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Letter Report

STATUS OF THERMAL OBSERVATIONS AT YUCCA MOUNTAIN, NEVADA

by

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This document is preliminary and is for internal circulation only within the USGS and DOE.

INTRODUCTION

A series of precise temperature logs was obtained from all available wells at the Yucca Mountain site between March 8 and 11, 1983. At this point, we feel it appropriate to summarize informally, the status of thermal observations in the area. This report contains the latest temperature logs together with time series for wells that have been logged more than once. In addition to the logs, we present such comments as we feel are relevant to interpreting the wiggles. In this latest series of measurements, we have tried to obtain as much information as is practicable within the unsaturated zone.

NOTES ON PRESENTATION OF DATA

The most recent log (and occasionally the previous one) are presented as temperature-depth profiles together with smoothed gradient-depth profiles. This format was generally not suitable for displaying the time-series of logs. For these cases, we plotted relative temperature versus depth using an arbitrary temperature origin. The leftmost profile (e.g., Figure 2) is the earliest. Later profiles are identified by month and year and are stepped to the right by a sufficient amount relative to the first curve (shown below the date in °C) to separate data from successive logs. All measurements made in air in the unsaturated zone are indicated as discrete symbols joined by straight lines.

THE CONDUCTOR WELLS

This series of four shallow wells was originally drilled to investigate a geoelectric anomaly within the unsaturated zone in Drill Hole Wash. All but one (Ue25a-6) were drilled within the main drainage of the wash. The wells were drilled with mud and water and considerable fluid loss occurred. Early logs showed some quite bizarre departures from the linear temperature profiles characteristic of steady-state one-dimensional heat flow, including temperature reversals (Figures 2, 3, 5, and 7-9). Most of the reversals and high-frequency noise did decay conductively with time, indicating that they were drilling-related. There remain, however, irregularities and large contrasts in thermal gradient that cannot be explained by pure conduction, and must be associated with vertical and lateral movement of fluids (air, water vapor and liquid water) within the unsaturated zone in Drill Hole Wash.

Ue25a4 and 5 were not available for logging so that we show only the time series ending in December of 1981 (Figures 2 and 3). The most prominent steady-state anomalies are the large changes in gradient in the 250-300 foot depth range.

Ue25a6 which is sited above the main surface drainage of Drill Hole Wash and is close to USWG4, the site of the exploratory shaft (Figure 1), does not show this gradient break and has an average gradient of about 25°C km^{-1} below 180 feet (Figure 4). The time series for Ue25a6 (Figure 5) is a good example of the conductive decay of thermal transients resulting from the loss of drilling fluid. Temperatures in Ue25a7 (Figures 6-9) still indicate considerable disturbance. In fact, above 500 feet, the latest log (Figures 7-9) shows a remarkable resemblance to the first log made two years previously in March 1981. By contrast, temperature disturbances below a vertical depth of 500 feet appear to be decaying conductively. We know of no renewed circulation of fluids in this well between the last two logs (December 1981 and March 1983). We can speculate that the remarkable change in the temperature profile above 500 feet was the result of lateral water movement in the main drainage of Drill Hole Wash arising from a major storm that occurred a =ek or so before the log was obtained.

Ue25b1H. This well is also collared near the main surface drainage of Drill Hole Wash (Figure 1) and some degree of disturbance to the temperature field is evident in the unsaturated zone. Between 2000 and 2850 feet, the profile is nearly isothermal and suggests a substantial component of downward water flow. Below a depth of 3300 feet (1 km) the profile is linear with a gradient of about 25°C km^{-1} which should yield a heat flux of between 40 and 50 mWm^{-2}, depending on the thermal conductivities. This heat flux is typical of much of the test site and of the "Eureka Low."

Forty-Mile Wash Ue29a2. Ue29a2 is not shown on the map (Figure 1). It is located some 10 km NW of USWG2 near the main surface drainage of Forty-Mile Wash. Static water level was just below 100 feet below which temperatures increased very slightly (~10°C km^{-1}) to a depth of nearly 300 feet (Figure 12) whereupon there was a reversal and erratic temperature variations to the total accessible depth of 550 feet. It would appear that the thermal regime at this site is dominated by lateral water movement in Forty-Mile Wash with just over 0.5°C variation in temperature in the accessible portion of the hole.

The "G" Series, Yucca Mountain. These wells were drilled primarily to obtain geologic data, although considerable hydrologic and other information also was obtained from them. They generally were completely cored to allow for detailed studies of lithology, fracture density, and physical properties. We have made thermal conductivity measurements in all but G-4 for which measurements are in progress.

USW G1. Hole G1 has been instrumented by Sandia Corporation and is unavailable for temperature measurements. For completeness sake, we include here the time series comprising complete logs in September 1980 and April 1981. Temperature gradients (which unfortunately had not reached equilibrium by the time of our last log) increase systematically to 3500 feet or so whereupon they become essentially constant at about 30°C/km yielding a mean heat flux of about 53 mWm^{-2} below 1 km (see Table 2, USGS Open-File Report 82-973). Our preliminary interpretation involved vertical water movement with seepage velocity of ~1 cm/y to depths of 2 to 2.5 km, an interpretation that ignores the essentially constant heat flow below 1.1 km in this well but accounts for its anomalously low value.

USWG2: Temperatures to about 2000 feet are similar to those in G1 and other deep wells in the area. There is then a step rise in temperatures (Figures 14 and 15) followed by about 500 feet that is nearly isothermal whereupon a quasi-conductive gradient is established to total depth of 4100 feet. The least-squares gradient between 2600 and 4100 feet is about 41±0.1°C/km which when combined with the average thermal conductivity of 1.74±0.04 Wm^{-1} K^{-1} yields a typical Basin and Range heat flux of 71 mWm^{-2} (1.7 HFU). The high gradient is, however, probably reflecting the anomalously low temperature boundary at 2500 feet brought on by water moving vertically downward from ~2000 feet. A more realistic gradient would probably be obtained by joining the top edge of the "stairstep" at 2000 feet to the bottom-hole temperature. This gradient (31° km^{-1}) yields a heat flow of 54 mWm^{-2} -- in agreement with that from G1.

USWG-3. This is the most southerly of three wells drilled on the steep ridge immediately to the west of Drill Hole Wash. The water table here is exceptionally deep (~2500 feet, Figures 16 and 17). Below the water table, the temperature profile shows evidence for both upward and downward water movement. The linear part of the profile between about 3300 and 4200 feet has a thermal gradient of about 21°C km^{-1}. For a mean conductivity in the saturated zone of 1.58 ± 0.05 Wm^{-1} K^{-1} (25 samples), we estimate a heat flux of 33 mWm^{-2} (0.8 HFU).

USWG-4. G4 is the most recently completed well and is the proposed site of the exploratory shaft. The temperature gradient (Figure 18) increases from about 18°C km^{-1} between 500 and 1300 feet to about 30°C km^{-1} between 1300 and 1760 feet (approximate water table). The profile below the water table is nonconductive and is consistent with upward water movement from near the bottom of the well, exiting near the water table.

The "H" series, Yucca Mountain. By contrast with the previous series with which it is interspersed (Figure 1), these wells were drilled primarily for hydrologic studies. As such, they have larger diameters, typically contain a number of piezometer tubes, and have a very limited amount of core available for properties measurements. Between our November 1982 and March 1983 loggings, all of these sites (except H1) were reoccupied and packers were set near the bottom to aid in the estimation of head gradients.

USWH1. This well is only about 0.5 km WSW of G1, and it has a similar temperature profile with the exception of the lowermost 500 feet. Below 5500 feet, the gradient decreases systematically from ~30 to less than 20 °C km^{-1} (Figure 19). A piezometer was grouted in to nearly total depth in September(?) of 1982. Post-grout profiles show very little change from pre-grout (Figure 20) indicating that water is probably moving upward in the formation in this interval.

USWH3. The temperature gradient in USWH3 between 3200 and 3900 feet averages about 19°C km^{-1}, similar to that observed in the linear portion of

USWG3. H3 is about 1.5 km north of G3 on the west ridge of Yucca Mountain (Figure 1). The temperature profiles (Figures 21 and 22) illustrate once more the great depth to the water table and the abnormally low thermal gradients found on the ridge.

USWH4. H4 is located on the flank of the west ridge on one of the eastward drainages. The thermal profile becomes linear and apparently conductive below 3300 feet (Figures 23 and 24) with a value of 25.5 °C km^{-1}.

USWH5. This well is the northernmost of the three deep wells on the ridge. Characteristically, the water table is very deep (>2300 feet) and non-conductive processes predominate to a depth of over 3400 feet (Figures 25 and 26). Below this depth, there is a quasi-linear profile with gradient of 28.5 °C km^{-1}; the average gradient below the static water level is ~15°C km^{-1}.

USWH6. H6 is located on the west and slightly south of H5 in a subsidiary drainage northwest of Crater Flat (Figure 1). Because of its lower elevation, the static water level is higher than for G3, H3, and H5 on the ridge (compare Figures 26 and 28). Below 2900 feet, the temperature profile is essentially conductive, with a gradient of 36°C/km. For the same conductivities, this will yield a significantly higher heat flux (65 mWm^{-2} or 1.55 HFU) than that from many of the other wells.

SOME ADDITIONAL REMARKS AND SUMMARY

From the recent set of temperature logs, it appears that (with the possible exception of USWG4) temperatures in all wells are approaching thermal equilibrium. From the information contained in Figures 2 through 29, we may make the following observations:

1) Temperature profiles in the unsaturated zone show a great deal of variation from well to well. The general tendency is for gradients to increase with depth, consistent with a regional hydrologic recharge with vertical (Darcian) flow velocity of a few mm y^{-1}. The "conductor" wells situated in the main drainage of Drill Hole Wash show long-lived drilling disturbances combined with quasi steady-state and transient perturbations caused by fluid movement. In one instance (UE25a7) there appears to have occurred a sudden and dramatic change in the character of the temperature profile perhaps related to a major storm that occurred early in March.

2) Between the static water level and depths of about 1 km, temperature profiles are quite erratic and vary laterally, showing evidence of upward flow in some wells and downward or lateral flow in others. This thermally chaotic zone was the original focus of attention as potentially the most suitable repository depths.

3) Below depths of ~1 km (Figures 29 and 30), there is very little evidence for vertical water movement, and most temperature profiles reflect heat flow primarily by conduction. The gradients vary laterally, however, between 20 and 40 °C km^{-1}. It is very unlikely that these differences can be accounted for by corresponding variations in mean thermal conductivity, with the result that conductive heat flow is likely to vary between about 30 and 70 mWm^{-2} (.75 and 1.7 HFU) within the very small area defined by Figure 1.

This in turn suggests very shallow (in the range 2.5 to 5 km) heat sources and sinks as the cause of the variations. The most likely sources and sinks would be hydrologic.

4) The foregoing observation requires that we re-examine our early simplistic one-dimensional model (Sass and Lachenbruch, 1982) involving pervasive downward water movement in the Yucca Mountain tuffs to depths between 1.5 and 2.5 km. From the present series of measurements, it seems clear that various fluids are moving about in the unsaturated zone, that water is moving in a very complicated manner within the saturated zone to depths on the order of 1 km, and that in the Paleozoic rocks beneath the tuffs, there is also a complex hydrothermal circulation system.

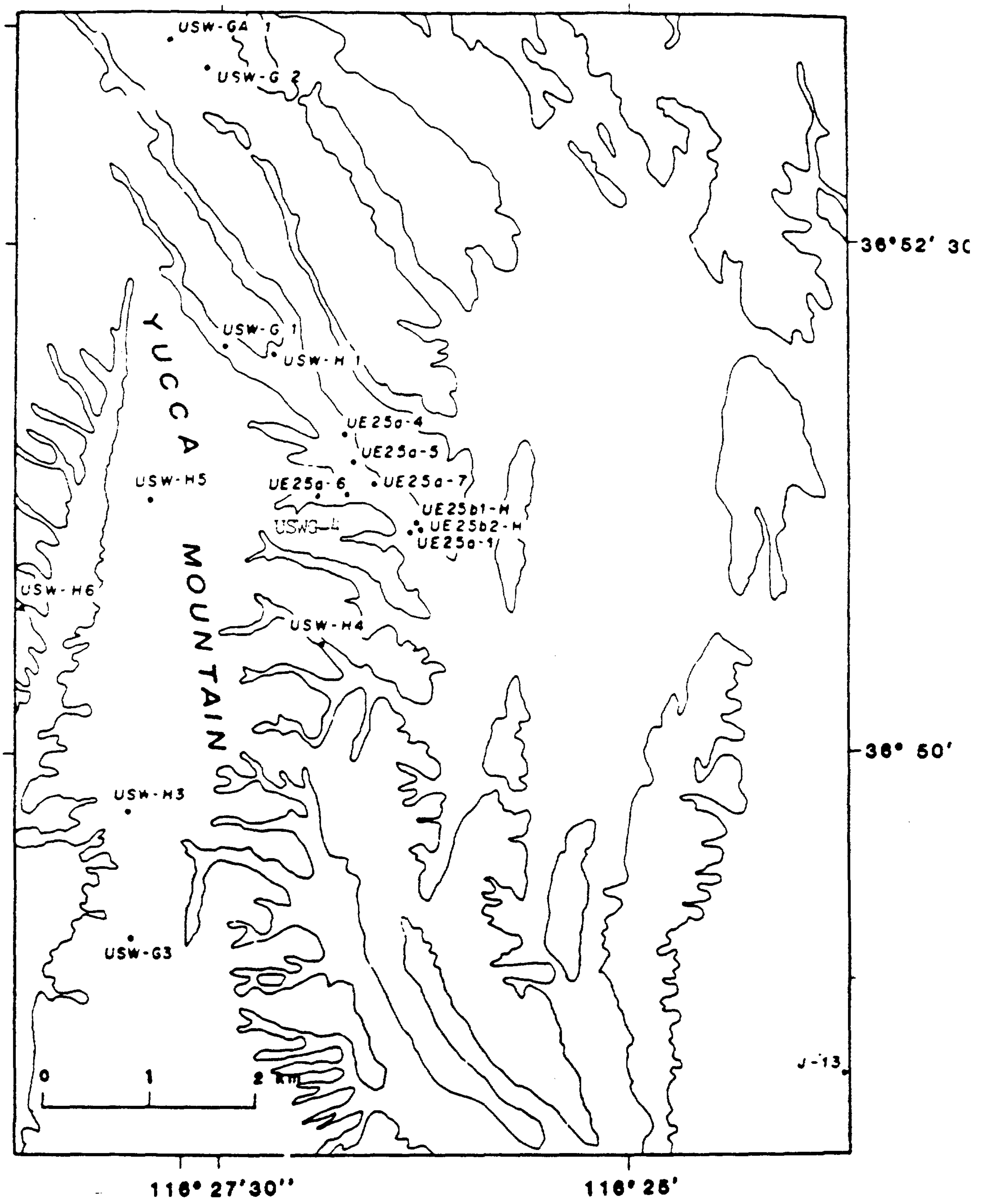


Figure 1. Sketch map showing the relative positions of test wells at Yucca Mountain.

