R)	35°-17. '	119°-31. '	1.26	53	5
EH6 (Elk Hills 385-24Z)	35°-18. '	119°-33. '	1.20	50	5
EH7 (Elk Hills 366-24Z)	35°-18. '	119°-34. '	1.00	42	5
TL1 (Temblor)	35°-21.3'	119°-49.7'	1.45	61	4
WB1 (West of Bakersfield)	35°-28. '	119°-45. '	1.29	54	1
ST1 (Sherman Thomas)	37°-10. '	120°-04. '	0.45	19	5
TR1 (Tracy DH2)	37°-48. '	121°-35. '	0.96	40	5
GUI (Guinda)	38°-50.4'	122°-12.0'	0.90	38	4
COL (Colusa Basin)	38°-53.0'	121°-53.7'	0.80	342	4

[1]Numbers refer to references.

SUBSURFACE TEMPERATURES

In addition to the three new holes, temperatures have been measured in 78 other holes in the Great Valley. The data from these measurements are summarized in Table 4 and 65 previously unpublished temperature-depth curves are presented in Appendix 3, Figures 10 through 74. Temperatures are affected by the hydrologic conditions in the Great Valley, and this is evident in some of the temperature-depth profiles. Temperatures in holes SV05, 08, 10, 11, 17, 55, GV16, and GUI are apparently influenced by upward water movement, in holes SV14, GV13, 18, and 19 by downward water movement and in holes SV02 and 09 by lateral water flow.

For the isotherm map, a depth of 200 meters was selected as temperatures at that depth are relatively unaffected by local variations in surface temperature. For holes deeper than 200 meters, the measured temperatures were used. For holes shallower than 200 meters, temperatures were extrapolated using the appropriate gradient. Since datum is ground level at each hole, the contour map of subsurface temperature at 200 meters reflects surface elevation to some extent, particularly near the sides of the valley. All temperature and gradient data are presented in Table 5. While the temperatures and gradient data from holes not in the sediments of the Great Valley are presented on the map, they were not used in constructing the contours because inconsistencies introduced by collar elevations greatly different from the valley holes.

The isotherm and gradient maps are each divided into a northern and southern portion, Figures 6 through 9. The direction of water flow (up, down, or lateral) is indicated by an arrow.

TABLE 4. Summary of temperature log data from the Great Valley, California

Hole	N. Lat.	W. Long.	Date logged	Depth (ft) and temperature (°C) logged From		To	
GV01	35°-02.9'	118°-53.7'	04-02-1969	152 ,	20.937	636 ,	23.026
ML1	35°-04.2'	119° 26.3'	08-09-1977	20 ,	13.595	721 ,	34.526
GV02	35°-07.7'	118°-53.6'	06-03-1969	160.1 ,	21.291	297.75,	21.291
EH1	35°-16. '	119°-23. '	04-16-1969	98.4 ,	23.624	7480.36,	104.287
EH2	35°-16. '	119°-24. '	04-21-1969	328 ,	26.279	6908.33,	100.121
EH3	35°-17. '	119°-22. '	04-22-1969	328 ,	26.275	7186.48,	102.028
EH4	35°-17. '	119°-28. '	04-17-1969	328 ,	25.874	6927.68,	100.771
EH5	35°-17. '	119°-31. '	04-20-1969	328 ,	25.857	6384.02,	95.897
GV03	35°-17.8'	119°-10.5'	06-02-1969	80.25,	21.108	552.05,	24.774
EH6	35°-18. '	119°-33. '	04-18-1969	328 ,	25.919	5953.52,	92.953
EH7	35°-18. '	119°-34. '	04-19-1969	328 ,	25.274	6020.76,	92.342
GV04	35°-19.4'	118°-57.8'	06-02-1969	200 ,	20.164	1067.9 ,	26.345
GV05	35°-21.1'	119°-24.2'	06-04-1969	125 ,	19.577	606 ,	22.673
TL1	35°-21.3'	119°-49.7'	02-14-1975	20 ,	16.564	533 ,	20.847
GV06	35°-25.2'	119°-15.0'	06-03-1969	175.1 ,	21.145	525 ,	24.74
WB1	35°-28. '	119°-45. '	06- -1936	100 ,	26.22	8680 ,	116.22
GV07	35°-28.8'	119°-10.3'	06-04-1969	225 ,	18.856	650 ,	25.59
GV08	35°-29.2'	119°-21.8'	06-04-1969	224.9 ,	23.005	656 ,	26.356
GV10	35°-55.7'	119°-16.6'	04-02-1969	152.43,	20.937	636.24,	23.026
GV11	35°-59.5'	119°-06.4'	07-21-1970	260 ,	22.475	1218.70,	28.057
GV12	36°-02.8'	119°-12.2'	05-15-1969	90 ,	19.126	397 ,	21.600
GV13	36°-03.4'	119°-21.4'	05-14-1969	50 ,	18.022	397.1 ,	22.115
GV14	36°-03.8'	119°-25.7'	05-14-1969	50 ,	18.791	327.2 ,	19.972

TABLE 4. Summary of temperature log data from the Great Valley, California (continued)

Hole	N. Lat.	W. Long.	Date logged	Depth (ft) and temperature (°C) logged From		To	
GV15	36°-08.0'	119°-12.4'	05-22-1969	70 ,	19.279	190 ,	19.318
GV16	36°-08.6'	119°-56.9'	05-13-1969	30 ,	19.978	376.2 ,	23.807
GV17	36°-10.4'	119°-07.7'	05-15-1969	60.3 ,	21.394	306 ,	23.088
GV18	36°-11.5'	119°-14.0'	05-15-1969	80 ,	18.972	841 ,	25.213
GV19	36°-12.2'	119°-30.0'	05-14-1969	40 ,	19.172	440 ,	21.154
GV20	36°-13.5'	120°-03.9'	08-20-1970	570 ,	25.11	860 ,	27.20
GV21	36°-14.7'	120°-18.8'	02-19-1964	1500 ,	29.203	3264.4 ,	37.824
GV22	36°-15.1'	120°-19.5'	02-19-1964	50 ,	21.956	1570 ,	34.004
GV23	36°-15.5'	119°-37.3'	05-14-1969	40 ,	20.211	160 ,	20.361
GV25	36°-19.2'	120°-14.2'	08-20-1970	460 ,	23.18	850 ,	25.43
GV26	36°-19.4'	119°-12.2'	05-20-1969	19.95,	14.063	332.7 ,	18.079
GV27	36°-22.6'	119°-25.7'	05-21-1969	50 ,	19.883	116.7 ,	20.52
GV28	36°-25.5'	120°-15.8'	05-13-1969	40 ,	22.611	597.5 ,	26.886
GV29	36°-26.4'	120°-18.4'	08-20-1970	600 ,	28.15	2317 ,	44.30
GV30	36°-29.2'	120°-19.8'	08-21-1970	550 ,	28.82	1019 ,	33.77
GV31	36°-34.4'	120°-16.7'	08-19-1970	225 ,	21.48	720 ,	26.90
GV32	36°-36.1'	120°-13.9'	05-23-1969	65 ,	18.292	328 ,	19.121
GV33	36°-37.4'	120°-37.1'	08-18-1970	100 ,	23.50	500 ,	29.28
GV34	36°-37.7'	120°-27.4'	05-23-1969	175.1 ,	20.768	525.1 ,	24.969
GV35	36°-38.7'	120°-31.8'	08-19-1970	550 ,	26.42	950 ,	30.69
GV36	36°-43.7'	120°-36.2'	08-18-1970	520 ,	25.48	732 ,	27.74
GV37	36°-45.8'	120°-18.8'	05-08-1969	125 ,	18.726	588 ,	22.633
GV38	36°-50.3'	120°-11.8'	05-08-1969	83 ,	18.418	629 ,	23.882

TABLE 4. Summary of temperature log data from the Great Valley, California (continued)

Hole	N. Lat.	W. Long.	Date logged	Depth (ft) and temperature (°C) logged From		To	
GV39	36°-52.8'	119°-56.8'	05-21-1969	70 ,	20.93	336.9 ,	23.767
GV40	36°-53.4'	120°-39.2'	08-17-1970	140 ,	23.62	965 ,	30.28
GV41	36°-54.5'	120°-08.2'	05-07-1969	100 ,	19.001	165 ,	19.55
GV42	36°-54.5'	120°-08.2'	05-07-1969	89 ,	18.993	340 ,	21.662
GV43	36°-55.5'	120°-20.4'	05-08-1969	65 ,	18.562	210 ,	20.000
GV44	36°-55.5'	120°-20.4'	05-08-1969	65 ,	18.587	758 ,	24.102
GV45	36°-57.3'	120°-45.0'	05-16-1969	40.1 ,	20.534	143 ,	22.133
GV46	36°-59.0'	120°-13.2'	05-08-1969	65 ,	19.308	127 ,	20.329
GV47	37°-06.6'	120°-20.0'	05-09-1969	94 ,	17.886	379 ,	20.050
GV48	37°-06.8'	120°-34.4'	07-16-1969	80 ,	19.937	323.45,	21.79
GV49	37°-07.7'	120°-12.0'	05-09-1969	69 ,	19.667	100 ,	23.738
GV50	37°-07.9'	120°-46.7'	07-16-1969	60 ,	18.530	418.4 ,	22.636
GV51	37°-08.2'	120°-56.8'	06-06-1969	60 ,	18.761	475.35,	25.114
GV52	37°-08.6'	120°-54.7'	06-06-1969	50 ,	19.09	499.8 ,	24.94
ST1	37°-10. '	120°-04. '	04-30-1968	58.22,	20.656	1408.59,	25.510
GV55	37°-12.5'	120°-27.5'	10-29-1979	10 ,	30.321	470.2 ,	38.591
TR1	37°-48. '	121°-35. '	05-21-1963	107.91,	19.137	747.8 ,	26.921
WDLD	38°-41.3'	121°-45.7'	04-01-1980	17.9 ,	18.059	530 ,	19.870
SV01	38°-50.4'	121°-50.6'	01-29-1980	4.7 ,	13.39	2121 ,	29.529
GUI	38°-50.4'	122°-12.0'	08-09-1977	14 ,	20.29	400 ,	21.86
COL	38°-53.0'	121°-53.7'	08-09-1977	13 ,	19.58	512 ,	19.05
SV03	38°-55.0'	121°-36.3'	02-03-1981	25 ,	17.577	1065 ,	24.702

TABLE 4. Summary of temperature log data from the Great Valley, California (continued)

Hole	N. Lat.	W. Long.	Date logged	Depth (ft) and temperature (°C) logged From		To	
SV13	38°-58.9'	122°-04.6'	01-30-1980	125 ,	18.679	390 ,	18.963
SV14	39°-06.3'	122°-09.7'	01-31-1980	65 ,	18.334	550 ,	18.859
SV07	39°-08. '	121°-28.3'	01-10-1980	110 ,	21.247	225 ,	21.447
SV05	39°-26.4'	122°-11.4'	01-18-1980	30 ,	17.396	555 ,	20.109
SV02	39°-27.4'	121°-59.5'	01-29-1980	10 ,	15.582	1000 ,	21.481
SV12	39°-34.8'	122°-36.2'	01-30-1980	115 ,	16.966	167.9 ,	17.394
SV04	39°-37.5'	122°-14.0'	01-22-1980	25 ,	18.109	303 ,	20.57
SV09	39°-44.0'	121°-52.4'	01-18-1980	40 ,	16.396	513.8 ,	17.634
SV06	40°-02. '	122°-22. '	01-25-1980	90 ,	19.149	258.5 ,	19.231
SV10	40°-02.0'	122°-11.3'	01-17-1980	35 ,	17.877	489.8 ,	21.168
SV08	40°-04.4'	122°-06.6'	01-17-1980	25 ,	16.911	831.9 ,	24.064
SV11	40°-19.8'	122°-16.7'	01-23-1980	50 ,	18.064	399.6 ,	20.135

TABLE 5. Temperature and gradient data for isotherm and gradient maps of the Great Valley, California

Hole	N. Lat.	W. Long.	T (°C) at 200-m depth	G (°C/km)
		San Joaquin Valley		
GV01	35°-02.9'	118°-53.7'	23.9	18.0
ML1	35°-04.2'	119°-26.3'	33.6	51.2
EH1	35°-16. '	119°-23. '	29.2	30.0
EH2	35°-16. '	119°-24. '	29.5	35.0
EH3	35°-17. '	119°-22. '	29.7	32.2
EH4	35°-17. '	119°-28. '	29.4	35.3
EH5	35°-17. '	119°-31. '	30.0	36.9
GV03	35°-17.8'	119°-10.5'	25.8	34.3
EH6	35°-18. '	119°-33. '	29.9	41.5
EH7	35°-18. '	119°-34. '	29.9	40.0
GV04	35°-19.4'	118°-57.8'	23.8	22.8
GV05	35°-21.1'	119°-24.2'	25.0	30.0
TL1	35°-21.3'	119°-49.7'	22.1	37.9
GV06	35°-25.2'	119°-15.0'	26.2	36.0
WB1	35°-28. '	119°-45. '	30.6	34.6
GV07	35°-28.8'	119°-10.3'	25.7	33.6
GV08	35°-29.2'	119°-21.8'	26.4	36.5
GV10	35°-55.7'	119°-16.6'	23.1	20.4
GV11	35°-59.5'	119°-06.4'	24.9	19.8
GV12	36°-02.8'	119°-12.2'	23.1	20.6
GV13	36°-03.4'	119°-21.4'	24.1	25.6
GV16	36°-08.6'	119°-56.9'	25.8	23.6

TABLE 5. Temperature and gradient data for isotherm and gradient maps of the Great Valley, California (continued)

Hole	N. Lat.	W. Long.	T (°C) at 200-m depth	G (°C/km)
		San Joaquin Valley (continued)		
GV17	36°-10.4'	119°-07.7'	25.6	32.8
GV18	36°-11.5'	119°-14.0'	23.9	24.7
GV19	36°-12.2'	119°-30.0'	22.6	17.8
GV20	36°-13.5'	120°-03.9'	25.7	24.6
GV21	36°-14.7'	120°-18.8'	23.0	19.9
GV22	36°-15.1'	120°-19.5'	26.8	30.0
GV23	36°-15.5'	119°-37.3'	24.6	28.0
GV25	36°-19.2'	120°-14.2'	24.4	18.0
GV26	36°-19.4'	119°-12.2'	22.7	18.6
GV28	36°-25.5'	120°-15.8'	25.6	33.2
GV29	36°-26.4'	120°-18.4'	28.5	31.5
GV30	36°-29.2'	120°-19.8'	26.0	27.8
GV31	36°-34.4'	120°-16.7'	26.1	39.8
GV33	36°-37.4'	120°-37.1'	29.2	51.0
GV34	36°-37.7'	120°-27.4'	26.6	37.8
GV35	36°-38.7'	120°-31.8'	27.3	38.4
GV36	36°-43.7'	120°-36.2'	26.8	38.4
GV37	36°-45.8'	120°-18.8'	23.0	20.2
GV38	36°-50.3'	120°-11.8'	24.1	25.6
GV39	36°-52.8'	119°-56.8'	25.8	20.0
GV40	36°-53.4'	120°-39.2'	27.1	38.4

TABLE 5. Temperature and gradient data for isotherm and gradient maps of the Great Valley, California (continued)

Hole	N. Lat.	W. Long.	T (°C) at 200-m depth	G (°C/km)
		San Joaquin Valley (continued)		
GV41	36°-54.5'	120°-08.2'	24.1	25.6
GV42	36°-54.5'	120°-08.2'	24.2	25.8
GV43	36°-55.5'	120°-20.4'	22.1	15.6
GV44	36°-55.5'	120°-20.4'	23.5	22.0
GV45	36°-57.3'	120°-45.0'	31.0	60.0
GV46	36°-59.0'	120°-13.2'	26.0	35.0
GV47	37°-06.6'	120°-20.0'	22.5	31.2
GV48	37°-06.8'	120°-34.4'	24.8	28.8
GV49	37°-07.7'	120°-12.0'	23.6	23.2
GV50	37°-07.9'	120°-46.7'	24.6	28.0
GV51	37°-08.2'	120°-56.8'	27.4	42.0
GV52	37°-08.6'	120°-54.7'	27.6	43.0
ST1	37°-10. '	120°-04. '	23.7	6.4
		Sacramento Valley		
TR1	37°-48. '	121°-35. '	24.7	29.3
WDLD	38°-41.3'	121°-45.7'	20.1	10.6
SV01	38°-50.4'	121°-50.6'	21.1	18.0
GUI	38°-50.4'	122°-12.0'	24.4	32.0
COL	38°-53.0'	121°-53.7'	20.1	21.0
SV03	38°-55.0'	121°-36.3'	22.6	21.6

TABLE 5. Temperature and gradient data for isotherm and gradient maps of the Great Valley, California (continued)

Hole	N. Lat.	W. Long.	T (°C) at 200-m depth	G (°C/km)
		Sacramento Valley (continued)		
SV13	38°-58.9'	122°-04.6'	19.3	3.6
SV14	39°-06.3'	122°-09.7'	18.9	0
SV07	39°-08. '	121°-28.3'	21.5	0.5
SV05	39°-26.4'	122°-11.4'	20.5	12.4
SV02	39°-27.4'	121°-59.5'	19.0	24.5
SV04	39°-37.5'	122°-14.0'	21.4	7.5
SV09	39°-44.0'	121°-52.4'	17.3	12.0
SV06	40°-02. '	122°-22. '	19.6	6.0
SV10	40°-02.0'	122°-11.3'	22.2	21.0
SV08	40°-04.4'	122°-06.6'	23.2	22.0
SV11	40°-19.8'	122°-16.7'	20.8	8.4

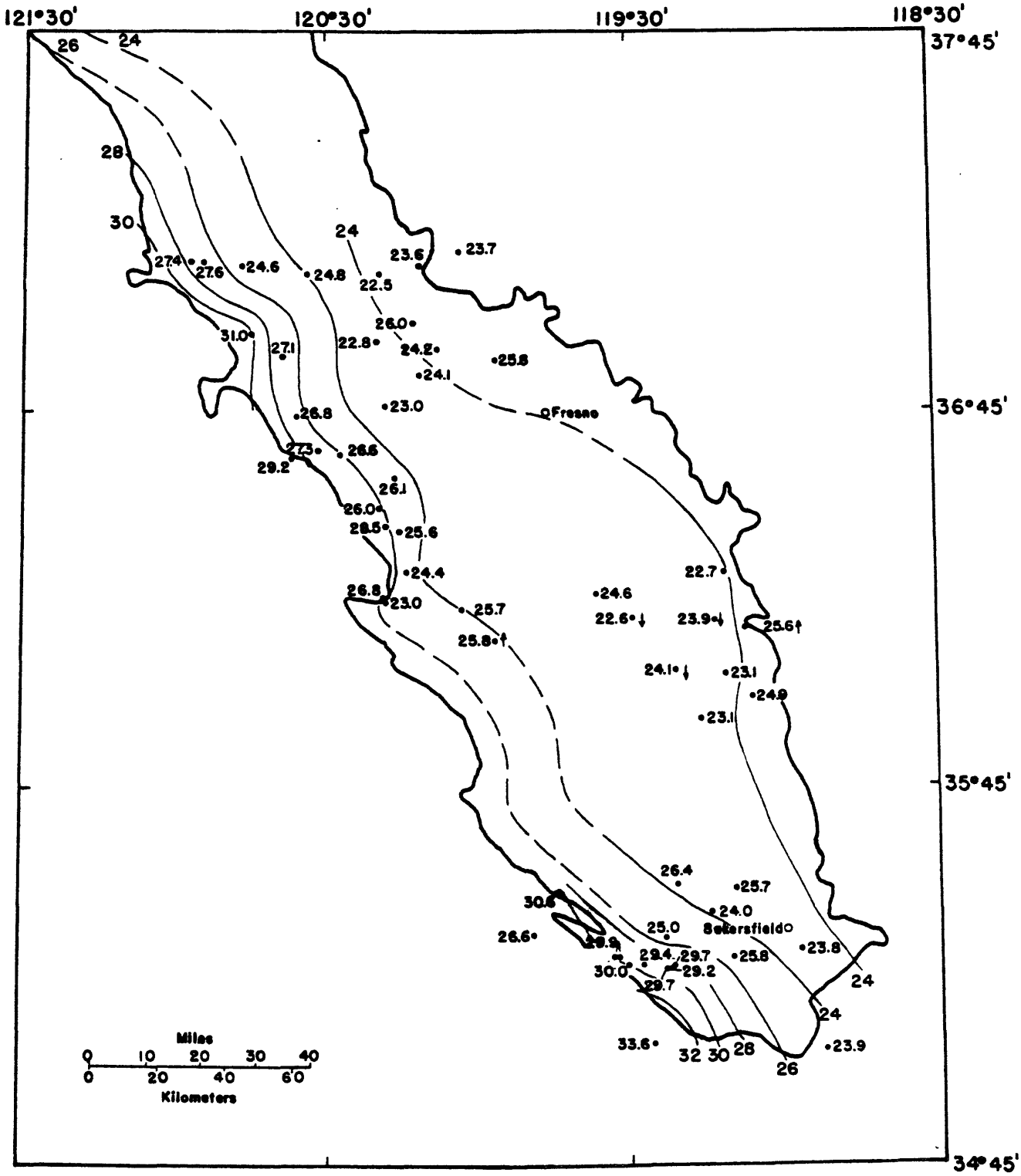

Figure 6. Isotherm map of the southern portion of the Great Valley, California. Temperatures at 200 meters. Contour interval = 2°C.

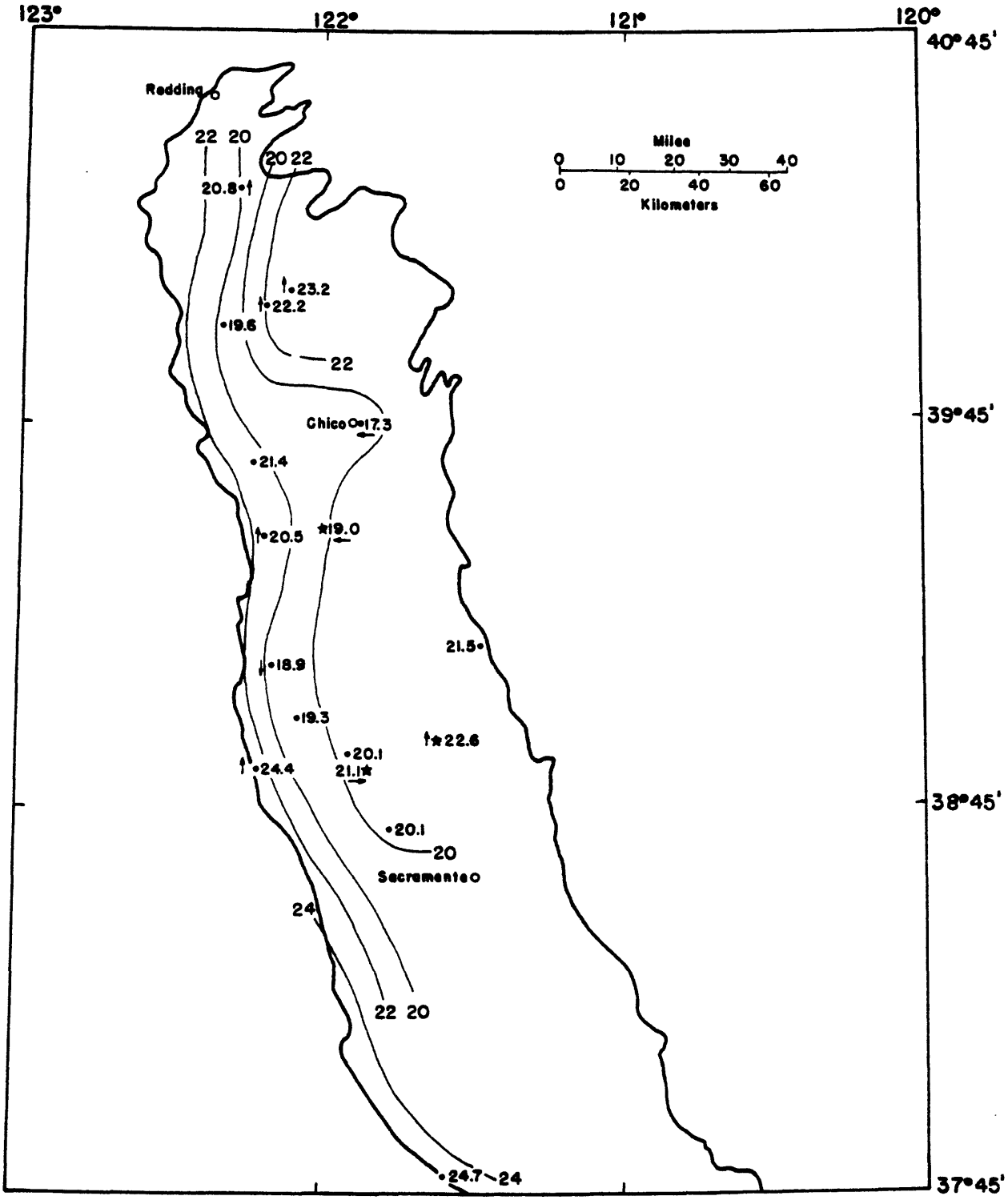

Figure 7. Isotherm map of the northern portion of the Great Valley, California. Temperatures at 200 meters. Contour interval = 2°C. New heat-flow sites are indicated by stars.

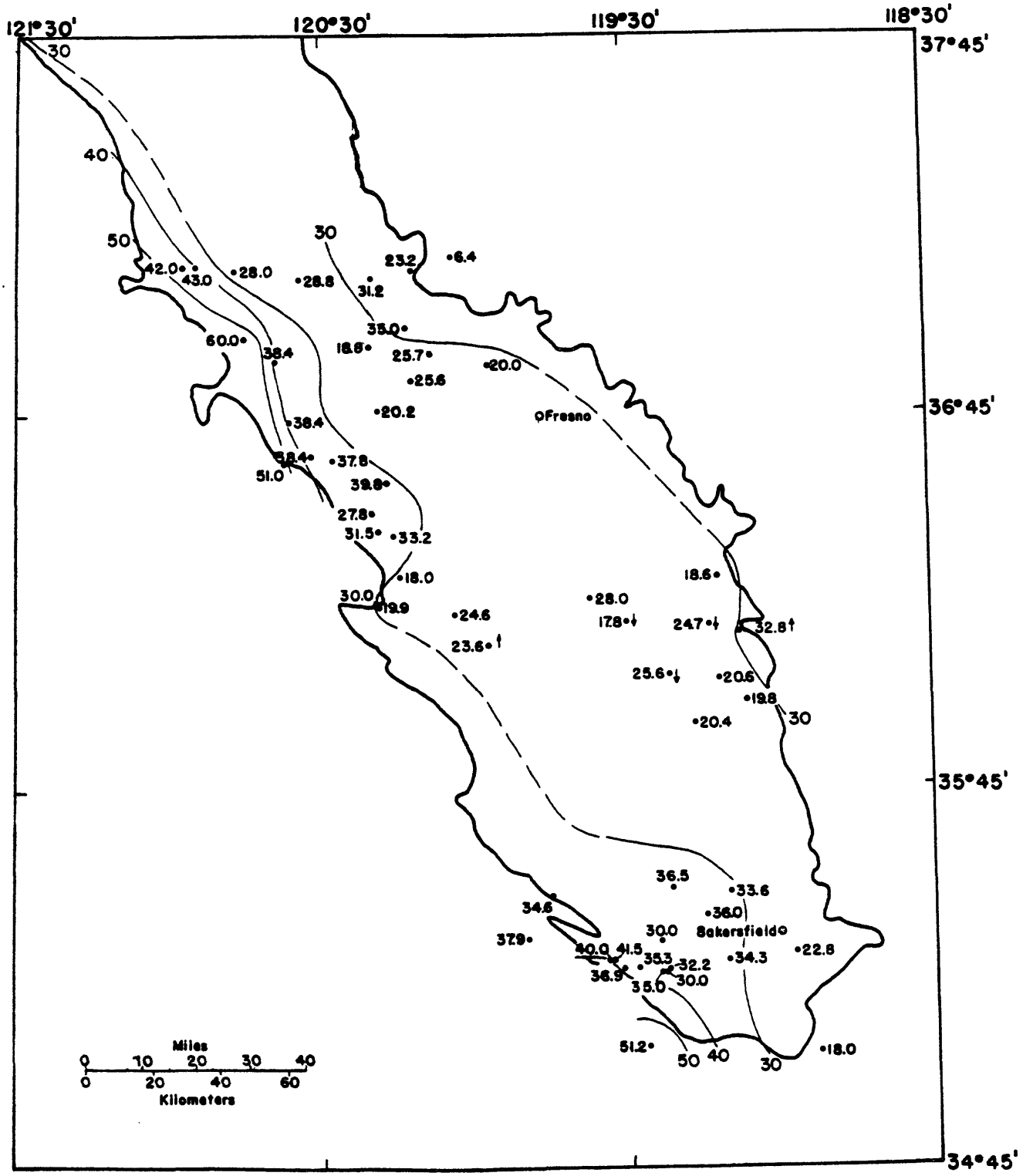

Figure 8. Gradient map of the southern portion of the Great Valley, California. Contour interval = 10°C/km.

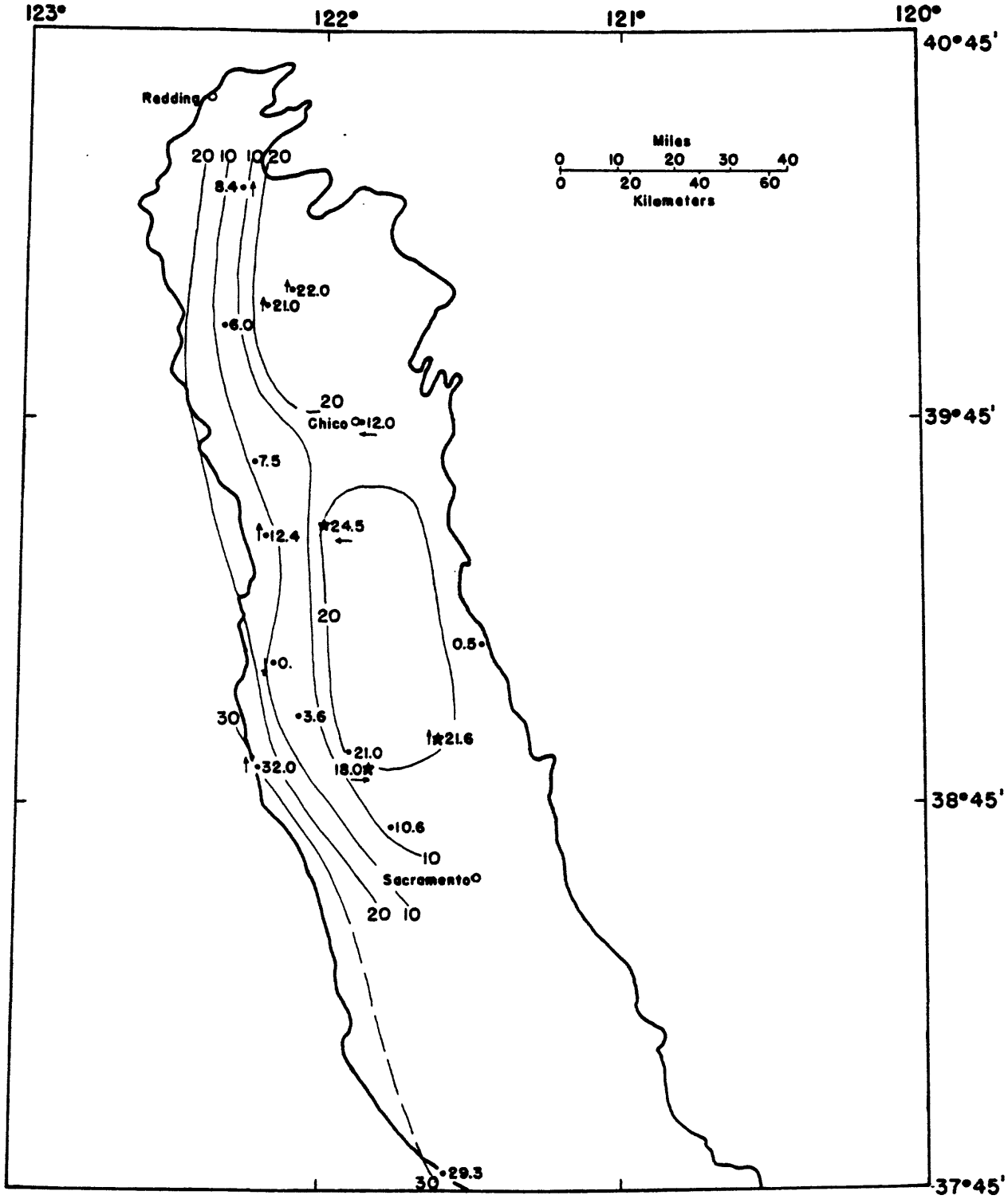

Figure 9. Gradient map of the northern portion of the Great Valley, California. Contour interval = 10°C/km.
New heat-flow sites are indicated by stars.

DISCUSSION

The isotherms and gradient maps are similar as expected and contain some features worth noting.

1. The Great Valley can be characterized as having temperatures of 20°C - 24°C at 200 meters and low-to-normal gradients of between 20°C/km-30°C/km.

2. Both subsurface temperatures and gradients at the western margin of the Great Valley are apparently higher than those at the eastern margin. This is consistent with the heat flow which is higher in the Coast Ranges (~80 mWm^{-2}) (Lachenbruch and Sass, 1980; Sass et al., 1971a) than in the Sierra Nevada (<40 mWm^{-2}) (Clark, 1957; Henyey and Lee, 1976; Lachenbruch, 1968; Lachenbruch et al., 1976; Roy et al., 1968; Sass et al., 1971a) and also consistent with the hydro-geological conditions in the region.

3. There is a suggestion of two anomalies common to both the subsurface temperature and gradient maps. The area of low temperature and low gradients between Bakersfield and Fresno on the east side of the San Joaquin Valley is apparently related to downward water flow. The area of anomalously high temperatures and gradients between Chico and Sacramento may be somehow related to igneous activity associated with the Sutter Buttes. The band of low subsurface temperatures and gradients on the west side of the Sacramento Valley may be related to transient heat sinks associated with the rapid filling of the deepest section of the Great Valley.

A more complete interpretation of subsurface temperatures and heat flow in the Great Valley will depend on:

1. Eliminating the data gap which exists between the Sacramento and San Joaquin Valleys by drilling a series of heat-flow holes in the area.

2. Correcting the heat-flow values in the Sacramento Valley for rapid accumulation of sediments.

3. Obtaining additional thermal conductivity data in laterally continuous formations for which reliable temperature gradients exist.

4. Integrating existing thermal and hydrologic data in an attempt to identify and separate conductive and convective components of heat flow.

