United States Department of the Interior

Geological Survey

PRELIMINARY HEAT-FLOW INVESTIGATIONS OF THE CALIFORNIA CASCADES

by

C. W. Mase, J. H. Sass, Arthur H. Lachenbruch, and R. J. Munroe

Open-File Report 82-150

1982

Table of contents

List of figures (for the main report only)

List of tables (for the main report only)

Abstract

A heat-flow reconnaissance of the Cascade Range in California combines results from shallow (200 m) drilling with less reliable values derived from temperature gradients measured in "holes of opportunity" and thermal conductivities of hand-sampled equivalent rock types. Although the distribution of sites is uneven (control is concentrated in the Medicine Lake, Mount Shasta, and Lassen Peak areas) the new data provide a considerable improvement over previous representations of the regional near-surface heat flow. Measurements to depths of 300 m and less show an elongate region of anomalously low heat flow (<30 mWm^{-2}) along the axis of the Range. There are two broad areas of zero heat flow: the northern one encompasses the Medicine Lake Highlands, and the southern one is situated north of Lassen Peak. We attribute observed low heat flow, contrasting with the high heat flow expected along a magmatic arc, to regional circulation of ground water. This low heat flow indicates that the surficial thermal regime of the California Cascades is dominated by convective heat transfer. The Cascades are bounded on the west by the Klamath Mountains, a region of uniformly low heat flow (~40 mWm^{-2}), and on the east by the Modoc Plateau, a region of variably high heat flow (70-100 mWm^{-2}) characteristic of the Basin and Range. The paucity of data prohibits the definition of a regional heat flow for the northern Sierra Nevada to the south. Conductive heat flux from the transition zones bounding the Cascades is effectively masked by hydrothermal circulation. Although data on discharge rates and temperatures are insufficient to calculate a thermal budget, the estimated thermal discharge from springs could conceal deeper conductive heat flows of 100 mWm^{-2} or more, values characteristic of other areas of Quaternary magmatic activity.

No page 1

INTRODUCTION

The Cascade Range has been formed and reshaped continuously during the late Cenozoic by magmatic activity accompanying the subduction of the Pacific Plate by the North American Plate. In view of this, it is reasonable to suppose that the Cascades should contain numerous commercially exploitable geothermal resources. A promising prospect has been identified at Meagher Mountain in British Columbia (Souther, 1975; Lewis and Souther, 1978; Read, 1979); however, both exploration and exploitation of geothermal resources to date have been rather small scale and spotty. To some extent, this reflects the scarcity of surface hydrothermal phenomena in the Cascades. This scarcity generally is attributed to a combination of high rainfall and extremely high permeabilities of younger volcanic rocks which causes geothermal fluids to be diluted and literally washed away by large aquifers which may be discharging at a degree or two above ambient temperature.

Blackwell and others (1978) recently have compiled and reviewed heat-flow data from Oregon as have Schuster and others (1978) for Washington and Lewis and Jessop (1981) and Hyndman (1976) for British Columbia. The U.S. results have been summarized by Blackwell and others in Sass and others (1981). Briefly from west to east, the Coast Ranges have a very uniform heat flow of $\sim$40 mWm^{-2} with a gradual transition to values of $\sim$60 mWm^{-2} in the western Cascades and an abrupt transition (within 10 km) to values of $\sim$100 mWm^{-2} in the high Cascades.

In 1979, as part of the USGS geothermal evaluation of the Cascade Ranges, we began a systematic program of temperature-gradient and heat-flow measurements. To begin with, we obtained temperature data from all available wells and drill holes. This procedure was continued in 1979 and 1980 and was supplemented by holes drilled specifically for heat flow in and near the Lassen KGRA (Mase and others, 1980) and further drilling near Mount Shasta and in the Northern Sierra. The status of heat-flow observations in northern California (including those discussed in this report) is illustrated in Figure 1.

The program is continuing, but we present here the preliminary results of the fieldwork through 1980 with some brief interpretive remarks.

The following notation and units are used throughout this report:

T, temperature, °C

K, thermal conductivity, 1 $W\ m^{-1}K^{-1}$ = 2.39 $mcal\ cm^{-1}s^{-1}{}^{\circ}C^{-1}$

z, depth, m positive downwards

v_z, volume flux of water or vertical (seepage) velocity, $m\ s^{-1}$ or $mm\ y^{-1}$

Γ, vertical temperature gradient, mKm = $^{\circ}C\ km^{-1}$

q, vertical conductive heat flow, mWm^{-2} = $kW\ km^{-2}$
or HFU (10^{-6} $cal\ cm^{-2}\ s^{-1}$): 1 HFU = 41.87 mWm^{-2}

Acknowledgments. We are grateful to our colleagues in the Forest Service and Bureau of Land Management for their help in locating holes of opportunity and for their timely processing of drilling permits. We are indebted to Julie Donnelly-Nolan for her valuable comments and criticisms.

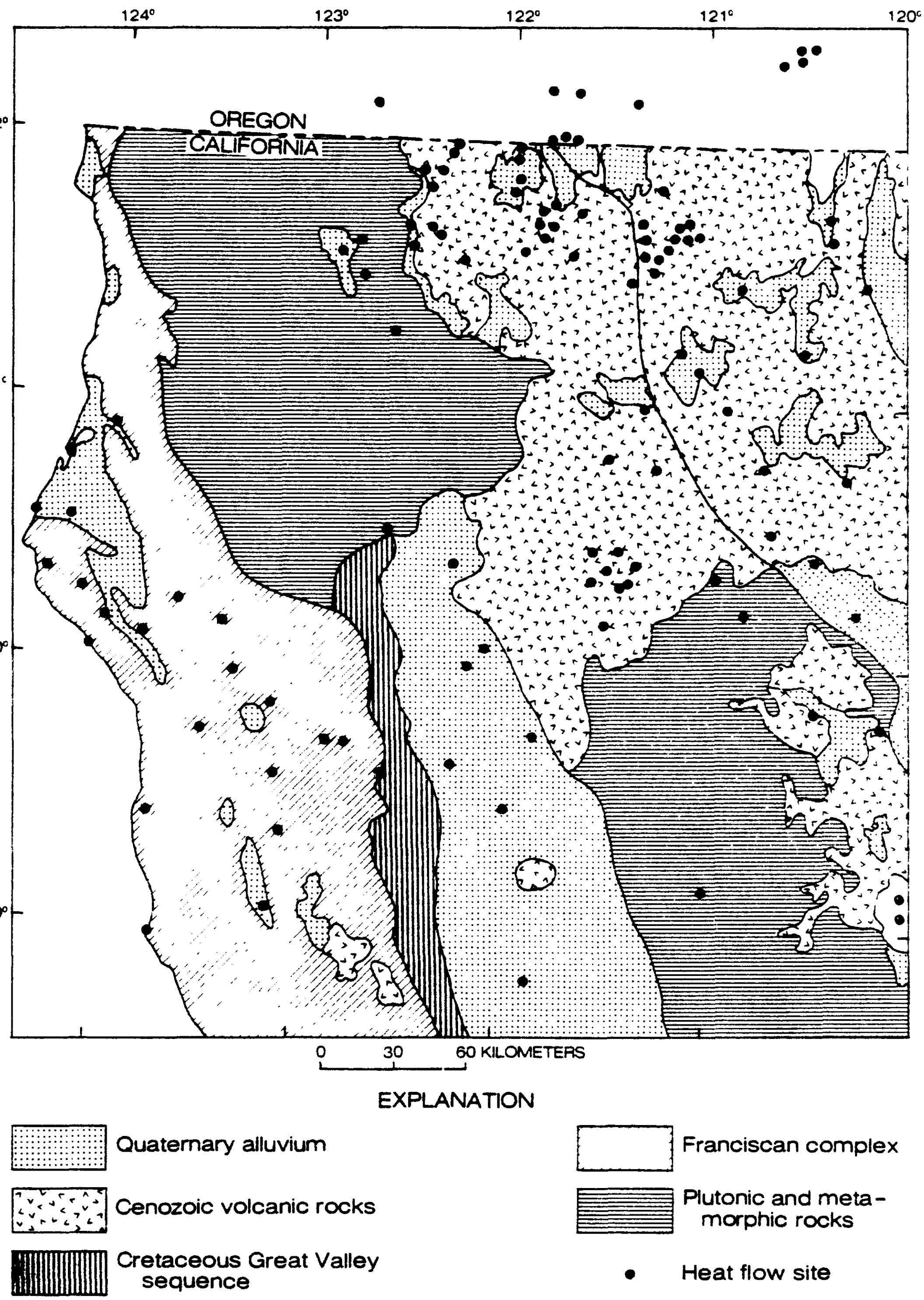

Figure 1. Geologic sketch map of northern California showing the locations of heat-flow determinations.

REGIONAL TECTONIC AND THERMAL SETTING

The Cascade Range is a chain of Quaternary volcanoes, dominated by large strato volcanoes, running roughly parallel to the North American plate margin and terminating in the south near the landward projection of the Mendocino fracture zone (i.e., the projected southern edge of the subducting oceanic plate). High-alumina basalt or basaltic andesite, similar to that of other convergent margins, characterizes the volcanism and is found throughout the chain. Within California, more of this magma has erupted than to the north in Oregon and Washington, perhaps because of extension of the "soft" margin of the North American plate. Common north-northwest - south-southeast alignment of coeval vents within the Cascades is in accord with a regional north-south maximum horizontal compressive stress deduced from faulting and focal mechanisms (Zoback and Zoback, 1980). The southern portion of the Cascades is bounded by the Basin and Range, Klamath Mountain, and Sierra Nevada provinces to the east, west, and south, respectively (Figure 2). The Basin and Range province is a region of extensional tectonics with variable but high heat flow that can be accounted for by upward mass flow into the lithosphere from the asthenosphere for plausible rates of lithospheric extension (Lachenbruch and Sass, 1978). Heat-flow control in the Klamath Mountains is poor but suggests a province of uniformly low heat flow ($\sim$40 mWm^{-2}) related to heat sinks associated with active subduction characteristic of the entire western coastal region north of Cape Mendocino. Although heat-flow data are also sparse for the northern Sierra Nevada, such data as do exist suggest a uniformly low heat flow (<40 mWm^{-2}) related to relict subduction off the North American coast south of the Mendocino Triple Junction (Henyey and Lee, 1976). Contrasting with the high heat flow (>100 mWm^{-2}) expected along a magmatic arc, near-surface (<200 m) heat-flow measurements indicate broad regions of low-to-zero heat flow along the axis of the Cascades. The low observed heat flow is attributed to the pervasive, large-scale circulation of ground water within the young, permeable volcanic rocks of the range.

Disequilibrium phenocryst assemblages common in Cascade volcanic rocks suggest complex petrogenetic histories involving repeated mixing and crustal interaction as the magma approaches the earth's surface from below (Eichelberger, 1975; Heiken, 1978; Eichelberger, 1978; Heiken and Eichelberger, 1980). The growth of large-scale silicic magma bodies that would support hydrothermal systems is dependent on a high upward flux of mafic magma and its prolonged residence in the crust (e.g., Lachenbruch and Sass, 1978). Areas of abnormal concentration of basaltic vents (e.g., Medicine Lake Highland) may also support hydrothermal systems. However, the pervasive circulation of large volumes of cold water within the young, permeable volcanic strata of the Cascades has serious implications for the development and thermal longevity of "shallow" crustal magma chambers. In such an environment, the enhancement of cooling by convective over conductive heat loss will have a profound effect on the cooling rate of the magma chamber, the amount of magma necessary to supply long-lived systems, and hence, the potential of the system as an economically exploitable resource.

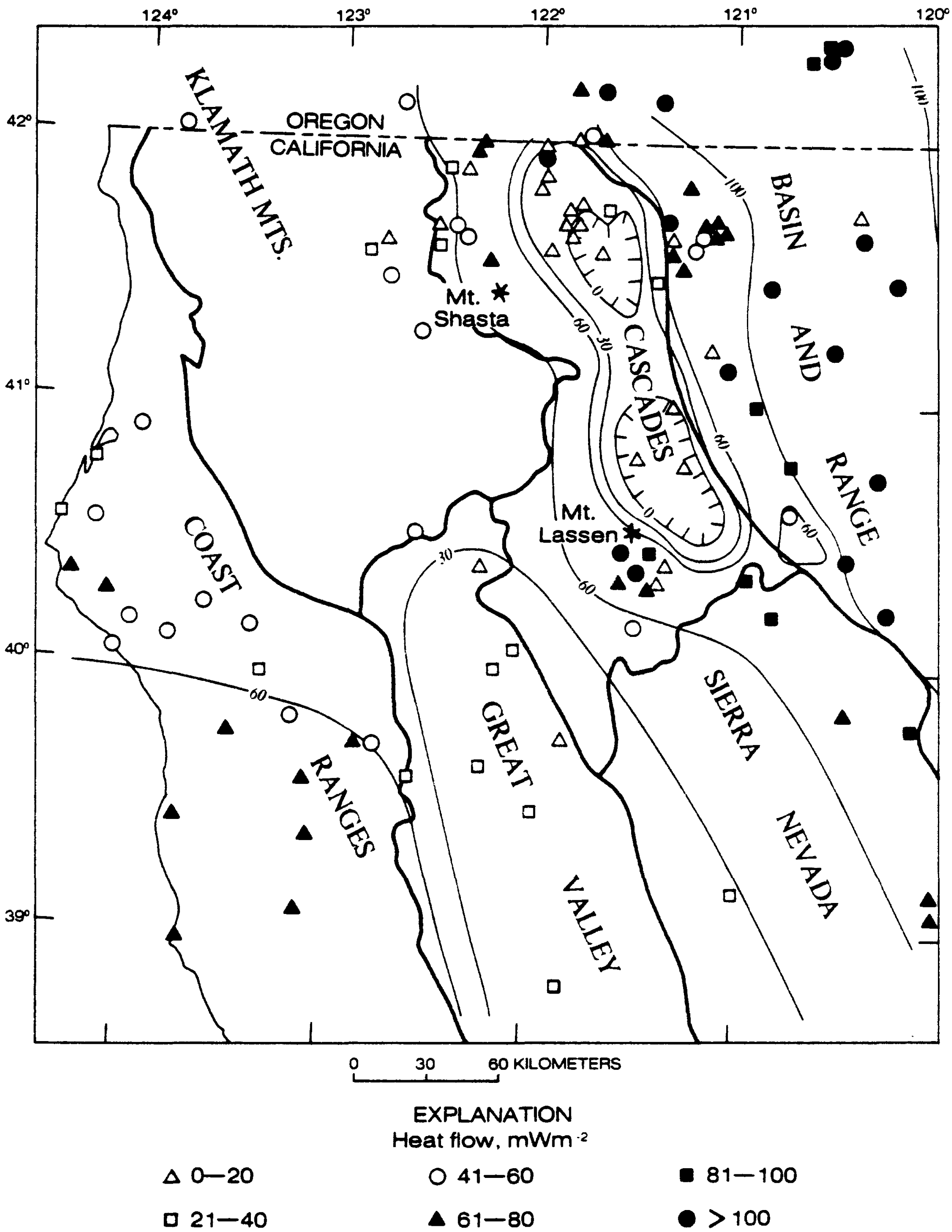

Figure 2. Heat-flow contour map of northern California showing major physiographic-tectonic provinces in northern California and adjacent areas of Oregon and Nevada (after Fenneman, 1928). Heat-flow control is shown as coded symbols.

HEAT-FLOW DATA

Heat-flow values for 83 new sites in northeastern California are listed in Table 1 (boreholes drilled specifically for heat-flow measurements) and Table 2 (holes of opportunity, mostly water wells). The vertical component of heat flow, q, was computed as the product of the measured thermal conductivity, K, and the least-squares temperature gradient, Γ, over each linear section of the borehole, and is given by

$$q = K\Gamma \qquad (1)$$

The most appropriate way of computing (1) depends on the actual distribution of conductivity and temperature at depth, and on how well these distributions are known within any borehole. For boreholes drilled specifically for heat-flow measurements (Table 1) thermal conductivities were measured on solid disks of core or from drill chips in a divided-bar apparatus following the methods described by Sass and others (1971a, 1971b). (The details of temperature and thermal conductivity measurements for Table 1 boreholes are contained in Appendix I.) Thermal conductivities for holes of opportunity (Table 2) were estimated from literature values for rocks of similar lithology. The rock type for a given borehole was determined from correlation of surface geology with driller's logs, well completion reports and private communications from local drillers and others with knowledge of the particular area. For holes where no information was available, the rock type was determined on the basis of surface geology. Assigning a single gradient to boreholes exhibiting the effects of lateral and vertical water movement, for the purpose of calculating a conductive heat loss, is somewhat arbitrary. In general, the most linear section of the near-surface temperature-depth curve was used to calculate the least-squares gradient. The resulting conductive heat loss obtained by itself is of little regional significance but is useful when combined with many measurements over a wide area, in defining regional ground water circulation patterns, and in estimating the amount of heat derived from the earth's interior that is redistributed by the influx of meteoric waters.

The heat flow determined from (1) usually is referred to as the uncorrected heat flow. It is based on the assumption that all the heat transfer is by one-dimensional steady-state conduction. Departures from this condition can lead to local and often regional heat-flow determinations quite unrepresentative of the regional heat flux from the earth's interior. An effort was made to identify such departures at each site and either to account for them or to allow for them in evaluating the reliability of the measurements. Effects considered include vertical and lateral ground water movements (e.g., Lachenbruch and Sass, 1977; Bredehoeft and Papadopulos, 1965), the steady-state effects of topographic relief (Birch, 1950; Lachenbruch, 1969), uplift, erosion and sedimentation (Birch, 1950), and thermal refraction in dissimilar rocks. Within the context of the present study, only the first two warrant discussion; however, many conditions leading to non-conductive, transient, and two- and three-dimensional heat flow can go undetected and must certainly contribute to the scatter of otherwise internally consistent data.

Convection by ground water in permeable volcanic rock that mantles the Cascades poses the greatest obstacle to determining, from surface observations, the heat flow associated with crustal conditions at depth. Large-scale downward percolation and lateral circulation of ground water attributable to a combination of of topographic relief, high rates of precipitation and permeable volcanic rocks can completely "wash out" the conductive flux, making it impossible to study heat flow by conventional means. Obvious hydrologic effects often can be eliminated by judicious selection of heat-flow sites; however, because hydrologic effects are often subtle, lingering uncertainties may persist. Furthermore, holes of opportunity (mostly water wells) are sited for reasons other than heat-flow measurements, and hence, are not selected so as to avoid hydrologically disturbed regions. Thus it is difficult to determine the regional significance of heat-flow determinations throughout the Cascades where the conductive flux can vary from zero to several times the expected regional value (>100 mWm^{-2}) over distances of a few kilometers and substantial amounts of heat may be discharged convectively by lateral underflow in shallow aquifers into streams and lakes or at the surface by springs. In general, the mean combined heat flow at the surface integrated over the recharge and discharge regions plus the convective loss into the surface drainage will equal the regional conductive flux associated with crustal conditions at depth. However, the large-scale circulation and discharge of low enthalpy thermal waters at slightly above ambient surface temperatures throughout the southern Cascades makes it extremely difficult to estimate the convective losses. The technique used in this study was to make as many heat-flow determinations in as wide a variety of hydrologic environments as possible. These determinations when combined with the limited hydrologic data available for the California Cascades may provide useful information on regional hydrologic patterns and a means for estimation of a deeper conductive flux. A further detailed analysis of hydrothermal convection and its effect on conductive heat transfer is beyond the scope of this paper and for further discussion the reader is referred to Lachenbruch and Sass (1977), Domenico and Palciauskas (1973), Bredehoeft and Papadopulos (1965), and Birch (1947).

Topographic relief can distort the temperature field sufficiently to cause errors in heat-flow determinations. This is especially true in the Klamath Mountains and Cascades where changes in elevation of up to 2 km commonly occur within a horizontal distance of several kilometers. For boreholes where the temperature-depth profile indicated an apparently conductive regime and a preliminary estimate of steady topography effects based on plane slopes (Lachenbruch, 1968, 1969) indicated a substantial correction (>5%) a three-dimensional Birch-type correction (Birch, 1950) was performed. This correction takes into account the effect of all topography outward from the borehole to at least 90% of the solid angle subtended by the lowest temperature measurement point recorded. The above calculation is dependent on the regional geothermal gradient, and consequently on the regional heat flow for a given area. Since convection dominates the "near-surface" regime of the Cascades and the depth to which circulation occurs is unknown, the heat flow is locally quite variable, and therefore, it is difficult to decide what value average gradient is appropriate to use. In general, for all topographic corrections we assumed an average thermal gradient equal to that determined for the borehole and that the ground-surface temperature decreased 6°C km^{-1} with increasing elevation (a generalized value obtained from Weather Bureau records and from shallow holes). Although this simple one-dimensional model for the lapse rate can introduce significant errors, particularly in areas where the surface temperature may either be depressed or elevated by near-surface water movements, the available information on local variations is usually too scant to define exact local conditions and the simple assumption is the best that can be made. The first-order correction of Birch (1950) can also result in large errors if steep slopes occur at or near the borehole (Lachenbruch, 1969).

For each site, the principal elements of the heat-flow calculations are given in Table 1 for boreholes drilled specifically for heat-flow studies and Table 2 for holes of opportunity (mostly water wells). The standard error or some other statistical measure of scatter is calculated for each of the principal elements (conductivity and temperature gradient). These are combined, using the method of propagation of errors, to arrive at a formal statistical estimate of the reliability of the heat-flow value. We have also defined four broad categories to take some account of the large-scale effects of convection within permeable volcanic rocks and the resulting disturbances to the temperature profiles. Both of the tables contain gradients in all of the following four categories (after Lachenbruch and others, 1976): 1) regions with conductive regimes to substantial depths, characterized by a linear temperature profile; 2) regions of hydrologic recharge, characterized by extremely low gradients, and by the tendency for the gradient to increase with increasing depth; 3) regions of hydrologic discharge characterized by anomalously high gradients and by a tendency for the gradient to decrease with increasing depth; 4) regions of substantial lateral movements usually characterized by gradients which change sign with depth. In assigning a gradient to one category or another, we were guided by the objective criteria listed above, but in some cases involving more than one possible category (e.g., recharge occurring with strong lateral movement of ground water), rather subjective judgments based on limited hydrologic data and experience in other areas dictated the choice of category. For boreholes that exhibited substantial hydrologic disturbances, the gradient and heat flow were not estimated.

Heat-flow determinations for the sites listed in Table 1 (most of which were drilled specifically for heat-flow studies) are of a higher quality than those of Table 2. Sufficient rock samples were available to characterize the effective conductivity of the measured section and to determine the effects (if any) of conductivity variations on the shape of the temperature-depth profiles. Typical uncertainties for heat flows listed in Table 1 are $\sim\pm 5\%$. Conductive heat-flow values for the holes of opportunity (Table 2) are little more than rough estimates. Included in both tables are boreholes in which there are substantial hydrologic disturbances and for which no heat flow has been estimated owing to complexities in the temperature-depth profiles. Although these boreholes contain little information regarding the conductive flux at depth, they can be quite useful, when combined with many measurements over a wide area, in defining regional patterns of ground water circulation and in estimating the amount of heat derived from the earth's interior that is redistributed by the influx of meteoric waters.

TABLE 1. Locations, conductive temperature gradients, lithologies, conductivities, and estimated heat flows for USGS holes in the Cascades, Klamath Mountains, and Northern Sierra Nevada

Designation	N. Lat.	W. Long.	Elev. (m)	Depth range (m)	Γ (mKm^{-1})	Type Γ†	Lithology	Conductivity ($Wm^{-1}K^{-1}$)	Uncorr. q (mWm^{-2})	Corr. q (mWm^{-2})
BSS	42° 01.2'	123° 50.5'	1070	76-182	15.97 (.01)	c	ultramafic	2.85 (.06)	46 (1)	47 (1)
CVN	39° 50.9'	120° 28.2'	975	60-235	24.45 (.02)	c	granodiorite	2.77 (.06)	68 (2)	63 (2)
GRP	42° 29.3'	123° 22.7'	350	91-189	14.68 (.01)	c	qtz. monzonite	2.74 (.05)	40 (1)	40 (1)
HAP	41° 51.6'	123° 21.9'	975	122-213	14.3 (.1)	c	meta. seds.	2.49 (.07)	36 (1)	42 (1)
IGO	40° 30.5'	122° 36.5'	470	76-145	16.6 (.2)	c	granodiorite	2.79 (.05)	46 (2)	42 (1)
				145-229	13.3 (.1)	c	granodiorite	3.06 (.08)	41 (1)	39 (1)
LSNB	40° 23.5'	121° 32.2'	1890	0-165	**	r	dacite	2.26 (.07)	**	**
LSNC	40° 20.9'	121° 33.0'	1735	91-256	28.14 (.03)	c	dacite	2.29 (.09)	64 (3)	69 (3)
LSND	40° 22.4'	121° 28.0'	1828	0-105	**	r	andesite	1.88 (.10)	**	**
LSNE	40° 20.4'	121° 27.0'	1770	46-168	36.26 (.04)	c	andesite	2.00 (.03)	73 (1)	65 (1)
LSNF	40° 21.3'	121° 29.9'	1500	30-224	91.93 (.13)	c,d	andesite	2.51 (.15)	231 (14)	*
LSNG	40° 24.4'	121° 26.8'	1905	0-165	**	r	andesite	1.64 (.03)	**	**
				165-172	51.88 (.86)	c	andesite	1.64 (.03)	85 (3)	*
LSNH	40° 23.6'	121° 21.6'	1786	0-185	**	r	andesite	1.87 (.04)	**	**
LSNI	40° 20.4'	121° 23.1'	1817	0-186	**	r	andesite	2.15 (.11)	**	**
LSNL	40° 22.6'	121° 24.5'	1740	0- 93	**	d	andesite	2.36 (.05)	**	**
LSNM	40° 10.0'	121° 35.2'	975	0-122	**	r	quartz diorite	2.43 (.05)	**	**
				122-182	22.20 (.04)	c	quartz diorite	2.43 (.05)	54 (1)	46 (1)
LSNO	40° 21.9'	120° 56.7'	1585	76-187	32.63 (.08)	c	granodiorite	2.97 (.03)	97 (1)	93 (1)
RVN	40° 31.2'	120° 40.8'	1640	160-229	21.66 (.01)	c	granodiorite	2.41 (.05)	52 (1)	47 (1)
SHAS	41° 33.2'	122° 15.4'	1126	64-216	24.45 (.07)	c	quartz diorite	2.52 (.06)	62 (2)	60 (1)
WC1	42° 08.1'	122° 43.5'	1025	283-310	16.27 (.08)	c	granodiorite	3.05 (.06)	50 (2)	42 (2)

†Type of Γ: c = conductive regime; d = discharge and/or upward movement of water; r = recharge and/or downward movement of water.

*No correction applied for surface topography.

**Gradient and heat flow have not been estimated for borehole exhibiting substantial hydrologic disturbances.

TABLE 2. Locations, elevations, thermal and lithologic data for holes of opportunity in northern California

Hole	N. Lat.	W. Long.	Elev. (m)	Depth range (m)	Γ (mKm^{-1})	Type Γ†	Lithology	Conductivity†† ($Wm^{-1} K^{-1}$)	q (mWm^{-2})
MP01	41° 28.3'	121° 24.9'	1315	54- 84	22 (2)	d+c	basalt	1.80 (.20)	40 (8)
MP02	41° 40.7'	121° 7.0'	1445	84-129	29 (3)	r+c	basalt	1.90 (.20)	55 (11)
MP03	41° 38.8'	121° 7.1'	1385	92-180	43 (1)	c	basalt	1.90 (.20)	82 (10)
MP04	41° 40.5'	121° 9.5'	1362	9-110	***	d	basalt	***	***
MP05	41° 38.9'	121° 10.5'	1340	20-119	41 (1)	c	basalt	1.90 (.20)	78 (10)
MP06	41° 36.7'	121° 12.6'	1345	20-113	18 (2)	d+c	basalt	1.80 (.20)	32 (7)
MP07	41° 42.2'	121° 20.6'	1330	15- 76	189 (10)	d	basalt	1.60 (.20)	302 (54)
MP08	41° 34.2'	121° 21.0'	1280	15-134	45 (4)	c	basalt	1.80 (.20)	81 (16)
MP09	41° 39.0'	121° 3.8'	1470	40-111	32 (3)	c	basalt	2.00 (.20)	64 (12)
MP10	41° 33.3'	121° 7.4'	1435	38- 60	92 (20)	c	basalt	1.60 (.20)	147 (50)
MP11	41° 48.5'	122° 0.6'	1295	30-390	13 (1)	l	lacustrine	1.20 (.10)	16 (2)
MP12	41° 40.9'	121° 48.8'	1365	15- 94	***	l	basalt	***	***
MP13	41° 41.0'	121° 48.6'	1370	15- 84	***	l+r	basalt	***	***
MP14	41° 46.0'	121° 47.7'	1340	57- 94	***	l+r	basalt	***	***
MP15	41° 41.6'	121° 52.5'	1395	90-104	14 (1)	r+c	basalt	2.80 (.20)	25 (5)
MP16	41° 44.2'	121° 52.0'	1325	15- 46	6 (1)	l	alluvium	1.40 (.20)	8 (2)
MP17	41° 38.4'	121° 51.9'	1405	6-124	***	l+r	basalt	***	***
MP18	41° 43.8'	121° 40.0'	1415	60-173	10 (3)	r	basalt	1.40 (.20)	14 (6)
MP19	41° 35.4'	121° 57.3'	1475	20-194	9 (2)	l+r	basalt	1.40 (.20)	13 (5)
MP20	40° 59.8'	120° 53.2'	1745	40-128	90 (9)	c	alluvium	1.30 (.20)	98 (24)**
MP21	40° 12.3'	120° 14.9'	1225	91-	102 (8)	c	lacustrine	1.10 (.10)	112 (19)

TABLE 2. Locations, elevations, thermal and lithologic data for holes of opportunity in northern California (continued)

Hole	N. Lat.	W. Long.	Elev. (m)	Depth range (m)	Γ (mKm^{-1})	Type Γ†	Lithology	Conductivity†† ($Wm^{-1}K^{-1}$)	q (mWm^{-2})
MP22	41° 28.2'	120° 10.8'	1455	30-152	92 (8)	c	alluvium	1.20 (.20)	90 (23)**
MP23	41° 12.0'	121° 8.2'	1260	15- 37	18 (3)	r	lacustrine	1.10 (.10)	20 (5)
MP24	41° 8.9'	121° 3.6'	1260	20-109	132 (15)	d	alluvium	1.40 (.20)	185 (47)
MP25	41° 44.0'	120° 22.8'	1465	18- 79	***	r	lacustrine	***	***
MP26	40° 57.6'	120° 31.1'	1610	12- 55	***	r	lacustrine	***	***
MP27	40° 59.8'	121° 19.4'	1010	18-122	***	r	basalt	***	***
MP28	41° 16.4'	122° 36.4'	1300	42-121	16 (1)	c	serpentinite	2.30 (.30)	37 (6)
MP29	41° 38.5'	121° 21.0'	1315	15-120	***	r+l	basalt	***	***
MP30	41° 48.5'	122° 0.5'	1295	150-305	14 (1)	r+l	lacustrine	1.20 (.2)	17 (3)
MP31	40° 46.1'	120° 43.4'	1680	15-114	***	r+d	basalt	***	***
MP32	41° 49.9'	121° 15.1'	1455	150-274	33 (2)	c	basalt	1.98 (.09)*	67 (7)
MP33	40° 45.5'	121° 15.5'	1735	49-177	***	r	basalt	***	***
MP34	41° 13.8'	120° 30.8'	1635	15-104	82 (6)	c	basalt	***	***
MP35	41° 34.1'	121° 42.4'	1940	6- 71	***	r	basalt	***	***
MP36	41° 30.4'	121° 17.2'	1365				basalt	1.82 (.12)*	
MP37	40° 43.9'	120° 18.8'	1650	75-198	64 (7)	c	basalt	1.60 (.20)	107 (25)
MP38	41° 28.7'	122° 46.3'	1006	1- 16	***	c	alluvium	***	***
MP39	41° 34.8'	122° 52.7'	991	102-124	16 (3)	c,r+l	meta. seds.	2.40 (.30)	38 (12)
MP40	41° 34.4'	122° 53.6'	1052	50- 76	6 (1)	c+r	meta. seds.	2.40 (.30)	14 (4)
MP41	41° 34.1'	122° 52.9'	853	44- 63	13 (2)	c+r	alluvium	1.40 (.20)	18 (5)
MP42	41° 37.2'	122° 46.9'	866	0- 29	***	r	alluvium	***	***

TABLE 2. Locations, elevations, thermal and lithologic data for holes of opportunity in northern California (continued)

Hole	N. Lat.	W. Long.	Elev. (m)	Depth range (m)	Γ (mKm^{-1})	Type $\Gamma^{\dagger}$	Lithology	Conductivity[††] ($Wm^{-1}K^{-1}$)	q (mWm^{-2})
MP43	41° 36.5'	122° 31.9'	802	3- 25	54 (8)	c	alluvium	1.40 (.20)	76 (22)
MP44	41° 38.6'	122° 23.4'	823	13- 47	***	r	basalt	***	***
MP45	41° 36.9'	122° 31.7'	774	1- 43	***	d	alluvium	***	***
MP46	41° 33.1'	122° 32.2'	841	21- 52	***	r	alluvium	***	***
MP47	41° 33.3'	122° 32.0'	829	28- 42	21 (3)	c	alluvium	1.40 (.20)	29 (8)
MP48	41° 33.3'	122° 31.6'	829	1- 40	***	r	alluvium	***	***
MP49	41° 25.5'	122° 29.9'	1122	40- 67	17 (2)	c	serpentinite	2.30 (.30)	39 (10)
MP50	41° 53.3'	122° 29.3'	671	3- 90	***	r	basalt	***	***
MP51	41° 49.4'	122° 26.1'	786	57- 77	23 (1)	c	basalt	1.80 (.20)	41 (6)
MP52	41° 40.3'	122° 25.8'	814	87- 95	30 (10)	c	basalt	1.80 (.20)	54 (24)
MP53	41° 53.5'	122° 23.8'	789	35- 51	6 (2)	r+c	basalt	1.80 (.20)	11 (5)
MP54	41° 57.3'	122° 19.8'	957	122-150	41 (3)	r+c	basalt	1.80 (.20)	74 (14)
MP55	41° 58.6'	122° 18.9'	838	44- 70	40 (3)	c	basalt	1.80 (.20)	72 (13)
MP56	41° 53.2'	122° 28.9'	668	10- 32	***	r	basalt	***	***
MP57	41° 53.9'	122° 29.0'	664	20- 63	13 (1)	c	basalt	1.80 (.20)	23 (4)
MP58	41° 53.9'	122° 31.5'	658	20- 46	6 (1)	r	basalt	1.80 (.20)	11 (3)
MP59	41° 58.4'	121° 58.8'	1298	15-136	***	d	lacustrine	***	***
MP60	41° 57.1'	121° 59.7'	1292	15- 64	118 (7)	c+d	lacustrine	1.20 (.20)	142 (32)
MP61	41° 51.3'	121° 59.7'	1291	10- 67	***	d	alluvium	***	***
MP62	41° 44.0'	120° 22.7'	1460	56- 77	6 (1)	r+c	alluvium	1.40 (.20)	8 (3)

TABLE 2. Locations, elevations, thermal and lithologic data for holes of opportunity in northern California (continued)

Hole	N. Lat.	W. Long.	Elev. (m)	Depth range (m)	Γ (mKm^{-1})	Type Γ[†]	Lithology	Conductivity[††] ($Wm^{-1}K^{-1}$)	q (mWm^{-2})
MP63	41° 38.5'	120° 23.9'	1445	15- 26	69 (2)	c	alluvium	1.40 (.20)	97 (17)
MP64	40° 48.3'	121° 30.8'	1020		***	r+l	basalt	***	***

†Type of Γ: c = conductive regime; d = discharge and/or upward movement of water; r = recharge and/or downward movement of water; l = lateral movement of water.

††Conductivities estimated from literature values for rocks of similar type lithology.

*Conductivities were estimated on the basis of the harmonic mean of the solid component, $\langle K_s \rangle$, as measured from drill cuttings using "the chip method" (Sass and others, 1971).

**Heat flow corrected for topographic effects using plane slopes (Lachenbruch, 1969).

***Gradient and heat flow have not been estimated for these boreholes which exhibit easily identifiable hydrologic disturbances.

DISCUSSION

The foregoing tables contain 66 new heat-flow estimates plus an additional 17 measurements which until now have received only preliminary mention in the literature. As these data fill an existing gap in the heat-flow coverage for northern California, it is worth looking briefly at the present status of the observations.

The variation of temperature-depth profiles within a geologic province can be diagnostic of the near-surface thermal and fluid flow regime within the province. Three composite temperature-depth plots, one for each of the three main physiographic provinces in northern California, are shown in Figures 3 through 5. Within the Klamath Mountains and Coastal Provinces, the majority of boreholes are characterized by linear temperature profiles (Figure 3) indicative of regions where the predominant mode of heat transfer is conductive to substantial depths. Boreholes within the Basin and Range (Figure 4) are characterized by generally high and quite variable thermal gradients. Although the figure contains both low and high gradients (associated with hot spring activity), the profiles generally are linear indicating the thermal regime, at least near the surface, is dominated by conductive heat transfer. Figure 5 reveals the complexity of temperature-depth profiles for boreholes within the Cascades. The non-linearity of the temperature profiles and the tendency for the thermal gradient to be quite variable with depth, as shown in Figure 5, is common for boreholes located in or near strongly convecting zones. The low thermal gradients exhibited in the uppermost parts of most temperature profiles and the tendency for the gradient to increase with increasing depth suggests that heat from greater depths is being absorbed by downward percolation and lateral movement of ground water. Because temperature-depth curves within or near strongly convecting zones are quite variable with depth, downward extrapolation of individual curves is not justified.

From Figure 5 and the above discussion, it is evident that a substantial part of the near-surface heat transfer is non-conductive owing to hydrothermal convection in permeable near-surface strata. The next step is to examine how pervasive (both laterally and vertically) is the convection of ground water, and the extent to which it modifies heat transfer in the upper crust. The temperature-depth curves for holes in the Quaternary basalts and andesites of the Cascades generally exhibit the low observed temperatures and near isothermal or negative gradients characteristic of holes which are located in major recharge areas. Negative gradients and temperature reversals are common in regions where there is substantial lateral movement of recharge waters, which originate from snow melt at high elevations, and are therefore at a lower temperature than the mean annual surface temperature. For systematically non-linear segments displaying curvature in the temperature-depth profile, a one-dimensional flow model similar to that described by Lachenbruch and Sass (1977, equations 10 and 11) or Bredehoeft and Papadopulos (1965) was used to estimate the downward volume flux of water in the recharge areas. (This model yields only a velocity estimate and provides no estimate on the depth of circulation.) Estimates of seepage velocities were quite variable and ranged from a few millimeters to hundreds of millimeters per year. For this model, we assumed broad vertical flow within the formation. An ambiguity exists in this assumption since the lack

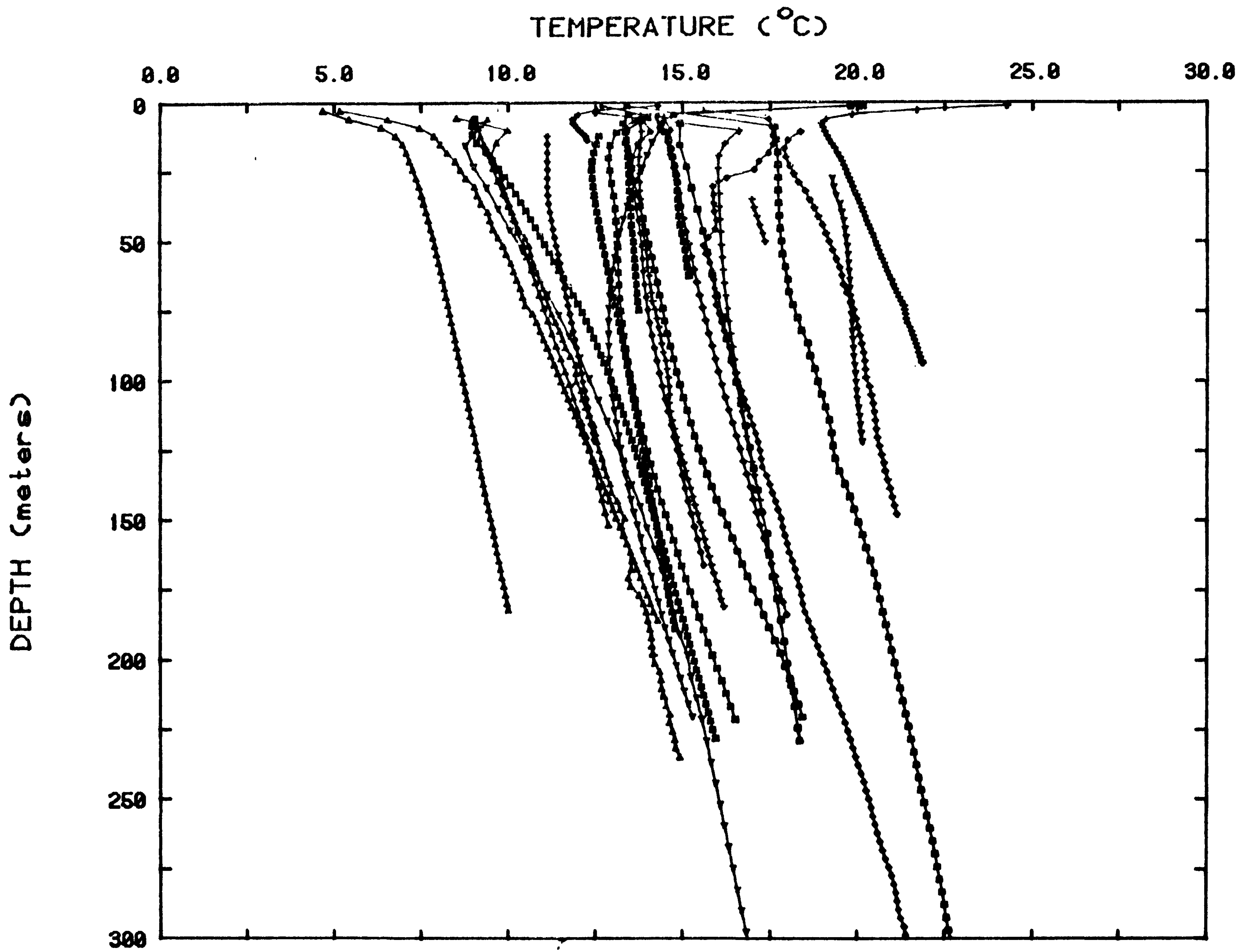

Figure 3. Temperature-depth profiles for the Coastal Provinces, Klamath Mountains, and Sierra Nevada

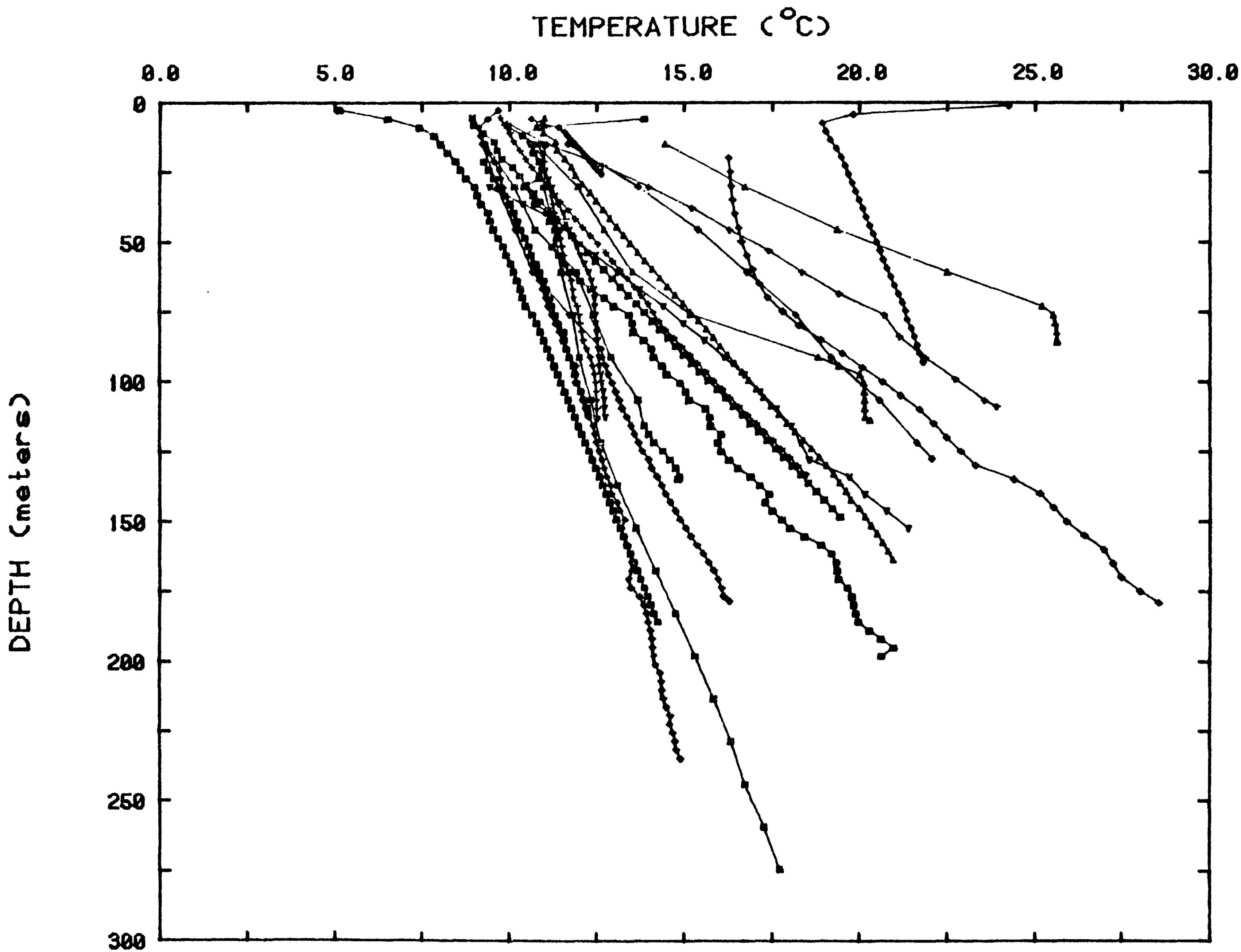

Figure 4. Temperature-depth profiles for the Basin and Range.

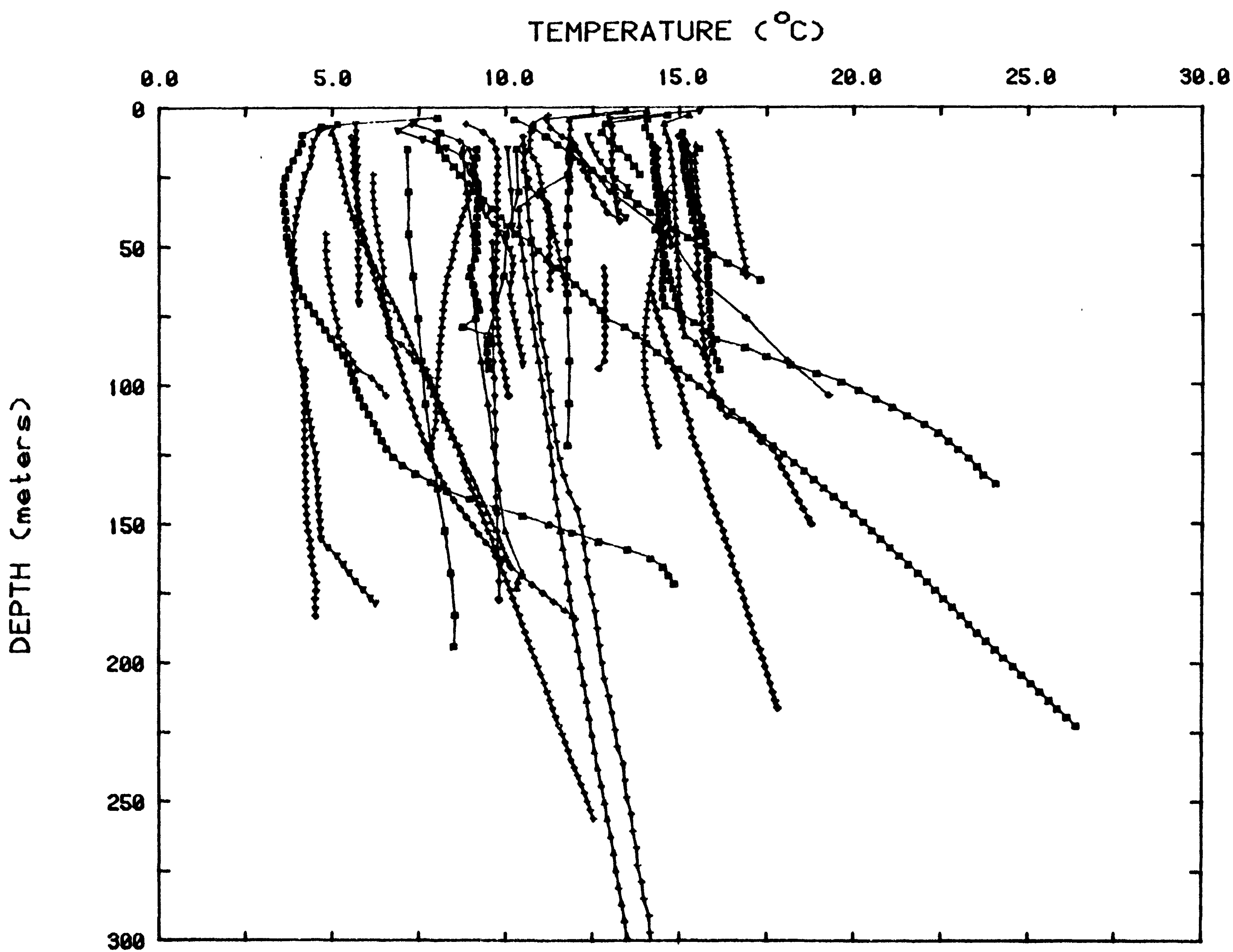

Figure 5. Temperature-depth profiles for the Cascades.

of a barrier between the casing and the borehole wall can result in fluid flow in the annulus which is indistinguishable in a temperature profile from fluid flow in the formation. Although for these calculations, we have assumed simple one-dimensional vertical flow, more complex patterns (two- and three-dimensional) can easily be envisioned to explain some temperature profiles.

The spatial variability of heat flow within the Cascades can be diagnostic of the fluid flow regime within the young volcanic rocks. In spite of the limited spatial coverage provided by the heat-flow determinations (concentrated primarily in the Mount Shasta - Medicine Lake and Lassen Peak areas), a heat-flow map of northern California has been constructed (Figure 2). In general, Figure 2 represents the heat flow one is likely to measure at the depths of conventional heat-flow measurements (100-300 m). For regions where the near-surface heat flow is zero, the heat flow from greater depths is almost certainly not zero; however, at the depths of conventional measurements the influx of meteoric water is sufficiently large to "wash out" and redistribute the conductive flux. Boreholes where the heat flow was not calculated due to substantial hydrologic disturbances have been indicated on the map as having "zero" conductive loss at the surface in order to delineate areas where recharge is taking place.

The extreme variations in heat flow are related to the complexities in geologic structure and lateral variations in hydrology within the young volcanic rocks. Based on the sparse control, and some geologic and topographic constraints, the heat-flow map (Figure 2) apparently is dominated by two regions of zero heat flow. The northernmost region is centered about the Medicine Lake Highland, one of the most active centers of volcanism within the Cascades. The Highland is a broad shield volcano of basaltic to rhyolitic flows and tuffs 50 km in diameter and more than 1 km high (Eichelberger, 1975; Heiken, 1978). The southernmost region of low heat flow is centered in the volcanic highlands northeast of Lassen Peak, a region of intimately associated andesite cones and dacite domes, with basalt flows along the margin. Both regions are characterized by Quaternary volcanism and an absence of surface drainage despite moderately high annual precipitation indicating that downward percolation of ground water through permeable volcanic rocks is occurring over large areas. For both convective systems, the regions of apparent recharge are associated with topographic highs while the regions of apparent discharge are associated with the topographic lows surrounding the highlands. For the Medicine Lake Highland, there is a trend of increasing ground water temperatures from 4°C to 6°C in the recharge areas of the Highland to values of 12°C to 18°C in the discharges to the north (Butte Valley and Klamath-Tule Lakes area) and south (Fall River - Big Valley area). Based on various estimates of spring discharge rates from these regions (State of California, Division of Water Resources Bulletin #83, p. 98; Division of Mines and Geology Bulletin 190) the combined rate of discharge for the Highland is $\sim$40,000 ℓ sec^{-1}. At this discharge rate, for every 1°C of warming that the thermal waters encounter, we may redistribute 25 mWm^{-2} of conductive flux over the area of the Highland. Although the available data are still insufficient to evaluate the regional heat flux below the zone of circulation, the estimated thermal discharge from springs could easily conceal a deeper conductive flux in excess of 100 mWm^{-2}.

The Coastal Provinces, north of the Mendocino Triple Junction and the Klamath Mountains have uniformly low heat flow (~40 mWm^{-2}) (see Blackwell, in Sass and others, 1981). Evidence of convective heat transfer either in local ground water systems or in regional hydrothermal systems in general does not exist for these provinces and the predominant mode of heat transfer (as illustrated in Figure 3) is by conduction. The observed pattern of low heat flow is consistent with thermal sinks within the mantle associated with a presently active subduction zone along the Pacific Coast north of the Mendocino Triple Junction. This situation is characteristic of subduction zones all over the world. In addition, the region has a rather mafic crust containing few radiogenic heat sources, an observation consistent with the low observed heat flow and a moderate heat flow from the mantle.

Although there is considerable scatter in the data for the Basin and Range province within northeastern California, the region is characterized by high and quite variable heat flow with a mean value of 86 ± 12 mWm^{-2}. It is probable that much of the scatter can be attributed to hydrothermal convective systems near the surface and to deeper convective processes related to extensional tectonics during the last 15-20 my. The high heat flow can be accounted for by upward mass flow into the lithosphere from the asthenosphere for plausible rates of lithospheric extension (Lachenbruch and Sass, 1978).

The present scarcity of data prohibits the definition of a regional heat flow for the northern Sierra Nevada (Figure 2). However, based on data obtained farther south, the Sierra Nevada is one of the best documented regions of low heat flow on the continent (Lachenbruch, 1968; Roy and others, 1968; Sass and others, 1971; Henyey and Lee, 1976). Theoretical considerations indicate that the low heat flow results primarily from anomalously low heat flow from the mantle underlying the Sierra Nevada province and secondarily from the low heat production of granitic rocks in the western part of the Sierra. Henyey and Lee (1976) proposed that the low heat flow observed for the Sierra Nevada is consistent with thermal sinks within the mantle associated with a relic subduction zone of the California Coast, south of the Mendocino Triple Junction. Thus we would also expect a uniformly low heat flow (~40 mWm^{-2}) for the northern Sierra Nevada, which is consistent with the one measured value (46 mWm^{-2}) at Deer Creek (LSNM).

An east-west heat-flow profile across the Cascades at the latitude of Mount Shasta (41° 30' N. Lat.) is shown in Figure 6. For this profile, boreholes within the Lassen Peak area have been shown as a function of distance from the Cascades western physiographic boundary. The profile is consistent with the heat flow at trench-island arc type continental margins in other areas of the world (McKenzie and Sclater, 1968; Uyeda and Horai, 1964). However, the expected high heat flow within the Cascades and the thermal transition zones bounding the Cascades (cf. Blackwell and others, 1978) are apparently masked by hydrothermal circulation.

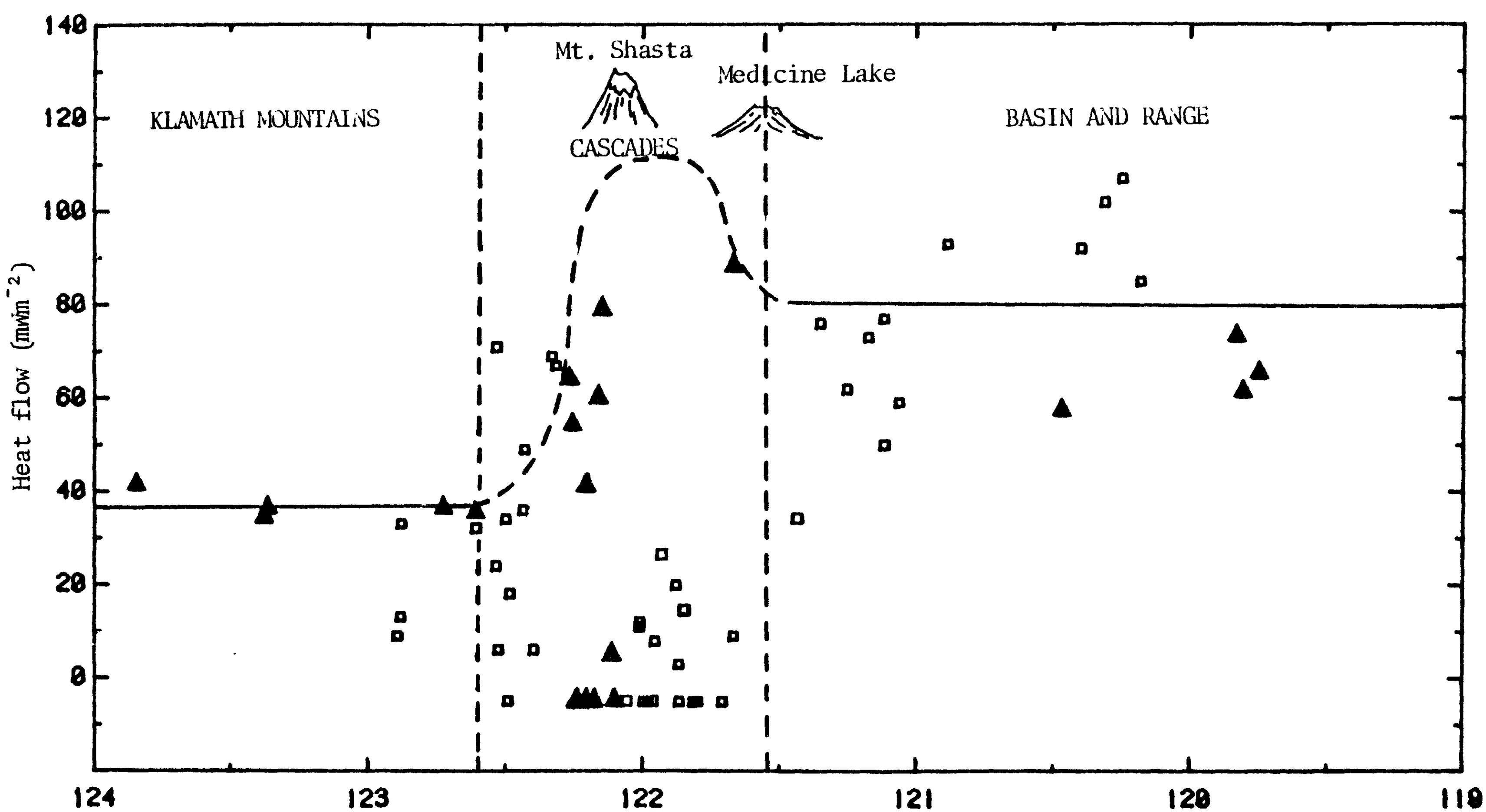

Figure 6. Heat flow as a function of longitude (°W) at the latitude of Mt. Shasta (~41° 30'N). Data from the Lassen Peak region are projected at about 0.8° west of their actual longitude to account for the NW strike of the California Cascades (Figure 2). Profile shown is based on that of Blackwell and others (1978) at 44° 30'N latitude. Triangles are wells drilled for heat flow; squares are holes of opportunity.

References

Birch, Francis, 1950, Flow of heat in the Front Range, Colorado: Geological Society of America Bulletin, v. 61, p. 567-630.

Blackwell, D. D., Hull, D. A., Bowen, R. G., and Steele, J. L., 1978, Heat flow of Oregon: Oregon Department of Geology and Mineral Industries Special Paper 4, 42 p.

Bredehoeft, J. D., and Papadopulos, I. S., 1965, Rates of vertical groundwater movement estimated from the earth's thermal profile: Water Resources Research, v. 1, p. 325-328.

Domenico, P. A., and Palciauskas, V. V., 1973, Theoretical analysis of forced convective heat transfer in regional groundwater flow: Geological Society of America Bulletin, v. 84, p. 3803-3814.

Eichelberger, J. C., 1975, Origin of andesite and dacite: Evidence of mixing at Glass Mountain in California and at other circum-Pacific volcanoes: Geological Society of America Bulletin, v. 86, p. 1381-1391.

Eichelberger, J. C., 1978, Andesitic volcanism and crustal evolution: Nature, v. 275, p. 21-27.

Fenneman, N. M., 1928, Physiographic division of the United States: Ann. Ass. Amer. Geogr, v. 18, p. 261-353.

Heiken, Grant, 1978, Plinian-type eruptions in the Medicine Lake Highland, California, and the nature of the underlying magma: Journal of Volcanology and Geothermal Research, v. 4, p. 375-402.

Heiken, Grant, and Eichelberger, J. C., 1980, Eruptions at Chaos Crags, Lassen Volcanic National Park, California: Journal of Volcanology and Geothermal Research, v. 7, p. 443-481.

Henyey, T. L., and Lee, T. C., 1976, Heat flow in Lake Tahoe, California-Nevada, and the Sierra Nevada Basin and Range transition: Geological Society of America Bulletin, v. 87, p. 1179-1187.

Hotz, P. E., 1971, Plutonic rocks of the Klamath Mountains, California and Oregon: U.S. Geological Survey Professional Paper 684-B, 20 p.

Hyndman, R. D., 1976, Heat flow measurements in the inlets of south-western British Columbia: Journal of Geophysical Research, v. 81, p. 337-349.

Irwin, W. P., 1960, Geologic reconnaissance of the northern Coast Ranges and Klamath Mountains, California, with a summary of the mineral resources: California Division of Mines and Geology Bulletin 179, 80 p.

Lachenbruch, A. H., 1968, Rapid estimation of the topographic disturbance to superficial thermal gradients: Reviews of Geophysics, v. 6, p. 365-400.

Lachenbruch, A. H., 1969, The effect of two-dimensional topography on superficial thermal gradients: U.S. Geological Survey Bulletin 1203-E.

Lachenbruch, A. H., and Sass, J. H., 1977, Heat flow in the United States and the thermal regime of the crust, in Heacock, J. G., ed., The Earth's Crust--Its Nature and Physical Properties: American Geophysical Union Geophysical Monograph 20, p. 626-675.

Lewis, T. J., and Jessop, A. M., 1981, Heat flow in the Garibaldi volcanic belt, a possible geothermal energy resource area: Canadian Journal of Earth Science, v. 18, p. 366-375.

Lewis, T. J., and Souther, J. G., 1978, Meager Mountain, British Columbia, a possible geothermal energy resource: Earth Physics Branch, Department of Energy, Mines and Resources, Canada, Geothermal Series No. 9.

Moses, T. H., Jr., and Sass, J. H., 1979, Drilling techniques presently in use by the Geothermal Studies Project, USGS: U.S. Geological Survey Open-File Report 79-763.

Read, P. B., 1979, Geology of the Meager Creek geothermal area, British Columbia: Geological Survey of Canada Open File 603.

Sass, J. H., Blackwell, D. D., Chapman, D. S., Costain, J. K., Decker, E. R., Lawver, L. A., and Swanberg, C. A., 1981, Heat flow from the crust of the United States, in Touloukian, Y. S., Judd, W. R., and Roy, R. F., eds., Physical Properties of Rocks and Minerals: McGraw-Hill Book Company, p. 503-548.

Sass, J. H., Lachenbruch, A. H., and Munroe, R. J., 1971a, Thermal conductivity of rocks from measurements on fragments and its application to heat-flow determinations: Journal of Geophysical Research, v. 76, p. 3392-3401.

Sass, J. H., Lachenbruch, A. H., Munroe, R. J., Greene, G. W., and Moses, T. H., Jr., 1971b, Heat flow in the western United States: Journal of Geophysical Research, v. 76, p. 6376-6413.

Souther, J. G., 1975, Geothermal potential of western Canada, in Proceedings of the 2nd United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, California, v. 1, p. 259-267.

Zoback, M. L., and Zoback, Mark, 1980, State of stress in the conterminous United States: Journal of Geophysical Research, v. 85, p. 6113-6156.