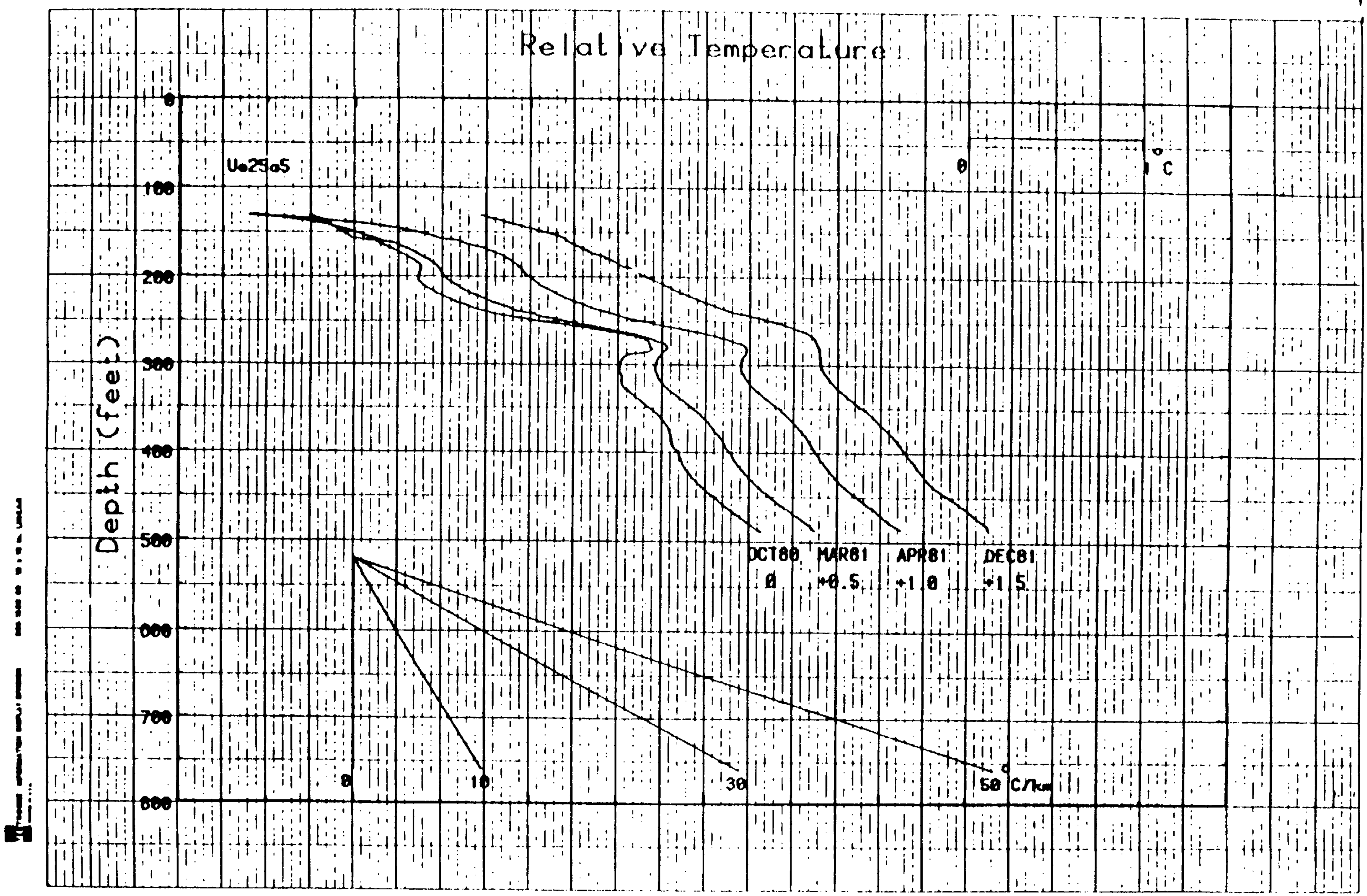
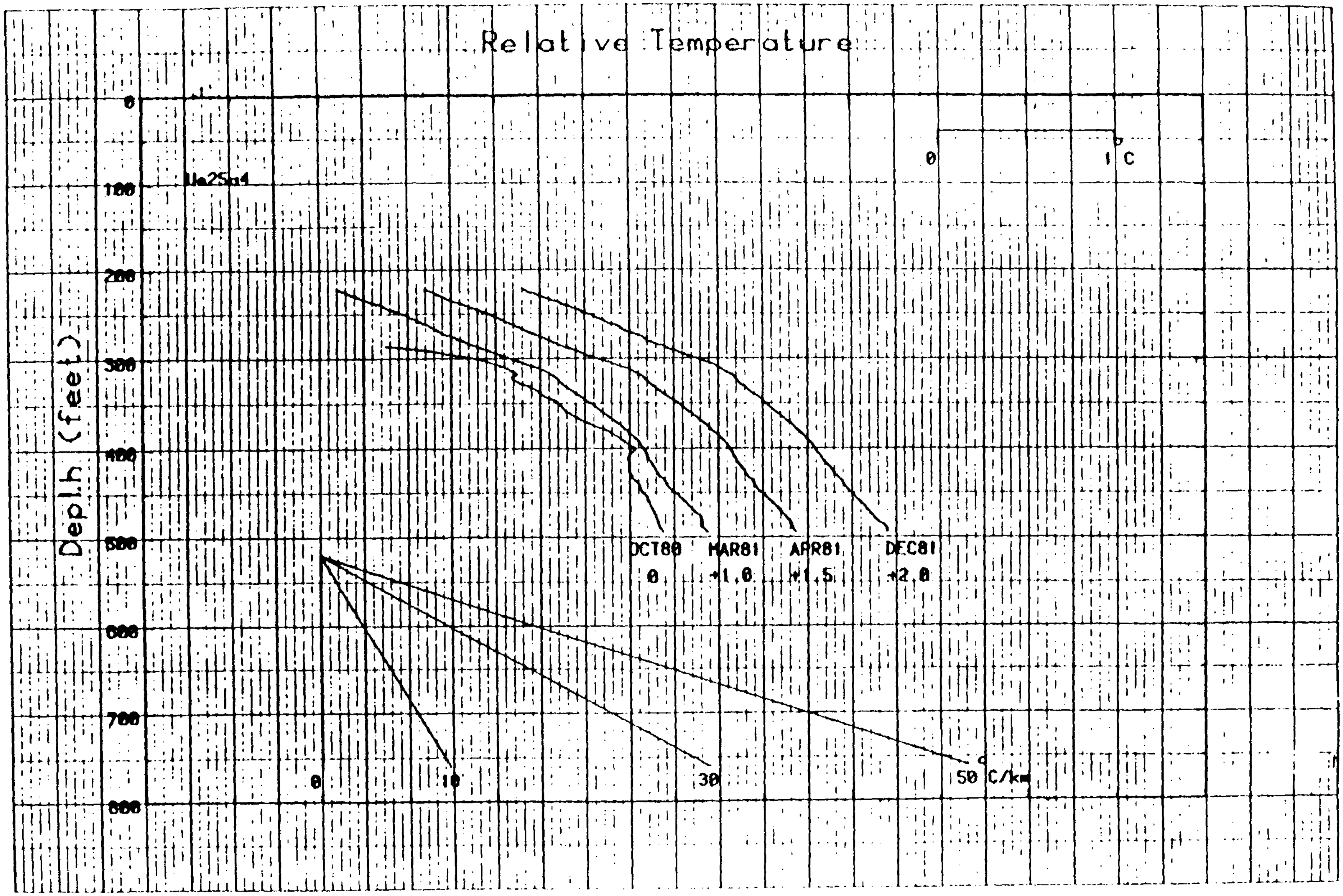

Relative Temperature
Ue25a5
0
°C
Depth (feet)
0
100
200
300
400
500
600
700
800
OCT80
0
MAR81
+0.5
APR81
+1.0
DEC81
+1.5
0
10
30
50 °C/km

Figure 3



Relative Temperature
Depth (feet)
0
100
200
300
400
500
600
700
800
Wa2Sa4
0
1 °C
OCT80
0
MAR81
+1.0
APR81
+1.5
DEC81
+2.0
0
10
30
50 °C/km

Figure 2

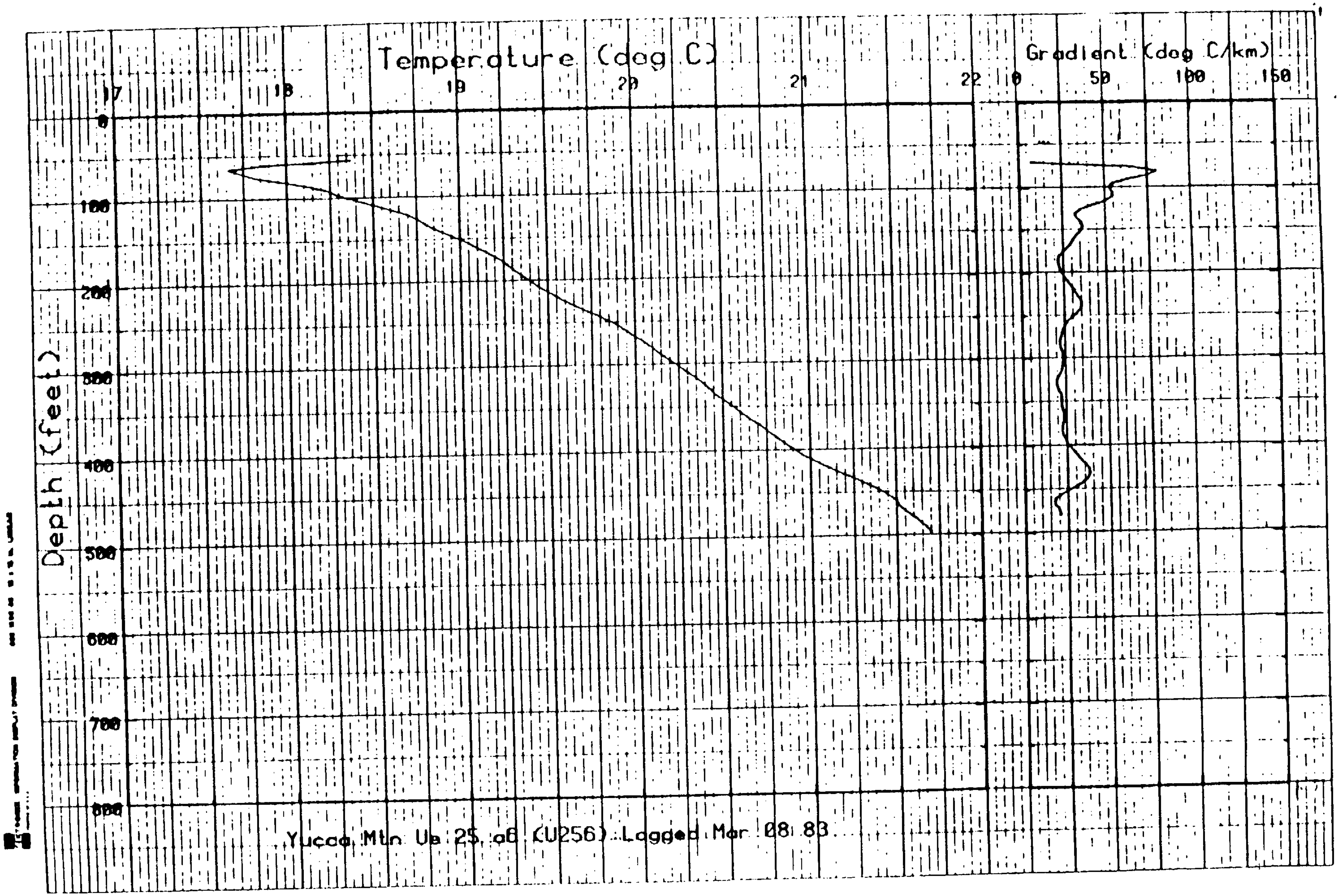

Temperature (deg C)
17
18
19
20
21
22
Gradient (deg C/km)
0
50
100
150
Depth (feet)
0
100
200
300
400
500
600
700
800
Yucca Mtn Ue 25 a6 (U256) Logged Mar 08 83