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APPENDIX 1: Thermal conductivity data for holes SV01, SV02, and SV03

TABLE 2. Thermal conductivity data from holes SV01, SV02, and SV03

Hole	Depth range (m)	K	
		mcal cm^{-1} sec^{-1} $°C^{-1}$	Wm^{-1} K^{-1}
SV01 (Zamora)	223	3.37	1.41
	225	3.53	1.47
	275-525	3.52	1.47
	539	3.24	1.36
	541.5	3.13	1.31
	544	3.03	1.27
	571-694	3.23	1.35
	814	3.10	1.30
	816	3.39	1.42
	817	3.24	1.35
	818	3.32	1.39
	819.5	2.90	1.21
	824	2.33	0.98
	848	4.55	1.90
	849.5	3.52	1.47
	851	3.64	1.52
	898-942	5.00	2.09
	974	3.32	1.39
	975	3.05	1.28
	976	3.24	1.36
	977	2.77	1.16
	979	2.02	0.84
	1000-1195	4.06	1.69

TABLE 2. Thermal conductivity data
from holes SV01, SV02, and SV03 (continued)

Hole	Depth range (m)	K	
		mcal cm^{-1} sec^{-1} $°C^{-1}$	Wm^{-1} K^{-1}
SV01 (Zamora)	1201	4.01	1.67
	1202	4.48	1.87
	1205-1509	4.29	1.79
	1519	3.50	1.46
	1520	3.46	1.45
	1549-1699	3.53	1.47
	1755.5	3.22	1.35
	1757	3.32	1.39
	1789-1864	3.95	1.65
	1882.5	1.94	0.81
	1885	2.45	1.02
	1919-1980	3.44	1.44
	2025	3.22	1.35
	2027	3.66	1.53
	2029	3.54	1.48
	2029-2109	4.03	1.68
SV02 (Butte City)	400-670	3.70	1.54
	680-683	2.85	1.19
	700	2.73	1.14
	730-733	3.32	1.39
	772-775	2.65	1.11
	820-823	3.13	1.31

TABLE 2. Thermal conductivity data
from holes SV01, SV02, and SV03 (continued)

Hole	Depth range (m)	K	
		mcal cm^{-1} sec^{-1} $^{o}C^{-1}$	Wm^{-1} K^{-1}
SV02 (Butte City)	951-954	2.92	1.22
	1026-1029	3.06	1.28
	1087-1090	4.06	1.70
	1146-1149	3.58	1.50
SV03 (Nicolaus)	261-264	3.04	1.27
	270	3.04	1.27
	281-284	3.41	1.43
	291	3.12	1.30
	308-311	3.03	1.27
	314	3.27	1.36
	330	3.27	1.36
	341	3.25	1.36
	360	3.24	1.35
	361-364	3.22	1.34
	380	3.37	1.41
	391	4.45	1.86
	391-394	2.55	1.07
	405	3.97	1.66
	421	3.53	1.47
	421-424	3.19	1.34
	441	3.34	1.39
	451	3.31	1.38

TABLE 2. Thermal conductivity data
from holes SV01, SV02, and SV03 (continued)

Hole	Depth range (m)	K	
		mcal cm^{-1} sec^{-1} $°C^{-1}$	Wm^{-1} K^{-1}
SV03 (Nicolaus)	451-454	3.20	1.34
	461	3.68	1.54
	481	2.95	1.23
	481-484	3.10	1.30
	495	3.33	1.39
	501-504	3.10	1.30
	504	3.31	1.38
	521	3.85	1.61
	531	3.86	1.61
	541	3.38	1.41
	552	3.59	1.50
	557-558	4.08	1.71
	571	3.28	1.37
	581	3.28	1.37
	601	2.55	1.06
	601-604	2.75	1.15
	621	3.28	1.37
	623-626	3.20	1.34
	651-654	2.99	1.25
	654	3.23	1.35
	671	3.94	1.64
	681	3.96	1.65
	681-684	3.24	1.36

TABLE 2. Thermal conductivity data
from holes SV01, SV02, and SV03 (continued)

Hole	Depth range (m)	K	
		mcal cm^{-1} sec^{-1} $^{o}C^{-1}$	Wm^{-1} K^{-1}
SV03 (Nicolaus)	695	3.45	1.44
	711	3.54	1.48
	711-714	4.16	1.74
	714	4.29	1.79
	721	3.80	1.59
	741	3.32	1.39
	741-744	3.24	1.36
	763-764	3.60	1.51
	781-784	2.83	1.18

APPENDIX 2. Plots of temperatures for holes in the Great Valley, California

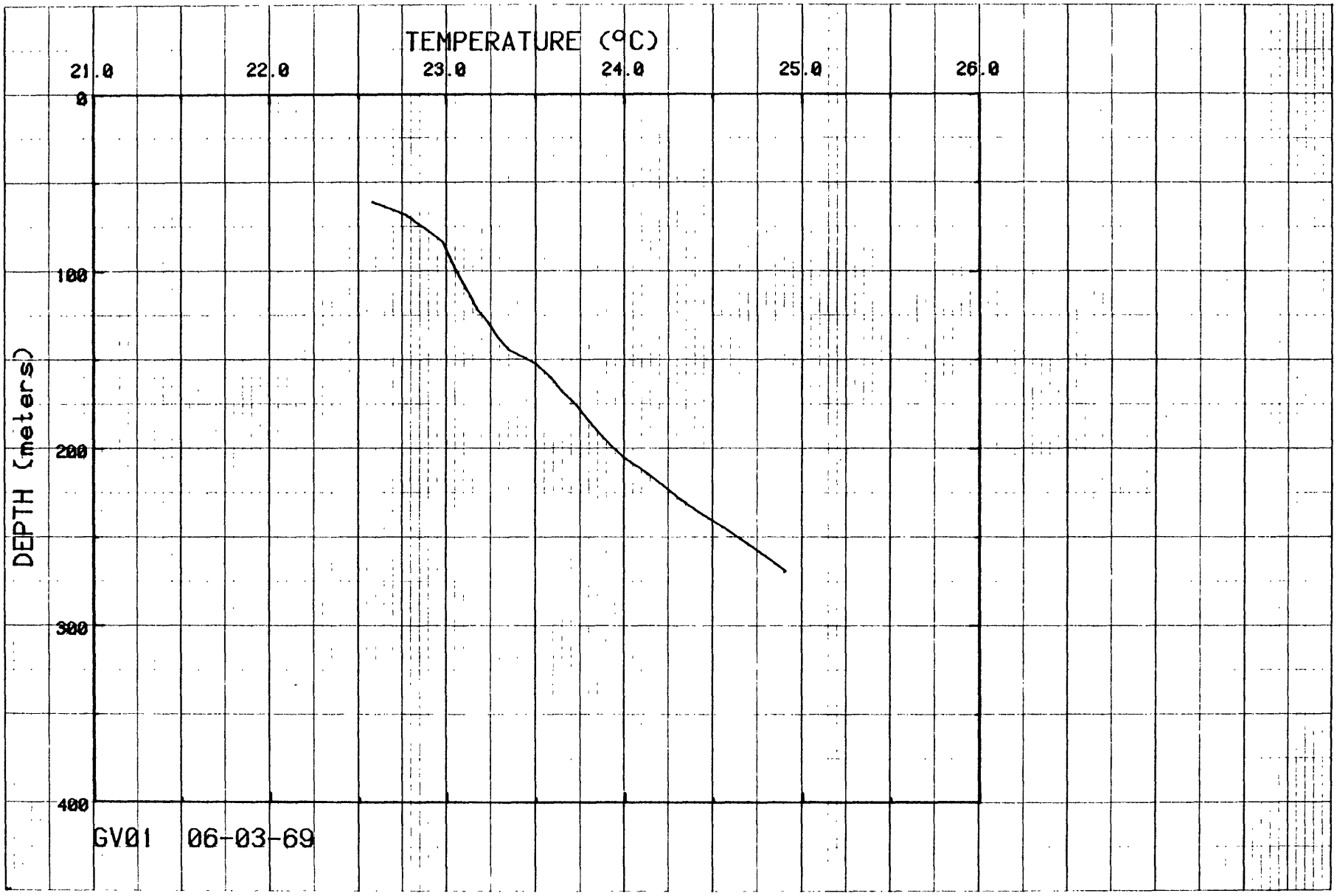

Figure 10. Temperatures for hole GV01.

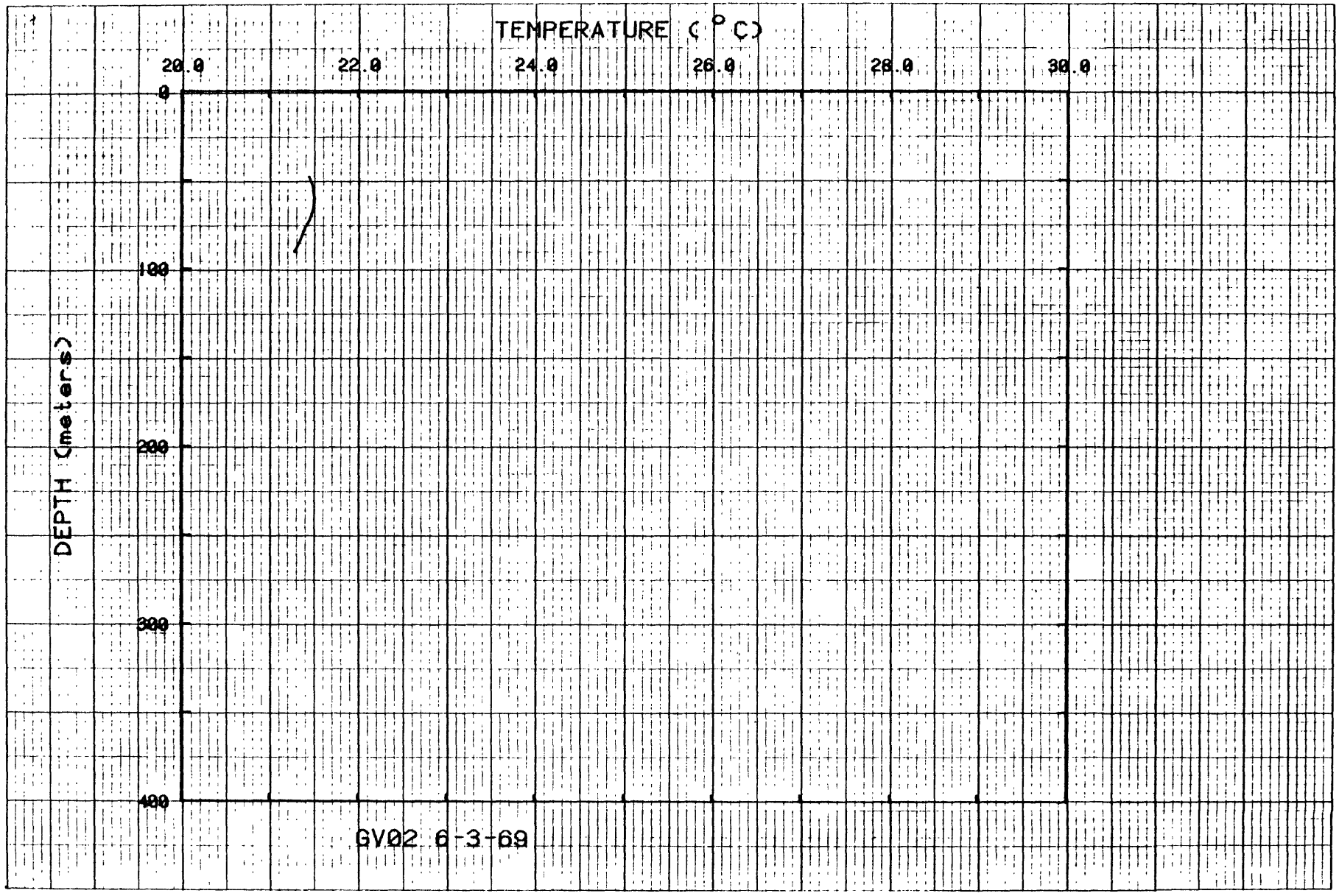

Figure 11. Temperatures for hole GV02.

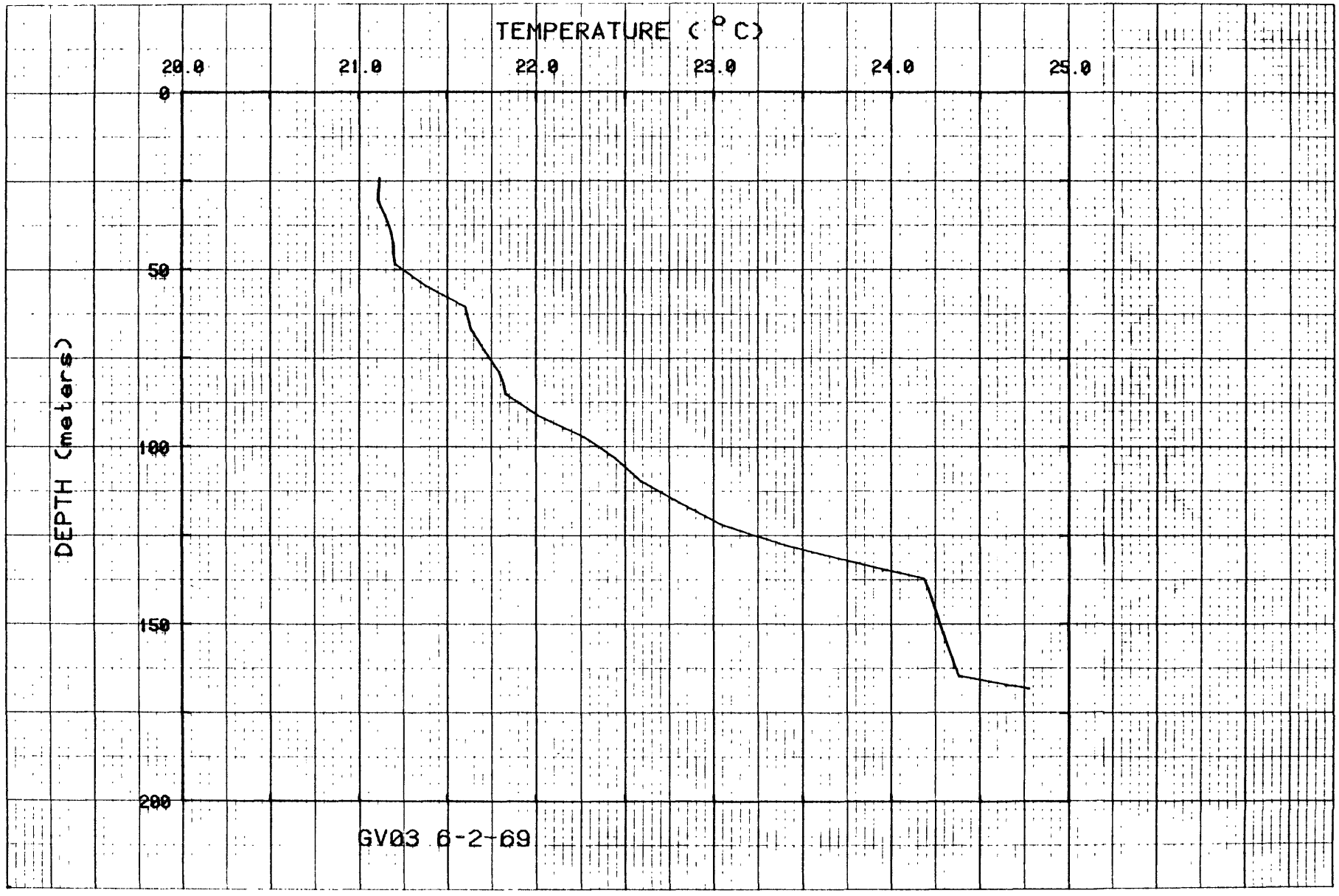

Figure 12. Temperatures for hole GV03.

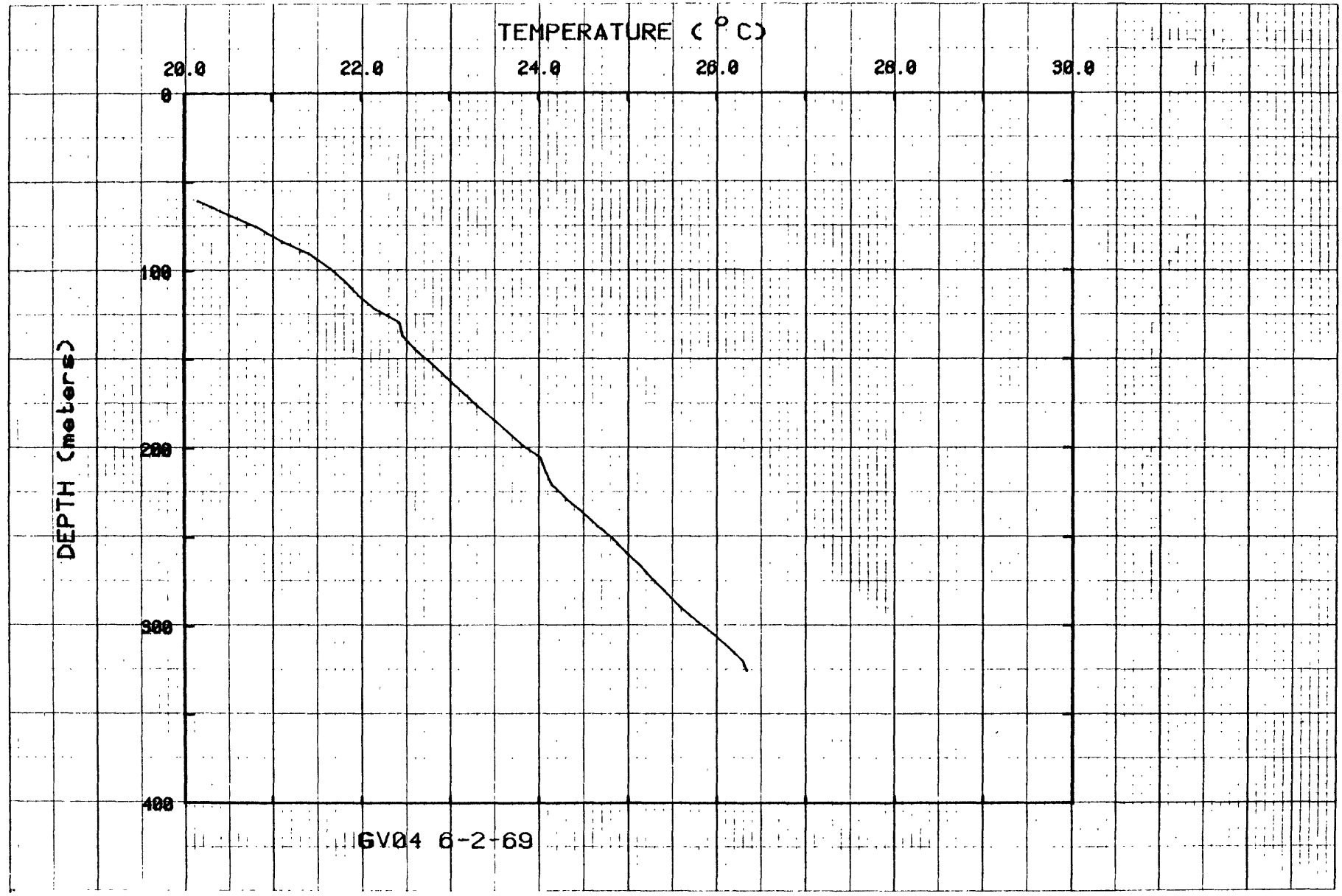

Figure 13. Temperatures for hole GV04.

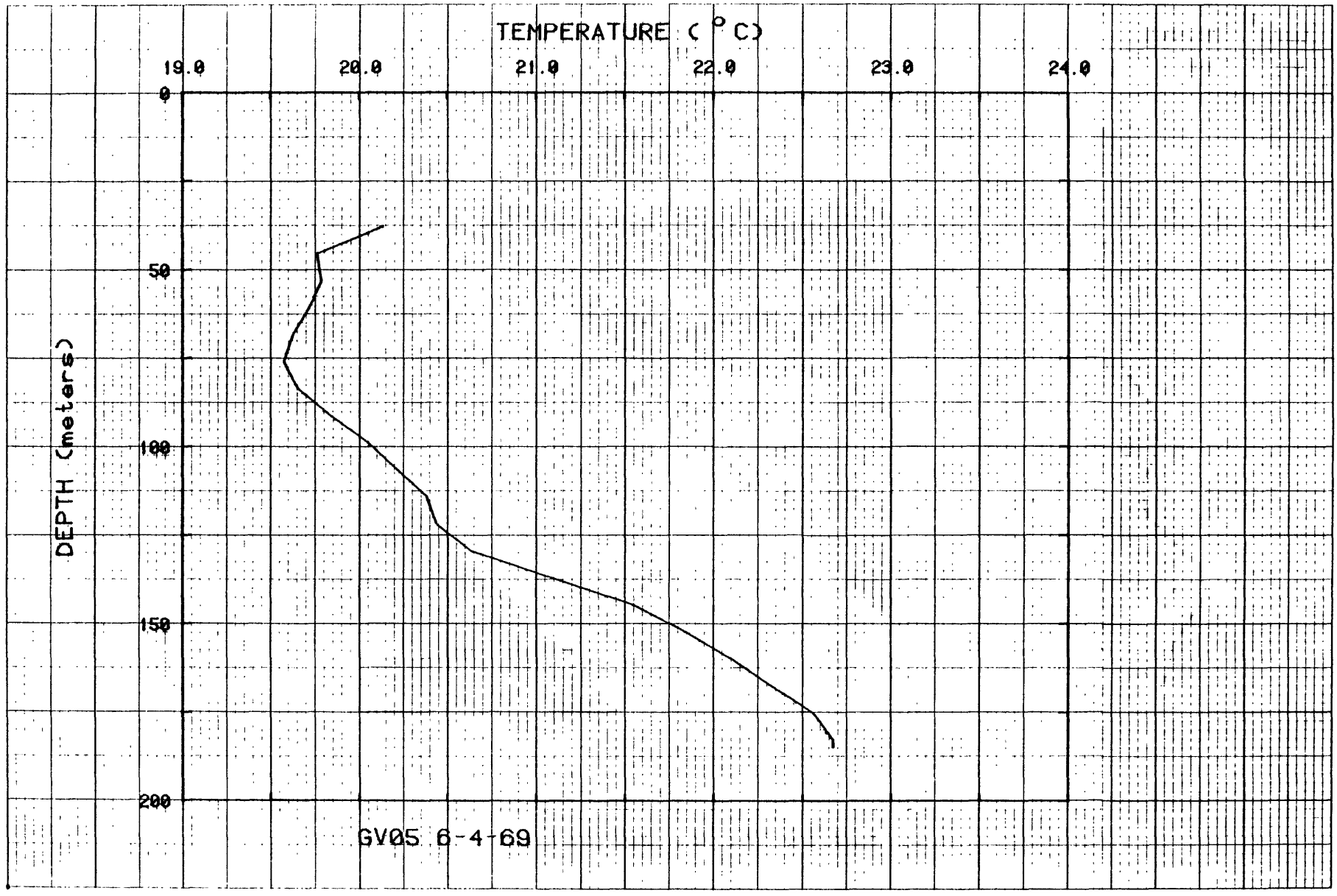

Figure 14. Temperatures for hole GV05.

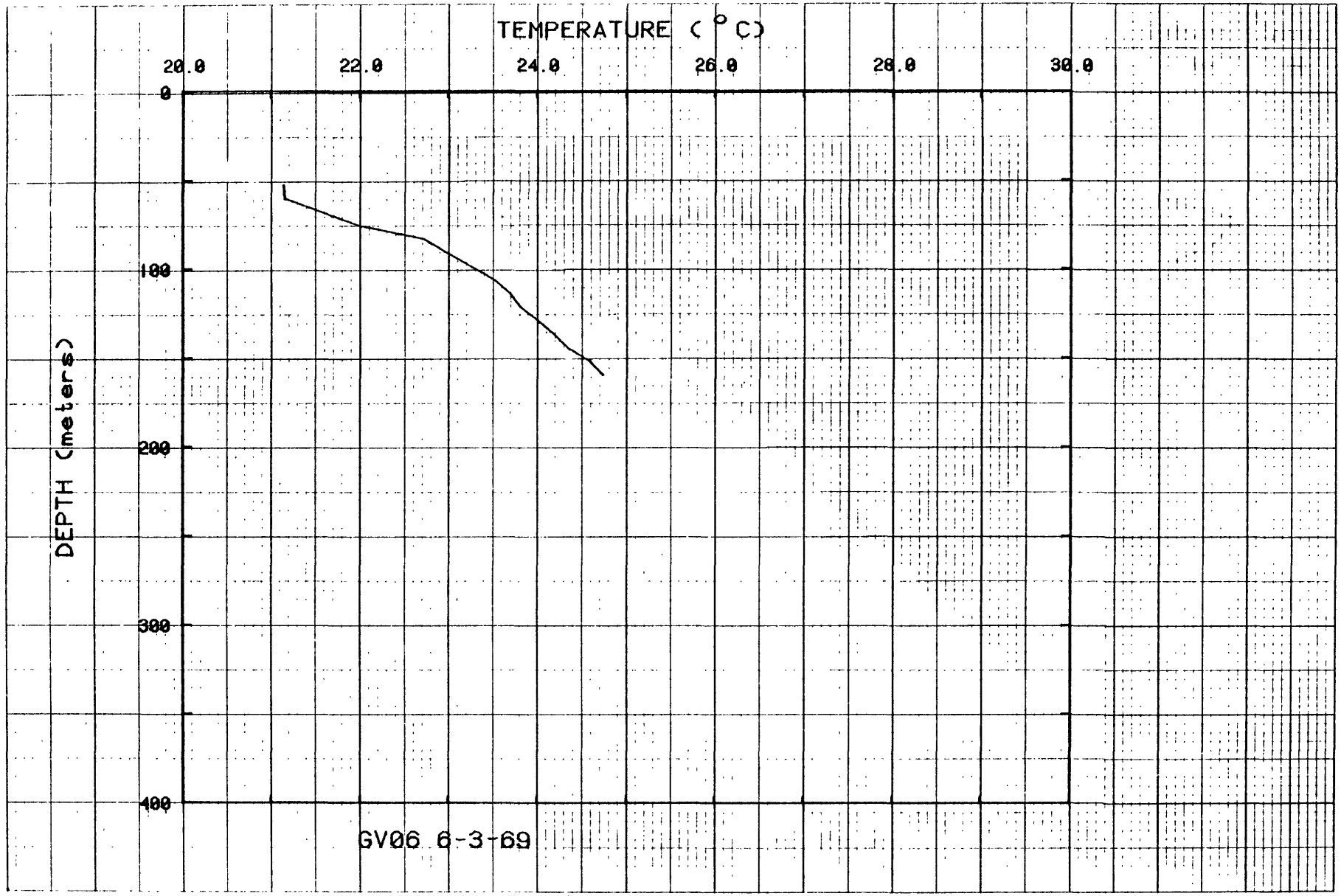

Figure 15. Temperatures for hole GV06.

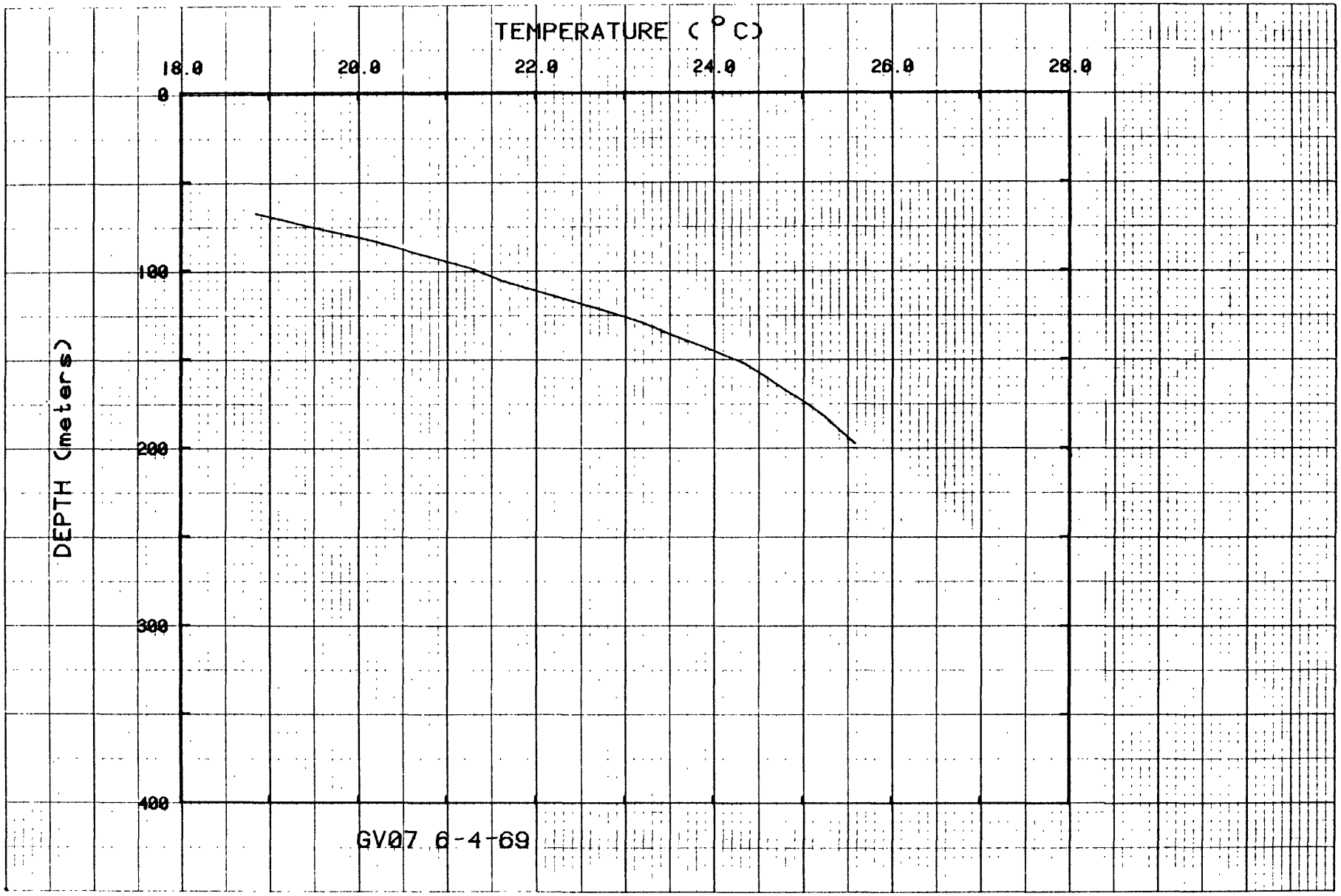

Figure 16. Temperatures for hole GV07.

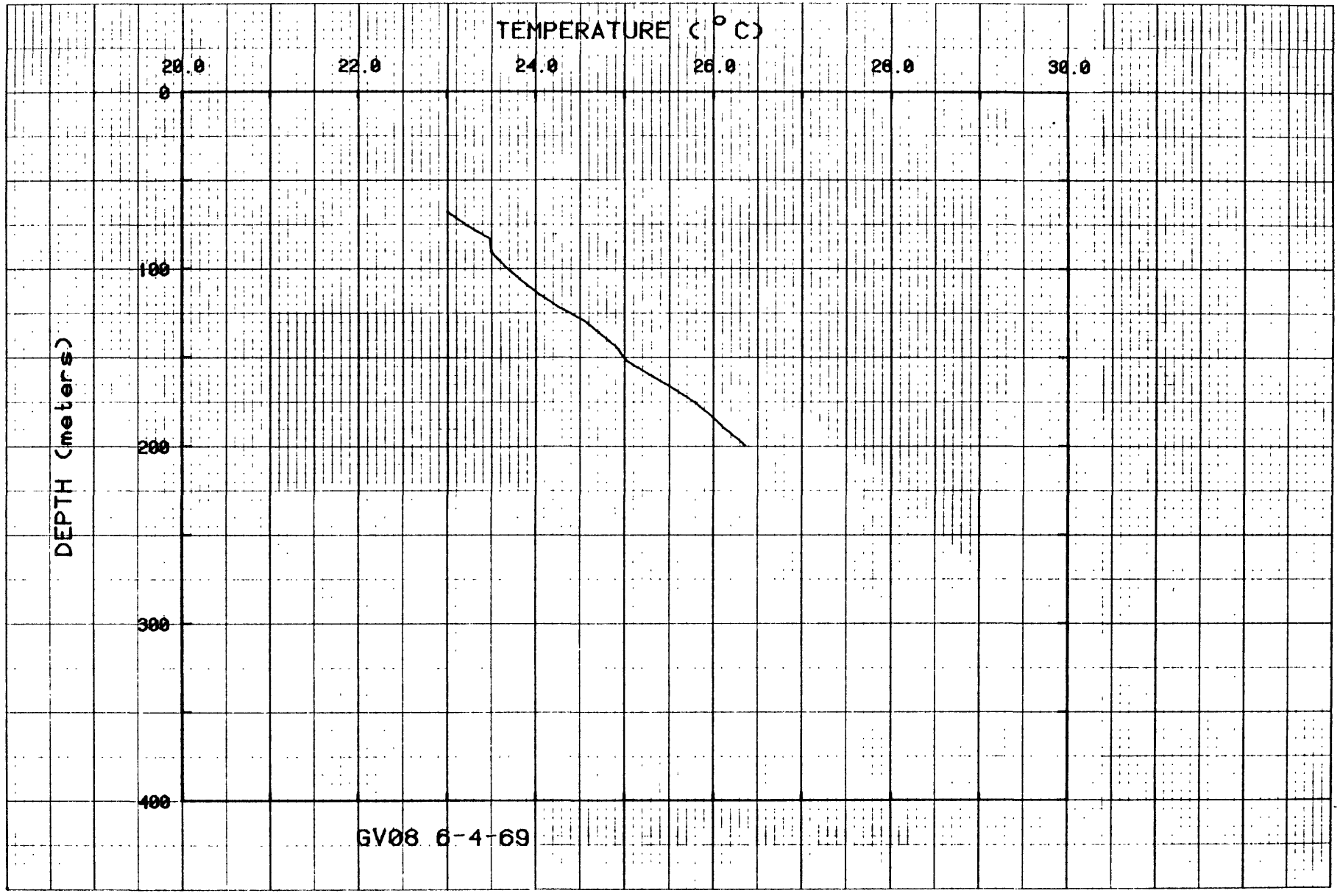

Figure 17. Temperatures for hole GV08.