APPENDIX I: Thermal conductivities and temperature-depth data for USGS boreholes in the Cascades, Klamath Mountains, Sierra Nevada and Basin and Range

Temperature-depth and conductivity data for boreholes drilled specifically for heat-flow measurements, along with a brief description of the borehole and locale, are summarized in alphabetical order in Tables I-1 through I-38 and Figures I-1 through I-19. Temperature measurements were made in boreholes of 100 to 310 m depths drilled using conventional corehole, air-hammer and/or mud-rotary techniques. With the exception of WC1 and HAP, well completion generally involved lowering 33 mm I.D. steel pipe to within a meter of bottom, then pumping about 0.7 m^3 of cement-bentonite grout through the pipe, followed by a wiping plug and clear water (for detailed description, see Moses and Sass, 1979). This amount of grout is usually sufficient to seal off the lowermost 50 m of the annulus around the pipe in these 130 mm nominal diameter holes; however, early temperature measurements indicated that for holes drilled in volcanic rock most of the cement was lost in fractures and at the most, a few meters of casing near the bottom of the hole were grouted off. An additional ~3 m of cement plug was emplaced at the top of the well after the remainder of the annulus had been backfilled with mud and cuttings. Upon completion of the well, the steel pipe was then filled with water and allowed to equilibrate to facilitate temperature measurements (better heat transfer between probe and surrounding rock). Temperatures were measured repeatedly to a few millidegrees until all transient disturbances resulting from drilling had vanished. Temperature profiles are presented graphically in Figures I-1 through I-19 along with a smoothed average gradient over 6 m intervals.

Two different methods were used to measure thermal conductivity of the drill samples. Conductivity measurements for core samples were determined with a variant of the divided-bar method (Birch, 1950 and Sass and others, 1971). Thermal conductivities of drill cuttings were determined using the method described by Sass and others (1971). This procedure involves packing crushed chips into a cell, water saturating them, measuring the aggregate conductivity on divided-bar equipment and finally calculating the conductivity of the solid component (drill cuttings) from a geometric mean model. The measured solid conductivity from the chip method must be combined with estimates of formation porosity (ϕ) to arrive at the conductivity of the formation (K_f). From measurements of core and surface samples, average porosities of <1% for granitic rocks and <5% for volcanic rock were determined; therefore, no correction for porosity was applied to the solid component conductivities. Tabulations of thermal conductivities are listed in Tables I-1 through I-38, along with the most recent temperature-depth data for the borehole.

BSS: Bain's Stage Station

BSS was drilled near the center of a large ultramafic body in the western body in the western Jurassic belt of the Klamath Mountains (Holtz, 1971). This body is probably part of a thrust plate lying over Franciscan type terrain (Irwin, 1960). The heat-flow determination here was straightforward, with uniform gradient and conductivity below 76 m (Figure I-1 and Table I-1). Relief near the drill site is subdued, and the mean topographic correction averages only +4%.

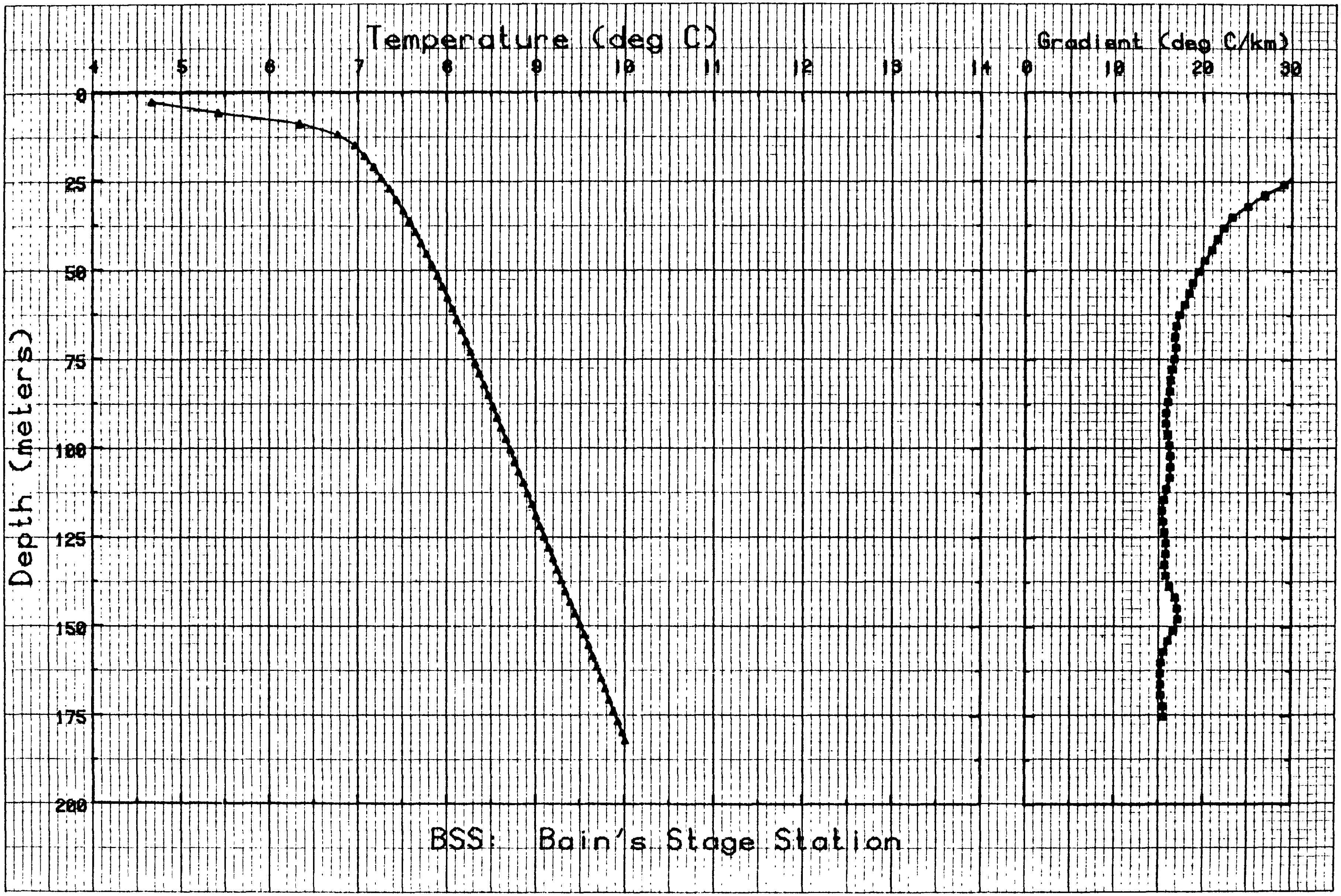

Figure I-1. Temperature and gradient profile for BSS.

TABLE I-1. Summary of thermal conductivities, densities, and porosities for borehole BSS

Depth (m)	<K> (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	φ (%)
15.2	2.22	2.58	0.5
22.9	2.26	2.58	0.5
30.5	2.65	2.67	0.1
31.3	2.88	2.72	0.1
38.1	2.87	2.71	0.0
45.7	2.63	2.61	0.4
53.3	2.95	2.83	0.0
61.0	2.77	2.76	0.0
62.3	2.64	2.76	0.0
68.6	2.82	2.72	0.4
76.2	2.41	2.58	2.4
83.8	3.30	2.62	0.1
91.4	2.94	2.80	0.0
92.9	2.84	2.78	0.0
99.1	2.93	2.68	0.1
106.7	2.78	2.65	0.7
114.3	3.21	2.75	0.0
121.9	3.07	2.60	0.5
121.9	2.97	2.63	0.1
129.5	2.92	2.65	0.0
137.2	3.11	2.66	0.1
146.3	2.44	2.65	0.2
148.4	2.27	2.95	0.2
153.3	2.74	2.58	2.3

TABLE I-1. Summary of thermal conductivities, densities, and porosities for borehole BSS (continued)

Depth (m)	<K> ($Wm^{-1} K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
160.0	3.22	2.74	0.0
167.6	2.96	2.73	0.0
175.3	2.94	2.71	0.0
182.9	3.12	2.75	0.0

TABLE I-2. Temperature tabulation

Hole: BSS BAIN'S STAGE STATION

Lat: 42- 1.20 Long: 123-50.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
3.05	4.662	6.10	5.422
9.14	6.343	12.19	6.769
15.24	6.969	18.29	7.073
21.34	7.173	24.38	7.259
27.43	7.356	30.48	7.436
33.53	7.511	36.58	7.579
39.62	7.647	42.67	7.713
45.72	7.777	48.77	7.839
51.82	7.898	54.86	7.953
57.91	8.011	60.96	8.066
64.01	8.118	67.06	8.169
70.10	8.218	73.15	8.273
76.20	8.323	79.25	8.373
82.30	8.423	85.34	8.472
88.39	8.522	91.44	8.570
94.49	8.616	97.54	8.666
100.58	8.717	103.63	8.765
106.68	8.814	109.73	8.867
112.78	8.914	115.82	8.960
118.87	9.008	121.92	9.054
124.97	9.101	128.02	9.152
131.06	9.199	134.11	9.247
137.16	9.294	140.21	9.341
143.26	9.397	146.30	9.447
149.35	9.501	152.40	9.553
155.45	9.601	158.50	9.648
161.54	9.693	164.59	9.741
167.64	9.788	170.69	9.831
173.74	9.882	176.78	9.929
179.83	9.976	182.06	10.010

CVN: Charles Valley North

CVN is situated in the Mesozoic granitic rocks of the Sierra Nevada batholith about 8 km west of the north end of Sierra Valley, the site of numerous geothermal manifestations. This site also provides a first-rate determination of heat flow (Figure I-2, Table 1) in a tectonic setting transitional between the Sierra Nevada and Basin and Range provinces.

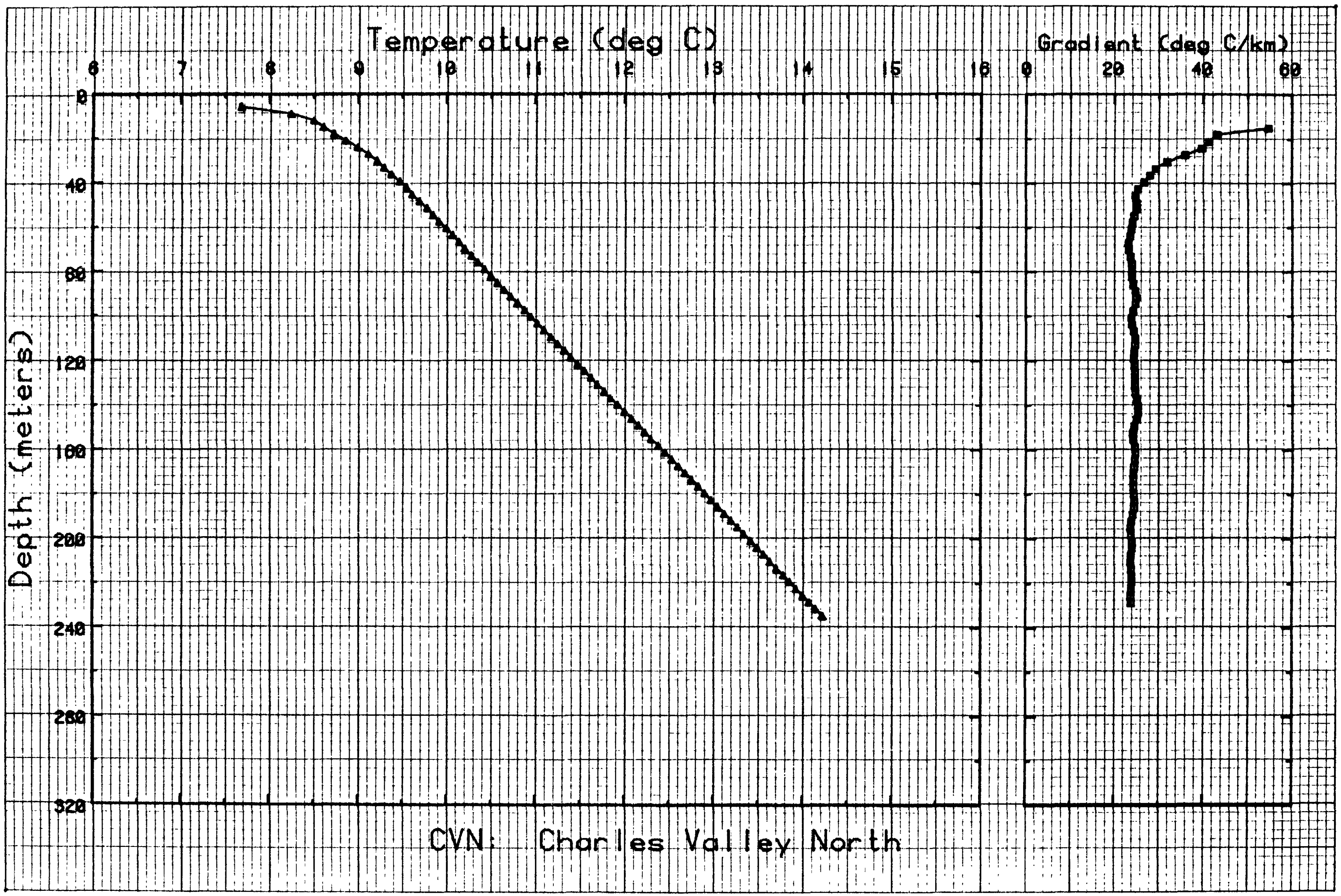

Figure I-2. Temperature and gradient profiles for CVN.

TABLE I-3. Summary of thermal conductivities, densities, and porosities for borehole CVN

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
15.2	3.63	2.59	0.3
30.5	2.72	2.72	0.6
45.7	2.73	2.73	0.5
61.0	2.82	2.71	0.3
76.2	2.86	2.70	0.5
91.4	2.72	2.71	0.1
106.7	2.83	2.73	0.3
121.6	2.88	2.74	0.2
137.2	2.76	2.73	0.4
152.1	2.77	2.71	0.3
167.3	2.77	2.72	0.4
182.3	2.66	2.73	0.5
198.1	2.78	2.74	0.4
213.4	2.79	2.73	0.2
228.6	2.75	2.73	0.3
244.4	2.80	2.74	0.4

TABLE I-4. Temperature tabulation

Hole: CVN CHARLES VALLEY NORTH

Lat: 39-50.90 Long: 120-28.20

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	7.680	9.14	8.244
12.19	8.501	15.24	8.608
18.29	8.729	21.34	8.859
24.38	8.993	27.43	9.116
30.48	9.216	33.53	9.296
36.58	9.380	39.62	9.476
42.67	9.557	45.72	9.614
48.77	9.695	51.82	9.783
54.86	9.852	57.91	9.919
60.96	10.001	64.01	10.071
67.06	10.144	70.10	10.207
73.15	10.283	76.20	10.356
79.25	10.430	82.30	10.502
85.34	10.574	88.39	10.648
91.44	10.727	94.49	10.803
97.54	10.880	100.58	10.952
103.63	11.022	106.68	11.094
109.73	11.173	112.78	11.248
115.82	11.323	118.87	11.396
121.92	11.470	124.97	11.547
128.02	11.622	131.06	11.696
134.11	11.773	137.16	11.846
140.21	11.924	143.26	12.004
146.30	12.080	149.35	12.158
152.40	12.230	155.45	12.302
158.50	12.378	161.54	12.455
164.59	12.530	167.64	12.605
170.69	12.680	173.74	12.753
176.78	12.828	179.83	12.902
182.88	12.976	185.93	13.053
188.98	13.126	192.02	13.202
195.07	13.274	198.12	13.342
201.17	13.420	204.22	13.491
207.26	13.568	210.31	13.638
213.36	13.708	216.41	13.783
219.46	13.859	222.50	13.928
225.55	14.003	228.60	14.075
231.65	14.147	234.70	14.221
235.00	14.228		

GRP: Grants Pass, Oregon

Selection of the Grants Pass site was based partly on a preliminary analysis (Hotz, 1971) suggesting a quartz monzonite composition with high heat production (K_2O = 4.6%). This pluton has been dated at 136 m.y. The rocks penetrated in the drill hole turned out to be of the same general composition (quartz-diorite, granodiorite) as those seen at Igo and Winburn Camp. The determination of heat flow at Grants Pass is quite straightforward. The gradient below 91 m is regular (Figure I-3), there is no systematic variation in thermal conductivity (Table I-5), and no topographic correction.

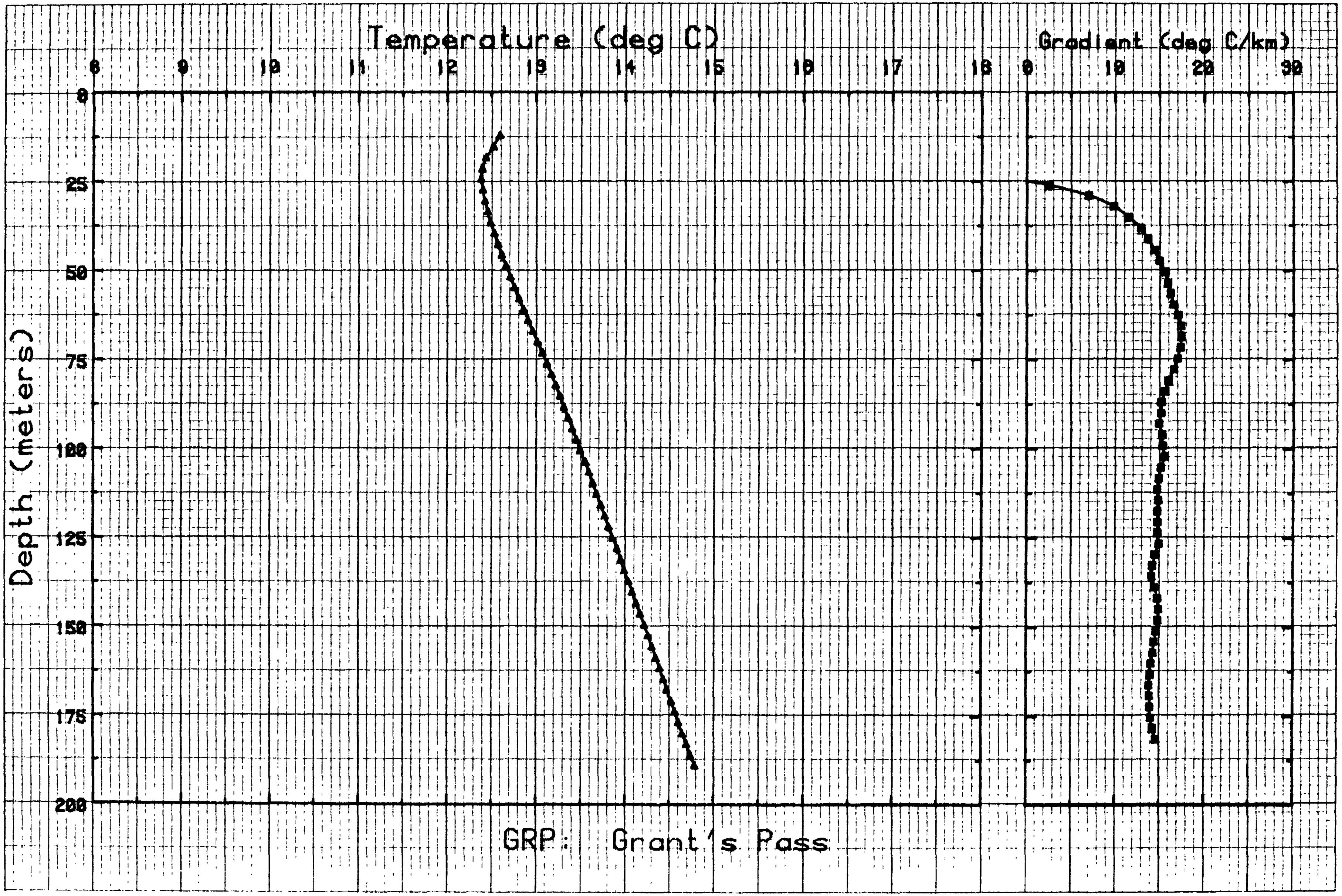

Figure I-3. Temperature and gradient profiles for GRP.

TABLE I-5. Summary of thermal conductivities, densities, and porosities for borehole GRP

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
27.4	2.71		
29.0	2.70	2.63	0.5
39.3	2.66	2.63	0.8
45.7	2.90	2.62	0.9
52.7	2.88	2.62	0.8
59.4	2.50		
61.0	2.86	2.65	0.3
68.3	2.83	2.61	1.1
76.2	2.73	2.63	0.4
83.2	2.88	2.65	0.5
89.9	2.80		
90.2	2.75	2.62	0.7
99.1	2.78	2.65	0.5
106.7	2.76	2.61	1.0
114.6	2.90	2.64	0.5
119.8	2.60		
120.4	2.54		
129.5	2.54	2.59	1.7
136.6	2.64		
140.2	2.74		
146.3	3.07		
150.9	2.82		
151.2	2.63		

TABLE I-5. Summary of thermal conductivities, densities, and porosities for borehole GRP (continued)

Depth (m)	$\langle K_f \rangle$ ($Wm^{-1} K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
154.6	2.55	2.63	0.7
160.0	2.80	2.66	0.3
168.2	2.77	2.66	0.3
175.5	2.76	2.65	0.6
183.3	2.77	2.65	0.5
190.6	2.64	2.66	0.2
197.9	2.81	2.67	0.2
206.0	2.78	2.66	0.4
212.5	2.78	2.66	0.3

TABLE I-6. Temperature tabulation

Hole: GRP GRANT'S PASS

Lat: 42-29.30 Long: 123-22.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
12.19	12.588	15.24	12.514
18.29	12.431	21.34	12.389
24.38	12.379	27.43	12.396
30.48	12.419	33.53	12.451
36.58	12.485	39.62	12.527
42.67	12.569	45.72	12.612
48.77	12.657	51.82	12.707
54.86	12.755	57.91	12.804
60.96	12.854	64.01	12.906
67.06	12.961	70.10	13.014
73.15	13.066	76.20	13.119
79.25	13.171	82.30	13.218
85.34	13.266	88.39	13.311
91.44	13.359	94.49	13.402
97.54	13.450	100.58	13.494
103.63	13.547	106.68	13.591
109.73	13.635	112.78	13.680
115.82	13.726	118.87	13.772
121.92	13.816	124.97	13.858
128.02	13.910	131.06	13.952
134.11	13.993	137.16	14.038
140.21	14.080	143.26	14.126
146.30	14.173	149.35	14.218
152.40	14.262	155.45	14.306
158.50	14.351	161.54	14.392
164.59	14.436	167.64	14.477
170.69	14.520	173.74	14.563
176.78	14.604	179.83	14.649
182.88	14.693	185.93	14.737
188.85	14.785		

HAP: Happy Camp

The Happy Camp site was not drilled specifically for heat flow, but the quality of the data (Figure I-4; Table I-7) is comparable to that of the other dedicated wells and better (particularly as regards thermal conductivity) than that of our holes of opportunity. Thus we felt it appropriate to include HAP in this group of data.

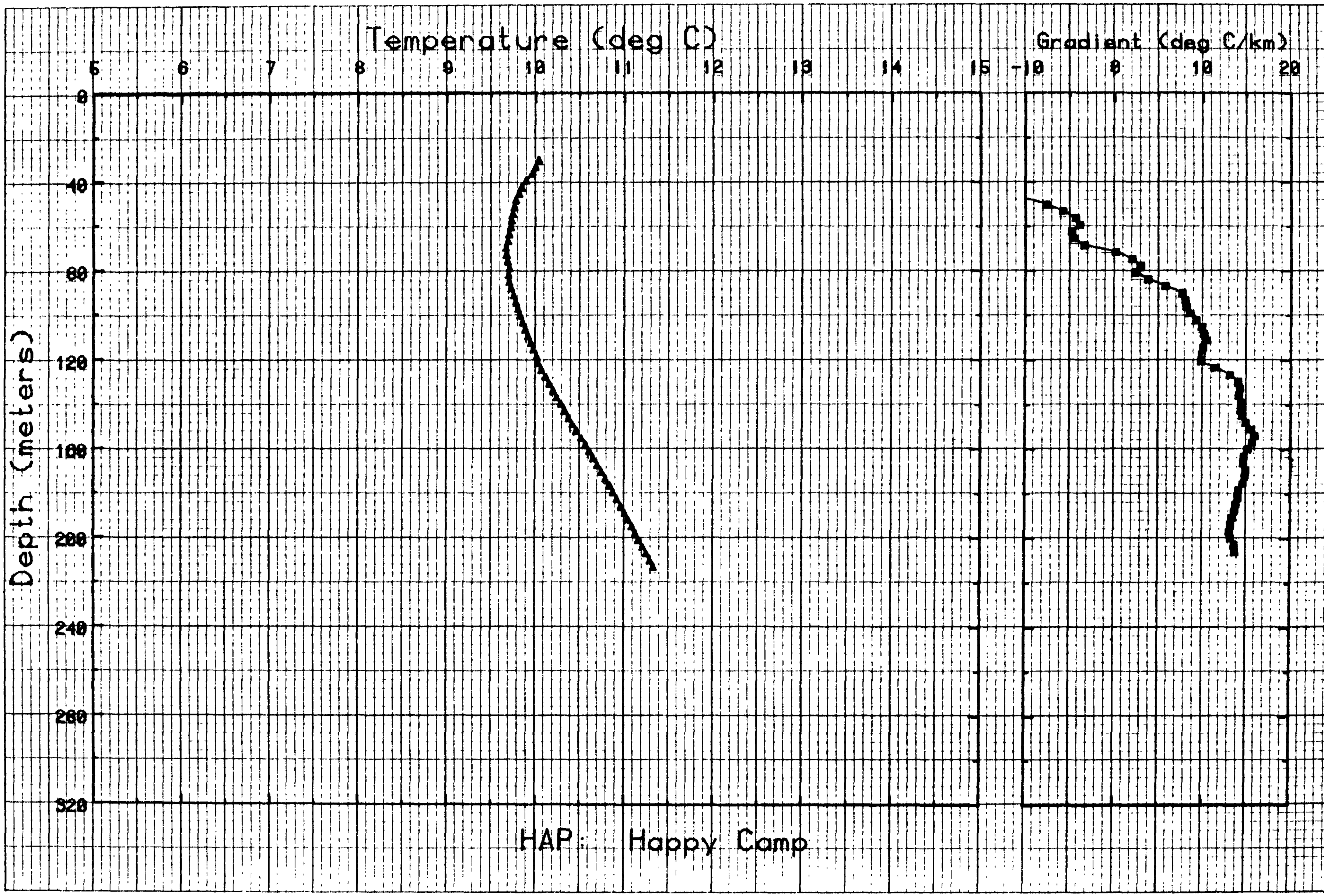

Figure I-4. Temperature and gradient profiles for HAP.

TABLE I-7. Summary of thermal conductivities, densities, and porosities for borehole HAP

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
121.3	2.28	2.90	0.8
126.8	2.33	3.00	0.5
131.7	2.23	3.00	0.1
135.9	2.79	2.92	0.3
142.8	2.32	2.86	0.6
150.6	2.36	2.86	0.5
155.4	2.64	2.81	0.9
160.9	2.96	2.82	0.5
174.2	2.40	2.93	1.4
176.9	2.63	2.81	0.6
195.6	2.36	2.80	0.3
200.6	2.85	2.80	0.7

TABLE I-8. Temperature tabulation

Hole: HAP HAPPY CAMP

Lat: 41-51.60 Long: 123-21.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
30.48	10.034	33.53	9.995
36.58	9.956	39.62	9.891
42.67	9.840	45.72	9.812
48.77	9.774	51.82	9.755
54.86	9.737	57.91	9.725
60.96	9.720	64.01	9.701
67.06	9.688	70.10	9.662
73.15	9.671	76.20	9.683
79.25	9.702	82.30	9.692
85.34	9.703	88.39	9.725
91.44	9.754	94.49	9.777
97.54	9.800	100.58	9.826
103.63	9.854	106.68	9.886
109.73	9.917	112.78	9.949
115.82	9.979	118.87	10.017
121.92	10.032	124.97	10.067
128.02	10.116	131.06	10.158
134.11	10.201	137.16	10.242
140.21	10.289	143.26	10.331
146.30	10.375	149.35	10.419
152.40	10.466	155.45	10.519
158.50	10.566	161.54	10.612
164.59	10.655	167.64	10.699
170.69	10.746	173.74	10.790
176.78	10.839	179.83	10.877
182.88	10.920	185.93	10.965
188.98	11.006	192.02	11.044
195.07	11.087	198.12	11.127
201.17	11.163	204.22	11.207
207.26	11.252	210.31	11.292
213.36	11.329		

IGO: Igo, California

This hole was drilled near the south end of the Shasta Bally pluton, a Cretaceous body (~130 m.y.) varying in composition from quartz diorite to granodiorite (Hotz, 1971). The mean SiO_2 content (Hotz, 1971, Table 1) is about 68%. The temperature profile (Figure I-5) exhibits a marked curvature above 150 meters and is linear below that depth. The curvature might be explained by a combination of an apparent increase in thermal conductivity below 150 m (Table I-9) and the steady-state effect of topography. A Bullard-type analysis at intervals of ~25 m using the corrected temperatures is linear below 75 m and gives a heat flux of 40 ± 1 mWm^{-2}.

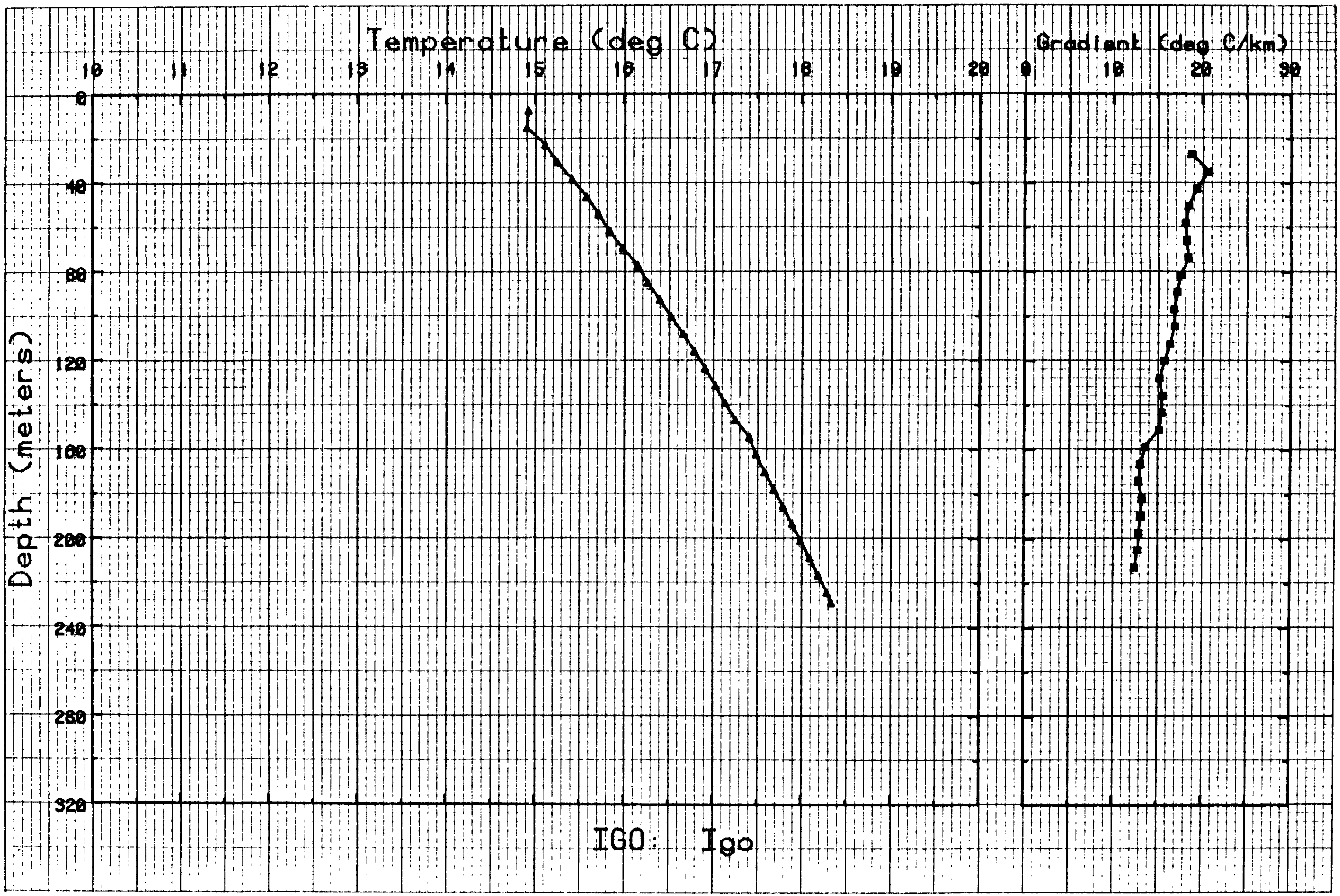

Figure I-5. Temperature and gradient profile for IGO.

TABLE I-9. Summaries of thermal conductivities, densities, and porosities for borehole IGO

Depth (m)	$\langle K_f \rangle$ ($Wm^{-1} K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
12.2	2.80	2.70	0.2
18.3	2.78	2.70	0.1
24.4	3.06	2.68	0.1
30.2	2.85	2.66	1.1
36.6	2.69	2.70	0.2
42.7	2.86	2.68	0.3
48.8	2.75	2.70	0.1
54.9	2.76	2.69	0.2
61.0	2.87	2.69	0.2
67.1	3.04	2.70	0.4
73.2	2.71	2.68	0.6
79.2	2.88	2.70	0.2
85.3	2.73	2.68	0.4
91.7	2.92	2.66	0.6
97.7	2.93	2.70	0.4
105.2	2.83	2.67	1.0
109.8	3.01	2.70	0.4
116.0	2.78	2.71	0.0
121.9	2.30	2.70	0.7
128.3	2.83	2.65	0.5
134.1	3.02	2.66	0.2
140.2	2.76	2.67	0.2
146.2	2.92	2.64	0.4
152.4	2.63	2.69	0.4

TABLE I-9. Summaries of thermal conductivities, densities, and porosities for borehole IGO (continued)

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
158.5	2.84	2.67	0.2
164.6	5.36	2.69	0.4
172.6	3.82	2.69	0.2
177.2	3.28	2.65	0.3
180.8	2.99	2.66	0.3
183.9	3.46	2.64	0.9
188.8	3.28	2.64	0.8
195.1	3.18		
201.2	2.94	2.69	0.2
207.3	2.84	2.68	0.0
213.5	2.89	2.69	0.1
219.5	2.75	2.66	0.3
224.9	2.85	2.69	0.1
229.3	2.96	2.70	0.0

TABLE I-10. Temperature tabulation

Hole: IGO IGO

Lat: 40-30.50 Long: 122-36.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
7.73	14.922	15.47	14.906
23.20	15.114	30.94	15.252
38.67	15.417	46.41	15.580
54.14	15.713	61.87	15.836
69.61	15.984	77.34	16.151
85.08	16.264	92.81	16.399
100.55	16.529	108.28	16.664
116.01	16.791	123.75	16.912
131.48	17.029	139.22	17.141
146.95	17.258	154.69	17.414
162.42	17.487	170.15	17.584
177.89	17.691	185.62	17.796
193.36	17.896	201.09	17.994
208.83	18.097	216.56	18.192
224.29	18.289	228.87	18.338

Lassen KGRA, California

As part of the U.S. Geological Survey's geothermal resource assessment of Lassen "Known Geothermal Resource Area," we conducted a heat-flow reconnaissance of the KGRA and its environs. The local thermal setting is the subject of a separate study (Mase and others, 1980); however, we shall summarize it briefly here. In the first phase of the study, nine holes (LSNB through LSNL) were drilled in volcanic rock within the KGRA and two holes (LSNM and LSNO) in granitic rock outside of it. The holes were completed according to established procedures which include a "10 sack grout" around the casing (Moses and Sass, 1979); however, early temperature measurements indicated that for holes drilled within volcanic rock, most of the cement was lost in fractures and that at the most, a few meters of casing near the bottom of the hole was grouted off. The temperature profiles (Figures I-6 through I-16) in the majority of the holes are non-linear and show the effects of ground water movement indicating a complex three-dimensional structure dominated by hydrothermal circulation within the KGRA.

Based on thermal considerations, the boreholes within Lassen KGRA may be divided up into three distinct groups. The first group (LSNC, LSNE, LSNM, and LSNO) yields a gradient consistent with a regional transition between low heat flow ($\sim$40 mWm^{-2}) in the Klamath Mountains - Coastal Provinces and Sierra Nevada to high heat flow (70-100 mWm^{-2}) within the Modoc Plateau, a subprovince of the Basin and Range. The upper part of the temperature profiles from these boreholes show the influence of downward and lateral water movement probably due to recharge in a shallow subsystem. The remaining two groups are considered to be characteristic of regions with hydrologic recharge (LSNB, LSND, LSNF, LSNH, LSNI) and regions of hydrologic discharge (LSNF, LSNL). In all instances, the regions of apparent recharge are associated with topographic highs and the regions of discharge with topographic lows. The circulatory systems are driven primarily by elevation differences; therefore, the movement of ground water must extend to a depth of several kilometers. This is necessary if the cell patterns are to be effectively forced by surface topography with horizontal wavelengths of that order.

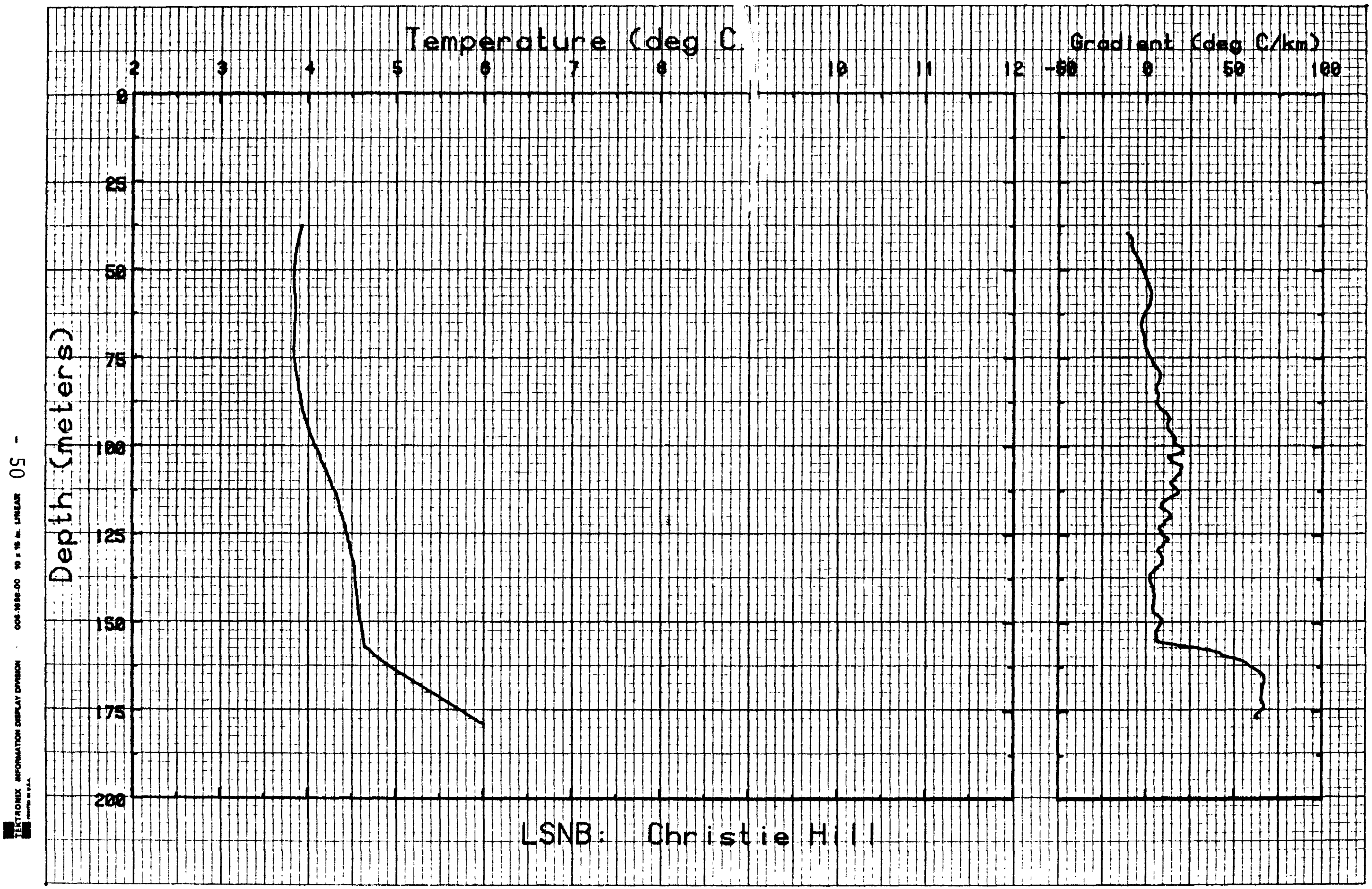

Figure I-6. Temperature and gradient profiles for LSNB.

TABLE I-11. Summary of thermal conductivities, densities, and porosities for borehole LSNB

Depth (m)	$<K_f>$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
10.7	2.37		
22.9	2.50		
35.1	2.11		
47.2	2.87		
59.4	2.98		
71.6	2.48		
83.8	2.12		
96.0	2.09		
106.7	2.19		
118.9	2.28		
131.1	2.15		
143.3	2.04		
155.4	2.03		
167.6	2.10		
178.3	2.07		

TABLE I-12. Temperature tabulation

Hole: LSNB CHRISTIE HILL

Lat: 40-23.50 Long: 121-32.20

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
38.10	3.934	39.62	3.914
41.15	3.900	42.67	3.888
44.20	3.875	45.72	3.865
47.24	3.857	48.77	3.852
50.29	3.847	51.82	3.846
53.34	3.847	54.86	3.848
56.39	3.853	57.91	3.858
59.44	3.861	60.96	3.864
62.48	3.864	64.01	3.861
65.53	3.856	67.06	3.852
68.58	3.849	70.10	3.848
71.63	3.846	73.15	3.847
74.68	3.849	76.20	3.854
77.72	3.860	79.25	3.873
80.77	3.884	82.30	3.897
83.82	3.904	85.34	3.914
86.87	3.925	88.39	3.934
89.92	3.946	91.44	3.963
92.96	3.984	94.49	4.002
96.01	4.021	97.54	4.045
99.06	4.071	100.58	4.093
102.11	4.132	103.63	4.148
105.16	4.176	106.68	4.207
108.20	4.235	109.73	4.260
111.25	4.281	112.78	4.309
114.30	4.337	115.82	4.353
117.35	4.365	118.87	4.382
120.40	4.404	121.92	4.424
123.44	4.437	124.97	4.446
126.49	4.462	128.02	4.484
129.54	4.493	131.06	4.506
132.59	4.521	134.11	4.533
135.64	4.539	137.16	4.546
138.68	4.548	140.21	4.555
141.73	4.561	143.26	4.570
144.78	4.575	146.30	4.582
147.83	4.589	149.35	4.603
150.88	4.617	152.40	4.625
153.92	4.634	155.45	4.645
156.97	4.657	158.50	4.728
160.02	4.790	161.54	4.876
163.07	4.965	164.59	5.064
166.12	5.167	167.64	5.269
169.16	5.368	170.69	5.468
172.21	5.567	173.74	5.668
175.26	5.769	176.78	5.865
179.22	6.045		

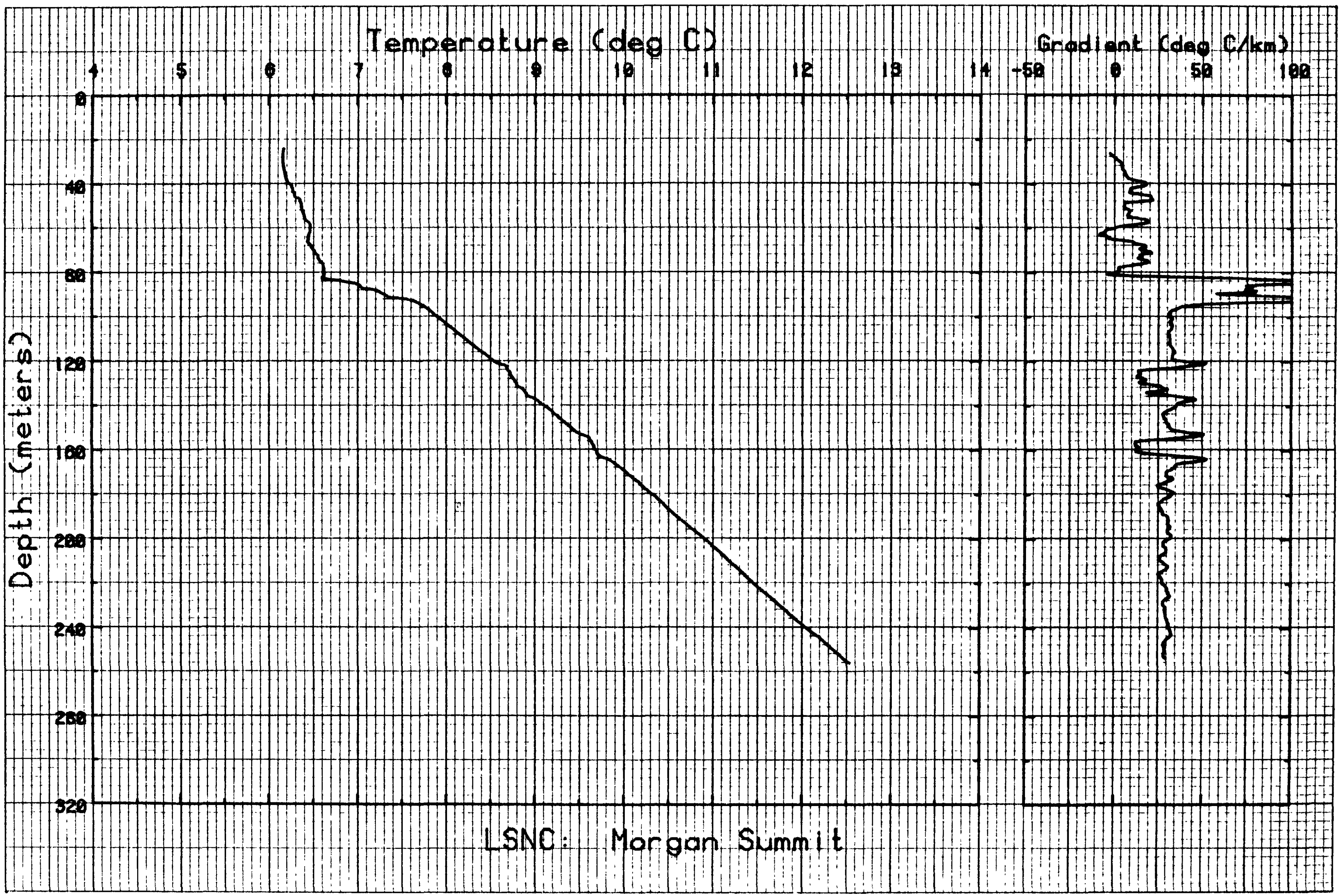

Figure I-7. Temperature and gradient profiles for LSNC.

TABLE I-13. Summary of thermal conductivities, densities, and porosities for borehole LSNC

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
0	1.49		
3.8	1.66		
16.8	1.63		
29.0	1.73		
39.6	1.86		
51.8	1.82		
64.0	1.99		
76.2	2.03		
88.4	2.02		
100.6	2.06		
112.8	2.13		
125.0	2.08		
137.2	2.92		
149.4	2.43		
161.5	2.09		
173.7	1.97		
185.9	2.83		
198.1	1.89		
210.3	2.49		
222.5	3.13		
234.7	2.02		
246.9	2.31		
256.6	2.42		

TABLE I-14. Temperature tabulation

Hole: LSNC MORGAN SUMMIT

Lat: 40-20.90 Long: 121-33.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
24.38	6.168	25.91	6.161
27.43	6.158	28.96	6.157
30.48	6.160	32.00	6.169
33.53	6.174	35.05	6.182
36.58	6.192	38.10	6.201
39.62	6.218	41.15	6.257
42.67	6.272	44.20	6.283
45.72	6.295	47.24	6.348
48.77	6.361	50.29	6.367
51.82	6.379	53.34	6.391
54.86	6.404	56.39	6.414
57.91	6.458	59.44	6.470
60.96	6.465	62.48	6.459
64.01	6.445	65.53	6.451
67.06	6.447	68.58	6.480
70.10	6.501	71.63	6.519
73.15	6.560	74.68	6.571
76.20	6.615	77.72	6.621
79.25	6.620	80.77	6.628
82.30	6.614	83.82	6.790
85.34	6.978	86.87	7.039
88.39	7.216	89.92	7.285
91.44	7.366	92.96	7.626
94.49	7.708	96.01	7.765
97.54	7.817	99.06	7.860
100.58	7.914	102.11	7.961
103.63	8.009	105.16	8.061
106.68	8.108	108.20	8.155
109.73	8.203	111.25	8.251
112.78	8.299	114.30	8.347
115.82	8.400	117.35	8.450
118.87	8.499	120.40	8.549
121.92	8.641	123.44	8.687
124.97	8.722	126.49	8.729
128.02	8.760	129.54	8.777
131.06	8.798	132.59	8.866
134.11	8.894	135.64	8.911
137.16	8.998	138.68	9.055
140.21	9.110	141.73	9.163
143.26	9.207	144.78	9.248
146.30	9.293	147.83	9.337
149.35	9.383	150.88	9.431
152.40	9.483	153.92	9.574
155.45	9.621	156.97	9.643
158.50	9.658	160.02	9.680
161.54	9.696	163.07	9.728
164.59	9.827	166.12	9.889
167.64	9.939	169.16	9.991
170.69	10.036	172.21	10.082
173.74	10.128	175.26	10.181
176.78	10.209	178.31	10.257

TABLE I-14. Temperature tabulation (continued)

Hole: LSNC MORGAN SUMMIT

Lat: 40-20.90 Long: 121-33.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
176.78	10.209	178.31	10.257
179.83	10.306	181.36	10.358
182.88	10.401	184.40	10.442
185.93	10.476	187.45	10.521
188.98	10.560	190.50	10.604
192.02	10.653	193.55	10.699
195.07	10.746	196.60	10.795
198.12	10.838	199.64	10.893
201.17	10.934	202.69	10.979
204.22	11.020	205.74	11.068
207.26	11.112	208.79	11.149
210.31	11.191	211.84	11.231
213.36	11.280	214.88	11.322
216.41	11.361	217.93	11.398
219.46	11.443	220.98	11.481
222.50	11.531	224.03	11.573
225.55	11.624	227.08	11.670
228.60	11.712	230.12	11.755
231.65	11.799	233.17	11.842
234.70	11.887	236.22	11.931
237.74	11.978	239.27	12.024
240.79	12.073	242.32	12.122
243.84	12.171	245.36	12.218
246.89	12.263	248.41	12.304
249.94	12.348	251.46	12.391
252.98	12.435	254.51	12.477
256.03	12.531		

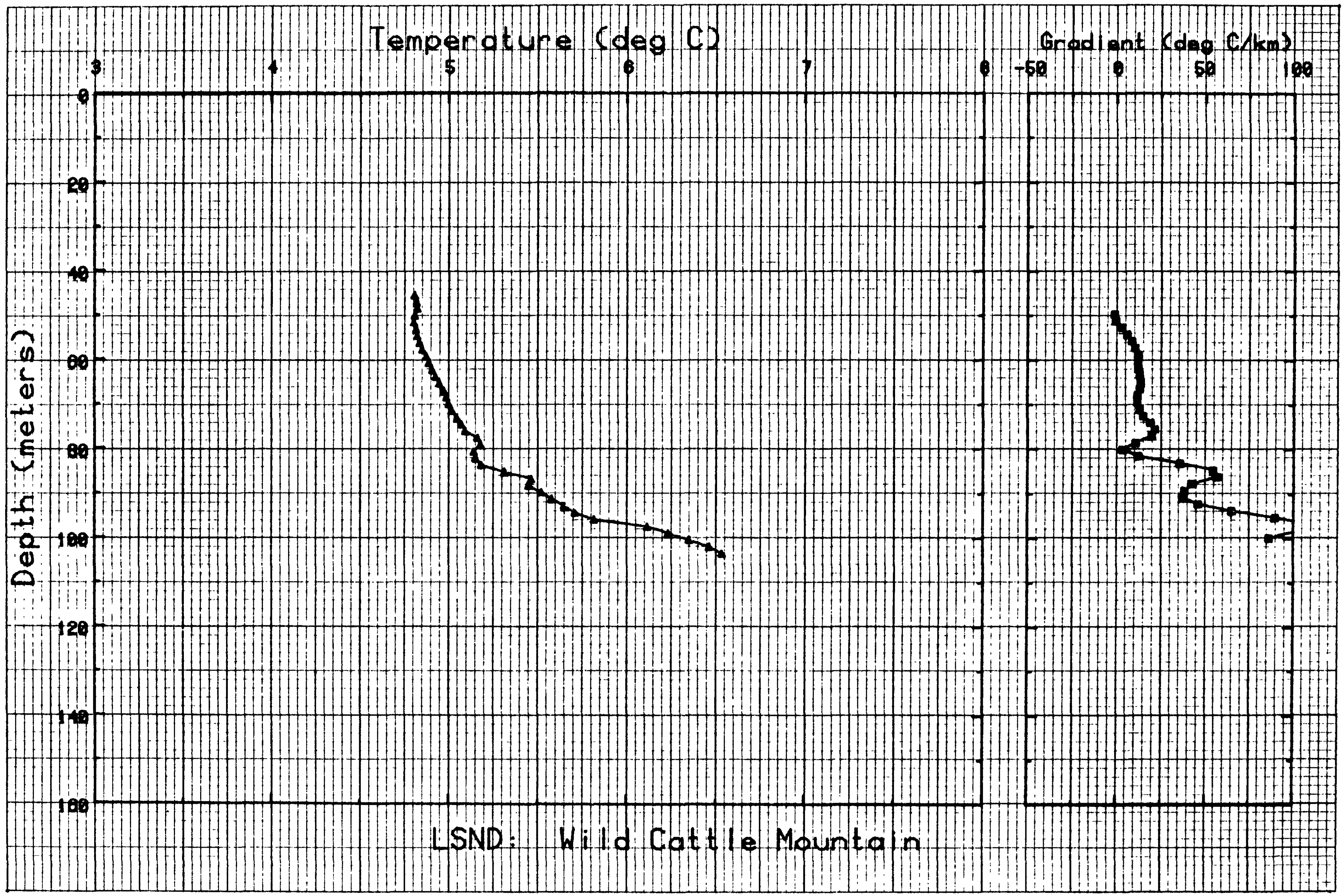

Figure I-8. Temperature and gradient profiles for LSND.

TABLE I-15. Summary of thermal conductivities, densities, and porosities for borehole LSND

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
0	1.87	2.55	5.0
10.7	1.57		
22.9	1.54		
35.1	2.01		
47.2	2.16		
59.4	2.15		
70.9	2.12		
83.8	2.08		
96.0	1.69		

TABLE I-16. Temperature tabulation

Hole: LSND WILD CATTLE MOUNTAIN

Lat: 40-22.40 Long: 121-28.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
32.00	4.620	33.53	4.600
35.05	4.598	36.58	4.592
38.10	4.588	39.62	4.589
41.15	4.604	42.67	4.616
44.20	4.628	45.72	4.656
47.24	4.666	48.77	4.675
50.29	4.676	51.82	4.680
53.34	4.692	54.86	4.706
56.39	4.720	57.91	4.739
59.44	4.762	60.96	4.784
62.48	4.807	64.01	4.824
65.53	4.852	67.06	4.875
68.58	4.896	70.10	4.913
71.63	4.941	73.15	4.973
74.68	4.997	76.20	5.025
77.72	5.080	79.25	5.101
80.77	5.092	82.30	5.109
83.82	5.149	85.34	5.265
86.87	5.380	88.39	5.396
89.92	5.471	91.44	5.539
92.96	5.606	94.49	5.678
96.01	5.780	97.54	6.047
99.06	6.688	100.58	6.747
102.11	6.532	103.42	6.411

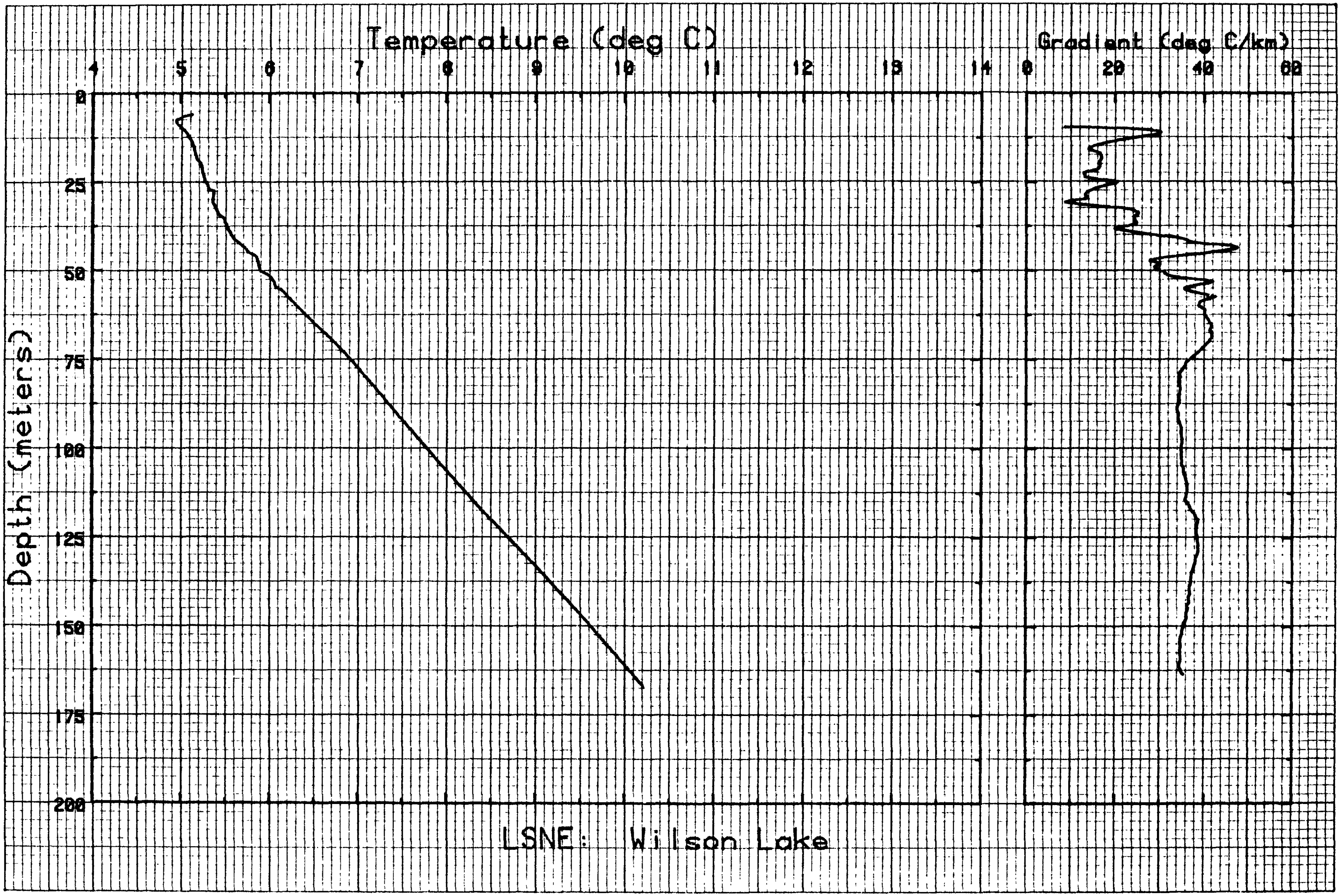

Figure I-9. Temperature and gradient profiles for LSNE.

TABLE I-17. Summary of thermal conductivities, densities, and porosities for borehole LSNE

Depth (m)	$\langle K_f \rangle$ ($Wm^{-1}\ K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
0	1.84	2.18	15.4
10.7	1.93		
22.9	2.08		
35.1	2.13		
47.2	2.20		
59.4	2.18		
71.6	1.96		
82.3	1.90		
94.5	2.02		
106.7	1.95		
118.9	1.98		
131.1	1.96		
143.3	1.96		
155.4	1.97		
165.8	1.94		

TABLE I-18. Temperature tabulation

Hole: LSNE WILSON LAKE

Lat: 40-20.40 Long: 121-27.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	5.133	7.62	4.956
9.14	4.982	10.67	5.044
12.19	5.091	13.72	5.127
15.24	5.150	16.76	5.164
18.29	5.183	19.81	5.230
21.34	5.252	22.86	5.263
24.38	5.281	25.91	5.312
27.43	5.349	28.96	5.371
30.48	5.368	32.00	5.394
33.53	5.423	35.05	5.475
36.58	5.512	38.10	5.539
39.62	5.572	41.15	5.601
42.67	5.675	44.20	5.752
45.72	5.828	47.24	5.878
48.77	5.893	50.29	5.914
51.82	6.016	53.34	6.061
54.86	6.088	56.39	6.175
57.91	6.234	59.44	6.293
60.96	6.351	62.48	6.411
63.70	6.471	65.23	6.523
66.75	6.588	68.28	6.651
69.80	6.715	71.32	6.777
72.85	6.839	74.37	6.895
75.90	6.951	77.42	7.003
78.94	7.057	80.47	7.109
81.99	7.160	83.52	7.213
85.04	7.267	86.56	7.320
88.09	7.371	89.61	7.424
91.14	7.474	92.66	7.527
94.18	7.580	95.71	7.633
97.23	7.687	98.76	7.740
100.28	7.793	101.80	7.846
103.33	7.900	104.85	7.951
106.38	8.005	107.90	8.060
109.42	8.114	110.95	8.169
112.47	8.225	114.00	8.279
115.52	8.333	117.04	8.387
118.57	8.446	120.09	8.505
121.62	8.564	123.14	8.621
124.66	8.680	126.19	8.738
127.71	8.798	129.24	8.856
130.76	8.916	132.28	8.974
133.81	9.030	135.33	9.087
136.86	9.144	138.38	9.200
139.90	9.256	141.43	9.313
142.95	9.368	144.48	9.422
146.00	9.480	147.52	9.533
149.05	9.587	150.57	9.642
152.10	9.695	153.62	9.748
155.14	9.801	156.67	9.854
158.19	9.906	159.72	9.959

TABLE I-18. Temperature tabulation (continued)

Hole: LSNE WILSON LAKE

Lat: 40-20.40 Long: 121-27.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
161.24	10.011	162.76	10.065
164.29	10.115	165.81	10.170
167.03	10.215		

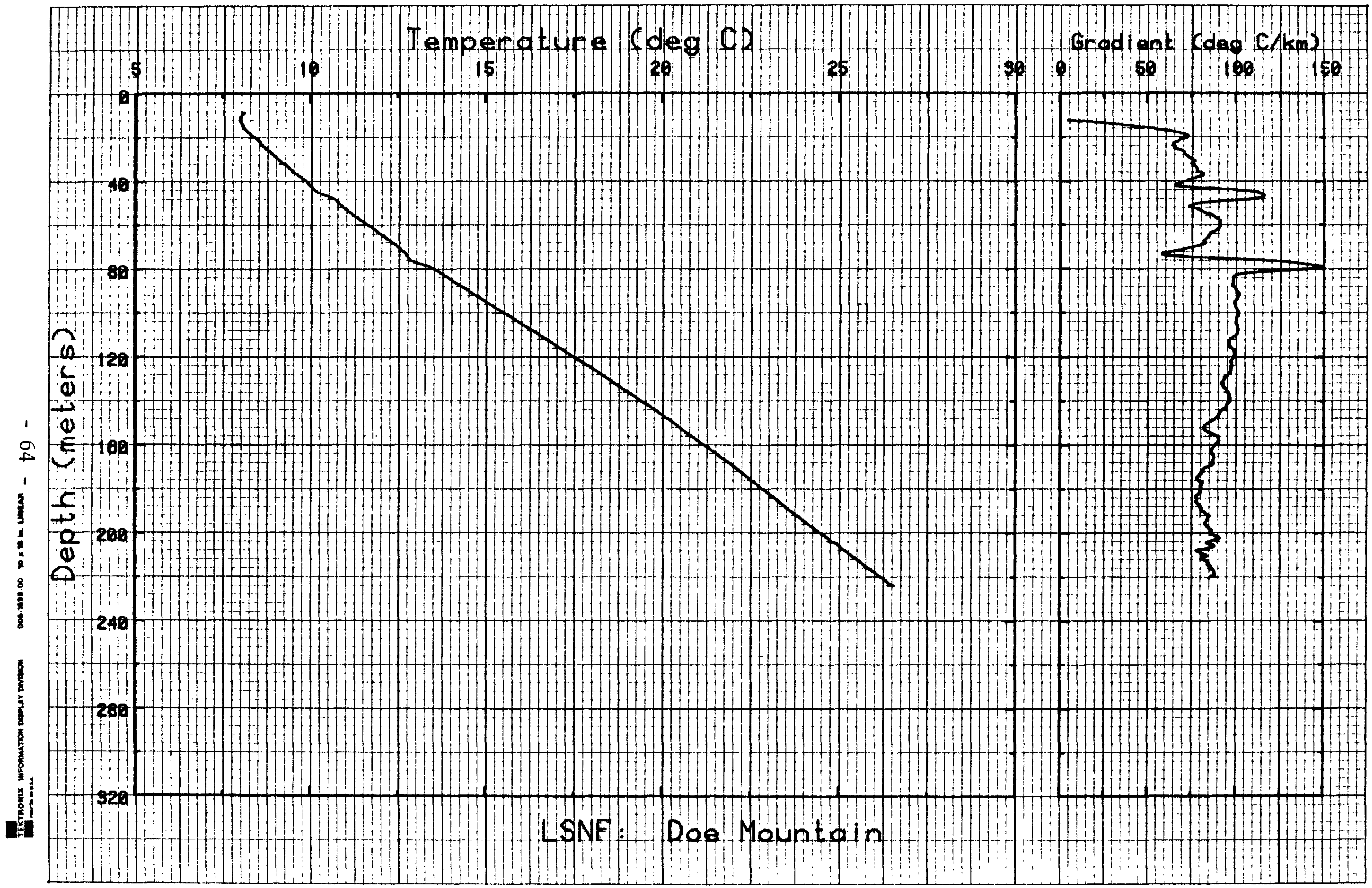

Figure I-10. Temperature and gradient profiles for LSNF.