Figure 4

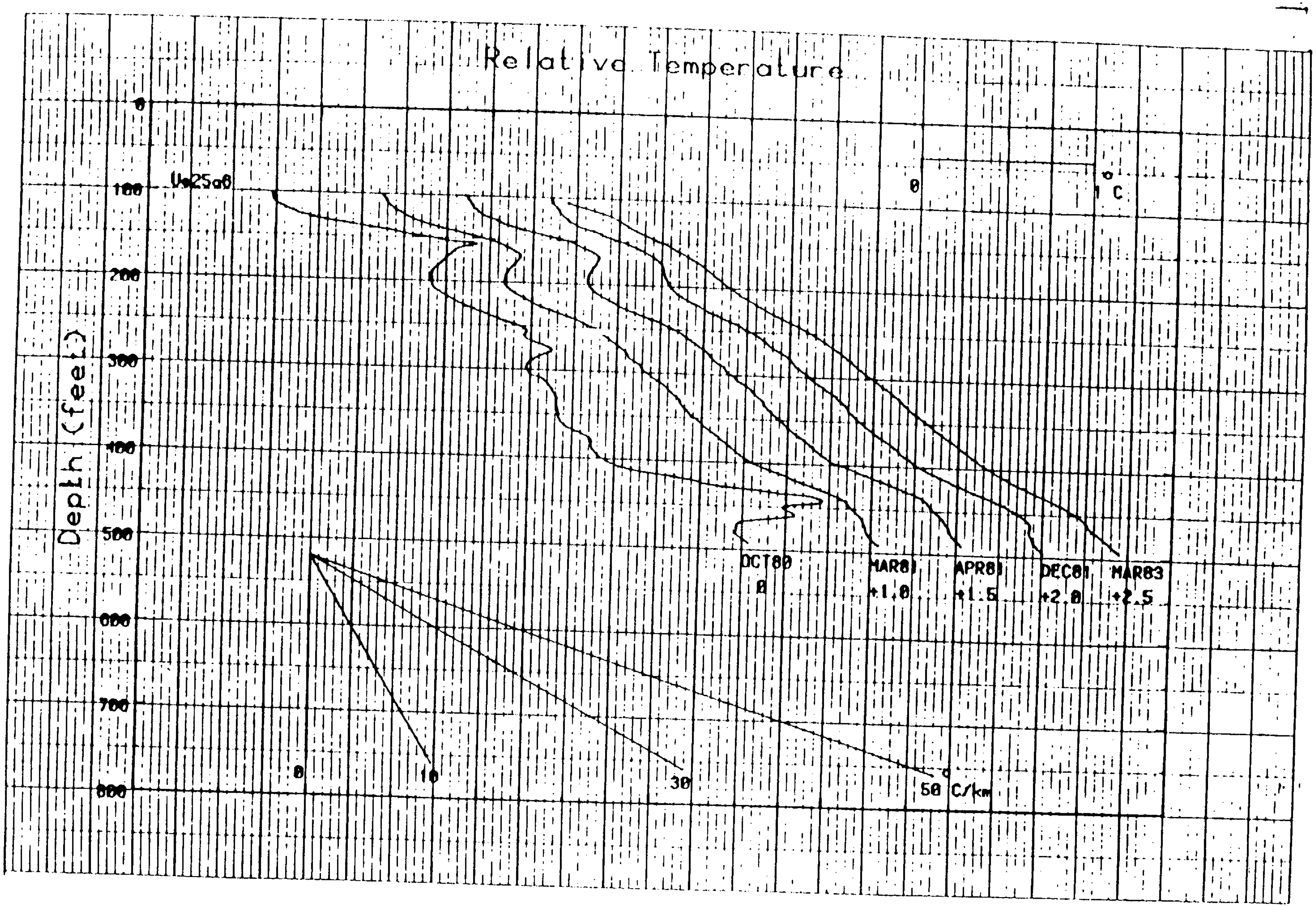

Relative Temperature
Depth (feet)
0
100
200
300
400
500
600
700
800
Ue25a6
0
1 °C
OCT80
0
MAR81
+1.0
APR81
+1.5
DEC81
+2.0
MAR83
+2.5
0
10
30
50 °C/km

Figure 5

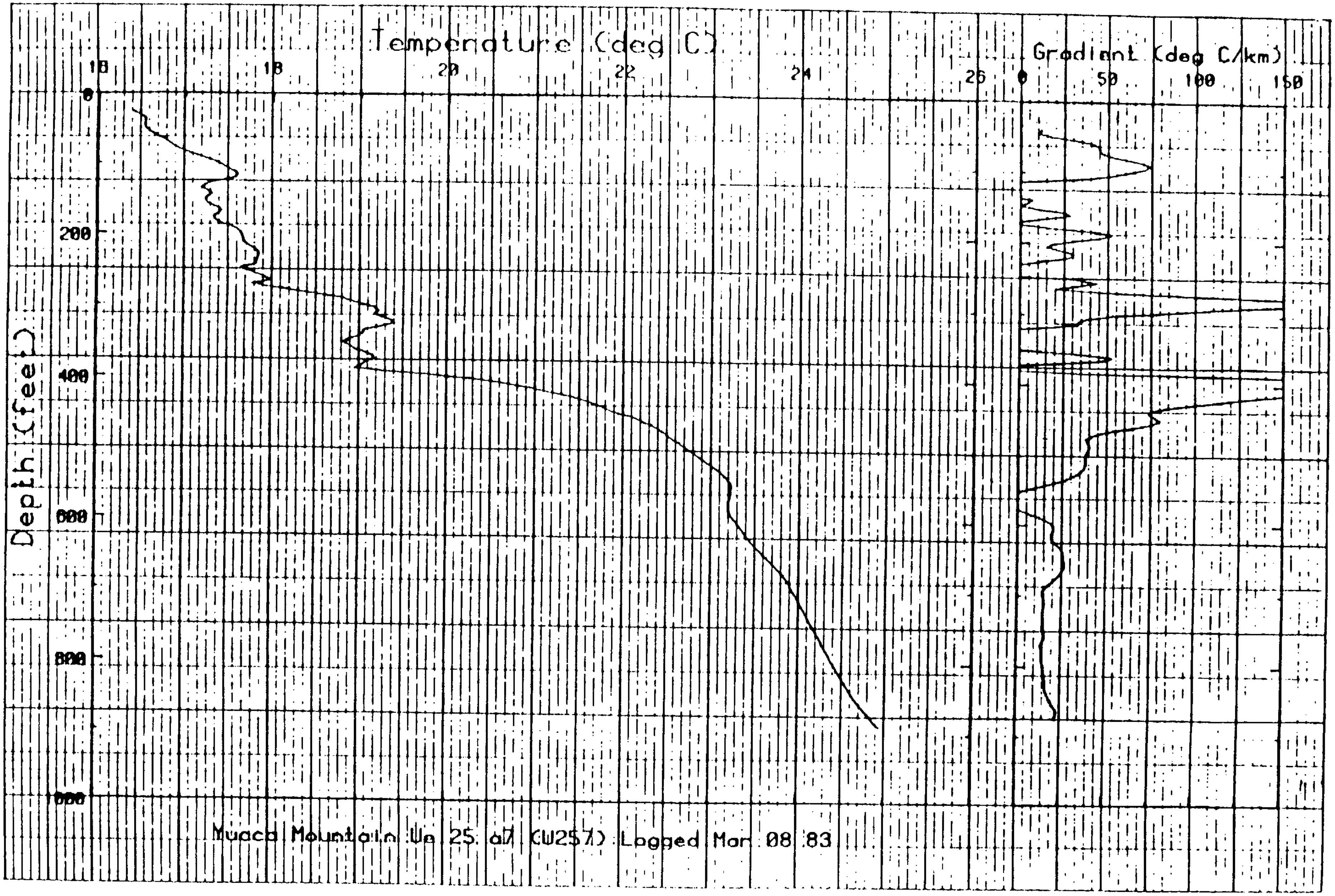

Temperature (deg C)
18
18
20
22
24
26
Gradient (deg C/km)
0
50
100
150
0
200
400
600
800
000
Depth (feet)
Yucca Mountain Ue 25 a7 (U257) Logged Mar 08 83

Figure 6

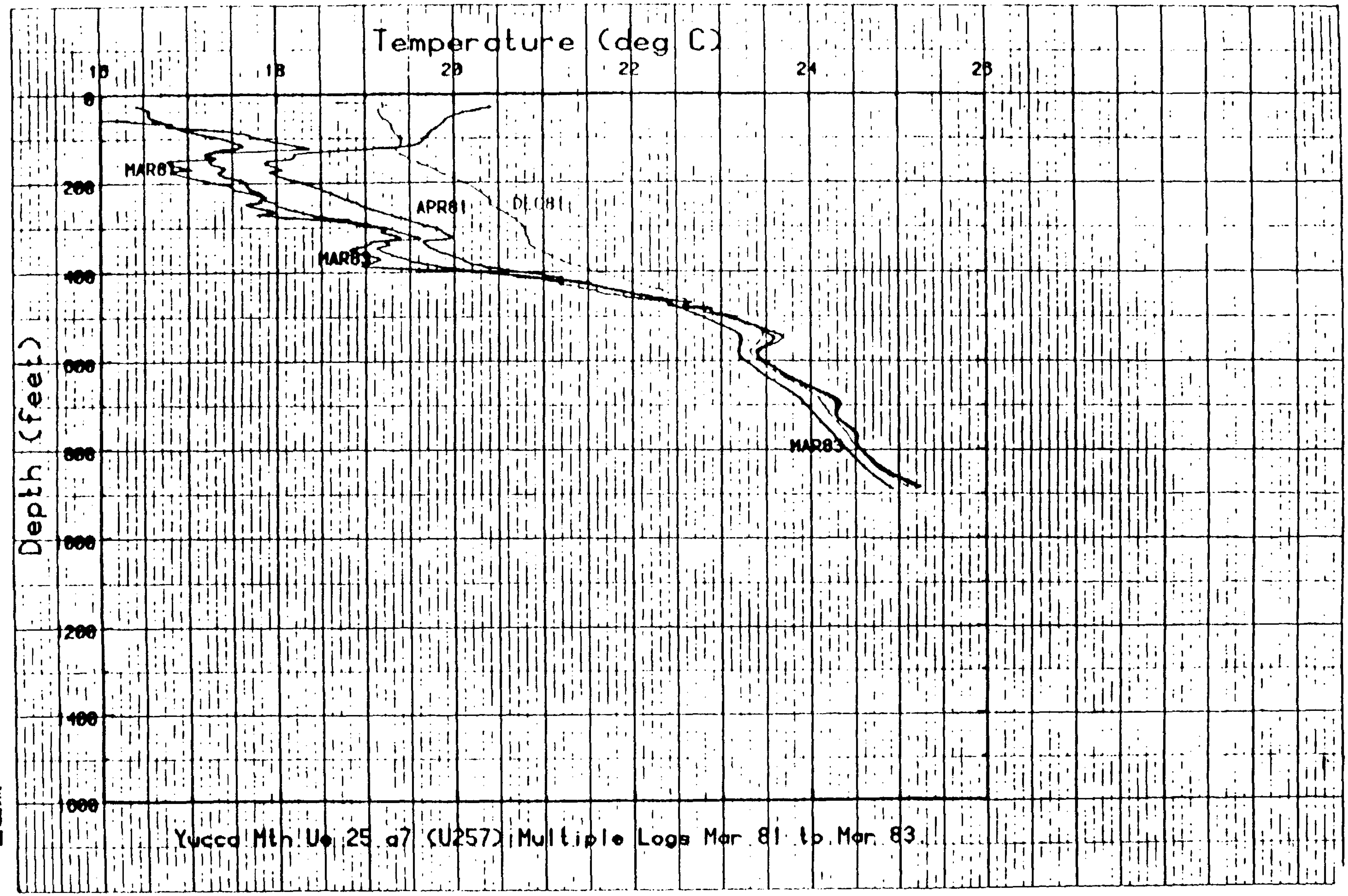
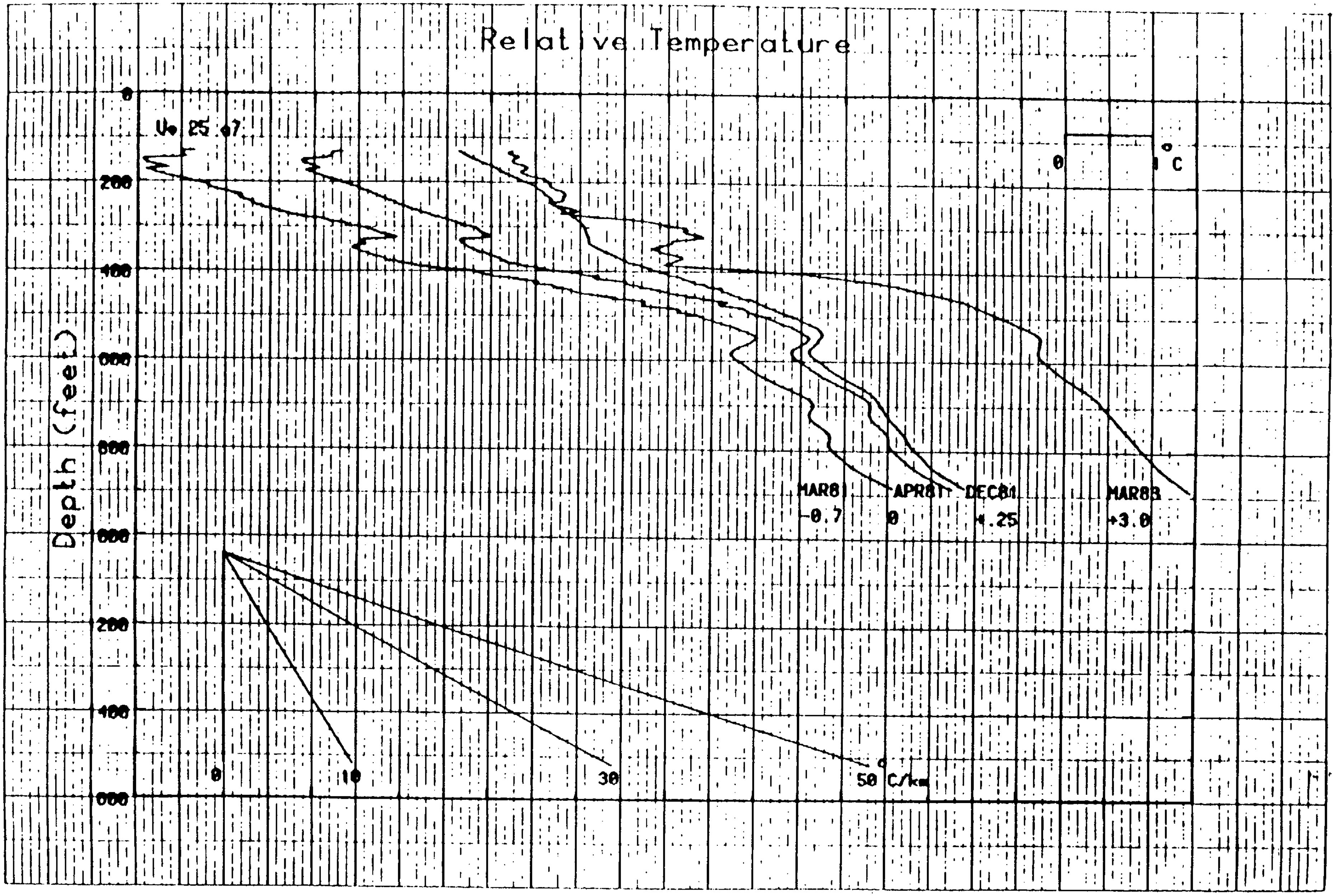

Temperature (deg C)
16
18
20
22
24
26
Depth (feet)
0
200
400
600
800
1000
1200
1400
1600
MAR81
APR81
DEC81
MAR83
MAR83
Yucca Mtn Ue 25 a7 (U257) Multiple Logs Mar 81 to Mar 83

Figure 7



Relative Temperature
Depth (feet)
U- 25.67
0
1°C
0
200
400
600
800
1000
1200
1400
1600
MAR81
-0.7
APR81
0
DEC81
+.25
MAR83
+3.0
0
10
30
50 °C/km