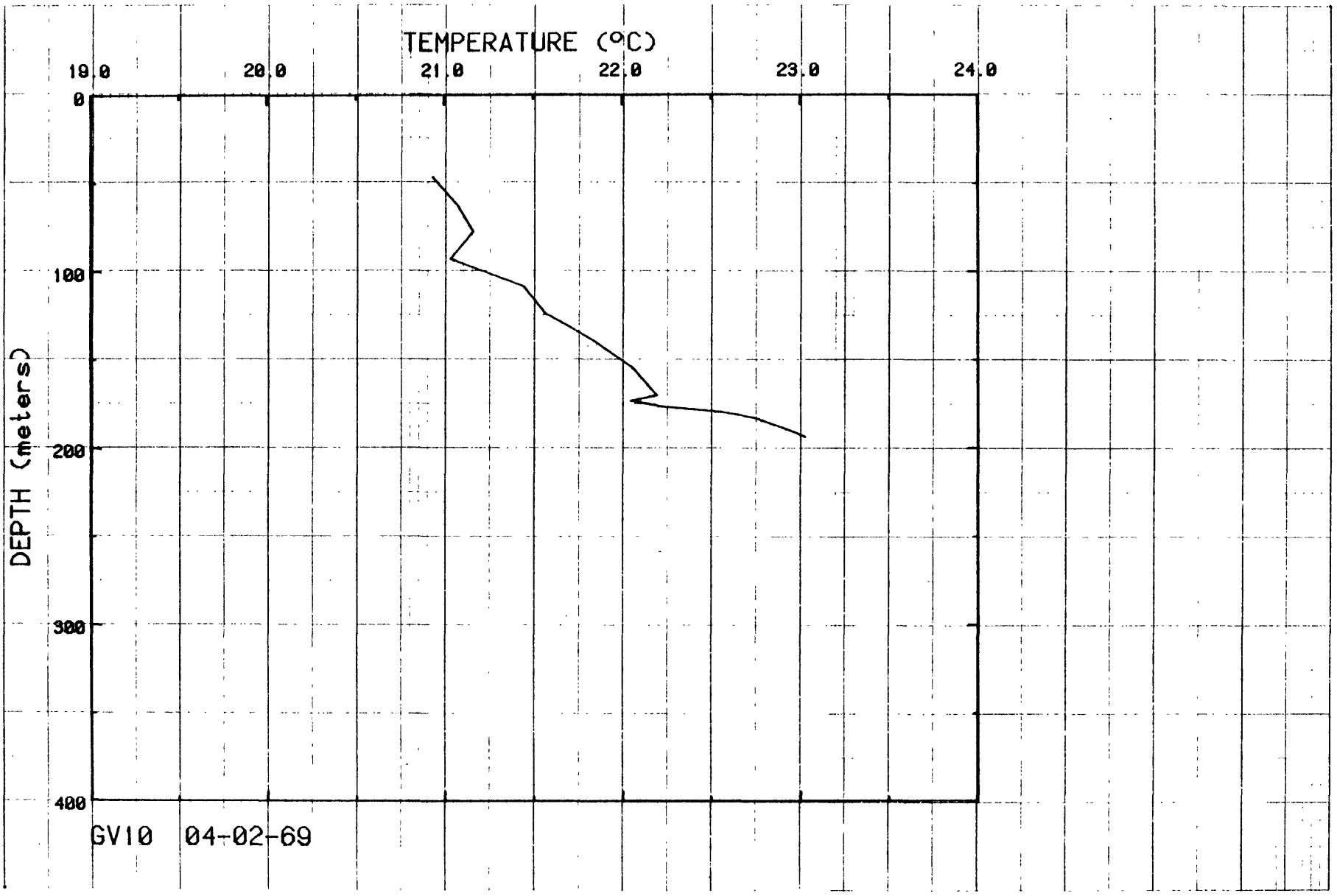

Figure 18. Temperatures for hole GV10.

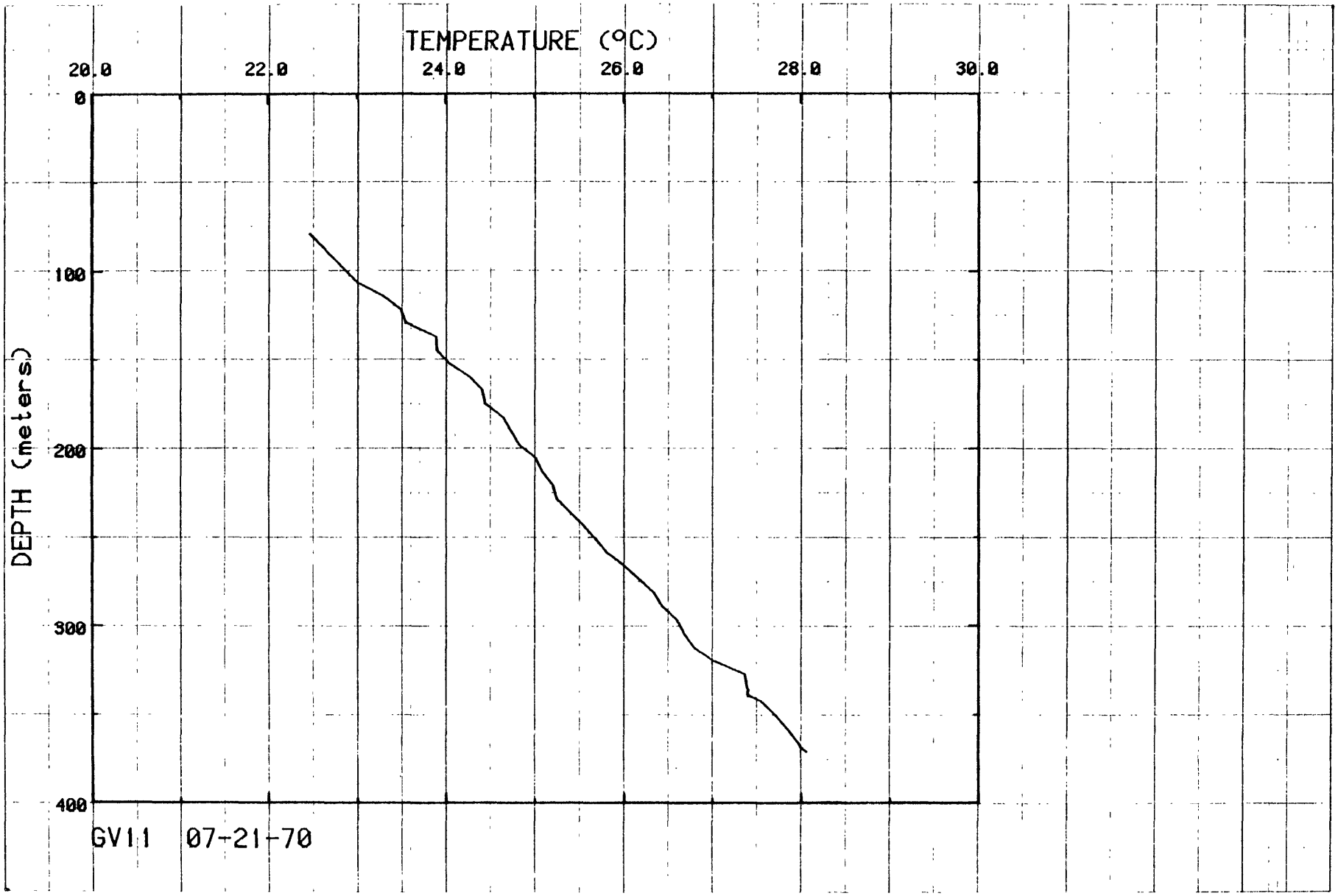

Figure 19. Temperatures for hole GV11.

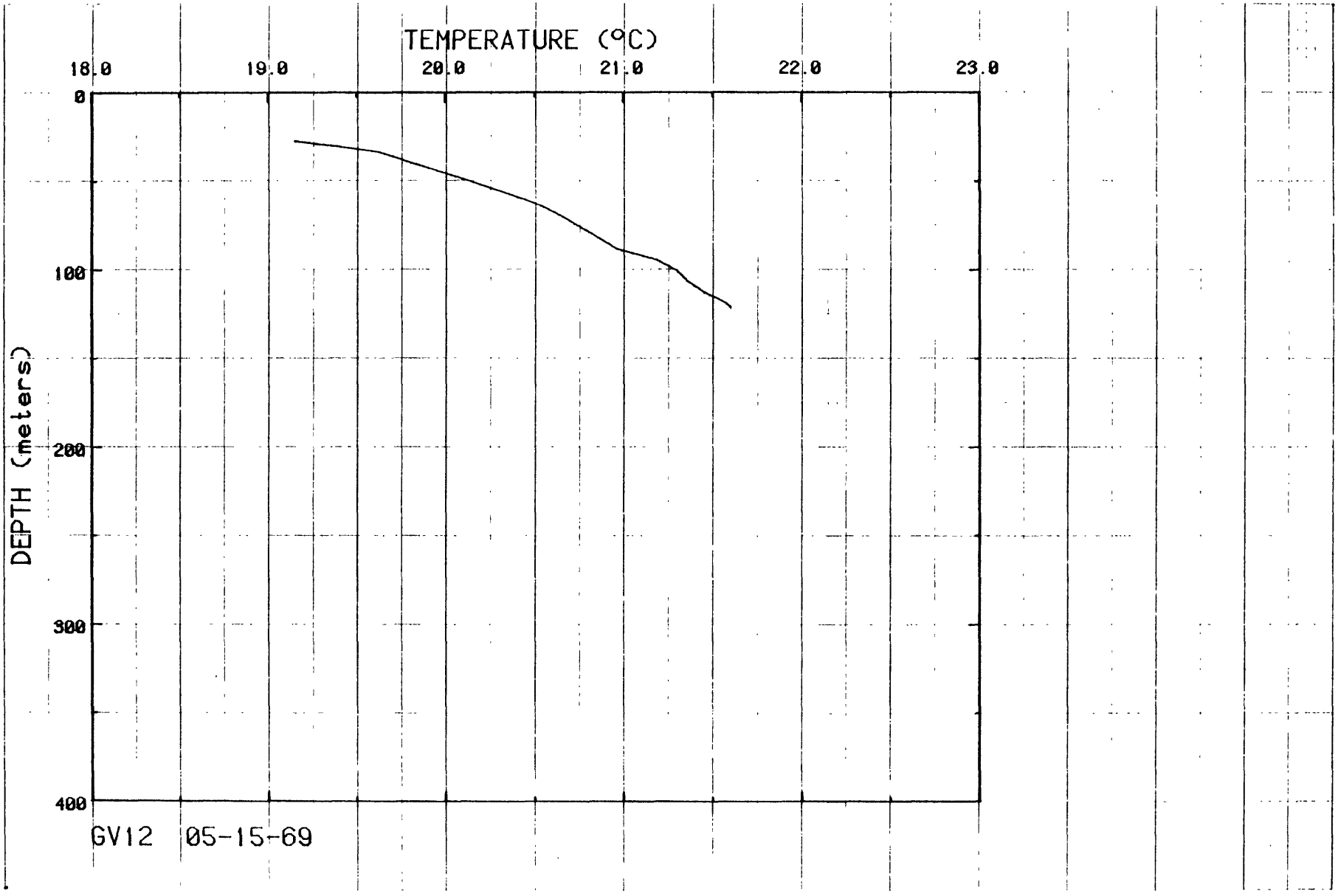

Figure 20. Temperatures for hole GV12.

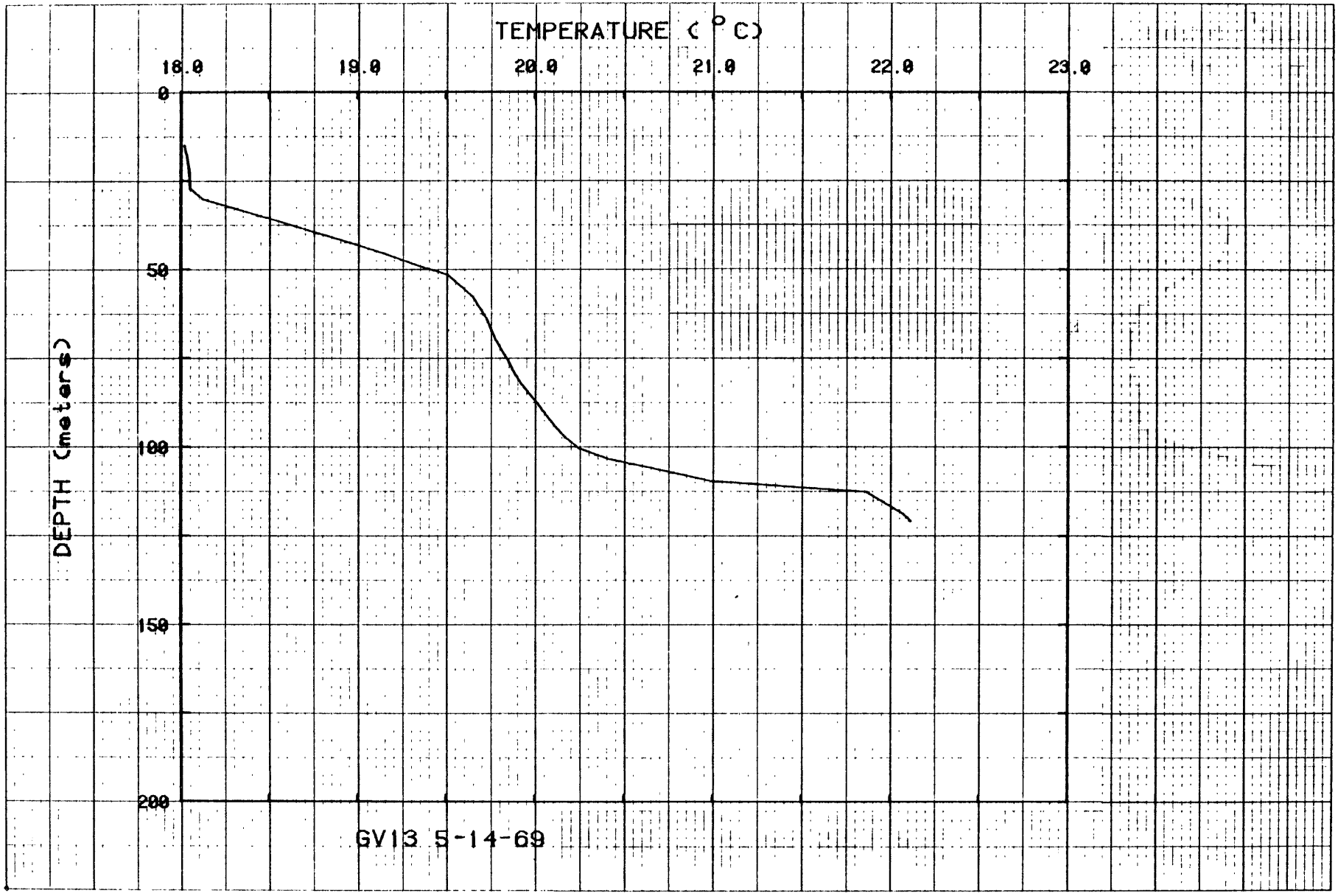

Figure 21. Temperatures for hole GV13.

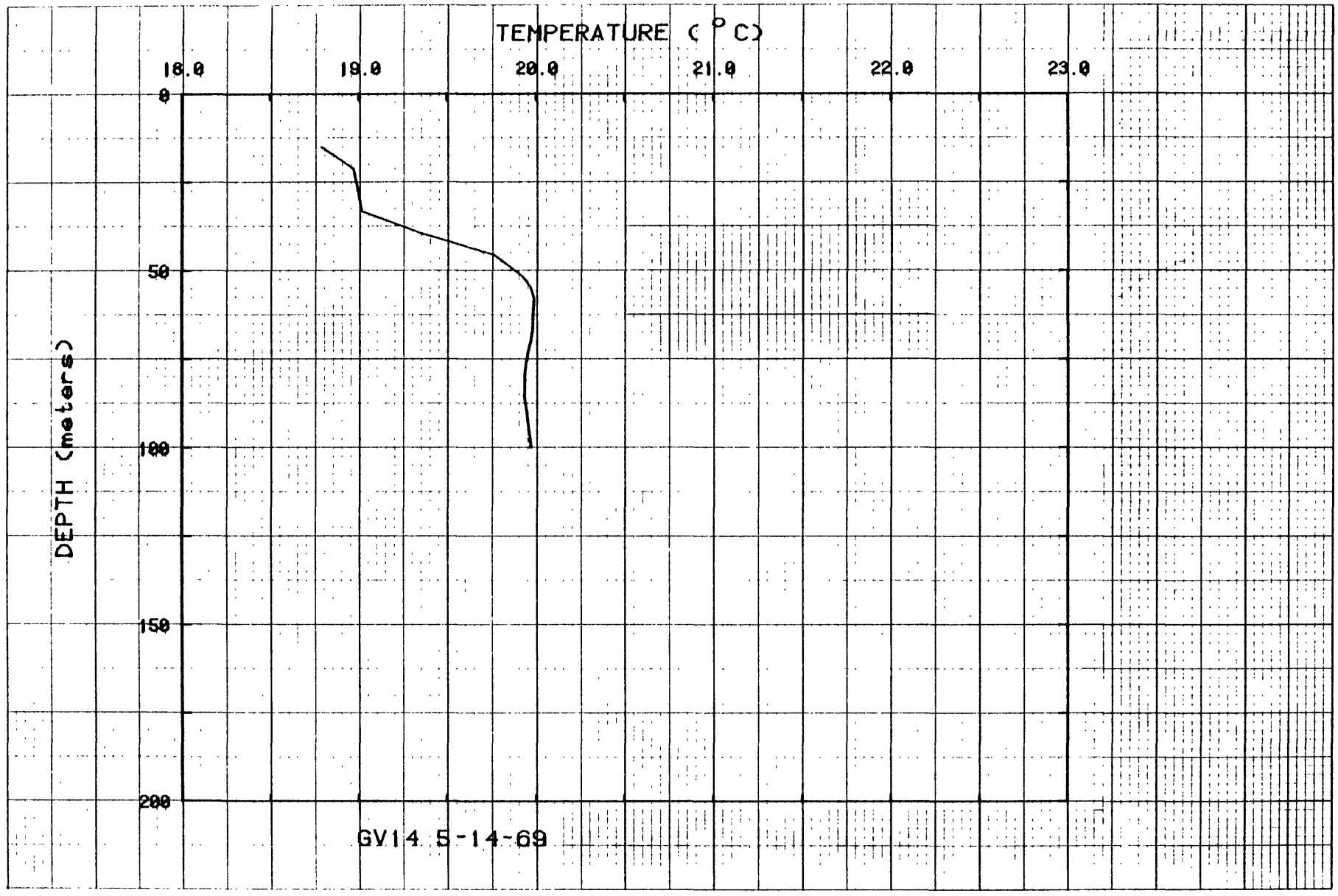

Figure 22. Temperatures for hole GV14.

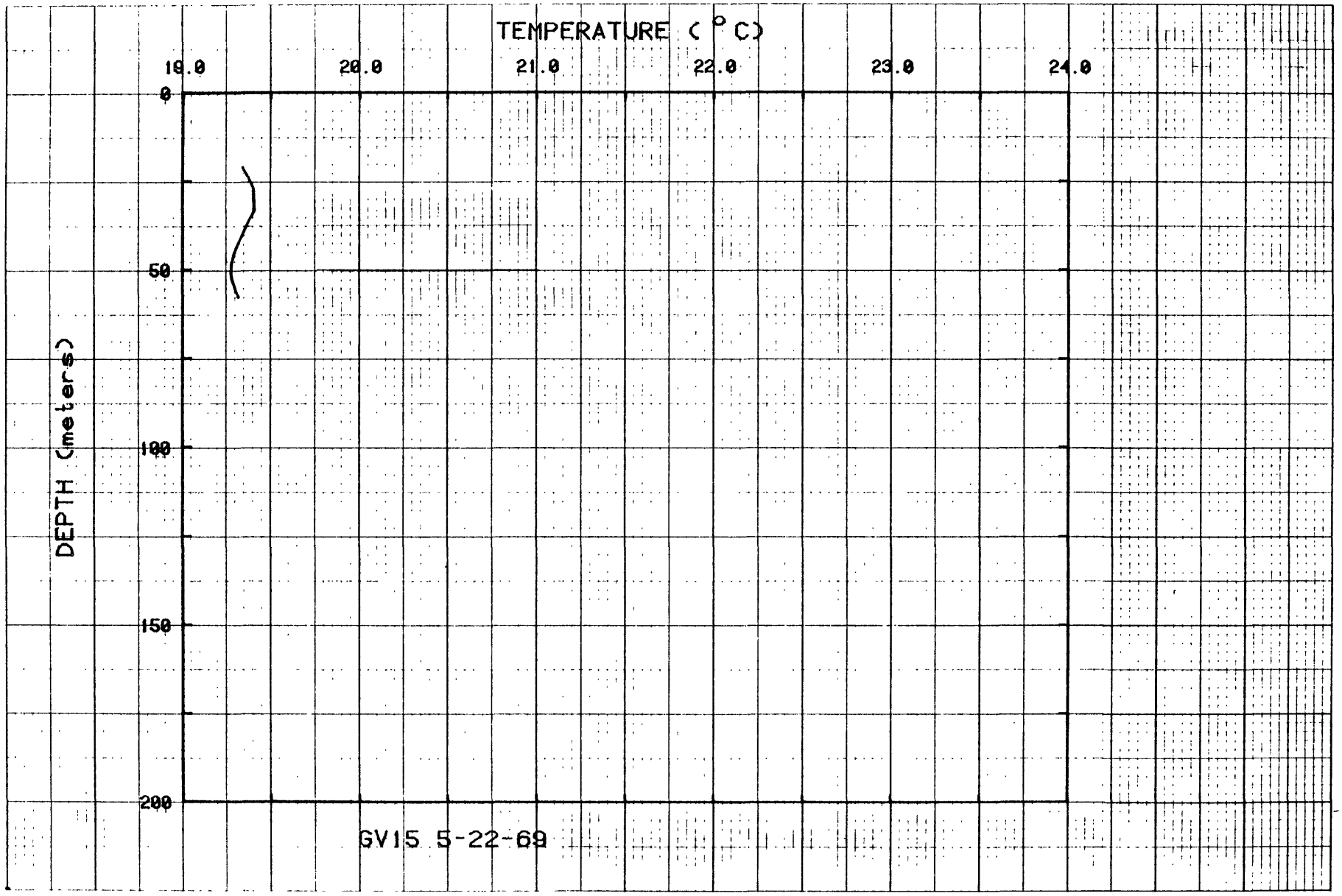

Figure 23. Temperatures for hole GV15.

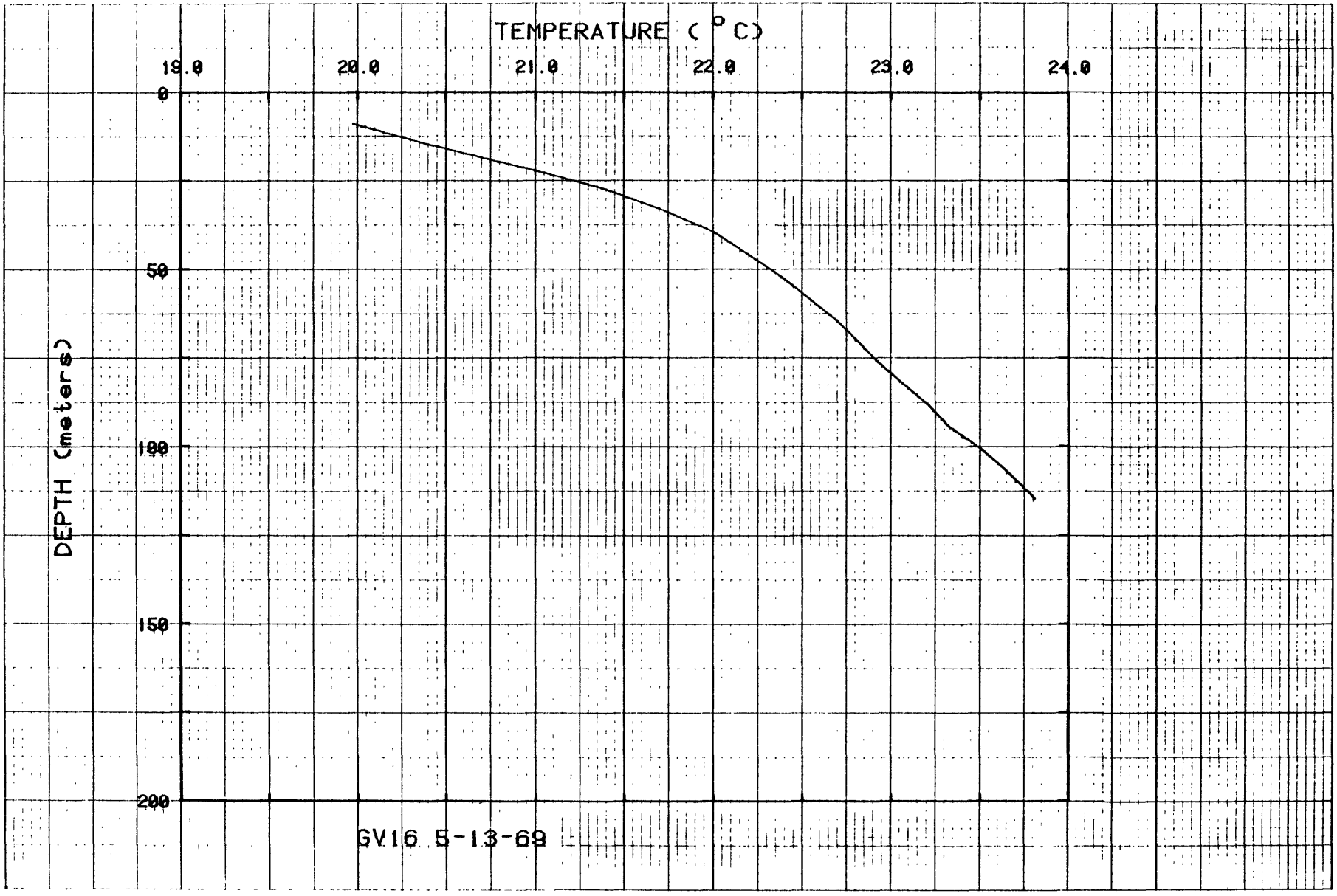

Figure 24. Temperatures for hole GV16.

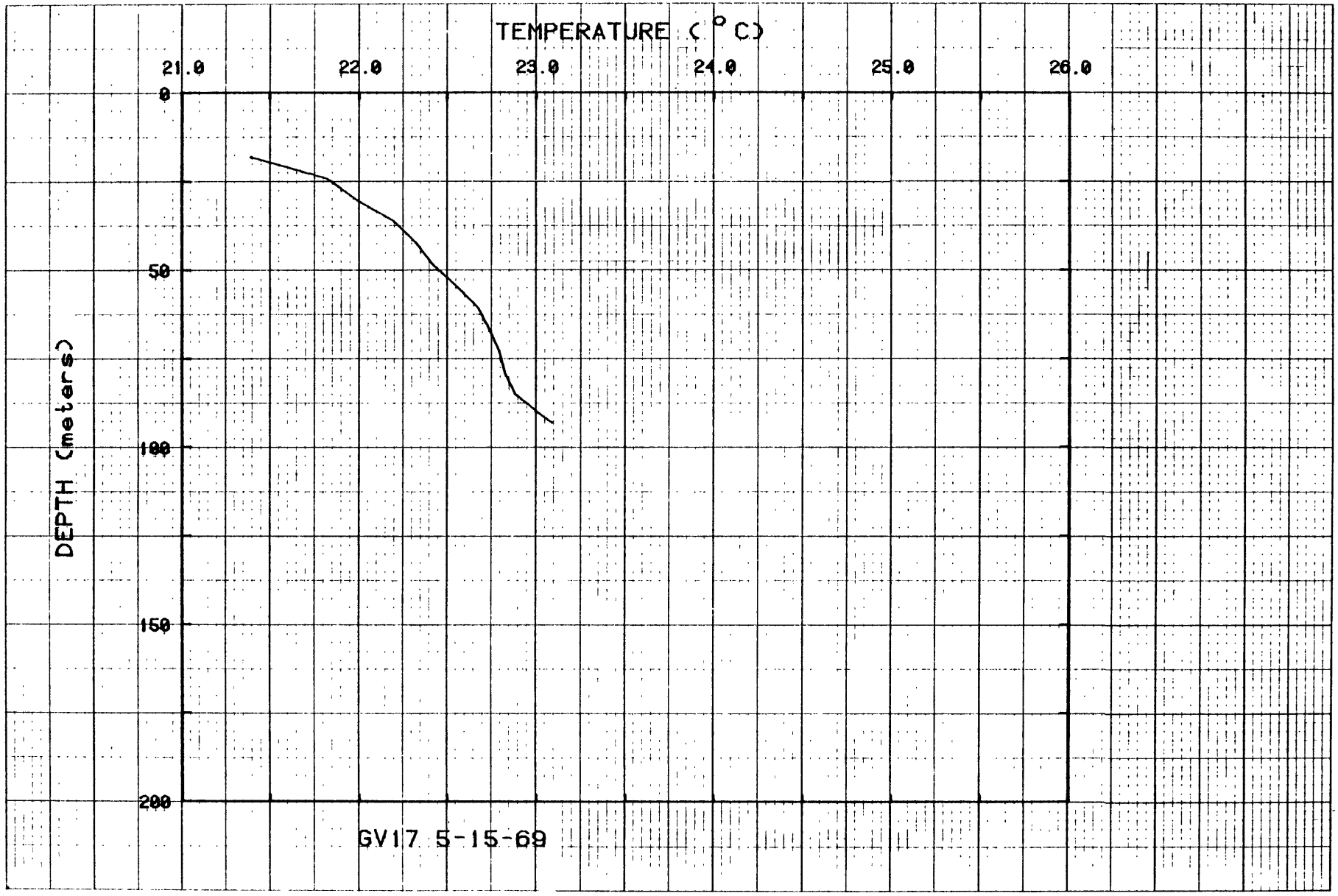

Figure 25. Temperatures for hole GV17.

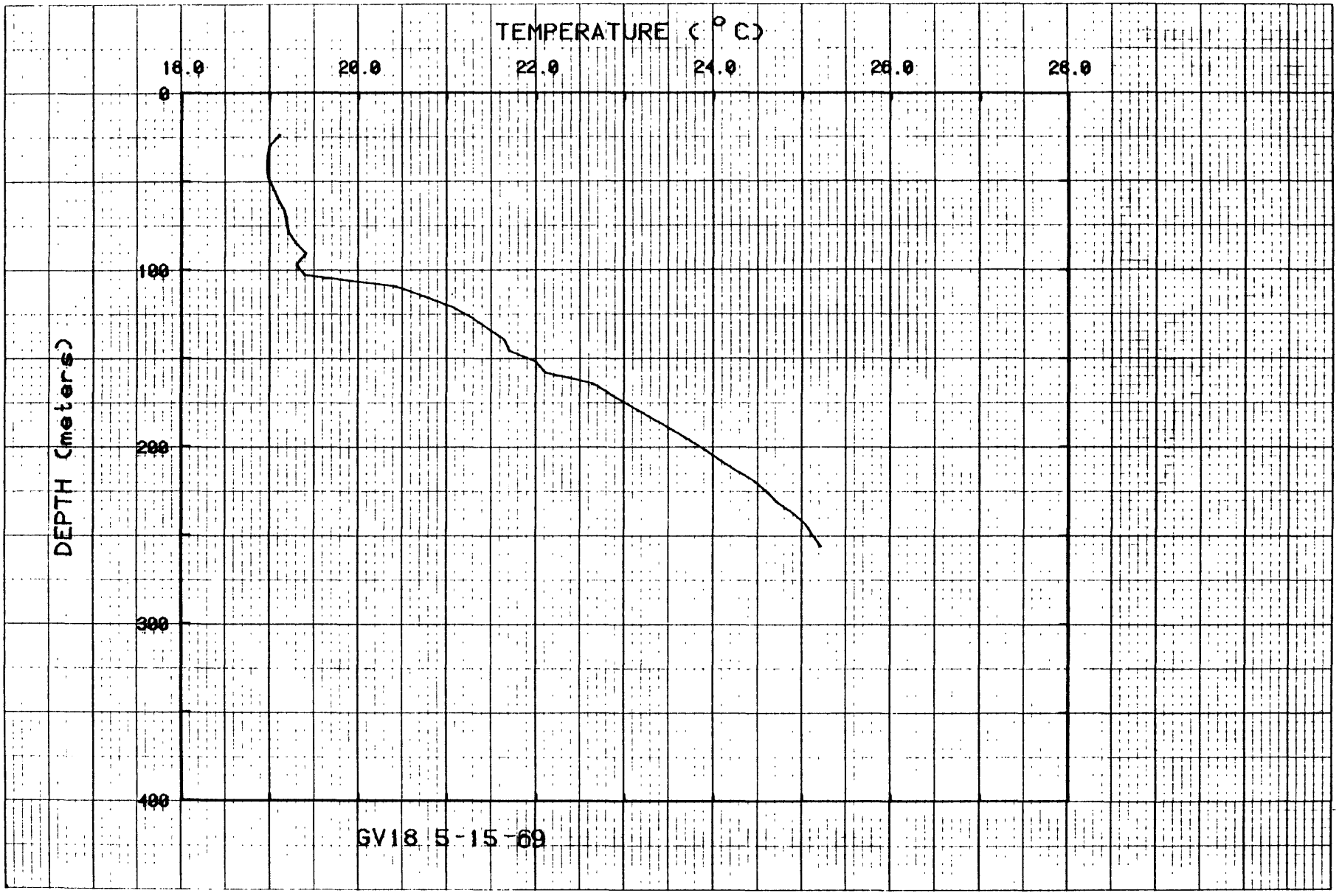

Figure 26. Temperatures for hole GV18.

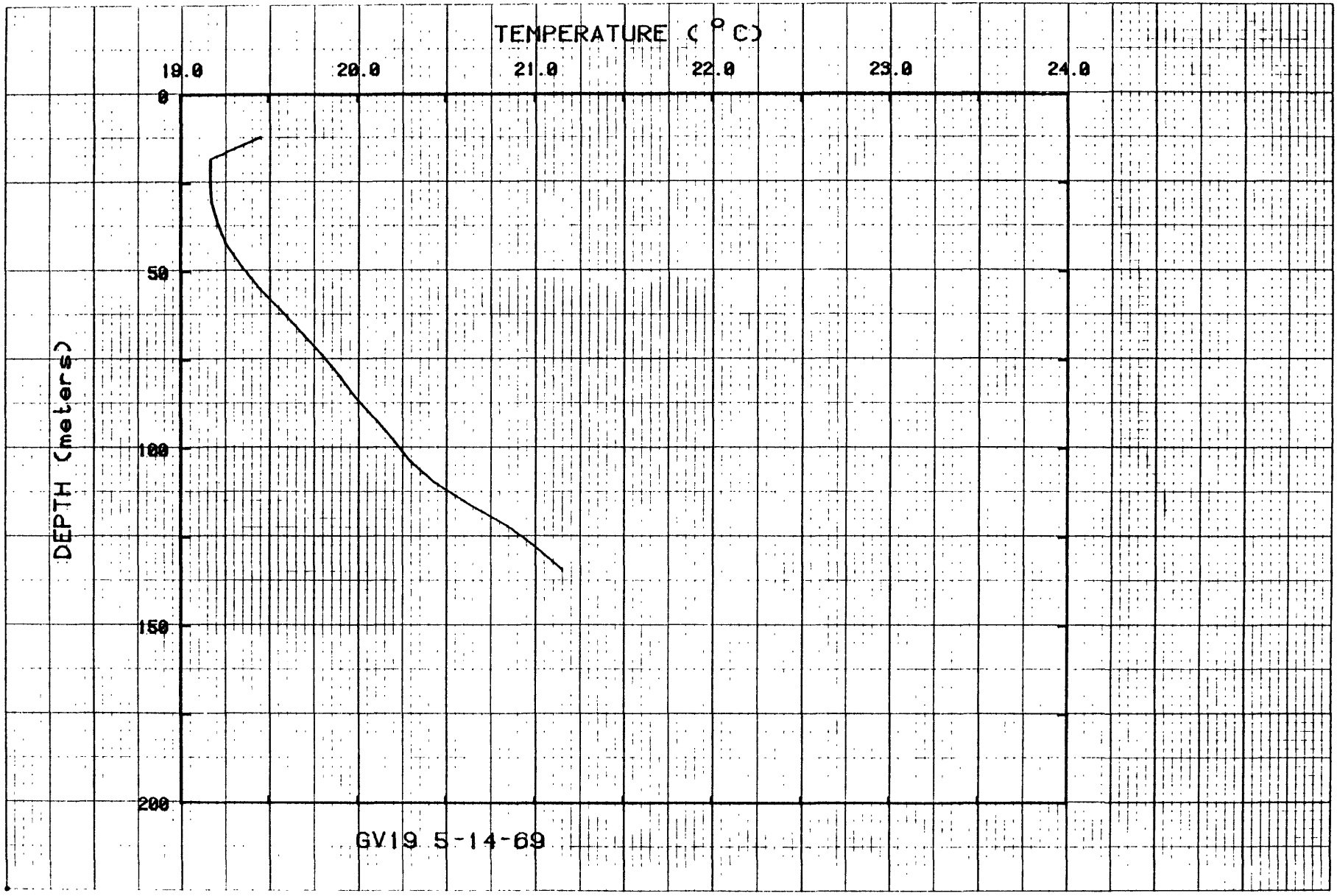

Figure 27. Temperatures for hole GV19.