TABLE I-19. Summary of thermal conductivities, densities, and porosities for borehole LSNF

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
3.8	2.18		
16.8	2.16		
29.0	2.04		
41.1	2.22		
53.3	1.92		
65.5	1.94		
77.7	1.94		
89.9	1.86		
101.3	1.93		
112.8	2.67		
125.0	3.00		
137.2	2.63		
149.4	3.44		
161.5	2.77		
173.7	3.81		
185.9	3.43		
198.1	3.38		
210.3	3.08		
222.2	3.29		

TABLE I-20. Temperature tabulation

Hole: LSNF DOE MOUNTAIN

Lat: 40-21.30 Long: 121-29.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
9.14	8.127	10.67	8.024
12.19	8.004	13.72	8.039
15.24	8.096	16.76	8.163
18.29	8.265	19.81	8.383
21.34	8.504	22.86	8.604
24.38	8.682	25.91	8.789
27.43	8.902	28.96	9.010
30.48	9.115	32.00	9.235
33.53	9.360	35.05	9.465
36.58	9.585	38.10	9.713
39.62	9.860	41.15	9.950
42.67	10.035	44.20	10.132
45.72	10.276	47.24	10.543
48.77	10.717	50.29	10.825
51.82	10.925	53.34	11.037
54.86	11.168	56.39	11.306
57.91	11.429	59.44	11.573
60.96	11.724	62.48	11.858
64.01	11.983	65.53	12.114
67.06	12.244	68.58	12.367
70.10	12.487	71.63	12.619
73.15	12.710	74.68	12.783
76.20	12.840	77.72	13.072
79.25	13.405	80.77	13.587
82.30	13.738	83.82	13.891
85.34	14.039	86.87	14.188
88.39	14.338	89.92	14.493
91.44	14.645	92.96	14.798
94.49	14.957	96.01	15.102
97.54	15.248	99.06	15.406
100.58	15.563	102.11	15.718
103.63	15.868	105.16	16.019
106.68	16.171	108.20	16.327
109.73	16.483	111.25	16.633
112.78	16.784	114.30	16.925
115.82	17.068	117.35	17.220
118.87	17.375	120.40	17.524
121.92	17.673	123.44	17.820
124.97	17.965	126.49	18.122
128.02	18.264	129.54	18.410
131.06	18.547	132.59	18.689
134.11	18.828	135.64	18.972
137.16	19.115	138.68	19.269
140.21	19.410	141.73	19.560
143.26	19.702	144.78	19.843
146.30	19.983	147.83	20.117
149.35	20.256	150.88	20.388
152.40	20.506	153.92	20.622
155.45	20.756	156.97	20.894
158.50	21.037	160.02	21.169
161.54	21.304	163.07	21.434

TABLE I-20. Temperature tabulation (continued)

Hole: LSNF DOE MOUNTAIN

Lat: 40-21.30 Long: 121-29.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
164.59	21.564	166.12	21.694
167.64	21.836	169.16	21.965
170.69	22.091	172.21	22.220
173.74	22.334	175.26	22.461
176.78	22.577	178.31	22.696
179.83	22.826	181.36	22.949
182.88	23.067	184.40	23.184
185.93	23.301	187.45	23.421
188.98	23.539	190.50	23.666
192.02	23.792	193.55	23.924
195.07	24.059	196.60	24.180
198.12	24.296	199.64	24.433
201.17	24.579	202.69	24.699
204.22	24.822	205.74	24.988
207.26	25.086	208.79	25.233
210.31	25.335	211.84	25.479
213.36	25.601	214.88	25.724
216.41	25.851	217.93	25.995
219.46	26.126	220.98	26.261
222.50	26.382	224.03	26.539

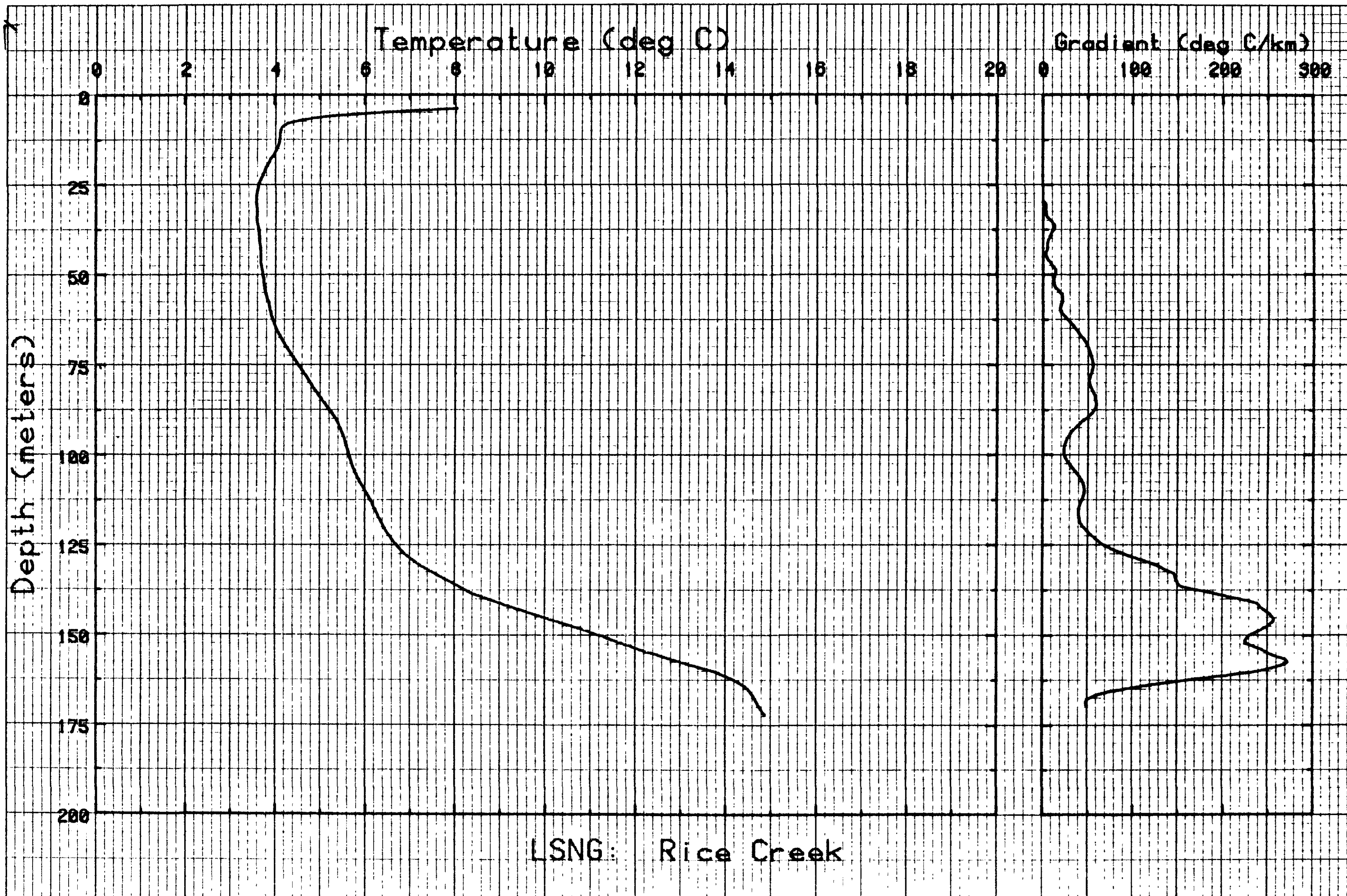

Figure I-11. Temperature and gradient profiles for LSNG.

TABLE I-21. Summary of thermal conductivities, densities, and porosities for borehole LSNG

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
29.0	1.54		
41.1	1.59		
53.3	1.56		
65.5	1.50		
77.7	1.72		
89.9	1.87		
102.1	1.59		
114.3	1.73		
126.5	1.91		
138.7	1.69		
150.9	1.61		
163.1	1.55		
172.8	1.57		

TABLE I-22. Temperature tabulation

Hole: LSNG RICE CREEK

Lat: 40-24.40 Long: 121-26.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
4.57	6.960	6.10	5.257
7.62	4.429	9.14	4.170
10.67	4.126	12.19	4.121
13.72	4.097	15.24	4.050
16.76	3.985	18.29	3.901
19.81	3.834	21.34	3.781
22.86	3.725	24.38	3.674
25.91	3.634	27.43	3.603
28.96	3.589	30.48	3.593
32.00	3.606	33.53	3.605
35.05	3.609	36.58	3.630
38.10	3.656	39.62	3.665
41.15	3.666	42.67	3.682
44.20	3.685	45.72	3.686
47.24	3.697	48.77	3.718
50.29	3.739	51.82	3.761
53.34	3.773	54.86	3.796
56.39	3.832	57.91	3.870
59.44	3.893	60.96	3.922
62.48	3.958	64.01	4.003
65.53	4.055	67.06	4.116
68.58	4.184	70.10	4.259
71.63	4.338	73.15	4.418
74.68	4.502	76.20	4.589
77.72	4.673	79.25	4.748
80.77	4.825	82.30	4.907
83.82	4.993	85.34	5.085
86.87	5.172	88.39	5.263
89.92	5.342	91.44	5.410
92.96	5.466	94.49	5.514
96.01	5.554	97.54	5.592
99.06	5.625	100.58	5.659
102.11	5.698	103.63	5.743
105.16	5.796	106.68	5.857
108.20	5.923	109.73	5.994
111.25	6.065	112.78	6.134
114.30	6.196	115.82	6.256
117.35	6.316	118.87	6.376
120.40	6.440	121.92	6.513
123.44	6.598	124.97	6.693
126.49	6.795	128.02	6.924
129.54	7.089	131.06	7.265
132.59	7.482	134.11	7.704
135.64	7.940	137.16	8.161
138.68	8.396	140.21	8.748
141.73	9.103	143.26	9.472
144.78	9.857	146.30	10.251
147.83	10.644	149.35	11.008
150.88	11.358	152.40	11.688
153.92	12.033	155.45	12.430
156.97	12.826	158.50	13.236

TABLE I-22. Temperature tabulation (continued)

Hole: LSNG RICE CREEK

Lat: 40-24.40 Long: 121-26.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
160.02	13.670	161.54	13.989
163.07	14.246	164.59	14.439
166.12	14.560	167.64	14.641
169.16	14.707	170.69	14.777
172.21	14.870		

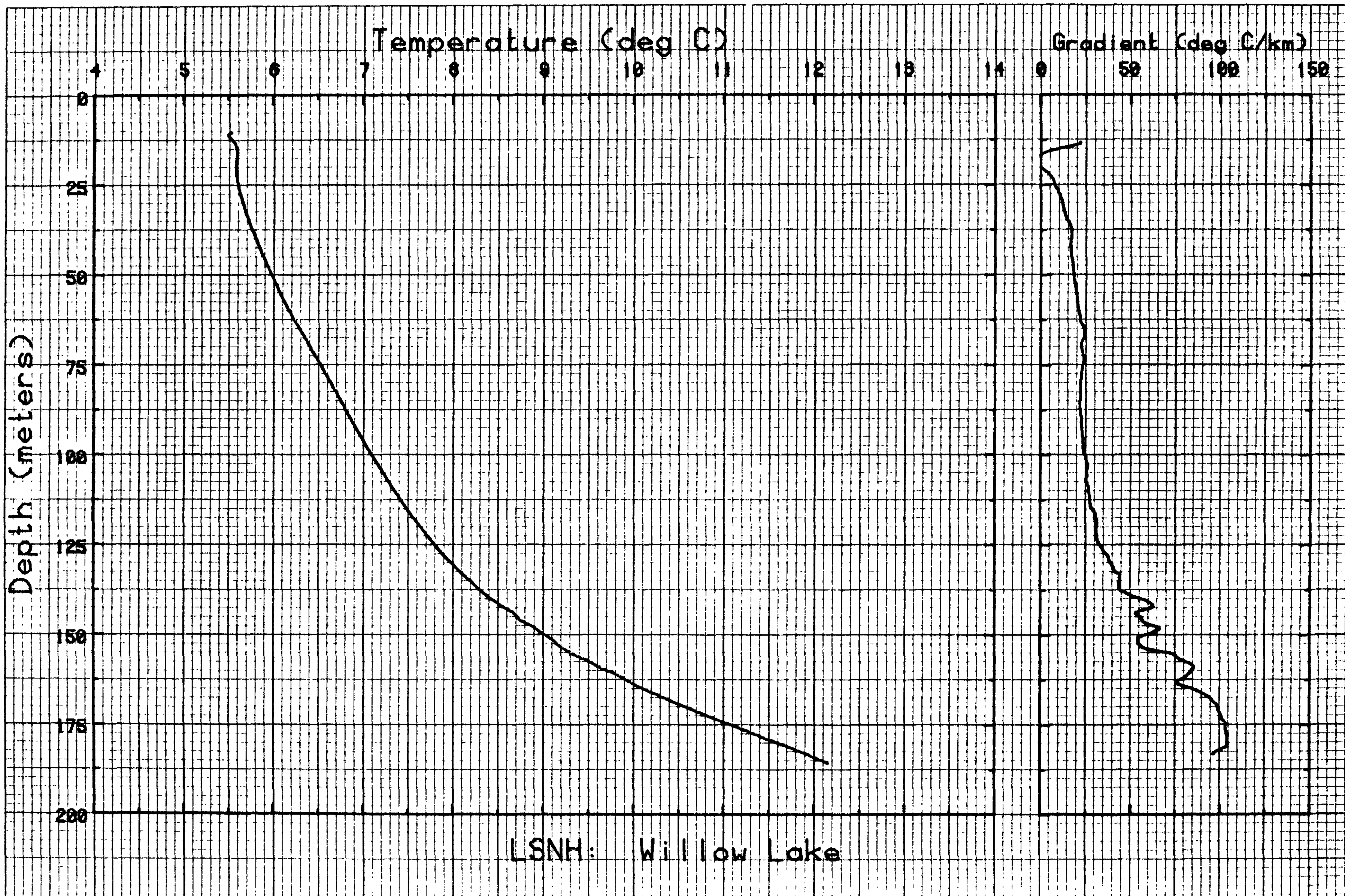

Figure I-12. Temperature and gradient profiles for LSNH.

TABLE I-23. Summary of thermal conductivities, densities, and porosities for borehole LSNH

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
0	1.55	2.32	21.9
3.8	1.89		
16.8	1.72		
29.0	1.83		
41.1	1.74		
53.3	1.71		
65.5	1.74		
77.7	1.83		
89.9	2.04		
102.1	2.03		
114.3	2.10		
126.5	2.10		
138.7	2.08		
150.9	2.12		
163.1	1.87		
175.3	1.67		
185.3	1.74		

TABLE I-24. Temperature tabulation

Hole: LSNH WILLOW LAKE

Lat: 40-23.60 Long: 121-26.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
10.67	5.535	12.19	5.525
13.72	5.576	15.24	5.598
16.76	5.599	18.29	5.594
19.81	5.588	21.34	5.589
22.86	5.598	24.38	5.610
25.91	5.621	27.43	5.635
28.96	5.652	30.48	5.670
32.00	5.690	33.53	5.708
35.05	5.731	36.58	5.753
38.10	5.780	39.62	5.808
41.15	5.832	42.67	5.857
44.20	5.882	45.72	5.908
47.24	5.935	48.77	5.963
50.29	5.989	51.82	6.018
53.34	6.046	54.86	6.076
56.39	6.107	57.91	6.138
59.44	6.169	60.96	6.203
62.48	6.235	64.01	6.270
65.53	6.304	67.06	6.344
68.58	6.381	70.10	6.412
71.63	6.447	73.15	6.485
74.68	6.521	76.20	6.556
77.72	6.591	79.25	6.624
80.77	6.660	82.30	6.693
83.82	6.726	85.34	6.759
86.87	6.792	88.39	6.827
89.92	6.860	91.44	6.893
92.96	6.929	94.49	6.964
96.01	7.001	97.54	7.036
99.06	7.072	100.58	7.108
102.11	7.147	103.63	7.185
105.16	7.228	106.68	7.263
108.20	7.306	109.73	7.343
111.25	7.385	112.78	7.425
114.30	7.467	115.82	7.511
117.35	7.557	118.87	7.607
120.40	7.653	121.92	7.700
123.44	7.747	124.97	7.796
126.49	7.846	128.02	7.902
129.54	7.959	131.06	8.019
132.59	8.081	134.11	8.147
135.33	8.207	136.86	8.269
138.38	8.332	139.90	8.410
141.43	8.499	142.95	8.601
144.48	8.692	146.00	8.740
147.52	8.864	149.05	8.957
150.57	9.050	152.10	9.137
153.62	9.206	155.14	9.305
156.67	9.426	158.19	9.548
159.72	9.672	161.24	9.821
162.76	9.923	164.29	10.039

TABLE I-24. Temperature tabulation (continued)

Hole: LSNH WILLOW LAKE

Lat: 40-23.60 Long: 121-26.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
165.81	10.171	167.34	10.310
168.86	10.457	170.38	10.605
171.91	10.759	173.43	10.911
174.96	11.068	176.48	11.228
178.00	11.382	179.53	11.543
181.05	11.702	182.58	11.853
184.10	12.004	185.68	12.147

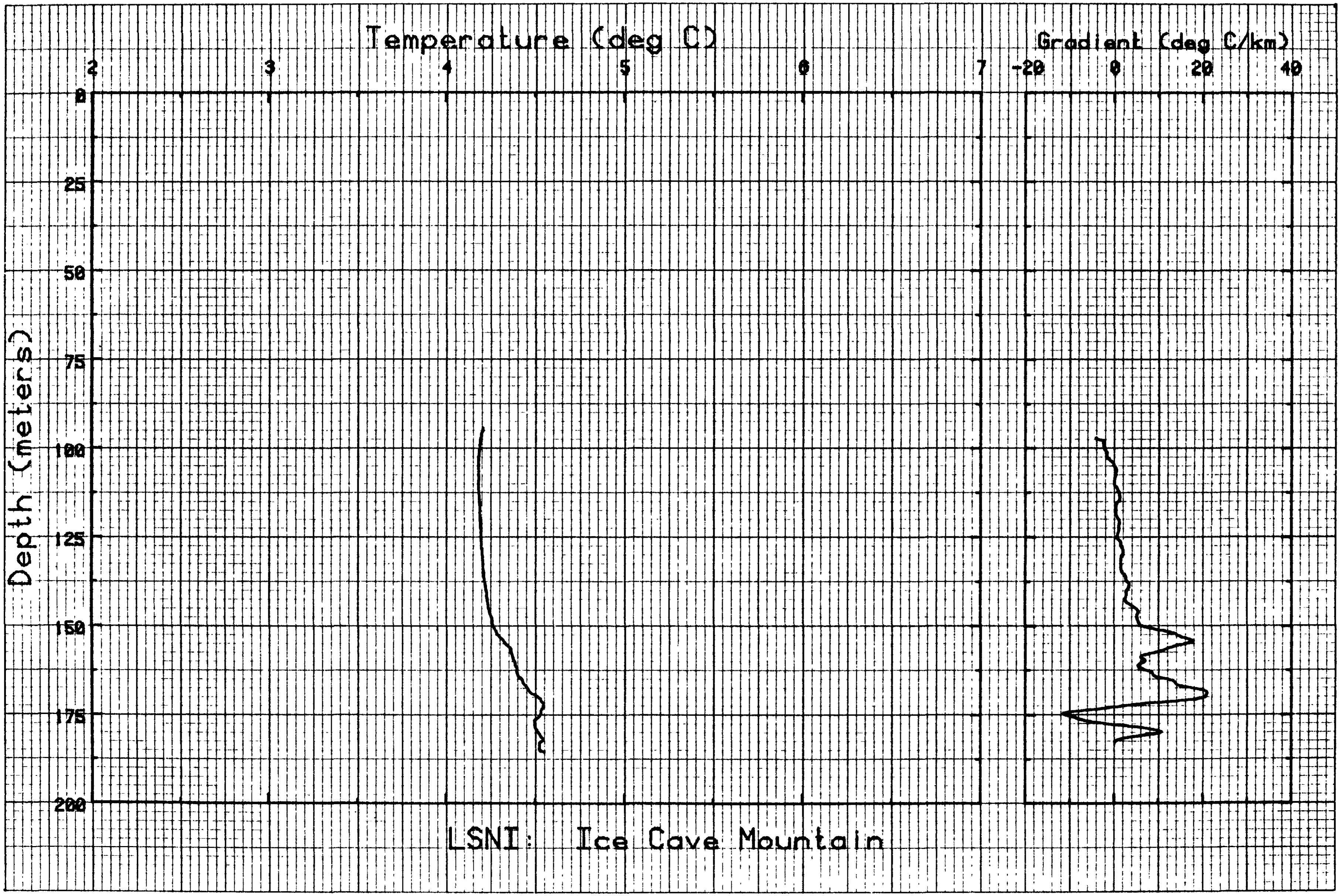

Figure I-13. Temperature and gradient profiles for LSNI.

TABLE I-25. Summary of thermal conductivities, densities, and porosities for borehole LSNI

Depth (m)	$\langle K_f \rangle$ ($Wm^{-1}\ K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
0	1.80	2.19	14.6
0	1.93	2.26	9.1
29.0	2.45		
41.1	2.50		
53.3	1.92		
77.7	2.20		
89.9	2.15		
102.1	2.12		
114.3	2.06		
126.5	2.30		
138.7	2.32		
150.9	2.30		
163.1	2.55		
175.3	2.26		
185.2	1.39		

TABLE I-26. Temperature tabulation

Hole: LSNI ICE CAVE MOUNTAIN

Lat: 40-20.40 Long: 121-23.10

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
94.49	4.209	96.01	4.201
97.54	4.196	99.06	4.192
100.58	4.191	102.11	4.187
103.63	4.185	105.16	4.185
106.68	4.186	108.20	4.187
109.73	4.186	111.25	4.186
112.78	4.188	114.30	4.191
116.13	4.192	117.65	4.192
119.18	4.192	120.70	4.193
122.22	4.196	123.75	4.197
125.27	4.198	126.80	4.199
128.32	4.204	129.84	4.205
131.37	4.207	132.89	4.210
134.42	4.212	135.94	4.214
137.46	4.218	138.99	4.225
140.51	4.230	142.04	4.232
143.56	4.237	145.08	4.241
146.61	4.251	148.13	4.262
149.66	4.264	151.18	4.278
152.70	4.292	154.23	4.323
155.75	4.349	157.28	4.366
158.80	4.376	160.32	4.387
161.85	4.398	163.37	4.400
164.90	4.422	166.42	4.439
167.94	4.460	169.47	4.497
170.99	4.533	172.52	4.549
174.04	4.534	175.56	4.524
177.09	4.499	178.61	4.501
180.14	4.521	181.66	4.541
183.18	4.524	185.59	4.550

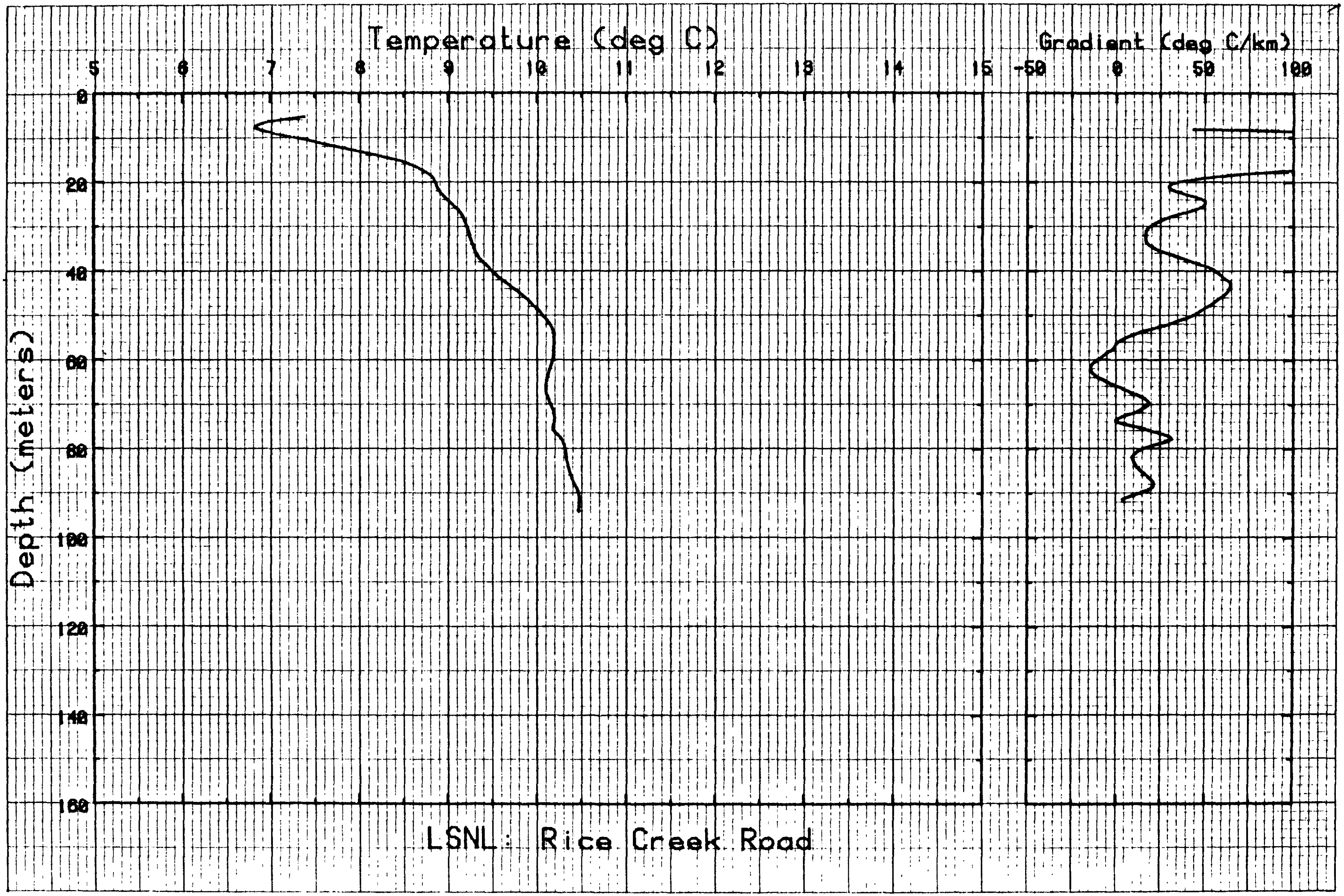

Figure I-14. Temperature and gradient profiles for LSNL.

TABLE I-27. Summary of thermal conductivities, densities, and porosities for borehole LSNL

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
0	1.40	2.41	19.4
0	1.28	2.26	21.8
32.8	2.23		
45.7	2.32		
57.9	2.41		
70.1	2.40		
82.3	2.60		
93.0	2.23		

TABLE I-28. Temperature tabulation

Hole: LSNL RICE CREEK ROAD

Lat: 40-22.60 Long: 121-24.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	7.124	7.62	6.830
9.14	7.012	10.67	7.403
12.19	7.729	13.72	8.087
15.24	8.420	16.76	8.639
18.29	8.781	19.81	8.852
21.34	8.878	22.86	8.931
24.38	9.003	25.91	9.088
27.43	9.156	28.96	9.192
30.48	9.222	32.00	9.247
33.53	9.268	35.05	9.297
36.58	9.332	38.10	9.392
39.62	9.470	41.15	9.552
42.67	9.650	44.20	9.751
45.72	9.846	47.24	9.933
48.77	10.012	50.29	10.078
51.82	10.140	53.34	10.181
54.86	10.194	56.39	10.195
57.91	10.191	59.44	10.188
60.96	10.166	62.48	10.142
64.62	10.111	67.36	10.108
68.88	10.136	70.41	10.166
71.93	10.192	73.46	10.201
74.98	10.185	76.50	10.206
78.03	10.279	79.55	10.315
81.08	10.327	82.60	10.343
84.12	10.355	85.65	10.377
87.17	10.405	88.70	10.440
90.22	10.474	91.74	10.481
94.18	10.476		

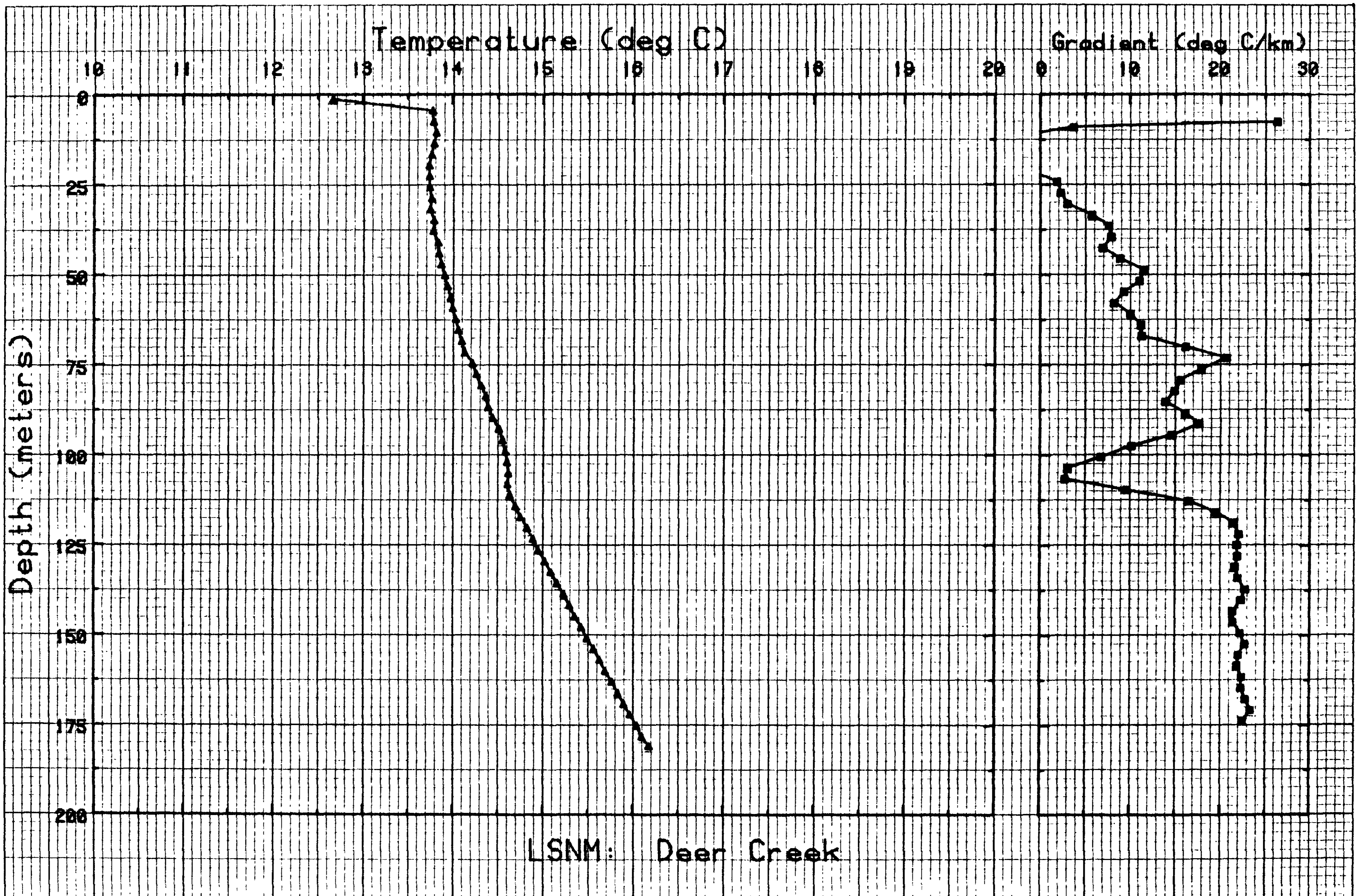

Figure I-15. Temperature and gradient profiles for LSNM.

TABLE I-29. Summary of thermal conductivities, densities, and porosities for borehole LSNM

Depth (m)	$<K_f>$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	φ (%)
0	2.72	2.71	0.6
22.9	2.40		
35.1	2.29		
47.2	2.34		
59.4	2.30		
71.6	2.54		
83.8	3.20		
96.0	2.36		
108.2	2.19		
120.4	2.41		
132.6	2.39		
144.8	2.43		
157.0	2.41		
169.2	2.48		
179.8	2.49		

TABLE I-30. Temperature tabulation

Hole: LSNM DEER CREEK

Lat: 40-10.00 Long: 121-30.30

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	12.666	3.05	13.715
4.57	13.780	6.10	13.801
7.62	13.786	9.14	13.798
10.67	13.818	12.19	13.818
13.72	13.796	15.24	13.768
16.76	13.765	18.29	13.753
19.81	13.741	21.34	13.740
22.86	13.745	24.38	13.748
25.91	13.746	27.43	13.755
28.96	13.765	30.48	13.761
32.00	13.756	33.53	13.766
35.05	13.794	36.58	13.803
38.10	13.786	39.62	13.826
41.15	13.841	42.67	13.845
44.20	13.848	45.72	13.855
47.24	13.875	48.77	13.905
50.29	13.916	51.82	13.930
53.34	13.945	54.86	13.975
56.39	13.979	57.91	13.985
59.44	14.002	60.96	14.010
62.48	14.031	64.01	14.056
65.53	14.064	67.06	14.085
68.58	14.102	70.10	14.108
71.63	14.134	73.15	14.190
74.68	14.222	76.20	14.249
77.72	14.268	79.25	14.287
80.77	14.317	82.30	14.341
83.82	14.369	85.34	14.381
86.87	14.396	88.39	14.427
89.92	14.447	91.44	14.480
92.96	14.515	94.49	14.535
96.01	14.554	97.54	14.573
99.06	14.587	100.58	14.594
102.11	14.604	103.63	14.618
105.16	14.620	106.68	14.606
108.20	14.610	109.73	14.627
111.25	14.636	112.78	14.674
114.30	14.703	115.82	14.724
117.35	14.757	118.87	14.792
120.40	14.827	121.92	14.857
123.44	14.895	124.97	14.929
126.49	14.953	128.02	14.996
129.54	15.026	131.06	15.061
132.59	15.093	134.11	15.121
135.64	15.160	137.16	15.192
138.68	15.233	140.21	15.260
141.73	15.299	143.26	15.333
144.78	15.358	146.30	15.392
147.83	15.430	149.35	15.459
150.88	15.491	152.40	15.529
153.92	15.566	155.45	15.602
156.97	15.629	158.50	15.662
160.02	15.695	161.54	15.733

TABLE I-30. Temperature tabulation (continued)

Hole: LSNM DEER CREEK

Lat: 40-10.00 Long: 121-30.30

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
160.02	15.695	161.54	15.733
163.07	15.768	164.59	15.799
166.12	15.832	167.64	15.868
169.16	15.901	170.69	15.940
172.21	15.971	173.74	16.016
175.26	16.043	176.78	16.075
178.31	16.101	179.83	16.151
180.93	16.179		

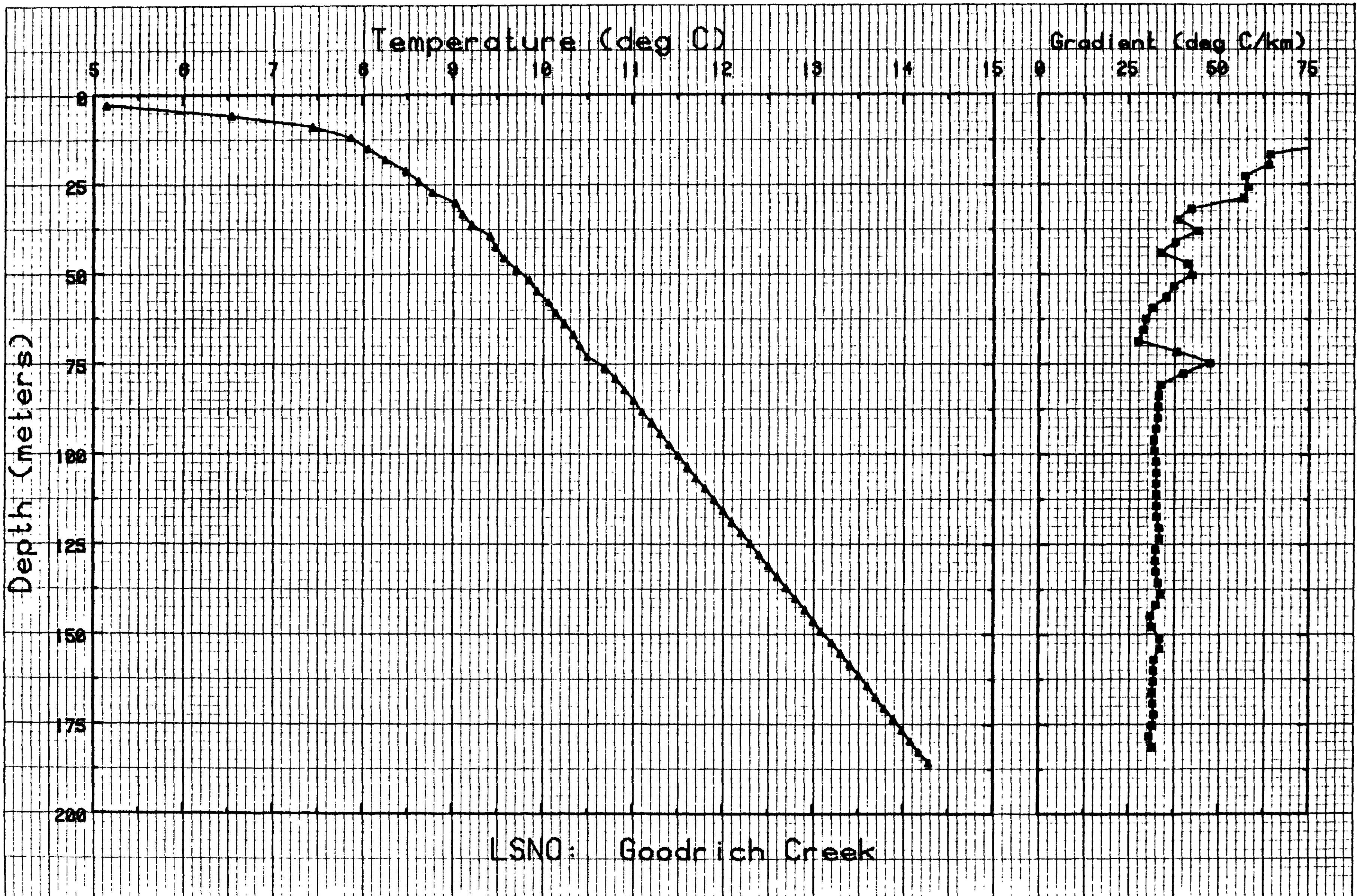

Figure I-16. Temperature and gradient profiles for LSNO.

TABLE I-31. Summary of thermal conductivities, densities, and porosities for borehole LSNO

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
29.0	3.12		
41.1	2.93		
53.3	3.06		
65.5	2.97		
77.7	2.88		
89.9	2.98		
102.1	3.11		
114.3	2.96		
126.5	3.11		
138.7	2.76		
150.9	2.83		
163.1	2.90		
175.3	3.03		
187.5	2.93		

TABLE I-32. Temperature tabulation

Hole: LSNO GOODRICH CREEK

Lat: 40-21.90 Long: 120-56.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
3.05	5.145	4.57	5.800
6.10	6.544	7.62	7.071
9.14	7.448	10.67	7.698
12.19	7.873	13.72	8.012
15.24	8.064	16.76	8.138
18.29	8.255	19.81	8.372
21.34	8.486	22.86	8.537
24.38	8.631	25.91	8.714
27.43	8.787	28.96	8.900
30.48	9.038	32.00	9.059
33.53	9.116	35.05	9.149
36.58	9.224	38.10	9.260
39.62	9.423	41.15	9.429
42.67	9.484	44.20	9.522
45.72	9.574	47.24	9.621
48.77	9.712	50.29	9.788
51.82	9.856	53.34	9.896
54.86	9.943	56.39	10.009
57.91	10.073	59.44	10.124
60.96	10.149	62.48	10.204
64.01	10.246	65.53	10.295
67.06	10.346	68.58	10.388
70.10	10.414	71.63	10.439
73.15	10.499	74.68	10.647
76.20	10.693	77.72	10.758
79.25	10.813	80.77	10.856
82.30	10.910	83.82	10.959
85.34	11.015	86.87	11.062
88.39	11.111	89.92	11.164
91.44	11.214	92.96	11.266
94.49	11.312	96.01	11.362
97.54	11.411	99.06	11.459
100.58	11.508	102.11	11.559
103.63	11.608	105.16	11.658
106.68	11.706	108.20	11.760
109.73	11.809	111.25	11.854
112.78	11.908	114.30	11.958
115.82	12.007	117.35	12.056
118.87	12.108	120.40	12.156
121.92	12.207	123.44	12.265
124.97	12.310	126.49	12.366
128.02	12.408	129.54	12.458
131.06	12.509	132.59	12.562
134.11	12.609	135.64	12.655
137.16	12.707	138.68	12.766
140.21	12.813	141.73	12.866
143.26	12.917	144.78	12.958
146.30	13.008	147.83	13.059
149.35	13.093	150.88	13.150
152.40	13.210	153.92	13.263
155.45	13.309	156.97	13.358
158.50	13.410	160.02	13.451
161.54	13.508	163.07	13.554

TABLE I-32. Temperature tabulation (continued)

Hole: LSNO GOODRICH CREEK

Lat: 40-21.90 Long: 120-56.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
161.54	13.508	163.07	13.554
164.59	13.607	166.12	13.645
167.64	13.701	169.16	13.748
170.69	13.794	172.21	13.846
173.74	13.895	175.26	13.942
176.78	13.994	178.31	14.039
179.83	14.086	181.36	14.130
182.88	14.178	184.40	14.225
185.93	14.290	186.78	14.321

RVN: Round Valley

RVN was drilled to obtain a value of heat flow in the northernmost accessible granitic body of the Sierra Nevada. The hole penetrated about 80 meters of alluvium and an additional ~80 meters of granite wash and decomposed bedrock before encountering solid granite. The curvature and gradient changes in the upper 160 m (Figure I17) can thus be attributed to lithologic changes; below 160 meters, the profile is linear. The resulting heat flow of 47 ± 1 mWm^{-2} is characteristic of the eastern Sierra Nevada province.

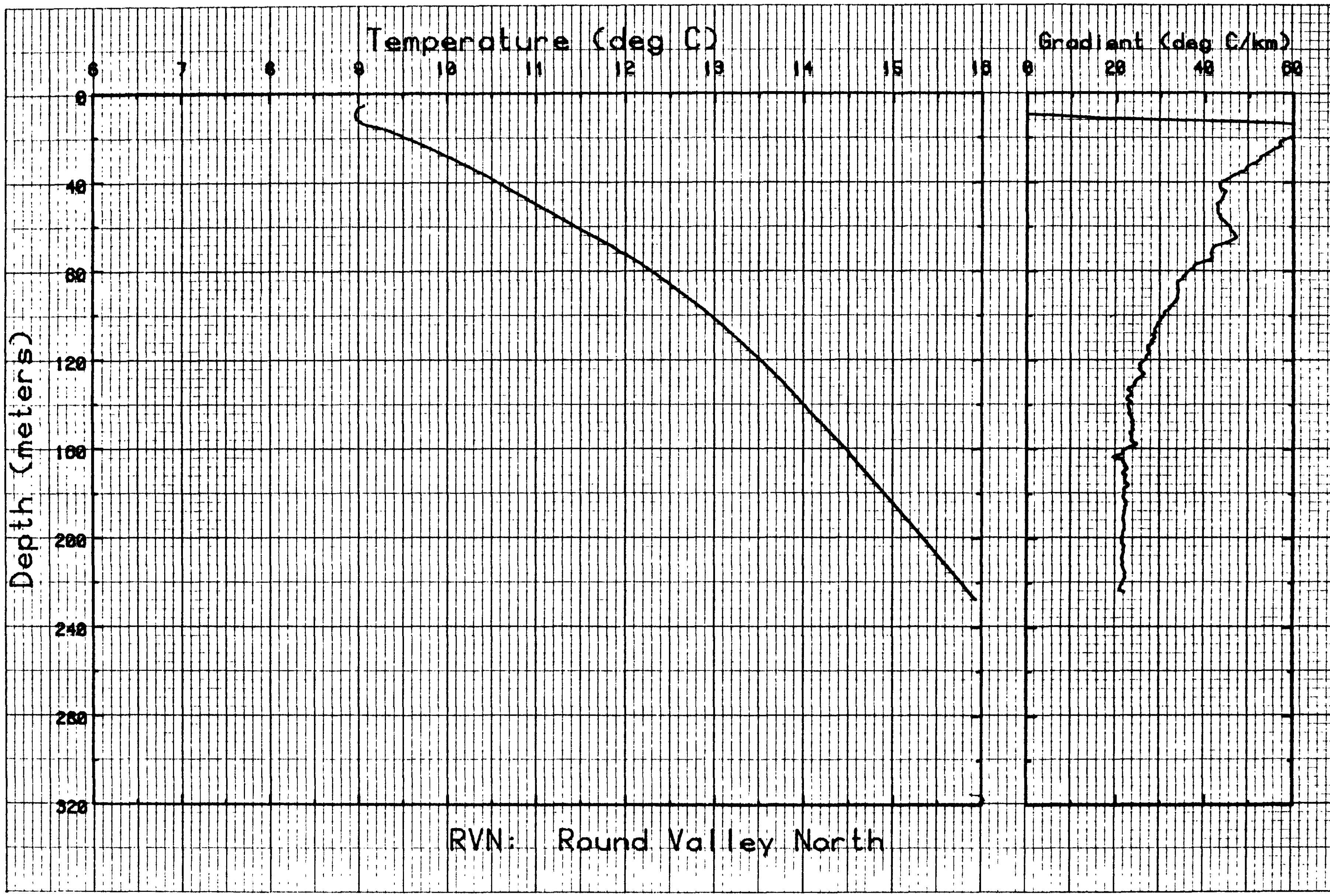

Figure I-17. Temperature and gradient profiles for RVN.

TABLE I-33. Summary of thermal conductivities, densities, and porosities for borehole RVN

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
66.8	1.40		
122.2	2.75		
124.1	2.39	2.62	1.8
131.7	2.22	2.54	2.7
132.2	2.48		
134.7	2.23	2.57	2.6
137.4	2.84		
138.7	2.35	2.65	1.7
145.6	2.50		
152.4	2.62	2.64	1.0
153.9	2.77		
160.8	2.43		
167.8	2.48		
176.0	2.18		
183.6	2.39		
190.5	2.38		
196.9	2.35	2.53	4.4
197.4	2.84		
206.0	2.24		
212.6	2.65		
221.8	2.41		
229.4	2.26		

TABLE I-34. Temperature tabulation

Hole: RVN ROUND VALLEY NORTH

Lat: 40-31.20 Long: 120-40.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	9.043	7.92	8.979
9.75	8.967	11.58	8.977
13.41	9.028	15.24	9.166
17.07	9.338	18.90	9.456
20.73	9.554	22.56	9.661
24.38	9.767	26.21	9.870
28.04	9.965	29.87	10.065
31.70	10.158	33.53	10.250
35.36	10.338	37.19	10.425
39.01	10.510	40.84	10.589
42.67	10.667	44.50	10.747
46.33	10.829	48.16	10.912
49.99	10.989	51.82	11.067
53.64	11.148	55.47	11.224
57.30	11.303	59.13	11.384
60.96	11.468	62.79	11.551
64.62	11.636	66.45	11.725
68.28	11.809	70.10	11.883
71.93	11.954	73.76	12.036
75.59	12.110	77.42	12.182
79.25	12.249	81.08	12.314
82.91	12.382	84.73	12.443
86.56	12.505	88.39	12.565
90.22	12.629	92.05	12.691
93.88	12.750	95.71	12.813
97.54	12.869	99.36	12.925
101.19	12.982	103.02	13.037
104.85	13.089	106.68	13.141
108.51	13.195	110.34	13.248
112.17	13.299	114.00	13.348
115.82	13.399	117.65	13.445
119.48	13.500	121.31	13.545
123.14	13.588	124.97	13.638
126.80	13.683	128.63	13.732
130.45	13.779	132.28	13.816
134.11	13.865	135.94	13.901
137.77	13.946	139.60	13.985
141.43	14.030	143.26	14.070
145.08	14.113	146.91	14.154
148.74	14.199	150.57	14.243
152.40	14.285	154.23	14.330
156.06	14.369	157.89	14.413
159.72	14.458	161.54	14.499
163.37	14.533	165.20	14.573
167.03	14.611	168.86	14.650
170.69	14.694	172.52	14.730
174.35	14.771	176.17	14.813
178.00	14.854	179.83	14.893
181.66	14.932	183.49	14.975
185.32	15.014	187.15	15.053
188.98	15.094	190.80	15.132

TABLE I-34. Temperature tabulation (continued)

Hole: RVN ROUND VALLEY NORTH

Lat: 40-31.20 Long: 120-40.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
188.98	15.094	190.80	15.132
192.63	15.171	194.46	15.213
196.29	15.252	198.12	15.292
199.95	15.330	201.78	15.368
203.61	15.408	205.44	15.448
207.26	15.488	209.09	15.527
210.92	15.565	212.75	15.605
214.58	15.644	216.41	15.684
218.24	15.725	220.07	15.764
221.89	15.802	223.72	15.841
225.55	15.877	228.90	15.975

SHAS: Mount Shasta

This well was drilled in an attempt to obtain heat-flow data as close as possible (~20 km) to Mount Shasta. The profile exhibits some minor excursions (Figure I-18), most probably attributable to small, local water movements. The profile is, however, linear on the whole, supporting an assumption of conductive heat flux.

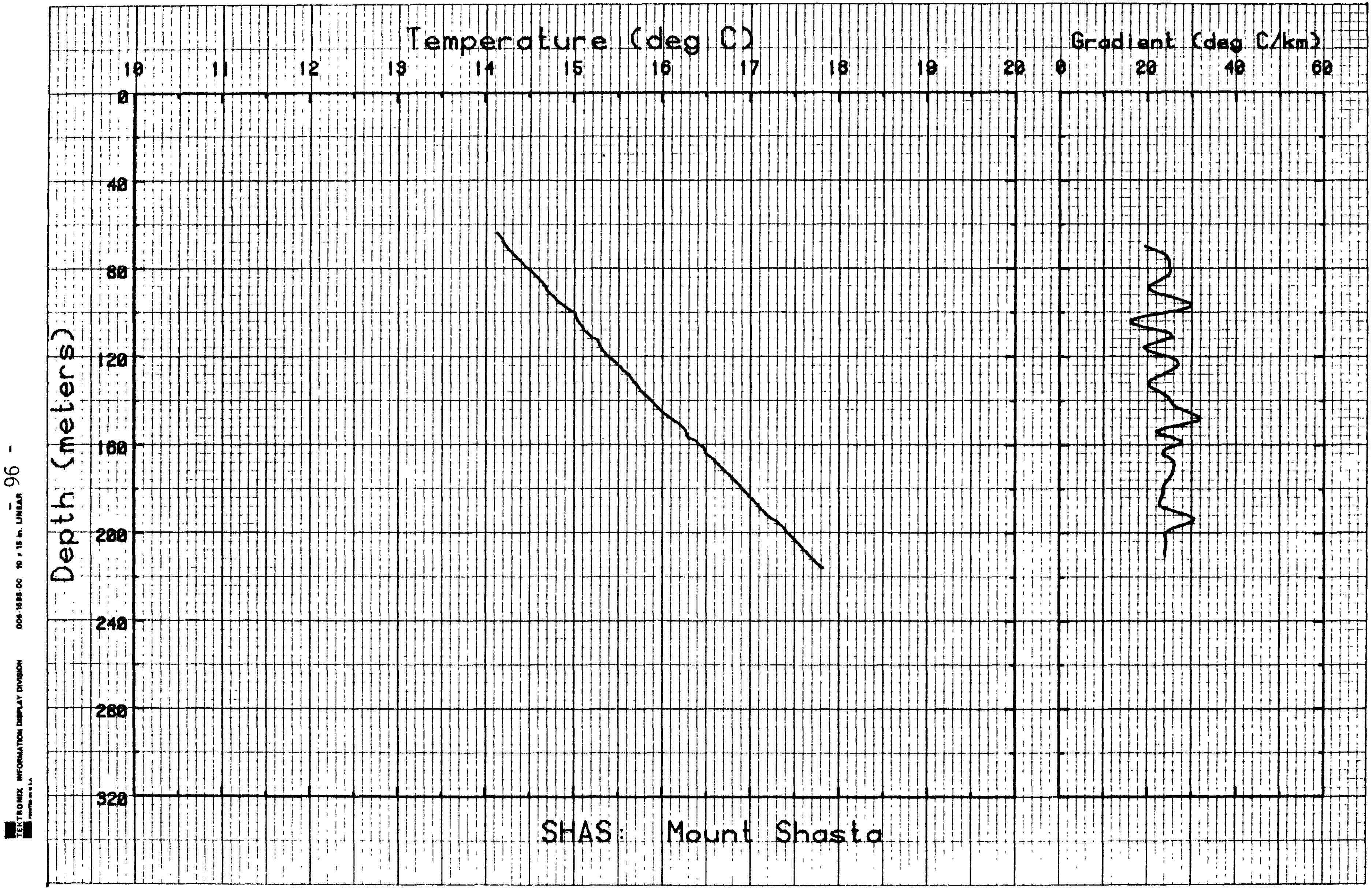

Figure I-18. Temperature and gradient profiles for SHAS.

TABLE I-35. Summary of thermal conductivities, densities, and porosities for borehole SHAS

Depth (m)	$\langle K_f \rangle$ ($Wm^{-1} K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
0	2.59	2.64	1.9
16.8	2.62		
29.0	2.61		
41.1	2.83		
53.3	2.31		
65.5	2.63		
77.7	2.58		
89.9	2.74		
102.1	2.50		
108.2	2.32		
114.3	1.86		
126.5	2.77		
138.7	2.58		
150.9	2.67		
163.1	2.44		
175.3	2.55		
187.5	2.48		
199.6	2.66		

TABLE I-36. Temperature tabulation

Hole: SHAS MOUNT SHASTA

Lat: 41-33.20 Long: 122-15.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
64.01	14.136	65.53	14.174
67.06	14.202	68.58	14.213
70.10	14.243	71.63	14.275
73.15	14.315	74.68	14.351
76.20	14.389	77.72	14.427
79.25	14.466	80.77	14.504
82.30	14.542	83.82	14.581
85.34	14.619	86.87	14.657
88.39	14.691	89.92	14.699
91.44	14.739	92.96	14.779
94.49	14.816	96.01	14.858
97.54	14.905	99.06	14.963
100.58	15.022	102.11	15.029
103.63	15.048	105.16	15.070
106.68	15.102	108.20	15.117
109.73	15.164	111.25	15.206
112.78	15.273	114.30	15.287
115.82	15.306	117.35	15.335
118.87	15.364	120.40	15.401
121.92	15.449	123.44	15.494
124.97	15.532	126.49	15.564
128.02	15.621	129.54	15.647
131.06	15.674	132.59	15.703
134.11	15.740	135.64	15.761
137.16	15.798	138.68	15.844
140.21	15.883	141.73	15.916
143.26	15.957	144.78	15.994
146.30	16.042	147.83	16.087
149.35	16.141	150.88	16.200
152.40	16.245	153.92	16.273
155.45	16.286	156.97	16.298
158.50	16.389	160.02	16.421
161.54	16.478	163.07	16.489
164.59	16.509	166.12	16.569
167.64	16.607	169.16	16.645
170.69	16.682	172.21	16.721
173.74	16.765	175.26	16.802
176.78	16.839	178.31	16.876
179.83	16.911	181.36	16.946
182.88	16.981	184.40	17.018
185.93	17.054	187.45	17.091
188.98	17.116	190.50	17.153
192.02	17.191	193.55	17.241
195.07	17.309	196.60	17.345
198.12	17.385	199.64	17.417
201.17	17.455	202.69	17.491
204.22	17.529	205.74	17.566
207.26	17.602	208.79	17.642
210.31	17.673	211.84	17.713
213.36	17.746	214.88	17.787
215.95	17.819		

WC1: Winburn Camp, Oregon

WC1 was drilled near the center of the Jurassic (~150 m.y.) Ashland pluton. This is a zoned body with compositions ranging from gabbro to granodiorite. WC1 was drilled in one of the more felsic parts of the intrusion; however, the SiO_2 content (62%, Hotz, 1971) of the nearest analyzed sample is somewhat lower than that at Igo.

Drilling was completed at this site on November 14, 1969, and the last complete set of temperature measurements was made on December 10, 1969. This profile (Figure I-19) shows considerable curvature in the upper 200 meters. The disturbance could be caused by superficial topography or possibly by a sudden drop in temperature of up to 4°C within the last century. There is no indication of a systematic increase in thermal conductivity (Table I-37) of anywhere near the magnitude necessary to compensate for the decreasing gradient. The three-dimensional Birch (1950) type topographic correction indicates a curvature in the right direction, but the magnitude is much too small, even if we assume a zero or negative lapse rate for ground surface temperatures. The calculated disturbances, varies from over 50% near the surface to about 20% in the lowermost 30 meters. A study of Lees valleys which bracket the close-in two-dimensional topography predict the same kind of curvature, but higher corrections (Figure 5). The observed gradients vary by a factor of 3 from ~50°/km at 50 m to ~16°/km between 250 and 300 meters.

The hole was drilled in a fairly steep-sided valley which strikes nearly N-S. This suggests that the drill site is shaded from direct sunlight for much of the day in comparison with higher elevations on the slopes, possibly resulting in a surface temperature inversion. The stream quite close to the hole carries melt-water for much of the summer. If a significant amount of this cold water percolates downward and outward from the stream through inter-connected fractures in the rock, we might expect to see a broad enough area of depressed near-surface temperatures to account for the high gradients in the upper 200 meters.

In any event, the gradient in the lowermost 50 meters is linear, and if we apply the steady-state three-dimensional topographic correction for the limiting cases of lapse rates of 0 and 5°/km, the gradient correction is between 2 and 3°C/km (~15% to 20% of the observed gradient). The resulting estimate of q is 42±2 mWm^{-2} (Table 1).

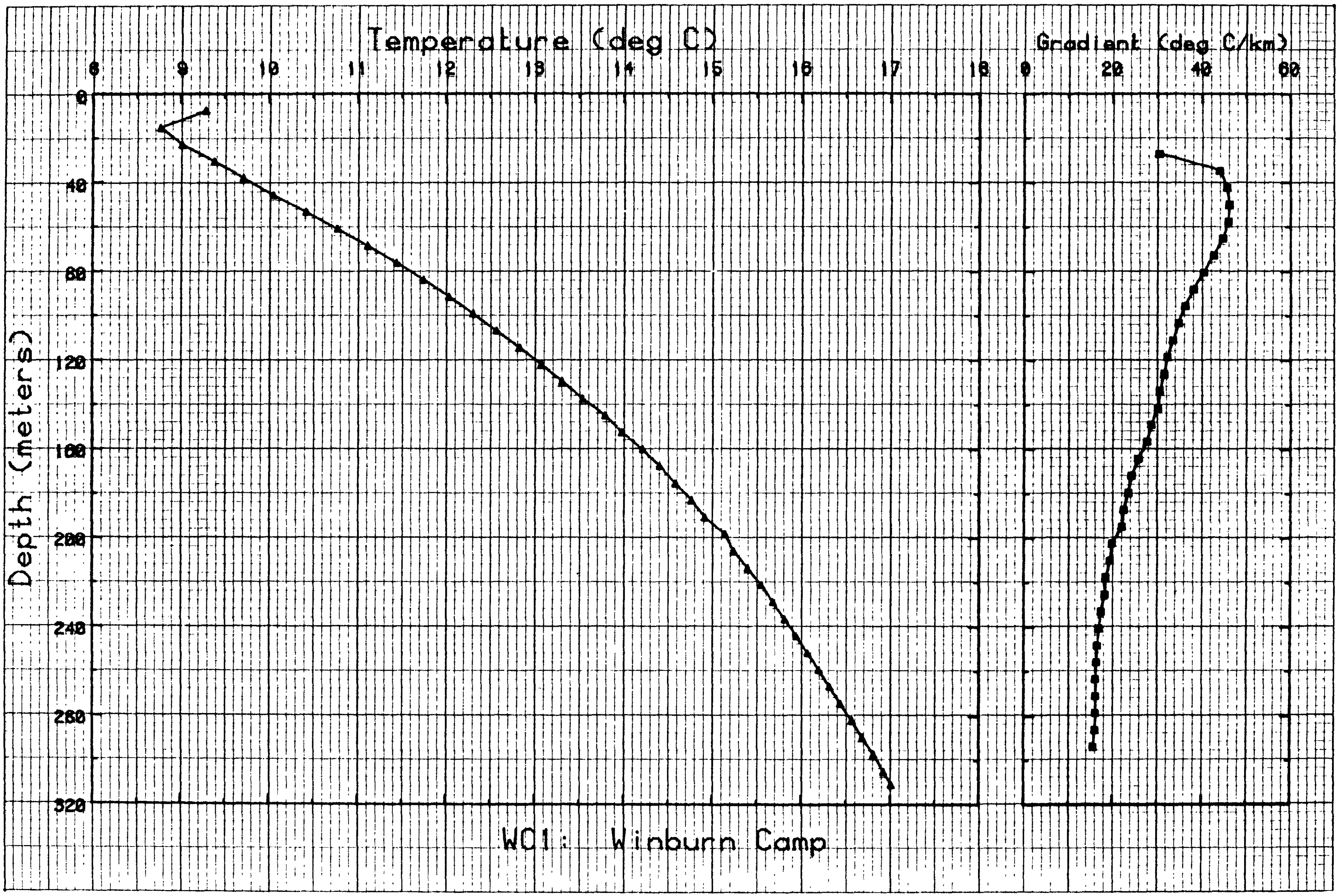

Figure I-19. Temperature and gradient profiles for WC1.