Figure 8

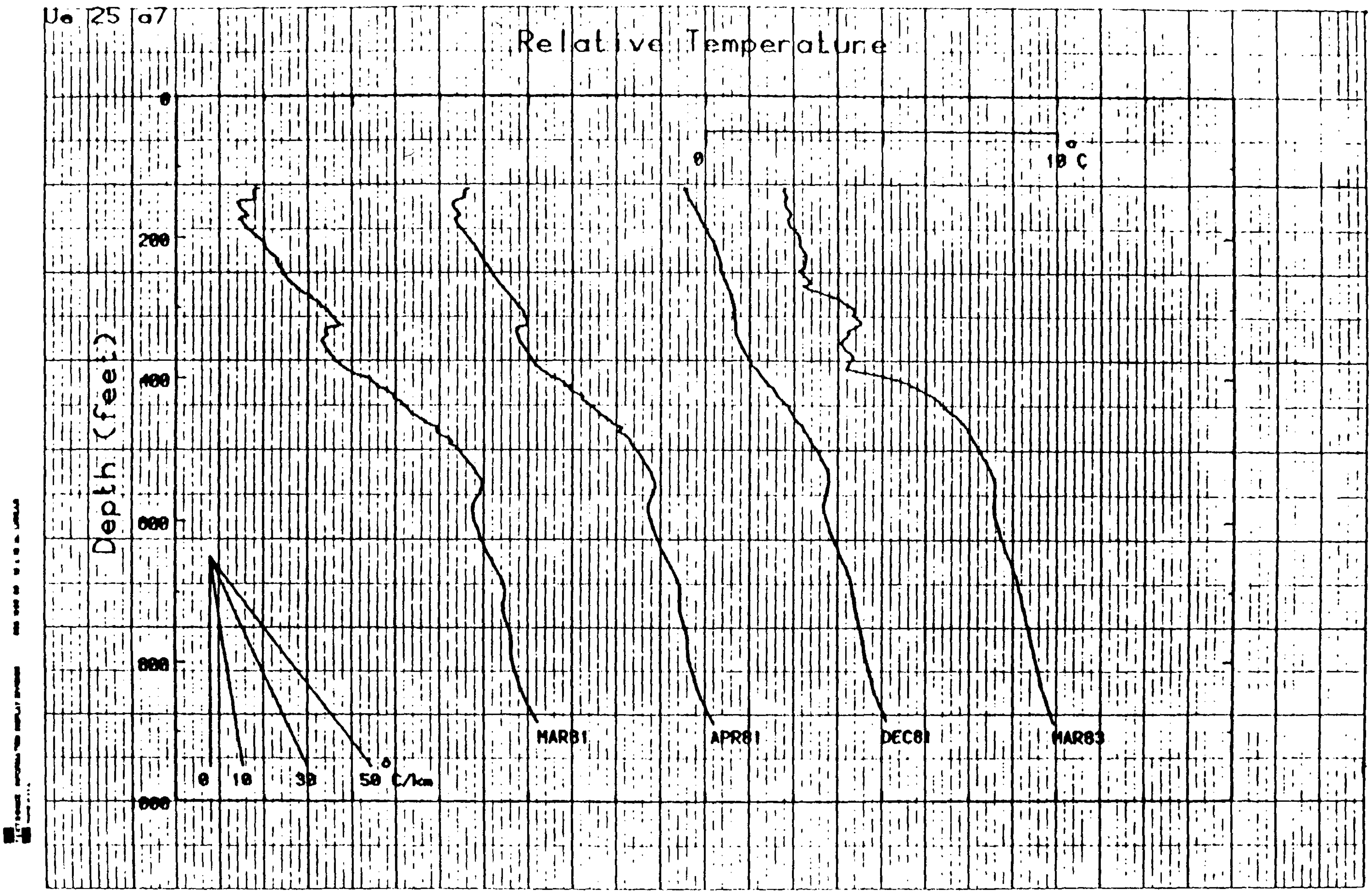

Ua 25 a7
Relative Temperature
Depth (feet)
0
200
400
600
800
1000
0
10 °C
MAR81
APR81
DEC81
MAR83
0
10
30
50 °C/km

Figure 9

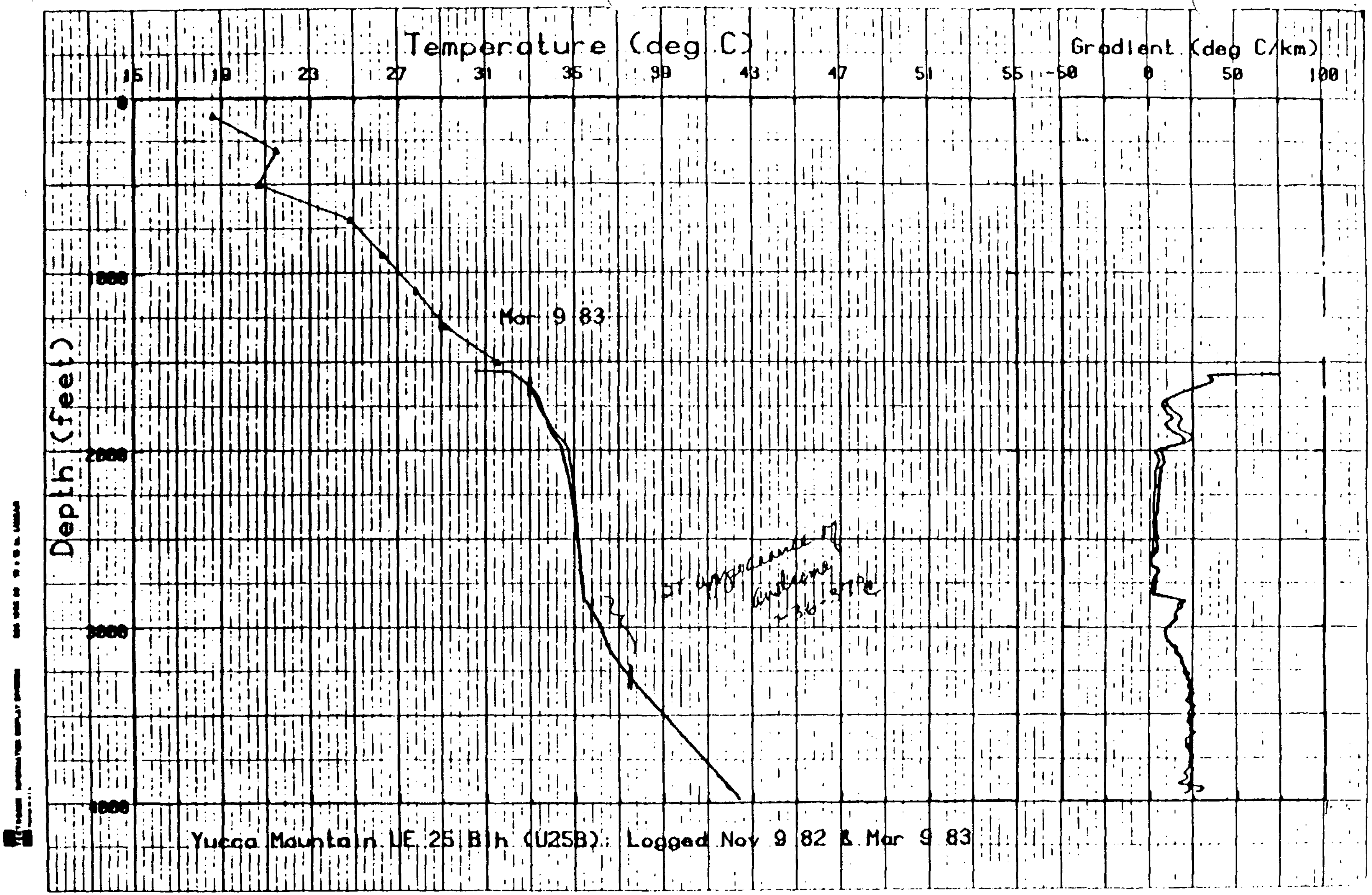

Temperature (deg C)
15
19
23
27
31
35
39
43
47
51
55
Gradient (deg C/km)
-50
0
50
100
Depth (feet)
0
1000
2000
3000
4000
Mar 9 83
Yucca Mountain UE 25 B1h (U25B): Logged Nov 9 82 & Mar 9 83

Figure 10

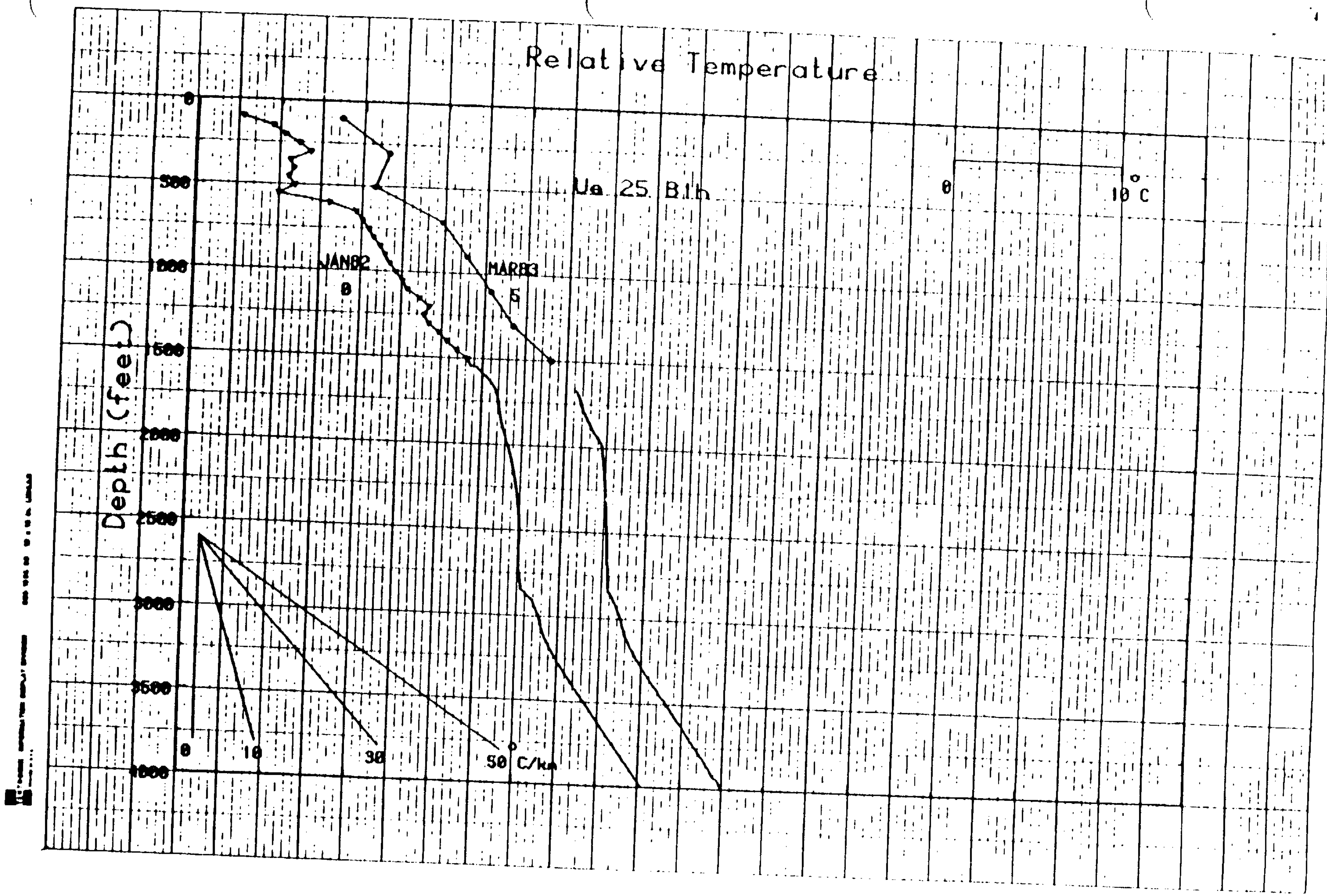

Relative Temperature
Ua 25 B1h
0
10 °C
JAN82
0
MAR83
5
Depth (feet)
0
500
1000
1500
2000
2500
3000
3500
4000
0
10
30
50 °C/km