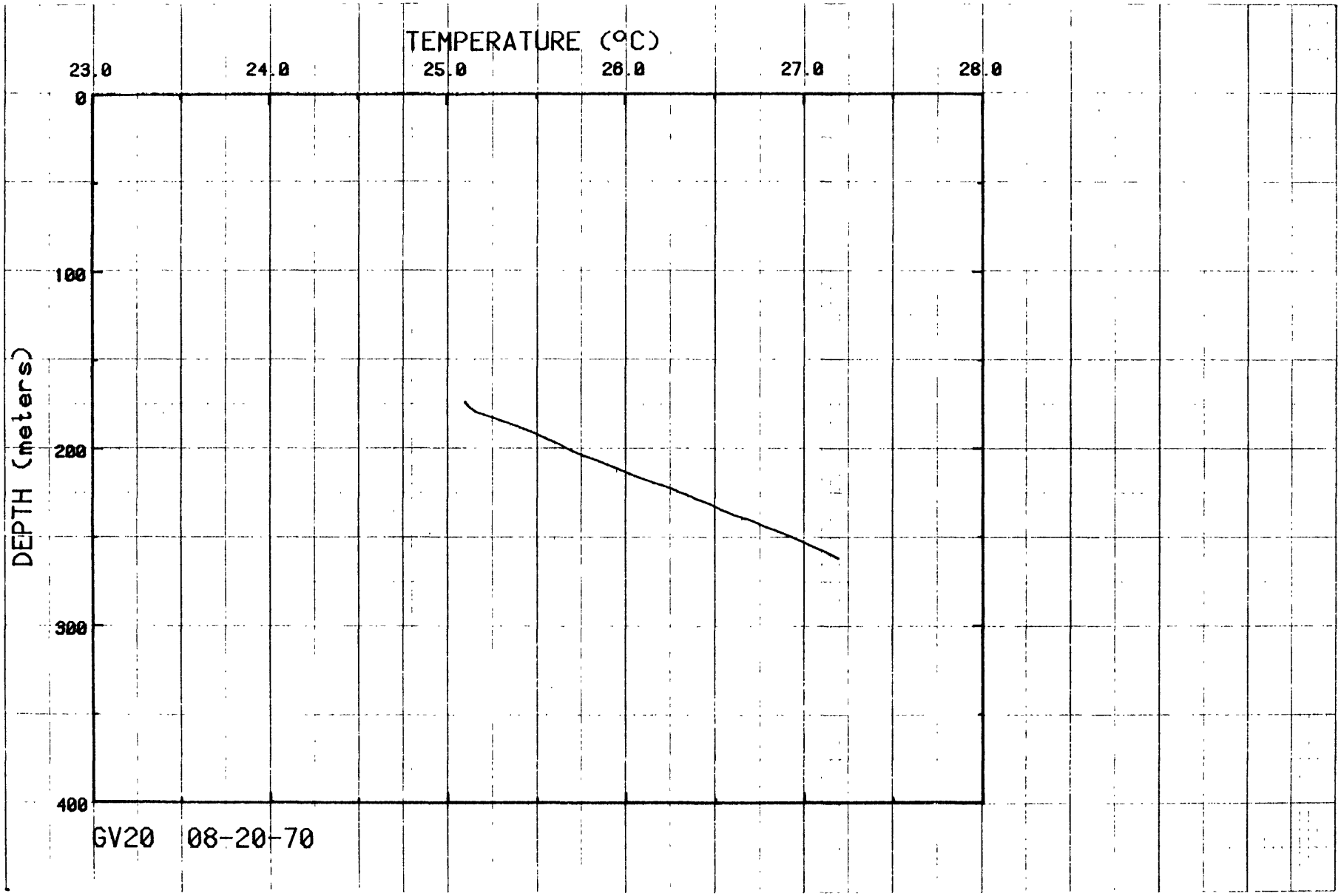

Figure 28. Temperatures for hole GV20.

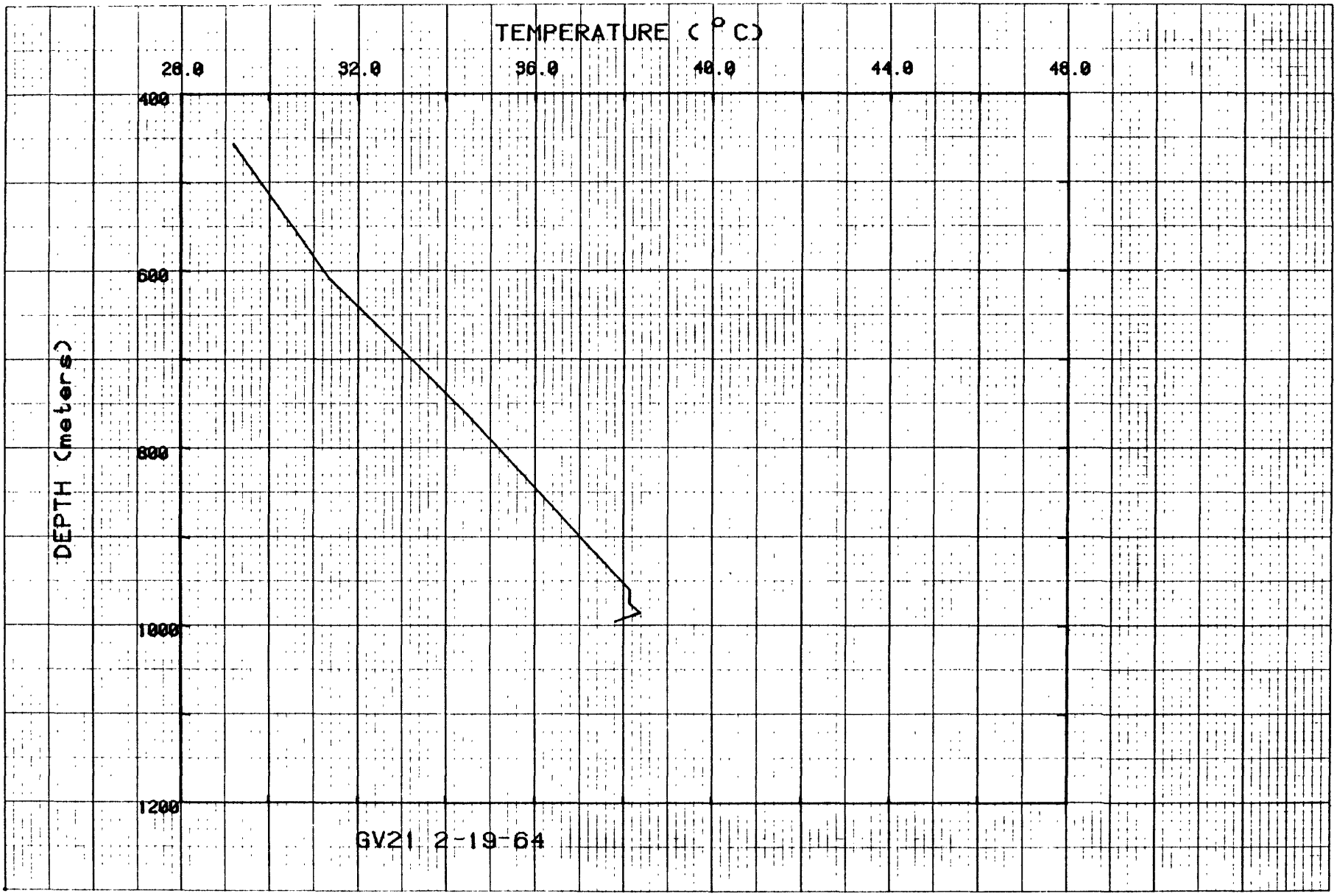

Figure 29. Temperatures for hole GV21.

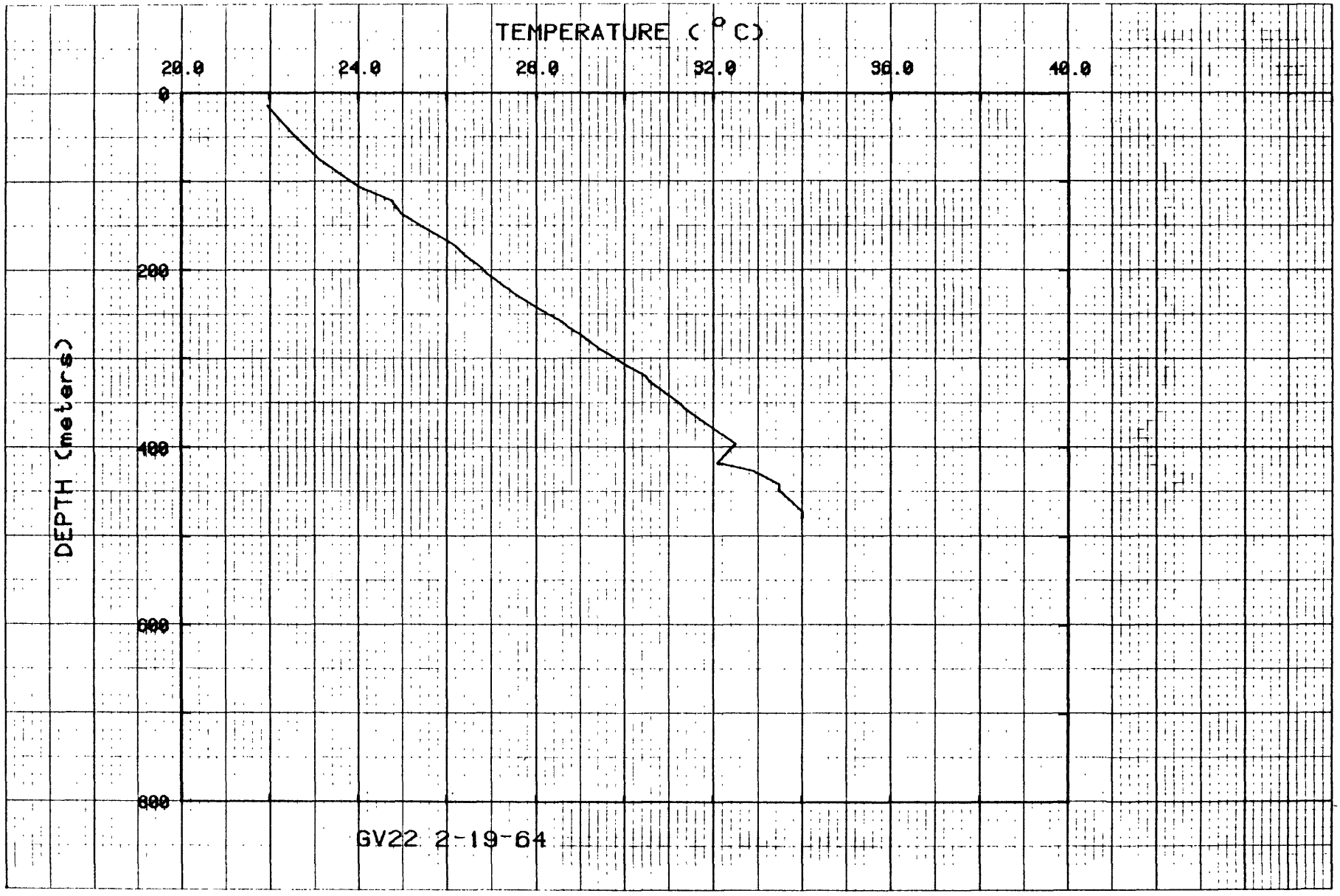

Figure 30. Temperatures for hole GV22.

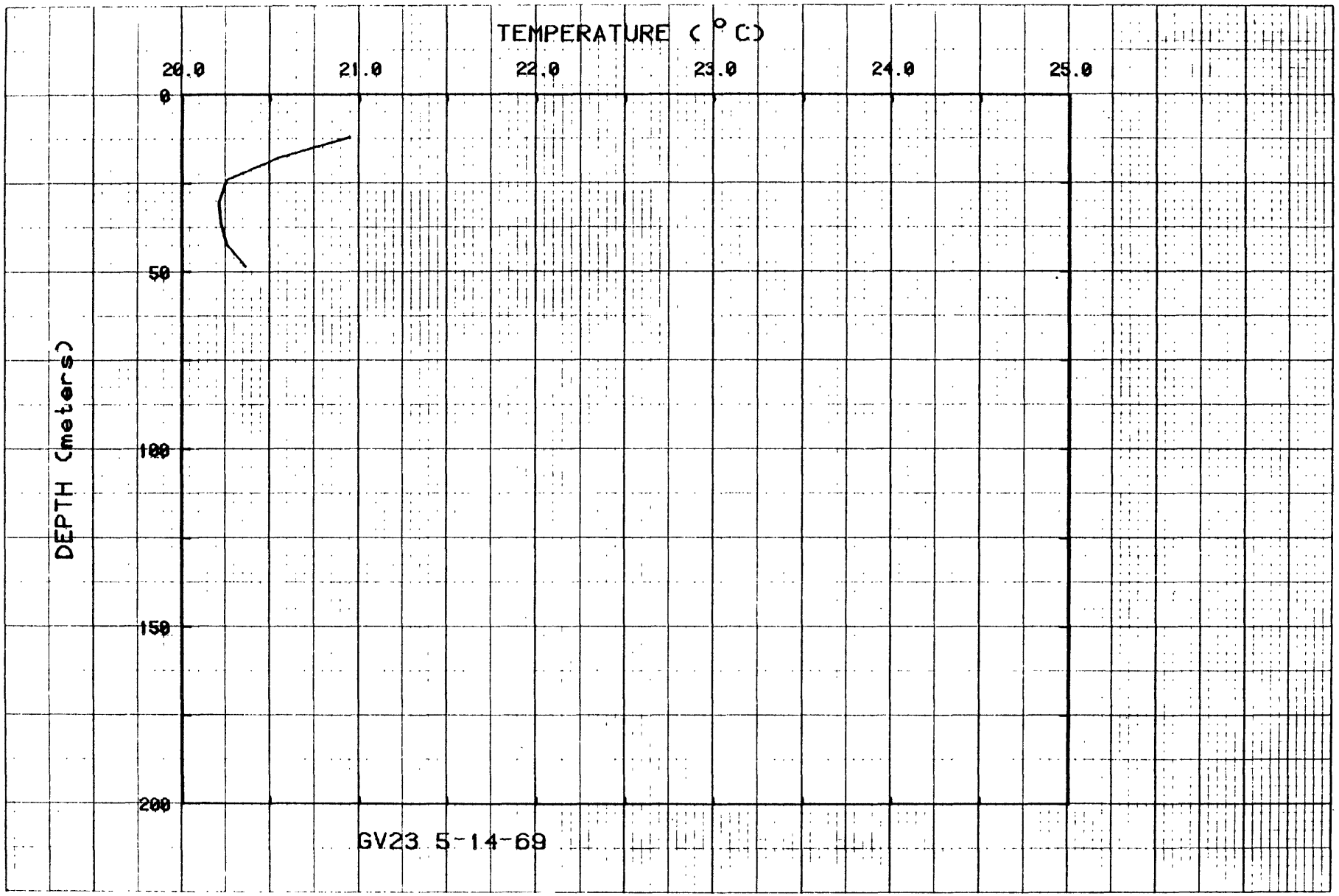

Figure 31. Temperatures for hole GV23.

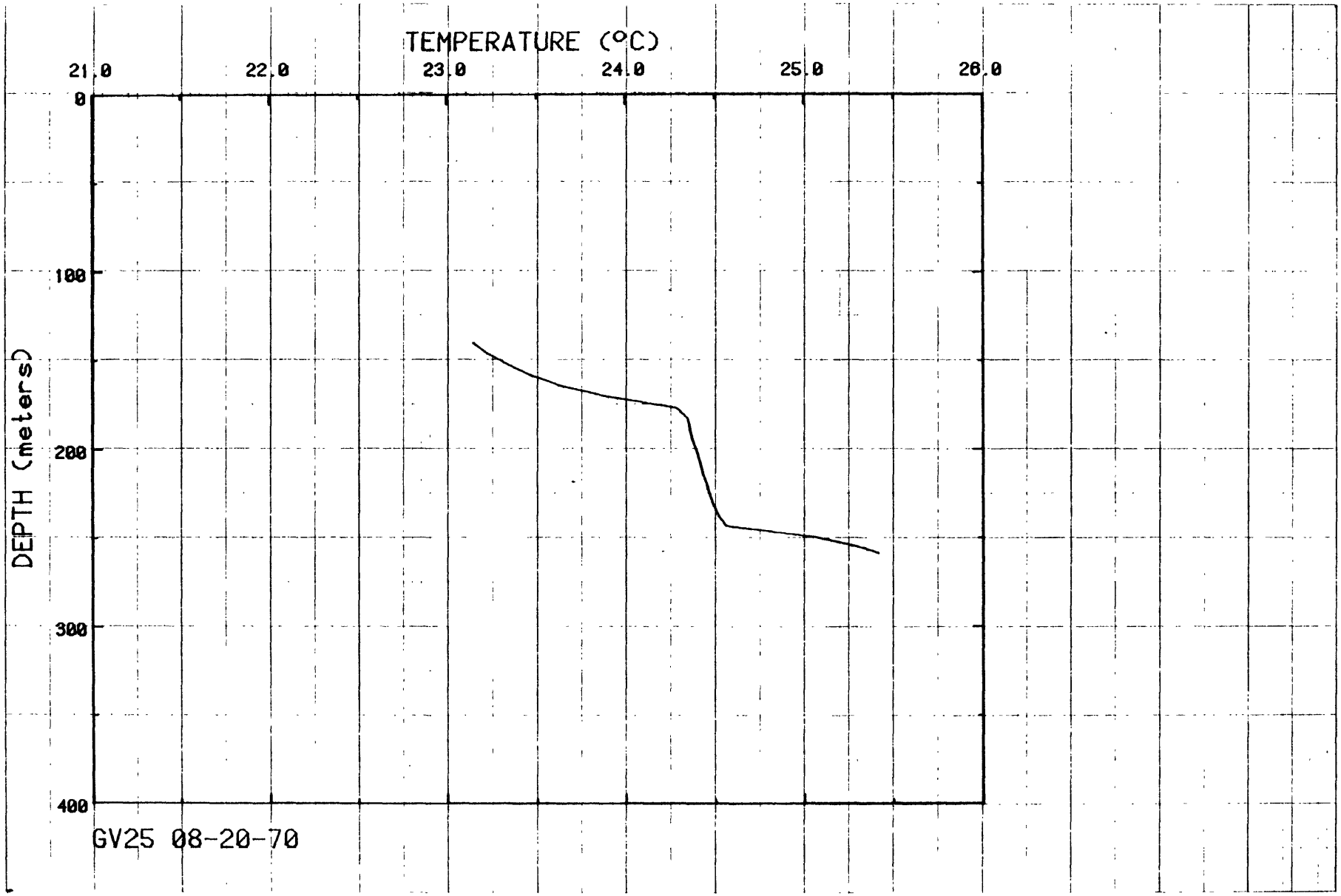

Figure 32. Temperatures for hole GV25.

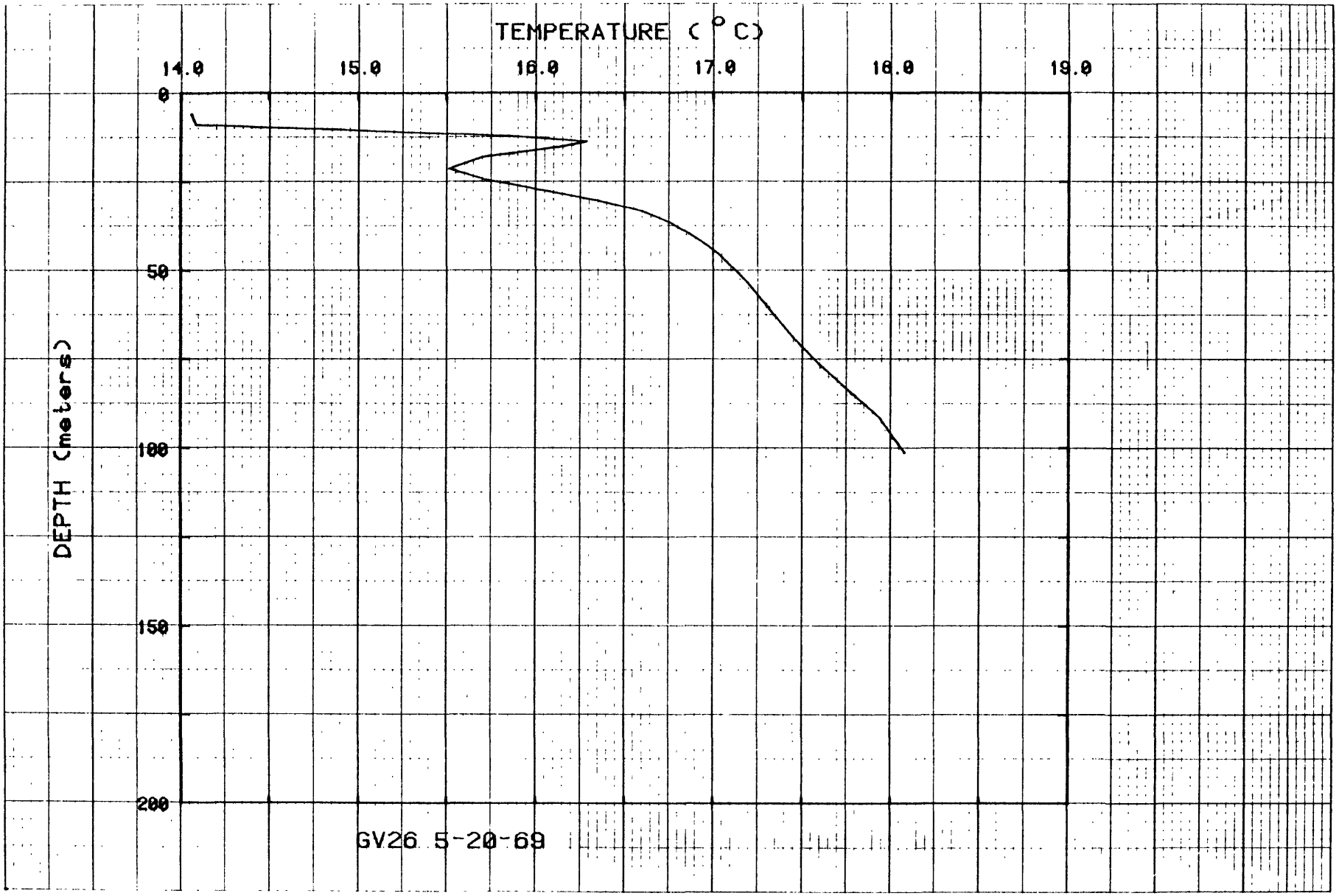

Figure 33. Temperatures for hole GV26.

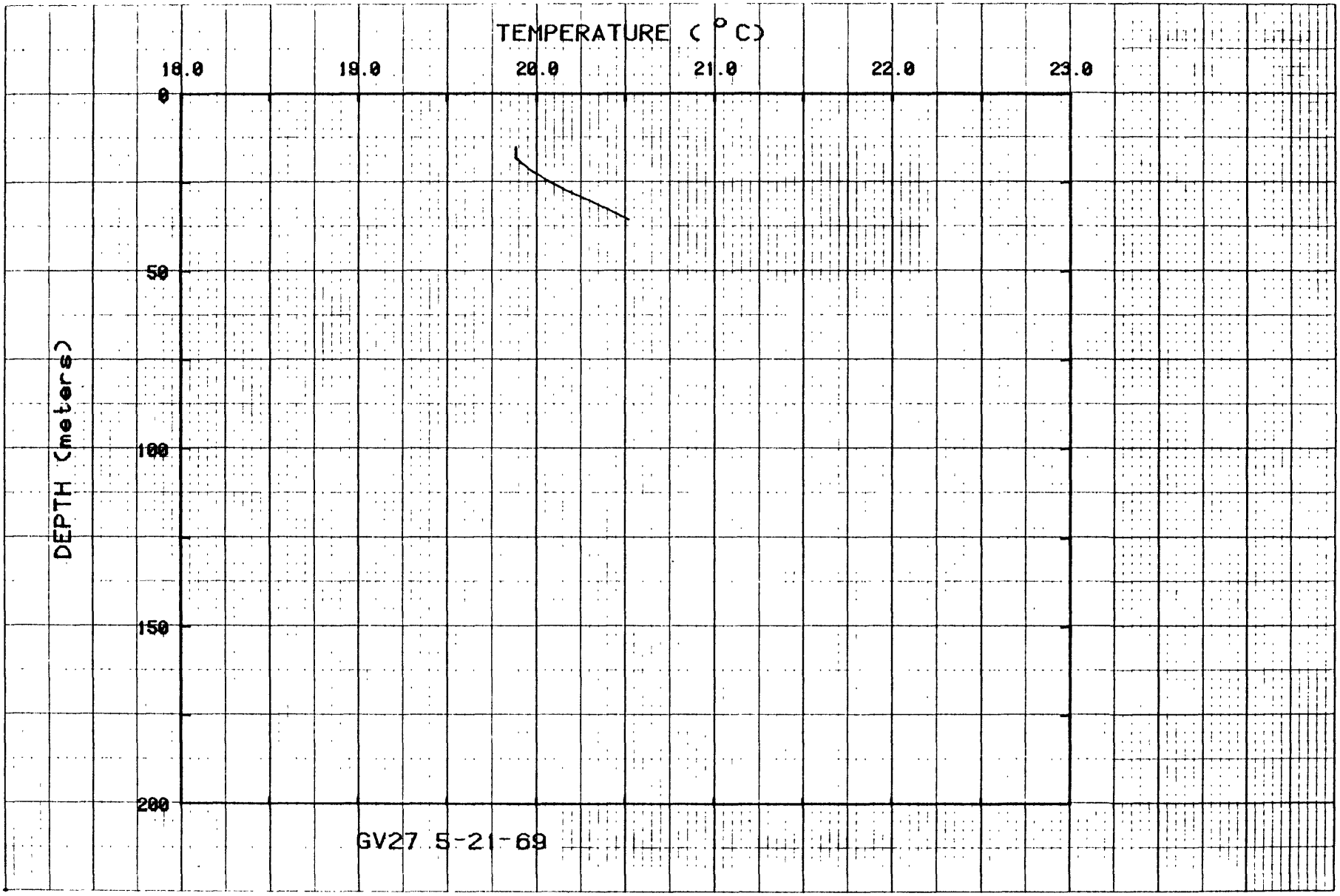

Figure 34. Temperatures for hole GV27.

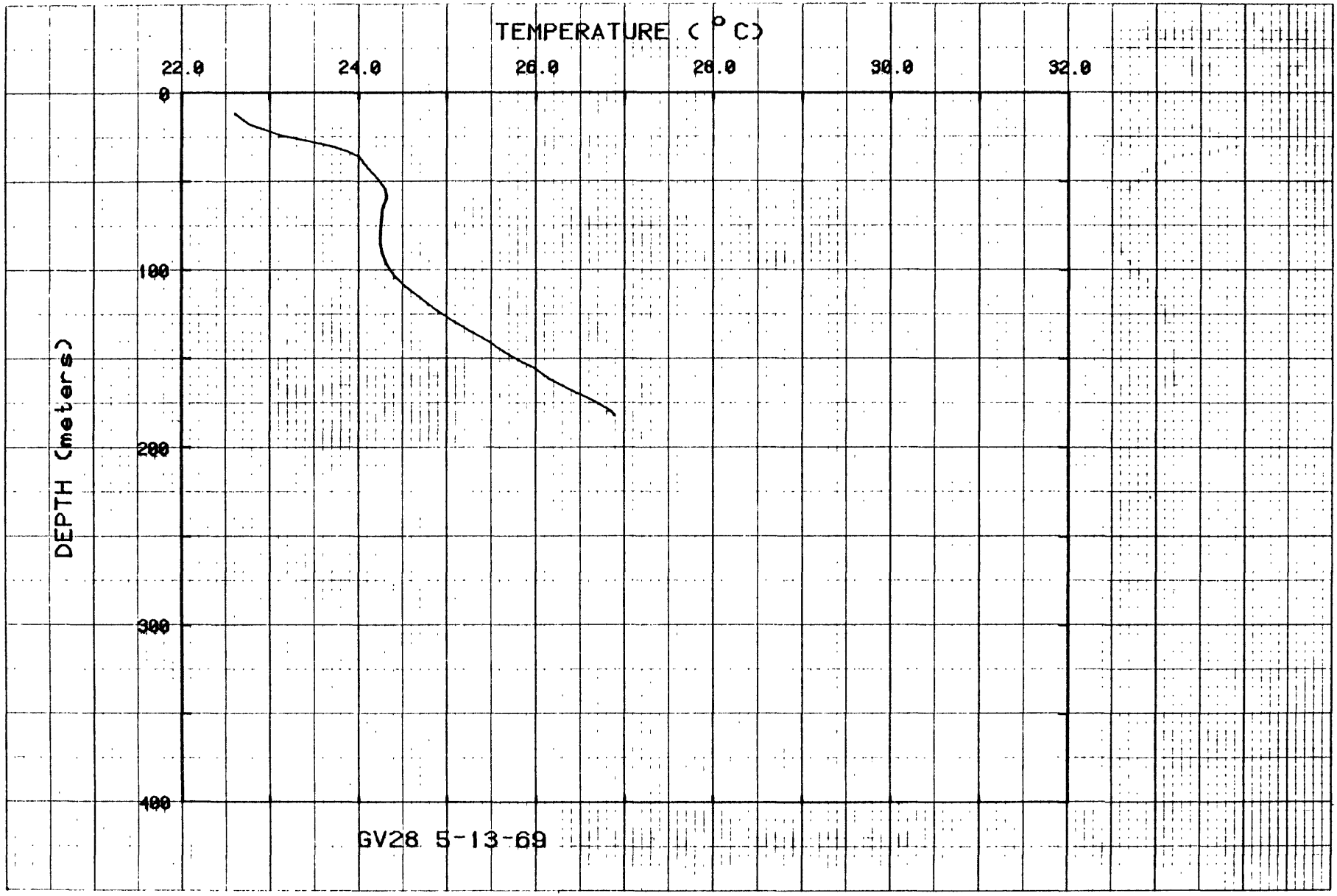

Figure 35. Temperatures for hole GV28.

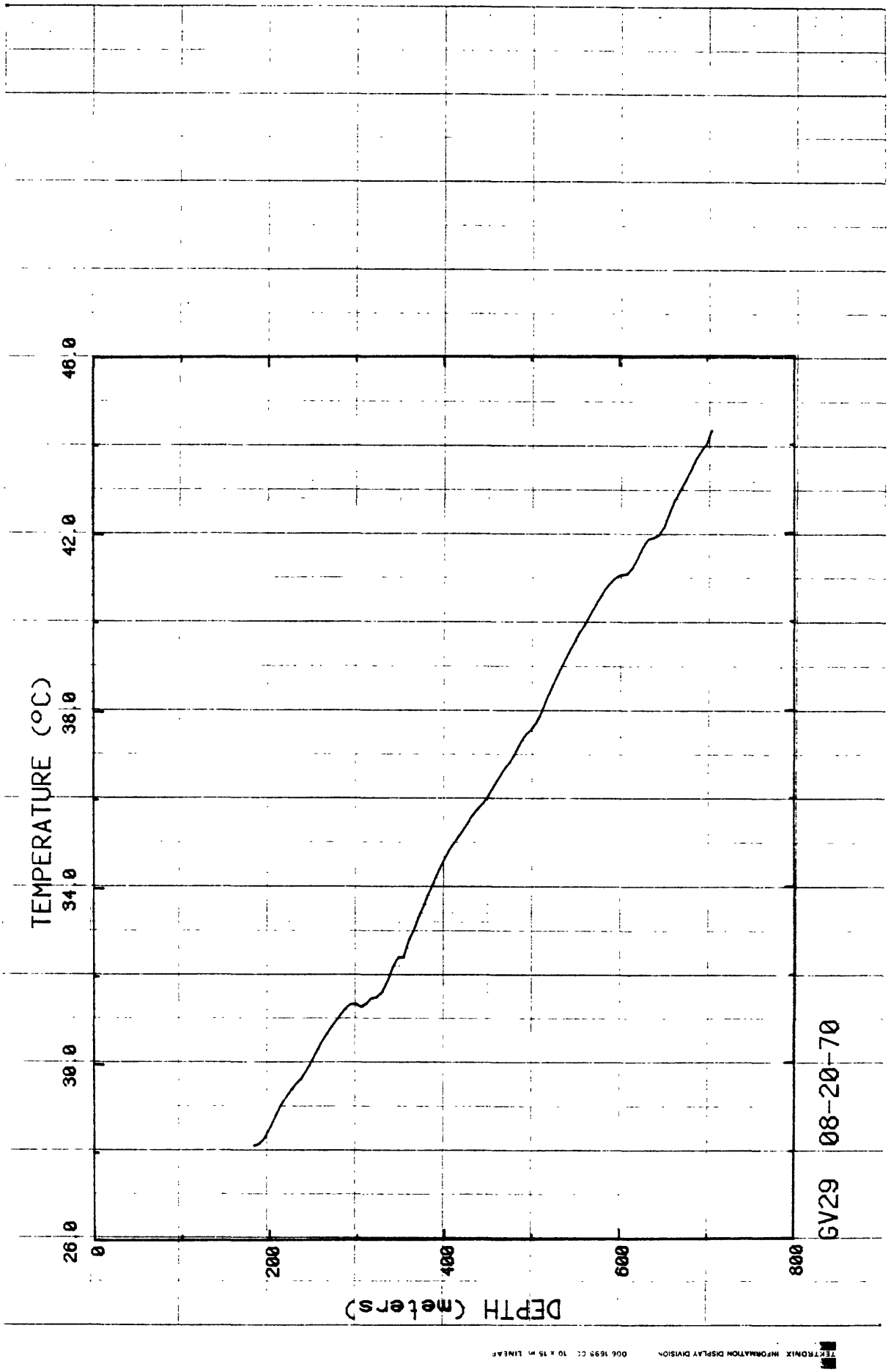

Figure 36. Temperatures for hole GV29.