TABLE I-37. Summary of thermal conductivities, densities, and porosities for borehole WC1

Depth (m)	$<K_f>$ ($Wm^{-1} K^{-1}$)	ρ ($gm\ cm^{-3}$)	ϕ (%)
16.7	3.56	2.58	1.3
41.2	2.80	2.54	2.2
47.0	2.25	2.49	3.0
66.1	2.90	2.58	1.3
70.5	2.58	2.51	3.0
91.2	3.36	2.61	0.4
96.4	2.97	2.60	0.4
99.3	3.45	2.61	0.4
113.5	3.08	2.60	0.7
117.8	3.32		
123.1	3.20	2.60	1.0
140.5	2.95	2.61	0.4
146.3	3.04	2.61	0.7
152.8	2.86	2.55	1.6
159.1	2.99	2.60	0.9
167.7	3.11	2.58	0.7
178.7	3.27	2.58	0.8
184.8	3.24	2.43	0.8
193.3	2.99	2.60	1.1
208.5	3.46	2.62	0.4
222.7	2.98	2.60	0.6
234.7	3.26	2.62	0.3
250.5	3.11	2.62	0.6

TABLE I-37. Summary of thermal conductivities, densities, and porosities for borehole WC1 (continued)

Depth (m)	$\langle K_f \rangle$ (Wm^{-1} K^{-1})	ρ (gm cm^{-3})	ϕ (%)
258.5	3.36	2.60	0.6
274.6	3.08	2.62	0.2
281.6	3.03	2.60	0.6
297.8	3.06	2.65	0.2
310.6	2.97	2.60	0.5

TABLE I-38. Temperature tabulation

Hole: WC1 WINBURN CAMP

Lat: 42- 8.10 Long: 122-43.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
7.92	9.277	15.54	8.769
23.16	9.014	30.78	9.385
38.40	9.713	46.02	10.049
53.64	10.420	61.26	10.772
68.88	11.114	76.50	11.443
84.12	11.747	91.74	12.037
99.36	12.307	106.98	12.571
114.60	12.830	122.22	13.074
129.84	13.309	137.46	13.538
145.08	13.793	152.70	13.980
160.32	14.219	167.94	14.408
175.56	14.589	183.18	14.766
190.80	14.920	198.42	15.145
206.04	15.244	213.66	15.400
221.28	15.552	228.90	15.686
236.52	15.816	244.14	15.946
251.76	16.072	259.38	16.196
267.00	16.317	274.62	16.441
282.24	16.566	289.86	16.687
297.48	16.811	305.10	16.925
311.20	17.011		

APPENDIX II: Temperature-depth data for "holes of opportunity" in the Cascades, Klamath Mountains, and Basin and Range

What follows is a series of temperature tabulations and temperature and gradient profiles for 63 "holes of opportunity" (mostly water wells) logged during the course of this study. As an aid in locating the individual sites, we include ten maps (Figures II-a through II-j) reduced from the appropriate 1:250,000 topographic sheets. The locations are shown as dots.

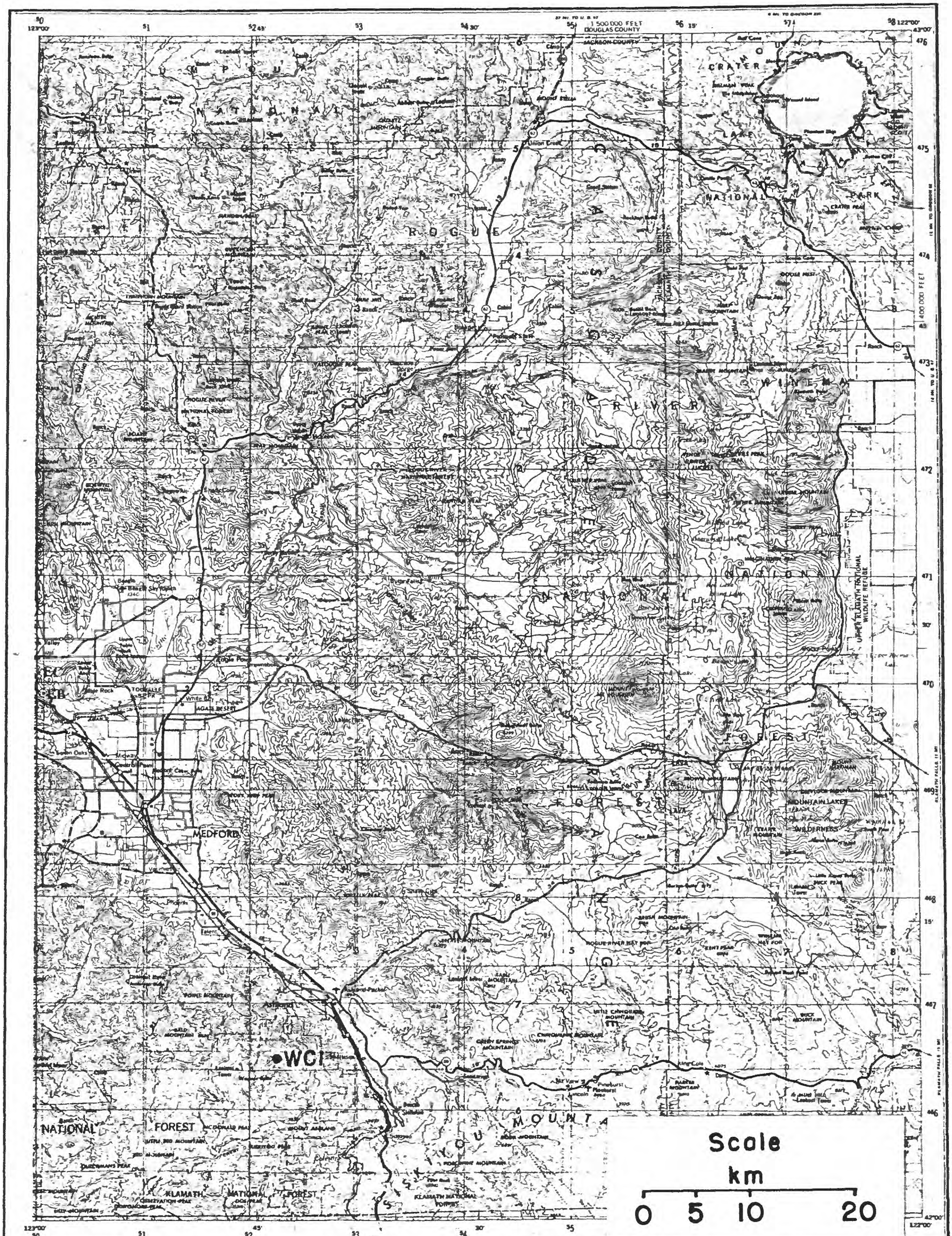

Figure IIa. Location map for the east half of the southern Oregon Cascades.

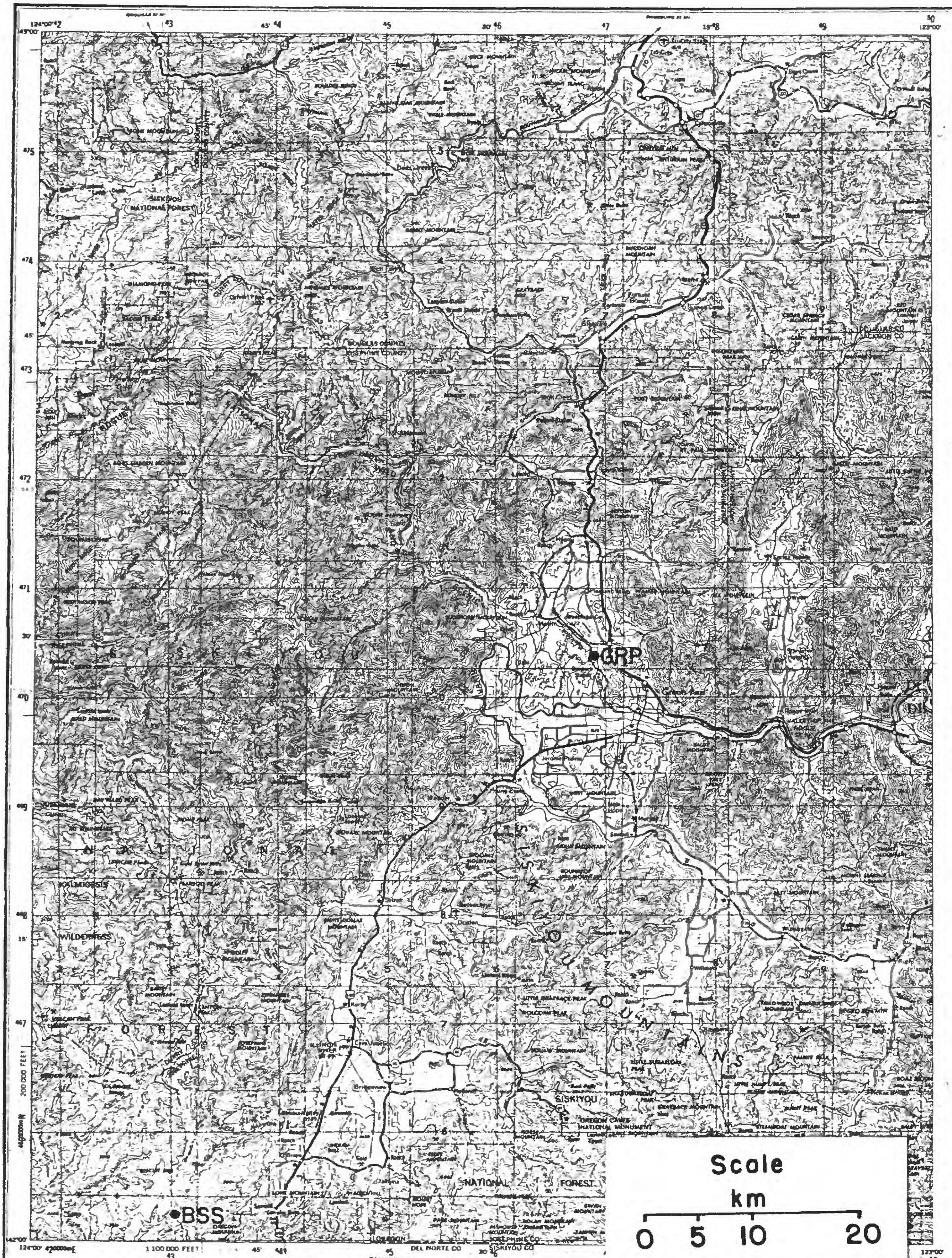

Figure IIb. Location map for the west half of the southern Oregon Cascades.

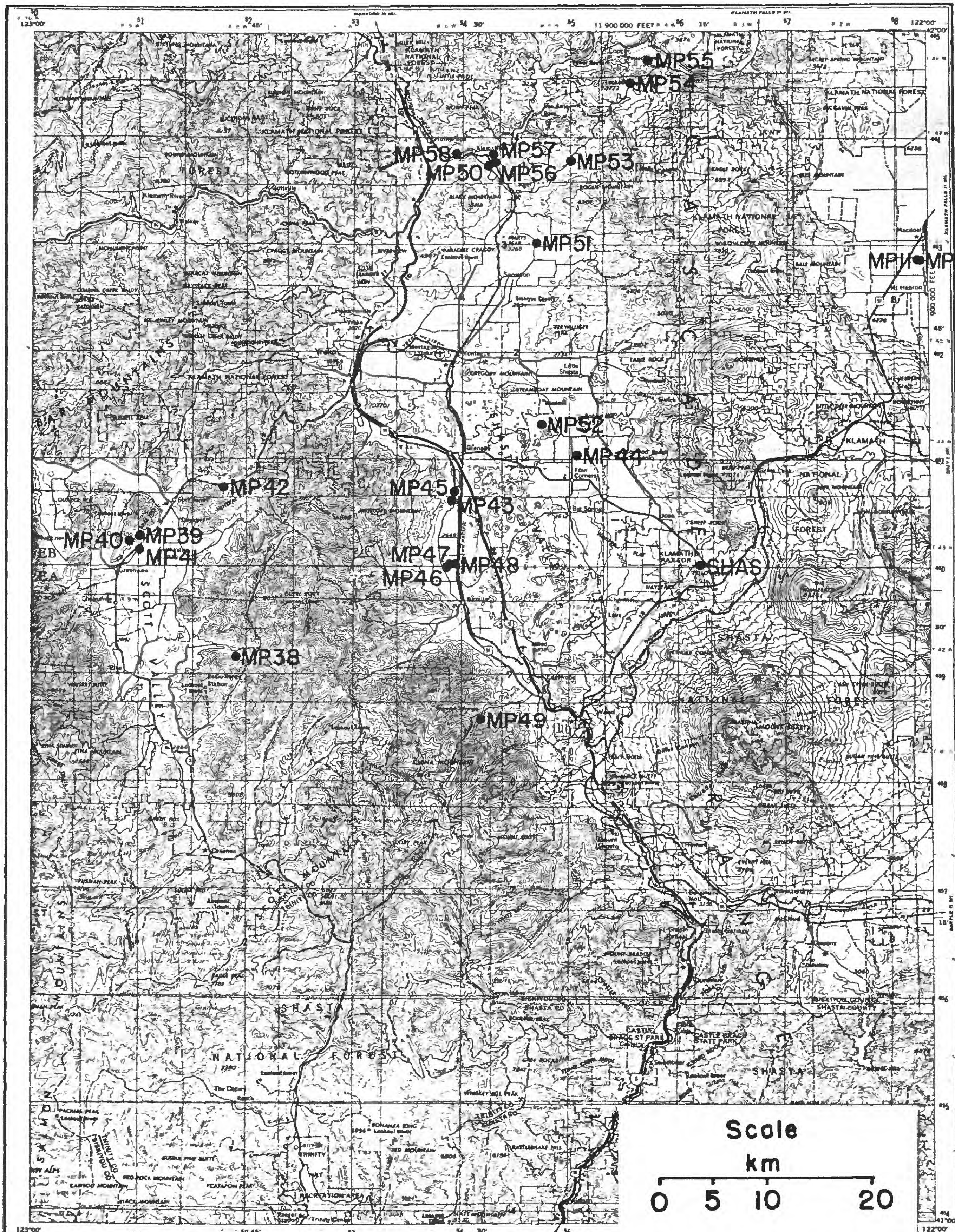

Figure IIc. Location map for the Mount Shasta region.

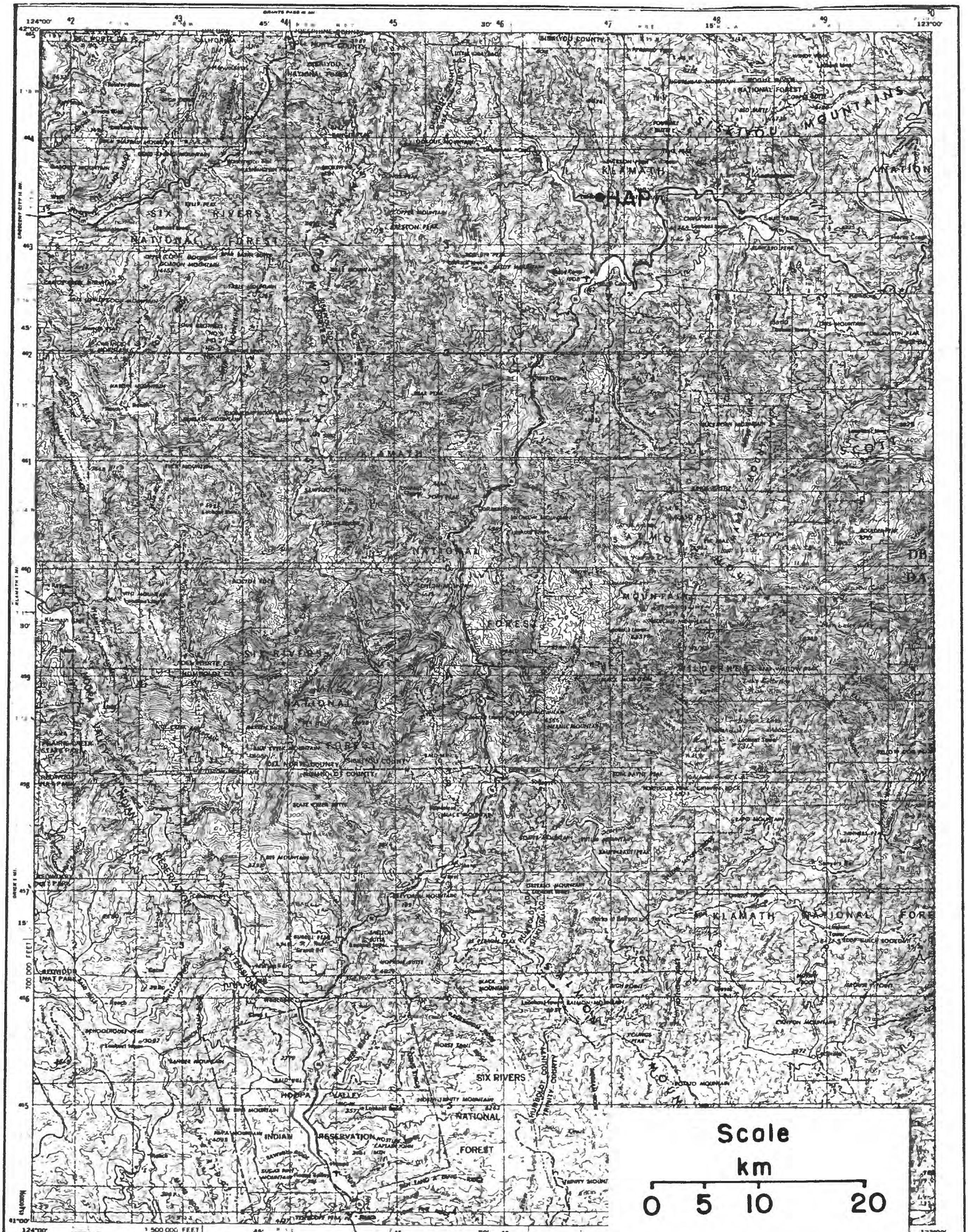

Figure IId. Location map for the northern Klamath region.

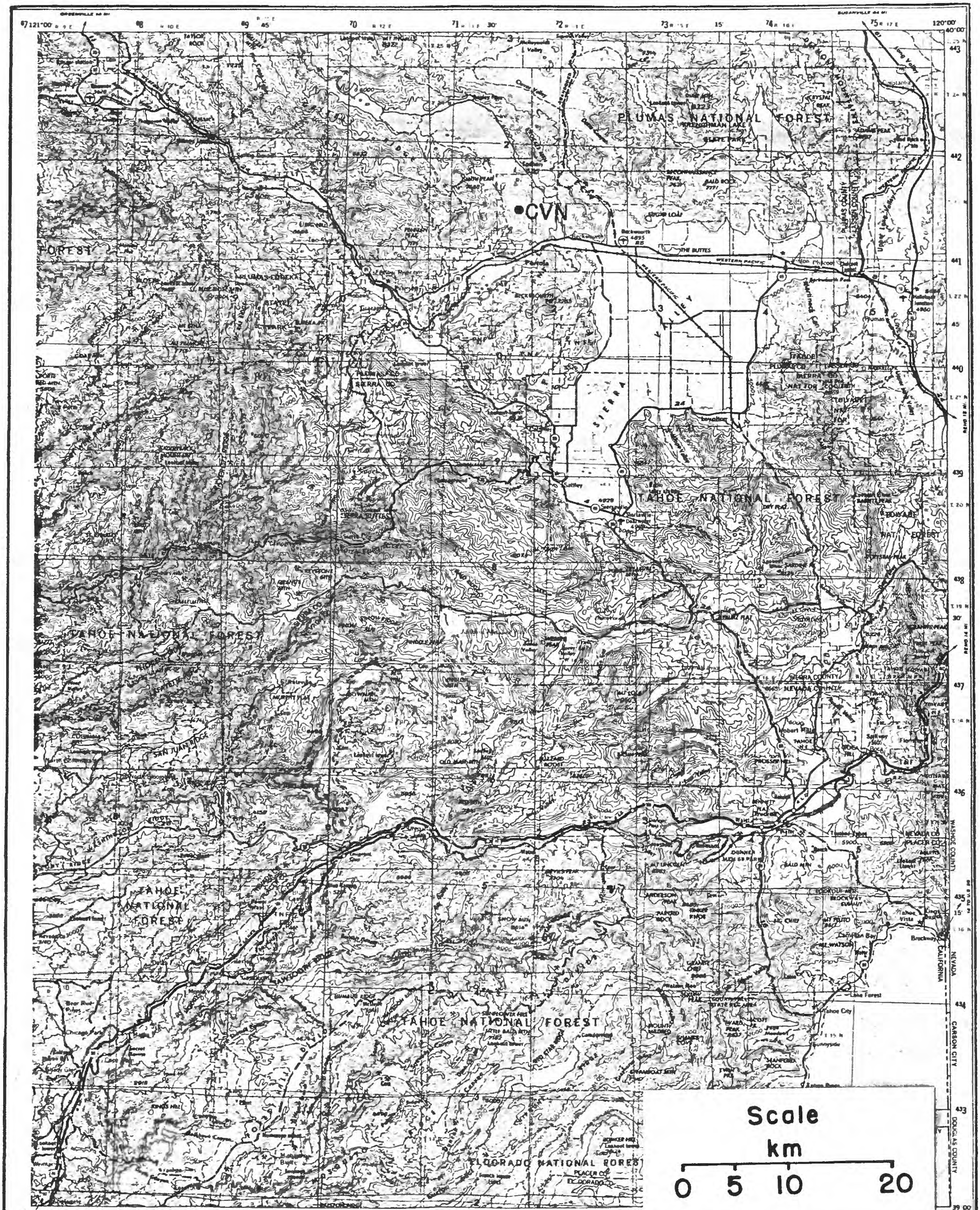

Figure IIe. Location map for the north-central Sierra Nevada.

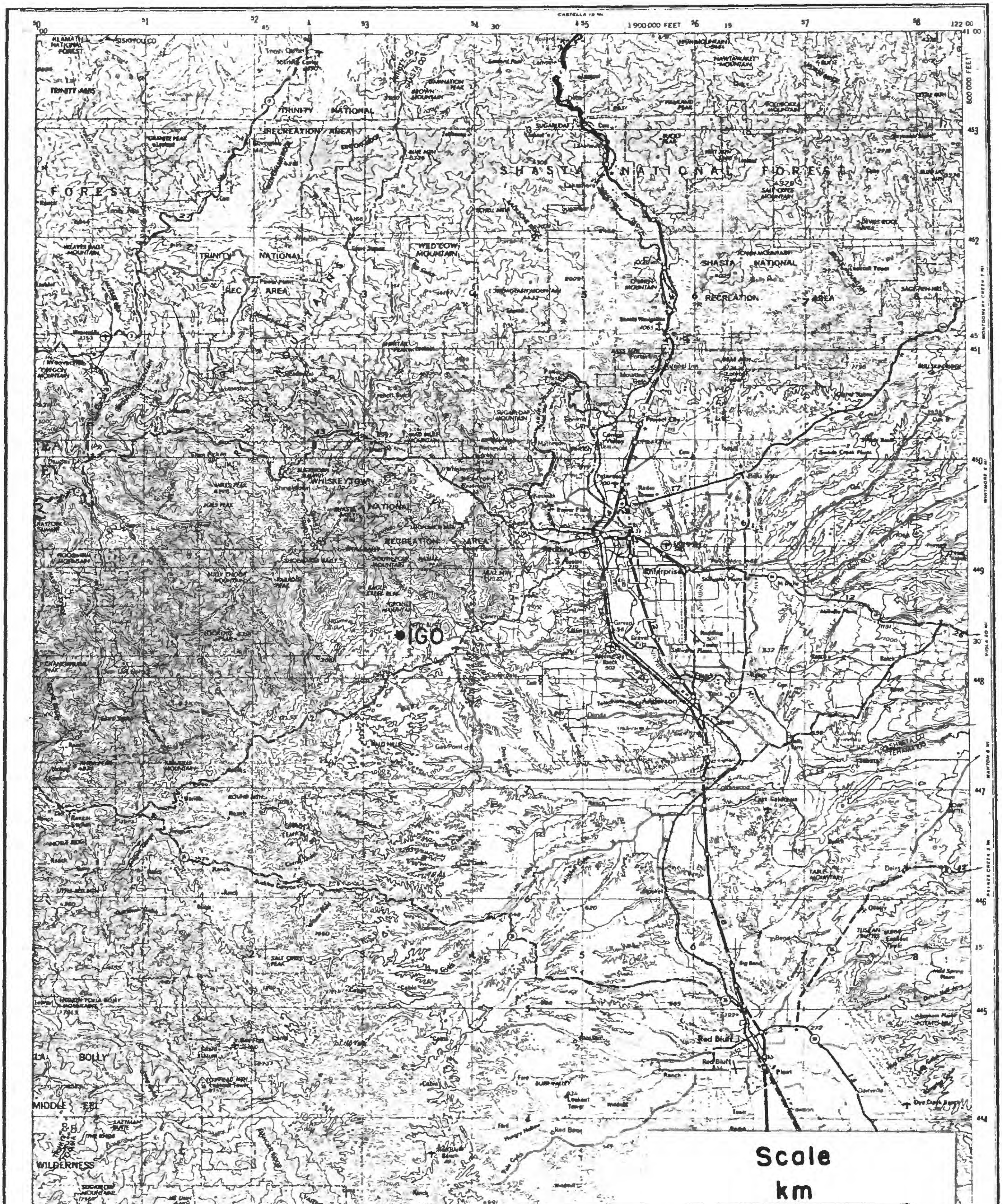

Figure IIf. Location map for the southern Klamath region.

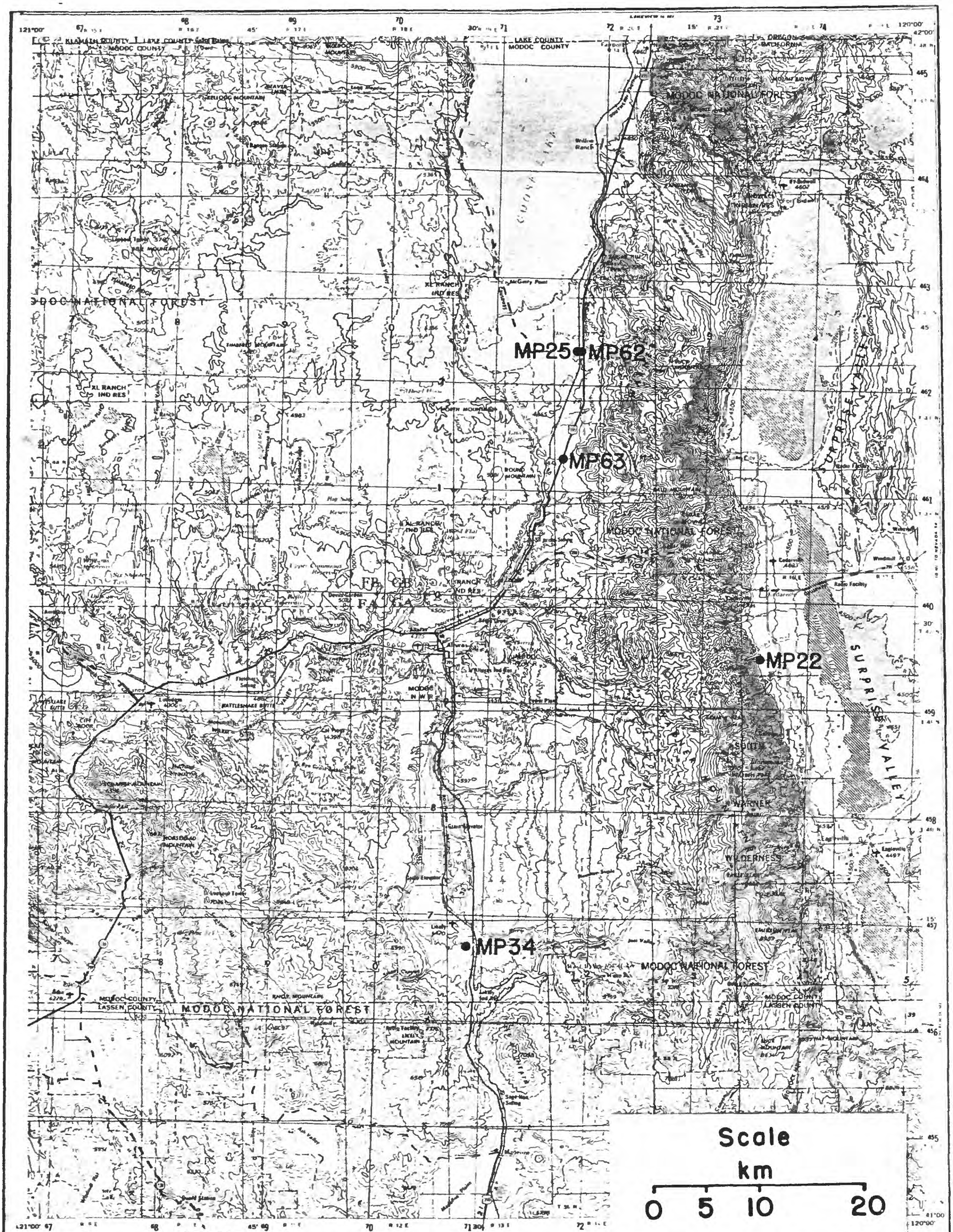

Figure IIg. Location map for the region northeast of Mount Lassen.

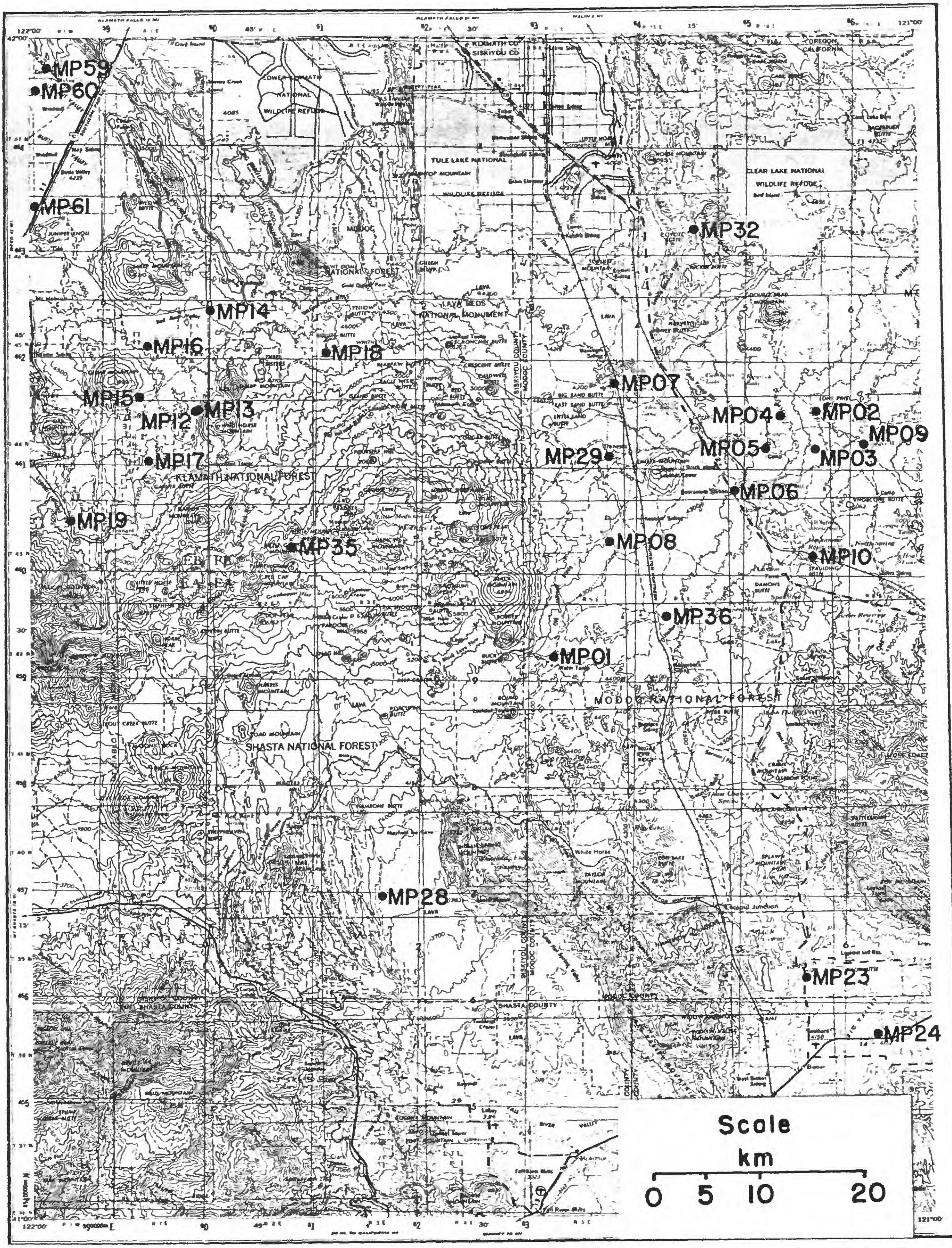

Figure IIh. Location map for the region east of Mount Shasta.

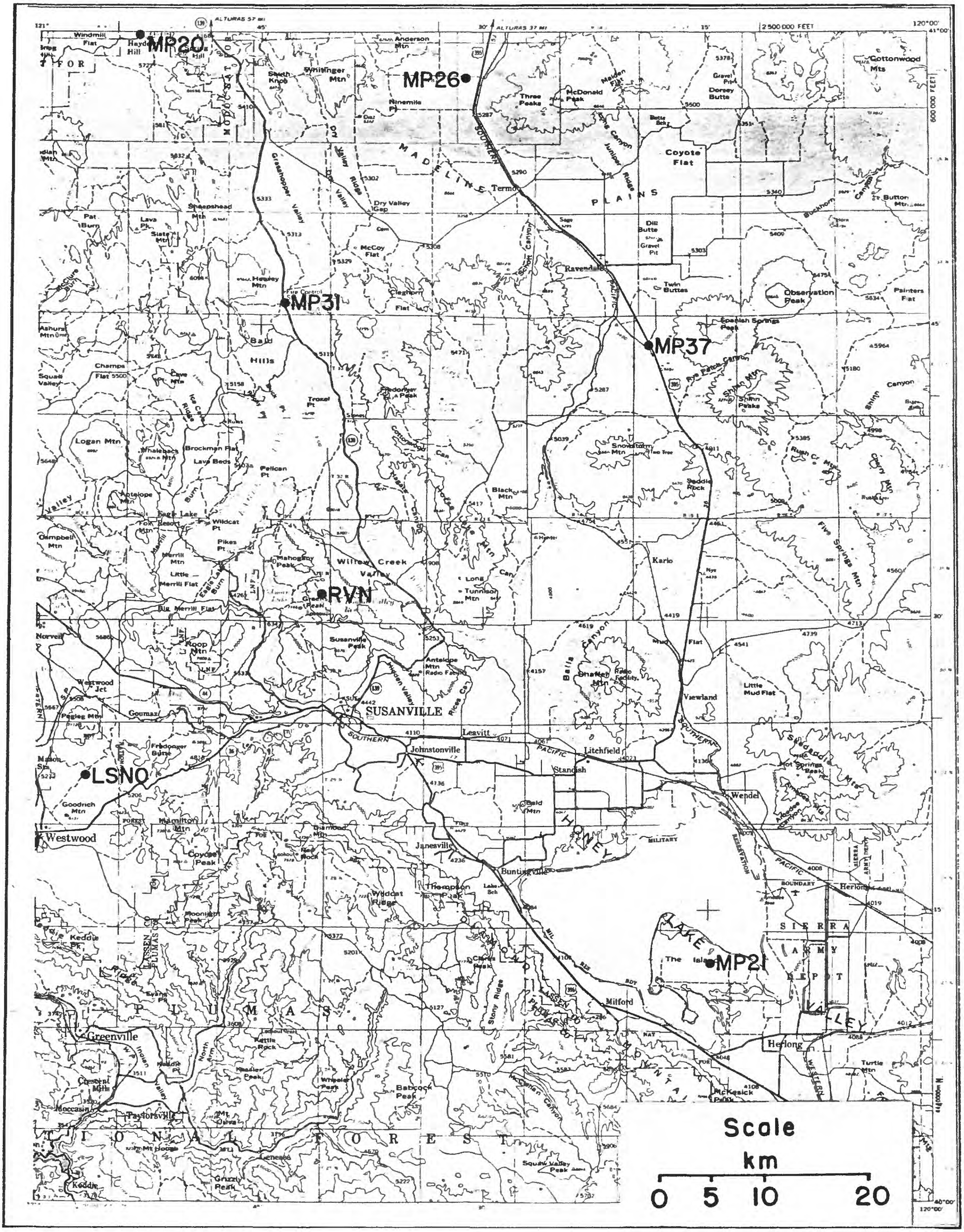

Figure IIi. Location map for the east half of the northern Sierra Nevada and Lassen region.

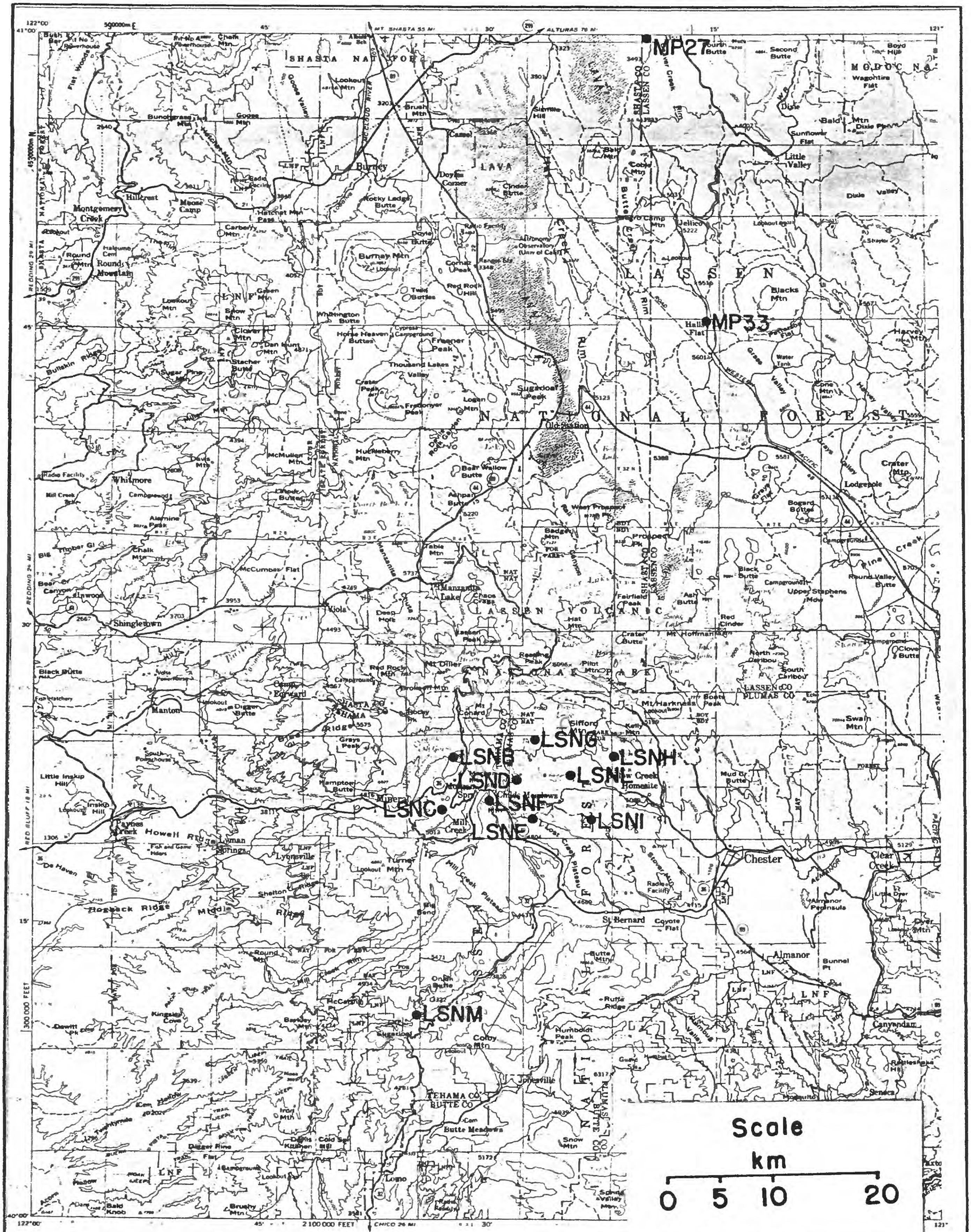

Figure IIj. Location map for the west half of the northern Sierra Nevada and Lassen region.

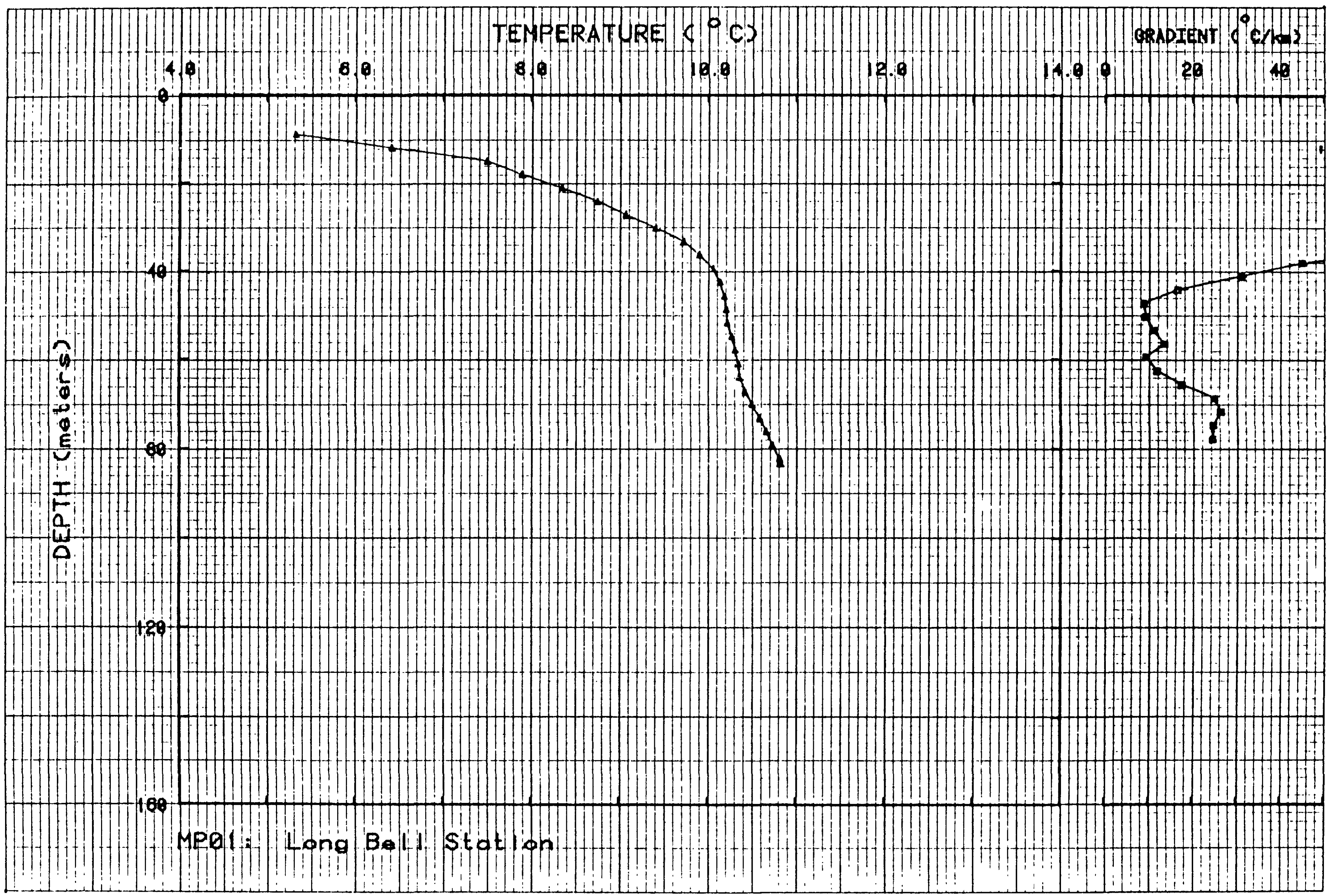

Figure II-1. Temperature and gradient profiles for MP01.

TABLE II-1. Temperature tabulation

Hole: MP01 LONG BELL STA.

Lat: 41-28.30 Long: 121-24.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
9.14	5.331	12.19	6.422
15.24	7.503	18.29	7.899
21.34	8.354	24.38	8.757
27.43	9.081	30.48	9.419
33.53	9.735	36.58	9.913
39.62	10.068	42.67	10.148
45.72	10.197	48.77	10.220
51.82	10.230	54.86	10.283
57.91	10.322	60.96	10.354
64.01	10.370	67.06	10.432
70.10	10.515	73.15	10.599
76.20	10.674	79.25	10.741
82.30	10.823	83.33	10.832

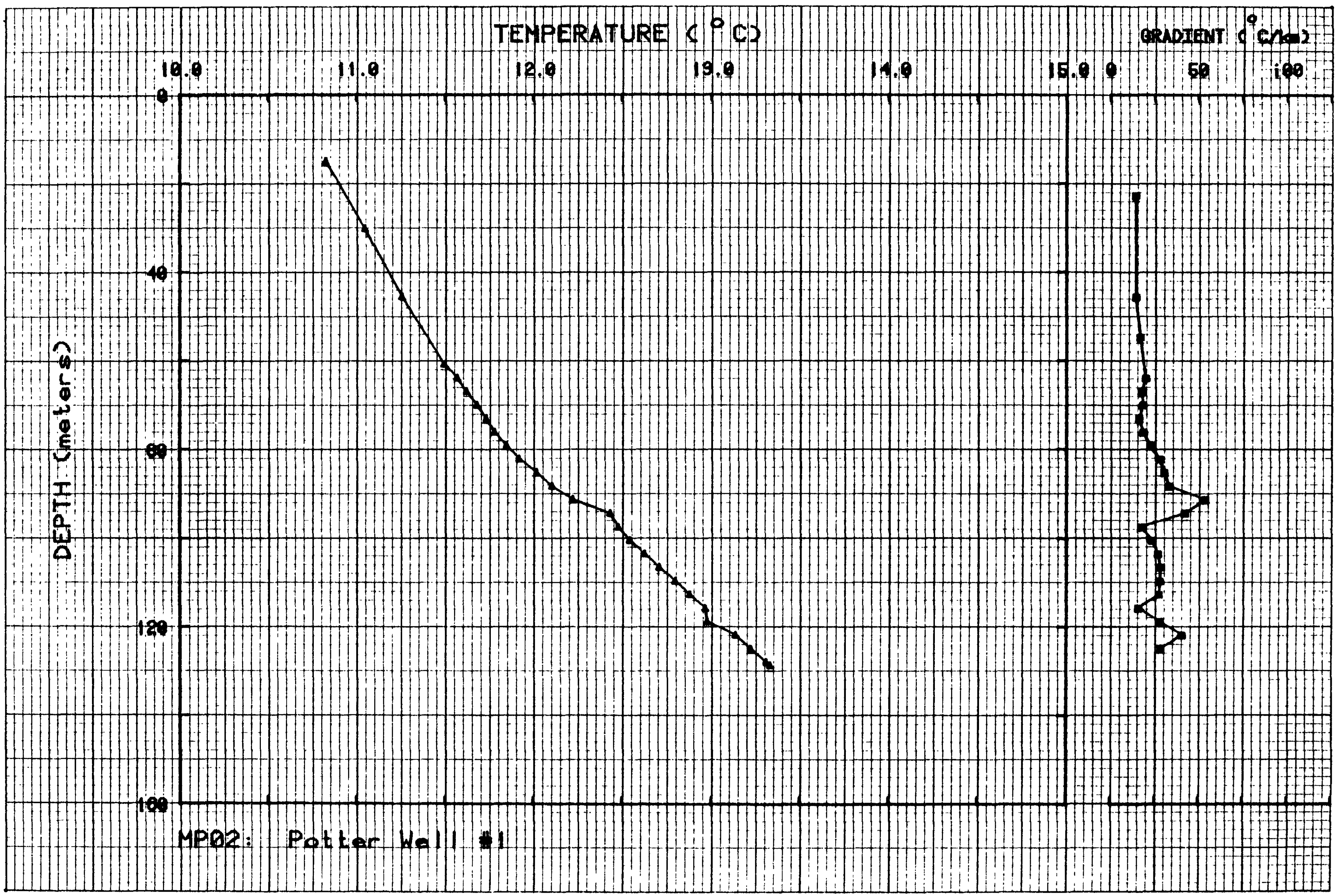

Figure II-2. Temperature and gradient profiles for MP02.

TABLE II-2. Temperature tabulation

Hole: MP02 POTTER WELL 1

Lat: 41-40.70 Lons: 121- 7.00

Derth (m)	Temr (des C)	Derth (m)	Temr (des C)
15.24	10.832	30.48	11.053
45.72	11.263	60.96	11.501
64.01	11.574	67.06	11.624
70.10	11.684	73.15	11.737
76.20	11.784	79.25	11.852
82.30	11.924	85.34	12.022
88.39	12.110	91.44	12.226
94.49	12.438	97.54	12.484
100.58	12.547	103.63	12.629
106.68	12.712	109.73	12.802
112.78	12.883	115.82	12.970
118.87	12.980	121.92	13.141
124.97	13.229	128.02	13.316
128.72	13.339		

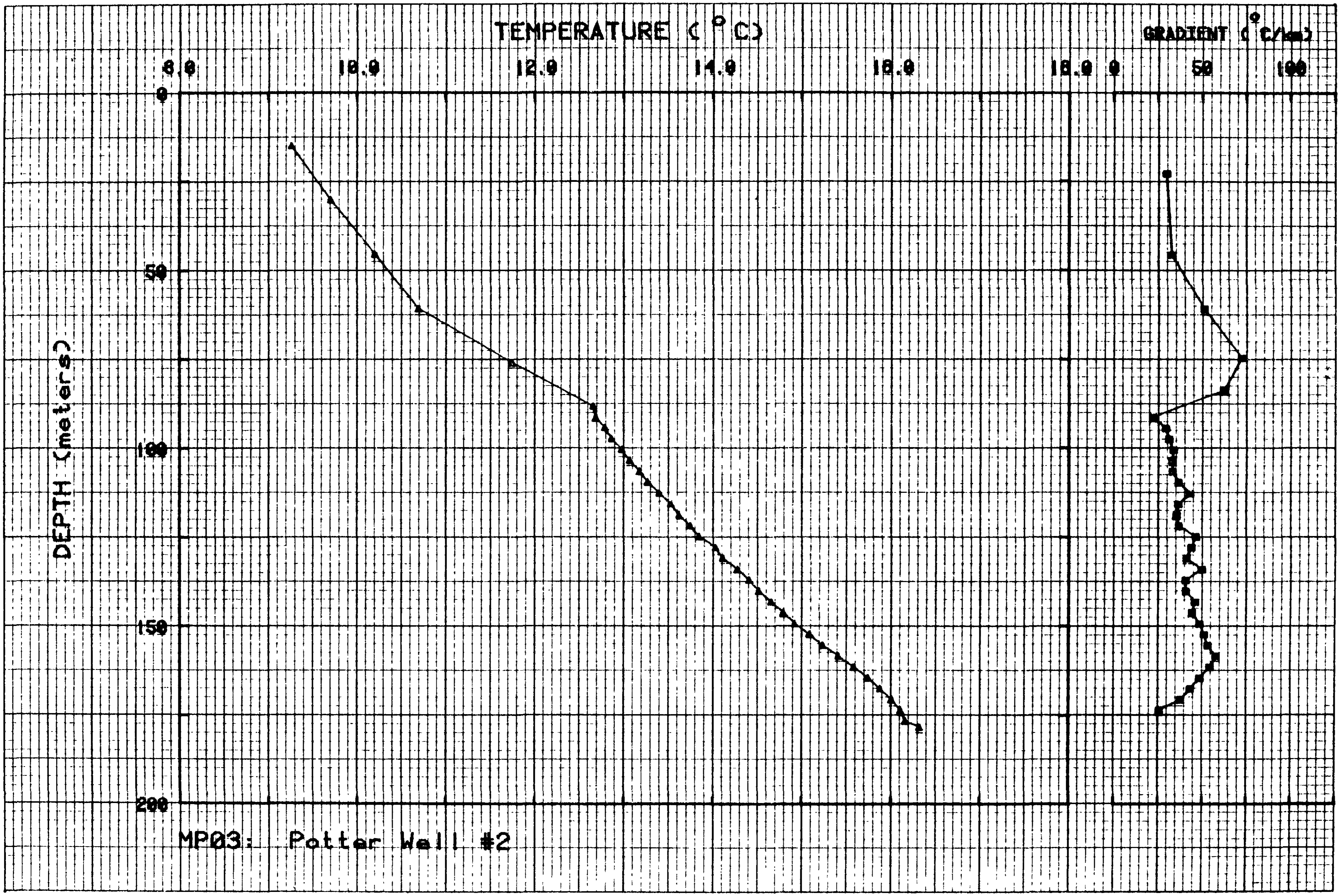

Figure II-3. Temperature and gradient profiles for MP03.

TABLE II-3. Temperature tabulation

Hole: MP03 POTTER WELL 2

Lat: 41-38.80 Long: 121- 7.10

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	9.256	30.48	9.703
45.72	10.202	60.96	10.688
76.20	11.742	88.39	12.656
91.44	12.685	94.49	12.788
97.54	12.862	100.58	12.975
103.63	13.064	106.68	13.173
109.73	13.264	112.78	13.394
115.82	13.525	118.87	13.614
121.92	13.739	124.97	13.837
128.02	14.019	131.06	14.102
134.11	14.267	137.16	14.403
140.21	14.512	143.26	14.650
146.30	14.790	149.35	14.918
152.40	15.085	155.45	15.228
158.50	15.408	161.54	15.578
164.59	15.738	167.64	15.873
170.69	16.000	173.74	16.102
176.78	16.155	178.46	16.315

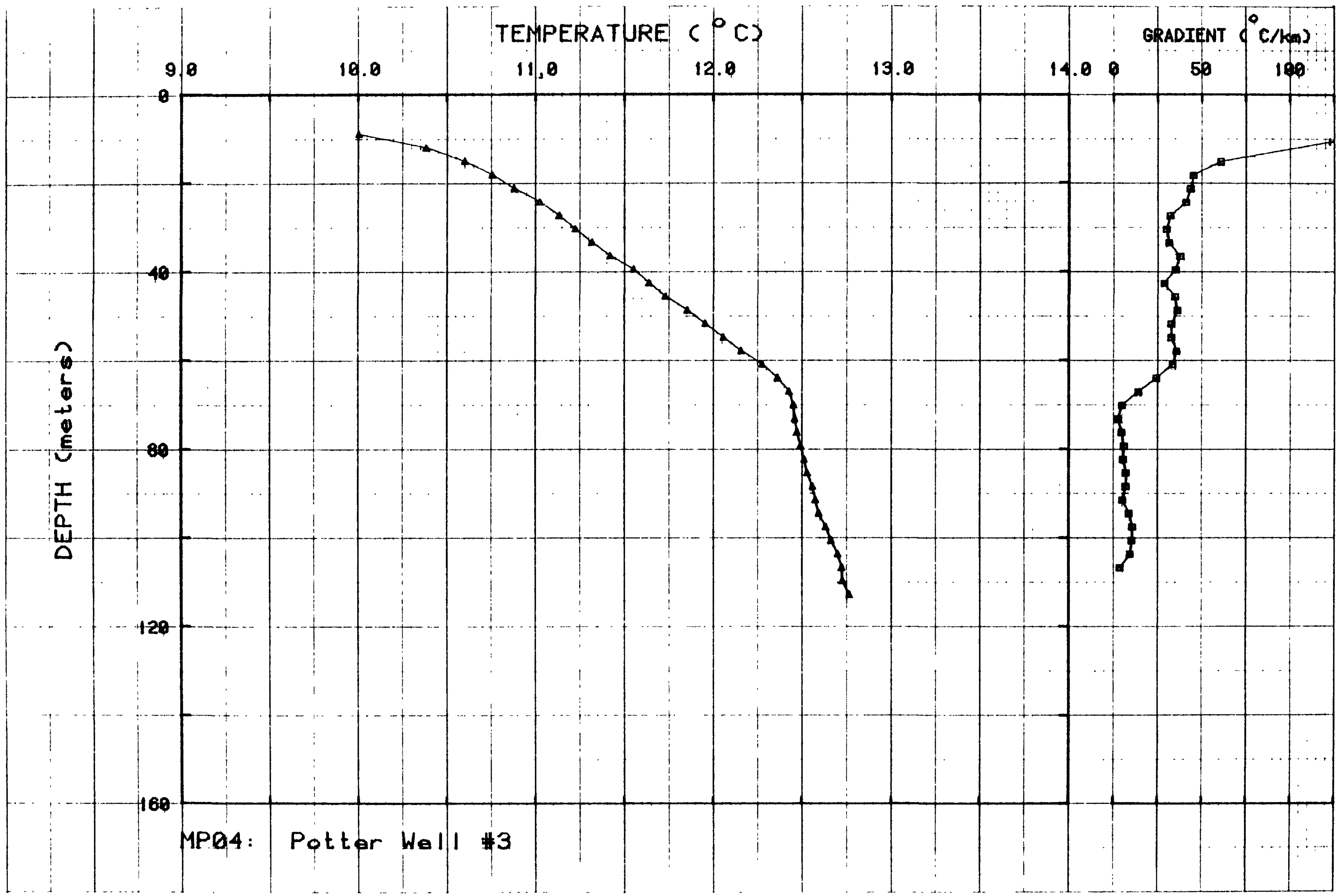

Figure II-4. Temperature and gradient profiles for MP04.

TABLE II-4. Temperature tabulation

Hole: MP04 POTTER WELL 3

Lat: 41-40.50 Long: 121- 9.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
9.14	10.009	12.19	10.389
15.24	10.607	18.29	10.762
21.34	10.886	24.38	11.031
27.43	11.139	30.48	11.231
33.53	11.325	36.58	11.426
39.62	11.558	42.67	11.643
45.72	11.736	48.77	11.859
51.82	11.960	54.86	12.062
57.91	12.163	60.96	12.283
64.01	12.370	67.06	12.434
70.10	12.460	73.15	12.467
76.20	12.479	79.25	12.499
82.30	12.519	85.34	12.536
88.39	12.566	91.44	12.582
94.49	12.601	97.54	12.640
100.58	12.670	103.63	12.707
106.68	12.730	109.73	12.733
112.78	12.771		

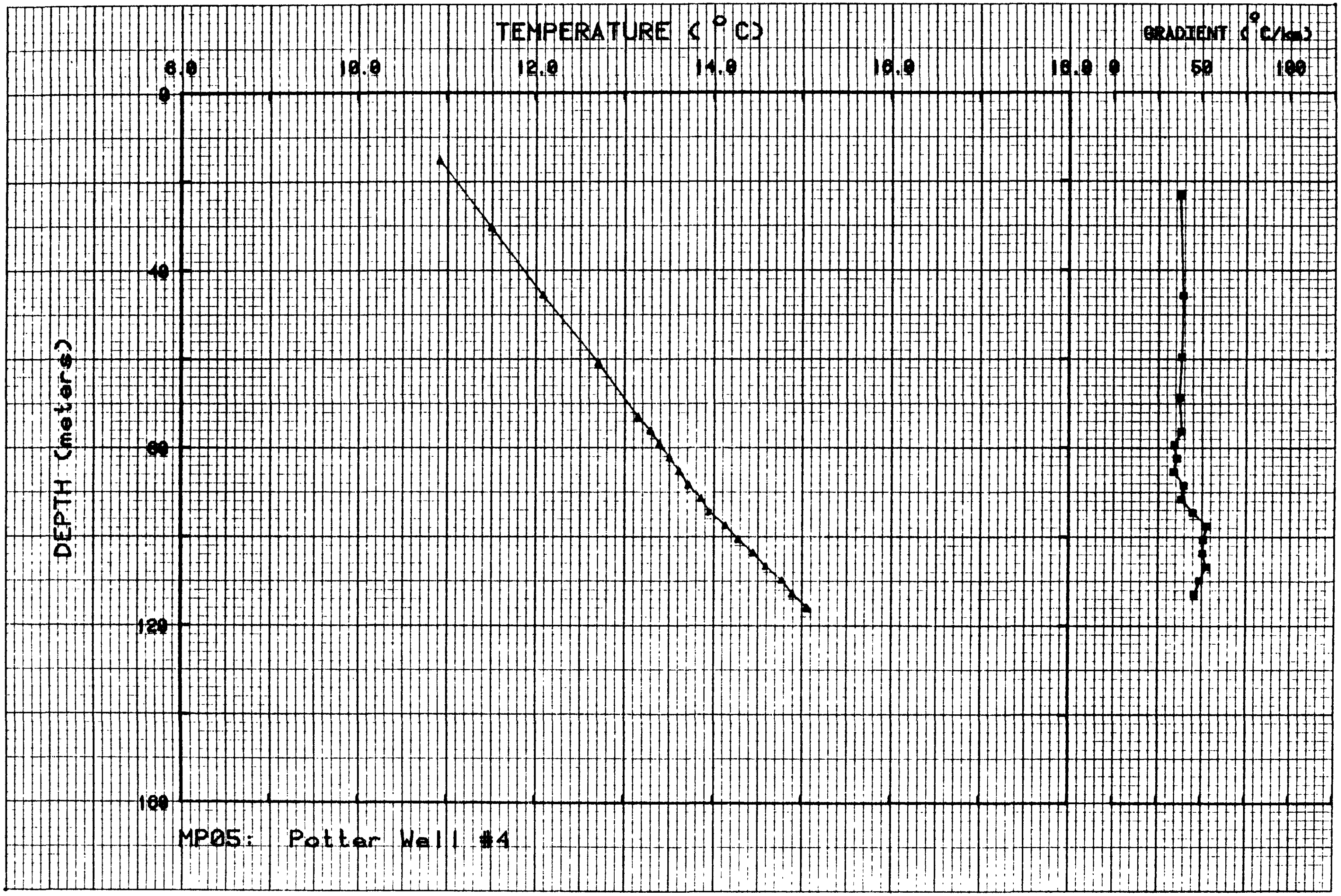

Figure II-5. Temperature and gradient profiles for MP05.

TABLE II-5. Temperature tabulation

Hole: MP05 POTTER WELL 4

Lat: 41-38.90 Long: 121-10.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	10.933	30.48	11.514
45.72	12.099	60.96	12.729
73.15	13.170	76.20	13.308
79.25	13.408	82.30	13.521
85.34	13.630	88.39	13.732
91.44	13.875	94.49	13.969
97.54	14.152	100.58	14.296
103.63	14.466	106.68	14.608
109.73	14.790	112.78	14.910
115.82	15.074	116.07	15.083

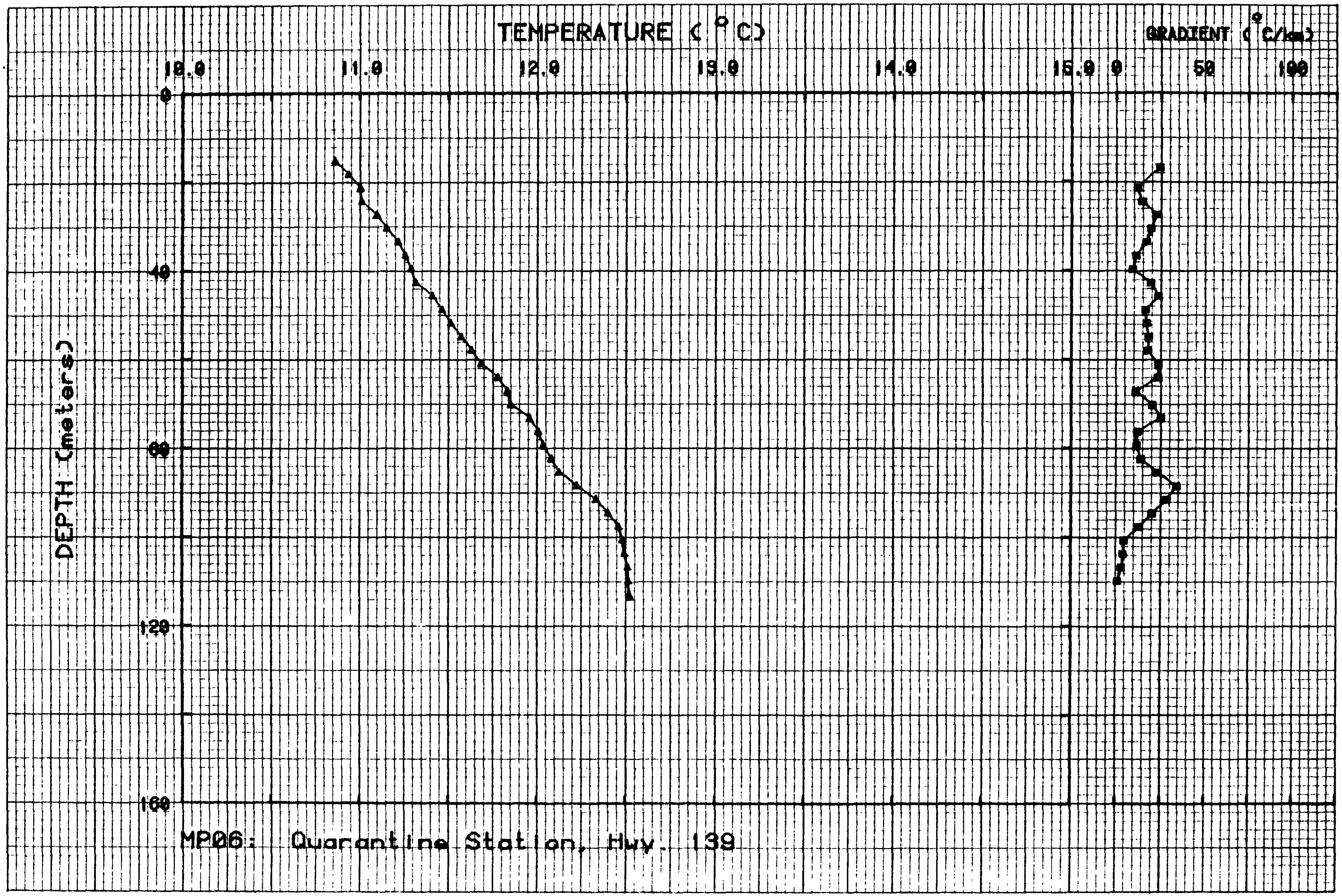

Figure II-6. Temperature and gradient profiles for MP06.