Figure 11

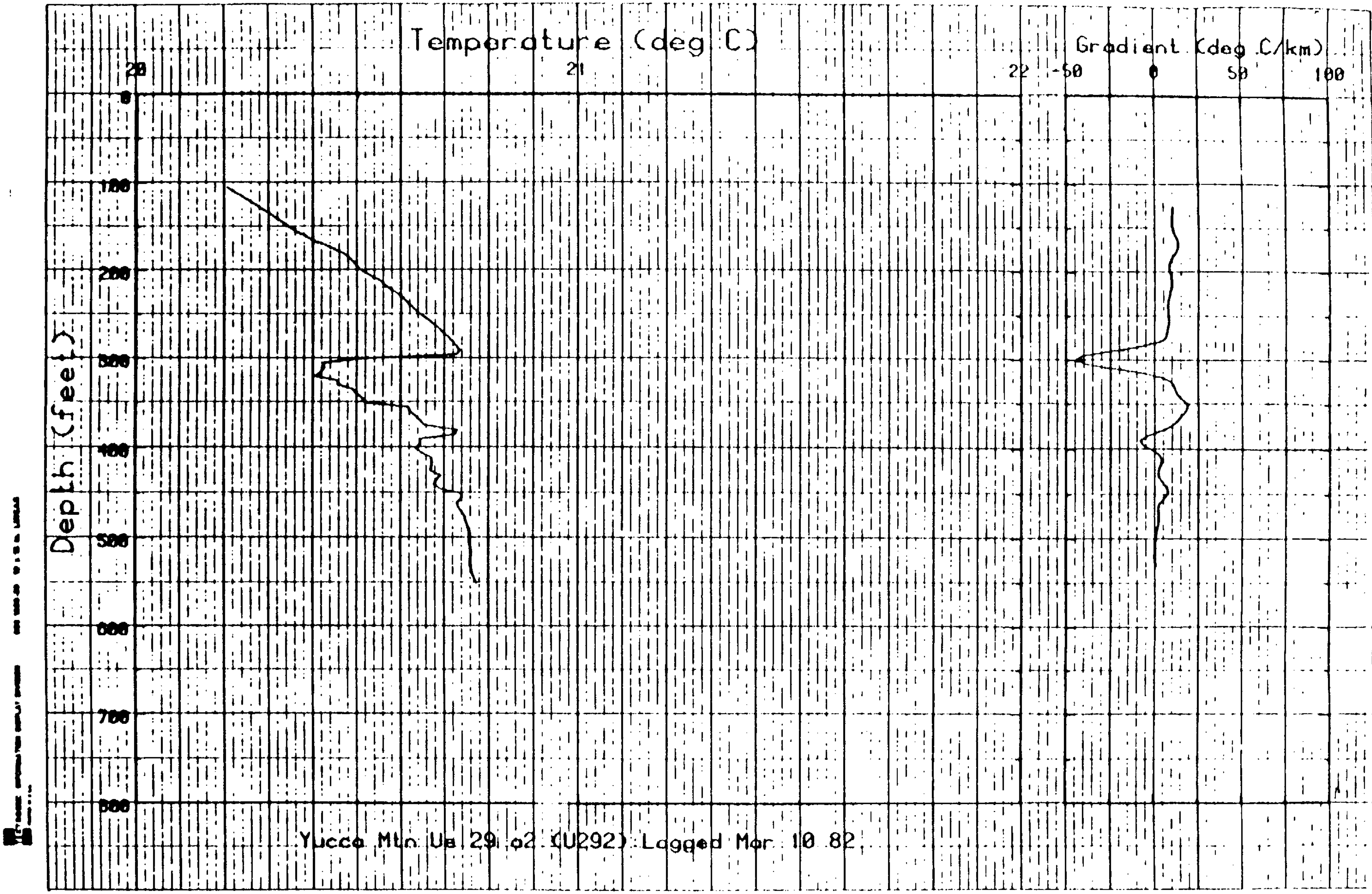
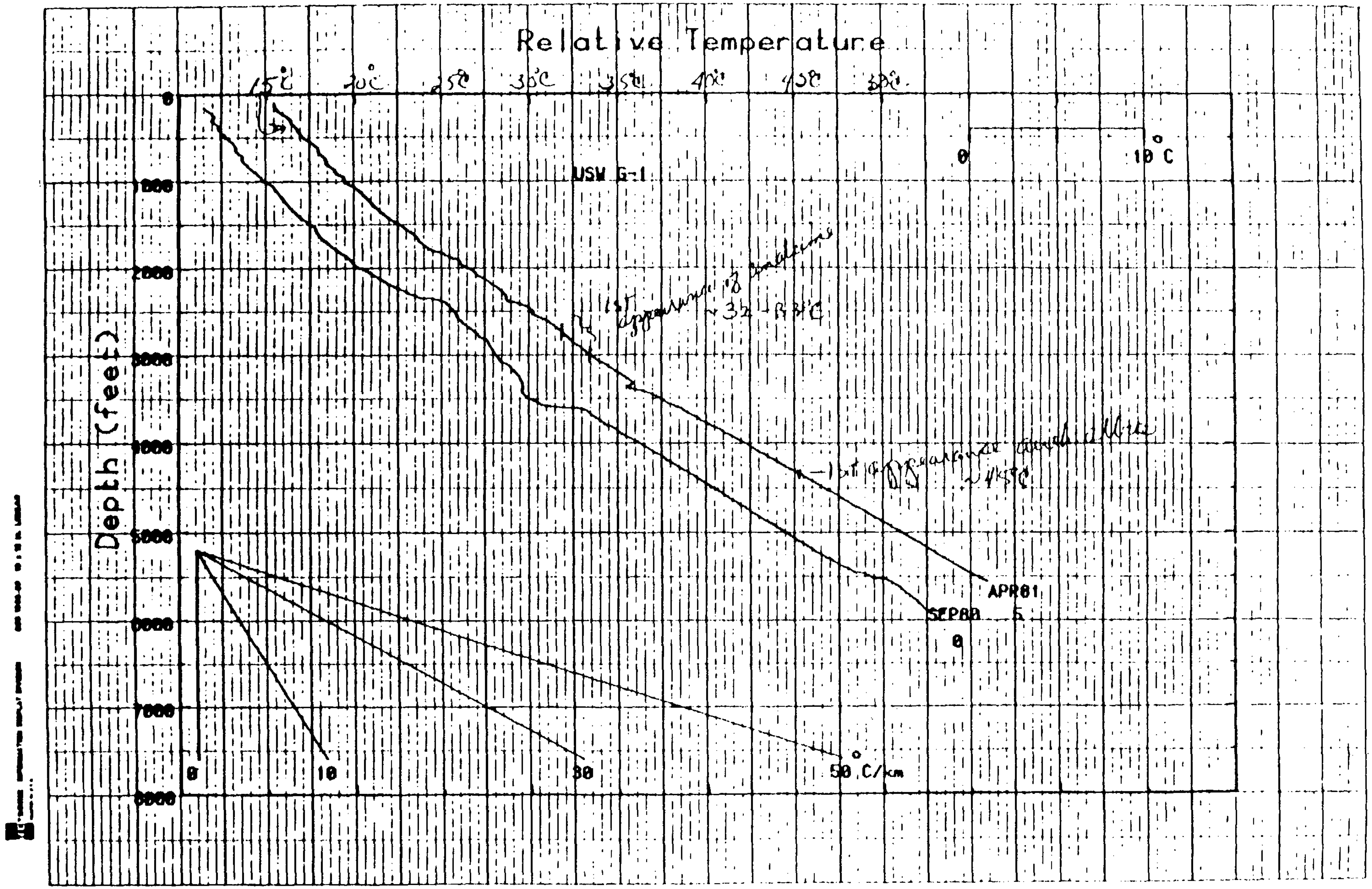
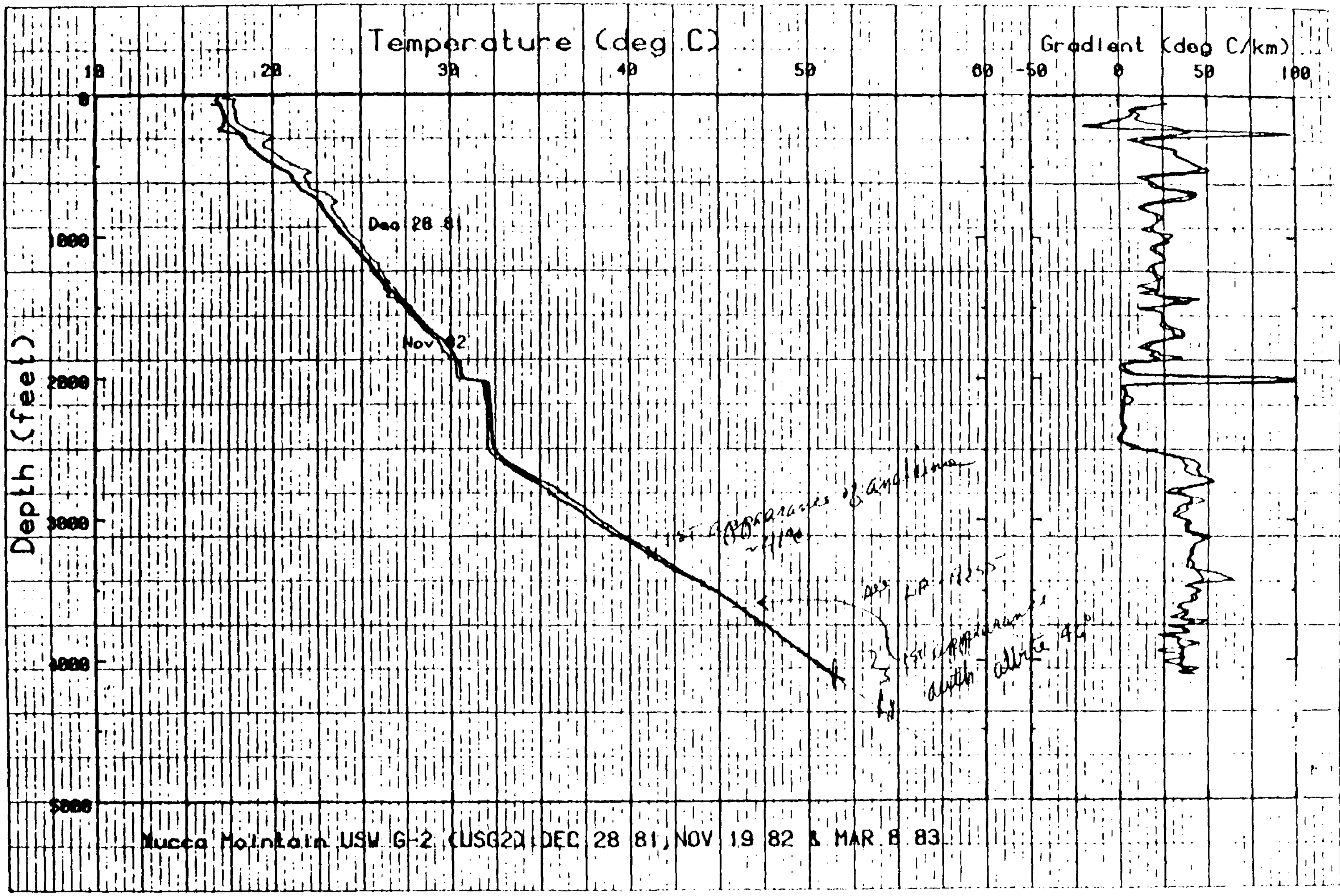

Temperature (deg C)
20
21
22
Gradient (deg C/km)
-50
0
50
100
Depth (feet)
0
100
200
300
400
500
600
700
800
Yucca Mtn Ue 29 a2 (U292) Logged Mar 10 82

Figure 12



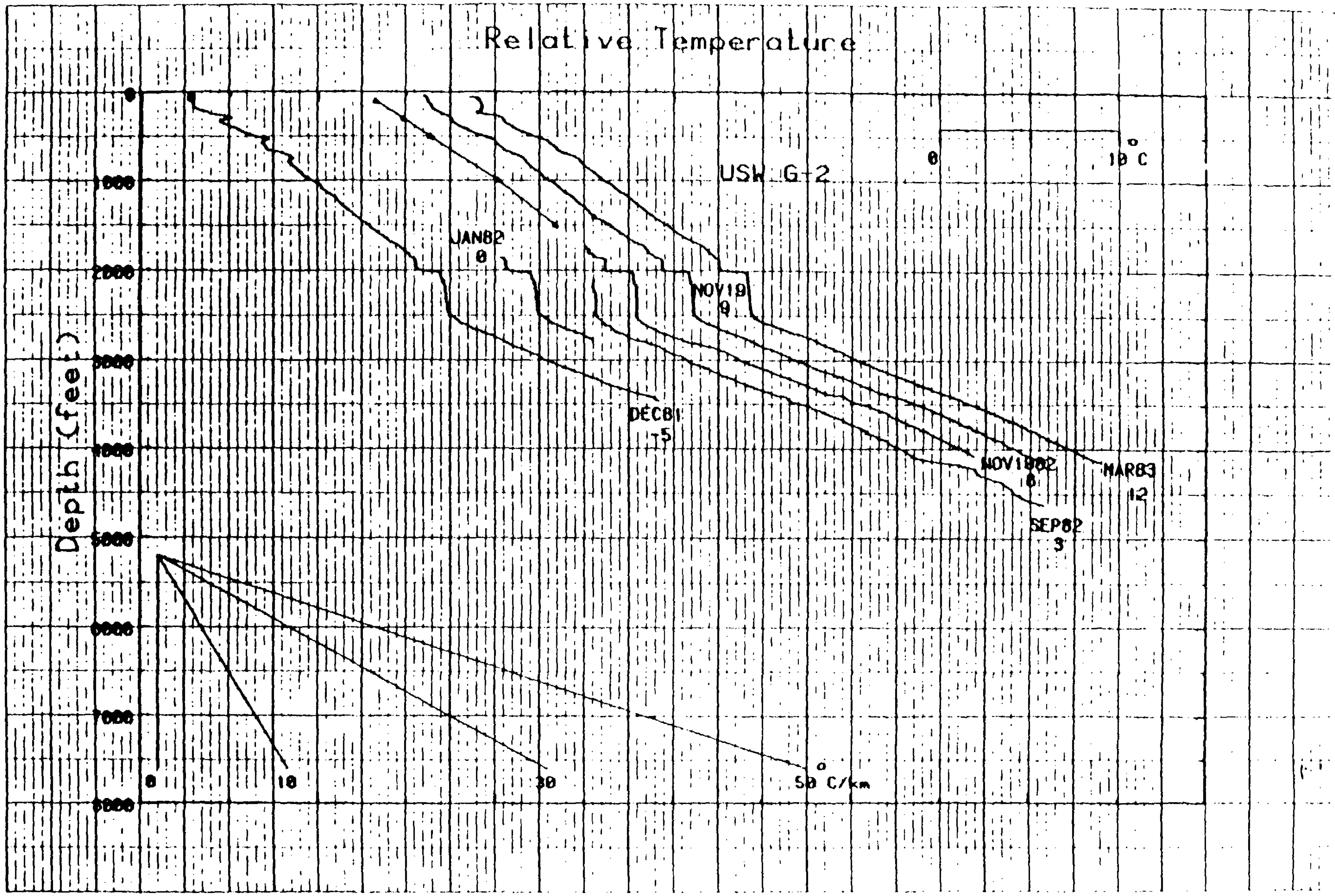
Relative Temperature
Depth (feet)
USW G-1
APR81
SEP80
0
1000
2000
3000
4000
5000
6000
7000
8000
0
10 °C
5
0
0
10
30
50 °C/km

Figure 13



Temperature (deg C)
Gradient (deg C/km)
Depth (feet)
Dec 28 81
Nov 82
Yucca Mountain USW G-2 (USG2) DEC 28 81, NOV 19 82 & MAR 8 83

Figure 14



Relative Temperature
USW G-2
0
10 °C
Depth (feet)
1000
2000
3000
4000
5000
6000
7000
8000
JAN82
0
NOV19
0
DEC81
-5
NOV1982
6
MAR83
12
SEP82
3
0
10
30
50 °C/km