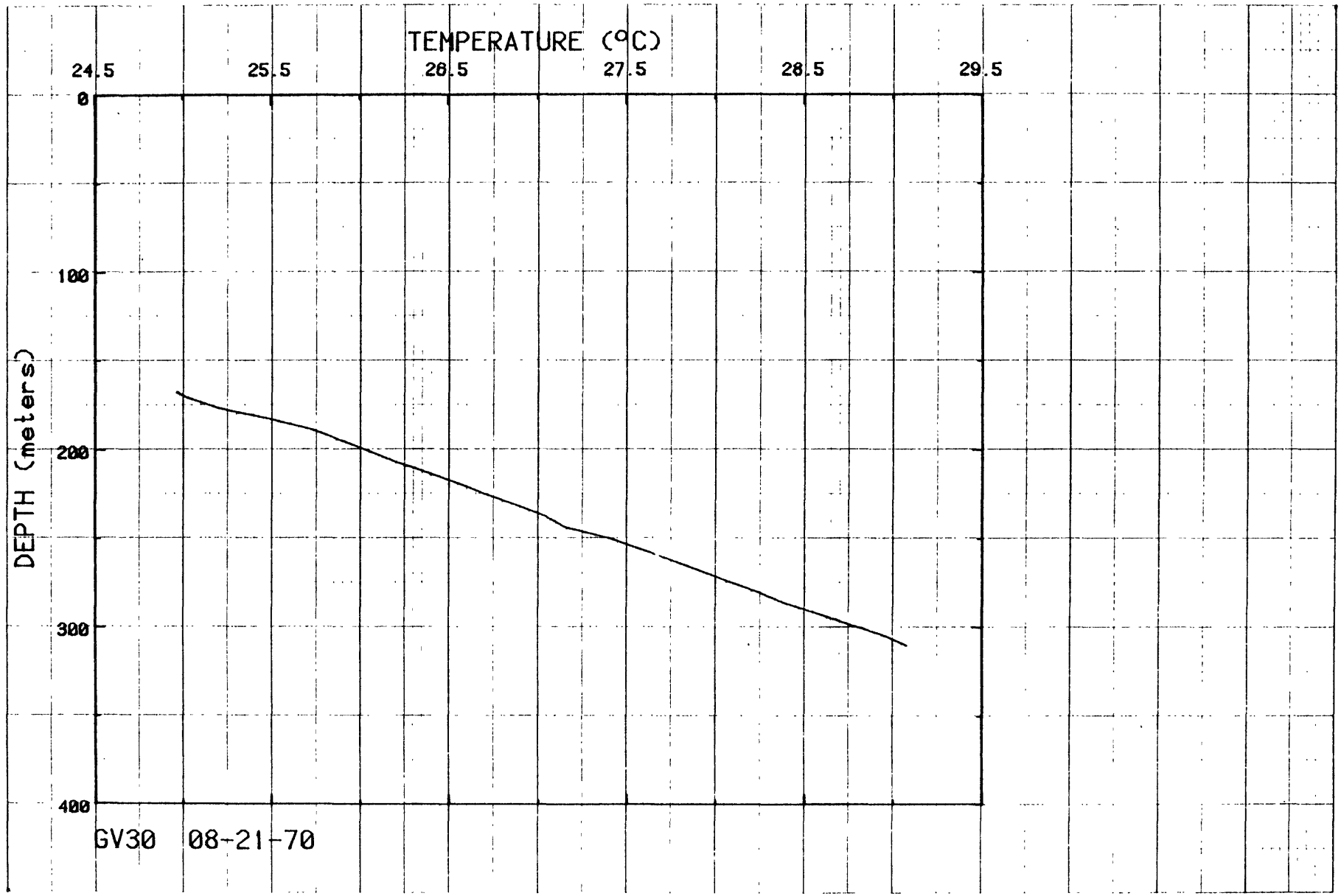

Figure 37. Temperatures for hole GV30.

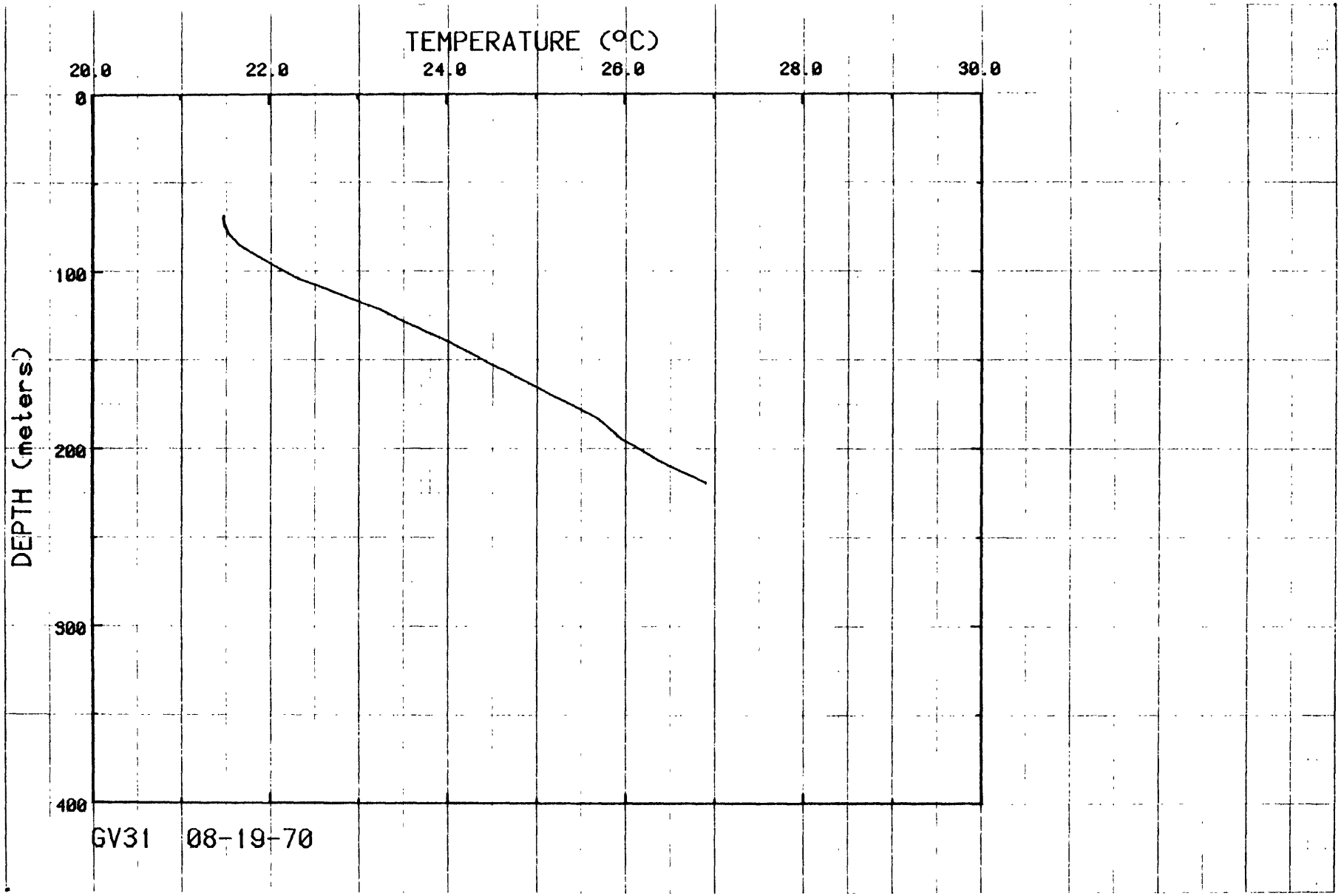

Figure 38. Temperatures for hole GV31.

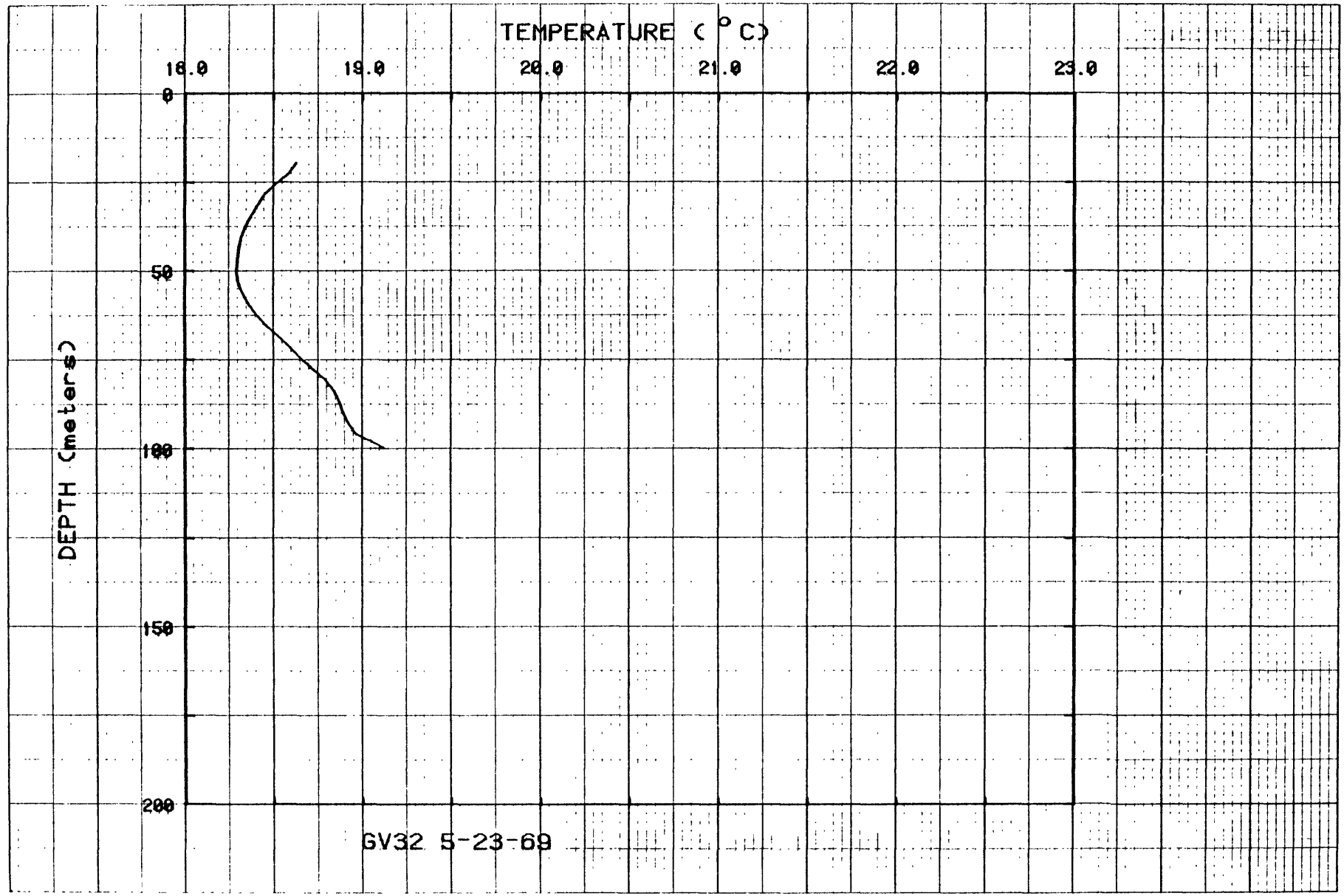

Figure 39. Temperatures for hole GV32.

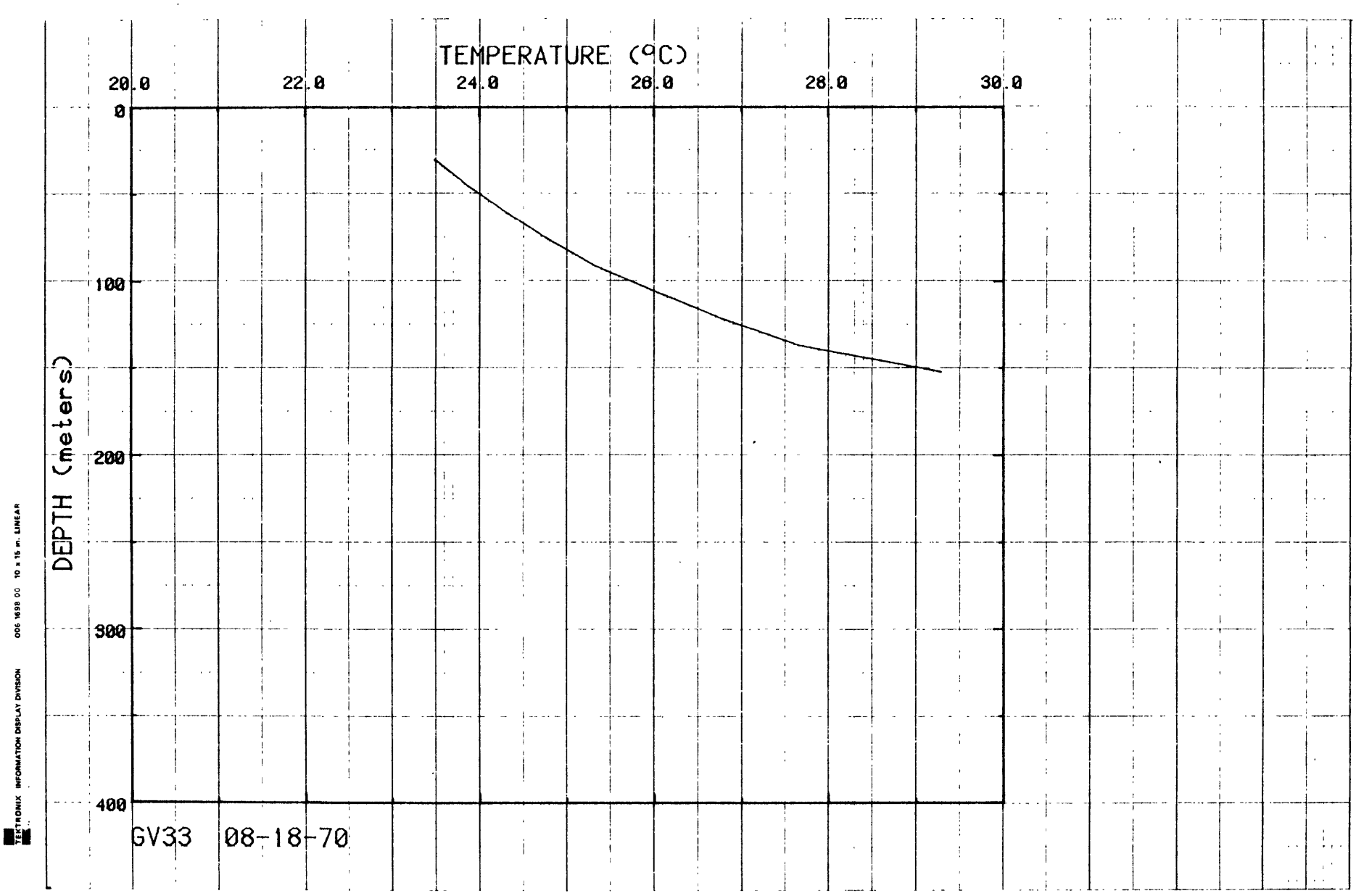

Figure 40. Temperatures for hole GV33.

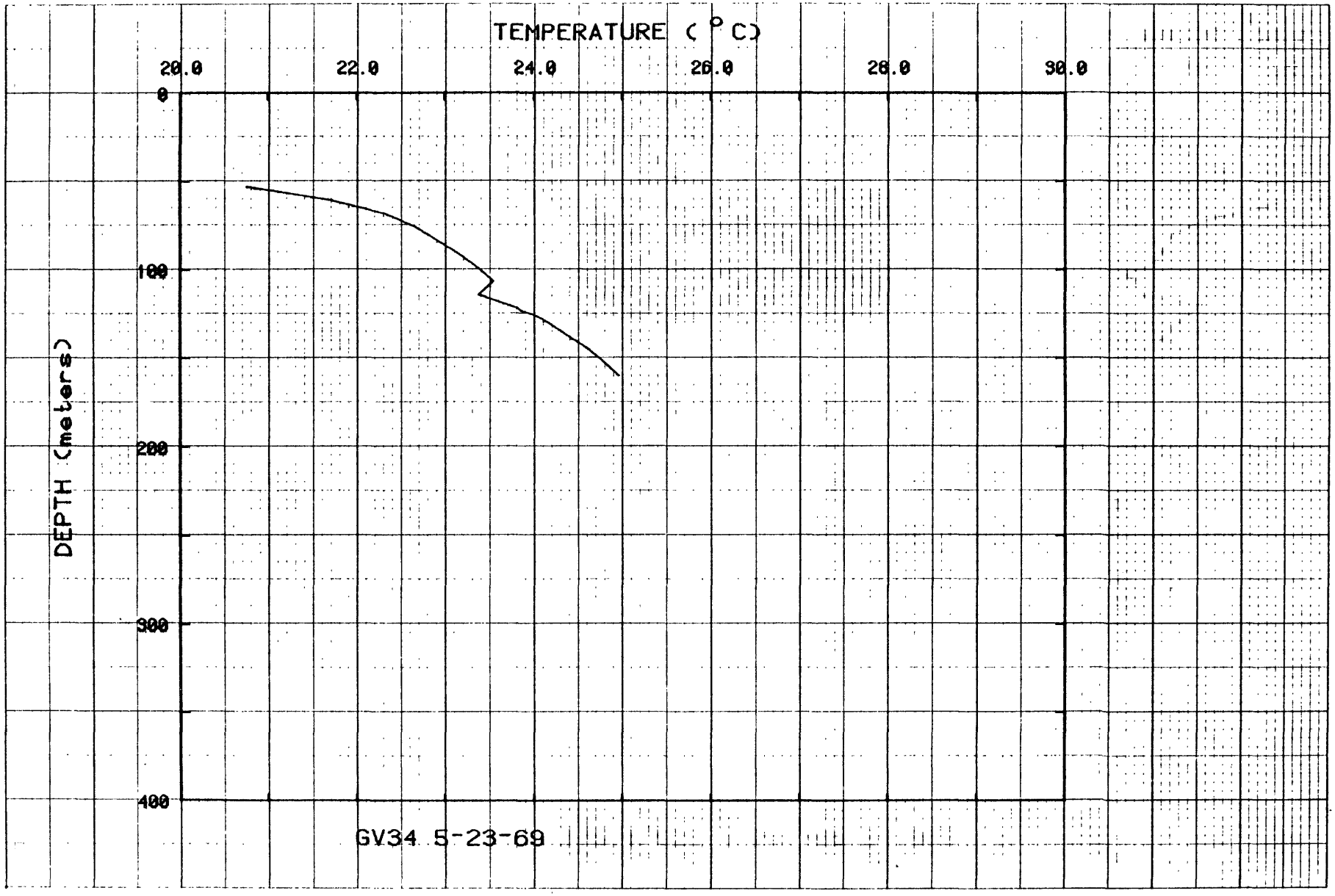

Figure 41. Temperatures for hole GV34.

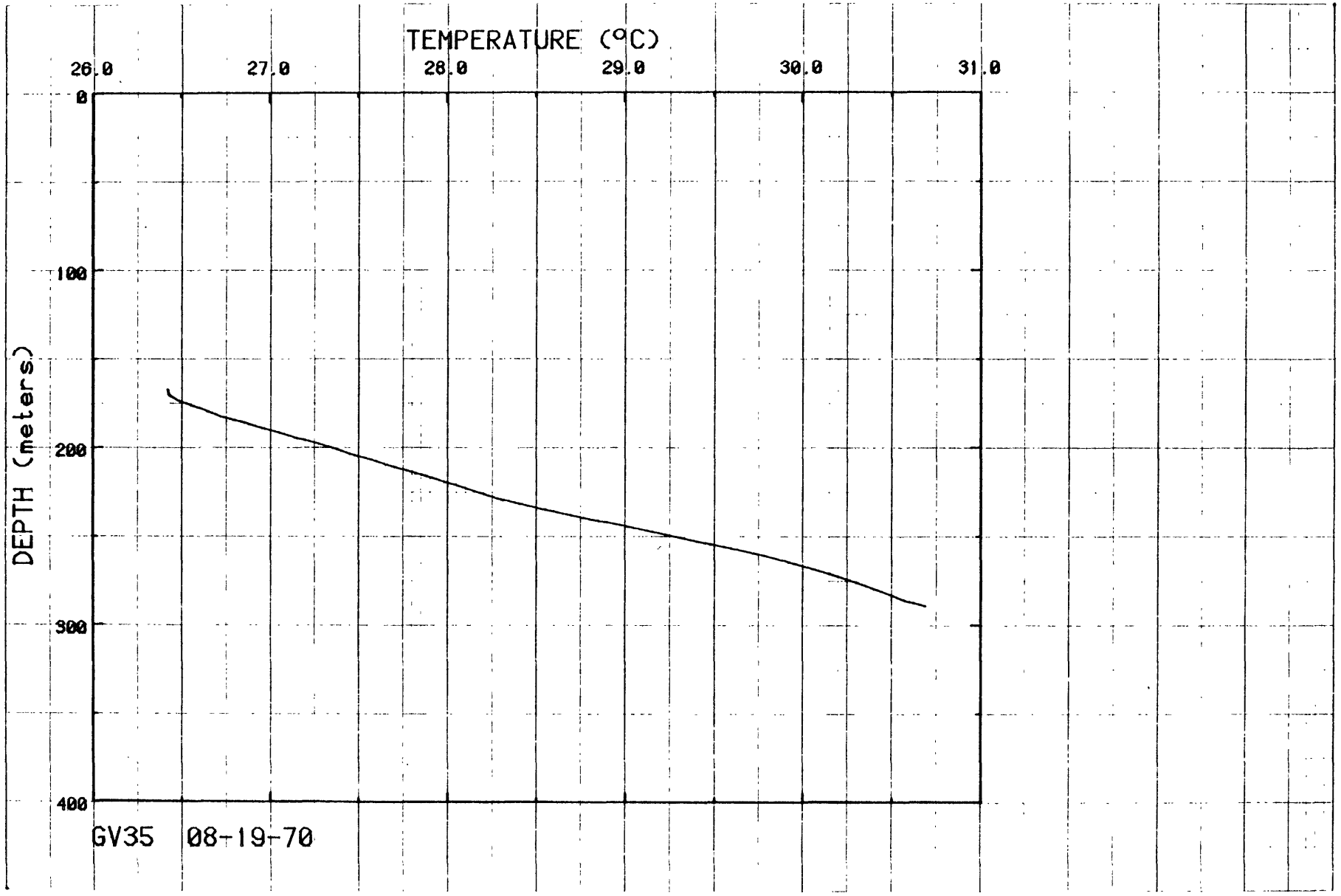

Figure 42. Temperatures for hole GV35.

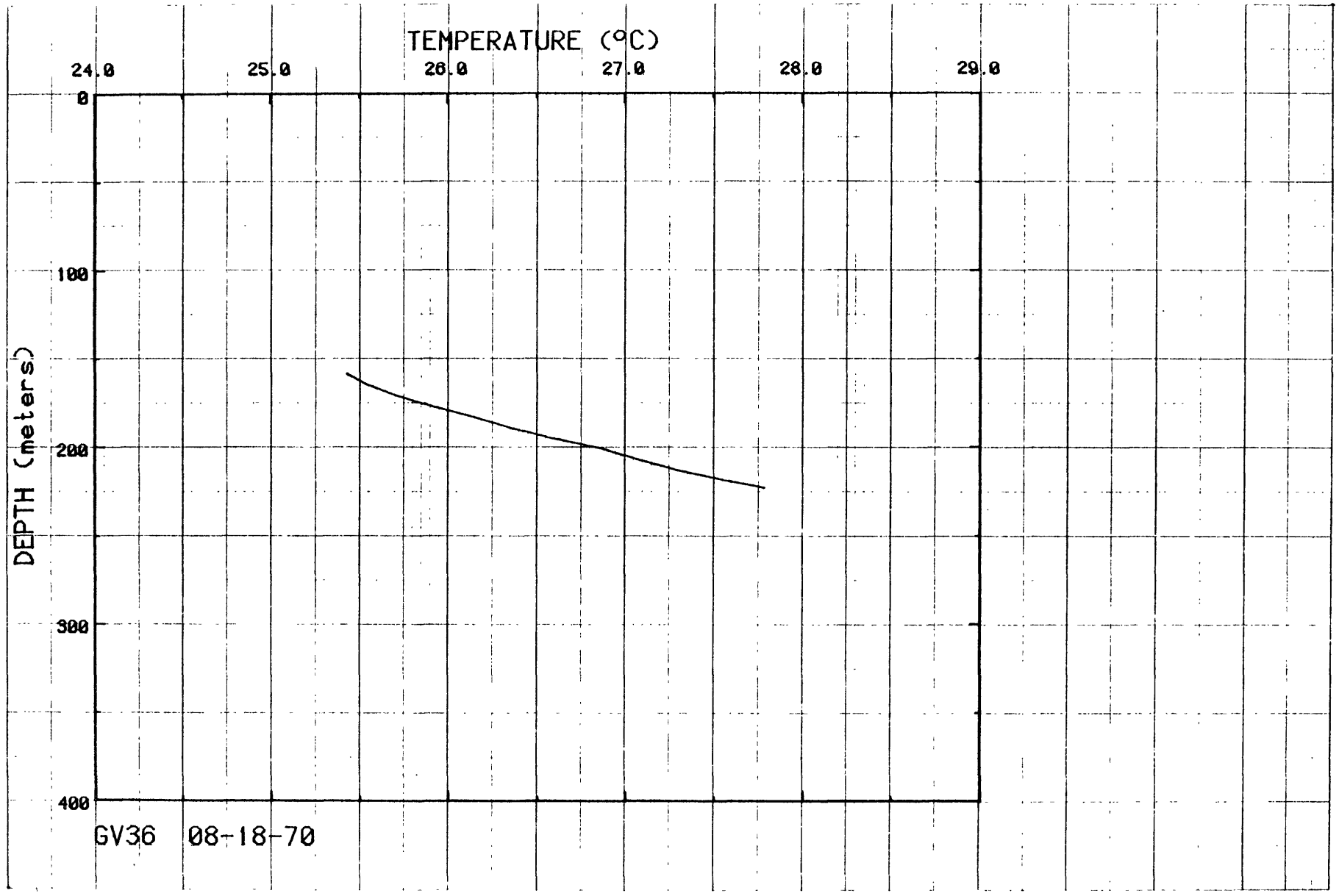

Figure 43. Temperatures for hole GV36.

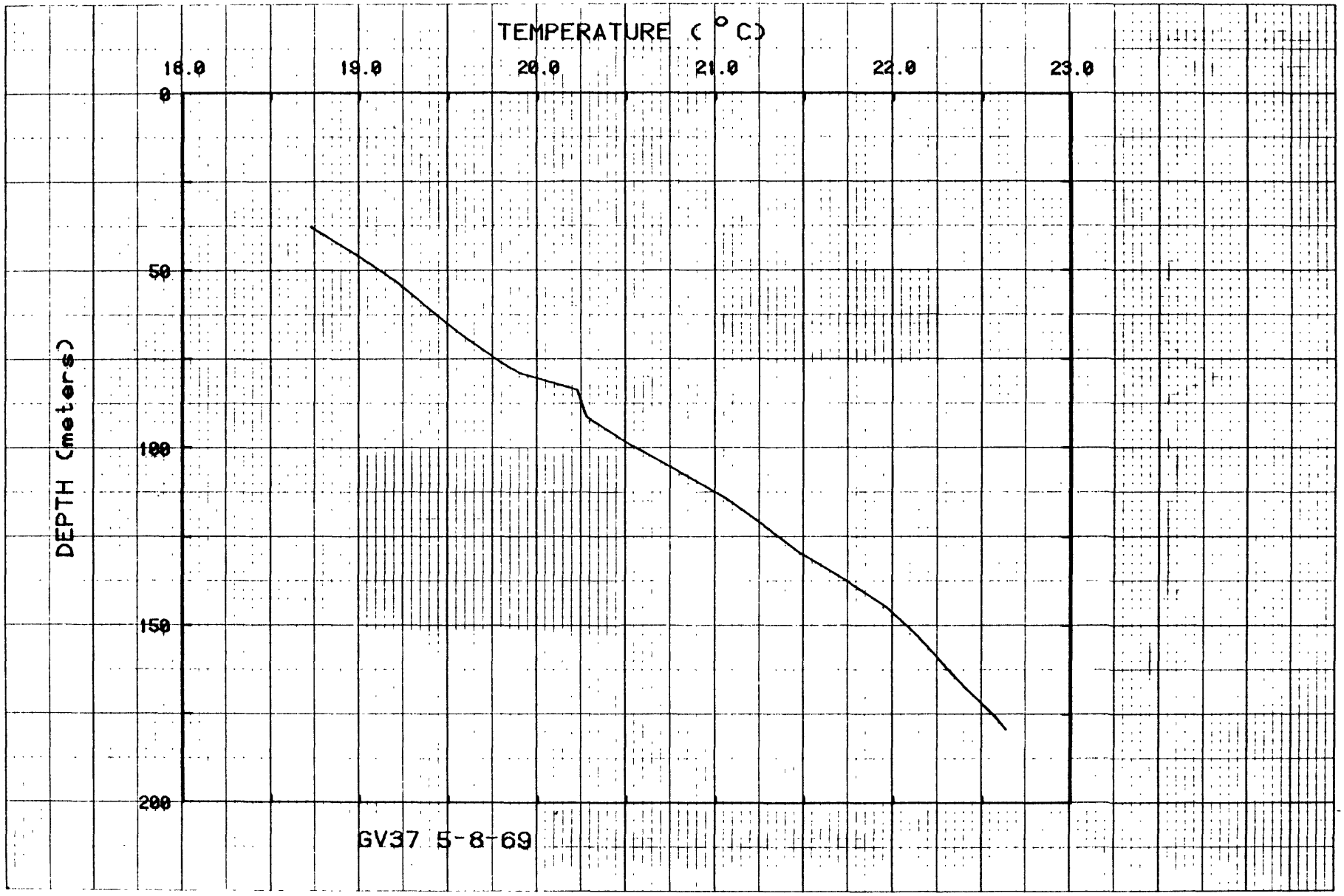

Figure 44. Temperatures for hole GV37.

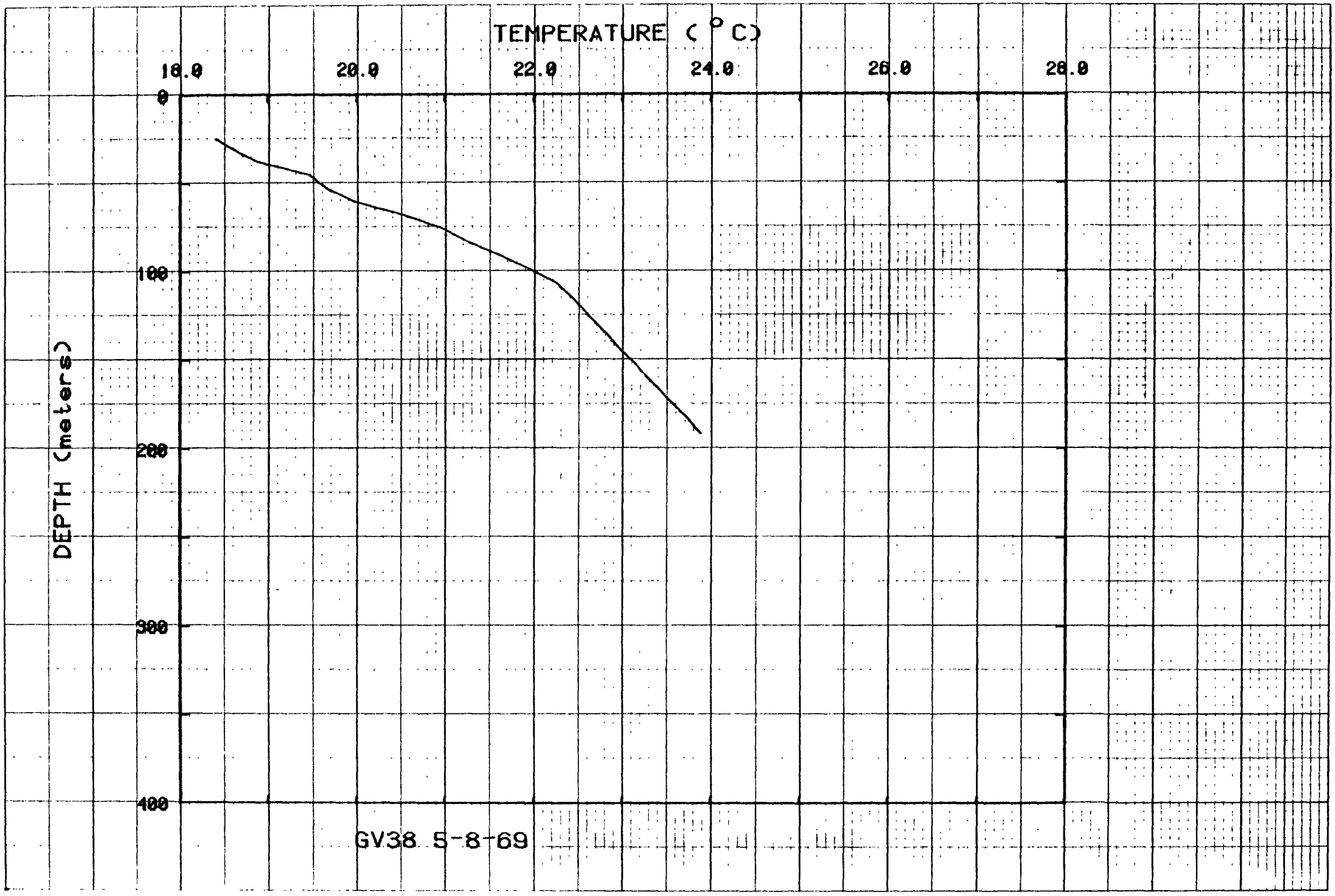

Figure 45. Temperatures for hole GV38.

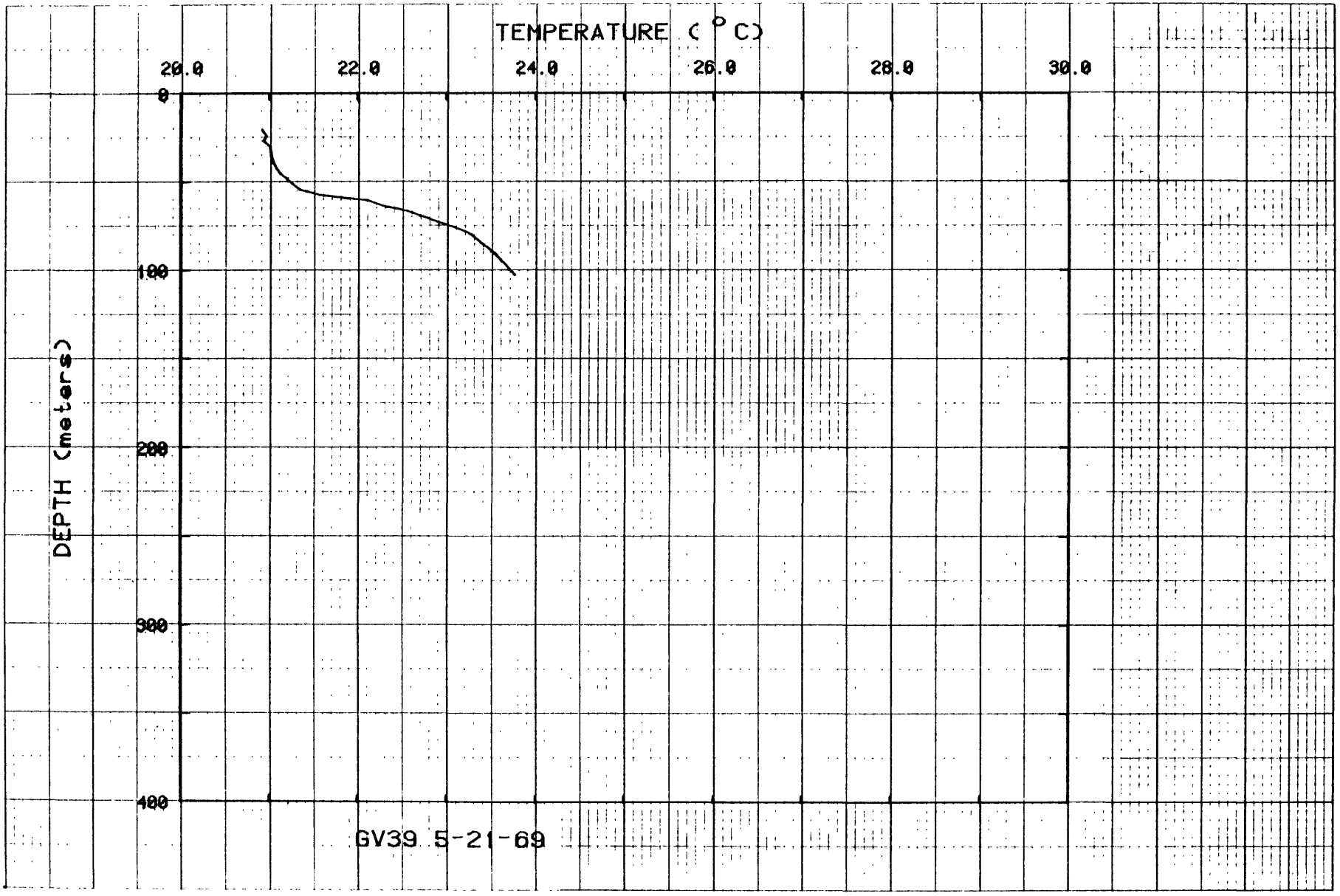

Figure 46. Temperatures for hole GV39.