TABLE II-6. Temperature tabulation

Hole: MF06 QUARANTINE STA.

Lat: 41-36.70 Long: 121-12.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	10.866	18.29	10.942
21.34	11.011	24.38	11.018
27.43	11.103	30.48	11.159
33.53	11.225	36.58	11.265
39.62	11.297	42.67	11.324
45.72	11.419	48.77	11.472
51.82	11.522	54.86	11.580
57.91	11.637	60.96	11.691
64.01	11.785	67.06	11.838
70.10	11.857	73.15	11.966
76.20	12.014	79.25	12.042
82.30	12.088	85.34	12.131
88.39	12.232	91.44	12.341
94.49	12.408	97.54	12.468
100.58	12.489	103.63	12.500
106.68	12.518	109.73	12.523
112.78	12.528	113.39	12.531

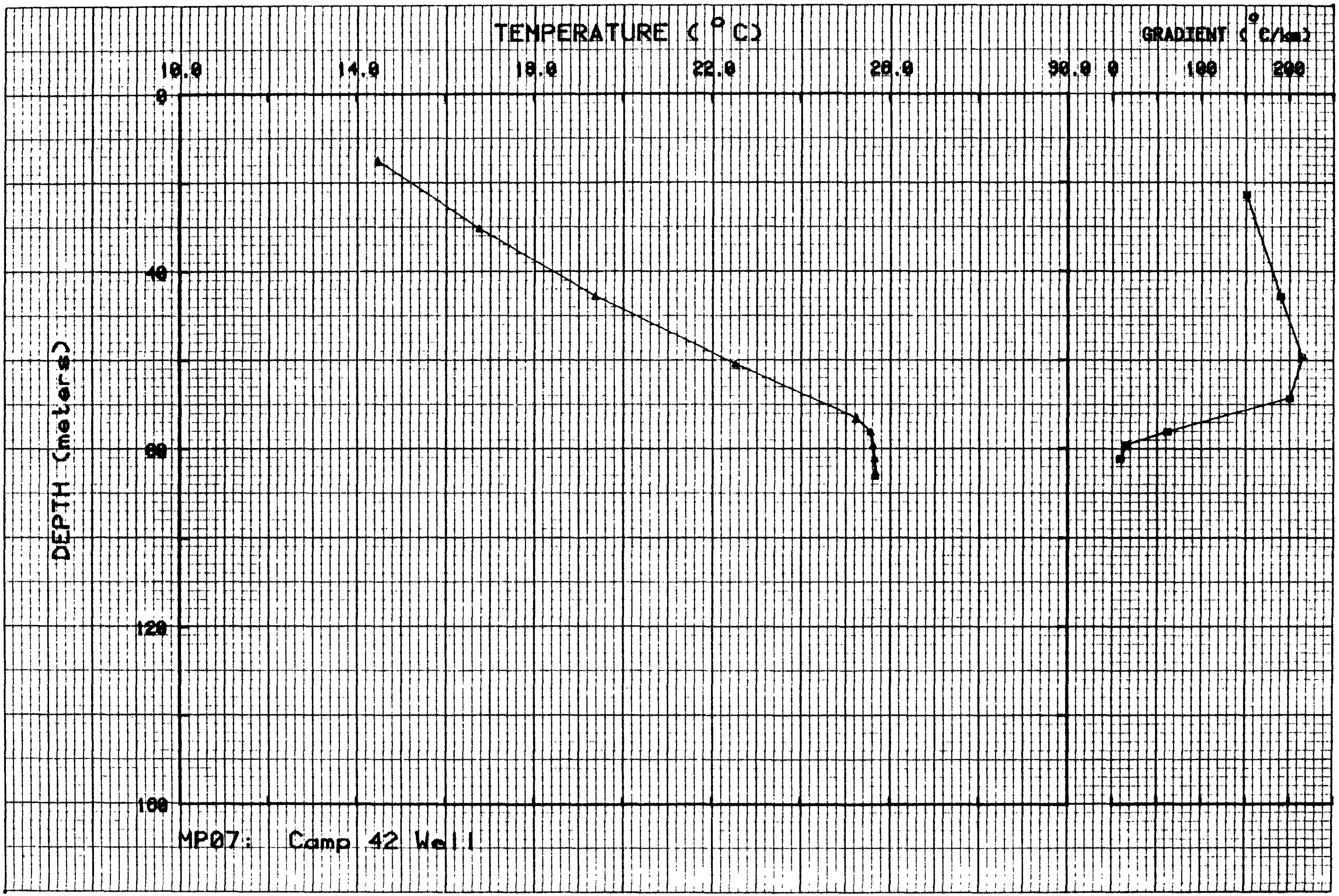

Figure II-7. Temperature and gradient profiles for MP07.

TABLE II-7. Temperature tabulation

Hole: MP07 CAMP 42 WELL

Lat: 41-42.20 Long: 121-20.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	14.475	30.48	16.755
45.72	19.381	60.96	22.515
73.15	25.232	76.20	25.551
79.25	25.605	82.30	25.640
85.34	25.655	86.17	25.647

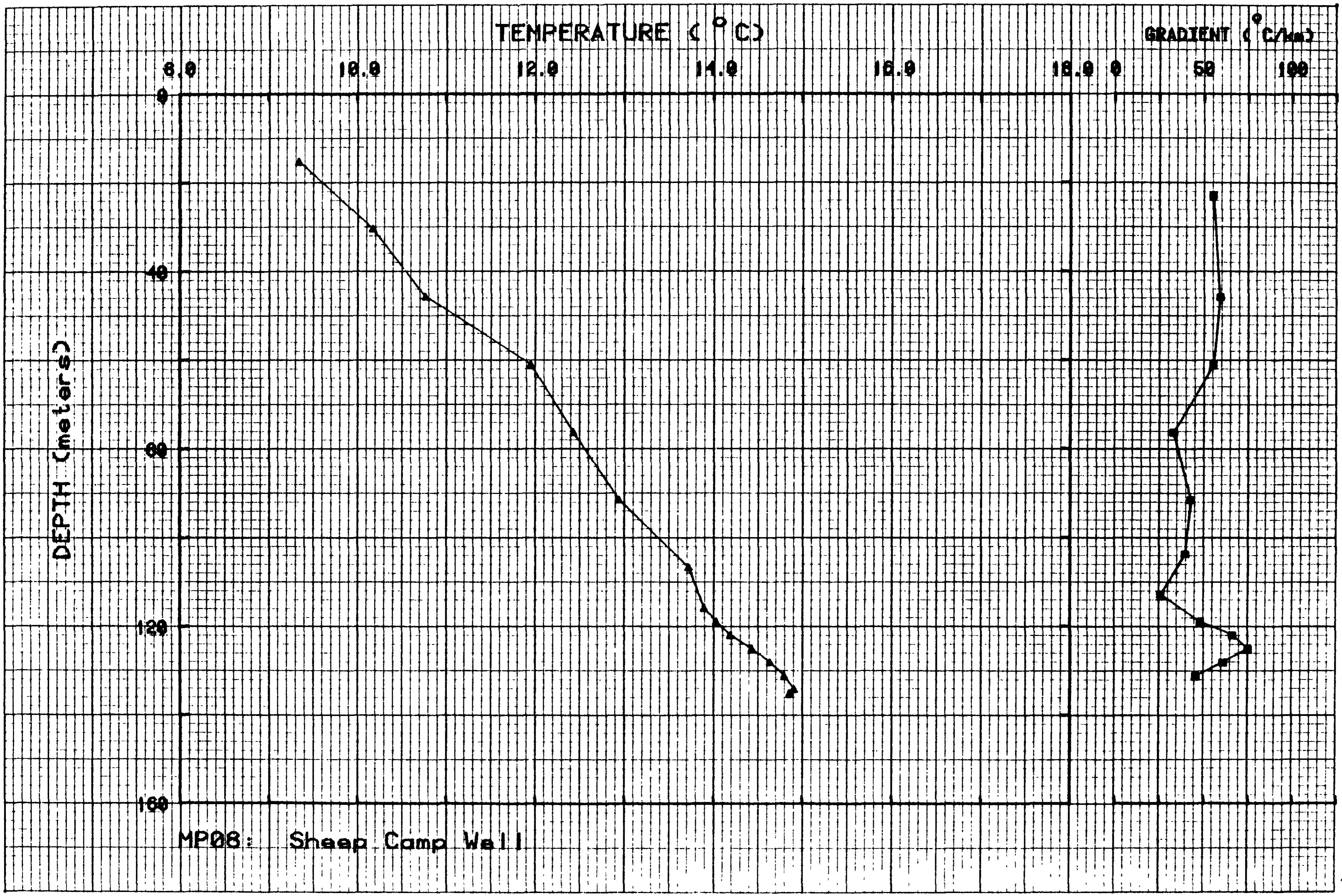

Figure II-8. Temperature and gradient profiles for MP08.

TABLE II-8. Temperature tabulation

Hole: MP08 SHEEP CAMP WELL

Lat: 41-34.20 Long: 121-21.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	9.338	30.48	10.171
45.72	10.763	60.96	11.947
76.20	12.429	91.44	12.936
106.68	13.713	115.82	13.886
118.87	14.023	121.92	14.176
124.97	14.423	128.02	14.629
131.06	14.790	134.11	14.903
135.06	14.849		

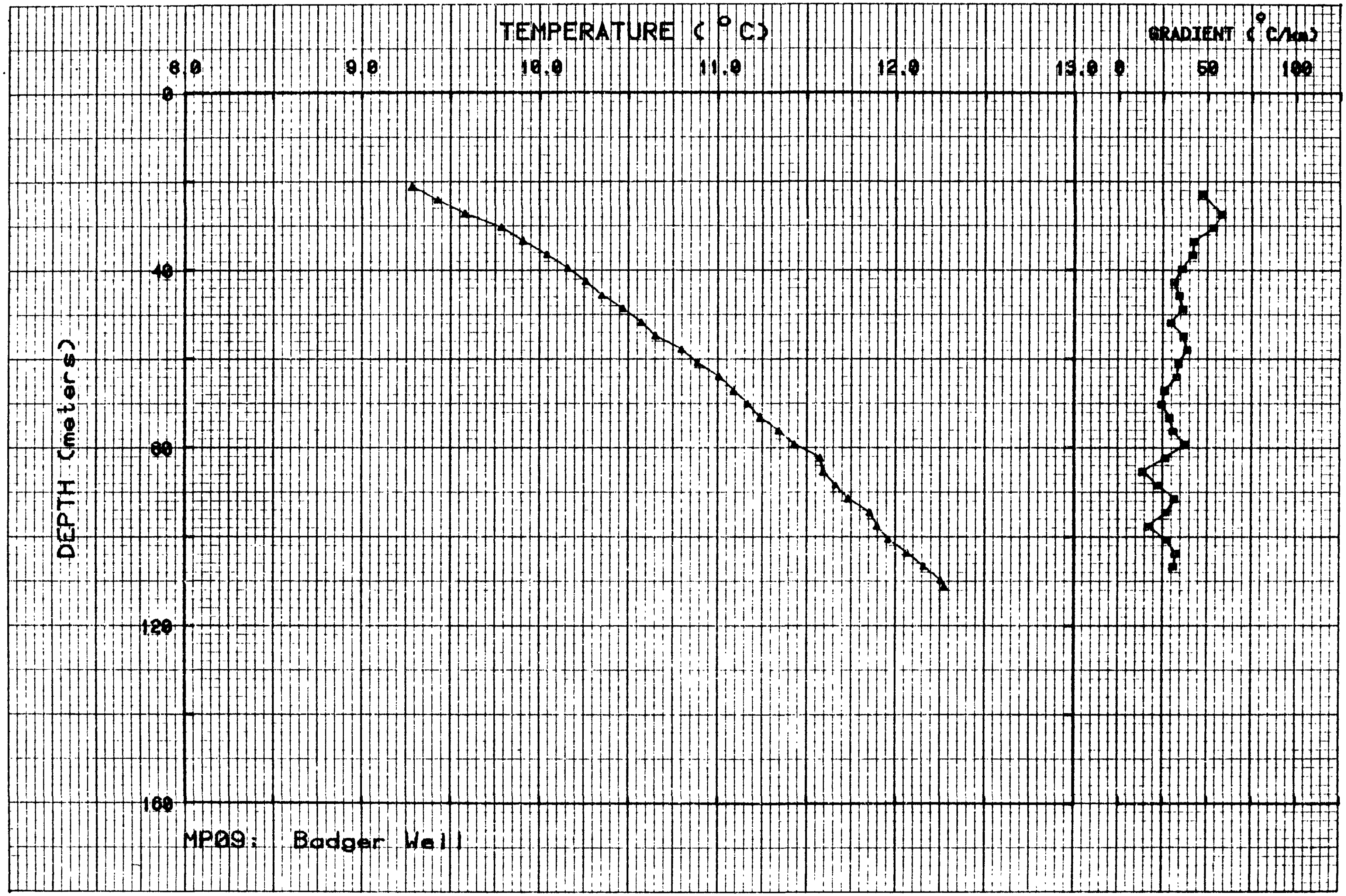

Figure II-9. Temperature and gradient profiles for MP09.

TABLE II-9. Temperature tabulation

Hole: MF09 BADGER WELL

Lat: 41-39.00 Long: 121- 3.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
21.34	9.290	24.38	9.434
27.43	9.585	30.48	9.788
33.53	9.910	36.58	10.046
39.62	10.164	42.67	10.265
45.72	10.357	48.77	10.475
51.82	10.579	54.86	10.656
57.91	10.803	60.96	10.892
64.01	11.011	67.06	11.093
70.10	11.172	73.15	11.244
76.20	11.349	79.25	11.434
82.30	11.579	85.34	11.597
88.39	11.665	91.44	11.737
94.49	11.859	97.54	11.902
100.58	11.964	103.63	12.069
106.68	12.163	109.73	12.259
111.25	12.279		

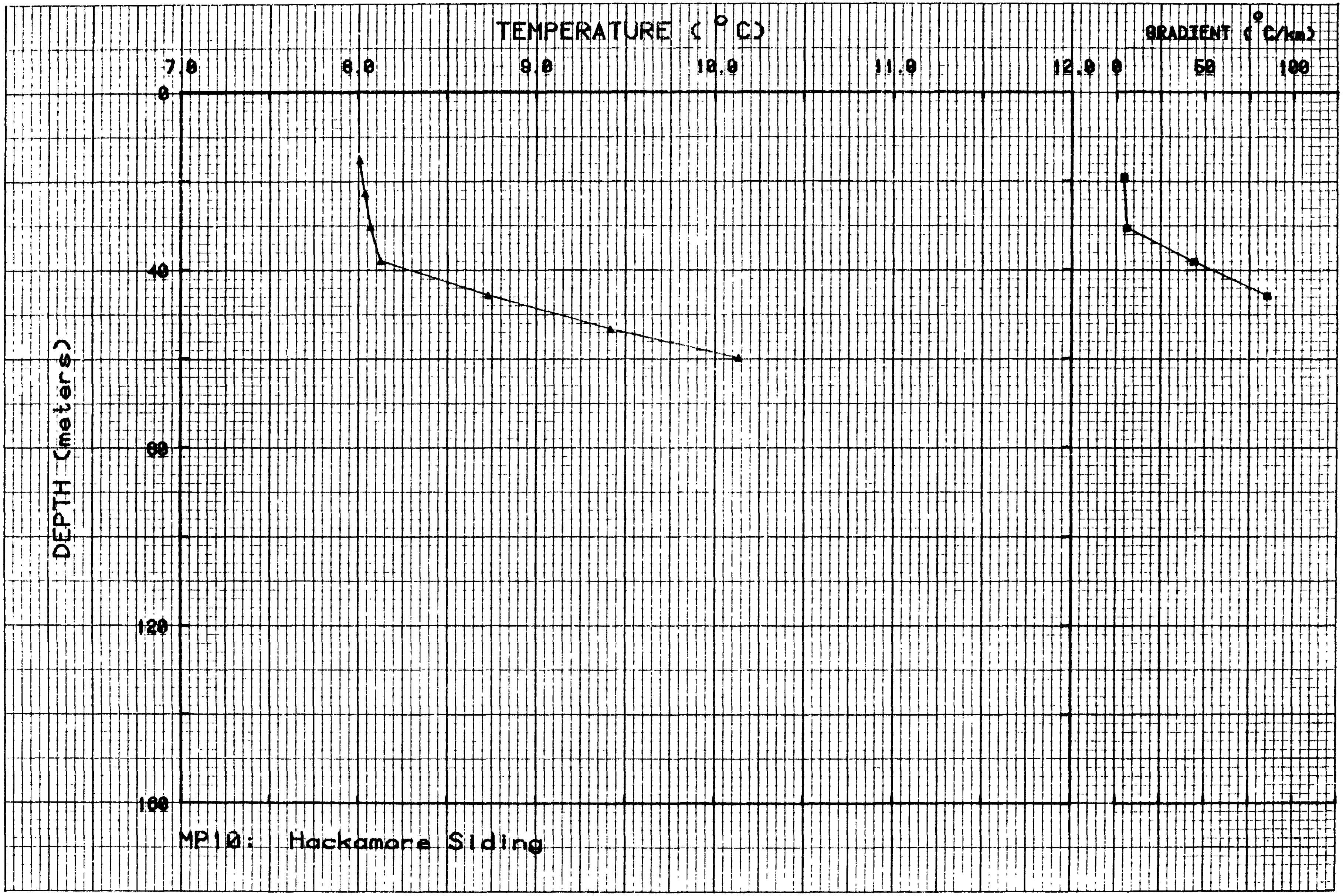

Figure II-10. Temperature and gradient profiles for MP10.

TABLE II-10. Temperature tabulation

Hole: MP10 HACKAMORE SIDING

Lat: 41-33.30 Long: 121- 7.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	8.005	22.86	8.037
30.48	8.069	38.10	8.125
45.72	8.728	53.34	9.414
59.74	10.131		

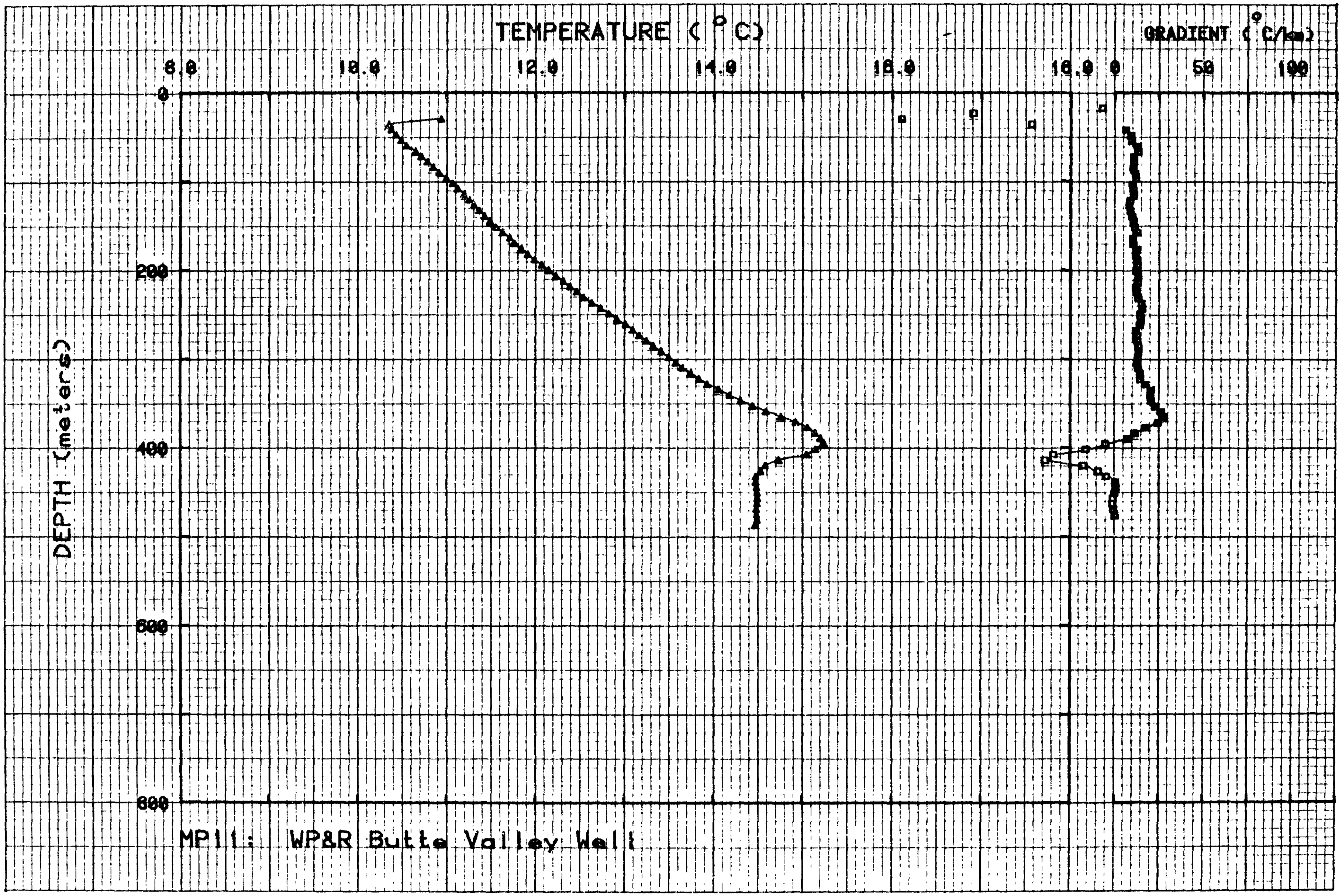

Figure II-11. Temperature and gradient profiles for MP11.

TABLE II-11. Temperature tabulation

Hole: MF11 BUTTE VALLEY

Lat: 41-48.50 Long: 122- 0.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
12.19	11.899	18.29	11.915
24.38	11.820	30.48	10.952
36.58	10.364	42.67	10.388
48.77	10.443	54.86	10.504
60.96	10.566	67.06	10.665
73.15	10.730	79.25	10.799
85.34	10.864	91.44	10.931
97.54	11.010	103.63	11.080
109.73	11.135	115.82	11.210
121.92	11.268	128.02	11.319
134.11	11.373	140.21	11.433
146.30	11.498	152.40	11.568
158.50	11.642	164.59	11.723
170.69	11.771	176.78	11.854
182.88	11.925	188.98	12.003
195.07	12.083	201.17	12.161
207.26	12.240	213.36	12.327
219.46	12.403	225.55	12.480
231.65	12.559	237.74	12.649
243.84	12.749	249.94	12.844
256.03	12.929	262.13	13.026
268.22	13.106	274.32	13.176
280.42	13.260	286.51	13.337
292.61	13.427	298.70	13.506
304.80	13.588	310.90	13.665
316.99	13.756	323.09	13.845
329.18	13.937	335.28	14.065
341.38	14.189	347.47	14.314
353.57	14.446	359.66	14.598
365.76	14.769	371.86	14.935
377.95	15.070	384.05	15.156
390.14	15.214	396.24	15.252
402.34	15.156	408.43	15.059
414.53	14.744	420.62	14.588
426.72	14.535	432.82	14.482
438.91	14.484	445.01	14.494
451.10	14.500	457.20	14.500
463.30	14.494	469.39	14.492
475.49	14.494	481.58	14.500
487.68	14.475		

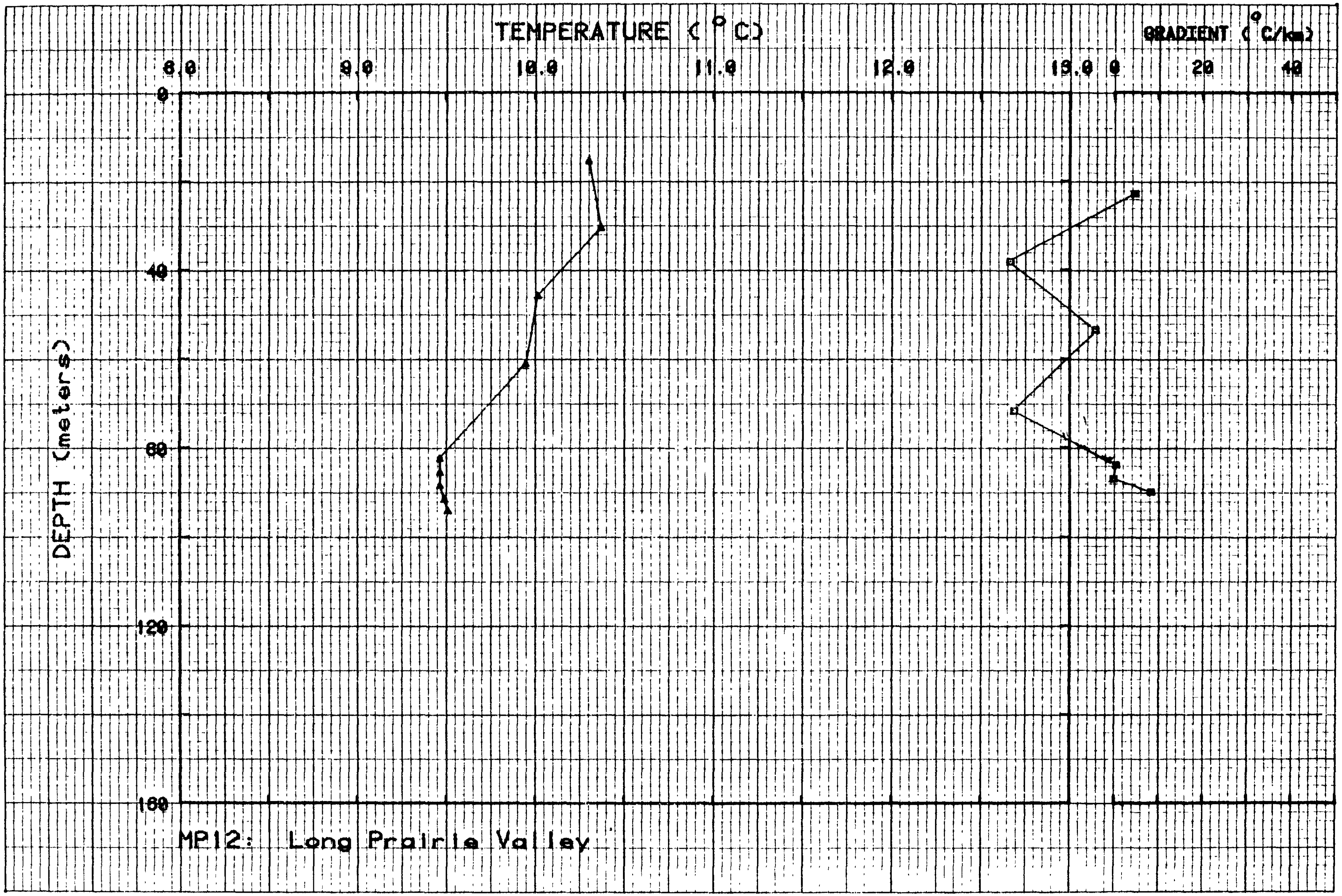

Figure II-12. Temperature and gradient profiles for MP12.

TABLE II-12. Temperature tabulation

Hole: MP12 LONG PRAIRIE VALLEY I.

Lat: 41-40.90 Long: 121-48.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	10.303	30.48	10.371
45.72	10.014	60.96	9.947
82.30	9.466	85.34	9.467
88.39	9.466	91.44	9.491
94.12	9.510		

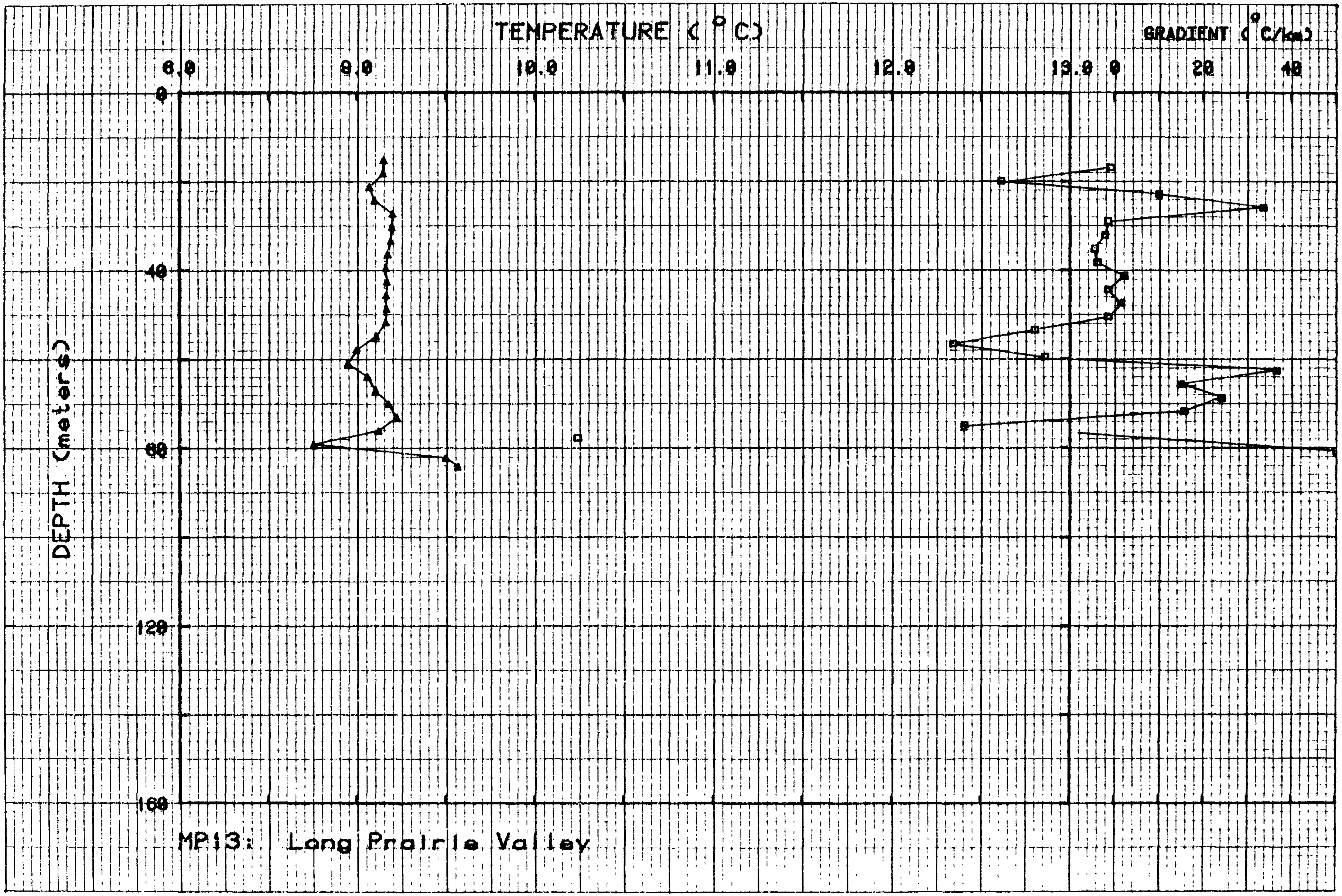

Figure II-13. Temperature and gradient profiles for MP13.

TABLE II-13. Temperature tabulation

Hole: MP13 LONG PRAIRIE VALLEY W.

Lat: 41-41.00 Long: 121-48.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	9.149	18.29	9.146
21.34	9.068	24.38	9.098
27.43	9.200	30.48	9.195
33.53	9.188	36.58	9.174
39.62	9.162	42.67	9.168
45.72	9.163	48.77	9.167
51.82	9.162	54.86	9.107
57.91	8.996	60.96	8.948
64.01	9.059	67.06	9.104
70.10	9.177	73.15	9.224
76.20	9.121	79.25	8.754
82.30	9.497	84.16	9.566

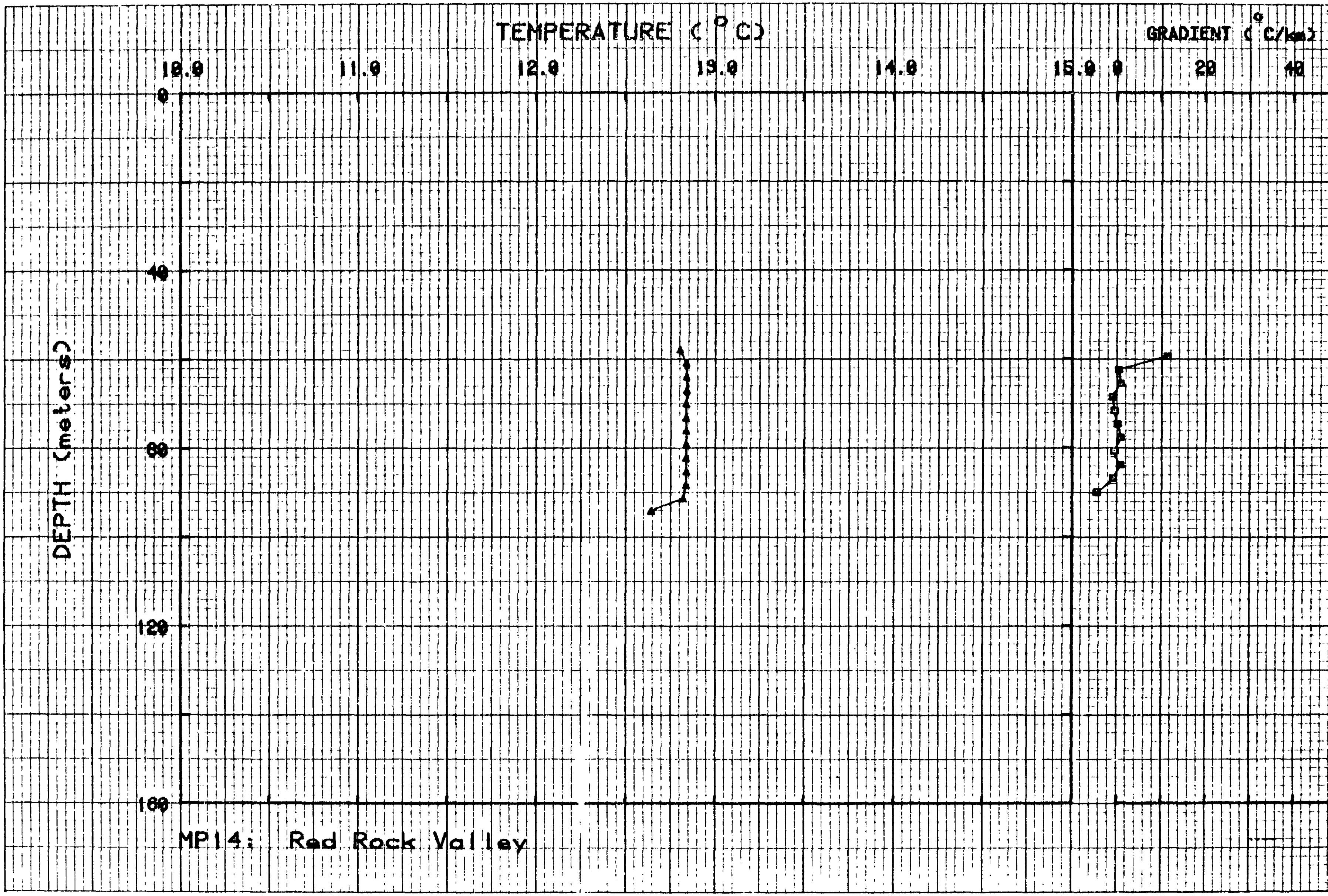

Figure II-14. Temperature and gradient profiles for MP14.

TABLE II-14. Temperature tabulation

Hole: MP14 RED ROCK VALLEY

Lat: 41-46.00 Long: 121-47.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
57.91	12.801	60.96	12.835
64.01	12.836	67.06	12.838
70.10	12.835	73.15	12.833
76.20	12.833	79.25	12.835
82.30	12.833	85.34	12.835
88.39	12.832	91.44	12.818
94.24	12.641		

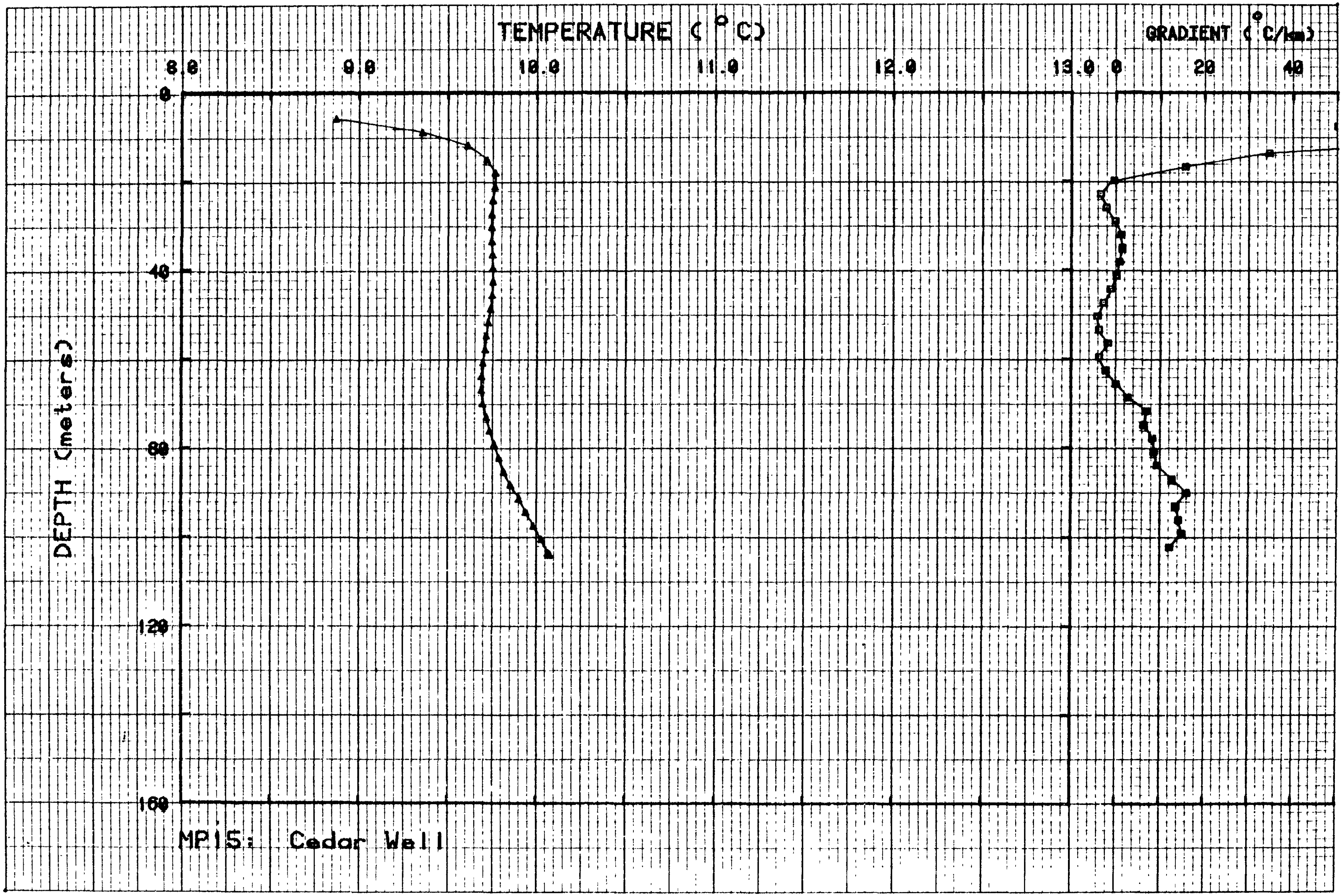

Figure II-15. Temperature and gradient profiles for MP15.

TABLE II-15. Temperature tabulation

Hole: MP15 CEDAR WELL

Lat: 41-41.60 Long: 121-52.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	8.867	9.14	9.354
12.19	9.608	15.24	9.713
18.29	9.760	21.34	9.758
24.38	9.747	27.43	9.740
30.48	9.739	33.53	9.742
36.58	9.746	39.62	9.748
42.67	9.748	45.72	9.744
48.77	9.735	51.82	9.722
54.86	9.710	57.91	9.704
60.96	9.692	64.01	9.685
67.06	9.685	70.10	9.693
73.15	9.714	76.20	9.733
79.25	9.758	82.30	9.784
85.34	9.812	88.39	9.850
91.44	9.898	94.49	9.939
97.54	9.982	100.58	10.027
103.63	10.064	104.00	10.074

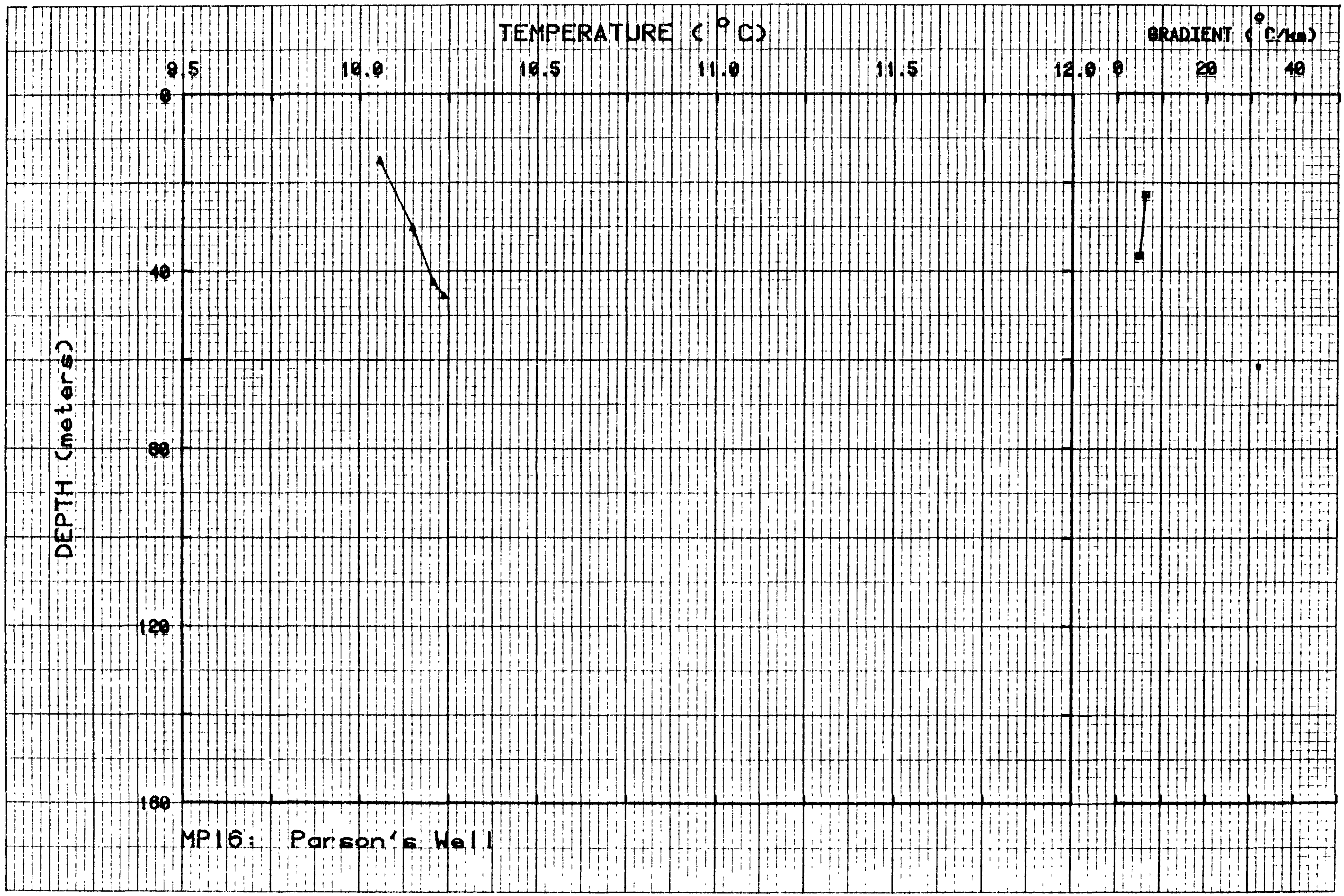

Figure II-16. Temperature and gradient profiles for MP16.

TABLE II-16. Temperature tabulation

Hole: MP16 PARSON'S WELL

Lat: 41-44.20 Long: 121-52.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	10.054	30.48	10.148
42.67	10.207	45.72	10.236

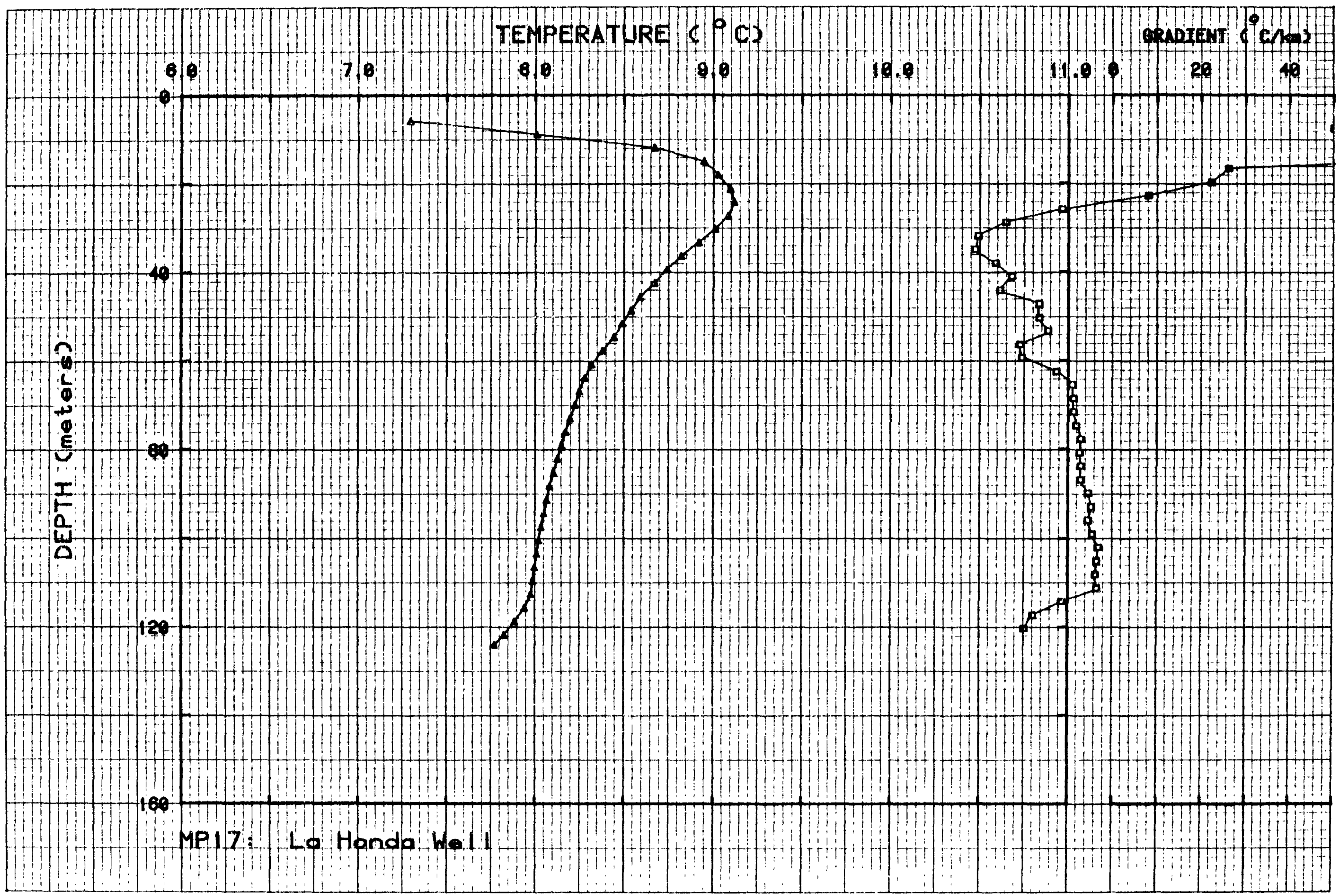

Figure II-17. Temperature and gradient profiles for MP17.

TABLE II-17. Temperature tabulation

Hole: MP17 LA HONDA WELL

Lat: 41-38.40 Long: 121-51.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	7.292	9.14	8.005
12.19	8.668	15.24	8.945
18.29	9.024	21.34	9.091
24.38	9.115	27.43	9.080
30.48	9.006	33.53	8.913
36.58	8.818	39.62	8.737
42.67	8.667	45.72	8.589
48.77	8.538	51.82	8.487
54.86	8.442	57.91	8.378
60.96	8.315	64.01	8.276
67.06	8.248	70.10	8.221
73.15	8.194	76.20	8.169
79.25	8.147	82.30	8.124
85.34	8.102	88.39	8.080
91.44	8.063	94.49	8.048
97.54	8.031	100.58	8.017
103.63	8.007	106.68	7.996
109.73	7.984	112.78	7.973
115.82	7.938	118.87	7.883
121.92	7.822	124.18	7.768

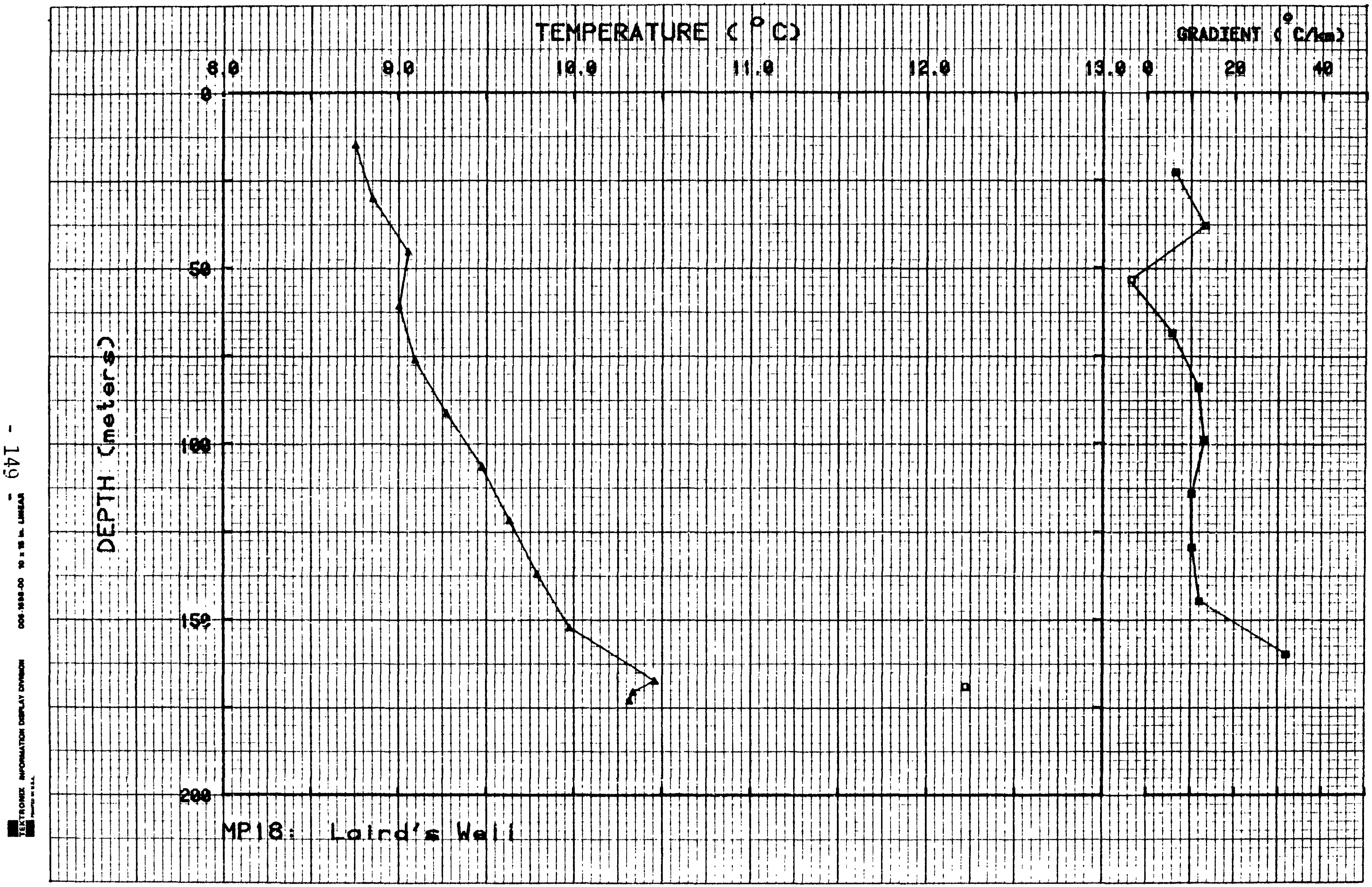

Figure II-18. Temperature and gradient profiles for MP18.

TABLE II-18. Temperature tabulation

Hole: MF18 LAIRD'S WELL

Lat: 41-43.80 Long: 121-40.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	8.759	30.48	8.859
45.72	9.062	60.96	9.011
76.20	9.100	91.44	9.280
106.68	9.480	121.92	9.637
137.16	9.795	152.40	9.980
167.64	10.466	170.69	10.341
173.16	10.320		

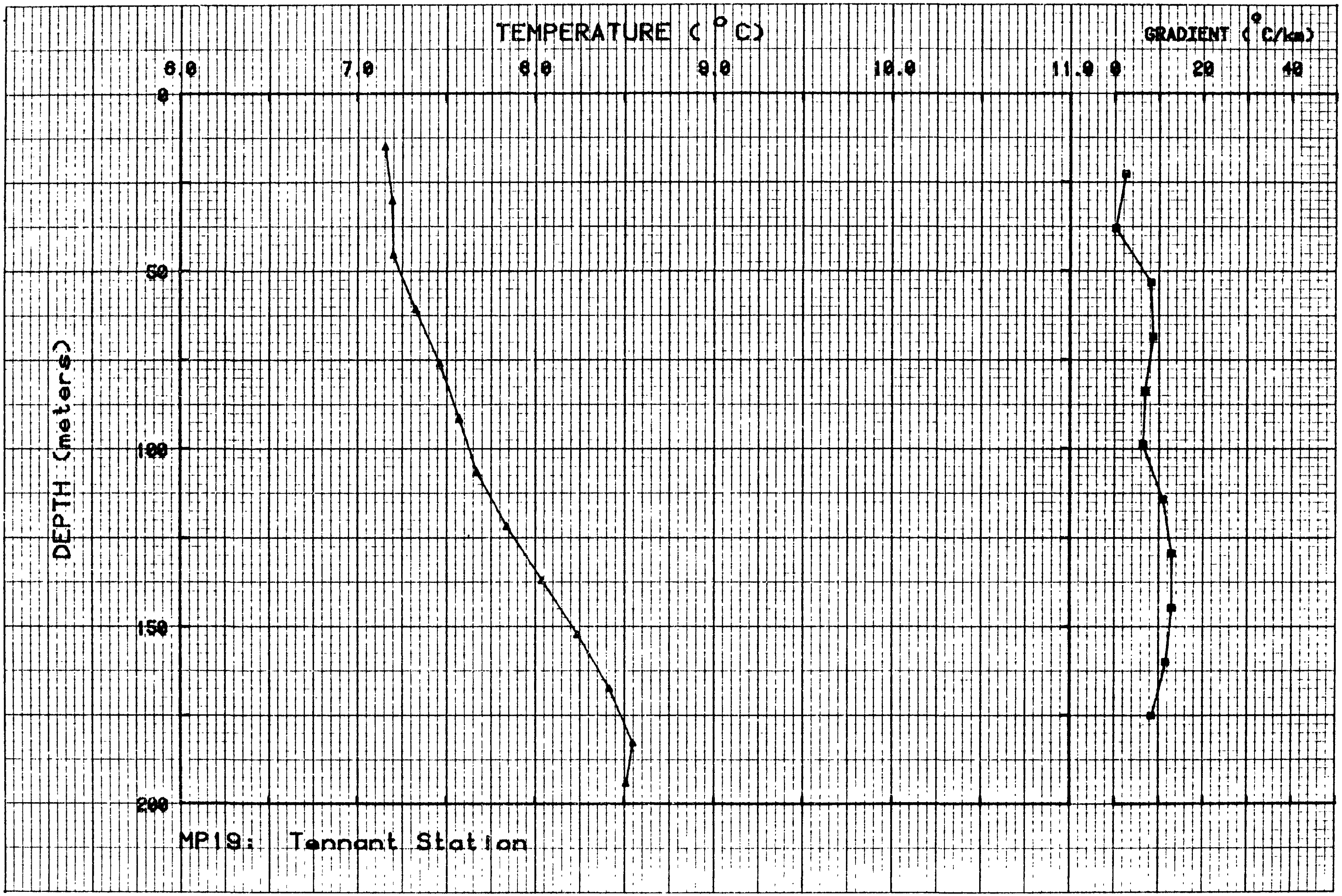

Figure II-19. Temperature and gradient profiles for MP19.

TABLE II-19. Temperature tabulation

Hole: MP19 TENNANT STA.

Lat: 41-35.40 Long: 121-57.30

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	7.161	30.48	7.201
45.72	7.207	60.96	7.335
76.20	7.470	91.44	7.577
106.68	7.677	121.92	7.845
137.16	8.044	152.40	8.244
167.64	8.423	182.88	8.553
194.16	8.514		

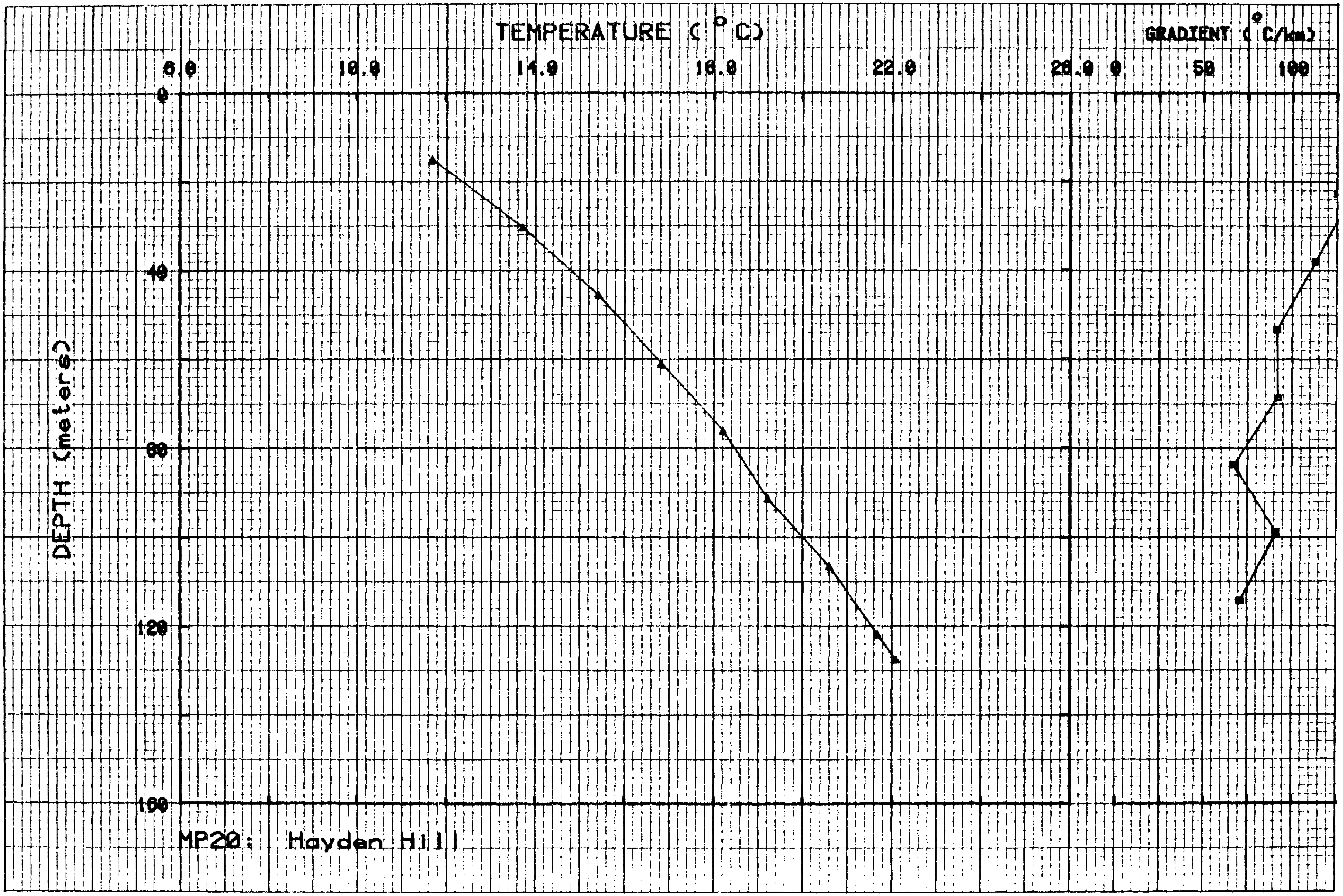

Figure II-20. Temperature and gradient profiles for MP20.