Figure 15

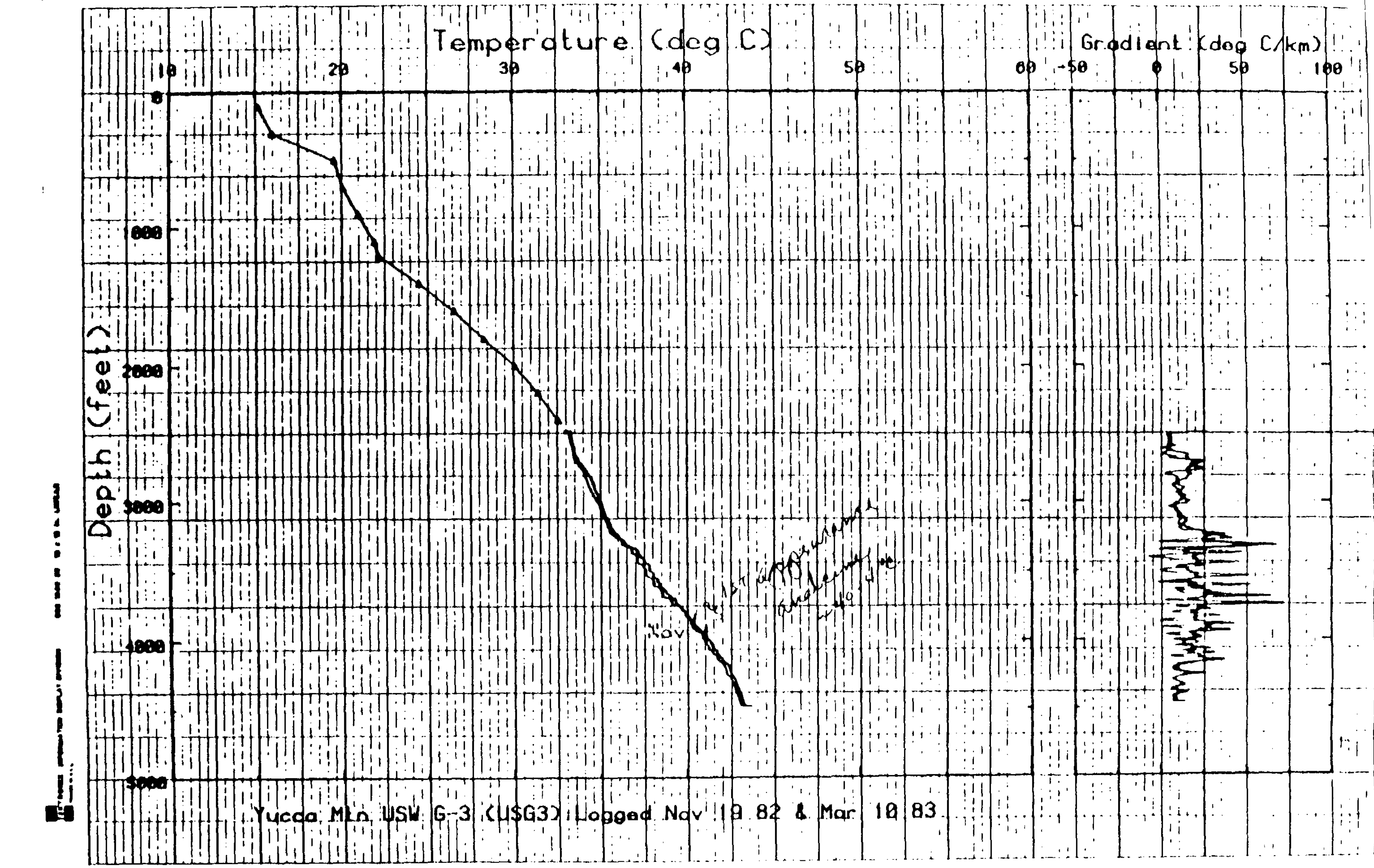

Temperature (deg C)
Gradient (deg C/km)
10
20
30
40
50
60
-50
0
50
100
0
1000
2000
3000
4000
5000
Depth (feet)
Yucca Mtn USW G-3 (USG3) Logged Nov 19 82 & Mar 10 83

Figure 16

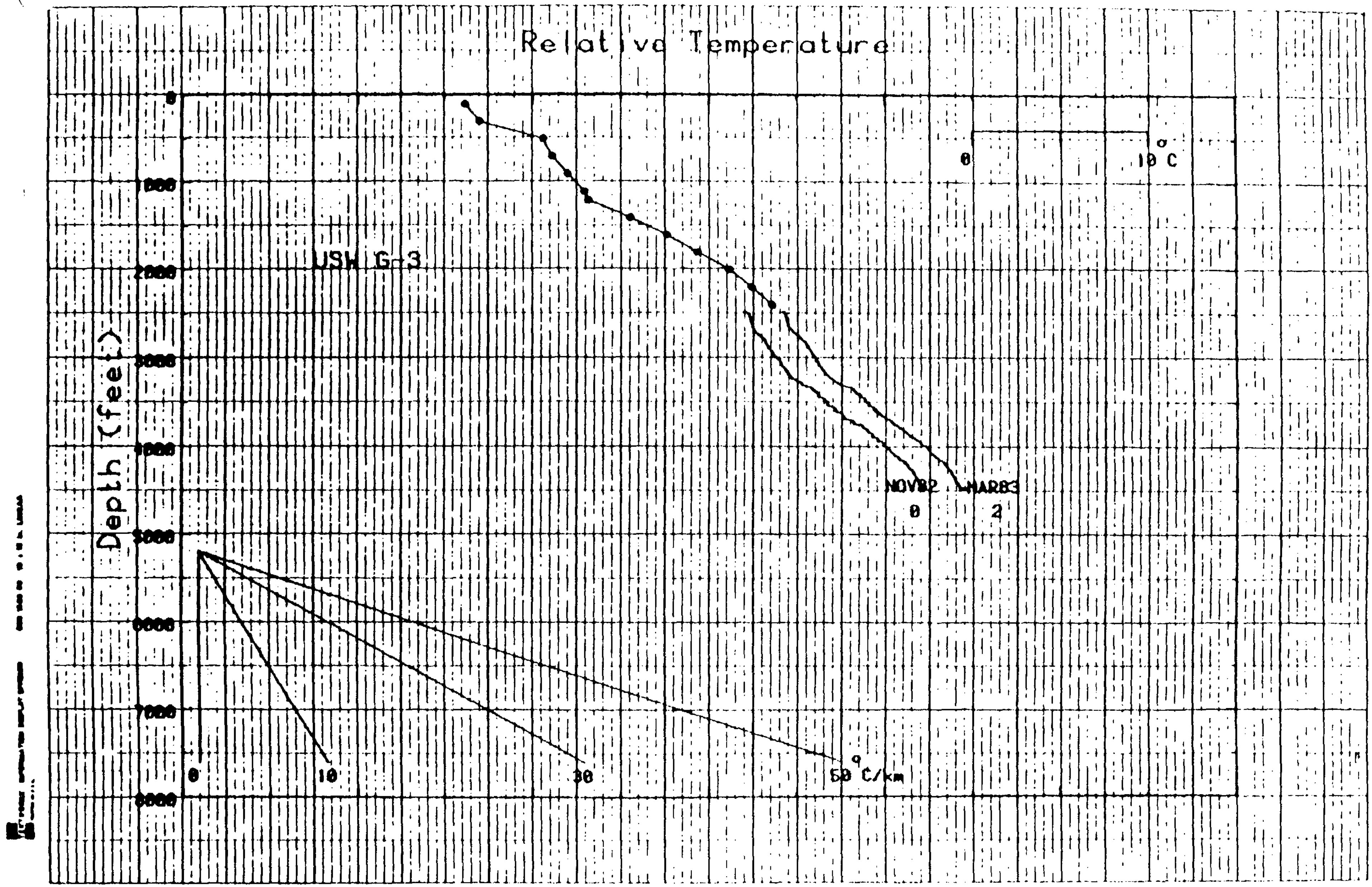
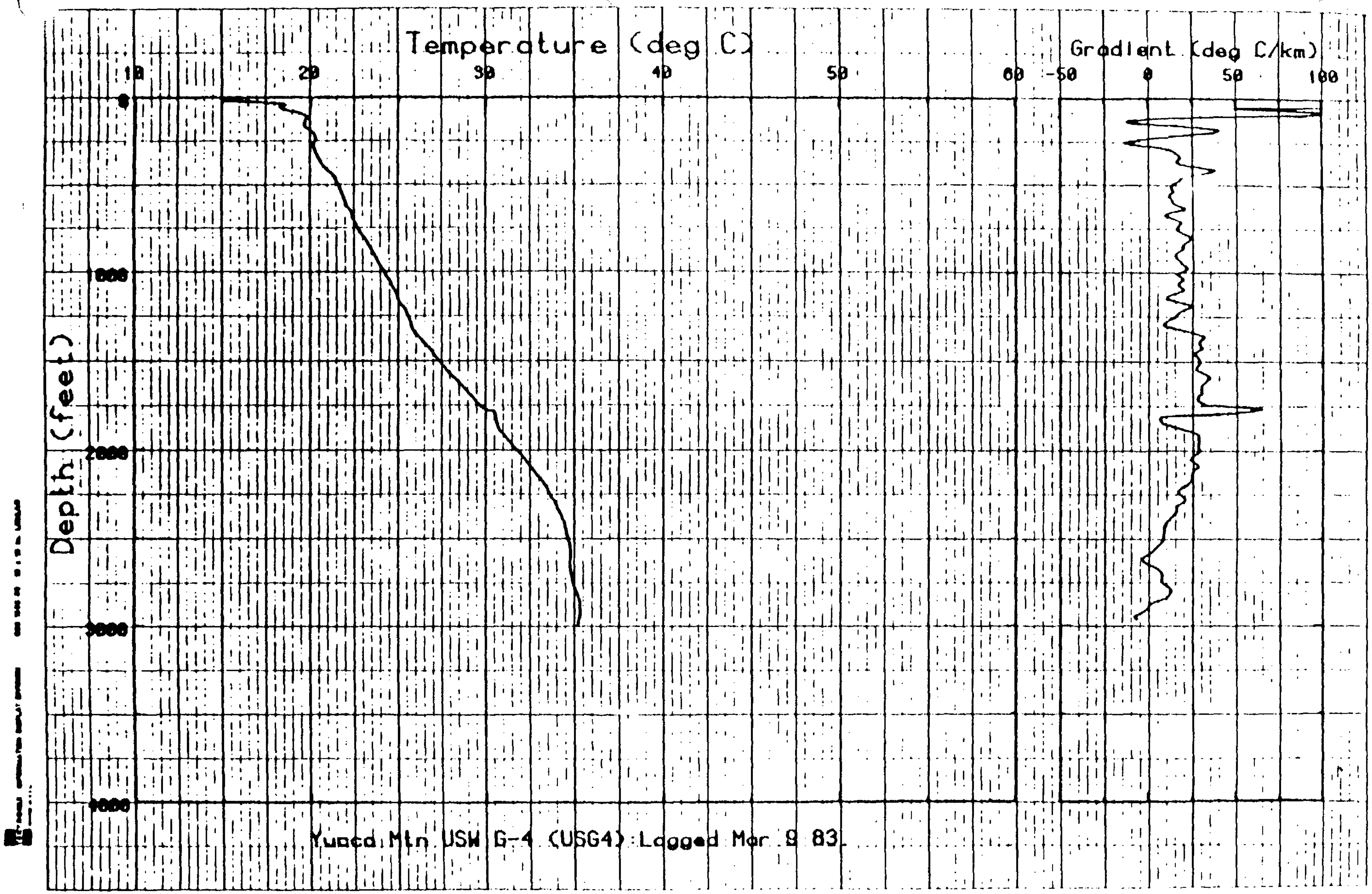

Relative Temperature
0
1000
2000
3000
4000
5000
6000
7000
8000
Depth (feet)
USW G-3
0
10 °C
NOV82
MAR83
0
2
0
10
30
50 °C/km

Figure 17



Temperature (deg C)
10
20
30
40
50
60
Gradient (deg C/km)
-50
0
50
100
0
1000
2000
3000
4000
Depth (feet)
Yucca Mtn USW G-4 (USG4) Logged Mar 8 83