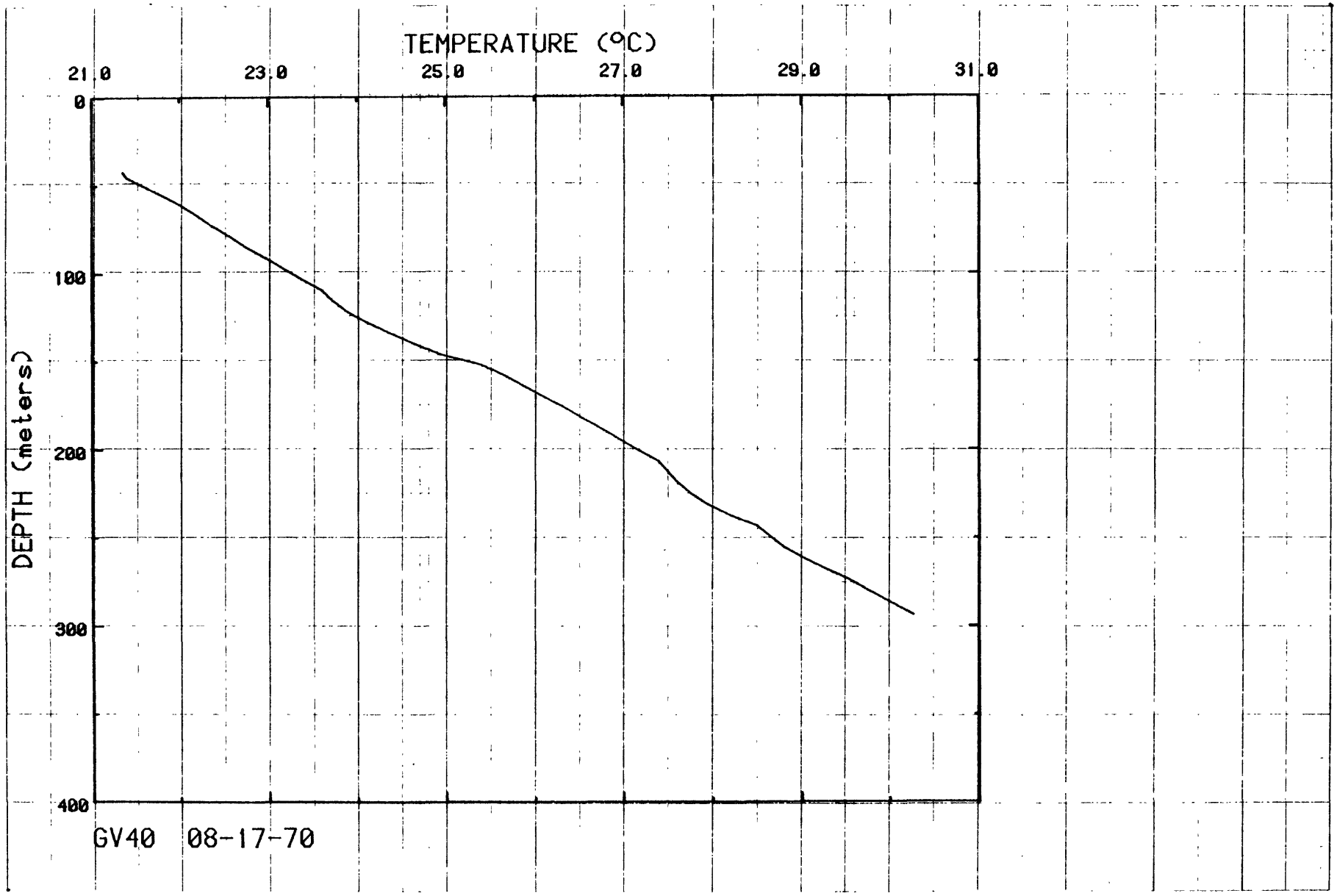

Figure 47. Temperatures for hole GV40.

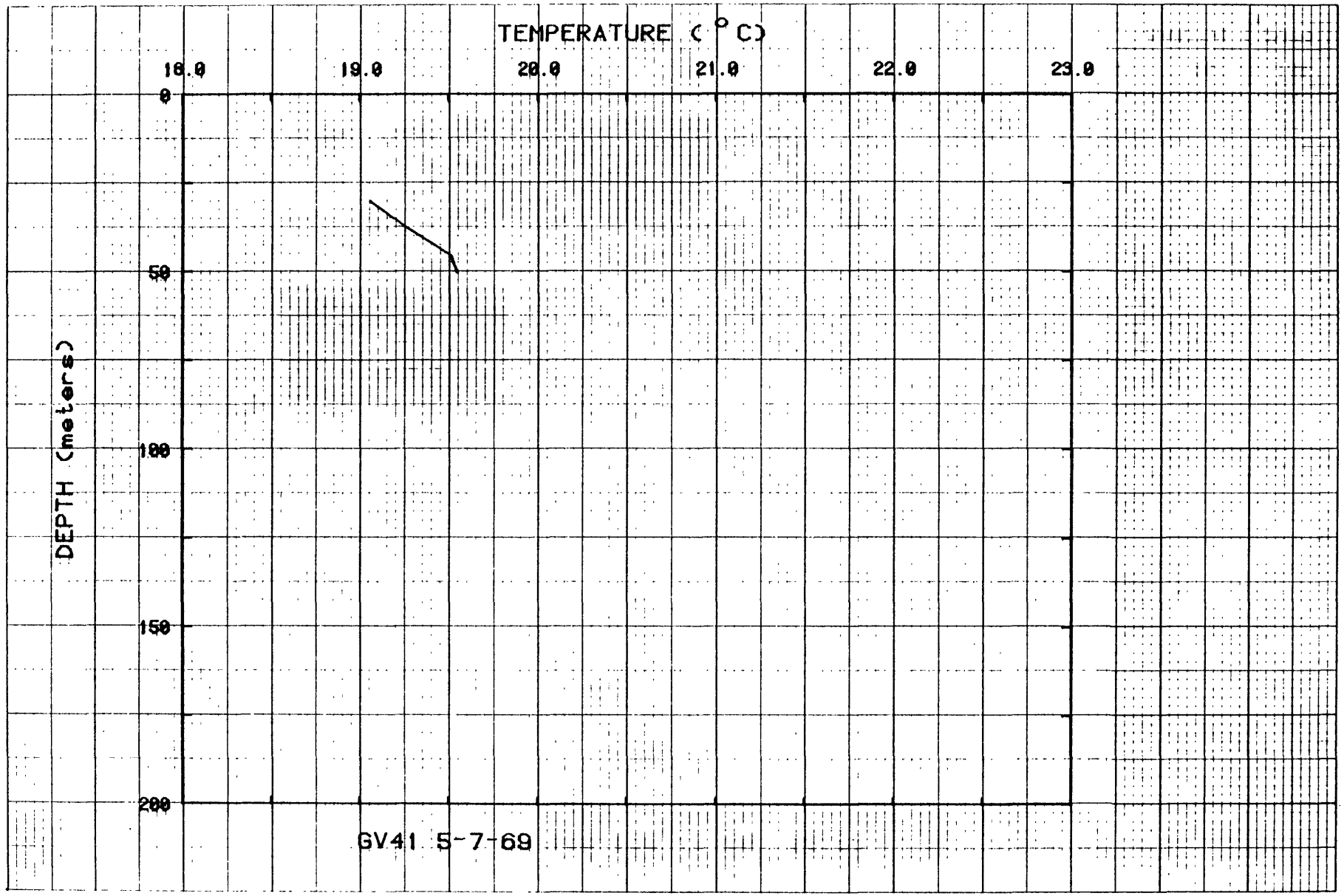

Figure 48. Temperatures in hole GV41.

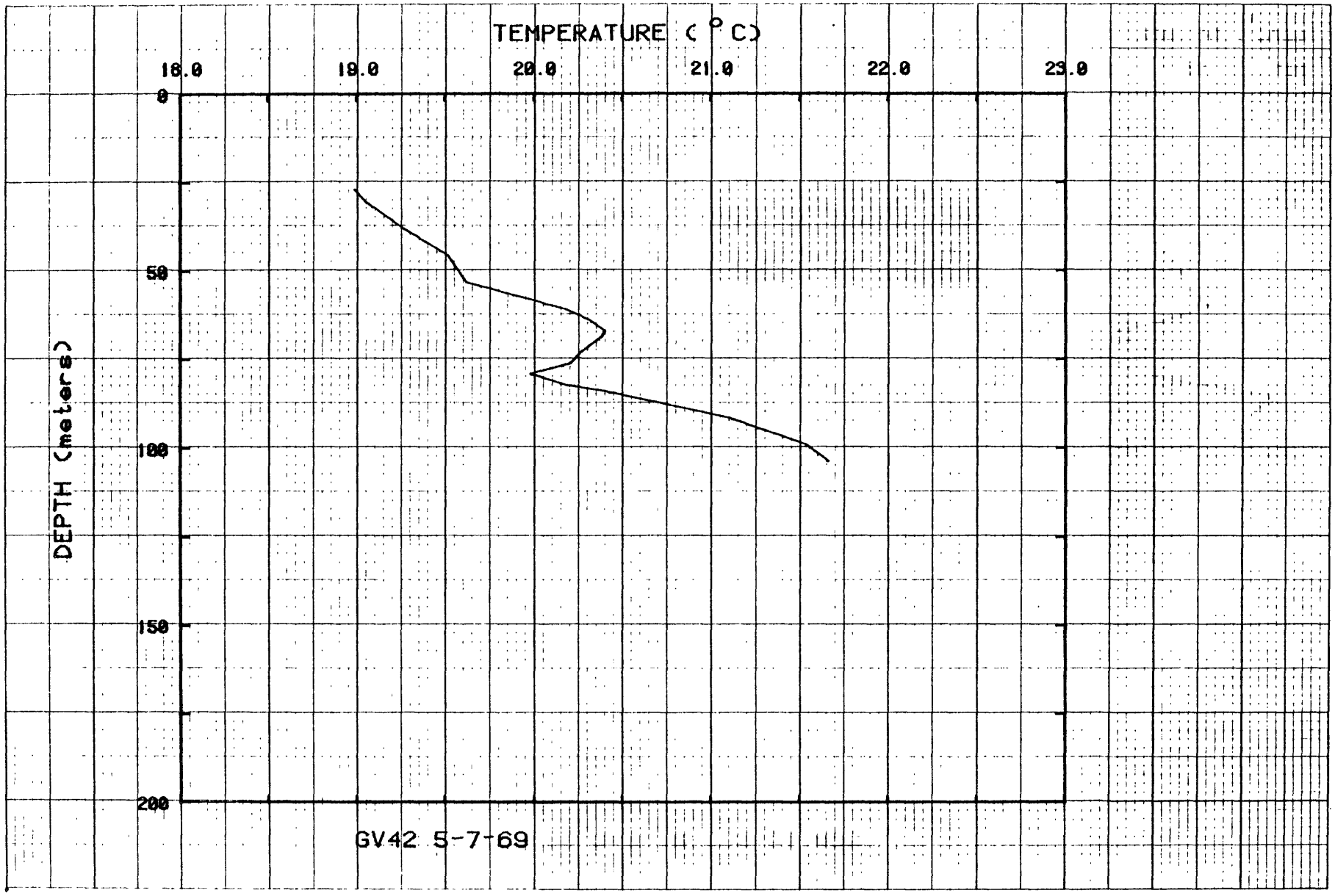

Figure 49. Temperatures for hole GV42.

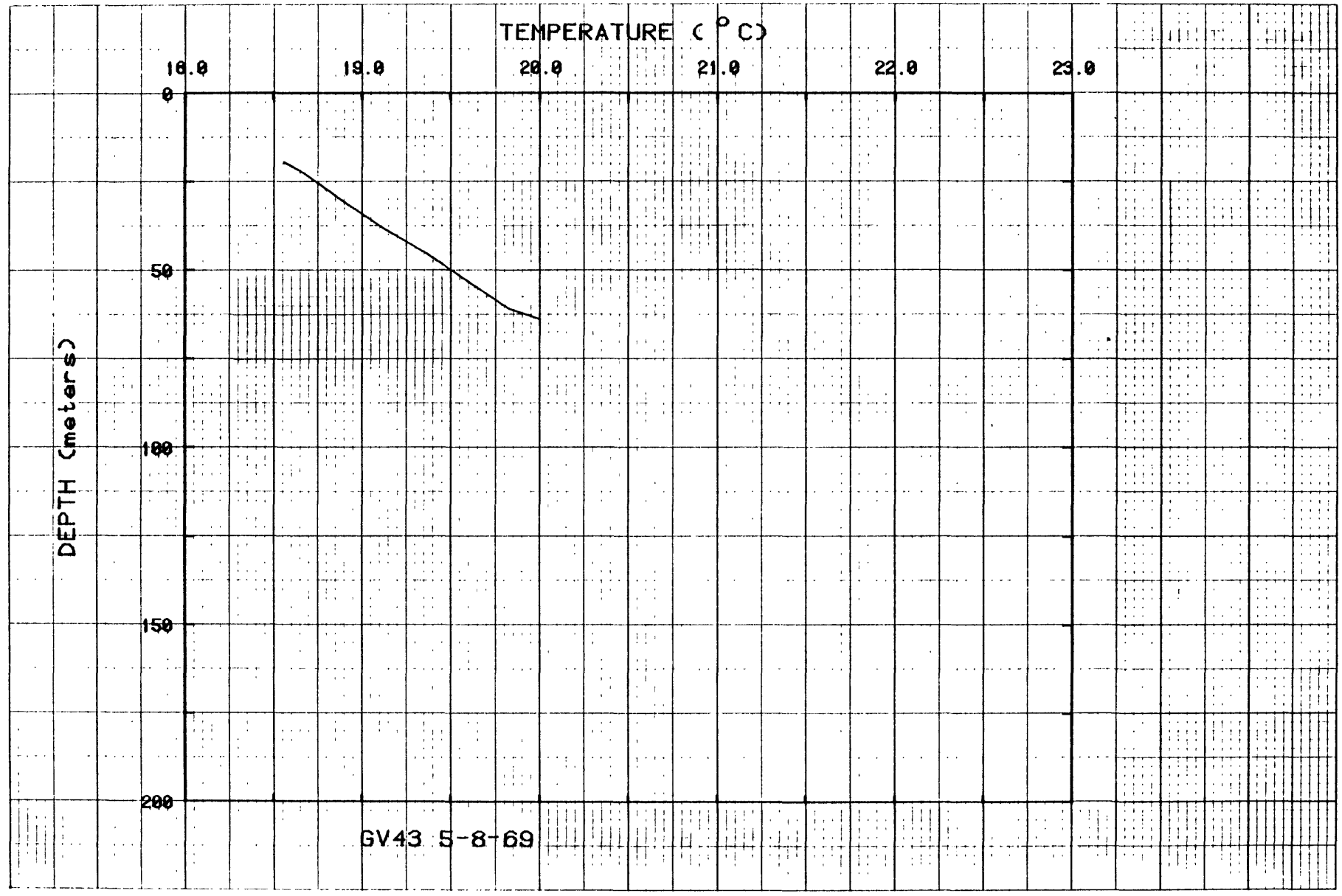

Figure 50. Temperatures for hole GV43.

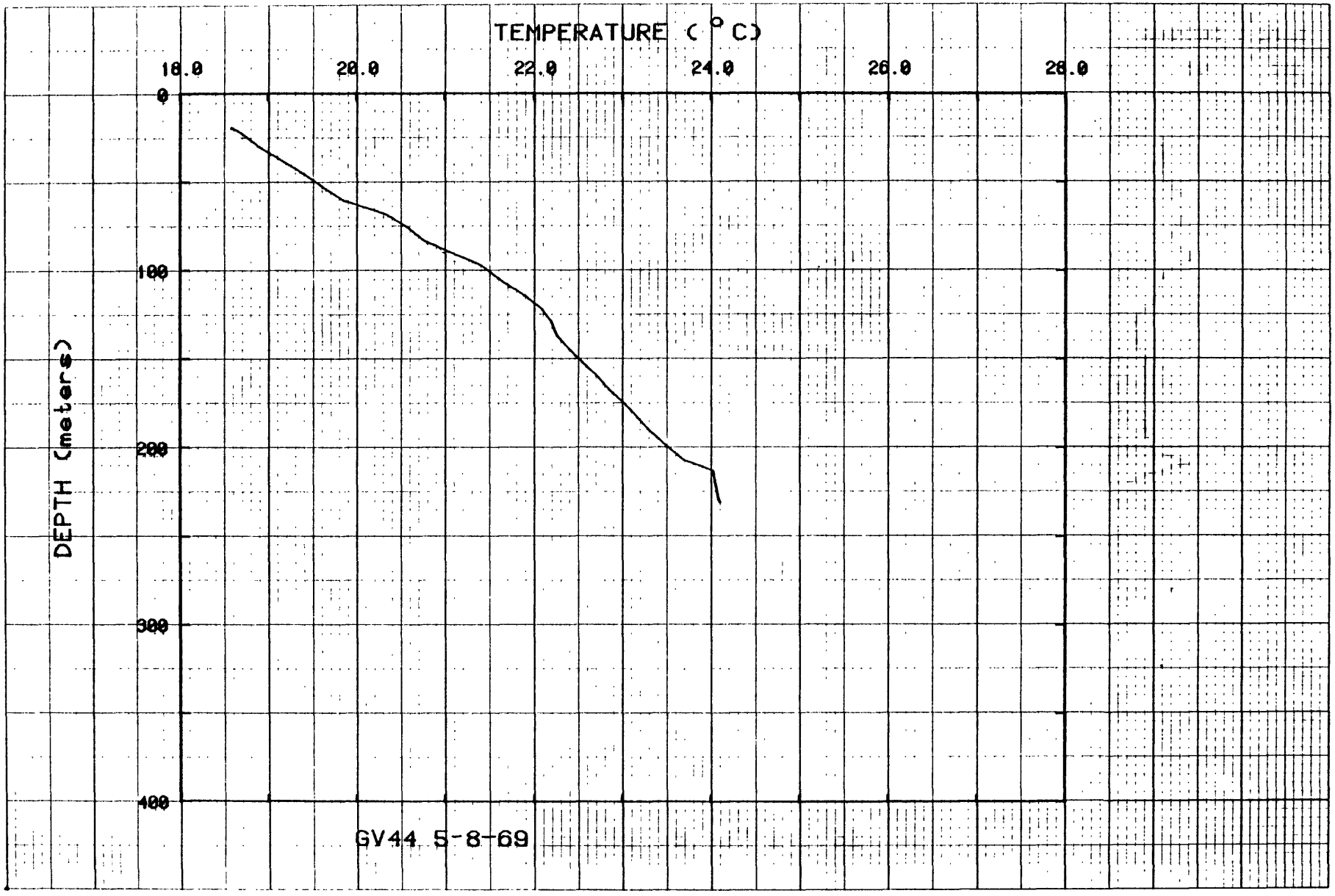

Figure 51. Temperatures for hole GV44.

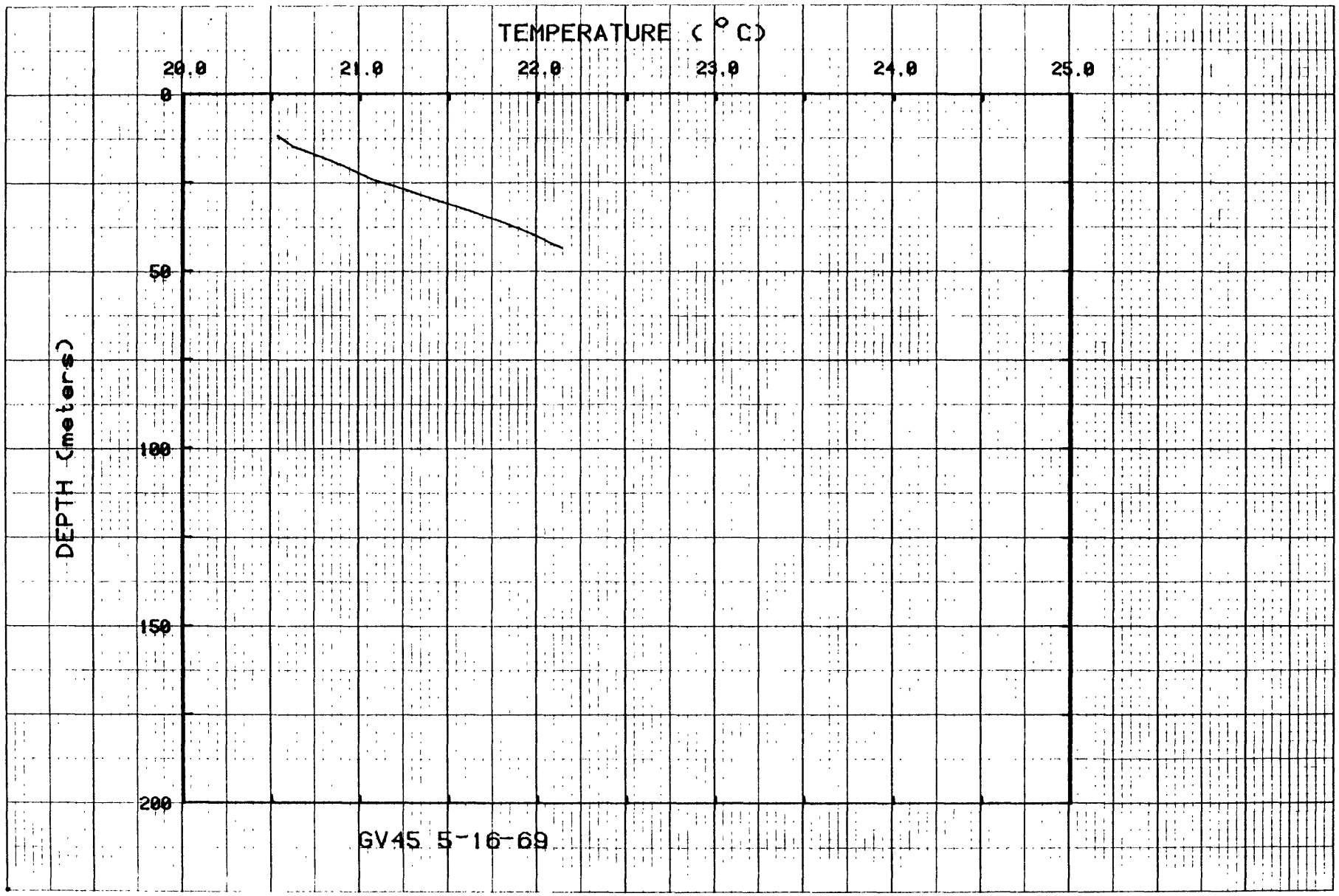

Figure 52. Temperatures for hole GV45.

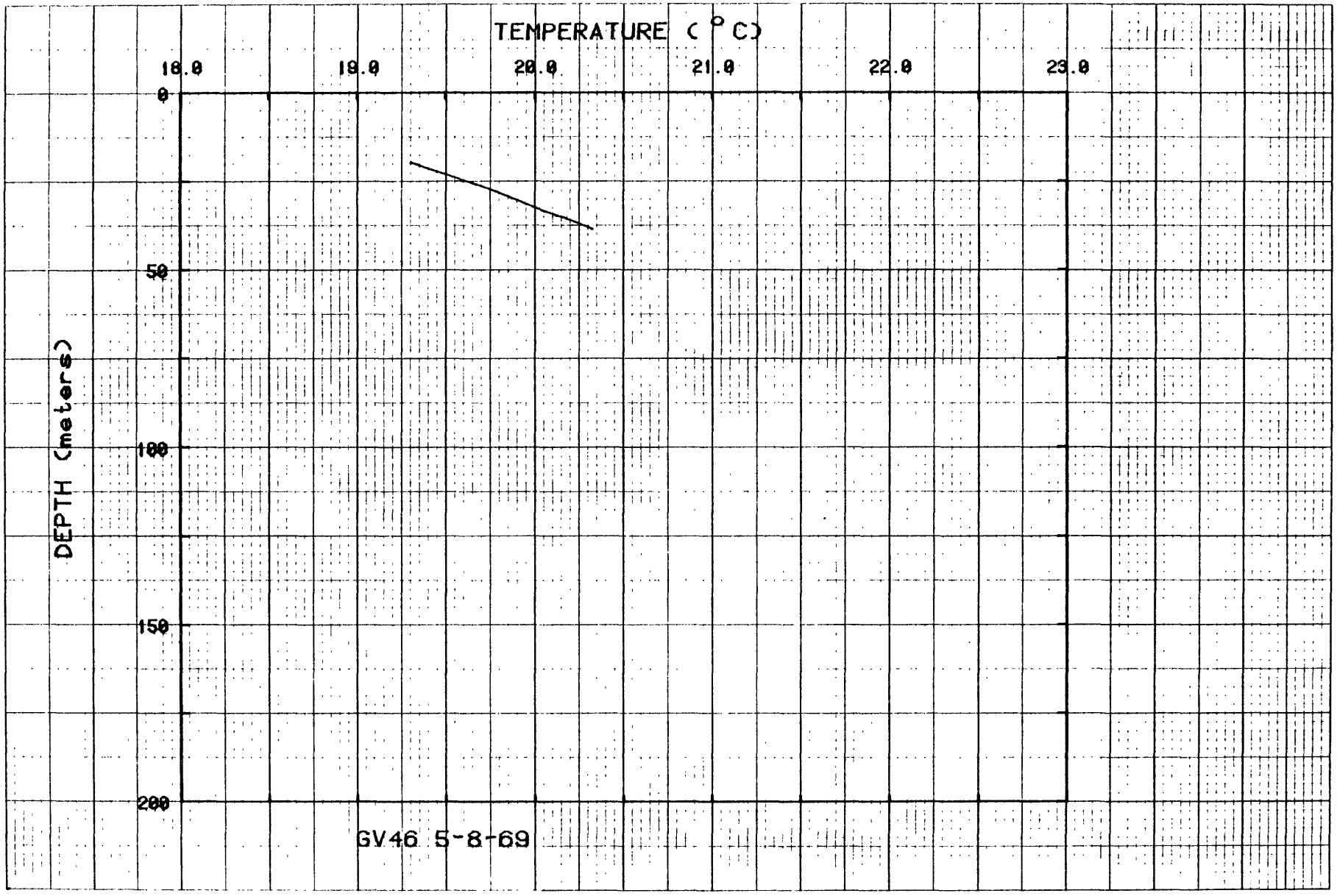

Figure 53. Temperatures for hole GV46.

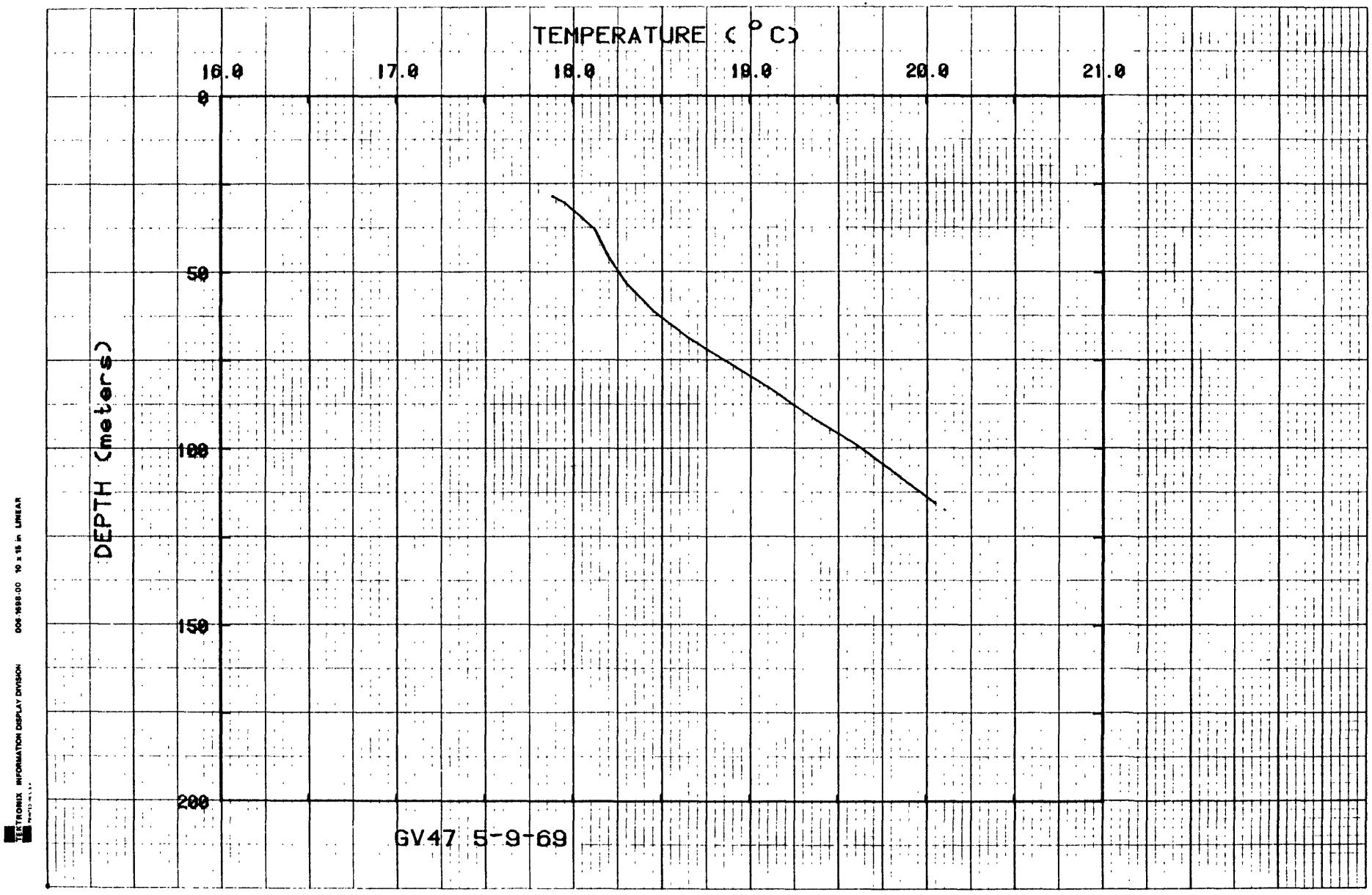

Figure 54. Temperatures for hole GV47.

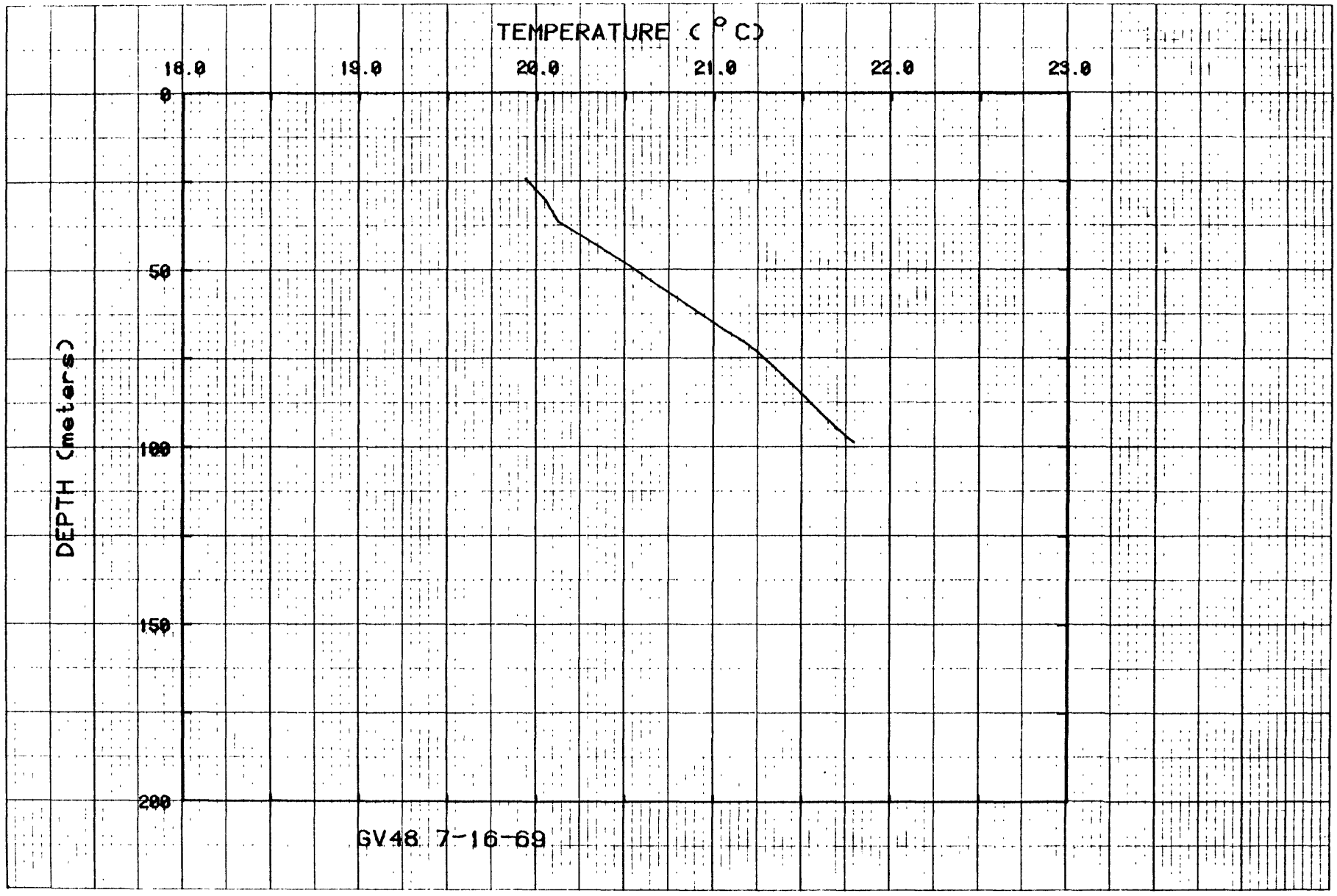

Figure 55. Temperatures for hole GV48.