TABLE II-20. Temperature tabulation

Hole: MP20 HAYDEN HILL

Lat: 40-59.80 Long: 120-53.20

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	11.684	30.48	13.706
45.72	15.420	60.96	16.805
76.20	18.196	91.44	19.213
106.68	20.594	121.92	21.668
127.71	22.088		

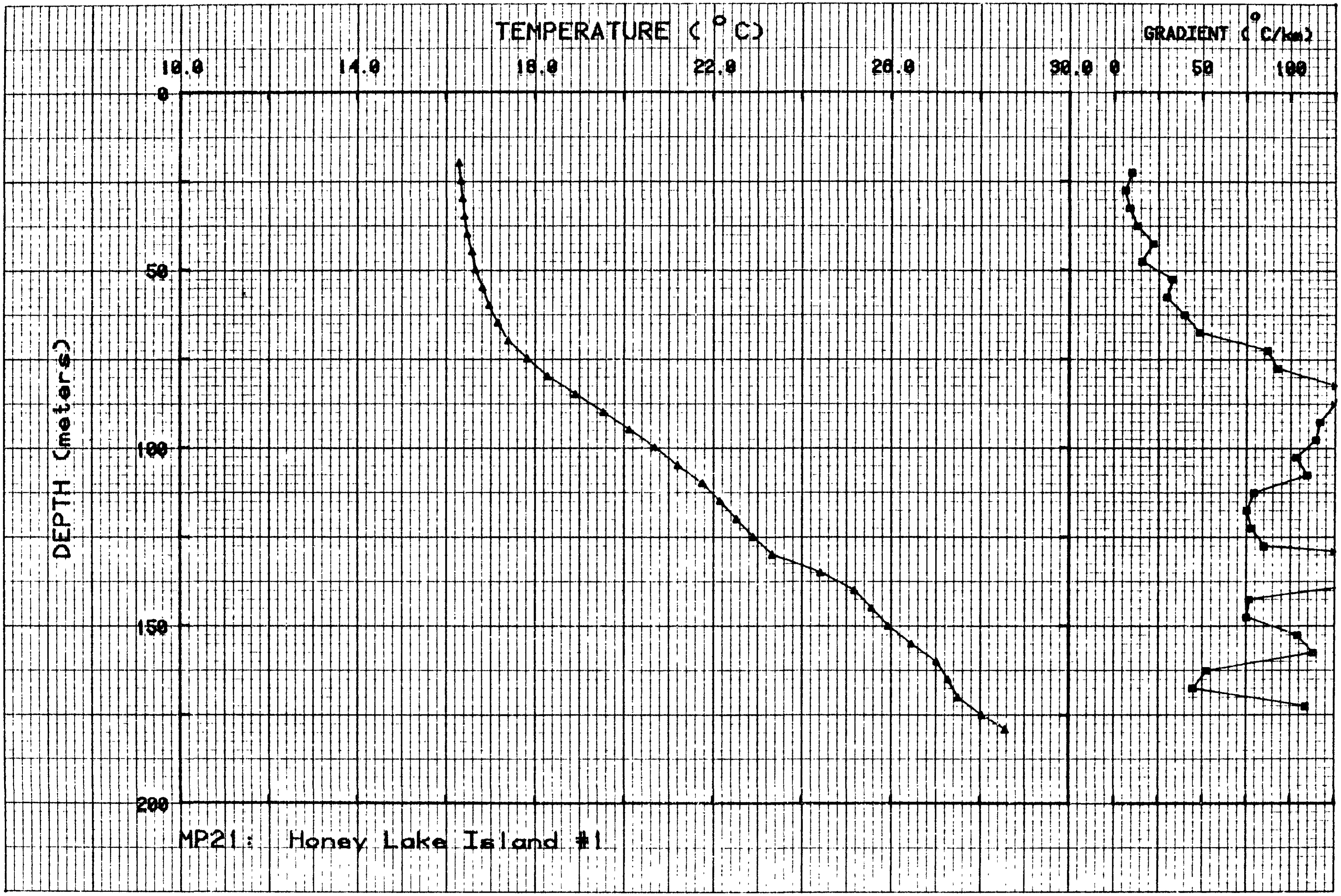

Figure II-21. Temperature and gradient profiles for MP21.

TABLE II-21. Temperature tabulation

Hole: MP21 HONEY LAKE ISLAND

Lat: 40-12.30 Long: 120-14.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
20.00	16.276	25.00	16.325
30.00	16.356	35.00	16.398
40.00	16.462	45.00	16.570
50.00	16.646	55.00	16.809
60.00	16.955	65.00	17.151
70.00	17.390	75.00	17.822
80.00	18.282	85.00	18.912
90.00	19.535	95.00	20.116
100.00	20.685	105.00	21.200
110.00	21.745	115.00	22.139
120.00	22.513	125.00	22.901
130.00	23.324	135.00	24.414
140.00	25.171	145.00	25.553
150.00	25.927	155.00	26.446
160.00	27.010	165.00	27.270
170.00	27.492	175.00	28.034
179.00	28.558		

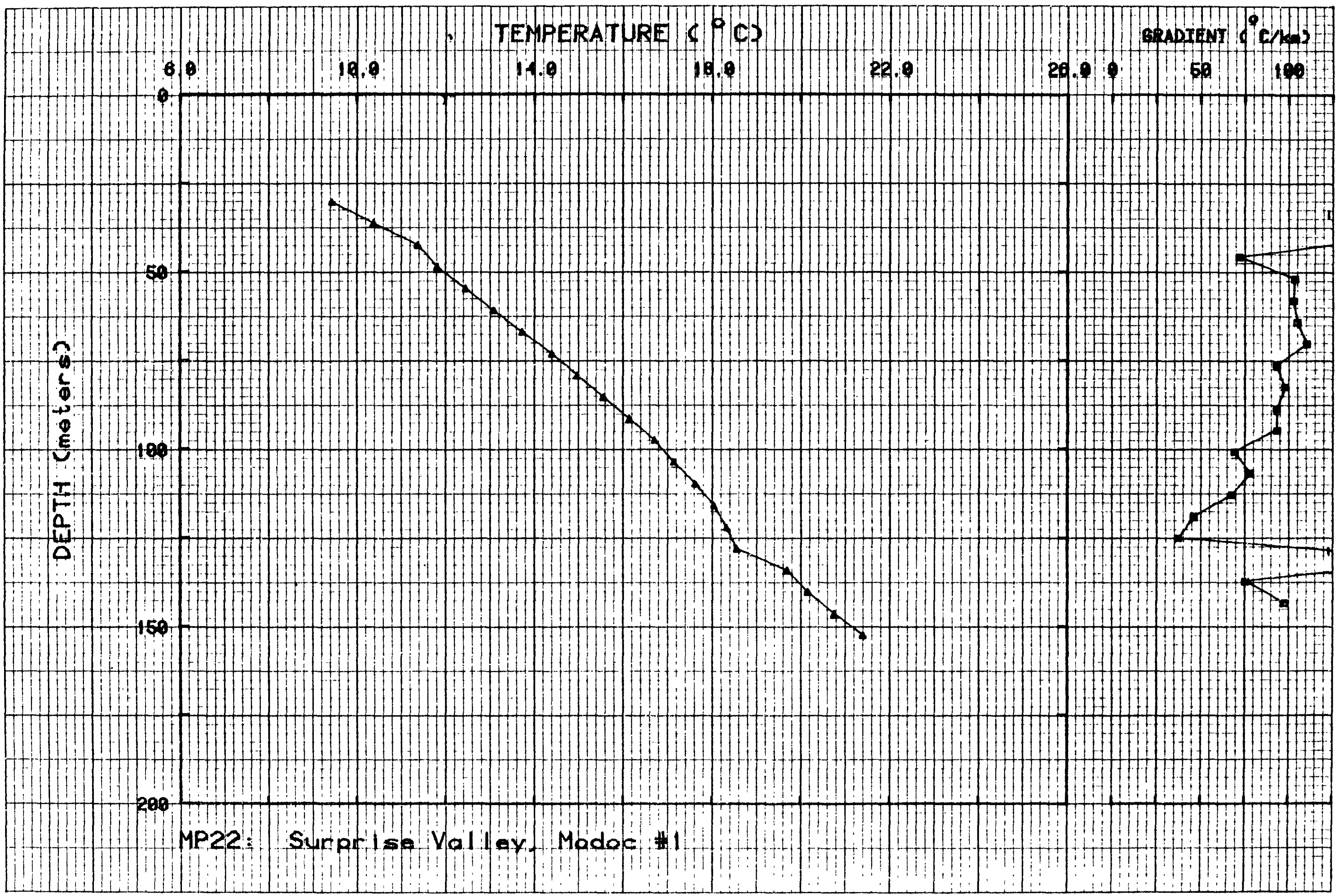

Figure II-22. Temperature and gradient profiles for MP22.

TABLE II-22. Temperature tabulation

Hole: MF22 MODOC #1, SURPRISE VAL.

Lat: 41-28.20 Long: 120-10.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
30.48	9.462	36.58	10.409
42.67	11.409	48.77	11.850
54.86	12.484	60.96	13.113
67.06	13.756	73.15	14.432
79.25	15.002	85.34	15.603
91.44	16.174	97.54	16.746
103.63	17.171	109.73	17.650
115.82	18.066	121.92	18.350
128.02	18.579	134.11	19.725
140.21	20.188	146.30	20.786
152.40	21.427		

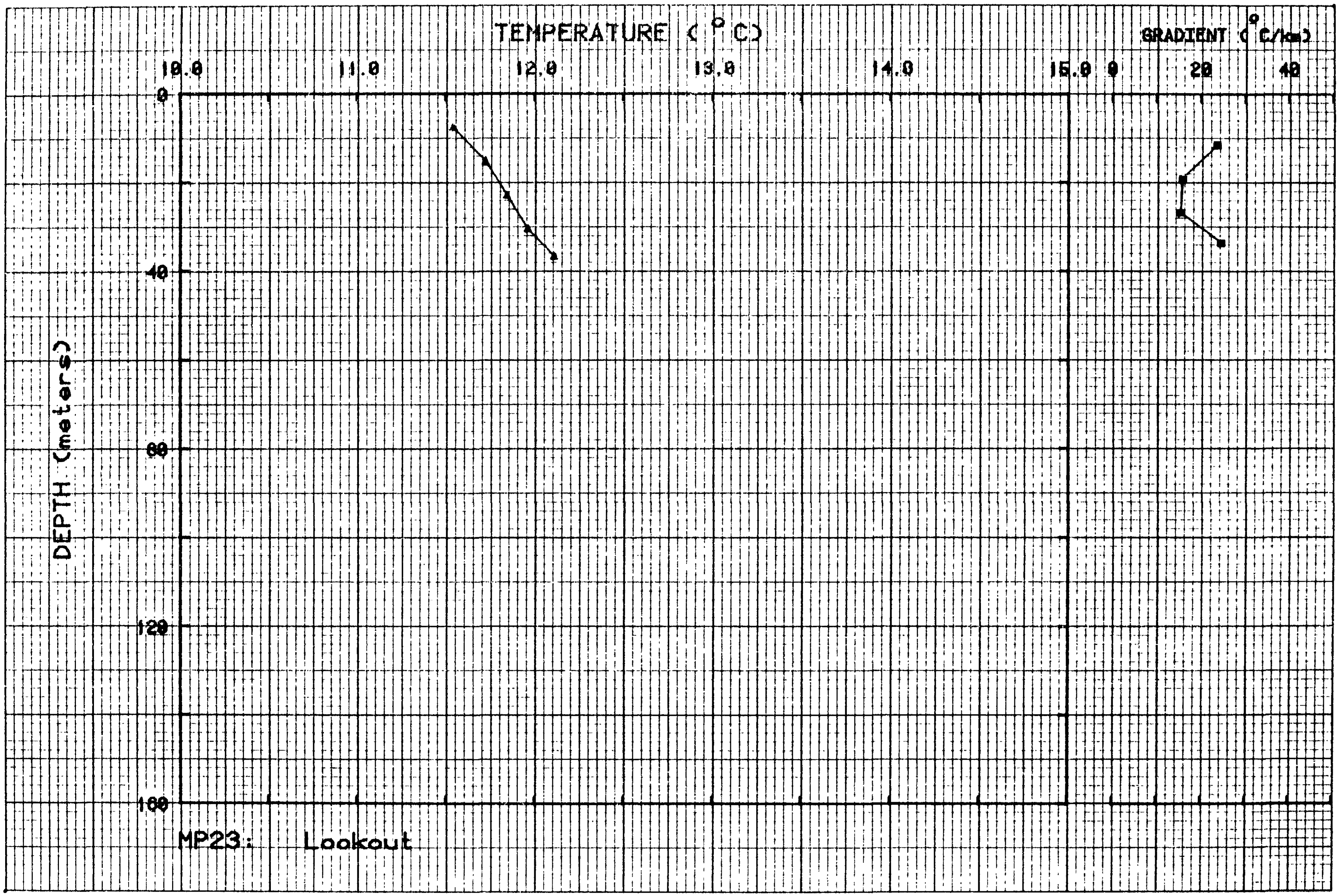

Figure II-23. Temperature and gradient profiles for MP23.

TABLE II-23. Temperature tabulation

Hole: MF23 LOOKOUT 1

Lat: 41-12.00 Long: 121- 8.20

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
7.62	11.548	15.24	11.729
22.86	11.850	30.48	11.968
36.58	12.118		

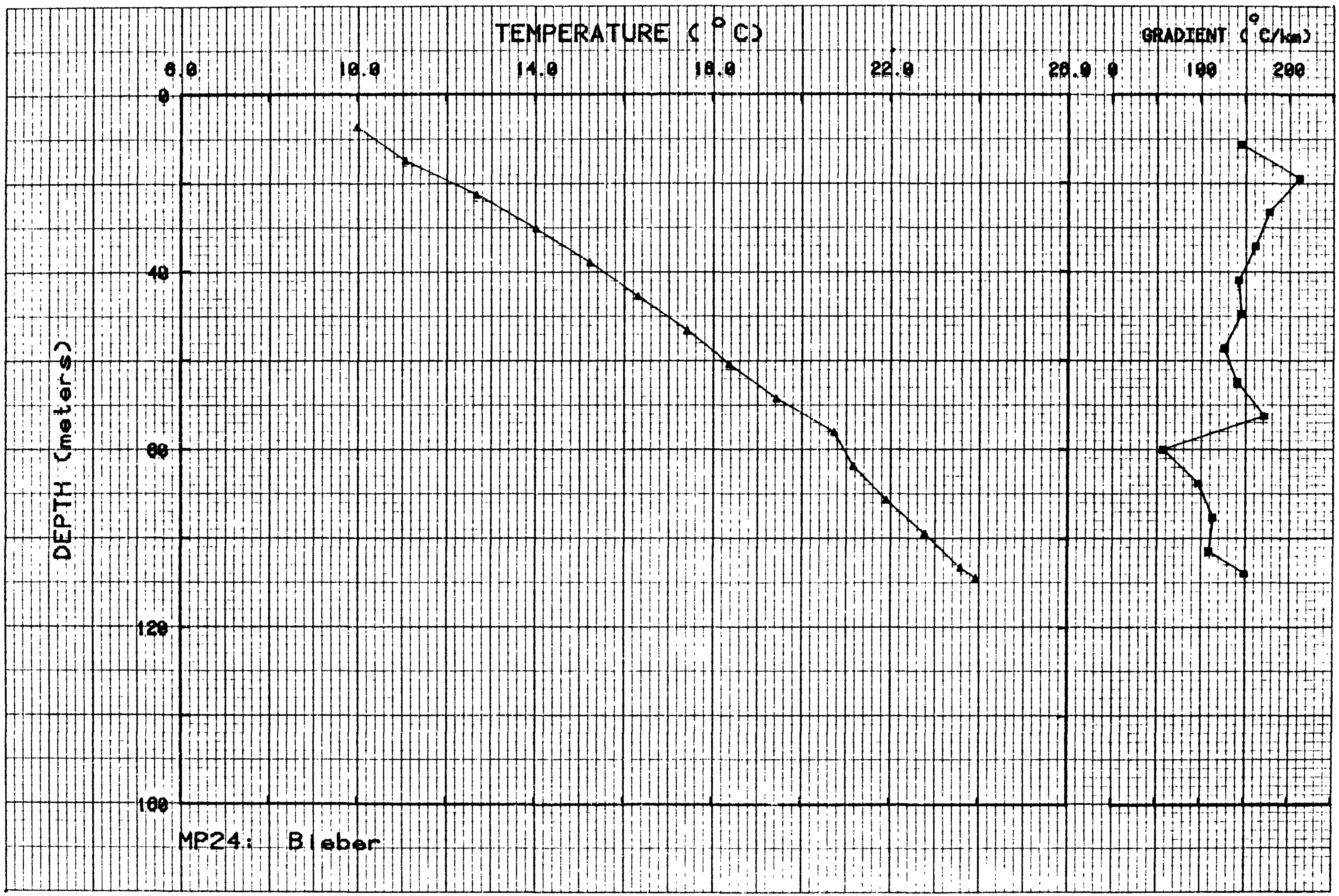

Figure II-24. Temperature and gradient profiles for MP24.

TABLE II-24. Temperature tabulation

Hole: MP24 BIEBER 1

Lat: 41- 8.90 Long: 121- 3.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
7.62	9.967	15.24	11.066
22.86	12.673	30.48	14.015
38.10	15.236	45.72	16.312
53.34	17.411	60.96	18.364
68.58	19.431	76.20	20.732
83.82	21.163	91.44	21.900
99.06	22.759	106.68	23.586
109.00	23.930		

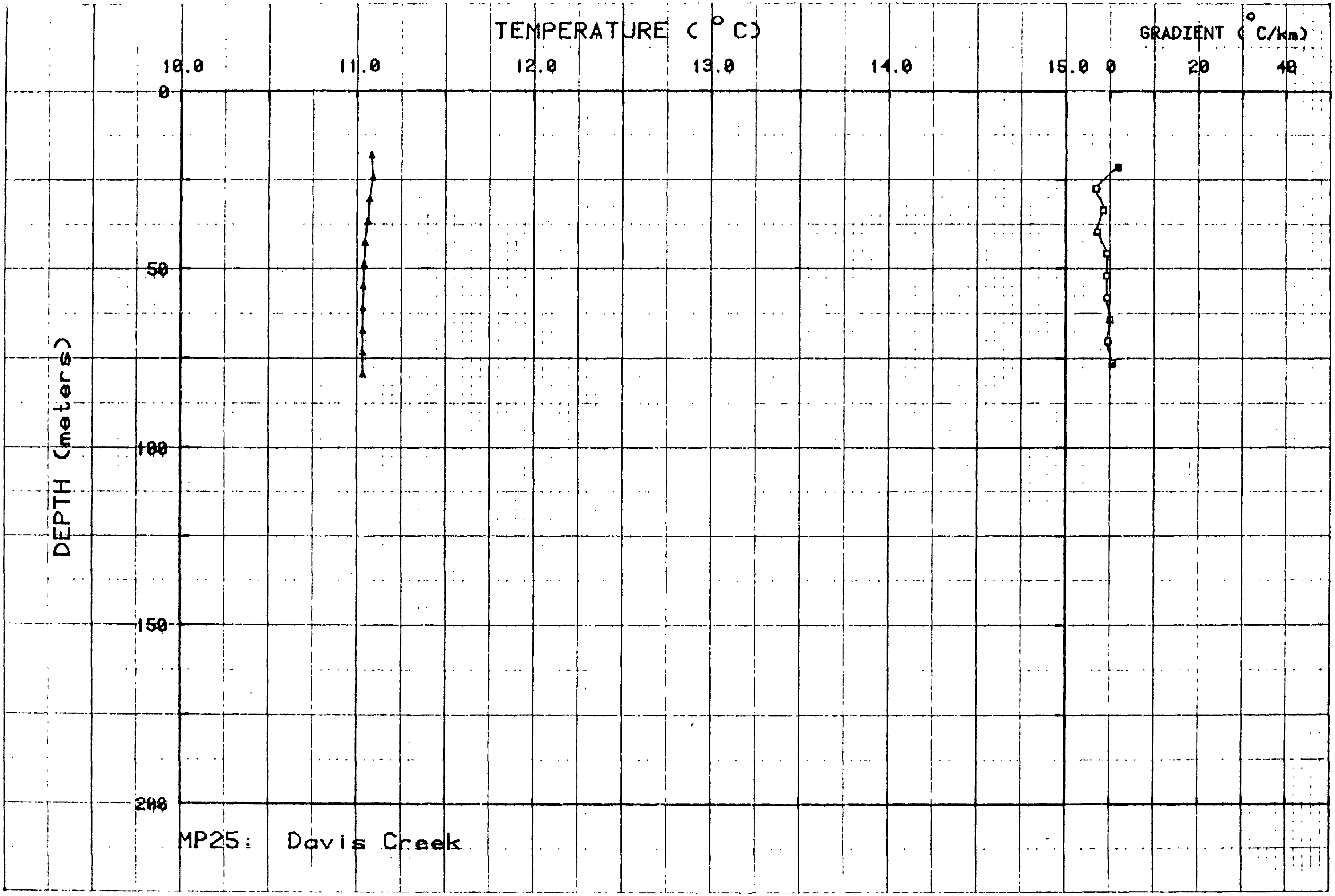

Figure II-25. Temperature and gradient profiles for MP25.

TEKTRONIX INFORMATION DISPLAY DIVISION 004 1698 00 10 x 15 in LINEAR

TABLE II-25. Temperature tabulation

Hole: MP25 DAVIS CREEK

Lat: 41-44.00 Long: 120-22.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
18.29	11.083	24.38	11.094
30.48	11.075	36.58	11.066
42.67	11.049	48.77	11.045
54.86	11.041	60.96	11.037
67.06	11.037	73.15	11.034
79.25	11.038		

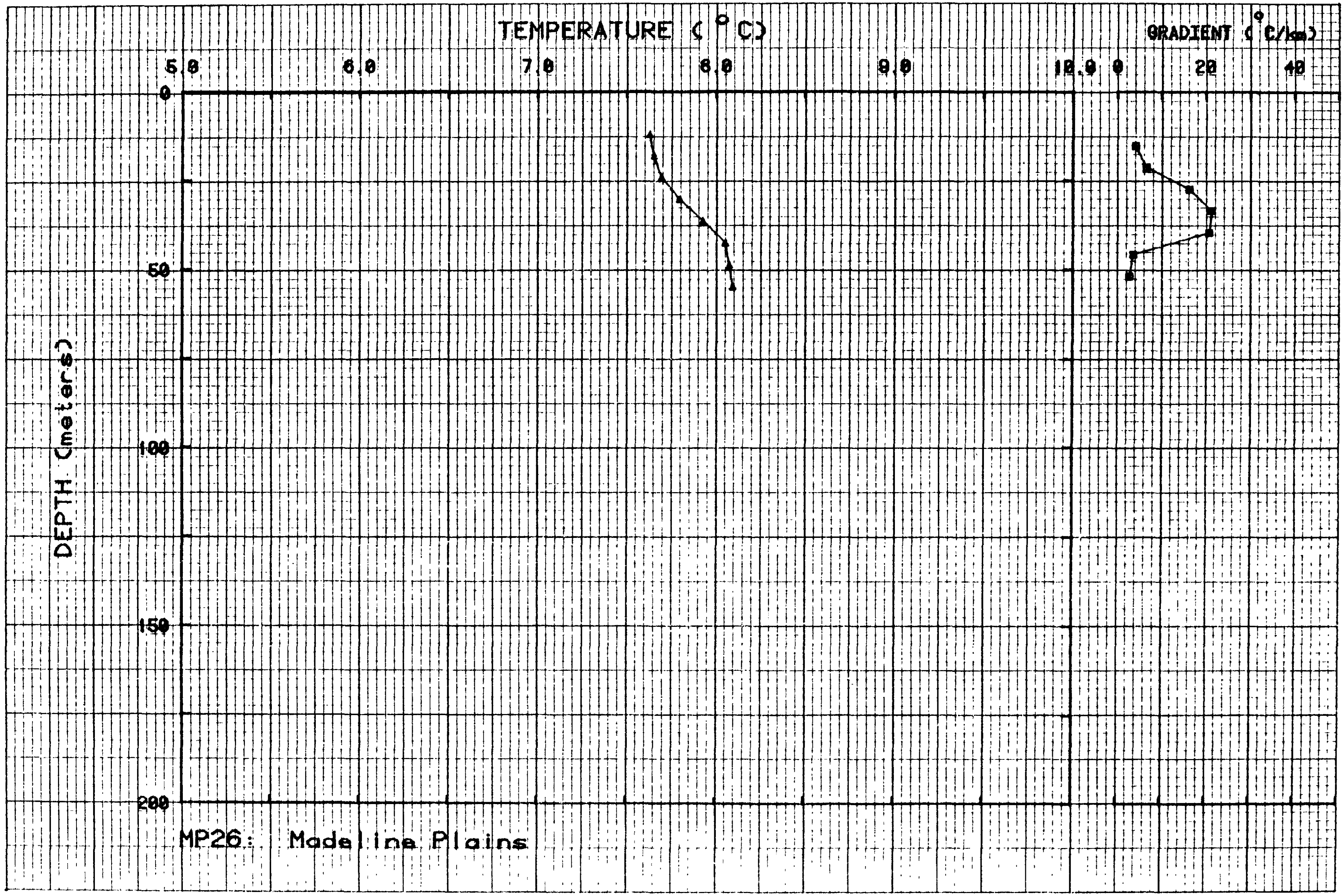

Figure II-26. Temperature and gradient profiles for MP26.

TABLE II-26. Temperature tabulation

Hole: MP26 MADELINE PLAINS

Lat: 40-57.60 Long: 120-31.10

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
12.19	7.633	18.29	7.659
24.38	7.700	30.48	7.800
36.58	7.930	42.67	8.057
48.77	8.080	54.86	8.098

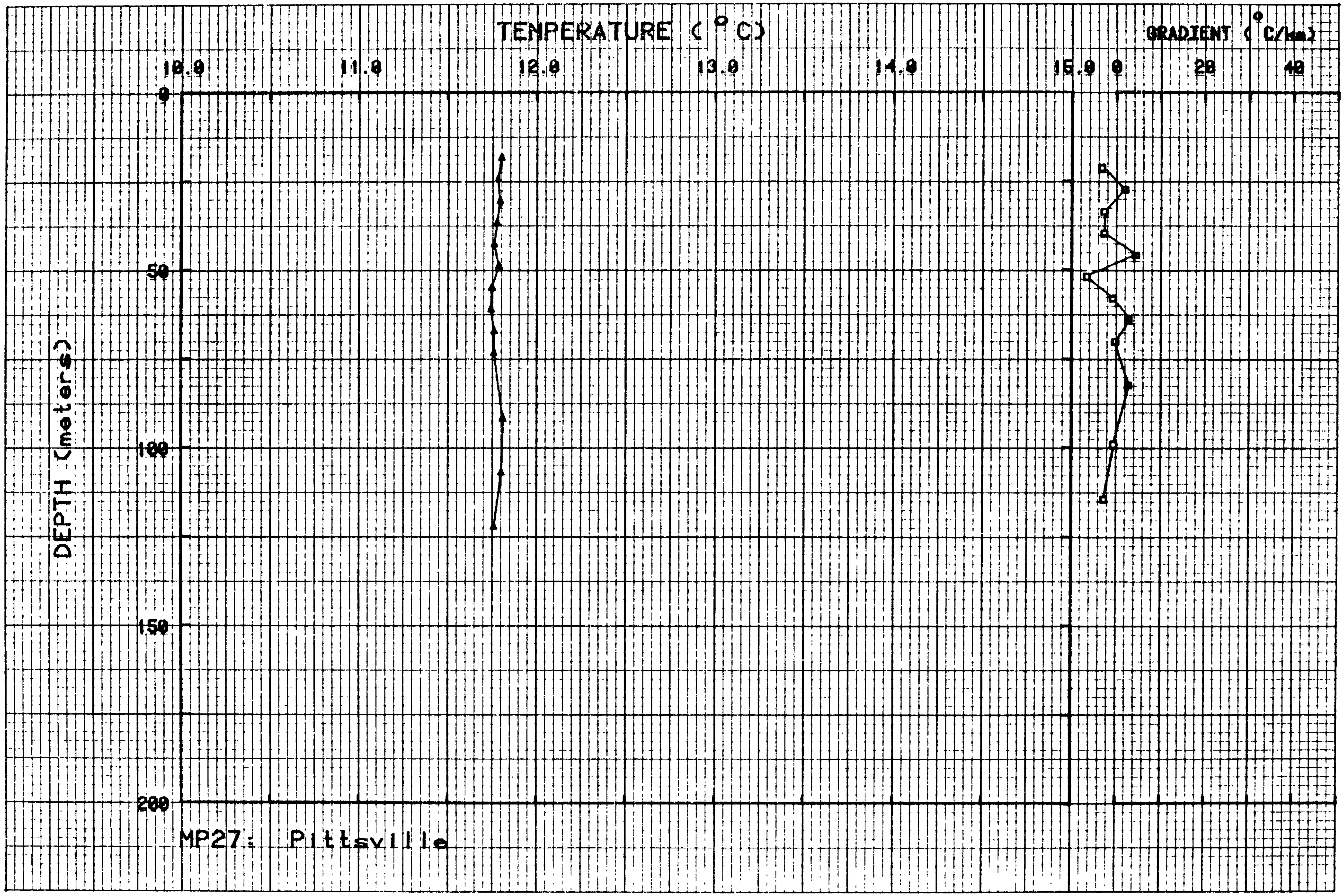

Figure II-27. Temperature and gradient profiles for MP27.

TABLE II-27. Temperature tabulation

Hole: MP27 PITTSVILLE 1

Lat: 40-59.80 Long: 121-19.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
18.29	11.805	24.38	11.785
30.48	11.797	36.58	11.781
42.67	11.764	48.77	11.791
54.86	11.751	60.96	11.747
67.06	11.764	73.15	11.763
91.44	11.813	106.68	11.805
121.92	11.764		

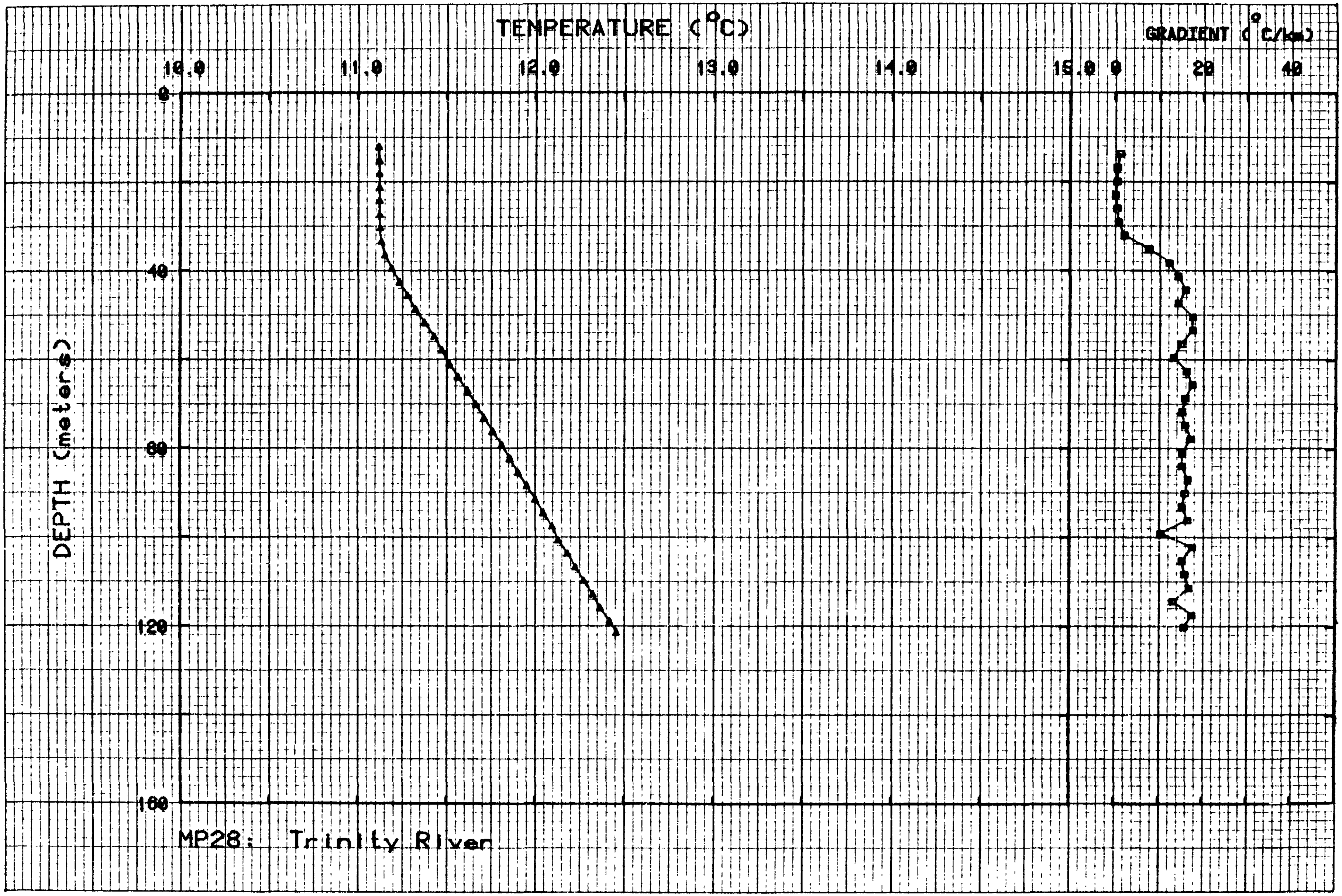

Figure II-28. Temperature and gradient profiles for MP28.

TABLE II-28. Temperature tabulation

Hole: MP28 HEADWATER TRINITY RIVER

Lat: 41-16.40 Long: 122-36.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
12.19	11.113	15.24	11.116
18.29	11.117	21.34	11.118
24.38	11.118	27.43	11.119
30.48	11.121	33.53	11.127
36.58	11.150	39.62	11.187
42.67	11.230	45.72	11.278
48.77	11.321	51.82	11.374
54.86	11.427	57.91	11.472
60.96	11.512	64.01	11.561
67.06	11.614	70.10	11.662
73.15	11.708	76.20	11.756
79.25	11.808	82.30	11.854
85.34	11.900	88.39	11.950
91.44	11.998	94.49	12.044
97.54	12.094	100.58	12.125
103.63	12.178	106.68	12.224
109.73	12.272	112.78	12.323
115.82	12.363	118.87	12.416
121.31	12.454		

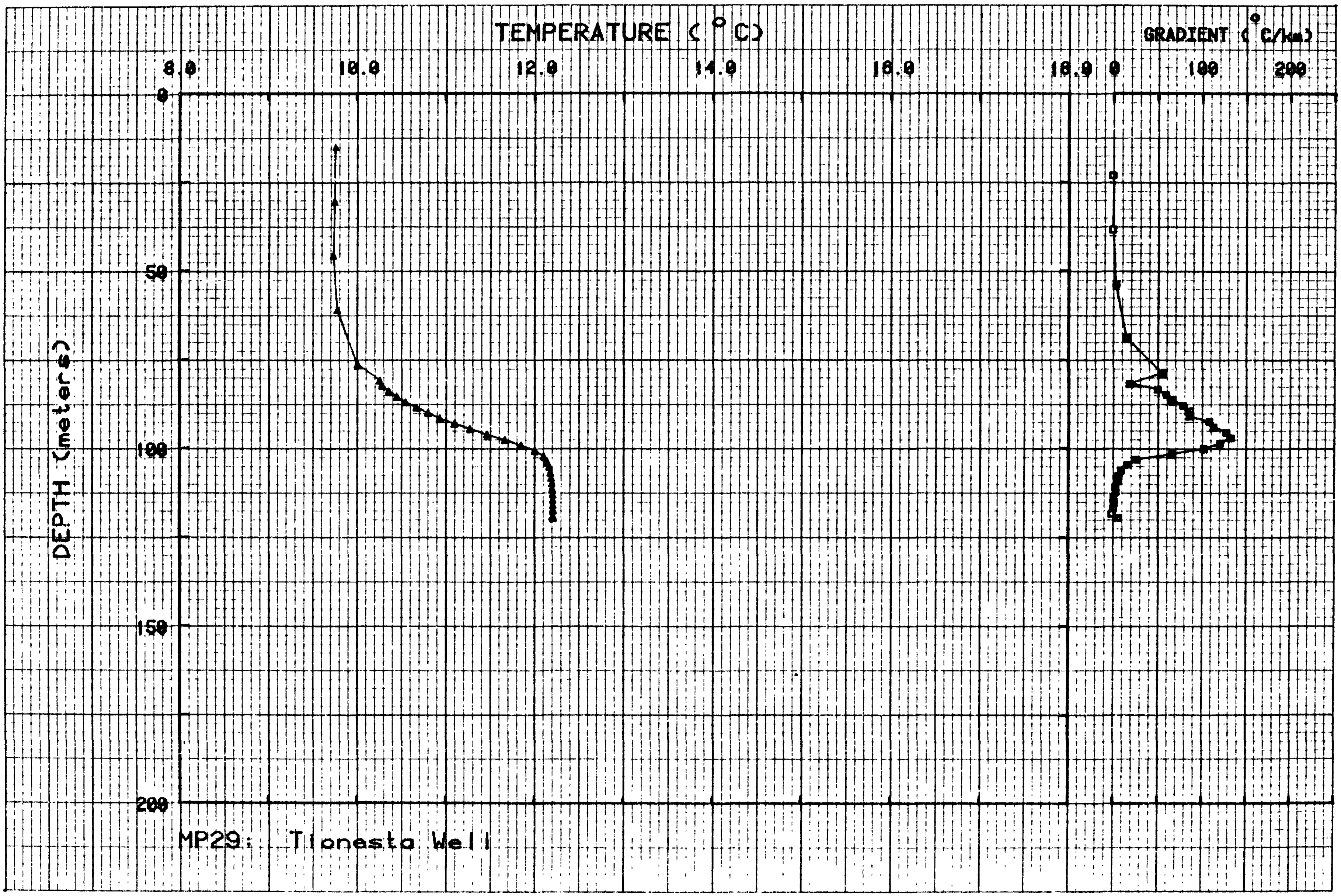

Figure II-29. Temperature and gradient profile for MP29.

TABLE II-29. Temperature tabulation

Hole: MP29 TIONESTA WELL

Lat: 41-38.50 Long: 121-21.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	9.761	30.48	9.752
45.72	9.740	60.96	9.786
76.20	10.015	80.77	10.264
82.30	10.292	83.82	10.368
85.34	10.458	86.87	10.559
88.39	10.679	89.92	10.810
91.44	10.941	92.96	11.106
94.49	11.278	96.01	11.472
97.54	11.674	99.06	11.857
100.58	12.012	102.11	12.113
103.63	12.151	105.16	12.175
106.68	12.188	108.20	12.197
109.73	12.205	111.25	12.209
112.78	12.214	114.30	12.215
115.82	12.217	117.35	12.217
118.87	12.215	119.48	12.218

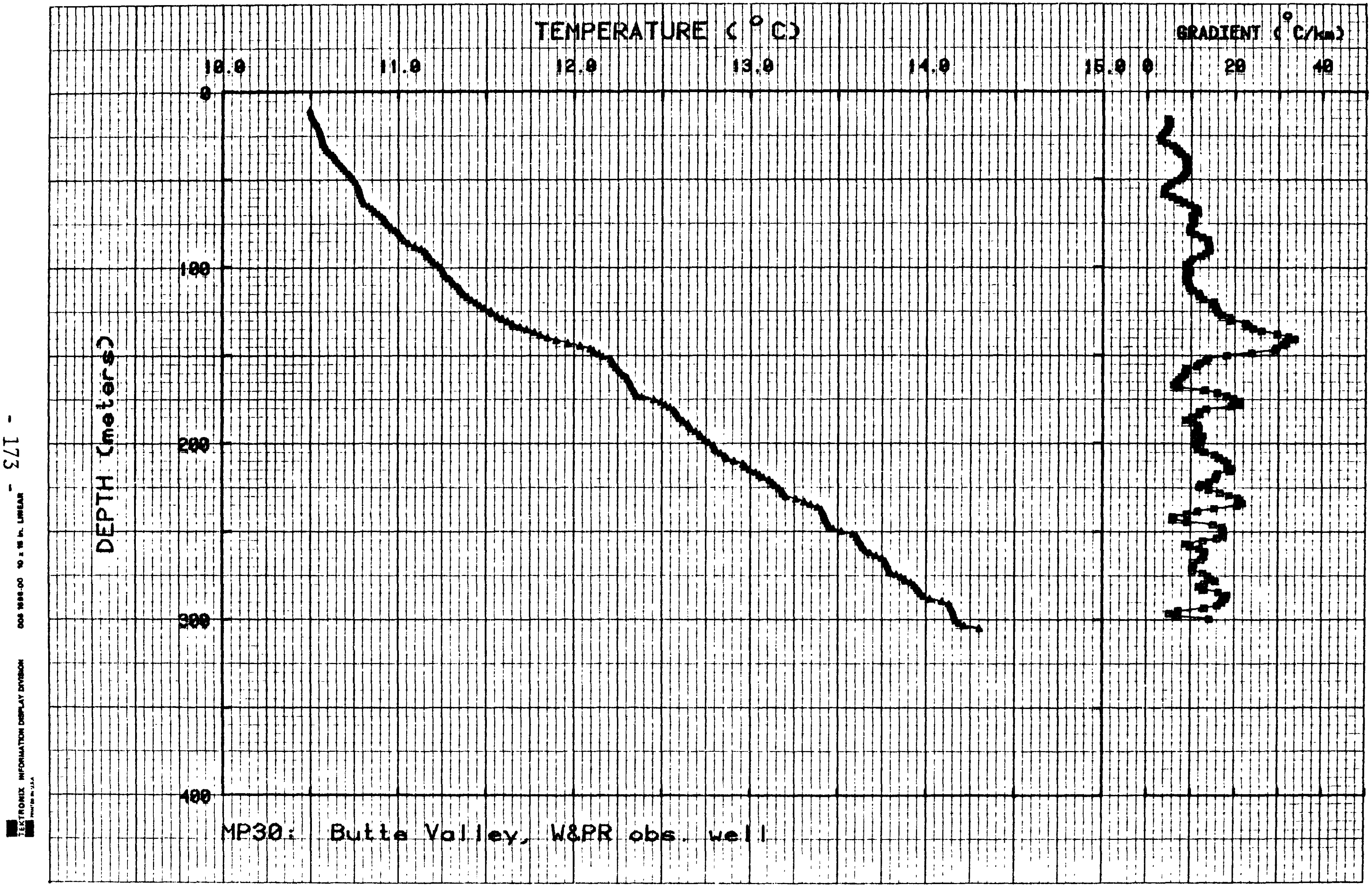

Figure II-30. Temperature and gradient profiles for MP30.

TABLE II-30. Temperature tabulation

Hole: MF30 BUTTE VALLEY OBS.

Lat: 41-48.50 Long: 122- 0.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
10.67	10.503	13.72	10.512
16.76	10.525	19.81	10.546
22.86	10.560	25.91	10.569
28.96	10.578	32.00	10.589
35.05	10.613	38.10	10.645
41.15	10.667	44.20	10.695
47.24	10.727	50.29	10.753
53.34	10.771	56.39	10.781
59.44	10.790	62.48	10.804
65.53	10.839	68.58	10.875
71.63	10.913	74.68	10.937
77.72	10.966	80.77	11.008
83.82	11.031	86.87	11.066
89.92	11.138	92.96	11.170
96.01	11.194	99.06	11.231
102.11	11.262	105.16	11.279
108.20	11.314	111.25	11.344
114.30	11.369	117.35	11.401
120.40	11.452	123.44	11.495
126.49	11.540	129.54	11.596
132.59	11.655	135.64	11.737
138.68	11.815	141.73	11.904
144.78	12.041	147.83	12.119
150.88	12.170	153.92	12.226
156.97	12.246	160.02	12.275
163.07	12.313	166.12	12.328
169.16	12.340	172.21	12.359
175.26	12.460	178.31	12.526
181.36	12.573	184.40	12.597
187.45	12.627	190.50	12.661
193.55	12.697	196.60	12.731
199.64	12.772	202.69	12.804
205.74	12.839	208.79	12.874
211.84	12.963	214.88	13.002
217.93	13.058	220.98	13.115
224.03	13.148	227.08	13.188
230.12	13.208	233.17	13.313
236.22	13.390	239.27	13.424
242.32	13.431	245.36	13.448
248.41	13.478	251.46	13.590
254.51	13.624	257.56	13.643
260.60	13.662	263.65	13.721
266.70	13.774	269.75	13.788
272.80	13.799	275.84	13.864
278.89	13.920	281.94	13.952
284.99	13.976	288.04	14.025
291.08	14.134	294.13	14.152
297.18	14.163	300.23	14.173
303.28	14.219		

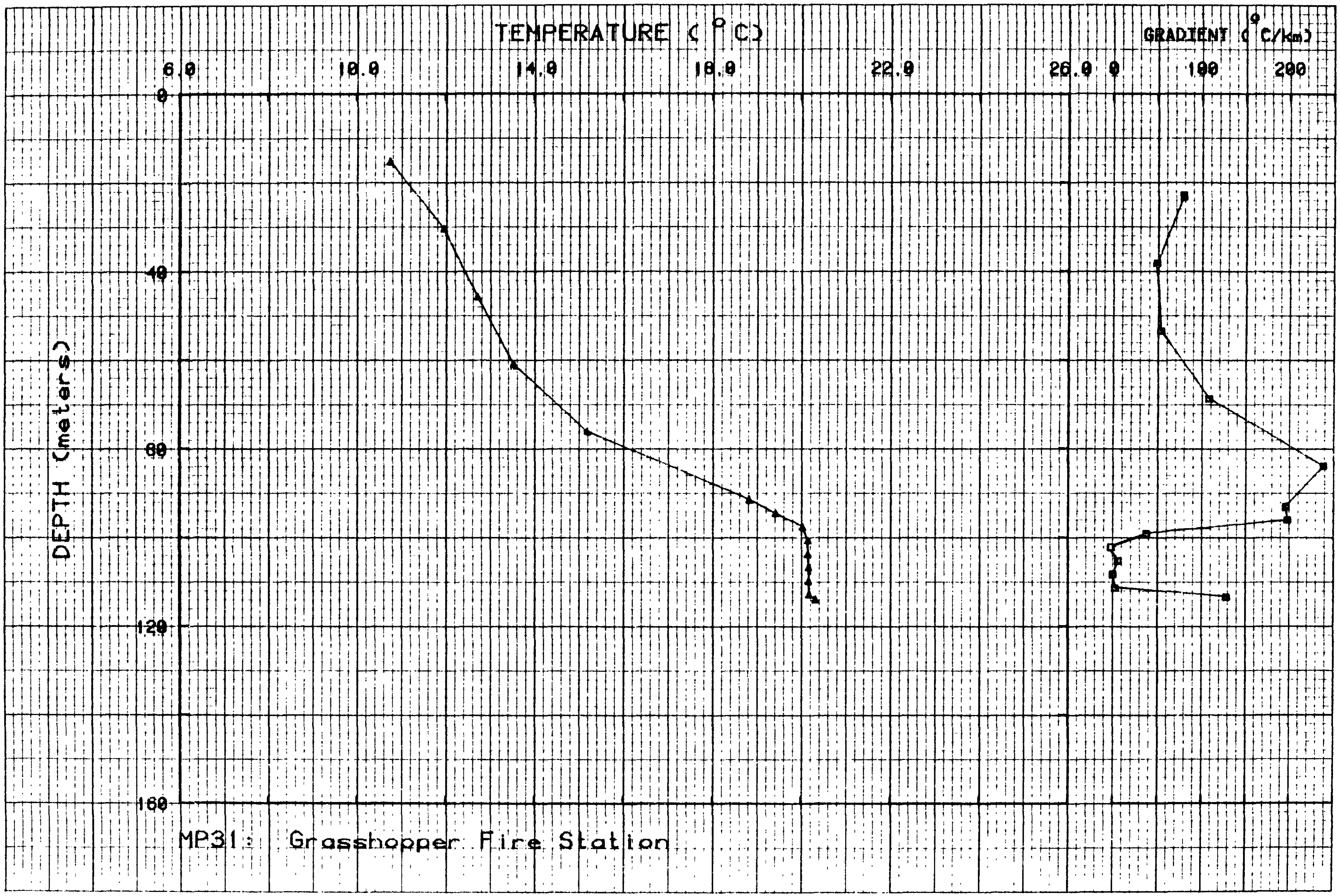

Figure II-31. Temperature and gradient profile for MP31.

TABLE II-31. Temperature tabulation

Hole: MP31 GRASS FIRE CONTROL STA.

Lat: 40-46.10 Long: 120-43.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	10.767	30.48	11.977
45.72	12.728	60.96	13.551
76.20	15.204	91.44	18.843
94.49	19.441	97.54	20.046
100.58	20.162	103.63	20.158
106.68	20.177	109.73	20.179
112.78	20.189	113.90	20.334

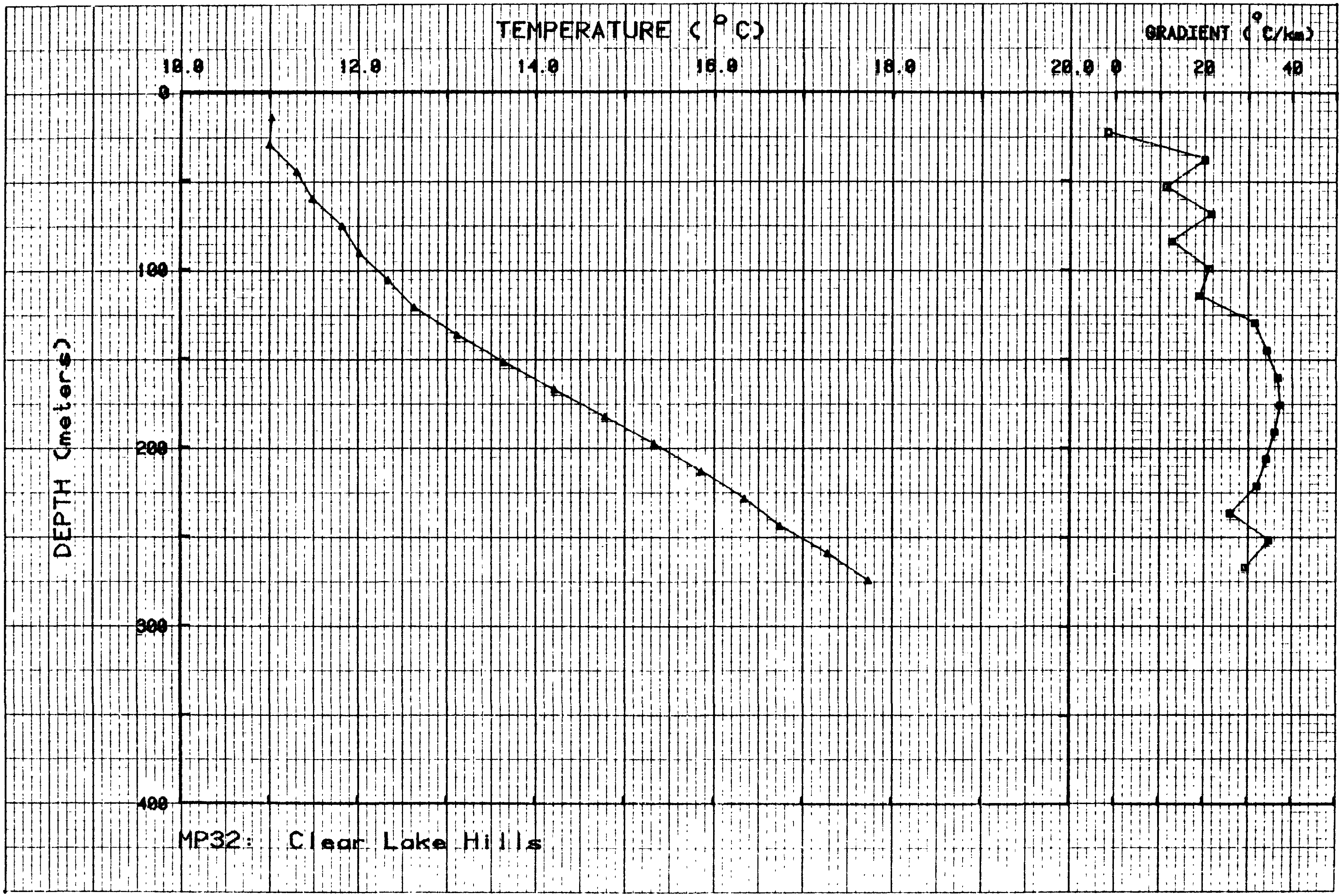

Figure II-32. Temperature and gradient profiles for MP32.

TABLE II-32. Temperature tabulation

Hole: MP32 CLEAR LAKE HILLS

Lat: 41-49.90 Long: 121-15.10

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	11.032	30.48	11.011
45.72	11.321	60.96	11.500
76.20	11.833	91.44	12.031
106.68	12.357	121.92	12.650
137.16	13.134	152.40	13.660
167.64	14.224	182.88	14.795
198.12	15.347	213.36	15.870
228.60	16.361	243.84	16.761
259.08	17.295	274.32	17.748

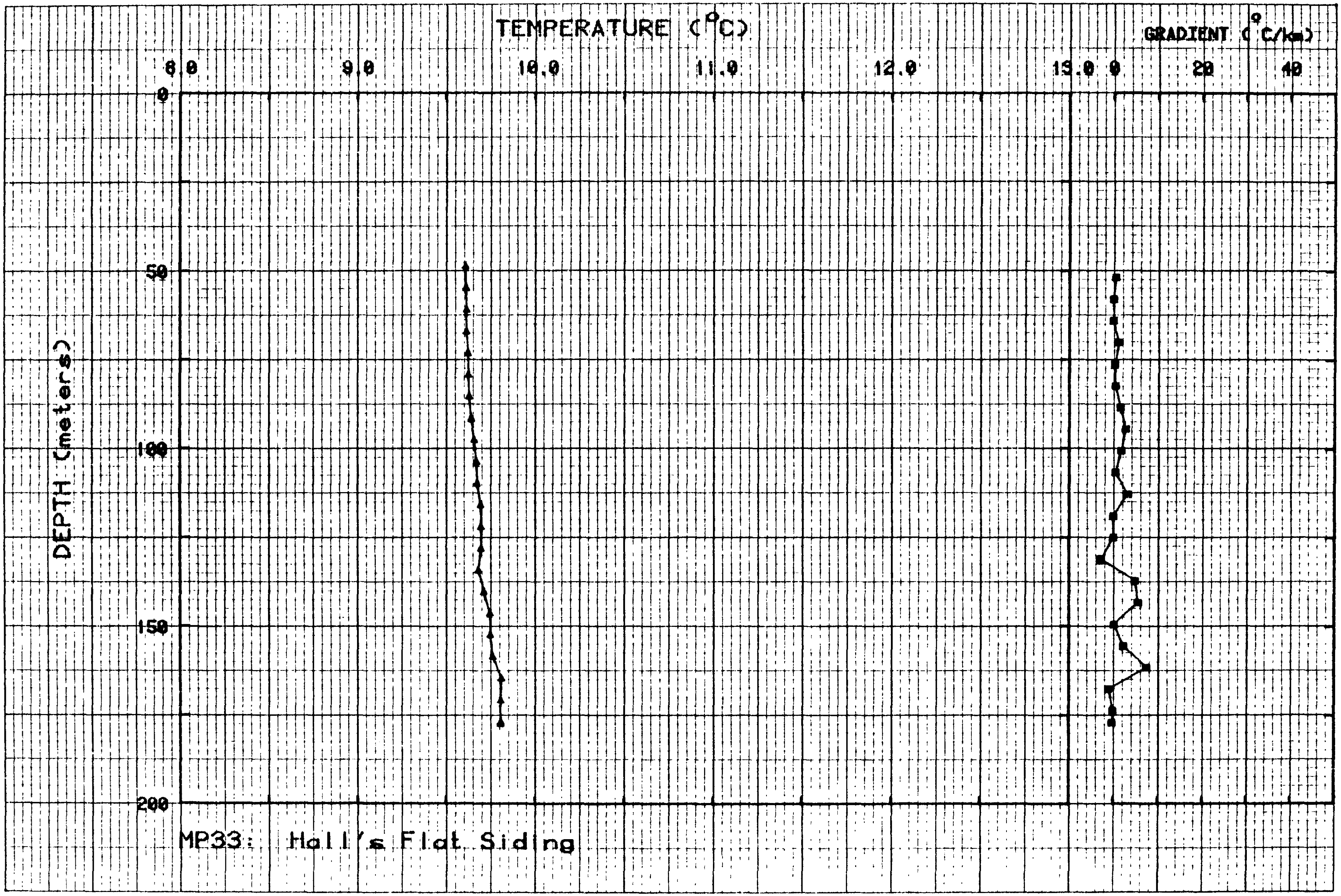

Figure II-33. Temperature and gradient profiles for MP33.

TABLE II-33. Temperature tabulation

Hole: MP33 HALL'S FLAT STA.

Lat: 40-45.50 Long: 121-15.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
48.77	9.613	54.86	9.617
60.96	9.618	67.06	9.619
73.15	9.627	79.25	9.630
85.34	9.634	91.44	9.645
97.54	9.663	103.63	9.675
109.73	9.679	115.82	9.699
121.92	9.700	128.02	9.701
134.11	9.685	140.21	9.716
146.30	9.751	152.40	9.753
158.50	9.768	164.59	9.815
170.69	9.810	176.78	9.811
177.39	9.811		

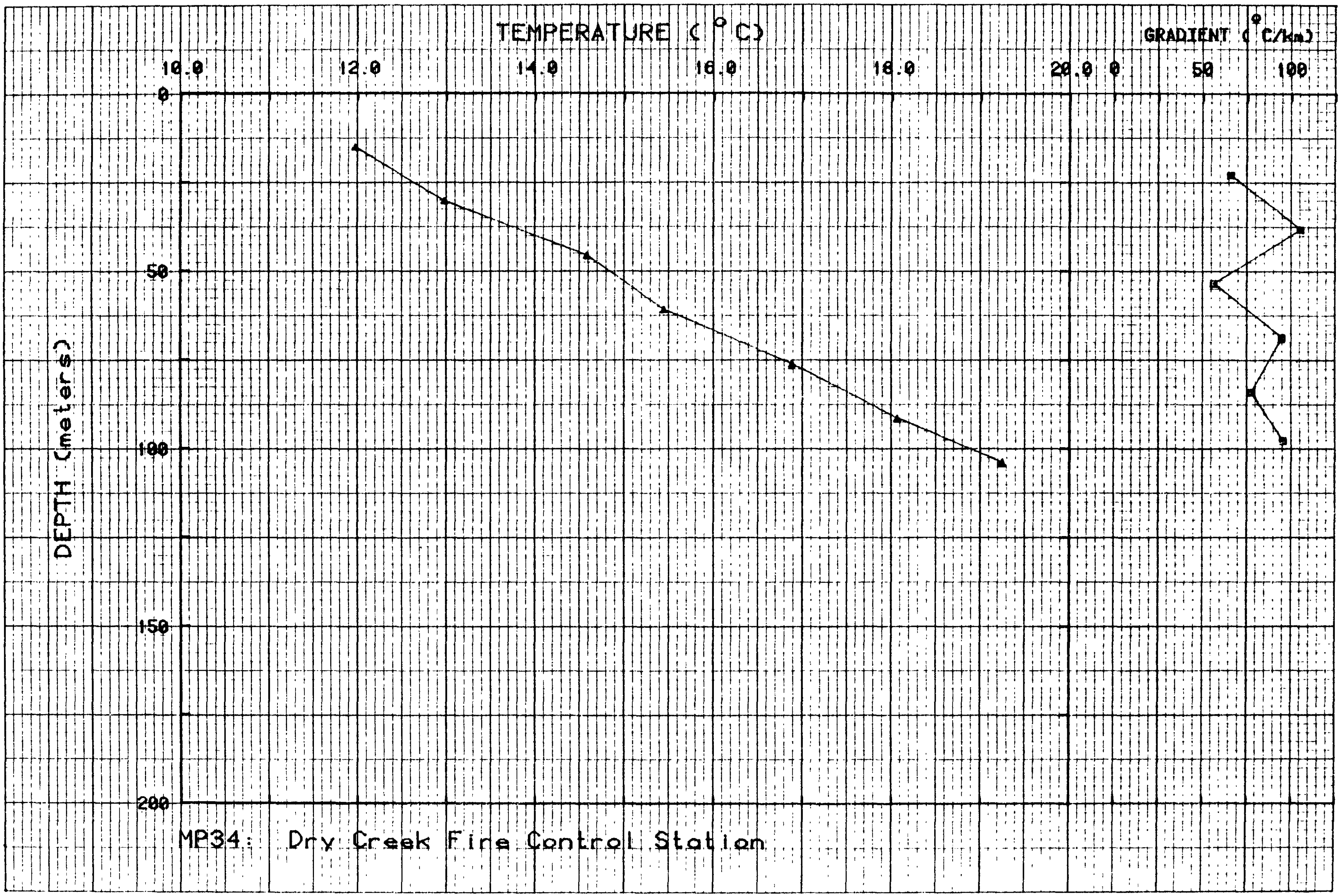

Figure II-34. Temperature and gradient profiles for MP34.

TABLE II-34. Temperature tabulation

Hole: MP34 DRY CREEK FIRE STA.

Lat: 41-13.80 Long: 120-30.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	11.977	30.48	12.982
45.72	14.589	60.96	15.448
76.20	16.890	91.44	18.070
103.81	19.250		

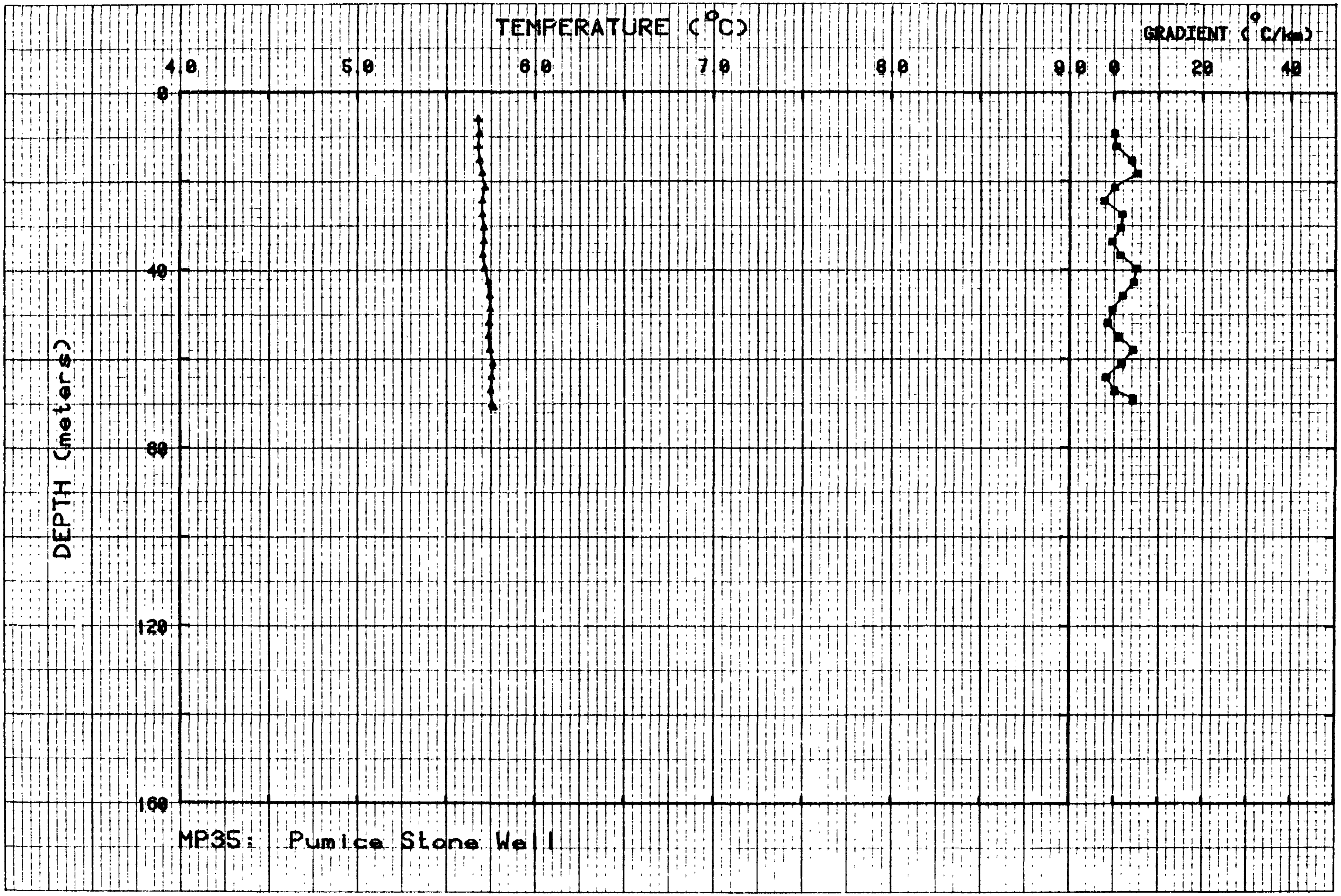

Figure II-35. Temperature and gradient profiles for MP35.