Figure 18

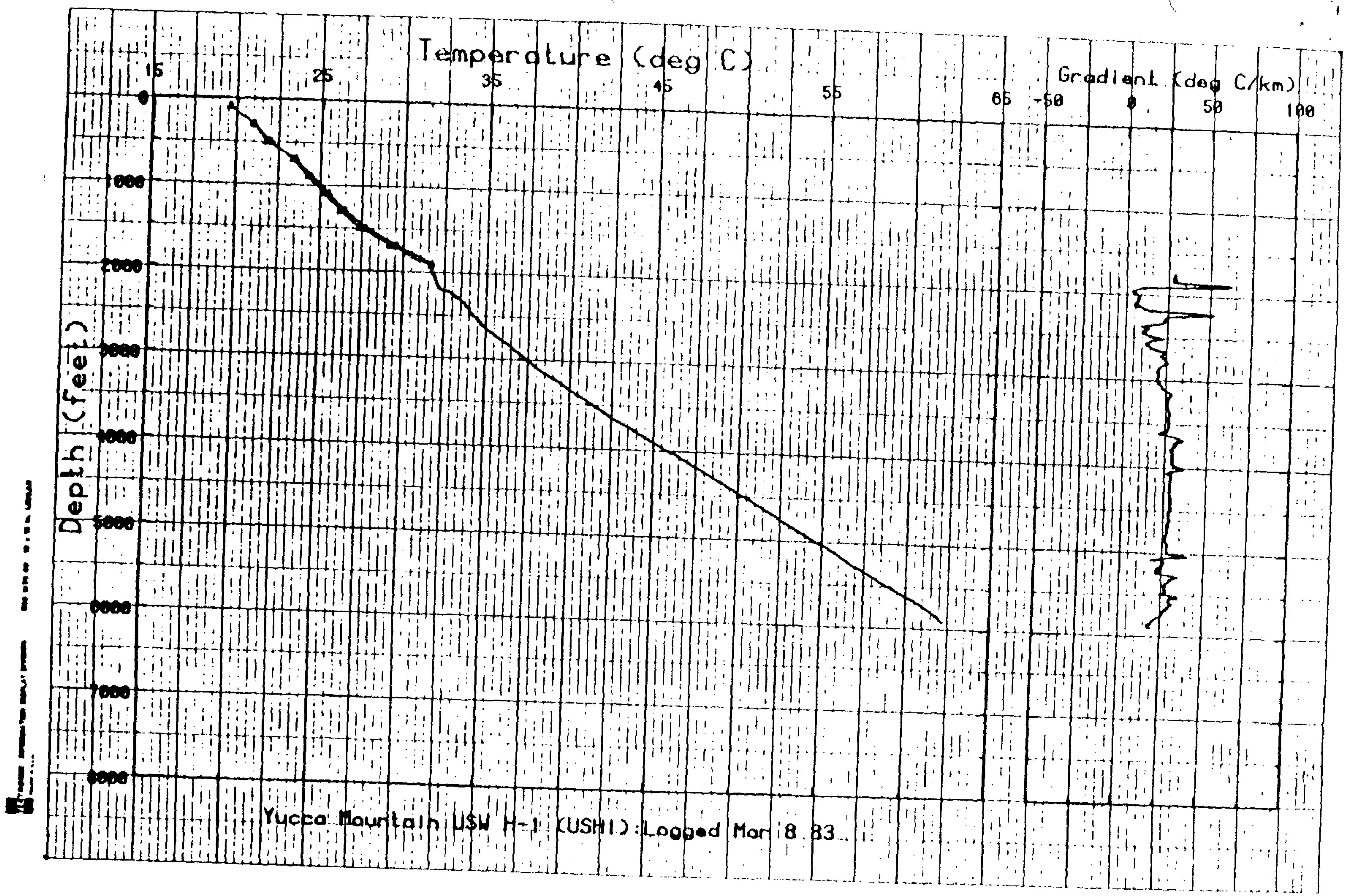
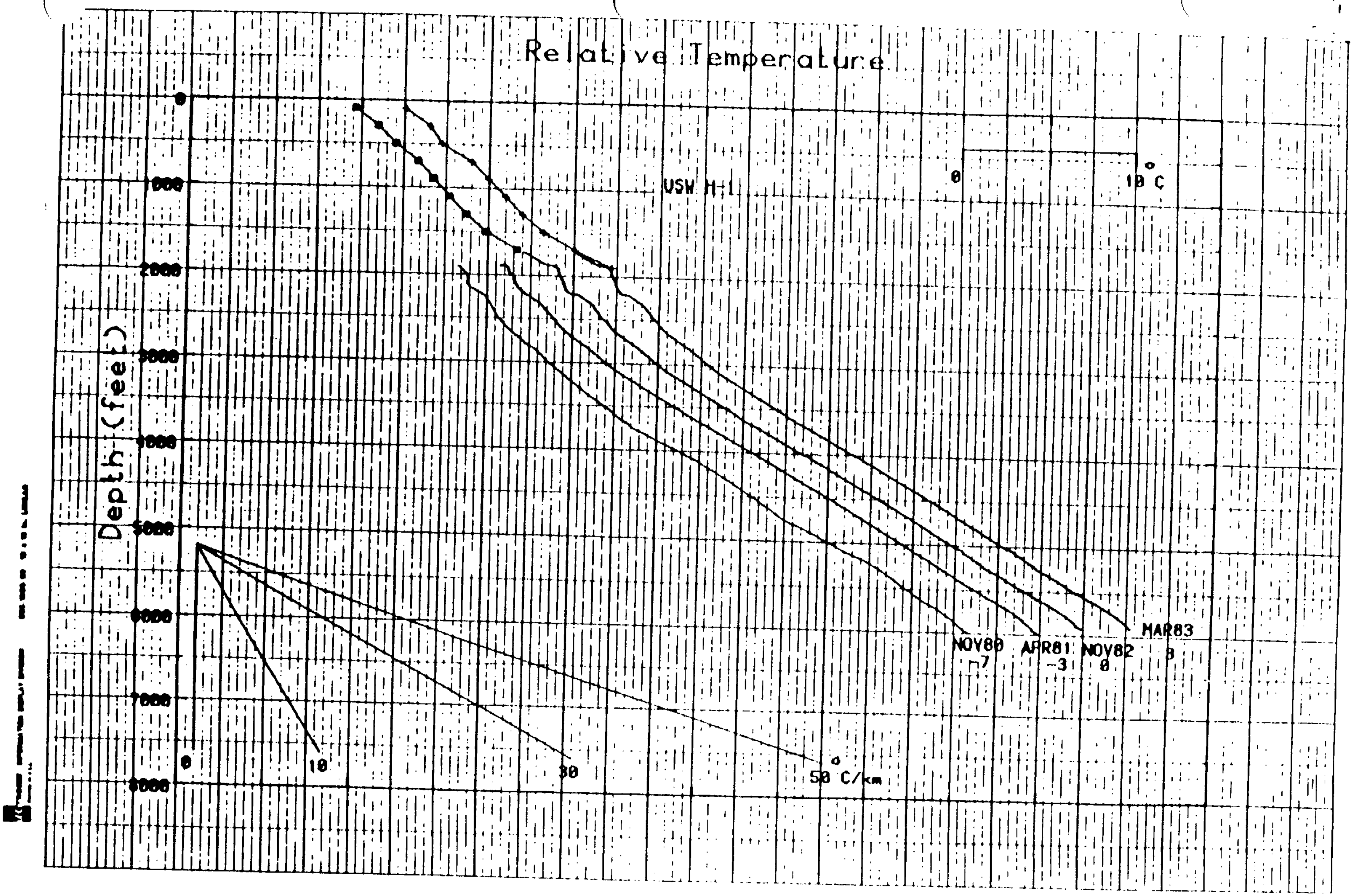
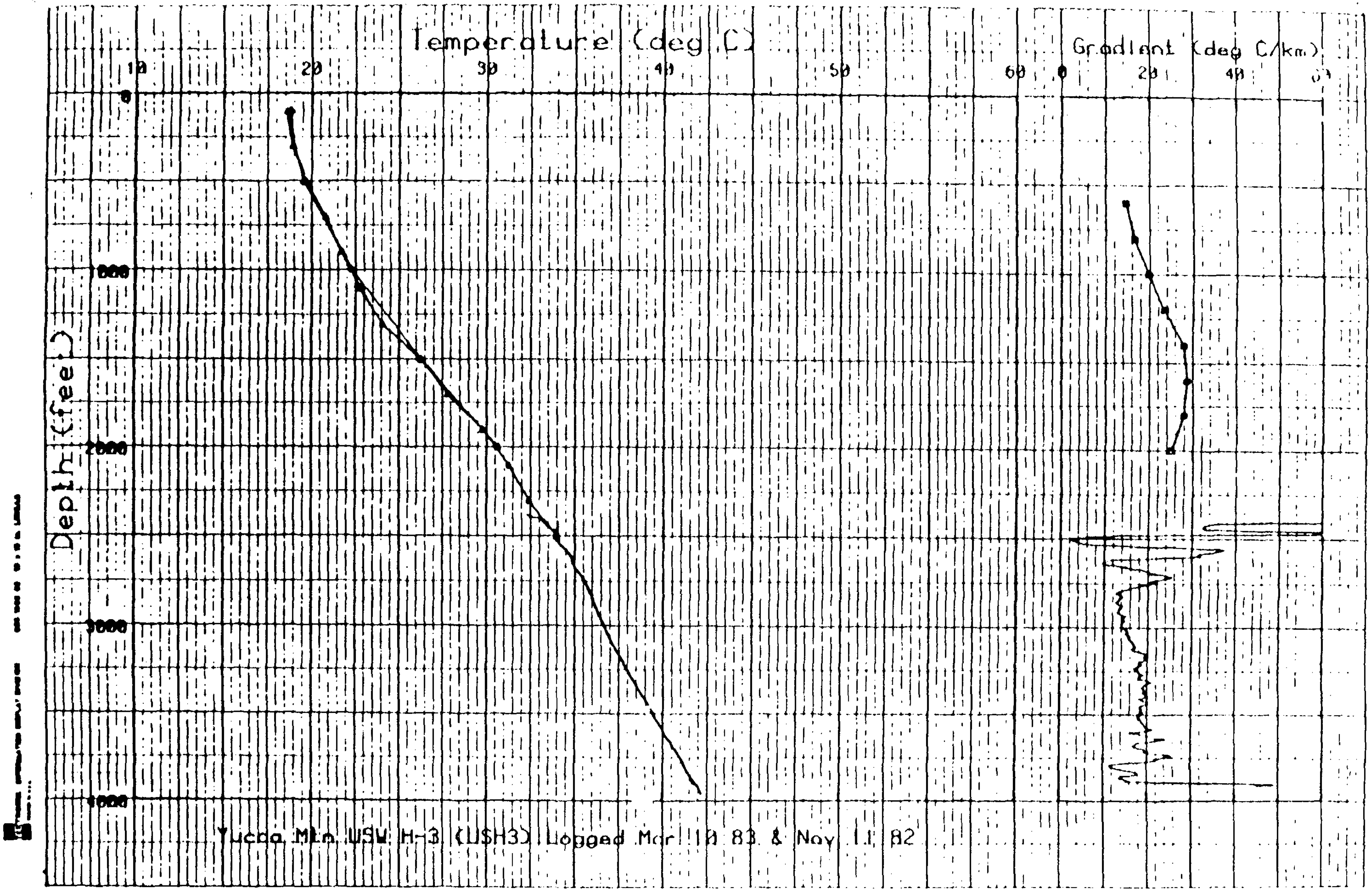

Temperature (deg C)
15
25
35
45
55
65
Gradient (deg C/km)
-50
0
50
100
Depth (feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
Yucca Mountain USW H-1 (USH1) Logged Mar 8 83

Figure 19



Relative Temperature
USW H-1
0
10 °C
Depth (feet)
1000
2000
3000
4000
5000
6000
7000
8000
NOV80
-7
APR81
-3
NOV82
0
MAR83
3
0
10
30
50 °C/km

Figure 20



Temperature (deg C)
10
20
30
40
50
60
Gradient (deg C/km)
0
20
40
60
0
1000
2000
3000
4000
Depth (feet)
Yucca Mtn USW H-3 (USH3) Logged Mar 10 83 & Nov 11 82

Figure 21

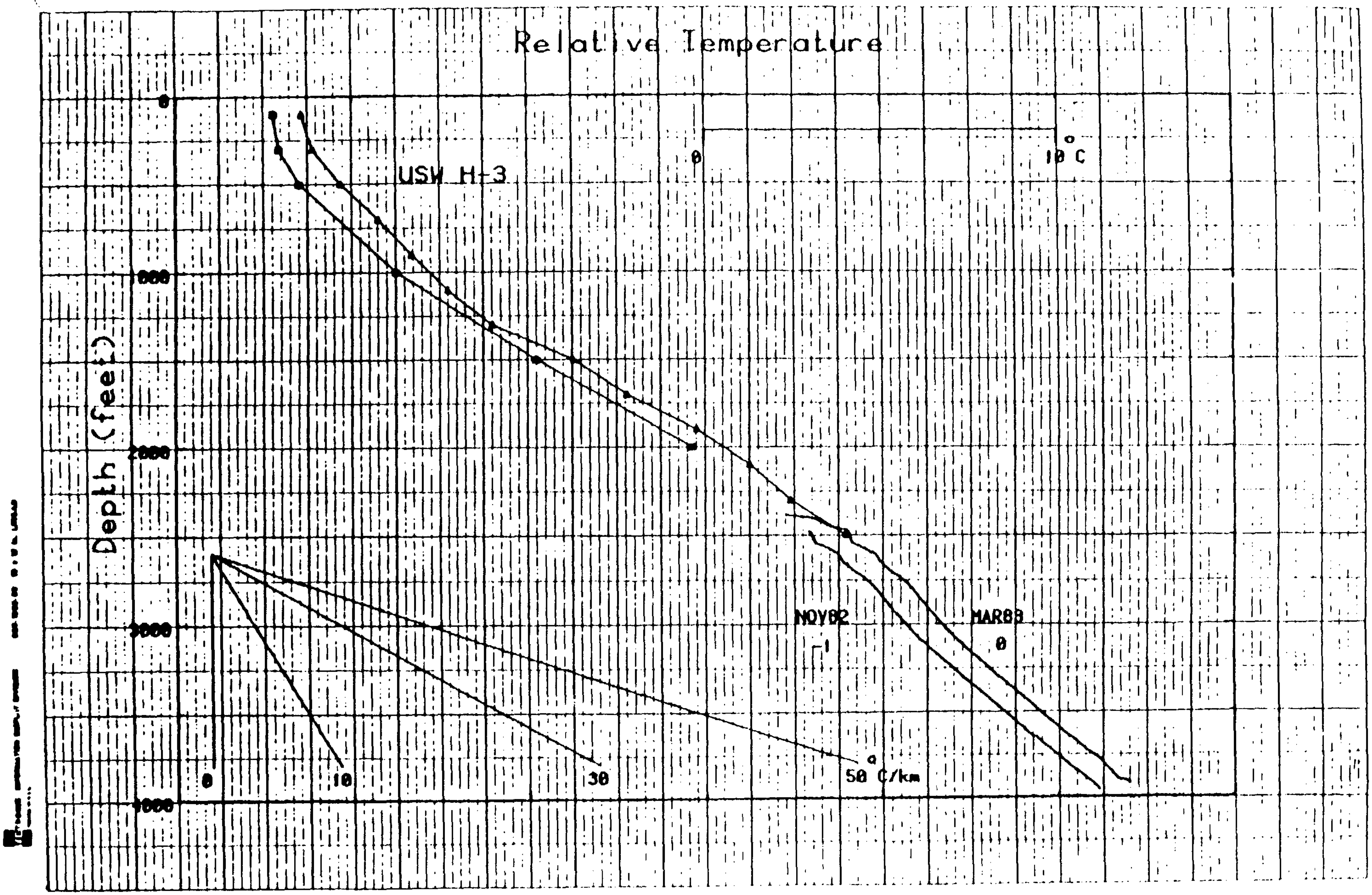
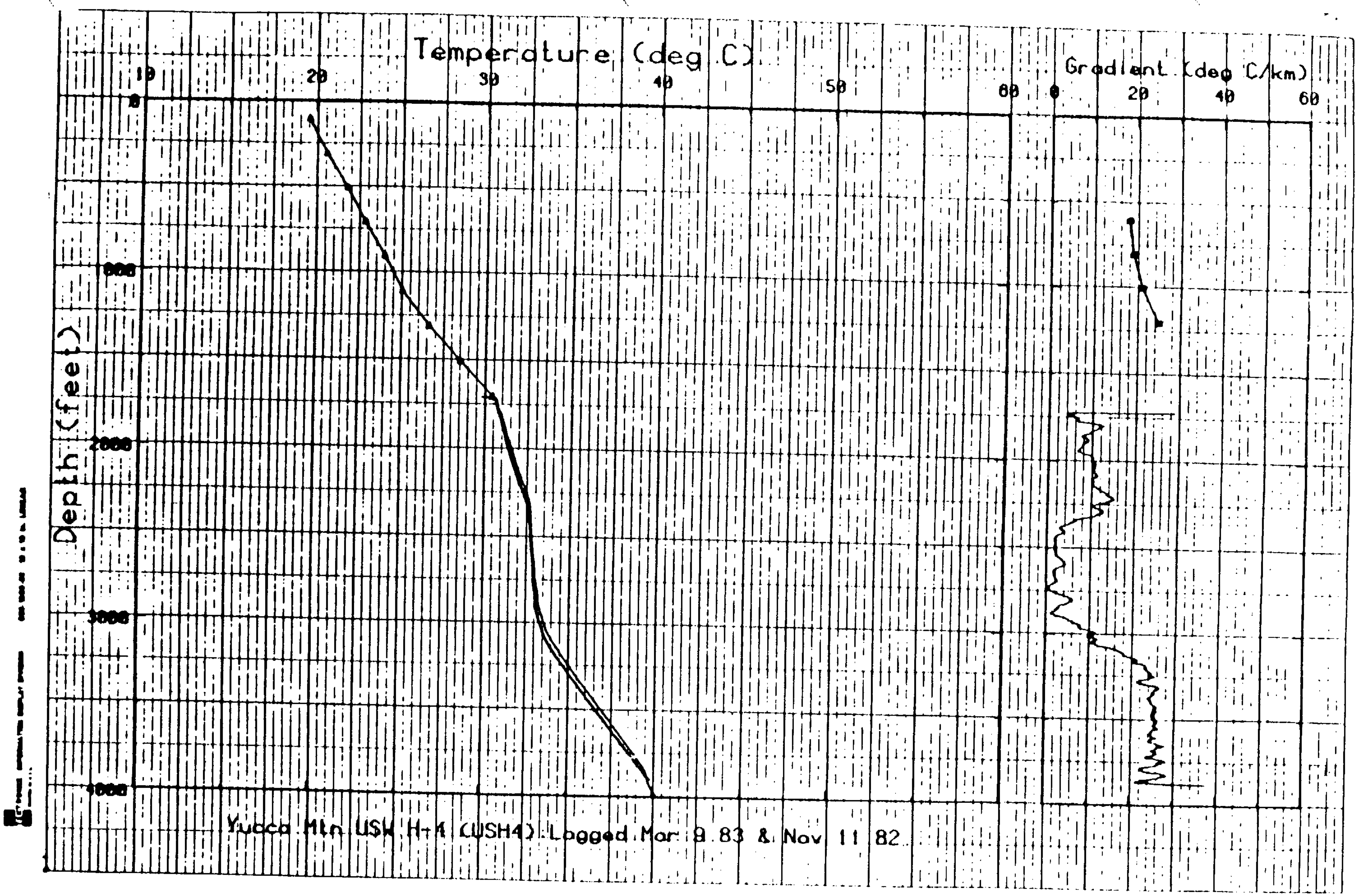