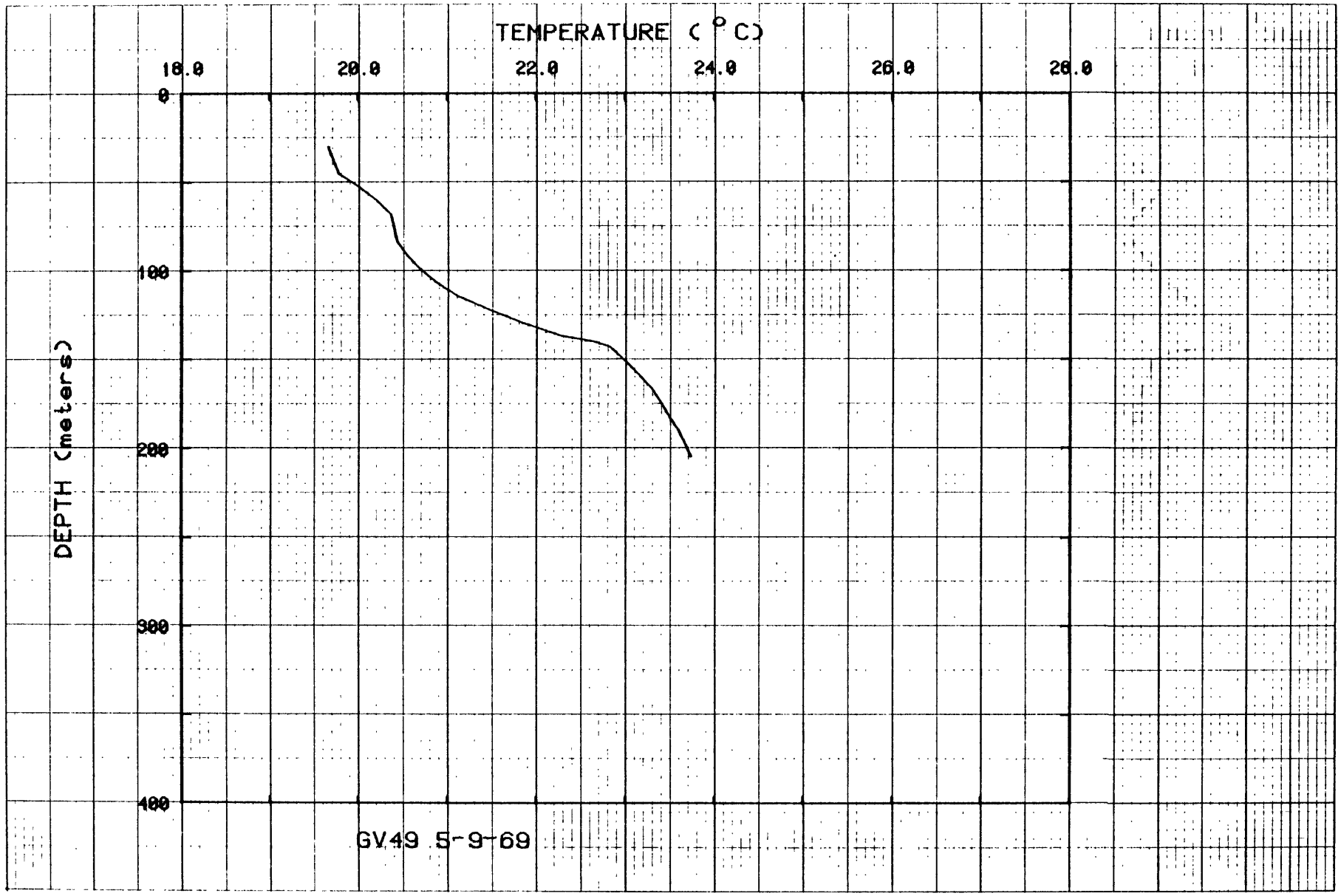

Figure 56. Temperatures for hole GV49.

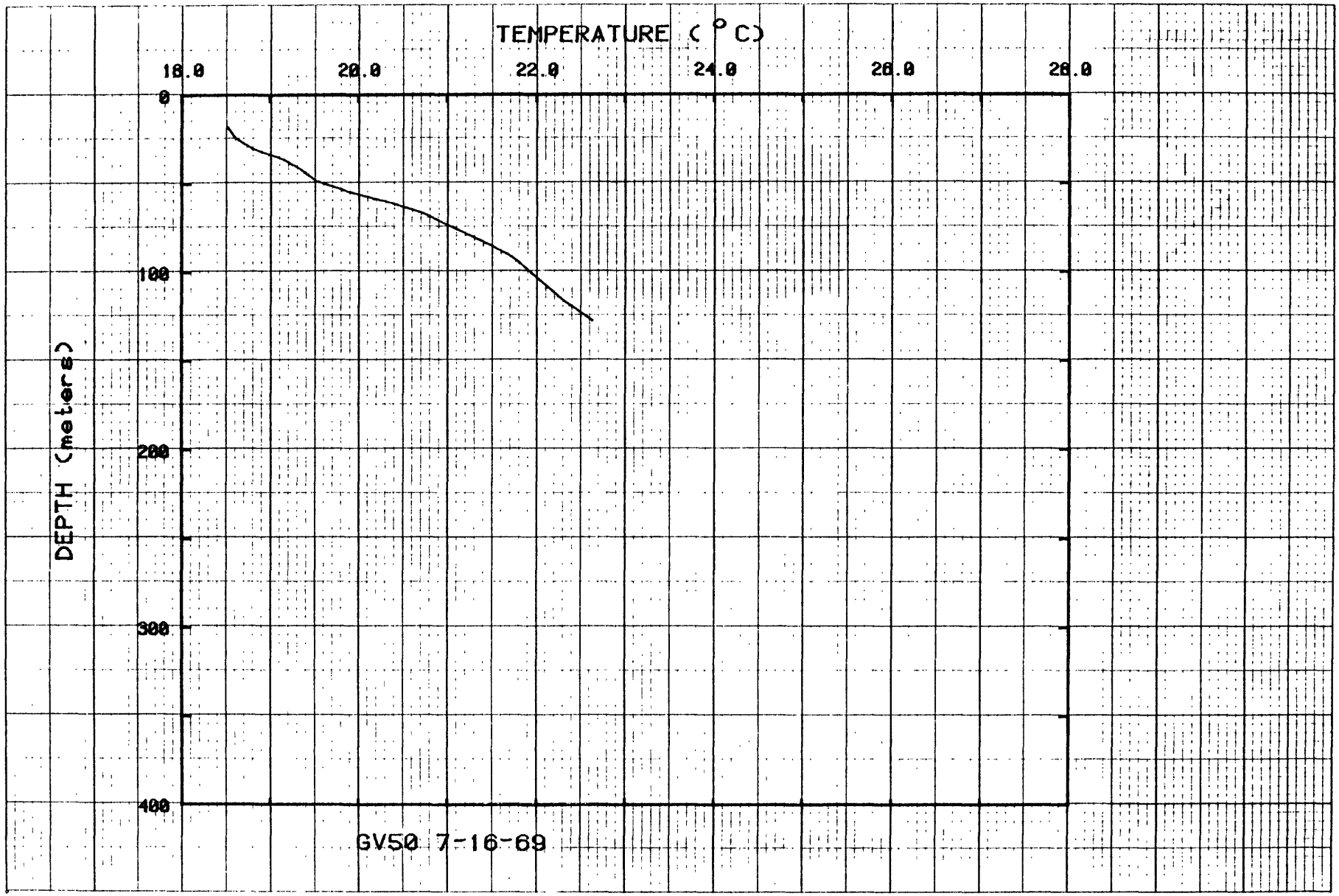

Figure 57. Temperatures for hole GV50.

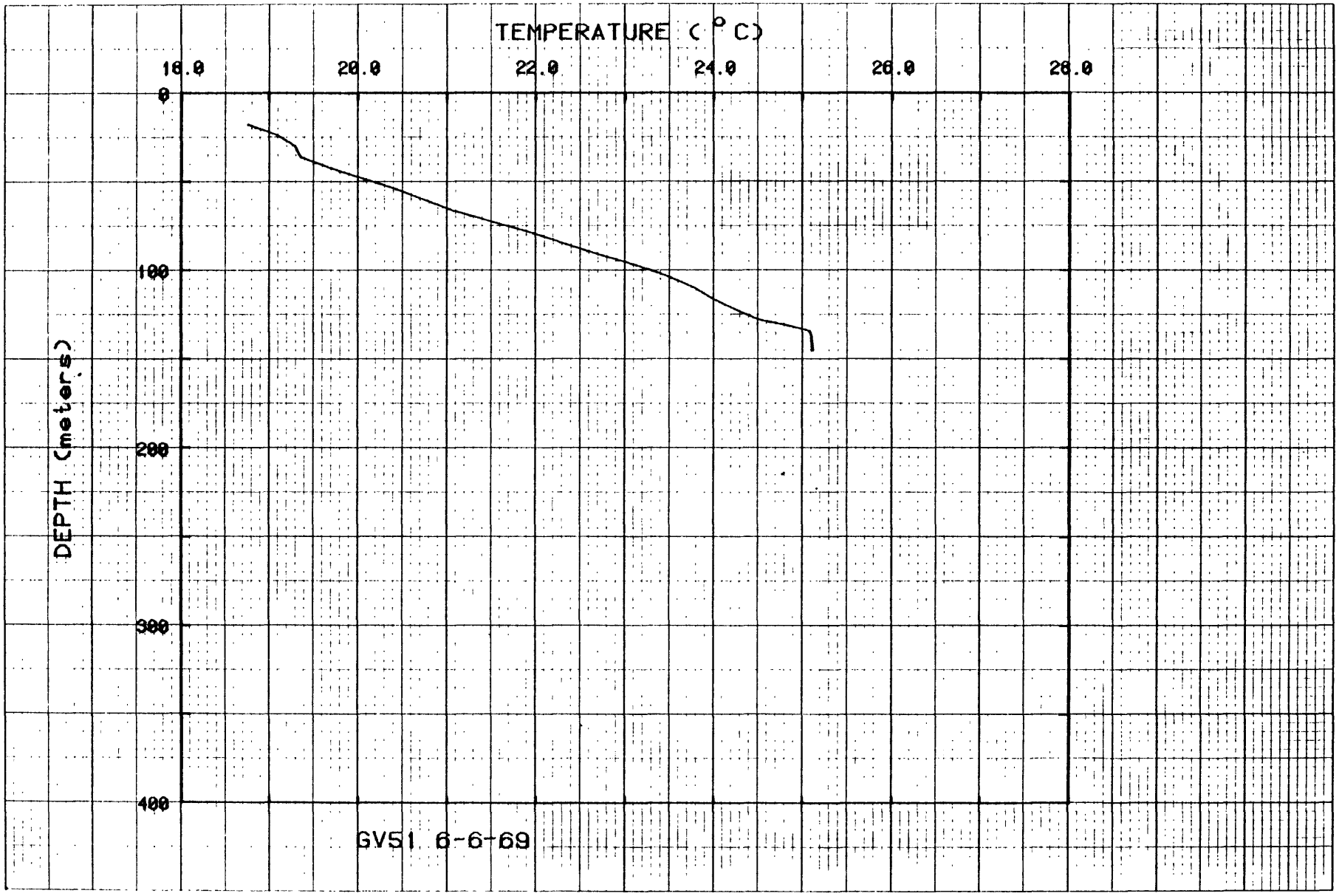

Figure 58. Temperatures for hole GV51.

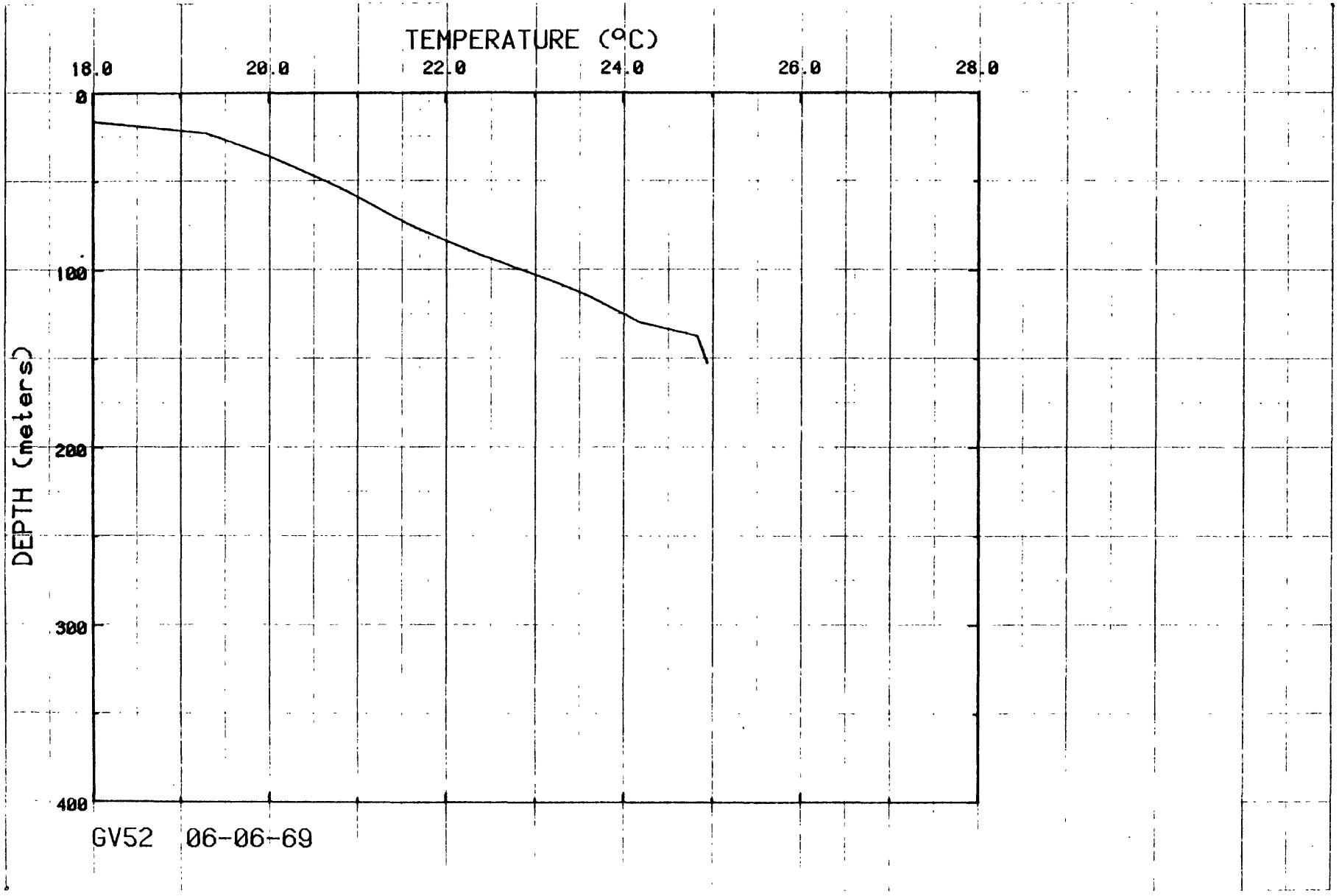

Figure 59. Temperatures for hole GV52.

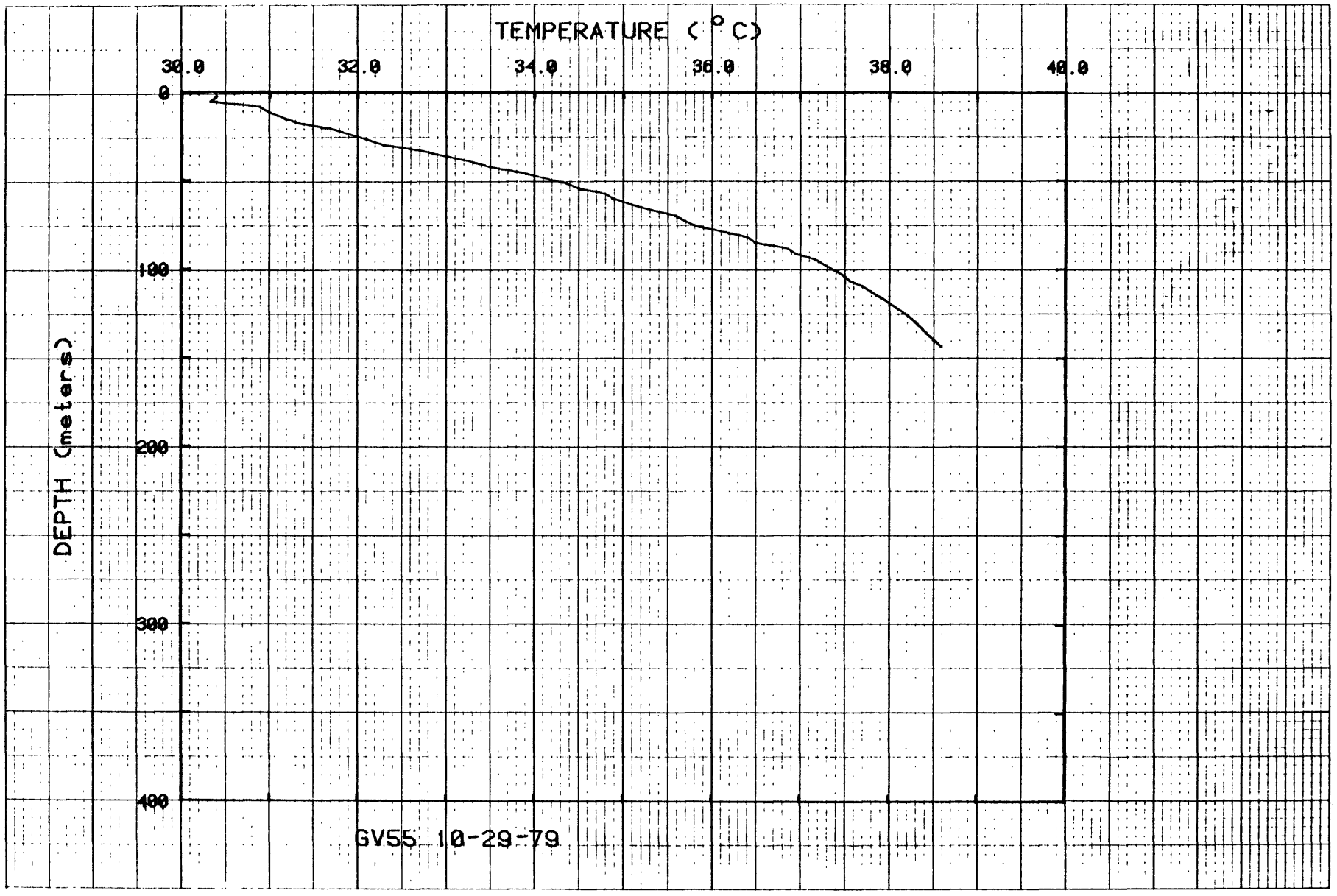

Figure 60. Temperatures for hole GV55.

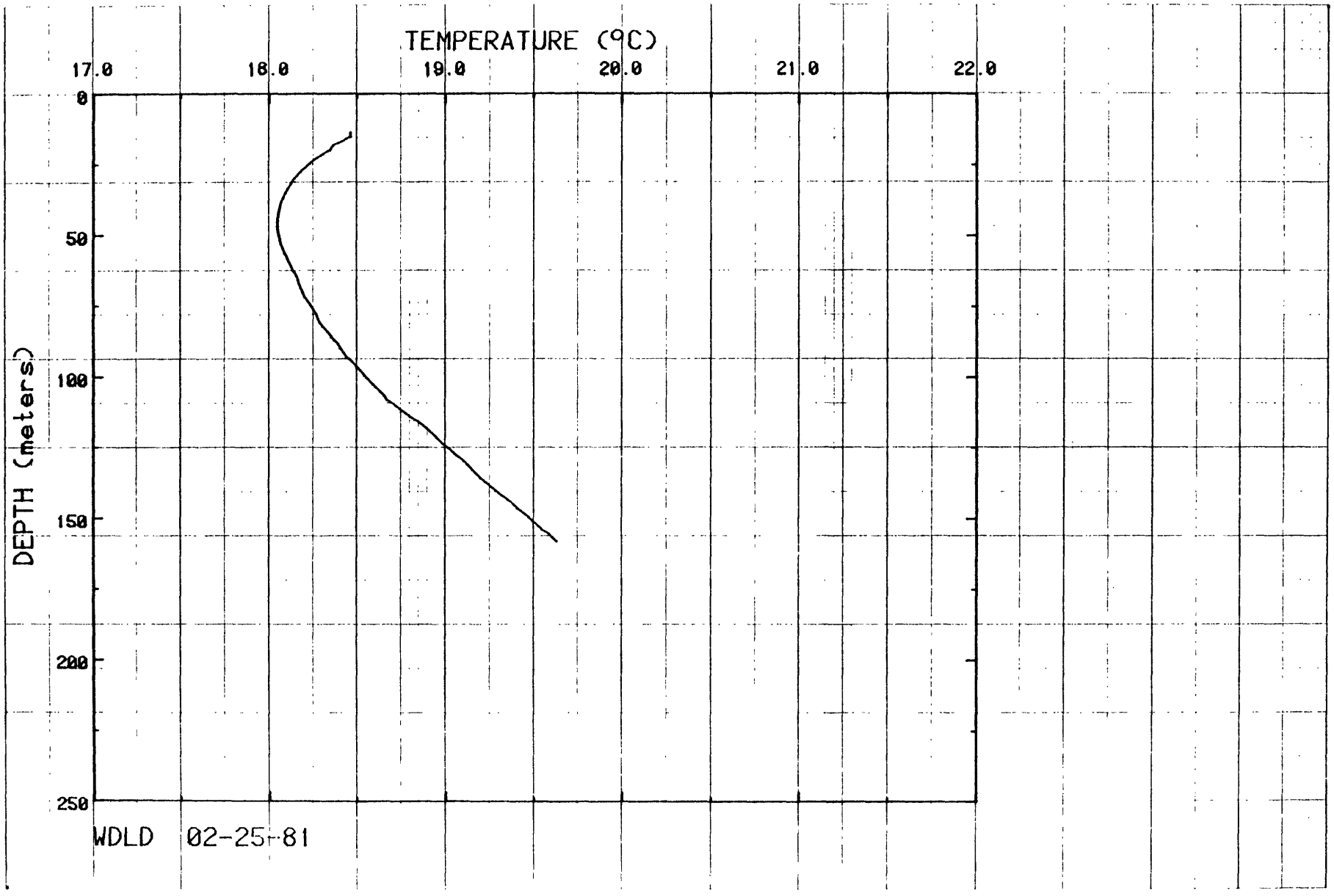

Figure 61. Temperatures for hole WDLD.

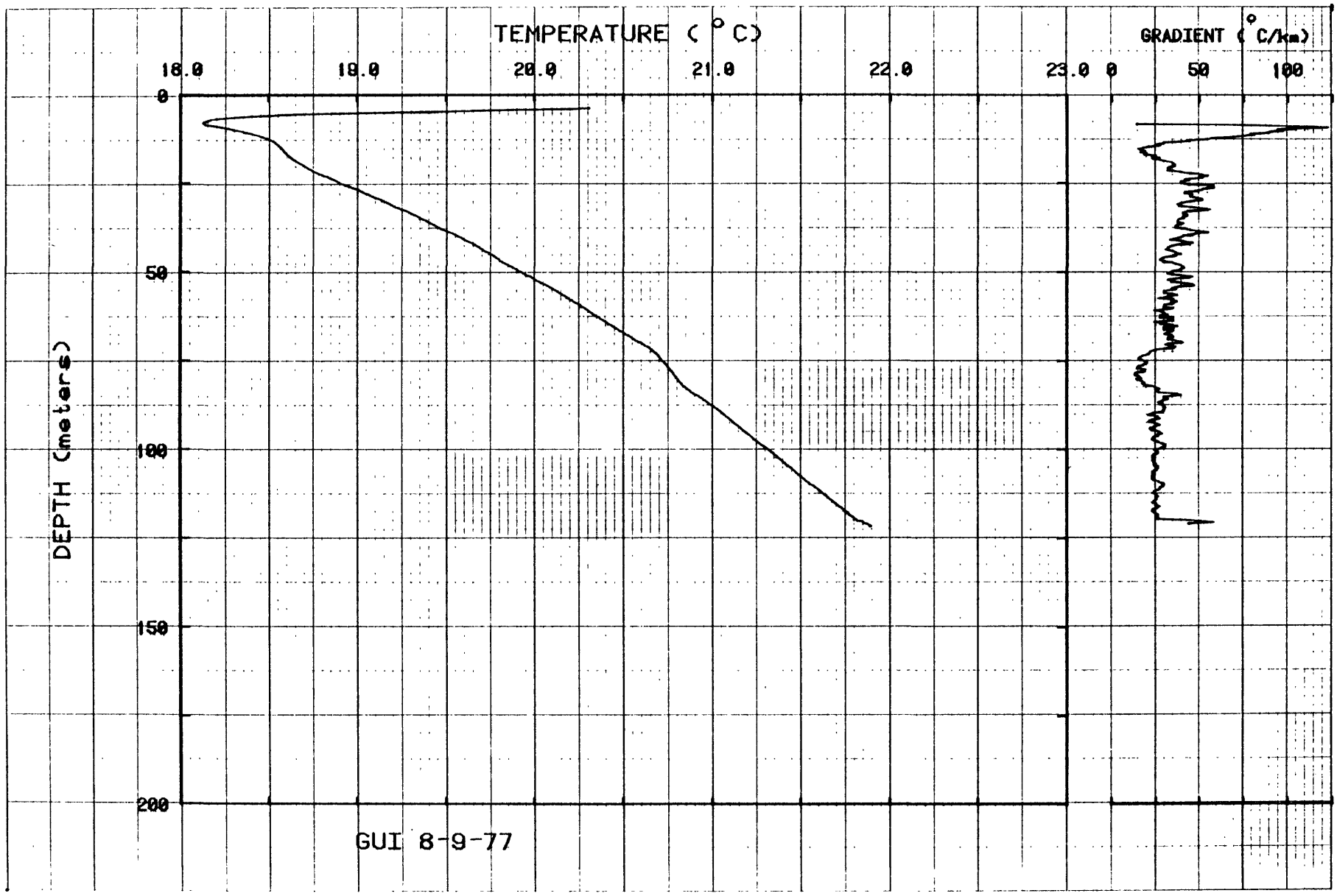

Figure 62. Temperatures and gradients for hole GUI.

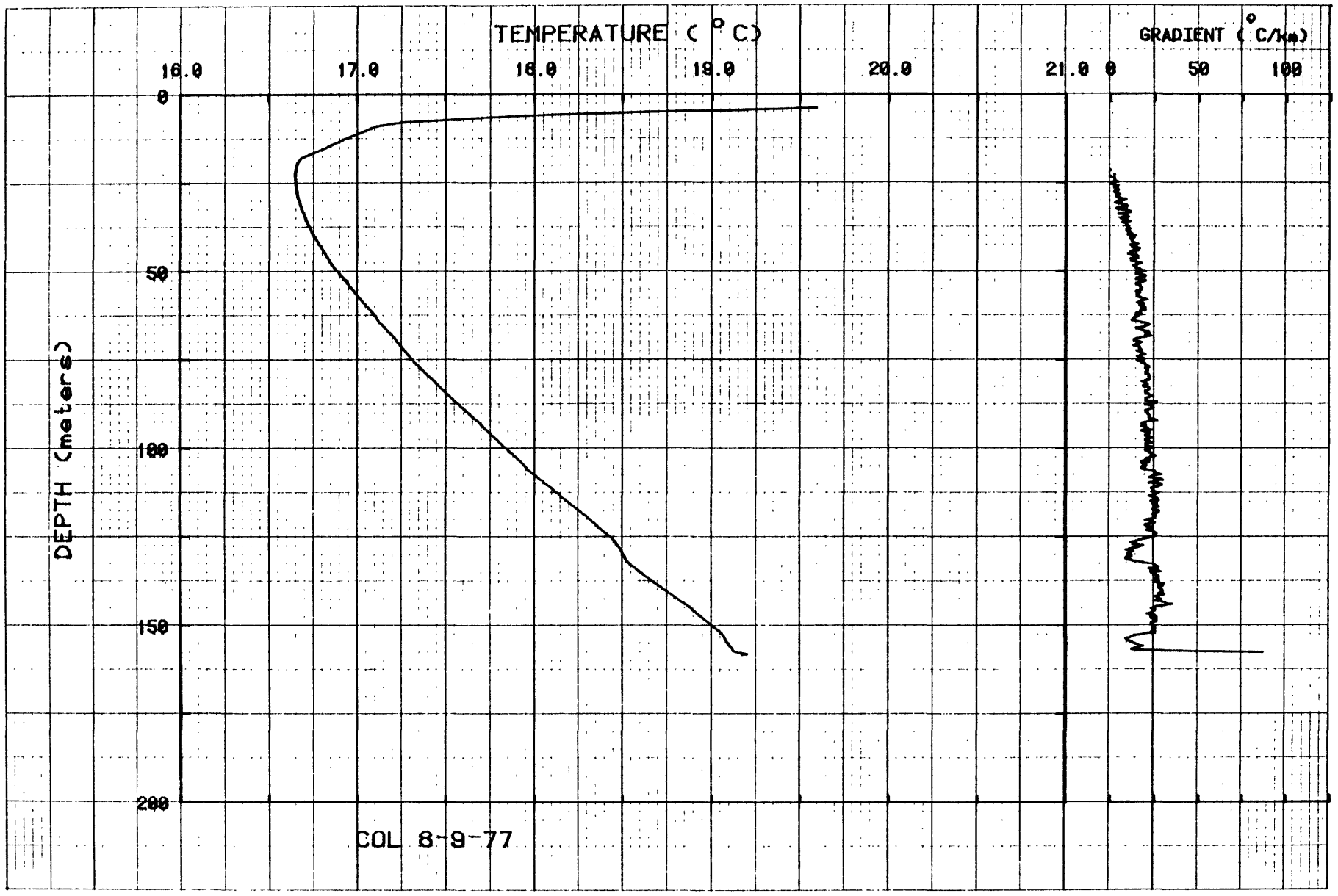

Figure 63. Temperatures and gradients for hole COL.

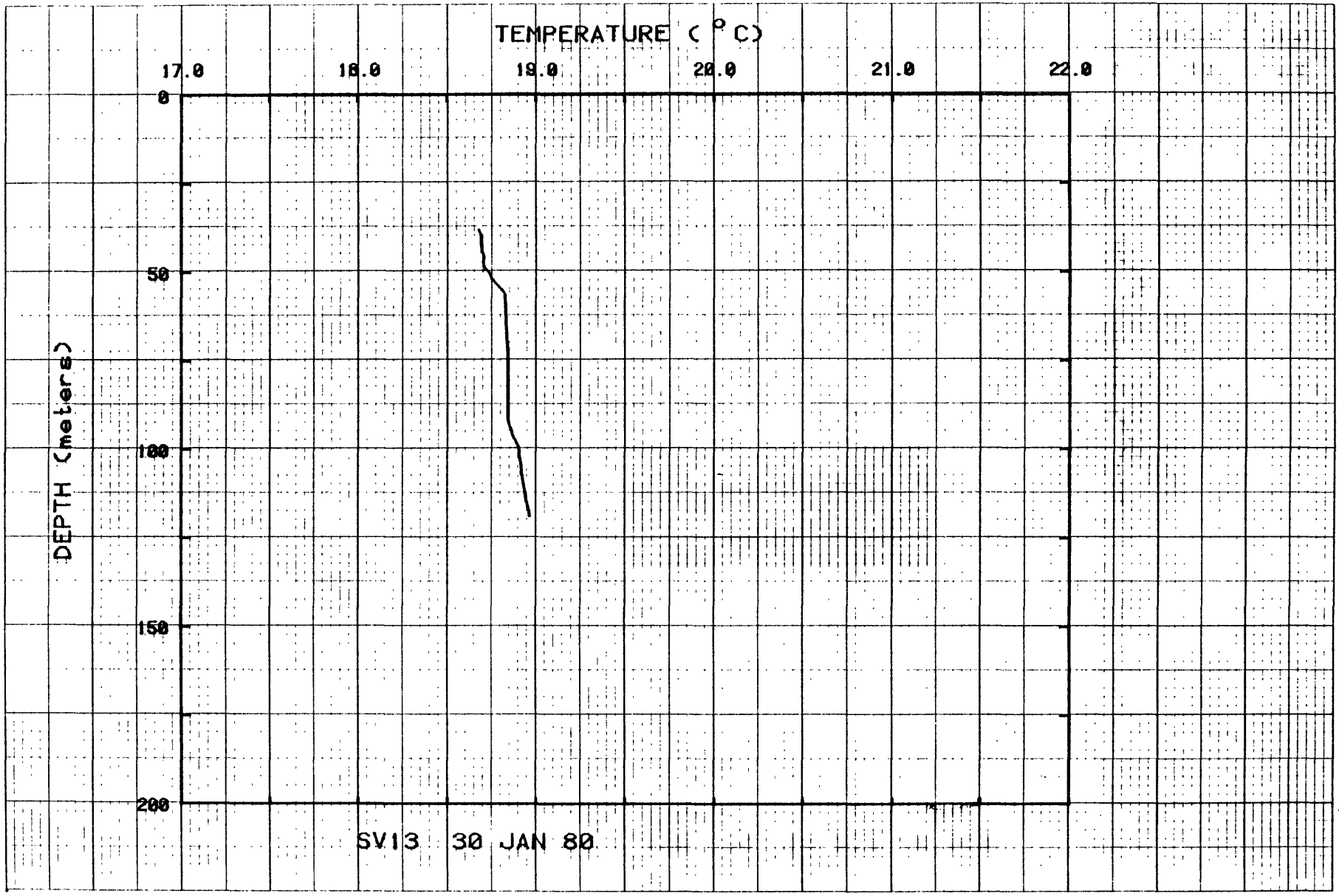

Figure 64. Temperatures for hole SV13.

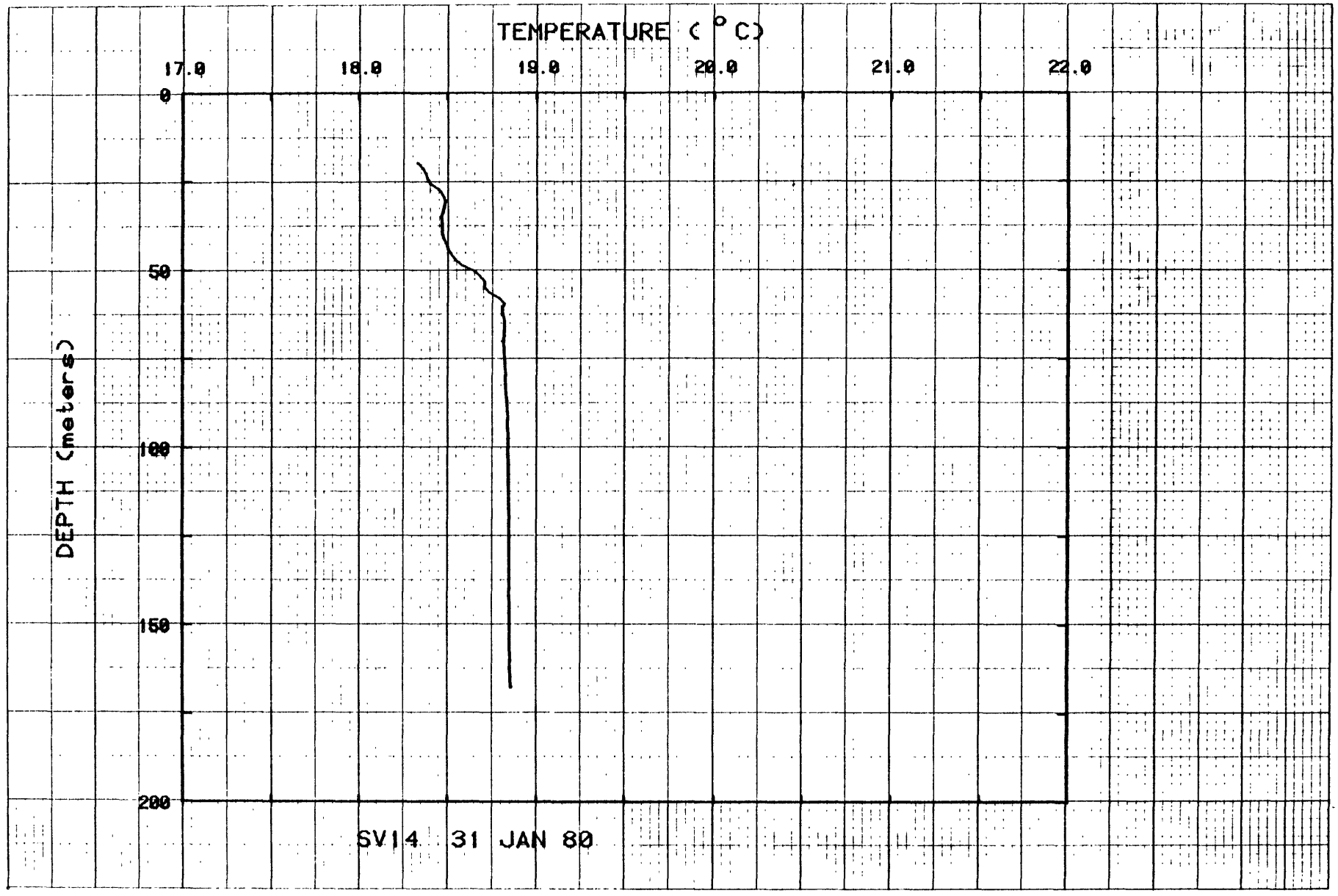

Figure 65. Temperatures for hole SV14.