TABLE II-35. Temperature tabulation

Hole: MP35 PUMICE STONE WELL

Lat: 41-34.10 Long: 121-42.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	5.673	9.14	5.679
12.19	5.673	15.24	5.681
18.29	5.696	21.34	5.712
24.38	5.696	27.43	5.697
30.48	5.706	33.53	5.705
36.58	5.702	39.62	5.713
42.67	5.732	45.72	5.739
48.77	5.743	51.82	5.736
54.86	5.733	57.91	5.741
60.96	5.758	64.01	5.750
67.06	5.746	70.10	5.750
70.71	5.761		

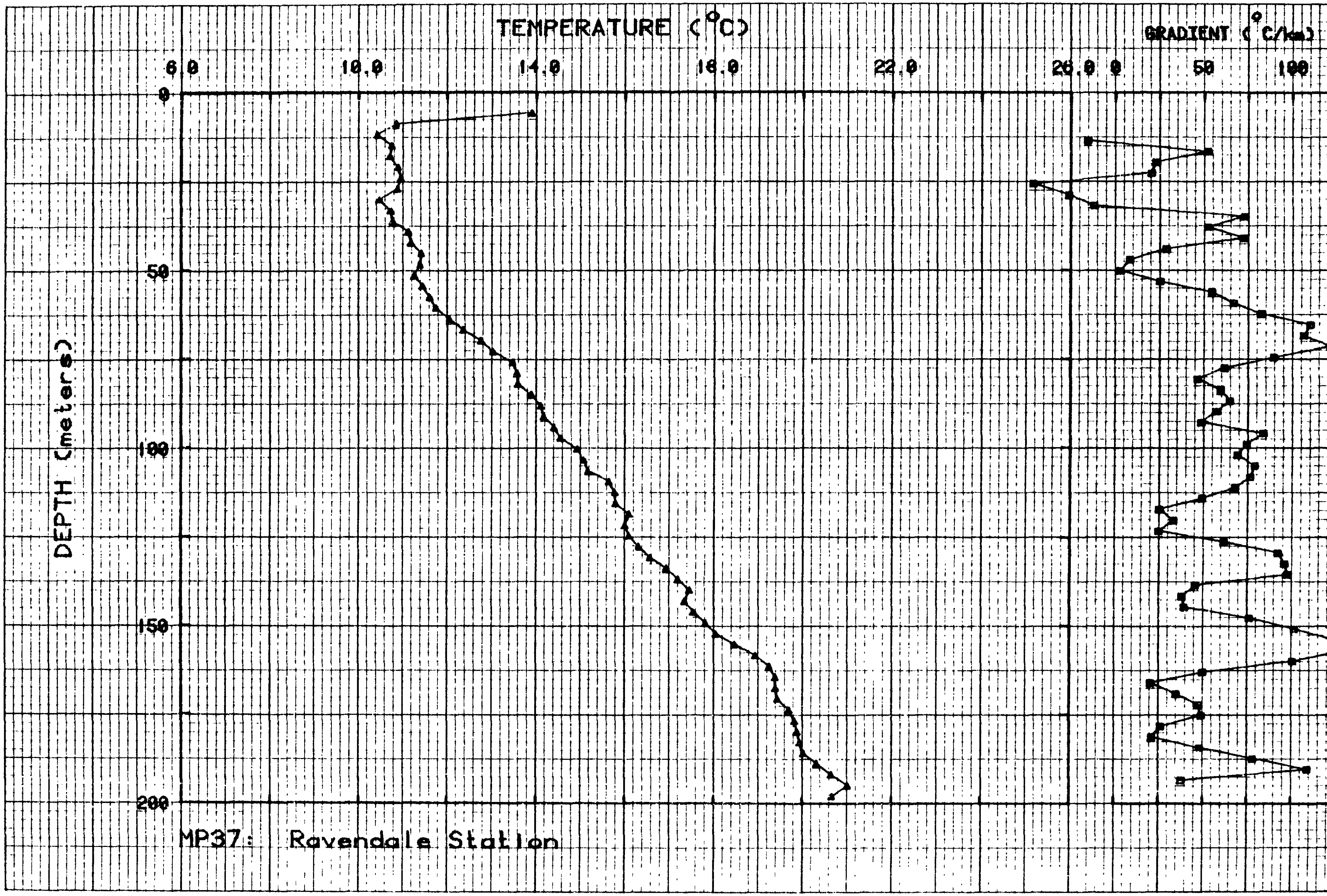

Figure II-36. Temperature and gradient profiles for MP37.

TABLE II-36. Temperature tabulation

Hole: MP37 RAVENDALE STA.

Lat: 40-43.90 Long: 120-18.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	13.879	9.14	10.830
12.19	10.403	15.24	10.738
18.29	10.686	21.34	10.876
24.38	10.943	27.43	10.868
30.48	10.452	33.53	10.701
36.58	10.755	39.62	11.113
42.67	11.173	45.72	11.414
48.77	11.372	51.82	11.245
54.86	11.435	57.91	11.599
60.96	11.739	64.01	12.041
67.06	12.350	70.10	12.740
73.15	13.010	76.20	13.457
79.25	13.555	82.30	13.570
85.34	13.878	88.39	14.094
91.44	14.158	94.49	14.396
97.54	14.536	100.58	14.920
103.63	15.070	106.68	15.165
109.73	15.638	112.78	15.766
115.82	15.782	118.87	16.084
121.92	15.993	124.97	16.081
128.02	16.308	131.06	16.554
134.11	16.921	137.16	17.181
140.21	17.444	143.26	17.334
146.30	17.526	149.35	17.801
152.40	18.028	155.45	18.453
158.50	18.927	161.54	19.236
164.59	19.371	167.64	19.379
170.69	19.421	173.74	19.689
176.78	19.813	179.83	19.869
182.88	19.927	185.93	20.004
188.98	20.307	192.02	20.641
195.07	21.000	198.12	20.650

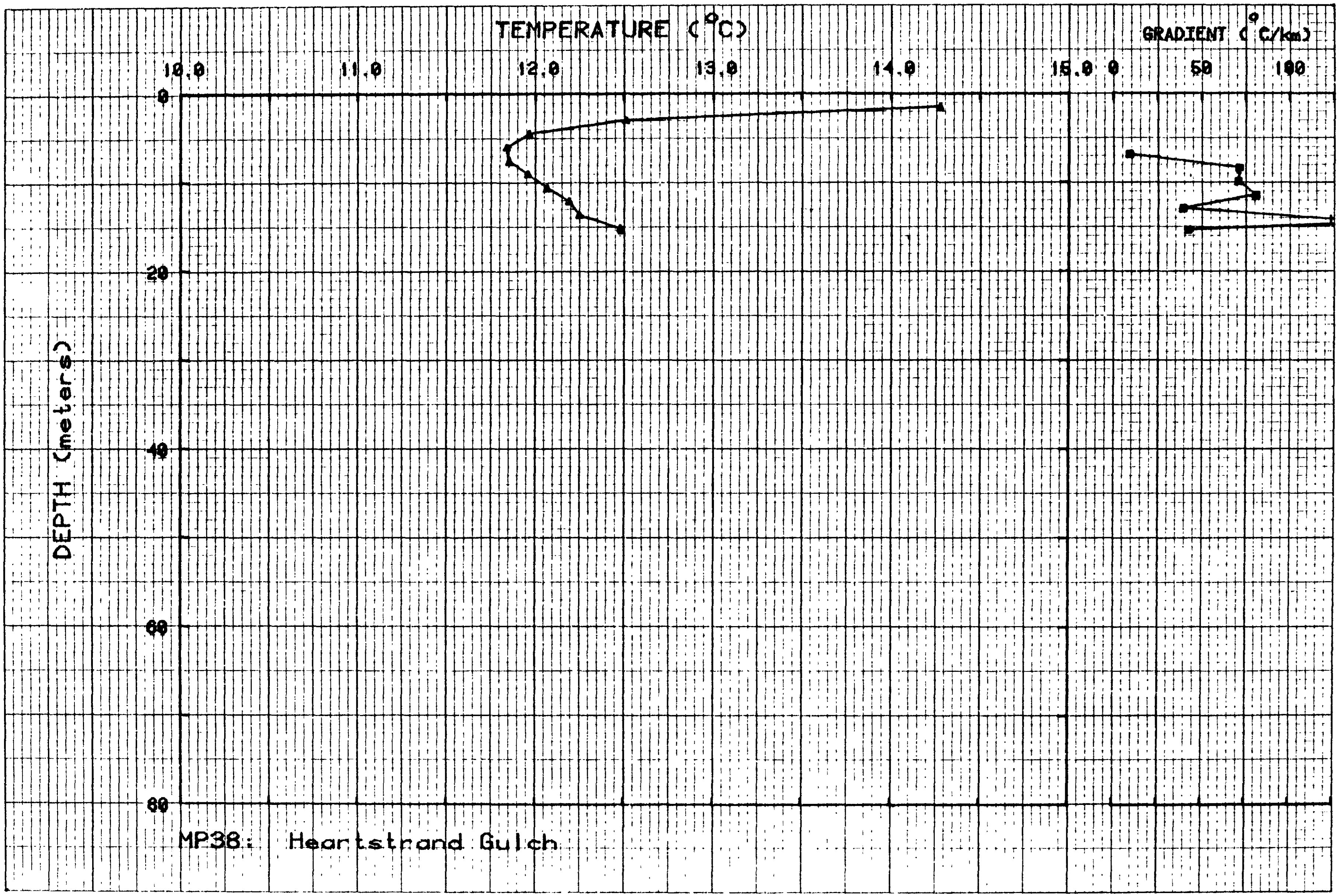

Figure II-37. Temperature and gradient profiles for MP38.

TABLE II-37. Temperature tabulation

Hole: MP38 HEARTSTRAND GULCH

Lat: 41-28.70 Long: 122-46.30

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	14.275	3.05	12.511
4.57	11.965	6.10	11.837
7.62	11.851	9.14	11.960
10.67	12.068	12.19	12.191
13.72	12.251	15.24	12.480
15.45	12.489		

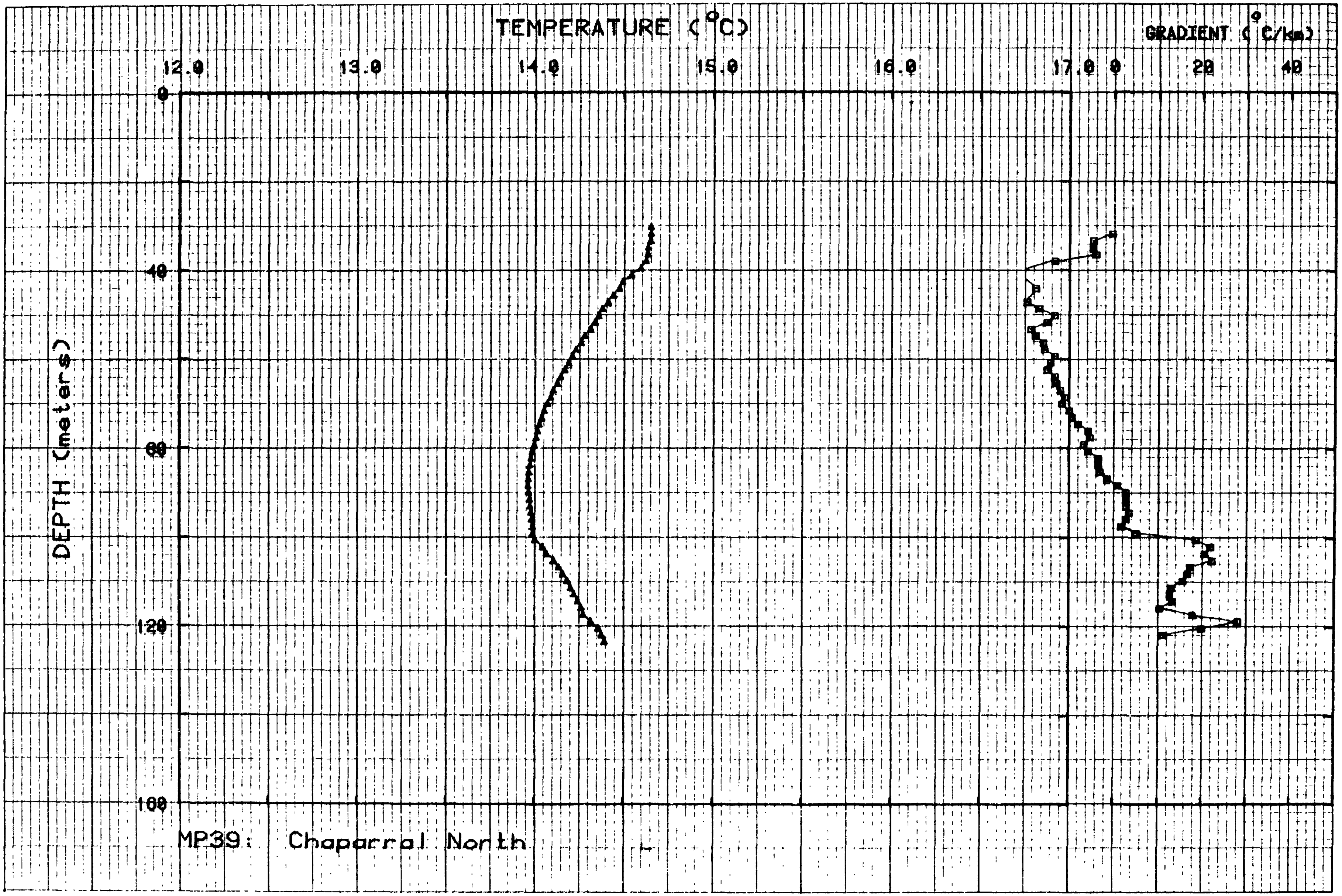

Figure II-38. Temperature and gradient profiles for MP39.

TABLE II-38. Temperature tabulation

Hole: MP39 CHAPARRAL HILL N

Lat: 41-34.80 Long: 122-52.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
30.48	14.647	32.00	14.647
33.53	14.645	35.05	14.632
36.58	14.630	38.10	14.619
39.62	14.589	41.15	14.539
42.67	14.489	44.20	14.469
45.72	14.435	47.24	14.408
48.77	14.375	50.29	14.356
51.82	14.334	53.34	14.310
54.86	14.277	56.39	14.256
57.91	14.228	59.44	14.208
60.96	14.187	62.48	14.164
64.01	14.141	65.53	14.123
67.06	14.101	68.58	14.086
70.10	14.067	71.63	14.050
73.15	14.036	74.68	14.021
76.20	14.011	77.72	14.003
79.25	13.994	80.77	13.982
82.30	13.976	83.82	13.971
85.34	13.965	86.87	13.961
88.39	13.960	89.92	13.963
91.44	13.968	92.96	13.971
94.49	13.976	96.01	13.981
97.54	13.984	99.06	13.986
100.58	13.999	102.11	14.042
103.63	14.065	105.16	14.104
106.68	14.132	108.20	14.156
109.73	14.182	111.25	14.203
112.78	14.221	114.30	14.241
115.82	14.261	117.35	14.272
118.87	14.315	120.40	14.357
121.92	14.375	123.38	14.390

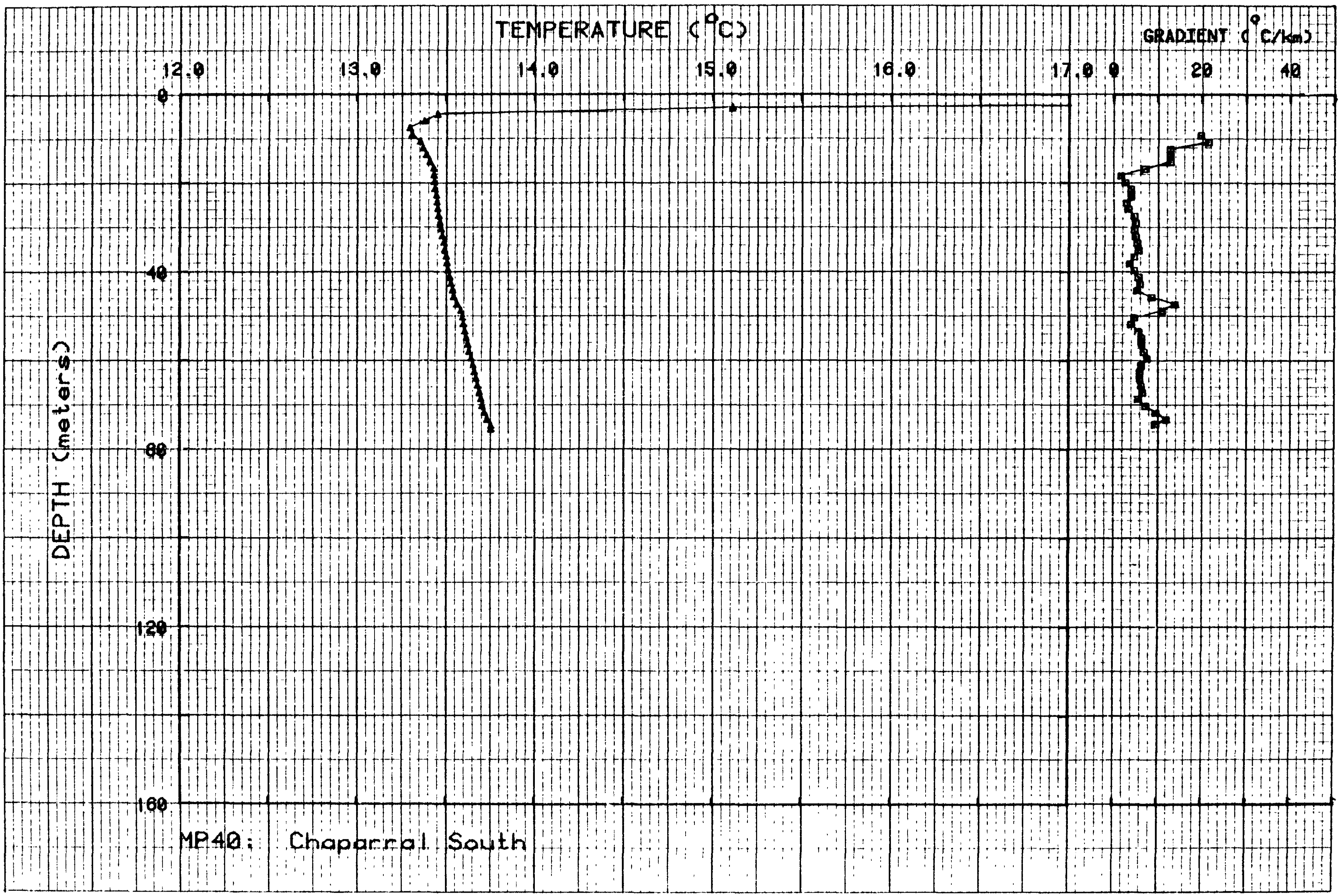

Figure II-39. Temperature and gradient profiles for MP40.

TABLE II-39. Temperature tabulation

Hole: MP40 CHAPARRAL HILL S

Lat: 41-34.40 Long: 122-53.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	20.155	3.05	15.099
4.57	13.443	6.10	13.371
7.62	13.288	9.14	13.302
10.67	13.347	12.19	13.366
13.72	13.385	15.24	13.404
16.76	13.423	18.29	13.424
19.81	13.427	21.34	13.431
22.86	13.438	24.38	13.442
25.91	13.446	27.43	13.451
28.96	13.459	30.48	13.465
32.00	13.472	33.53	13.479
35.05	13.487	36.58	13.495
38.10	13.500	39.62	13.505
41.15	13.513	42.67	13.521
44.20	13.530	45.72	13.536
47.24	13.555	48.77	13.577
50.29	13.587	51.82	13.590
53.34	13.598	54.86	13.606
56.39	13.616	57.91	13.624
59.44	13.636	60.96	13.646
62.48	13.654	64.01	13.663
65.53	13.671	67.06	13.681
68.58	13.690	70.10	13.697
71.63	13.711	73.15	13.725
74.68	13.746	75.47	13.746

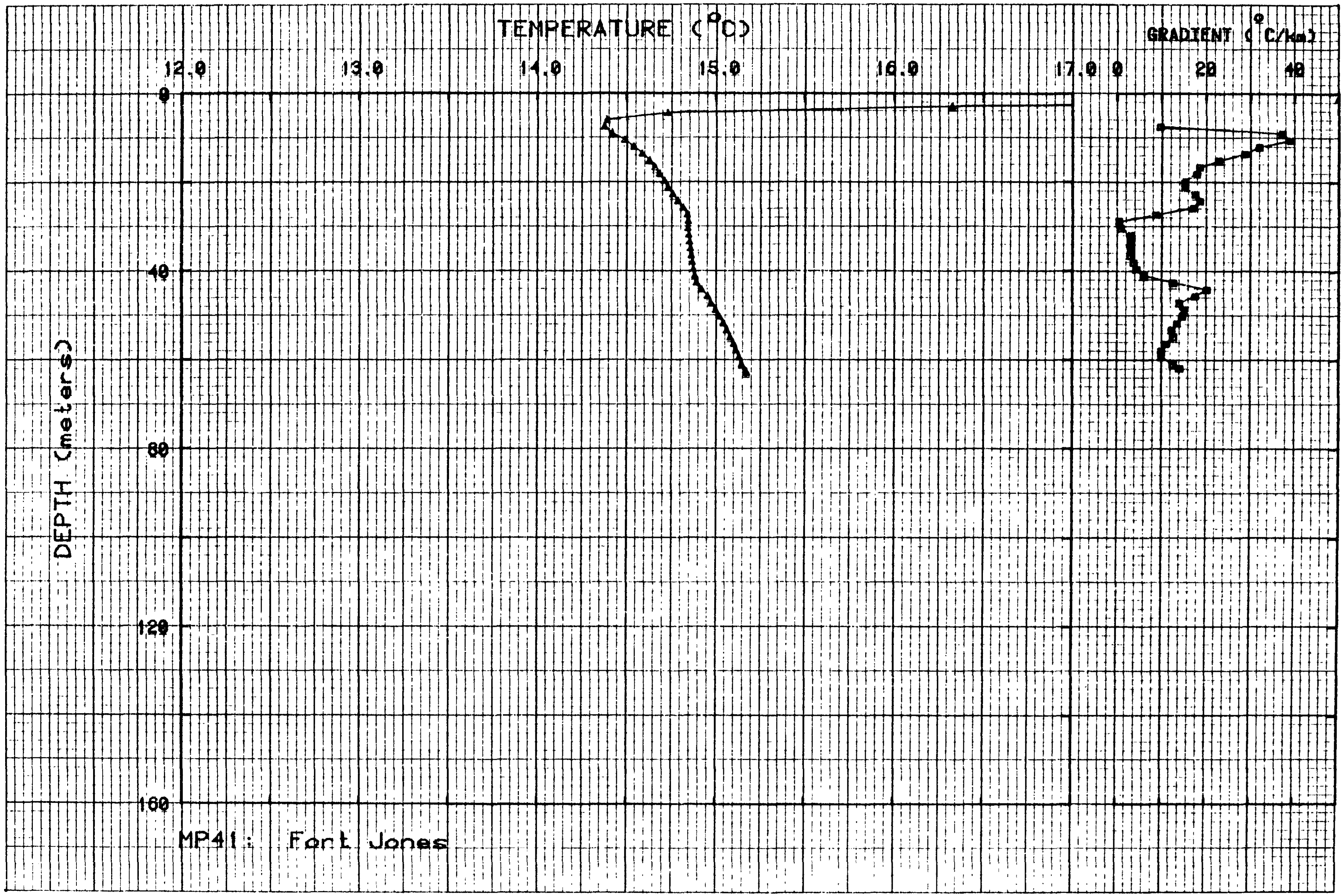

Figure II-40. Temperature and gradient profiles for MP41.

TABLE II-40. Temperature tabulation

Hole: MP41 FORT JONES

Lat: 41-34.10 Long: 122-52.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	19.790	3.05	16.329
4.57	14.736	6.10	14.397
7.62	14.382	9.14	14.427
10.67	14.496	12.19	14.547
13.72	14.594	15.24	14.635
16.76	14.664	18.29	14.692
19.81	14.719	21.34	14.739
22.86	14.766	24.38	14.793
25.91	14.823	27.43	14.846
28.96	14.850	30.48	14.848
32.00	14.853	33.53	14.858
35.05	14.863	36.58	14.868
38.10	14.873	39.62	14.880
41.15	14.887	42.67	14.899
44.20	14.926	45.72	14.961
47.24	14.980	48.77	15.004
50.29	15.027	51.82	15.049
53.34	15.068	54.86	15.087
56.39	15.107	57.91	15.121
59.44	15.138	60.96	15.152
62.48	15.177	62.85	15.179

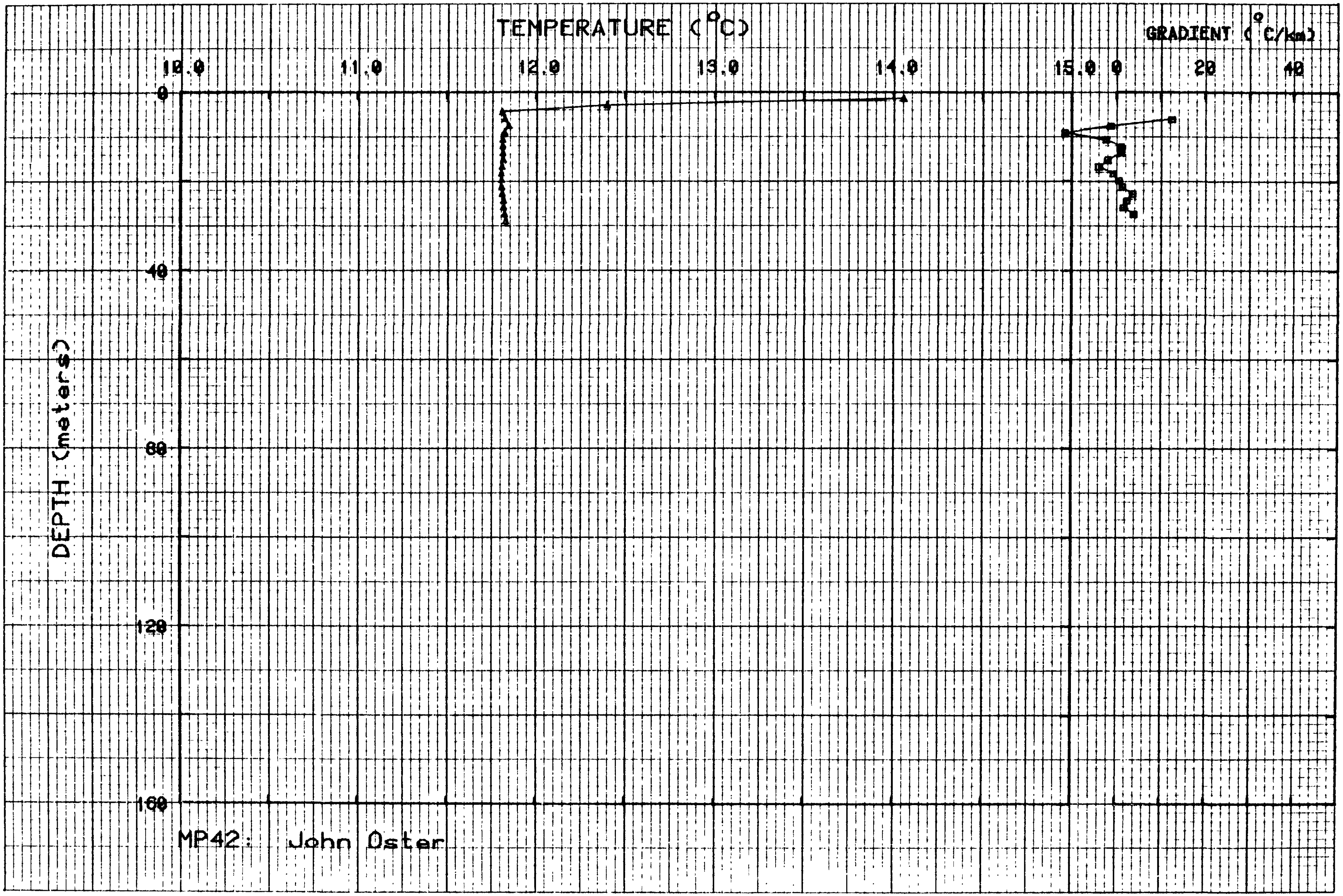

Figure II-41. Temperature and gradient profiles for MP42.

TABLE II-41. Temperature tabulation

Hole: MP42 JOHN OSTER

Lat: 41-37.20 Long: 122-46.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	14.057	3.05	12.400
4.57	11.810	6.10	11.826
7.62	11.848	9.14	11.822
10.67	11.813	12.19	11.815
13.72	11.816	15.24	11.818
16.76	11.810	18.29	11.806
19.81	11.808	21.34	11.808
22.86	11.812	24.38	11.819
25.91	11.819	27.43	11.824
28.96	11.831		

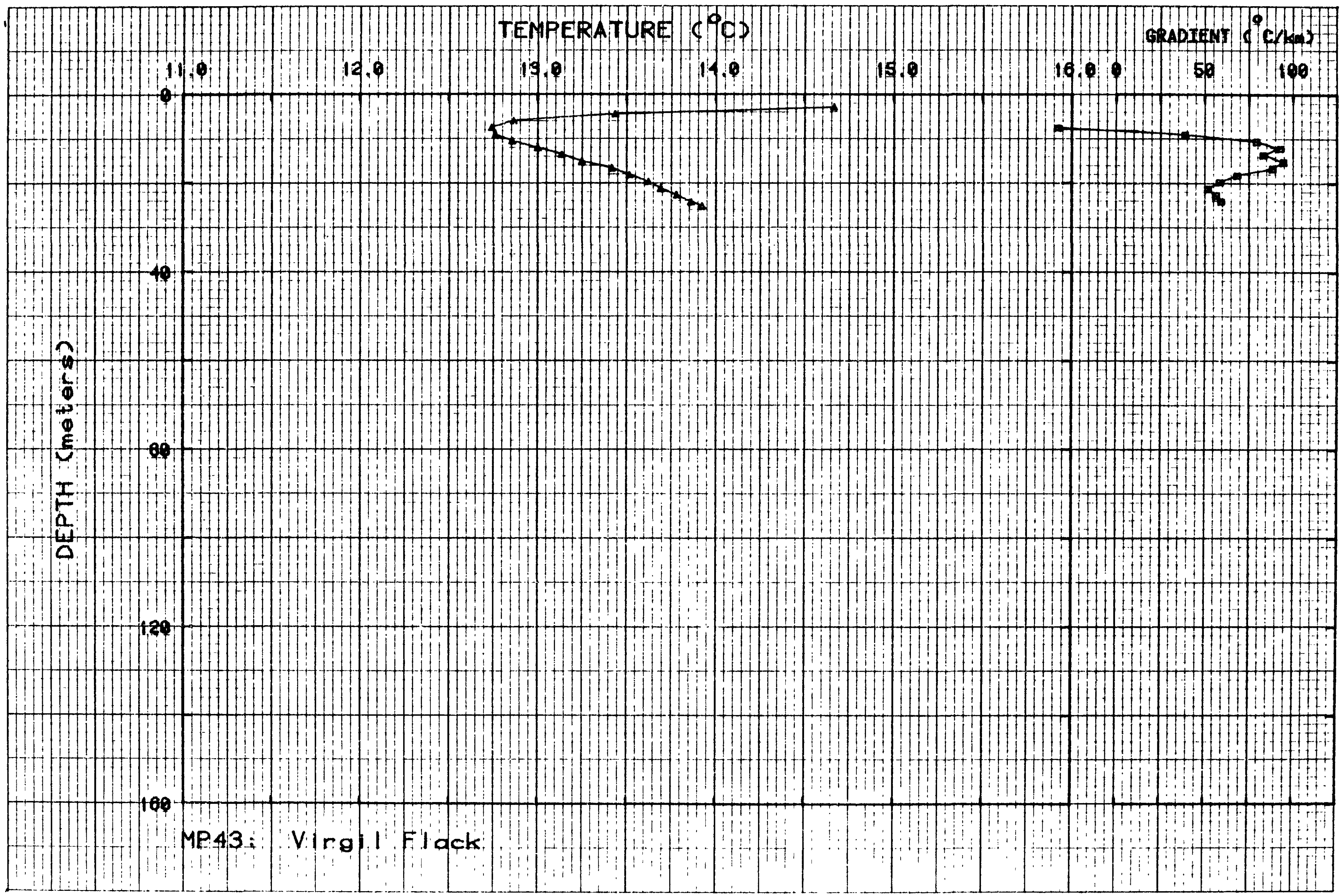

Figure II-42. Temperature and gradient profiles for MP43.

TABLE II-42. Temperature tabulation

Hole: MF43 VIRGIL FLACK

Lat: 41-36.50 Long: 122-31.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
3.05	14.657	4.57	13.429
6.10	12.856	7.62	12.732
9.14	12.754	10.67	12.848
12.19	12.993	13.72	13.127
15.24	13.243	16.76	13.412
18.29	13.509	19.81	13.617
21.34	13.684	22.86	13.772
24.38	13.853	25.30	13.914

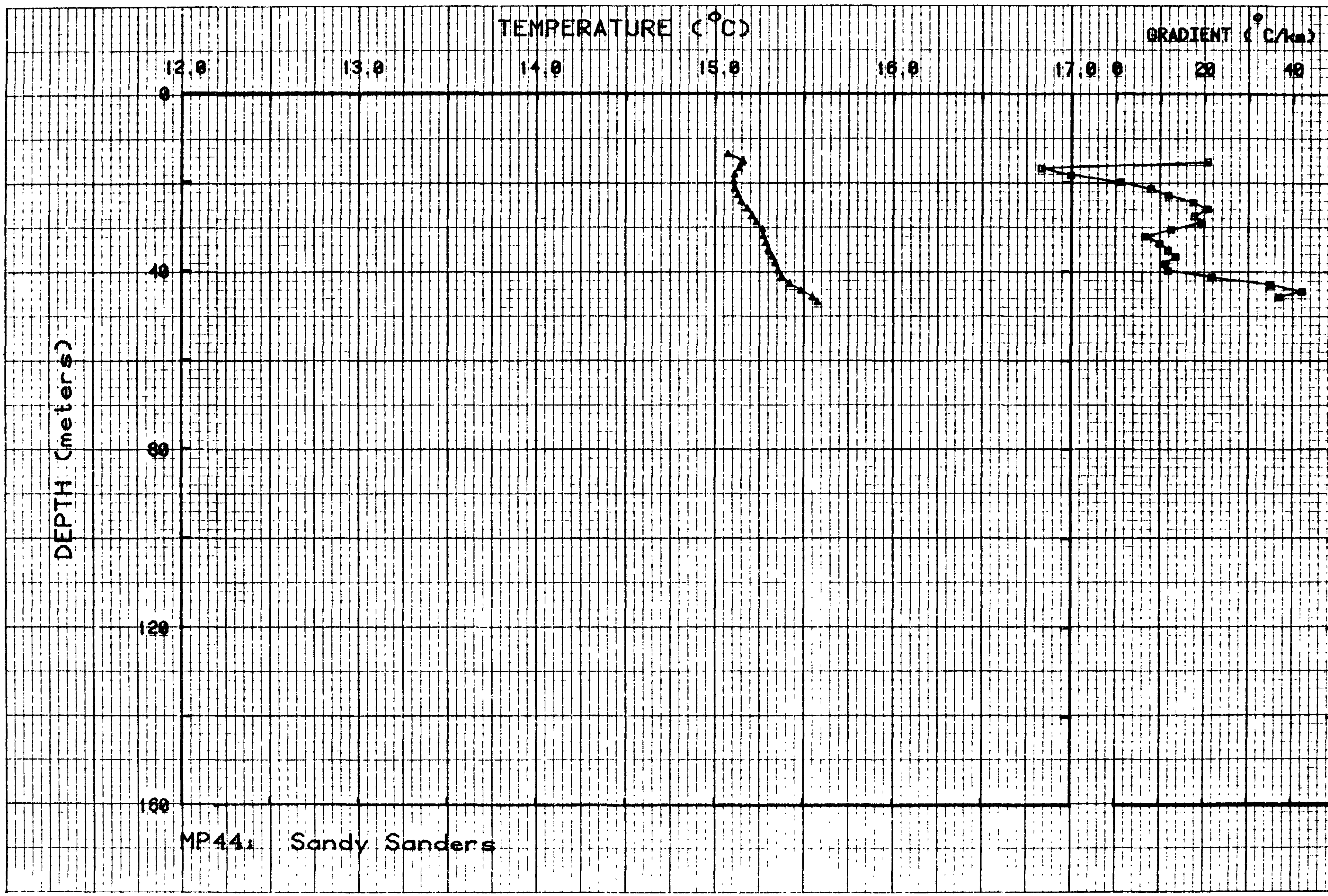

Figure II-43. Temperature and gradient profiles for MP44.

TABLE II-43. Temperature tabulation

Hole: MP44 SANDY SANDERS

Lat: 41-38.60 Long: 122-23.40

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
13.72	15.070	15.24	15.157
16.76	15.133	18.29	15.106
19.81	15.102	21.34	15.109
22.86	15.126	24.38	15.145
25.91	15.179	27.43	15.208
28.96	15.233	30.48	15.267
32.00	15.271	33.53	15.287
35.05	15.301	36.58	15.323
38.10	15.342	39.62	15.357
41.15	15.378	42.67	15.423
44.20	15.484	45.72	15.551
46.76	15.578		

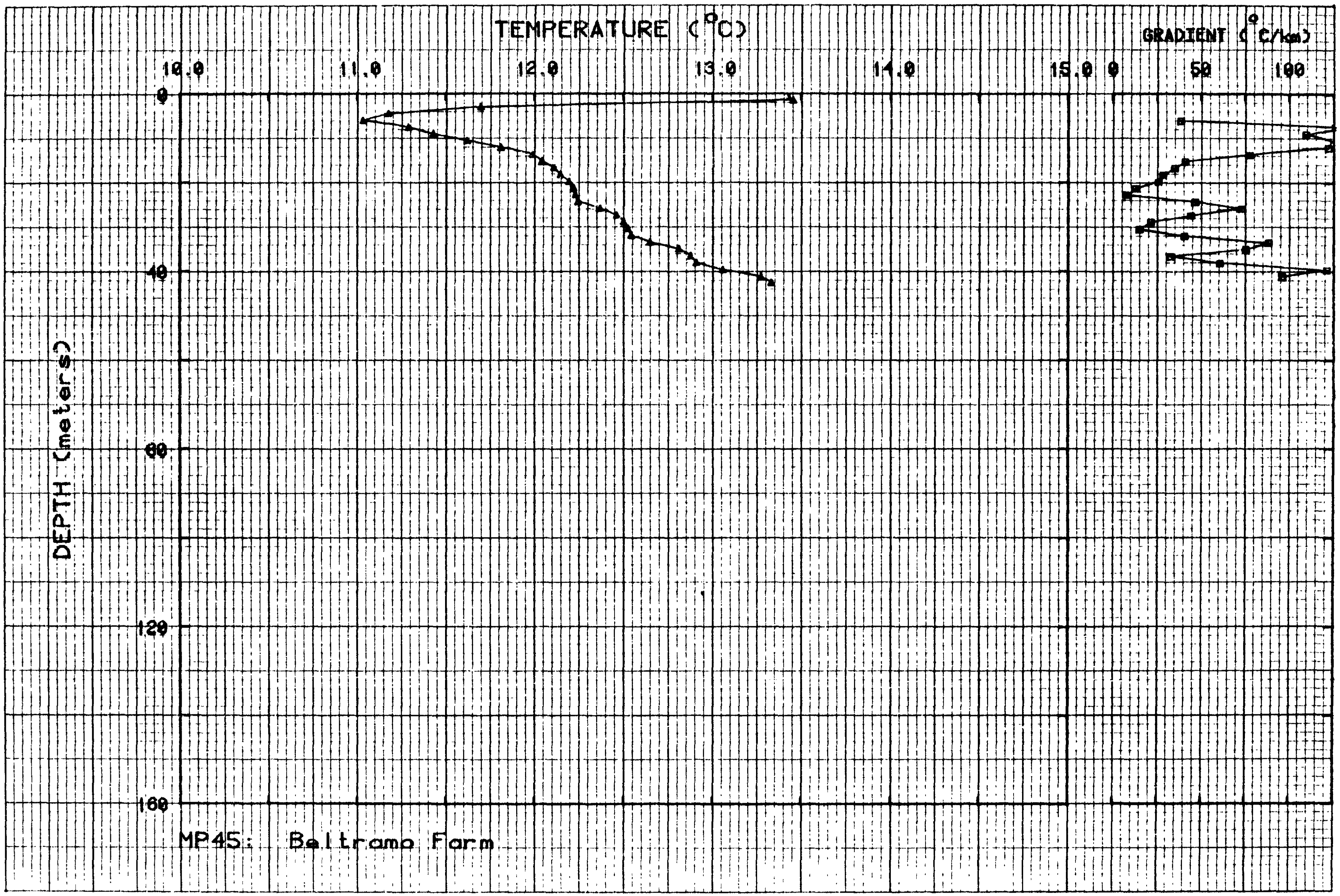

Figure II-44. Temperature and gradient profiles for MP45.

TABLE II-44. Temperature tabulation

Hole: MF45 BELTROMO FARM

Lat: 41-36.90 Long: 122-31.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	13.448	3.05	11.688
4.57	11.168	6.10	11.024
7.62	11.282	9.14	11.424
10.67	11.613	12.19	11.802
13.72	11.982	15.24	12.035
16.76	12.104	18.29	12.139
19.81	12.188	21.34	12.215
22.86	12.224	24.38	12.237
25.91	12.363	27.43	12.457
28.96	12.495	30.48	12.520
32.00	12.538	33.53	12.641
35.05	12.804	36.58	12.868
38.10	12.901	39.62	13.050
41.15	13.268	42.52	13.325

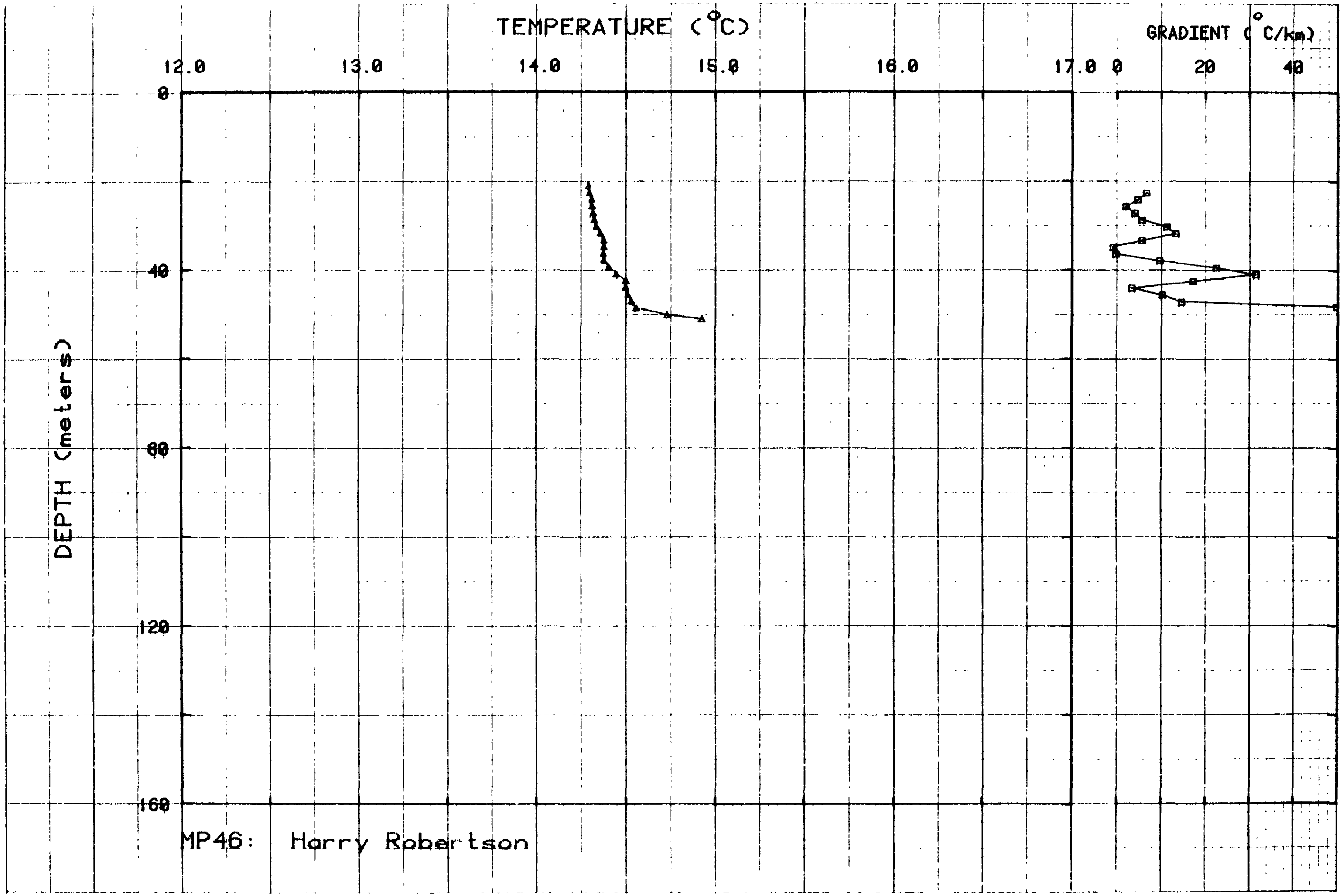

Figure II-45. Temperature and gradient profiles for MP46.

TABLE II-45. Temperature tabulation

Hole: MP46 HARRY ROBERTSON

Lat: 41-33.10 Long: 122-32.20

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
21.34	14.295	22.86	14.301
24.38	14.316	25.91	14.316
27.43	14.323	28.96	14.329
30.48	14.341	32.00	14.364
33.53	14.382	35.05	14.382
36.58	14.380	38.10	14.382
39.62	14.410	41.15	14.451
42.67	14.506	44.20	14.504
45.72	14.517	47.24	14.536
48.77	14.562	50.29	14.734
51.27	14.929		

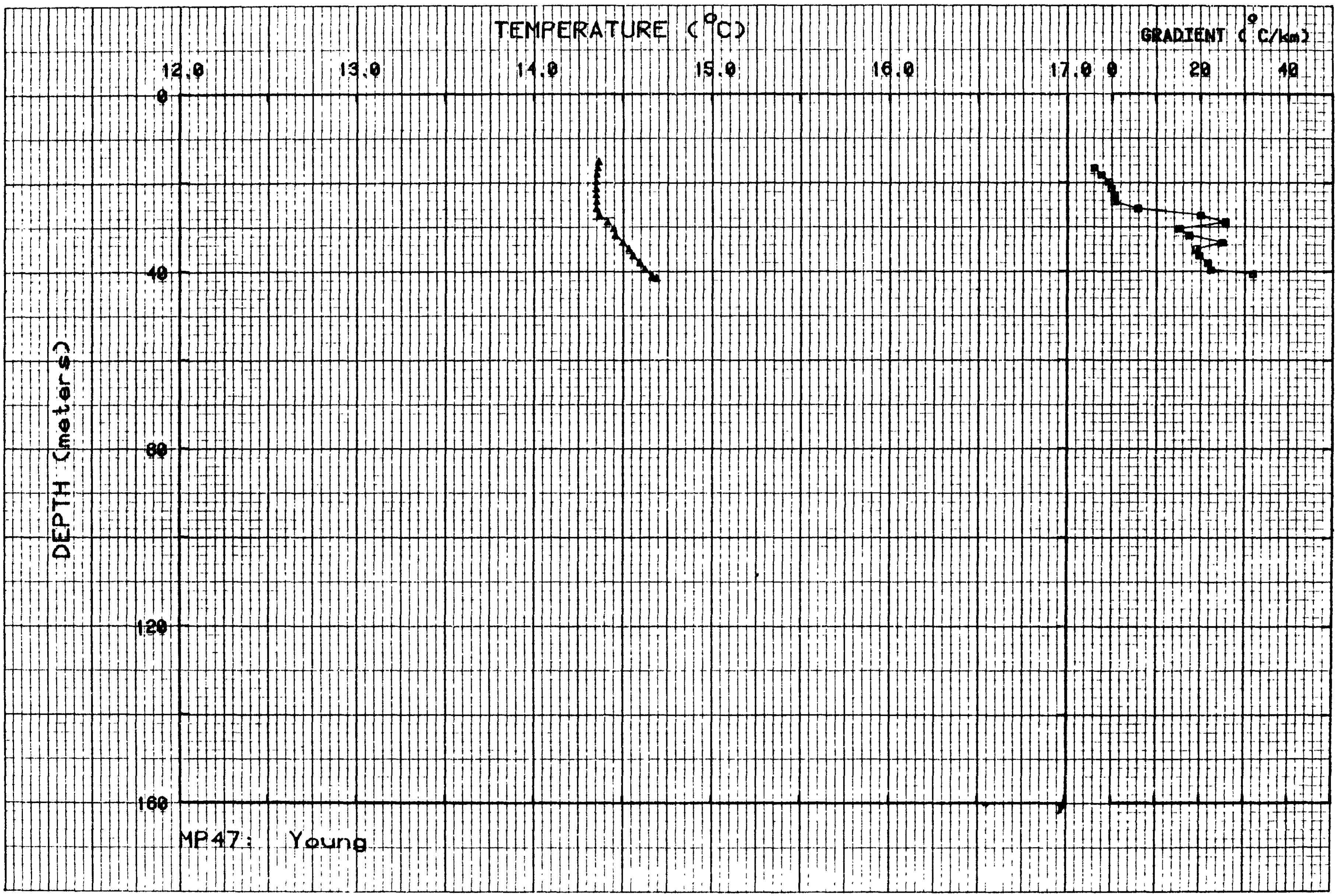

Figure II-46. Temperature and gradient profiles for MP47.

TABLE II-46. Temperature tabulation

Hole: MP47 YOUNG

Lat: 41-33.30 Long: 122-32.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	14.366	16.76	14.359
18.29	14.354	19.81	14.352
21.34	14.352	22.86	14.352
24.38	14.354	25.91	14.354
27.43	14.372	28.96	14.415
30.48	14.450	32.00	14.461
33.53	14.503	35.05	14.537
36.58	14.561	38.10	14.597
39.62	14.627	41.15	14.665
41.61	14.690		

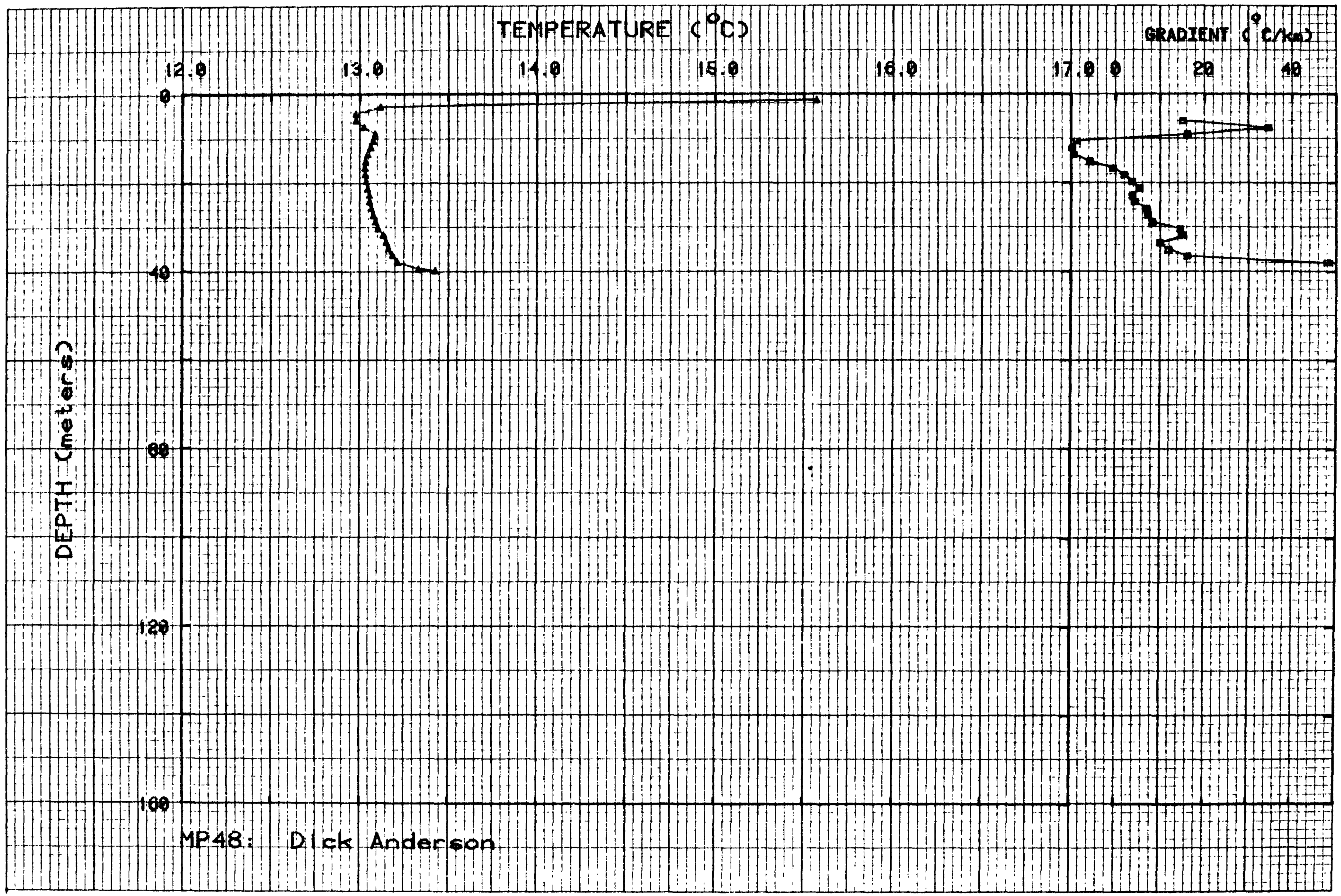

Figure II-47. Temperature and gradient profiles for MP48.

TABLE II-47. Temperature tabulation

Hole: MP48 DICK ANDERSON

Lat: 41-33.30 Long: 122-31.60

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
1.52	15.576	3.05	13.123
4.57	12.984	6.10	12.987
7.62	13.031	9.14	13.093
10.67	13.081	12.19	13.067
13.72	13.052	15.24	13.039
16.76	13.035	18.29	13.038
19.81	13.042	21.34	13.050
22.86	13.059	24.38	13.062
25.91	13.073	27.43	13.084
28.96	13.096	30.48	13.110
32.00	13.141	33.53	13.157
35.05	13.172	36.58	13.194
38.10	13.222	39.62	13.341
40.02	13.435		

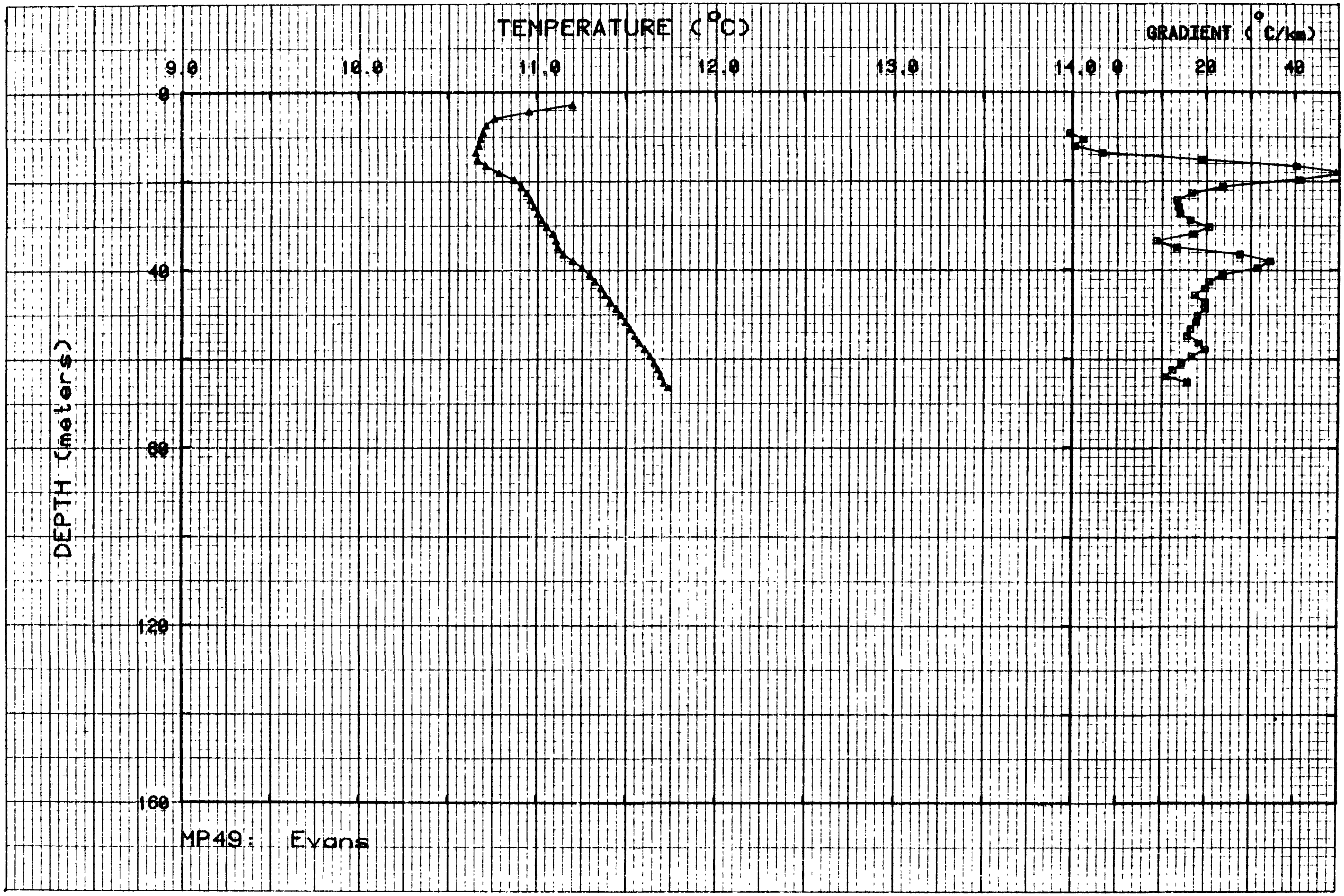

Figure II-48. Temperature and gradient profiles for MP49.

TABLE II-48. Temperature tabulation

Hole: MF49 JOHN EVANS

Lat: 41-25.50 Long: 122-29.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
3.05	11.202	4.57	10.957
6.10	10.763	7.62	10.716
9.14	10.698	10.67	10.684
12.19	10.675	13.72	10.655
15.24	10.665	16.76	10.713
18.29	10.788	19.81	10.872
21.34	10.913	22.86	10.944
24.38	10.964	25.91	10.985
27.43	11.006	28.96	11.028
30.48	11.056	32.00	11.091
33.53	11.108	35.05	11.118
36.58	11.149	38.10	11.202
39.62	11.254	41.15	11.298
42.67	11.326	44.20	11.361
45.72	11.386	47.24	11.414
48.77	11.446	50.29	11.474
51.82	11.501	53.34	11.528
54.86	11.551	56.39	11.576
57.91	11.607	59.44	11.636
60.96	11.658	62.48	11.680
64.01	11.696	65.53	11.713
66.48	11.735		

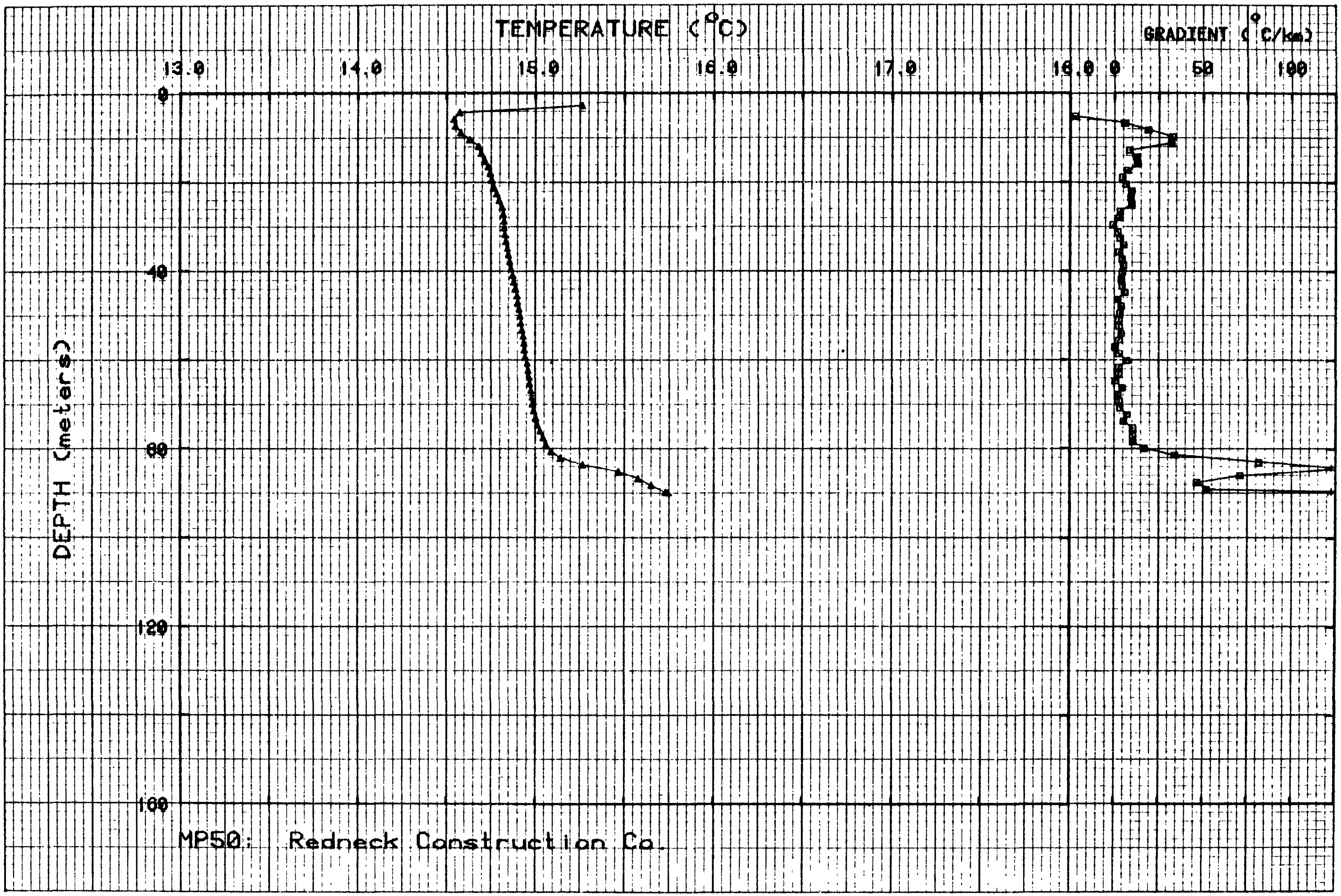

Figure II-49. Temperature and gradient profiles for MP50.

TABLE II-49. Temperature tabulation

Hole: MF50 REDNECK CONST.