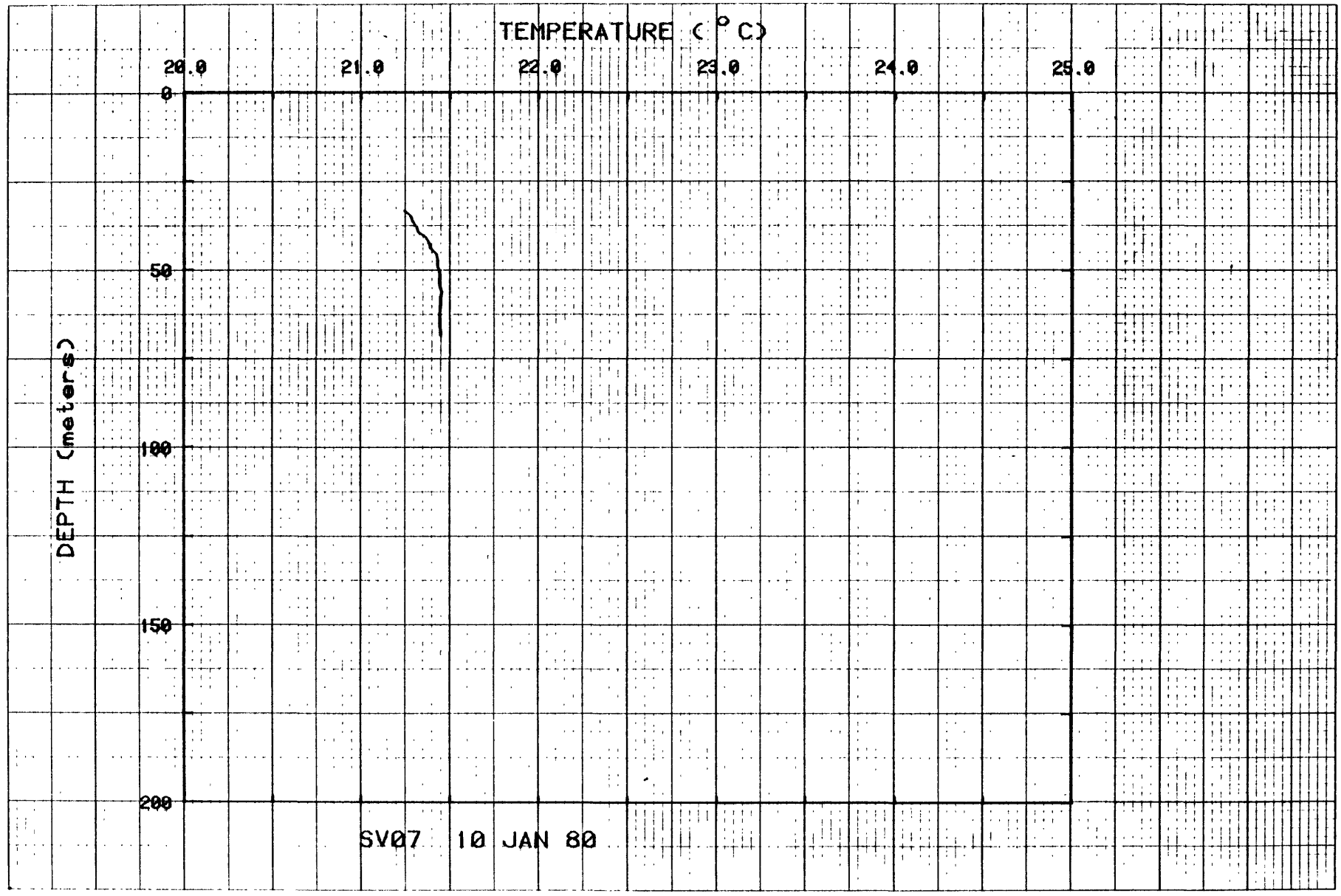

Figure 66. Temperatures for hole SV07.

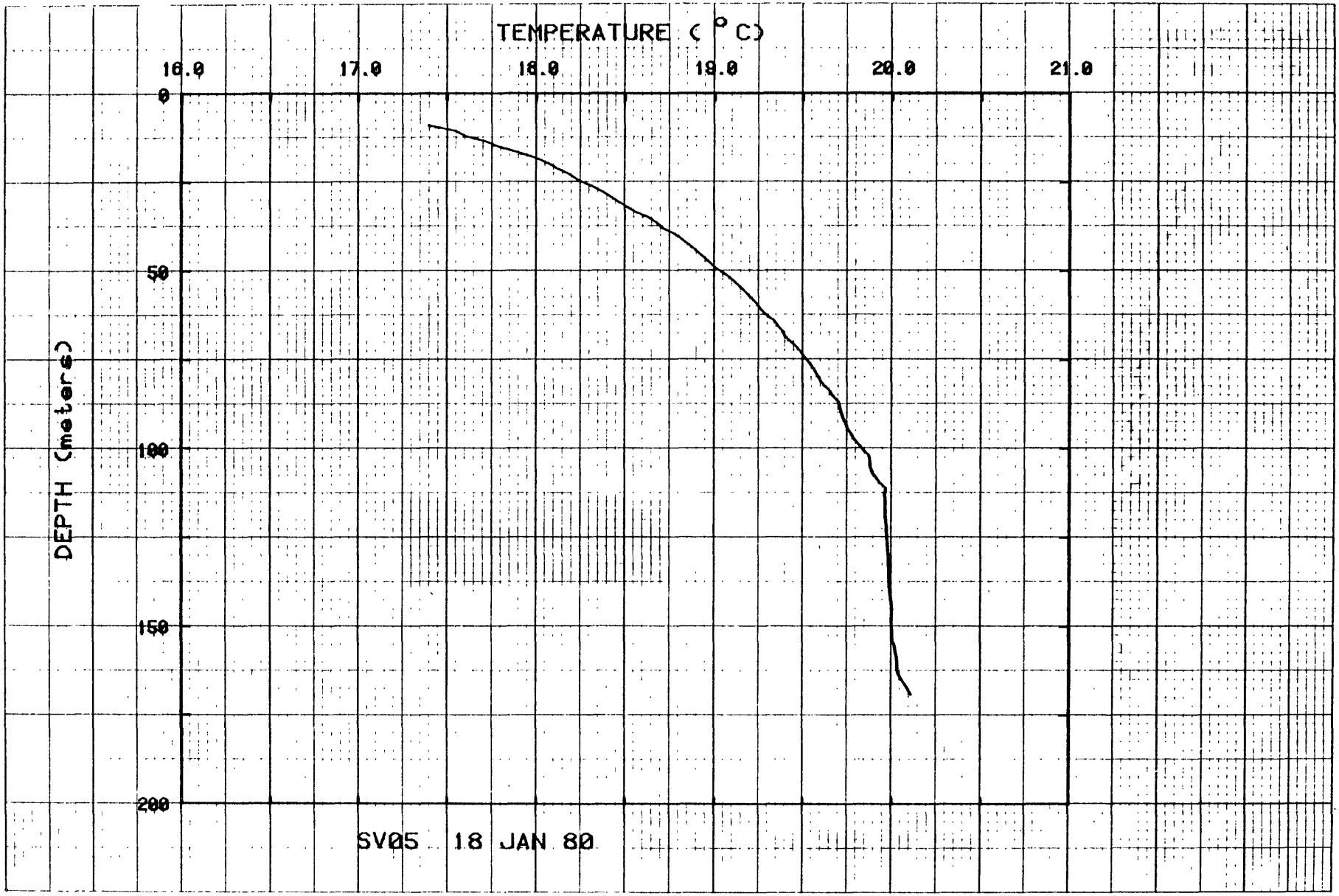

Figure 67. Temperatures for hole SV05.

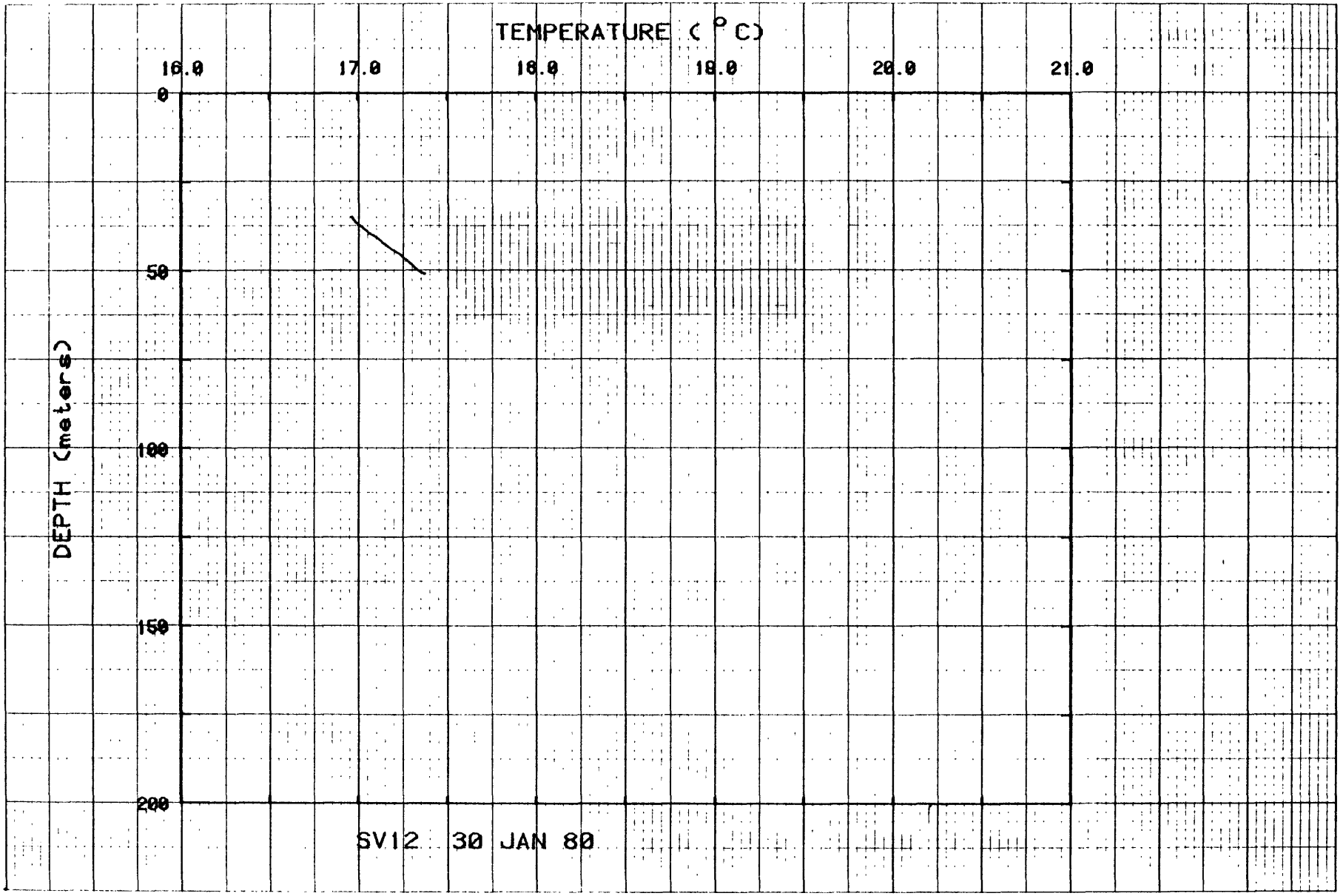

Figure 68. Temperatures for hole SV12.

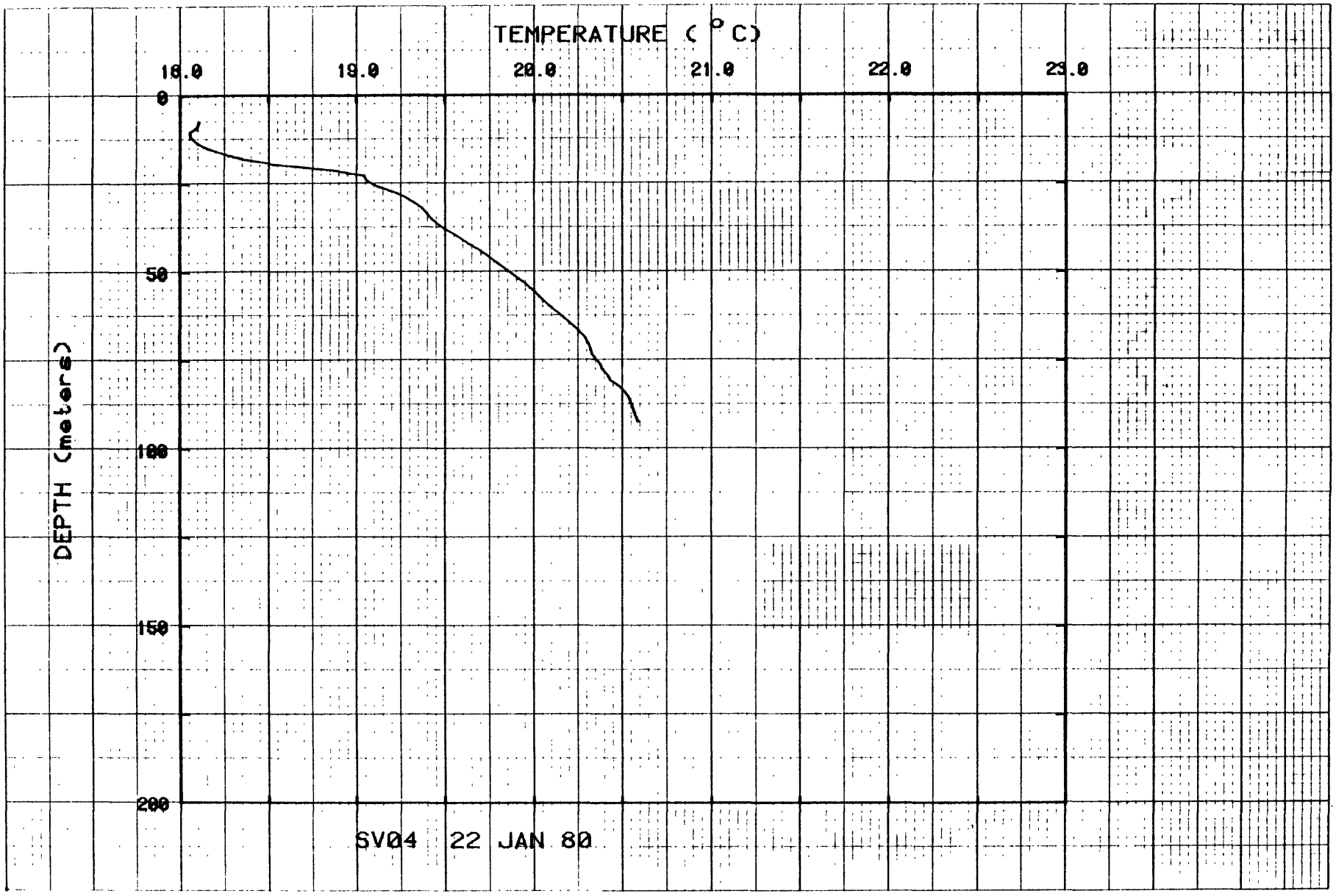

Figure 69. Temperatures for hole SV04.

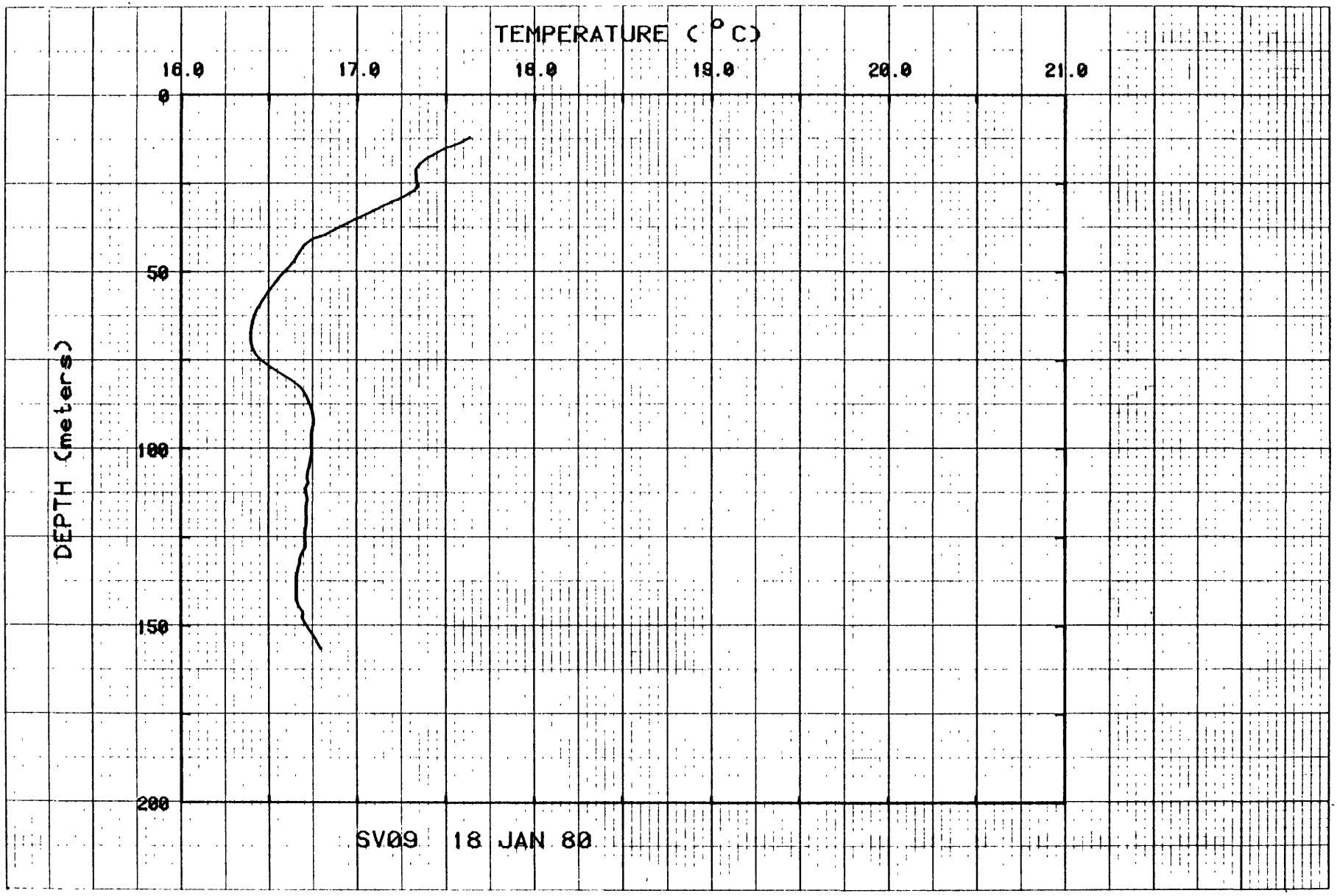

Figure 70. Temperatures for hole SV09.

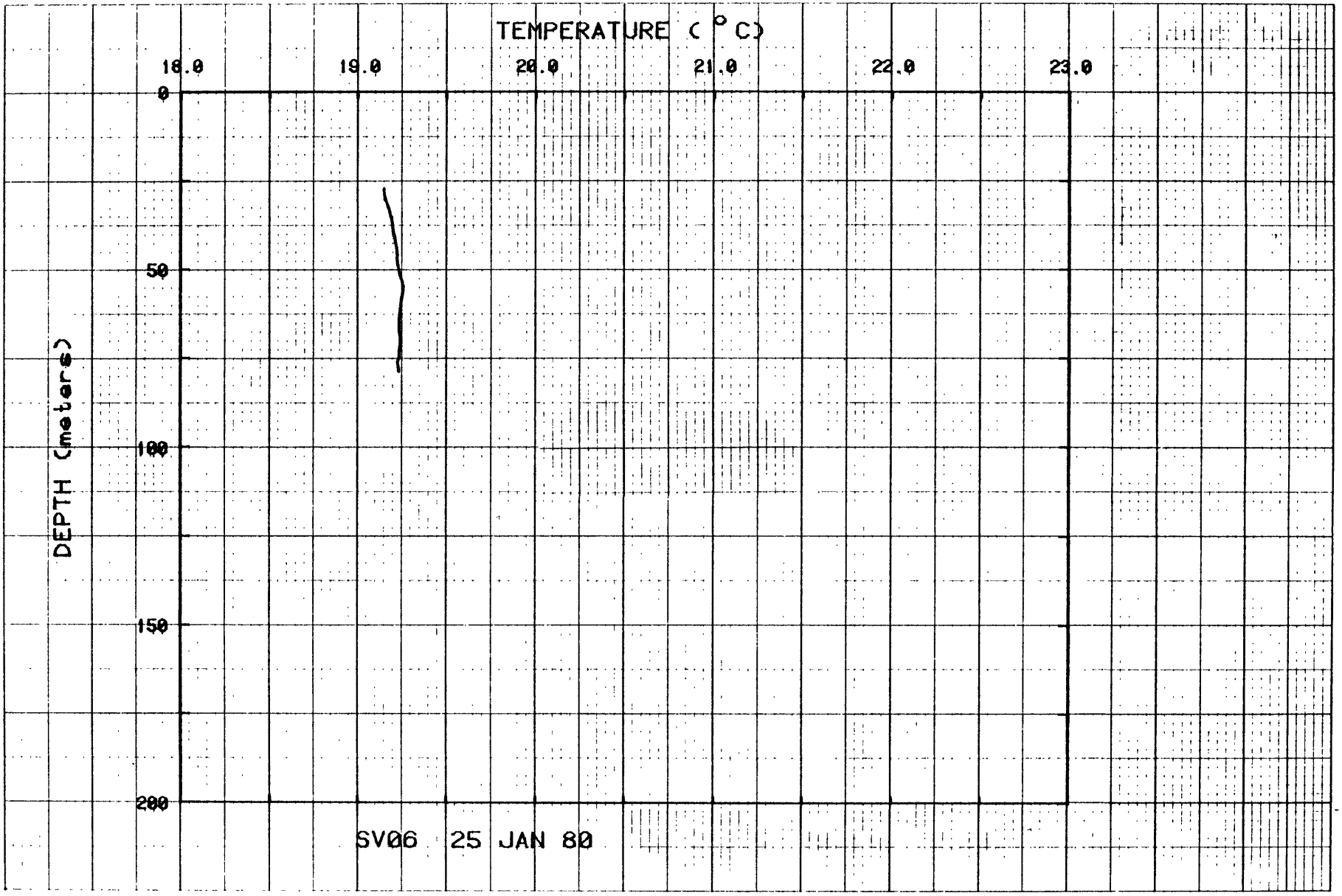

Figure 71. Temperatures for hole SV06.

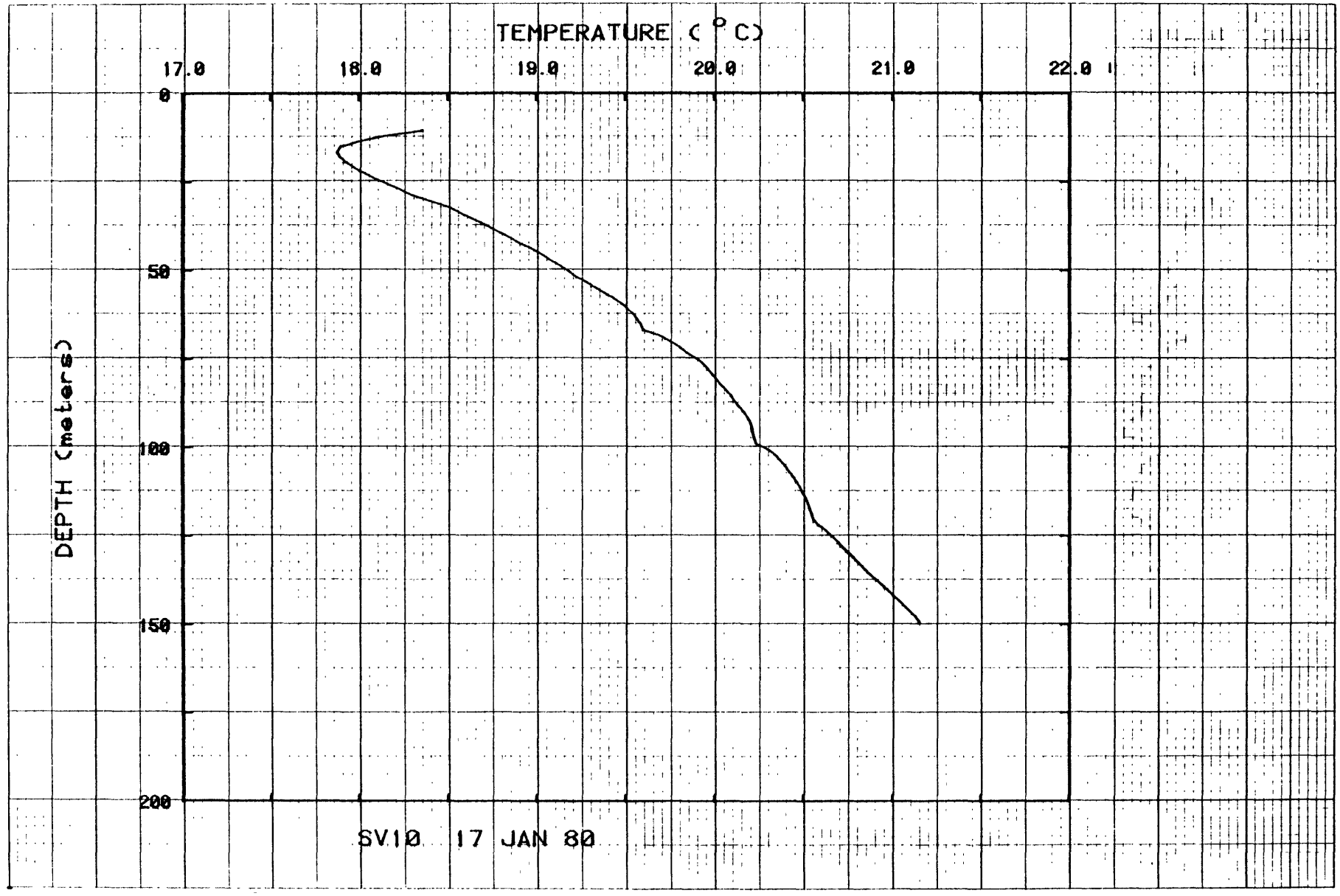

Figure 72. Temperatures for hole SV10.

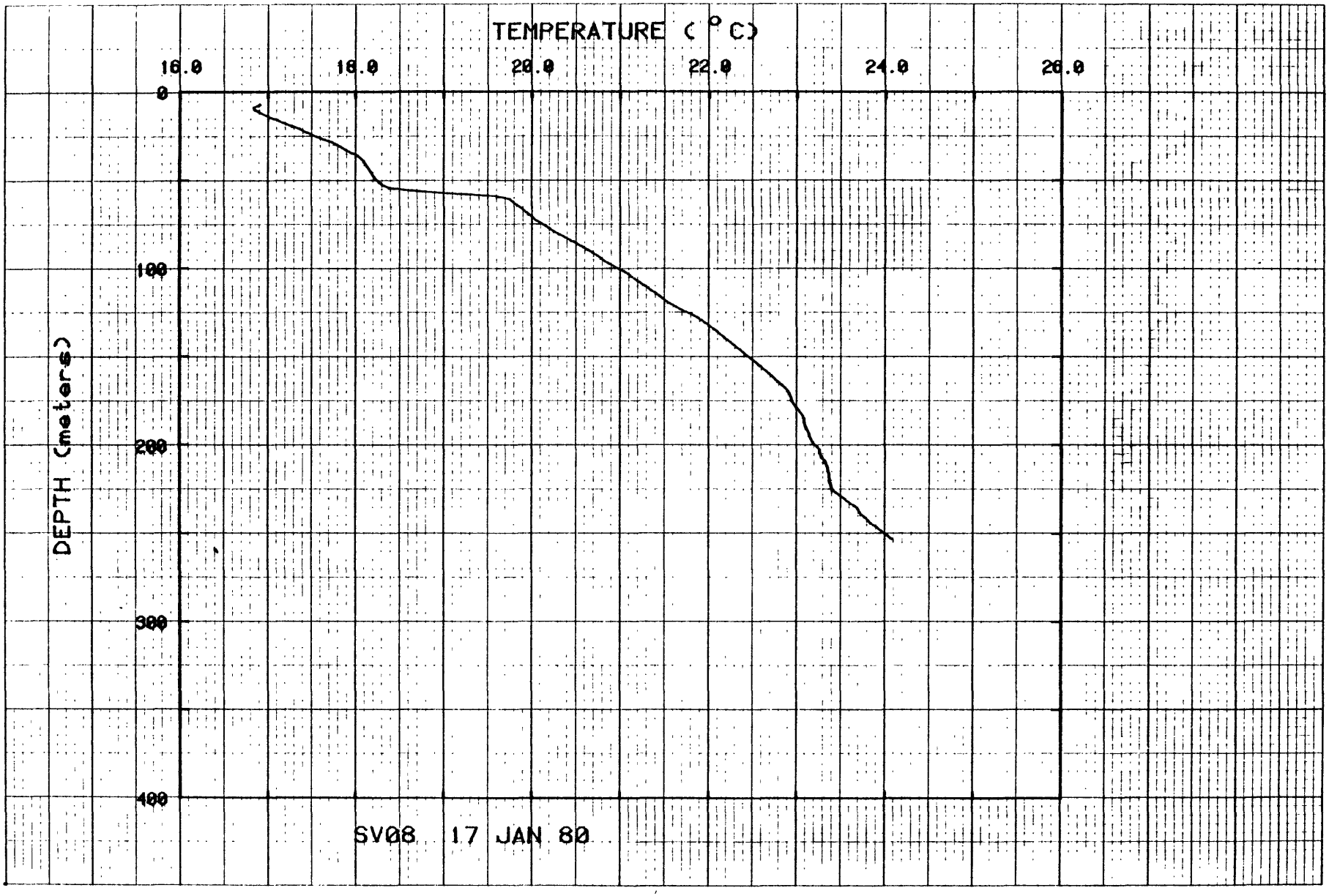

Figure 73. Temperatures for hole SV08.

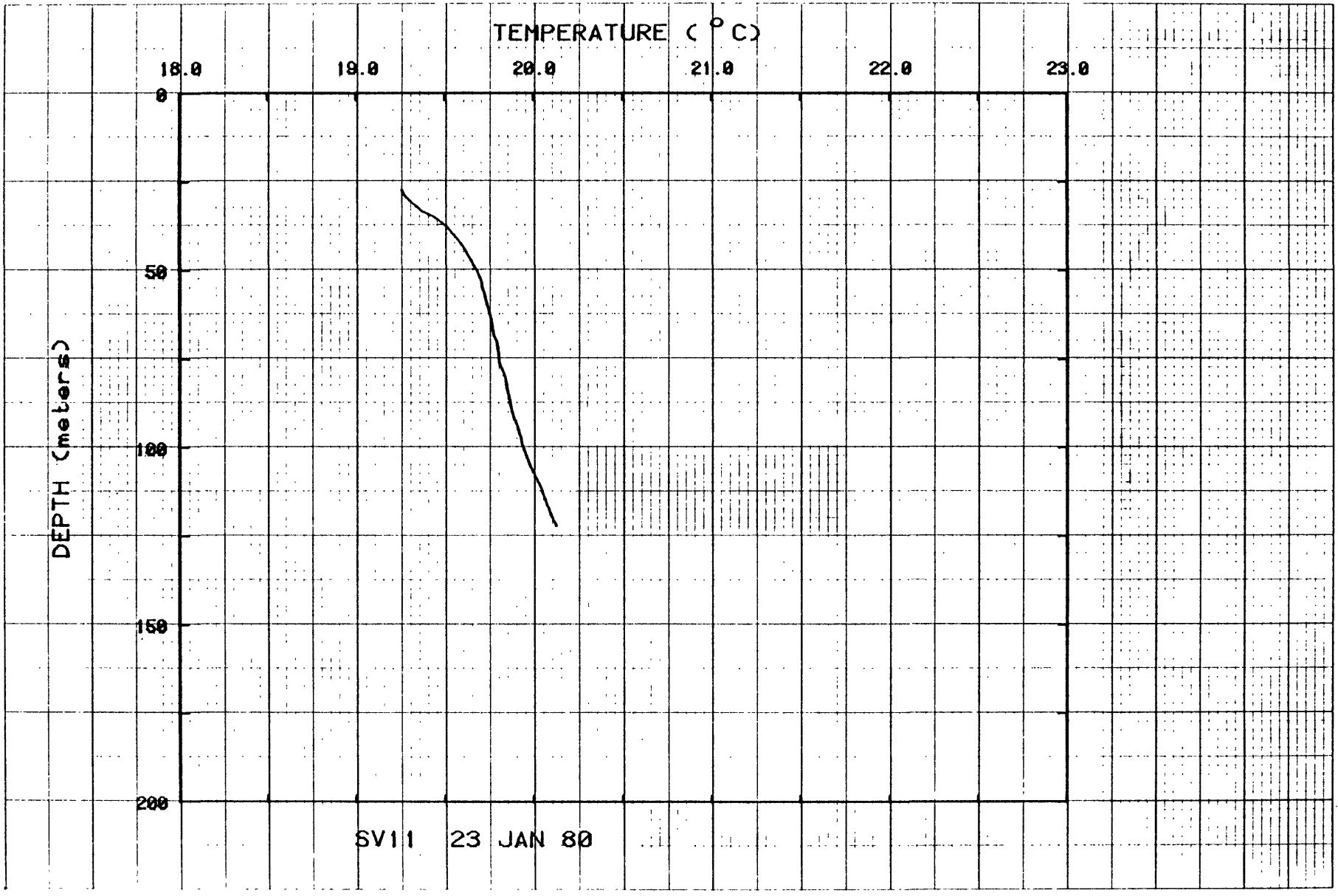

Figure 74. Temperatures for hole SV11.