Lat: 41-53.30 Long: 122-29.30

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
3.05	15.271	4.57	14.579
6.10	14.546	7.62	14.556
9.14	14.586	10.67	14.637
12.19	14.687	13.72	14.701
15.24	14.721	16.76	14.742
18.29	14.754	19.81	14.762
21.34	14.773	22.86	14.789
24.38	14.804	25.91	14.820
27.43	14.826	28.96	14.831
30.48	14.831	32.00	14.835
33.53	14.841	35.05	14.850
36.58	14.855	38.10	14.863
39.62	14.872	41.15	14.880
42.67	14.887	44.20	14.895
45.72	14.905	47.24	14.909
48.77	14.916	50.29	14.922
51.82	14.927	53.34	14.932
54.86	14.939	56.39	14.944
57.91	14.946	59.44	14.951
60.96	14.963	62.48	14.968
64.01	14.973	65.53	14.975
67.06	14.983	68.58	14.987
70.10	14.992	71.63	14.998
73.15	15.010	74.68	15.019
76.20	15.036	77.72	15.053
79.25	15.070	80.77	15.097
82.30	15.150	83.82	15.275
85.34	15.477	86.87	15.586
88.39	15.658	89.92	15.738
90.01	15.754		

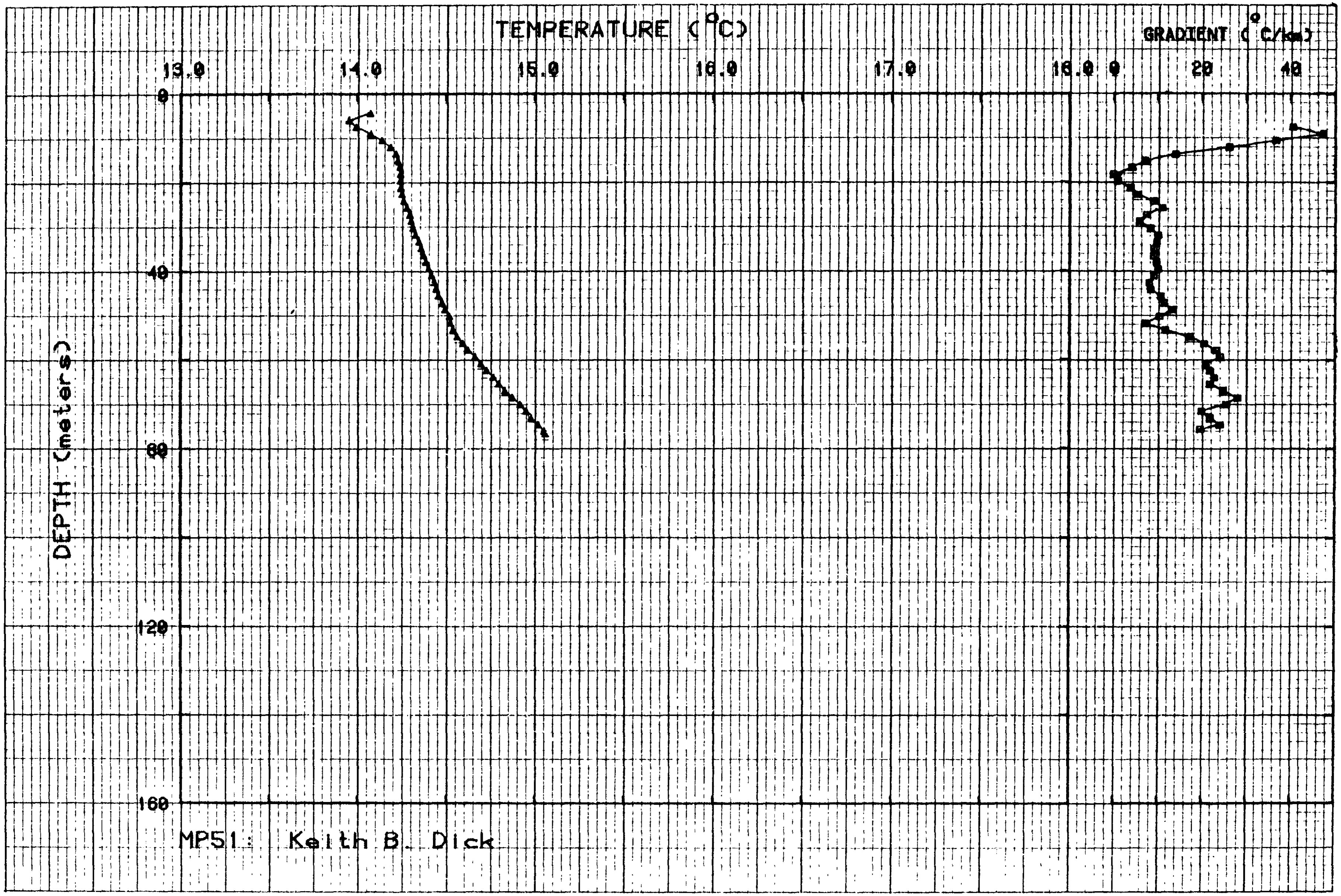

Figure II-50. Temperature and gradient profiles for MP51.

TABLE II-50. Temperature tabulation

Hole: MP51 KEITH B. DICK

Lat: 41-49.40 Long: 122-26.10

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
4.57	14.078	6.10	13.957
7.62	14.000	9.14	14.081
10.67	14.145	12.19	14.193
13.72	14.225	15.24	14.236
16.76	14.247	18.29	14.249
19.81	14.247	21.34	14.252
22.86	14.259	24.38	14.269
25.91	14.287	27.43	14.303
28.96	14.310	30.48	14.321
32.00	14.336	33.53	14.352
35.05	14.366	36.58	14.380
38.10	14.394	39.62	14.410
41.15	14.425	42.67	14.438
44.20	14.450	45.72	14.464
47.24	14.483	48.77	14.499
50.29	14.524	51.82	14.531
53.34	14.546	54.86	14.567
56.39	14.599	57.91	14.630
59.44	14.670	60.96	14.704
62.48	14.734	64.01	14.771
65.53	14.804	67.06	14.838
68.58	14.880	70.10	14.924
71.63	14.958	73.15	14.985
74.68	15.025	76.20	15.059
76.75	15.066		

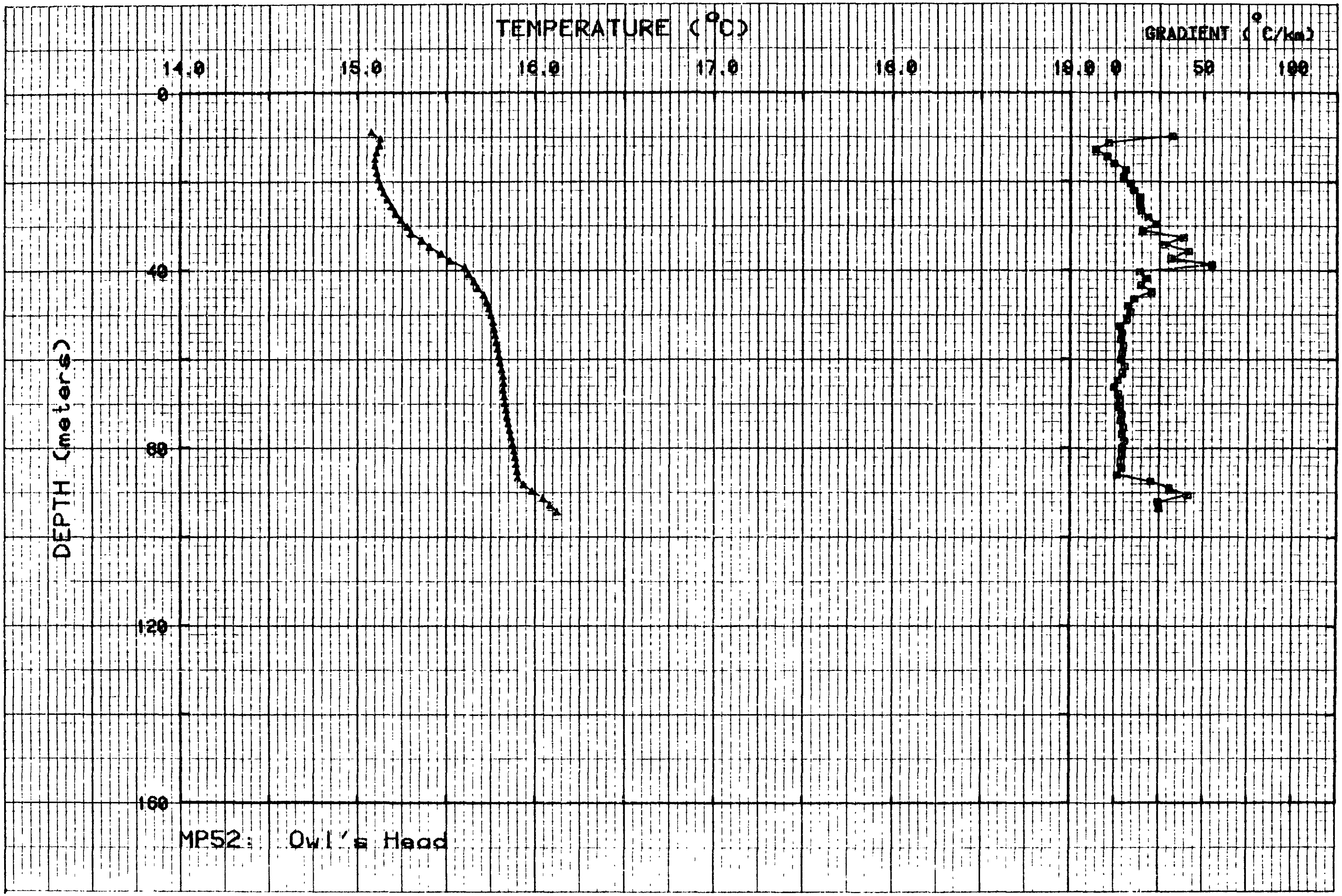

Figure II-51. Temperature and gradient profiles for MP52.

TABLE II-51. Temperature tabulation

Hole: MP52 OWL'S HEAD

Lat: 41-40.30 Long: 122-25.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
9.14	15.083	10.67	15.133
12.19	15.128	13.72	15.112
15.24	15.106	16.76	15.106
18.29	15.116	19.81	15.124
21.34	15.138	22.86	15.155
24.38	15.177	25.91	15.199
27.43	15.222	28.96	15.251
30.48	15.287	32.00	15.311
33.53	15.371	35.05	15.414
36.58	15.478	38.10	15.527
39.62	15.611	41.15	15.633
42.67	15.661	44.20	15.684
45.72	15.716	47.24	15.733
48.77	15.745	50.29	15.759
51.82	15.770	53.34	15.775
54.86	15.782	56.39	15.788
57.91	15.796	59.44	15.803
60.96	15.809	62.48	15.818
64.01	15.825	65.53	15.828
67.06	15.828	68.58	15.832
70.10	15.837	71.63	15.842
73.15	15.849	74.68	15.855
76.20	15.863	77.72	15.870
79.25	15.879	80.77	15.886
82.30	15.893	83.82	15.899
85.34	15.906	86.87	15.909
88.39	15.941	89.92	15.989
91.44	16.053	92.96	16.091
94.49	16.130		

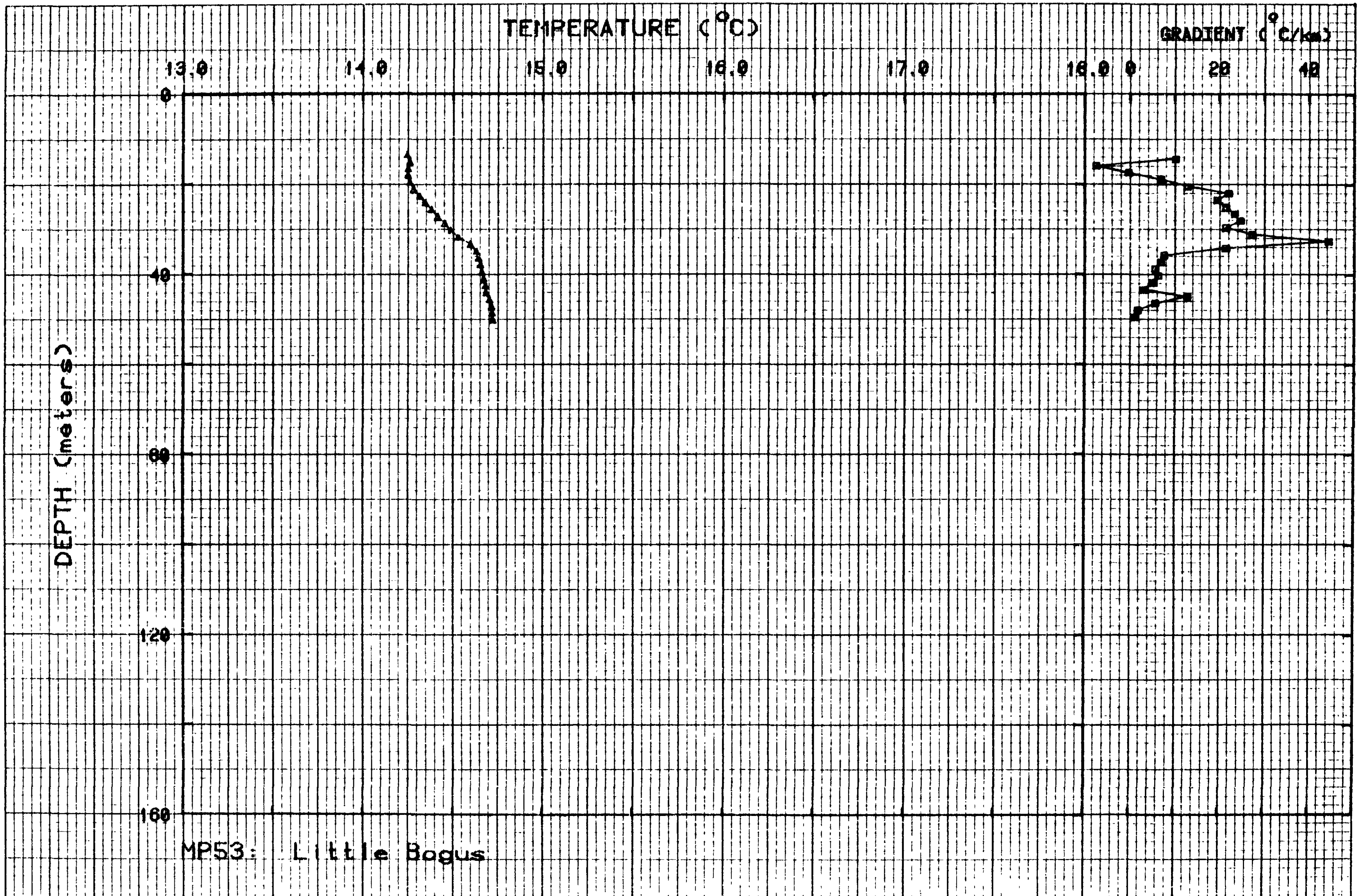

Figure II-52. Temperature and gradient profiles for MP53.

TABLE II-52. Temperature tabulation

Hole: MF53 LITTLE BOGUS

Lat: 41-53.50 Long: 122-23.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
13.72	14.254	15.24	14.270
16.76	14.259	18.29	14.259
19.81	14.270	21.34	14.290
22.86	14.324	24.38	14.354
25.91	14.387	27.43	14.423
28.96	14.461	30.48	14.494
32.00	14.536	33.53	14.604
35.05	14.637	36.58	14.649
38.10	14.660	39.62	14.669
41.15	14.679	42.67	14.687
44.20	14.692	45.72	14.712
47.24	14.721	48.77	14.724
50.29	14.726		

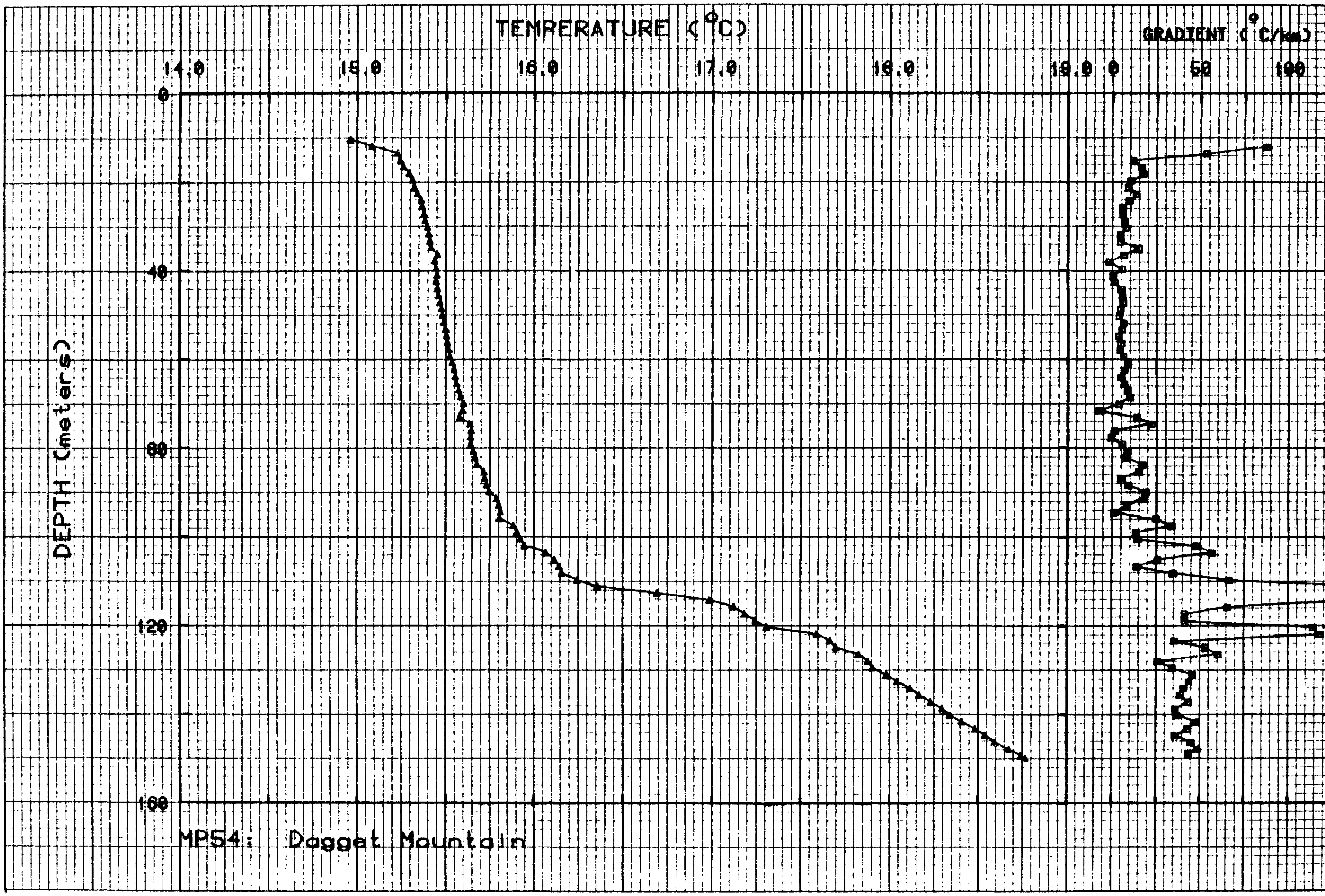

Figure II-53. Temperature and gradient profiles for MP54.

TABLE II-53. Temperature tabulation

Hole: MP54 DAGGETT MTN.

Lat: 41-57.30 Long: 122-19.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
10.67	14.960	12.19	15.080
13.72	15.225	15.24	15.241
16.76	15.259	18.29	15.290
19.81	15.311	21.34	15.320
22.86	15.337	24.38	15.359
25.91	15.364	27.43	15.375
28.96	15.380	30.48	15.394
32.00	15.401	33.53	15.406
35.05	15.414	36.58	15.449
38.10	15.432	39.62	15.442
41.15	15.447	42.67	15.442
44.20	15.449	45.72	15.456
47.24	15.465	48.77	15.473
50.29	15.478	51.82	15.484
53.34	15.496	54.86	15.499
56.39	15.506	57.91	15.513
59.44	15.518	60.96	15.531
62.48	15.543	64.01	15.550
65.53	15.557	67.06	15.569
68.58	15.581	70.10	15.598
71.63	15.591	73.15	15.574
74.68	15.632	76.20	15.640
77.72	15.635	79.25	15.637
80.77	15.651	82.30	15.661
83.82	15.672	85.34	15.712
86.87	15.716	88.39	15.726
89.92	15.742	91.44	15.782
92.96	15.796	94.49	15.805
96.01	15.798	97.54	15.879
99.06	15.899	100.58	15.918
102.11	15.941	103.63	16.062
105.16	16.112	106.68	16.139
108.20	16.153	109.73	16.243
111.25	16.354	112.78	16.689
114.30	16.983	115.82	17.117
117.35	17.181	118.87	17.241
120.40	17.305	121.92	17.587
123.44	17.663	124.97	17.694
126.49	17.823	128.02	17.876
129.54	17.901	131.06	17.979
132.59	18.039	134.11	18.111
135.64	18.162	137.16	18.228
138.68	18.293	140.21	18.336
141.73	18.405	143.26	18.481
144.78	18.535	146.30	18.589
147.83	18.671	149.35	18.736
149.93	18.762		

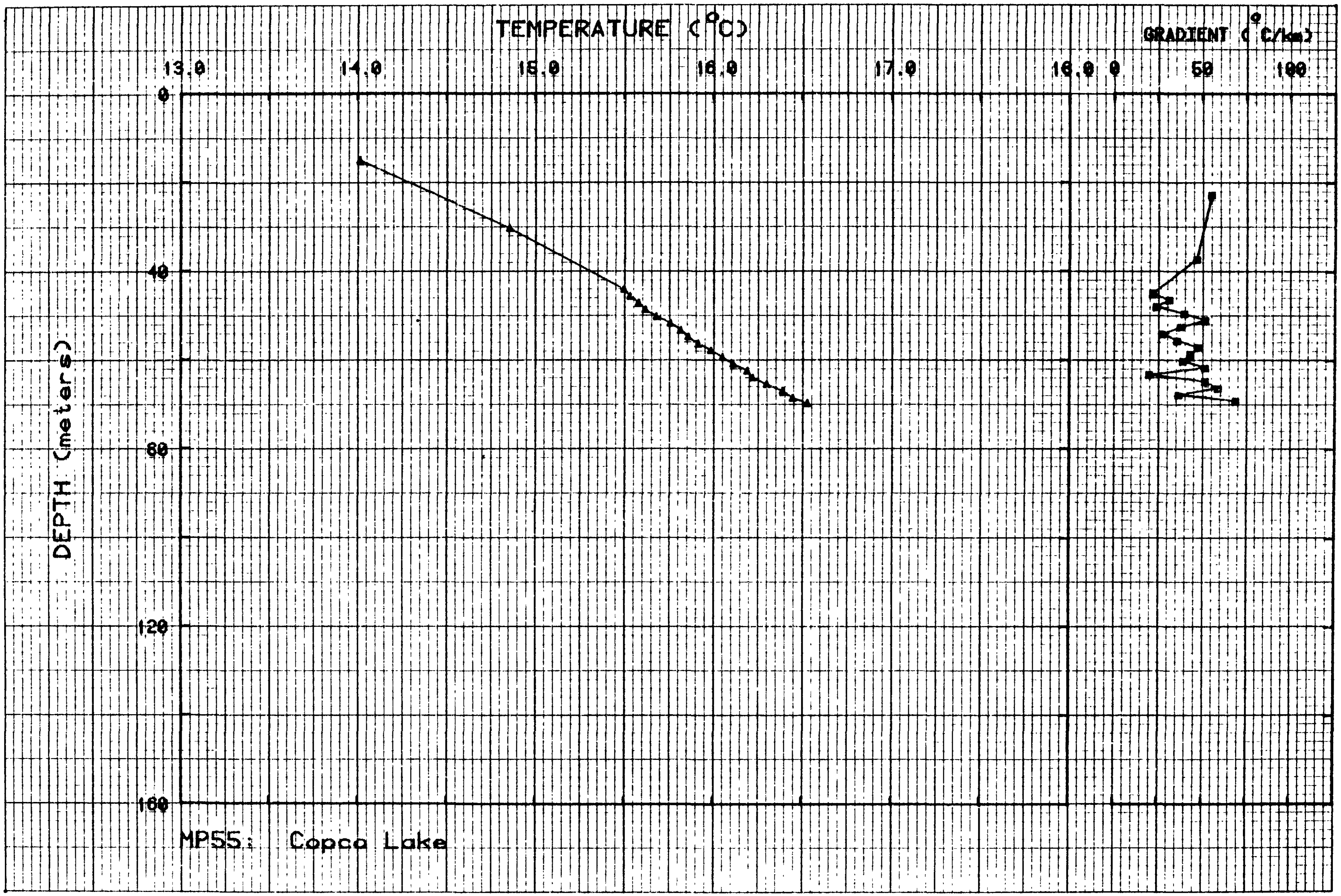

Figure II-54. Temperature and gradient profiles for MP55.

TABLE II-54. Temperature tabulation

Hole: MP55 FAZIOS

Lat: 41-58.60 Long: 122-18.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	14.017	30.48	14.860
44.20	15.504	45.72	15.538
47.24	15.586	48.77	15.623
50.29	15.684	51.82	15.763
53.34	15.821	54.86	15.863
56.39	15.918	57.91	15.991
59.44	16.057	60.96	16.117
62.48	16.196	64.01	16.227
65.53	16.306	67.06	16.396
68.58	16.452	69.77	16.534

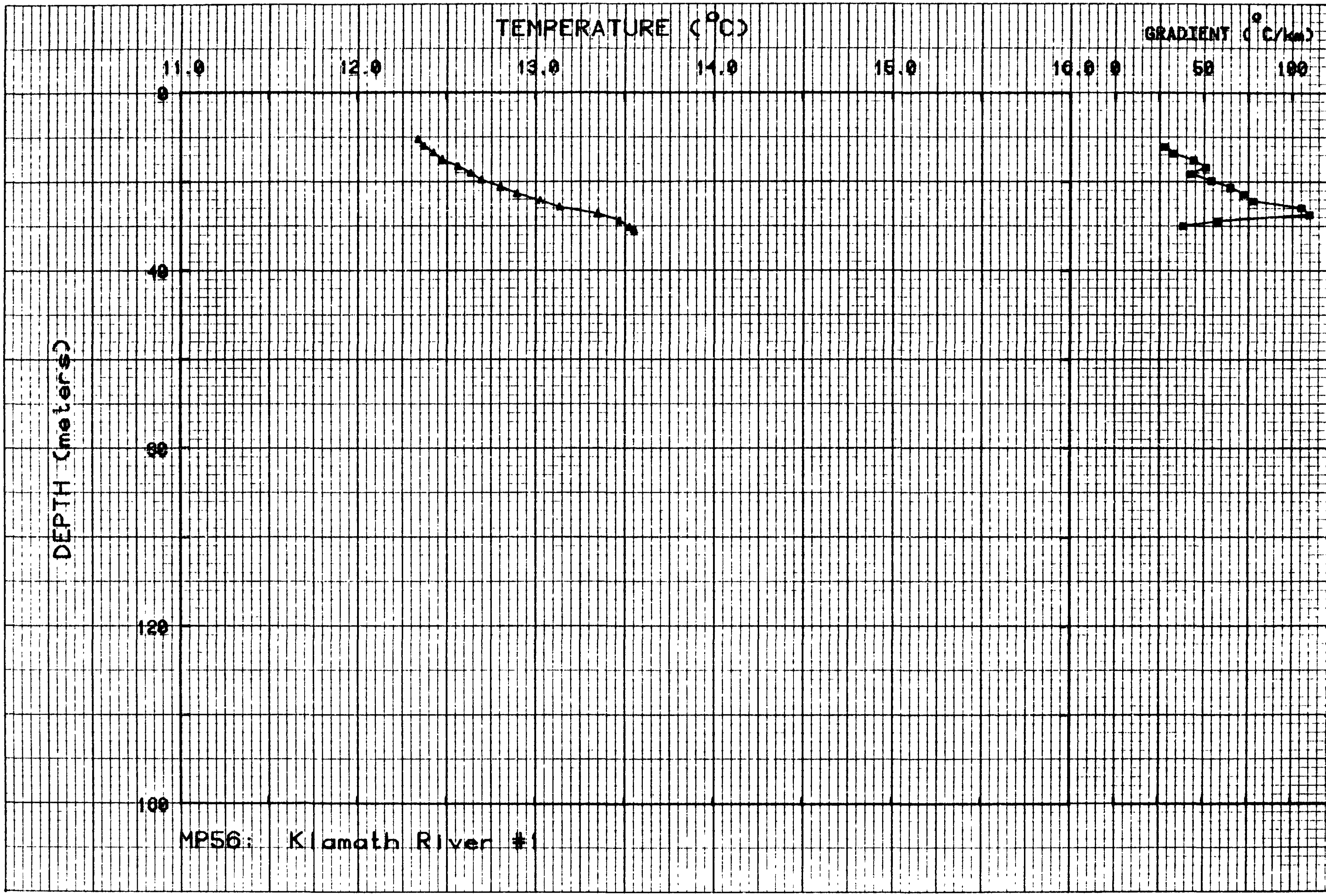

Figure II-55. Temperature and gradient profiles for MP56.

TABLE II-55. Temperature tabulation

Hole: MP56 COPCO

Lat: 41-53.20 Long: 122-28.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
10.67	12.348	12.19	12.382
13.72	12.436	15.24	12.486
16.76	12.573	18.29	12.644
19.81	12.705	21.34	12.812
22.86	12.905	24.38	13.035
25.91	13.144	27.43	13.358
28.96	13.481	30.48	13.536
31.06	13.563		

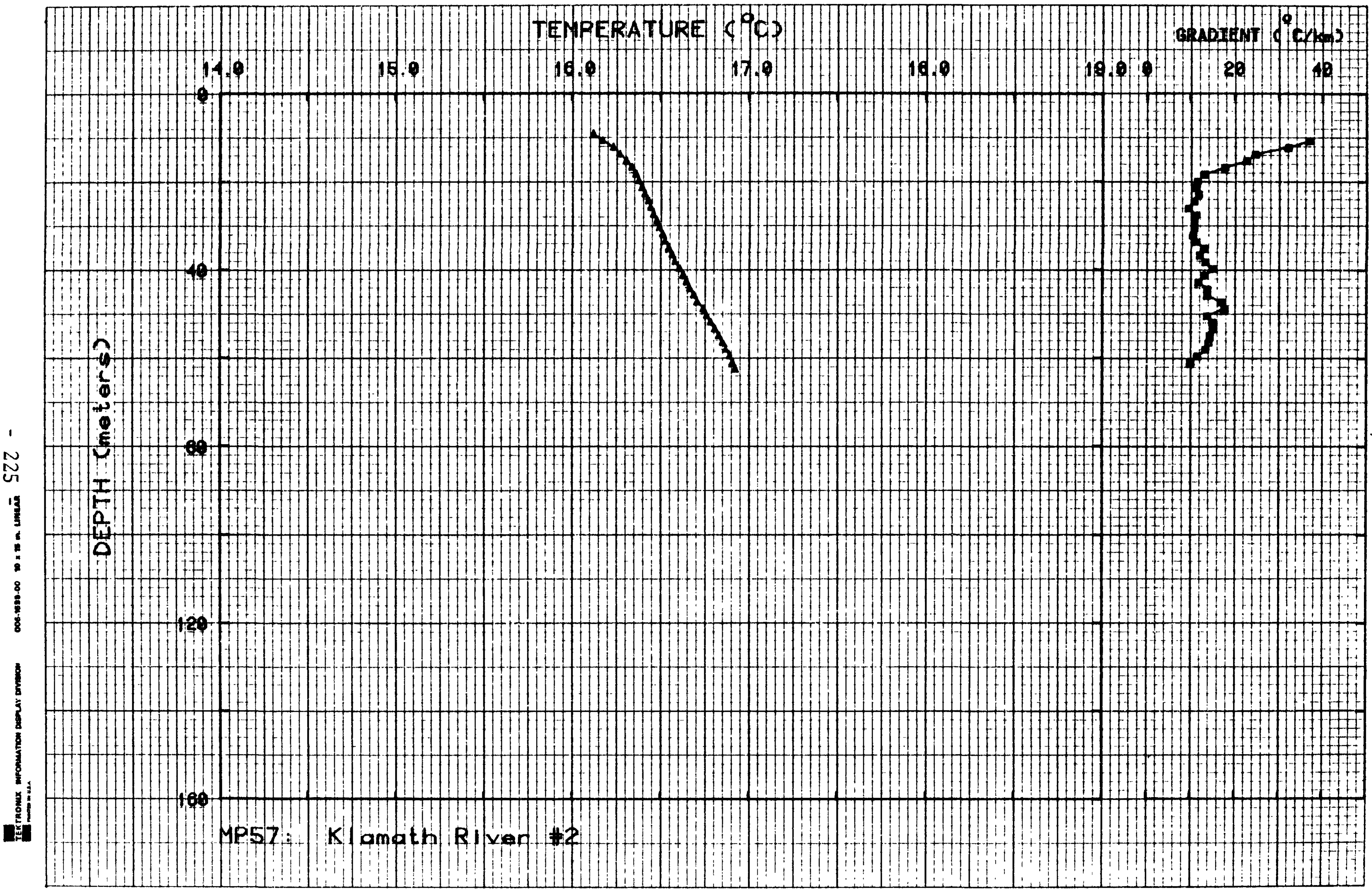

Figure II-56. Temperature and gradient profiles for MP57.

TABLE II-56. Temperature tabulation

Hole: MP57 JOE SCALERA

Lat: 41-53.90 Long: 122-29.00

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
9.14	16.123	10.67	16.175
12.19	16.236	13.72	16.273
15.24	16.311	16.76	16.342
18.29	16.365	19.81	16.382
21.34	16.400	22.86	16.416
24.38	16.436	25.91	16.449
27.43	16.465	28.96	16.483
30.48	16.498	32.00	16.516
33.53	16.530	35.05	16.550
36.58	16.570	38.10	16.587
39.62	16.611	41.15	16.633
42.67	16.651	44.20	16.669
45.72	16.693	47.24	16.711
48.77	16.745	50.29	16.765
51.82	16.787	53.34	16.811
54.86	16.833	56.39	16.855
57.91	16.876	59.44	16.896
60.96	16.911	62.42	16.926

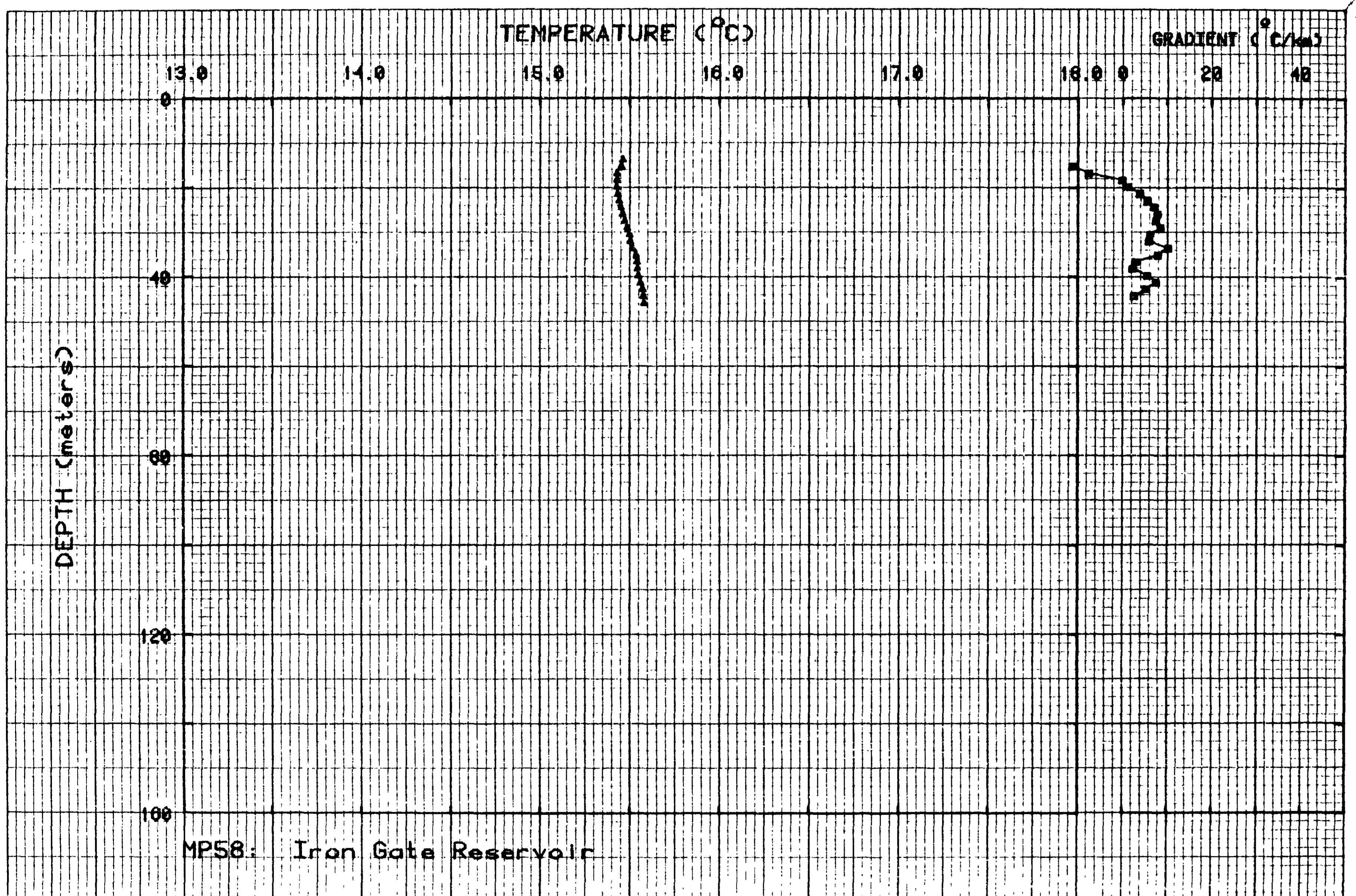

Figure II-57. Temperature and gradient profiles for MP58.

TABLE II-57. Temperature tabulation

Hole: MP58 TOM TREADWAY

Lat: 41-53.90 Long: 122-31.50

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
13.72	15.466	15.24	15.456
16.76	15.432	18.29	15.433
19.81	15.432	21.34	15.437
22.86	15.444	24.38	15.454
25.91	15.466	27.43	15.478
28.96	15.489	30.48	15.504
32.00	15.508	33.53	15.522
35.05	15.539	36.58	15.546
38.10	15.548	39.62	15.553
41.15	15.565	42.67	15.576
44.20	15.581	45.72	15.584

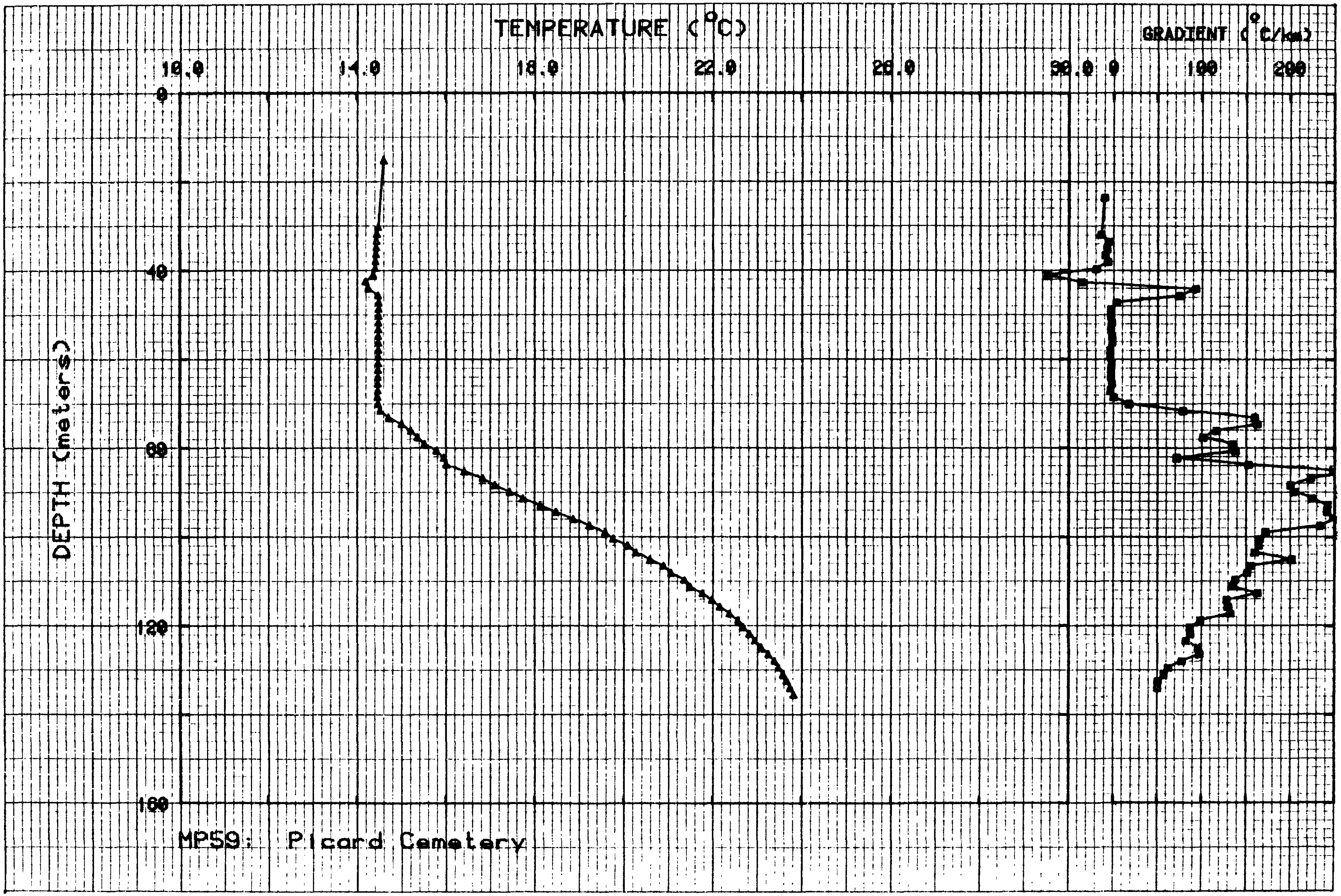

Figure II-58. Temperature and gradient profiles for MP59.

TABLE II-58. Temperature tabulation

Hole: MP59 PICARD CEMETARY

Lat: 41-58.40 Long: 121-58.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	15.553	30.48	14.517
32.00	14.488	33.53	14.479
35.05	14.478	36.58	14.461
38.10	14.453	39.62	14.446
41.15	14.398	42.67	14.225
44.20	14.293	45.72	14.512
47.24	14.526	48.77	14.526
50.29	14.521	51.82	14.521
53.34	14.519	54.86	14.517
56.39	14.519	57.91	14.517
59.44	14.511	60.96	14.509
62.48	14.508	64.01	14.504
65.53	14.504	67.06	14.503
68.58	14.498	70.10	14.508
71.63	14.556	73.15	14.752
74.68	15.046	76.20	15.251
77.72	15.404	79.25	15.564
80.77	15.819	82.30	15.986
83.82	16.041	85.34	16.454
86.87	16.863	88.39	17.138
89.92	17.476	91.44	17.767
92.96	18.164	94.49	18.509
96.01	18.904	97.54	19.273
99.06	19.621	100.58	19.800
102.11	20.127	103.63	20.304
105.16	20.616	106.68	20.922
108.20	21.090	109.73	21.386
111.25	21.512	112.78	21.797
114.30	22.012	115.82	22.191
117.35	22.411	118.87	22.598
120.40	22.714	121.92	22.867
123.44	22.984	124.97	23.122
126.49	23.280	128.02	23.422
129.54	23.519	131.06	23.615
132.59	23.698	134.11	23.733
135.64	24.055		

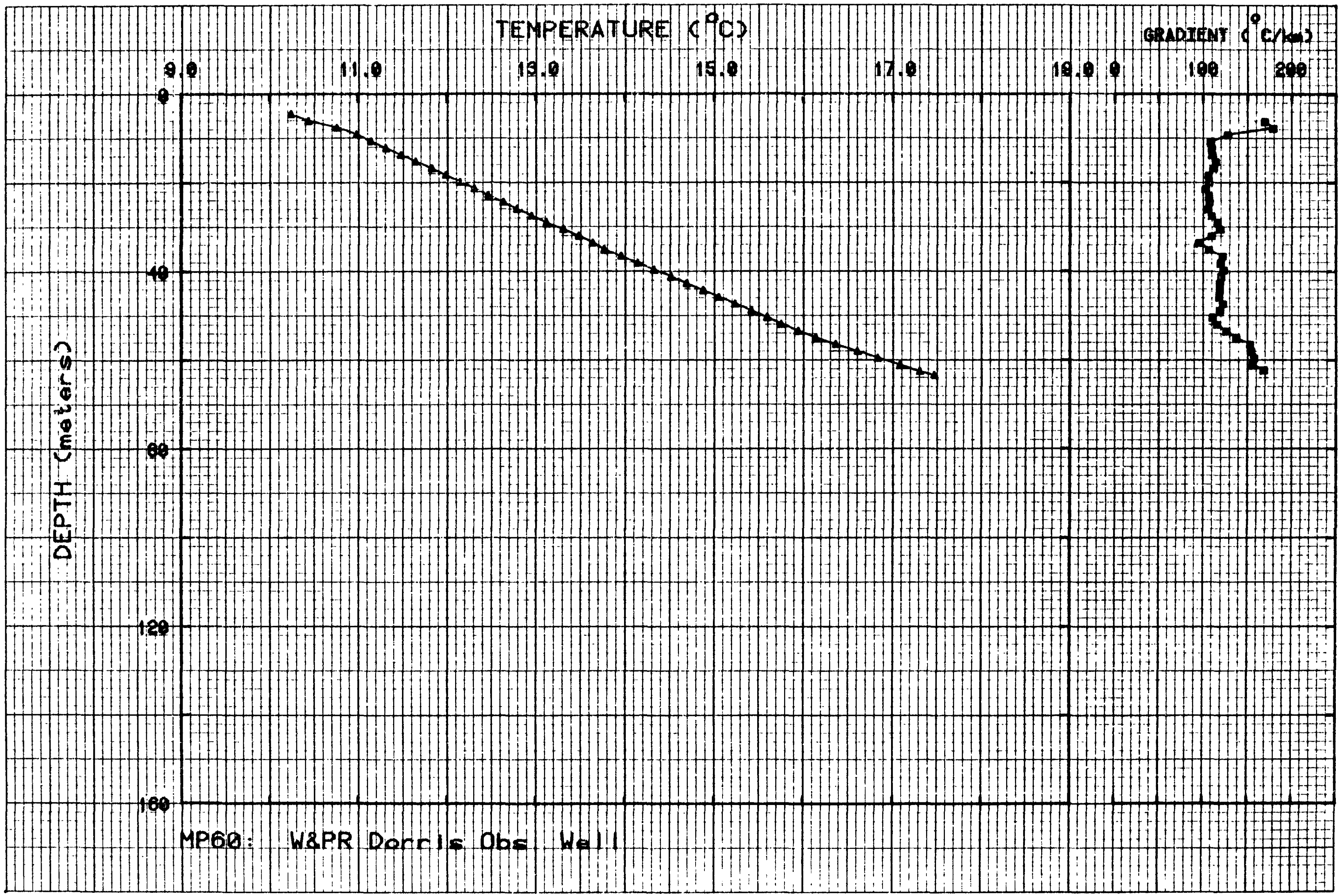

Figure II-59. Temperature and gradient profiles for MP60.

TABLE II-59. Temperature tabulation

Hole: MP60 DORRIS OBSERVATION

Lat: 41-57.10 Long: 121-59.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
4.57	10.245	6.10	10.440
7.62	10.761	9.14	10.985
10.67	11.149	12.19	11.314
13.72	11.482	15.24	11.649
16.76	11.828	18.29	11.987
19.81	12.150	21.34	12.310
22.86	12.462	24.38	12.634
25.91	12.787	27.43	12.954
28.96	13.120	30.48	13.307
32.00	13.481	33.53	13.638
35.05	13.770	36.58	13.961
38.10	14.141	39.62	14.324
41.15	14.514	42.67	14.689
44.20	14.875	45.72	15.049
47.24	15.234	48.77	15.420
50.29	15.595	51.82	15.756
53.34	15.946	54.86	16.139
56.39	16.363	57.91	16.603
59.44	16.831	60.96	17.080
62.48	17.304	63.28	17.468

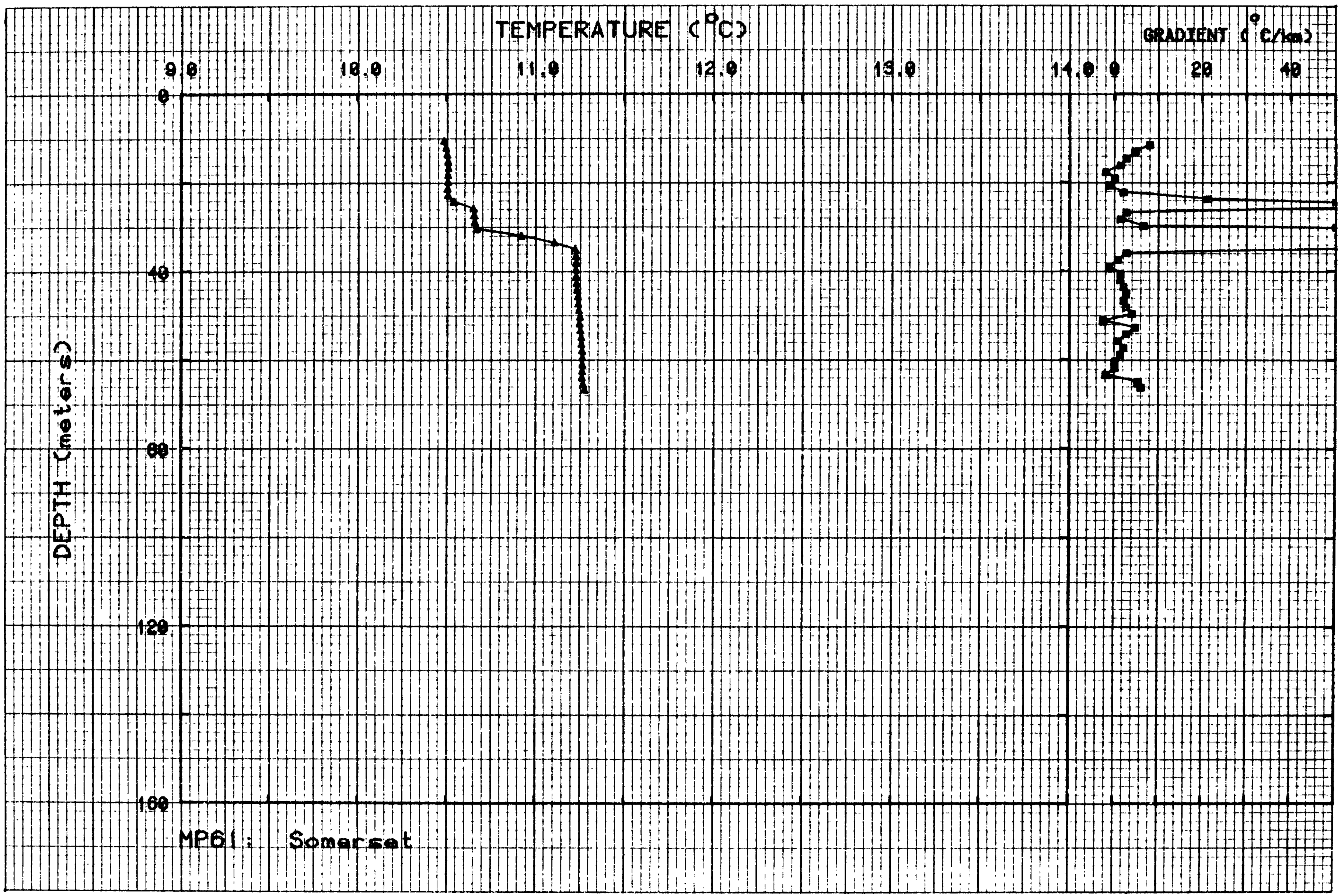

Figure II-60. Temperature and gradient profiles for MP61.

TABLE II-60. Temperature tabulation

Hole: MF61 SOMERSET

Lat: 41-51.30 Long: 121-59.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
10.67	10.484	12.19	10.496
13.72	10.503	15.24	10.507
16.76	10.509	18.29	10.506
19.81	10.506	21.34	10.504
22.86	10.507	24.38	10.539
25.91	10.651	27.43	10.655
28.96	10.657	30.48	10.667
32.00	10.920	33.53	11.106
35.05	11.223	36.58	11.227
38.10	11.228	39.62	11.226
41.15	11.228	42.67	11.230
44.20	11.233	45.72	11.237
47.24	11.240	48.77	11.244
50.29	11.250	51.82	11.246
53.34	11.253	54.86	11.257
56.39	11.258	57.91	11.261
59.44	11.263	60.96	11.263
62.48	11.263	64.01	11.260
65.53	11.268	66.69	11.275

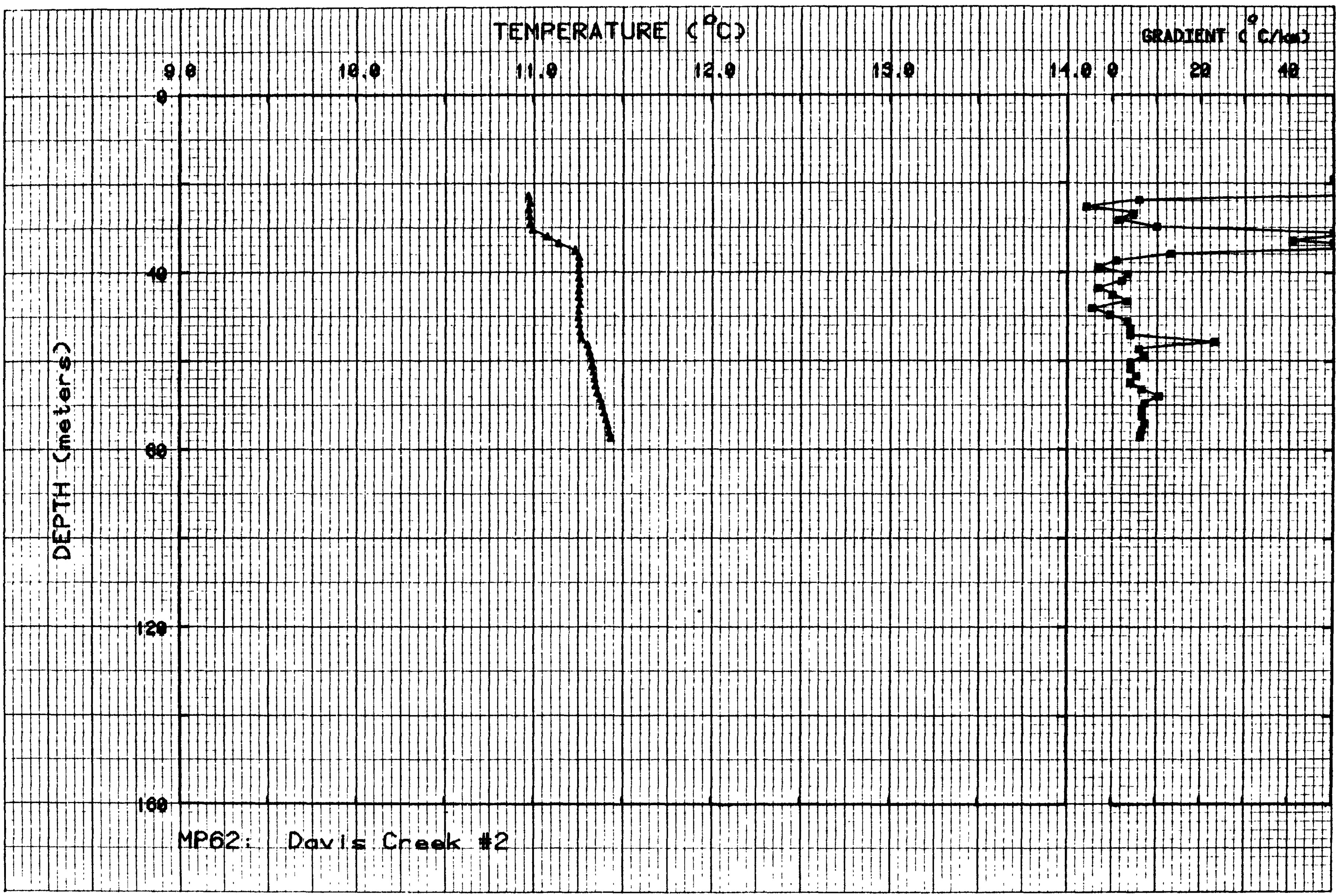

Figure II-61. Temperature and gradient profiles for MP62.

TABLE II-61. Temperature tabulation

Hole: MP62 WESTSIDE RANCH

Lat: 41-44.00 Long: 120-22.70

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
15.24	9.394	22.86	10.969
24.38	10.978	25.91	10.969
27.43	10.976	28.96	10.978
30.48	10.993	32.00	11.077
33.53	11.139	35.05	11.234
36.58	11.254	38.10	11.255
39.62	11.250	41.15	11.255
42.67	11.258	44.20	11.253
45.72	11.253	47.24	11.258
48.77	11.251	50.29	11.250
51.82	11.255	53.34	11.261
54.86	11.267	56.39	11.302
57.91	11.311	59.44	11.322
60.96	11.328	62.48	11.334
64.01	11.342	65.53	11.348
67.06	11.358	68.58	11.374
70.10	11.385	71.63	11.395
73.15	11.405	74.68	11.416
76.20	11.426	77.48	11.434

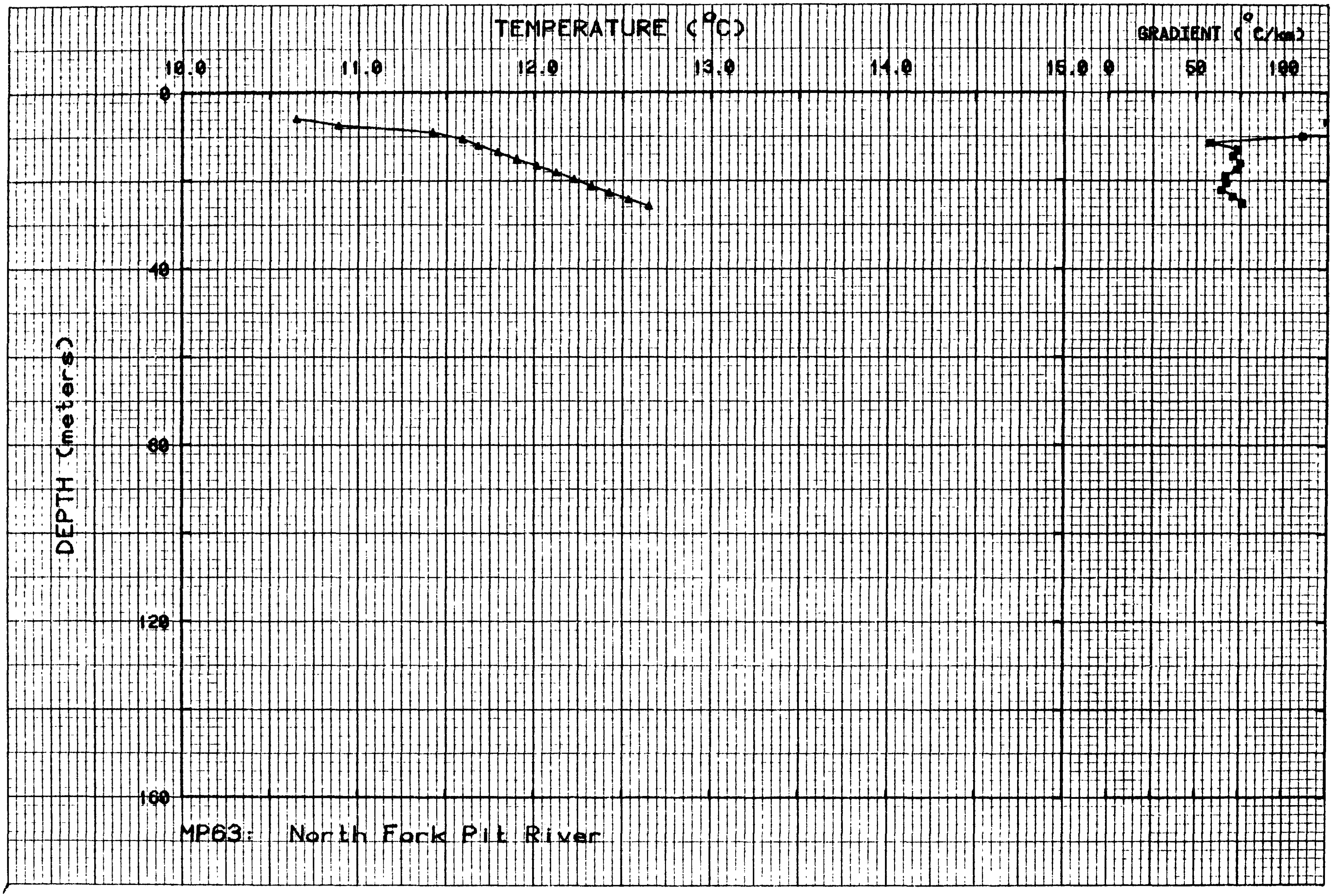

Figure II-62. Temperature and gradient profiles for MP63.

TABLE II-62. Temperature tabulation

Hole: MF63 DAVIS CREEK

Lat: 41-38.50 Long: 120-23.90

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	10.651	7.62	10.890
9.14	11.424	10.67	11.593
12.19	11.681	13.72	11.793
15.24	11.901	16.76	12.015
18.29	12.126	19.81	12.227
21.34	12.329	22.86	12.427
24.38	12.535	25.91	12.651

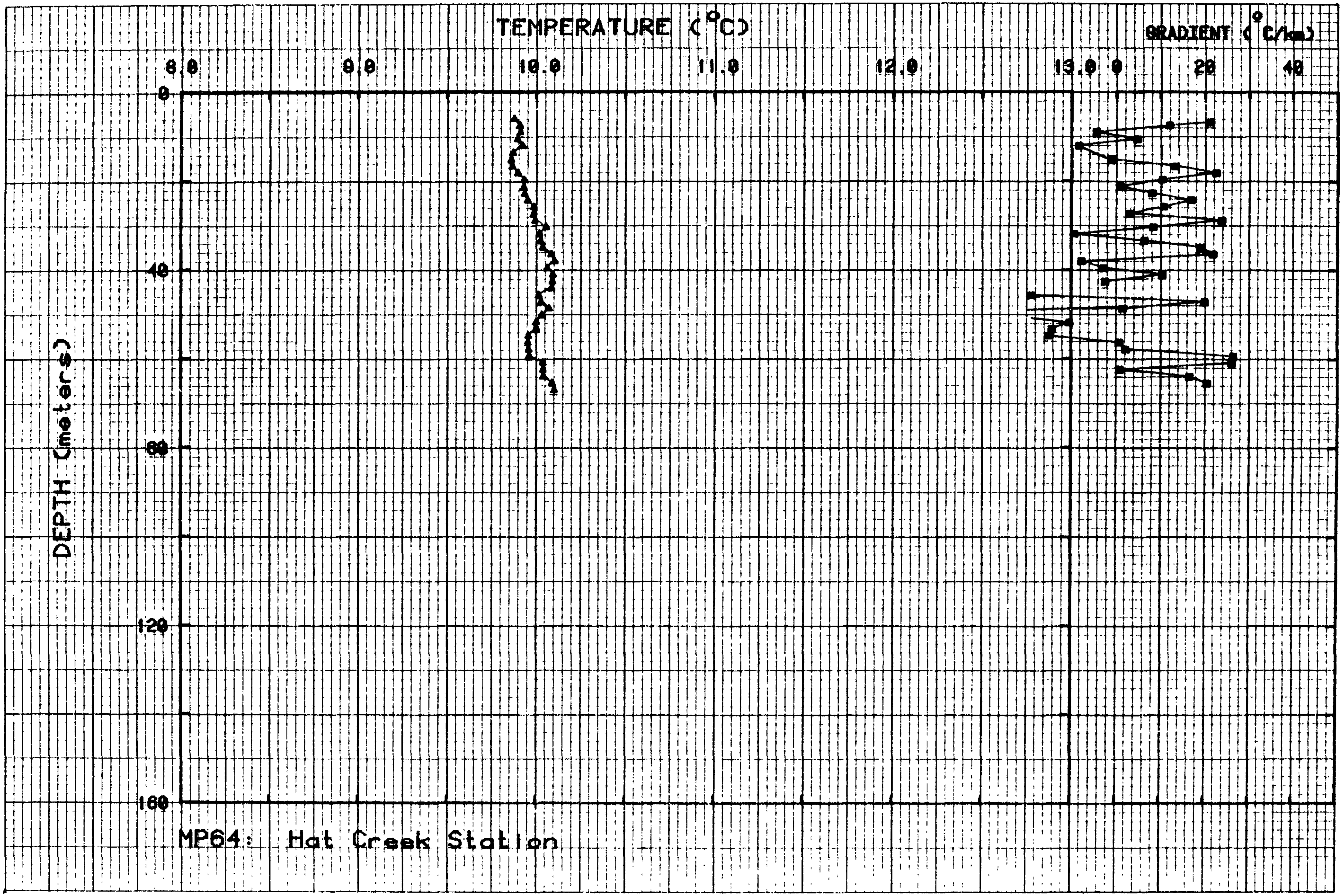

Figure II-63. Temperature and gradient profiles for MP64.

TABLE II-63. Temperature tabulation

Hole: MF64 HAT CREEK STATION

Lat: 40-48.30 Long: 121-30.80

Depth (m)	Temp (deg C)	Depth (m)	Temp (deg C)
6.10	9.873	6.10	9.871
7.62	9.905	9.14	9.907
10.67	9.891	12.19	9.921
13.72	9.865	15.24	9.854
16.76	9.861	18.29	9.894
19.81	9.929	21.34	9.925
22.86	9.931	24.38	9.949
25.91	9.982	27.43	9.981
28.96	9.991	30.48	10.053
32.00	10.016	33.53	10.024
35.05	10.035	36.58	10.082
38.10	10.101	39.62	10.058
41.15	10.092	42.67	10.089
44.20	10.084	45.72	10.011
47.24	10.026	48.77	10.071
50.29	10.030	51.82	9.998
53.34	9.998	54.86	9.954
56.39	9.952	57.91	9.956
59.44	9.958	60.96	10.036
62.48	10.037	64.01	10.038
65.53	10.087	67.06	10.100