Relative Temperature
0
10 °C
USW H-3
Depth (feet)
0
1000
2000
3000
4000
NOV82
-1
MAR83
0
0
10
30
50 °C/km

Figure 22



Temperature (deg C)
10
20
30
40
50
60
Gradient (deg C/km)
0
20
40
60
Depth (feet)
0
1000
2000
3000
4000
Yucca Mtn USW H-4 (USH4) Logged Mar 8 83 & Nov 11 82

Figure 23

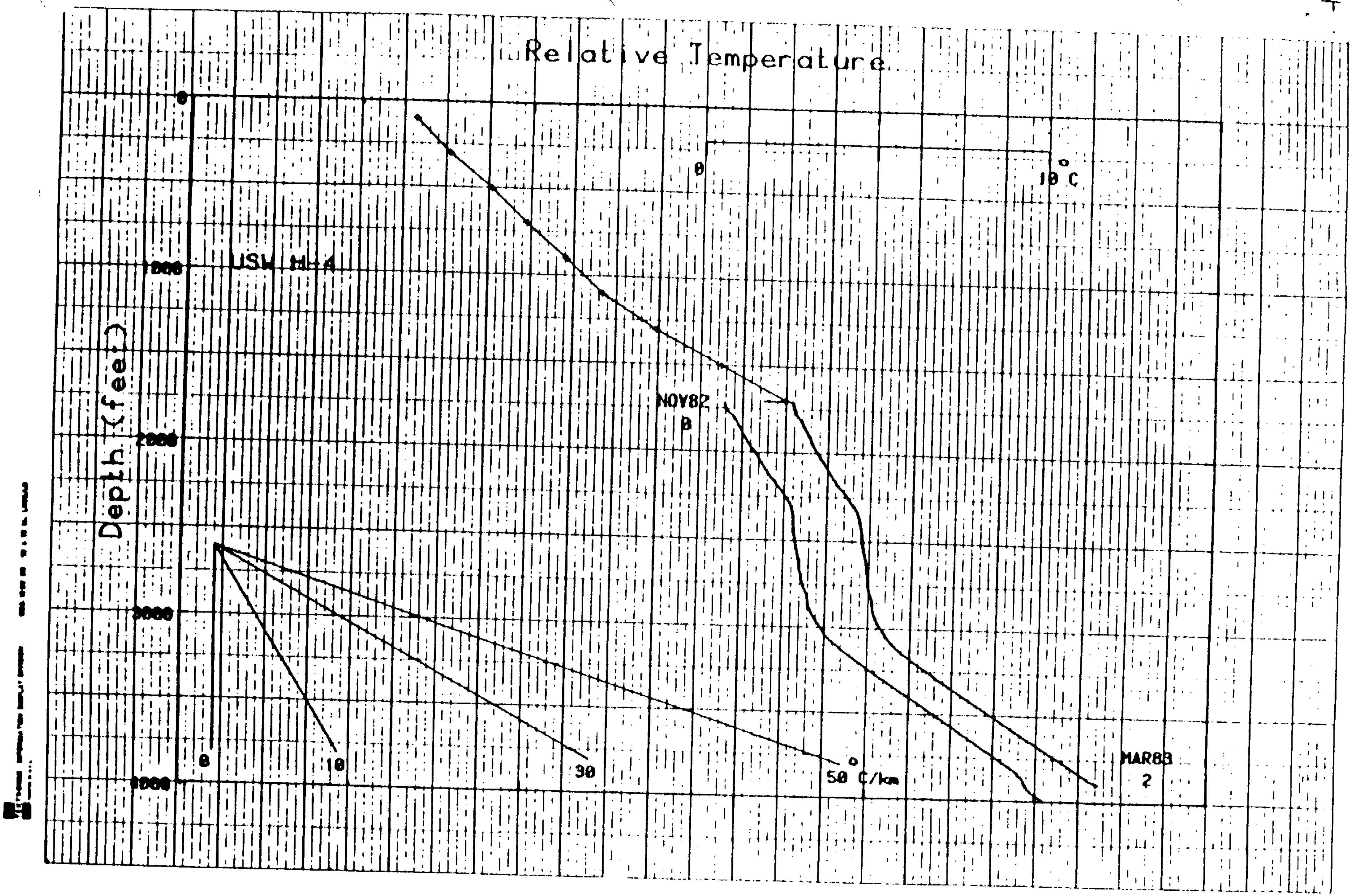

Relative Temperature
Depth (feet)
0
1000
2000
3000
4000
USW H-4
0
10 °C
NOV82
0
MAR88
2
0
10
30
50 °C/km

Figure 24

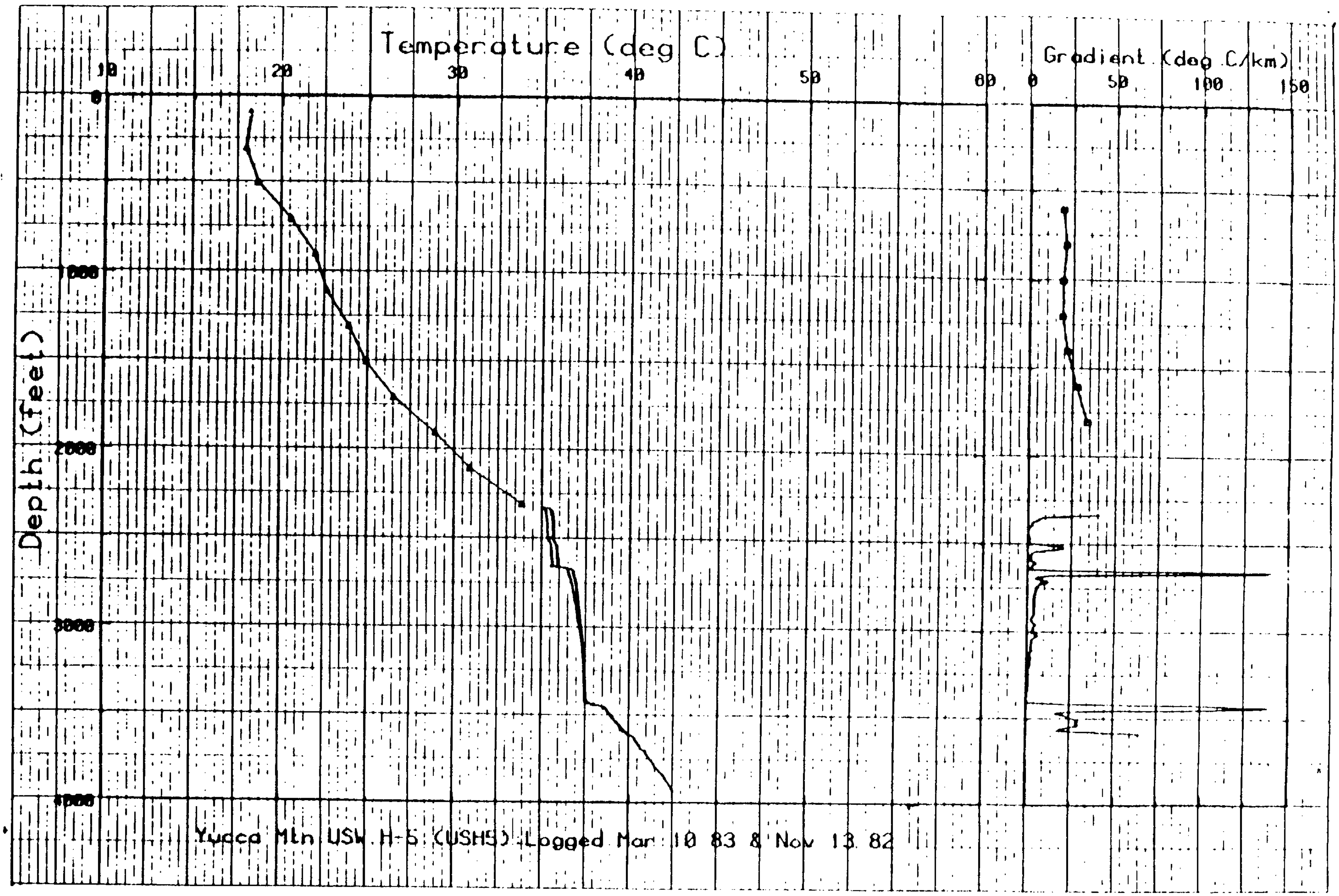
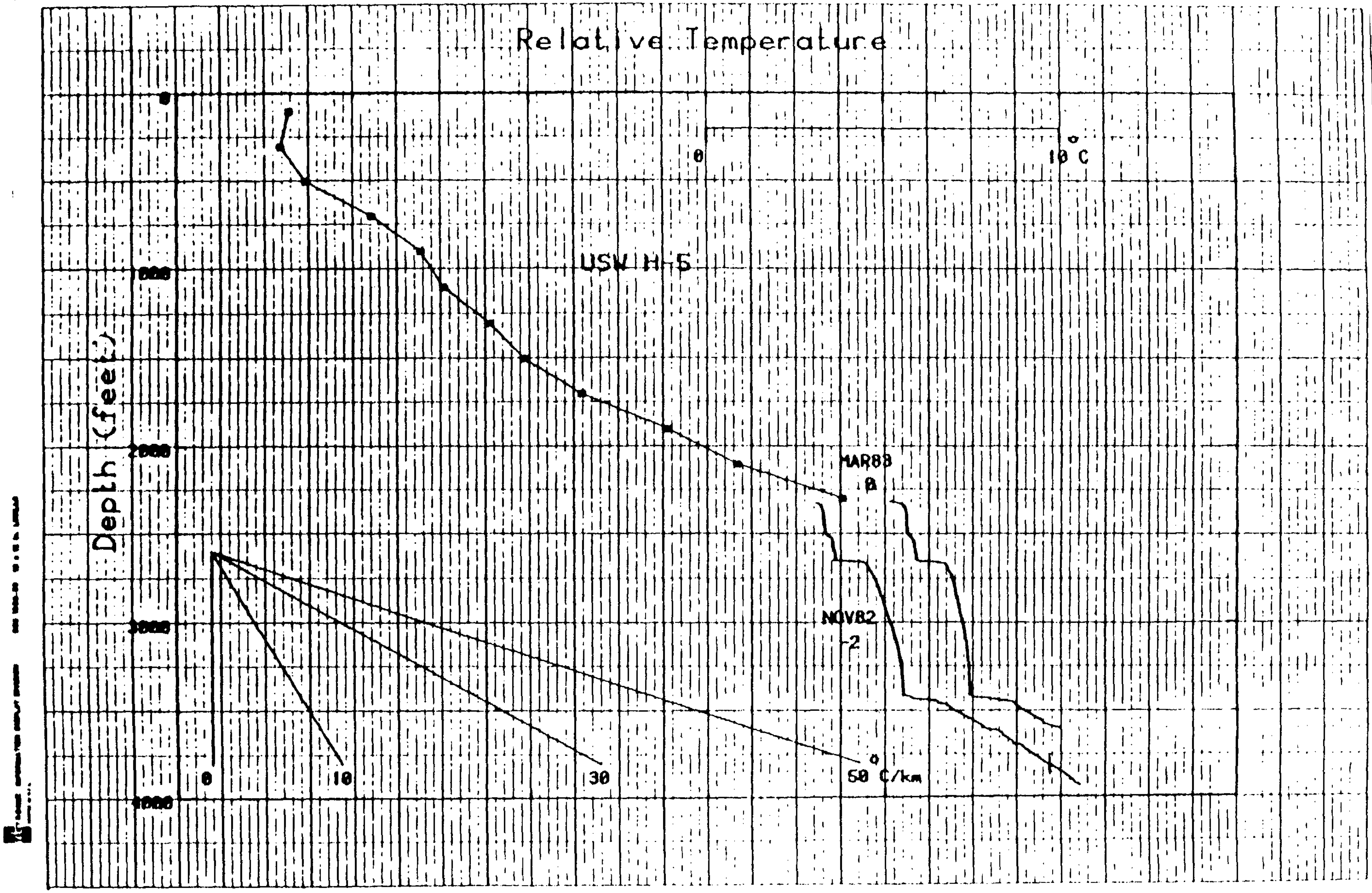
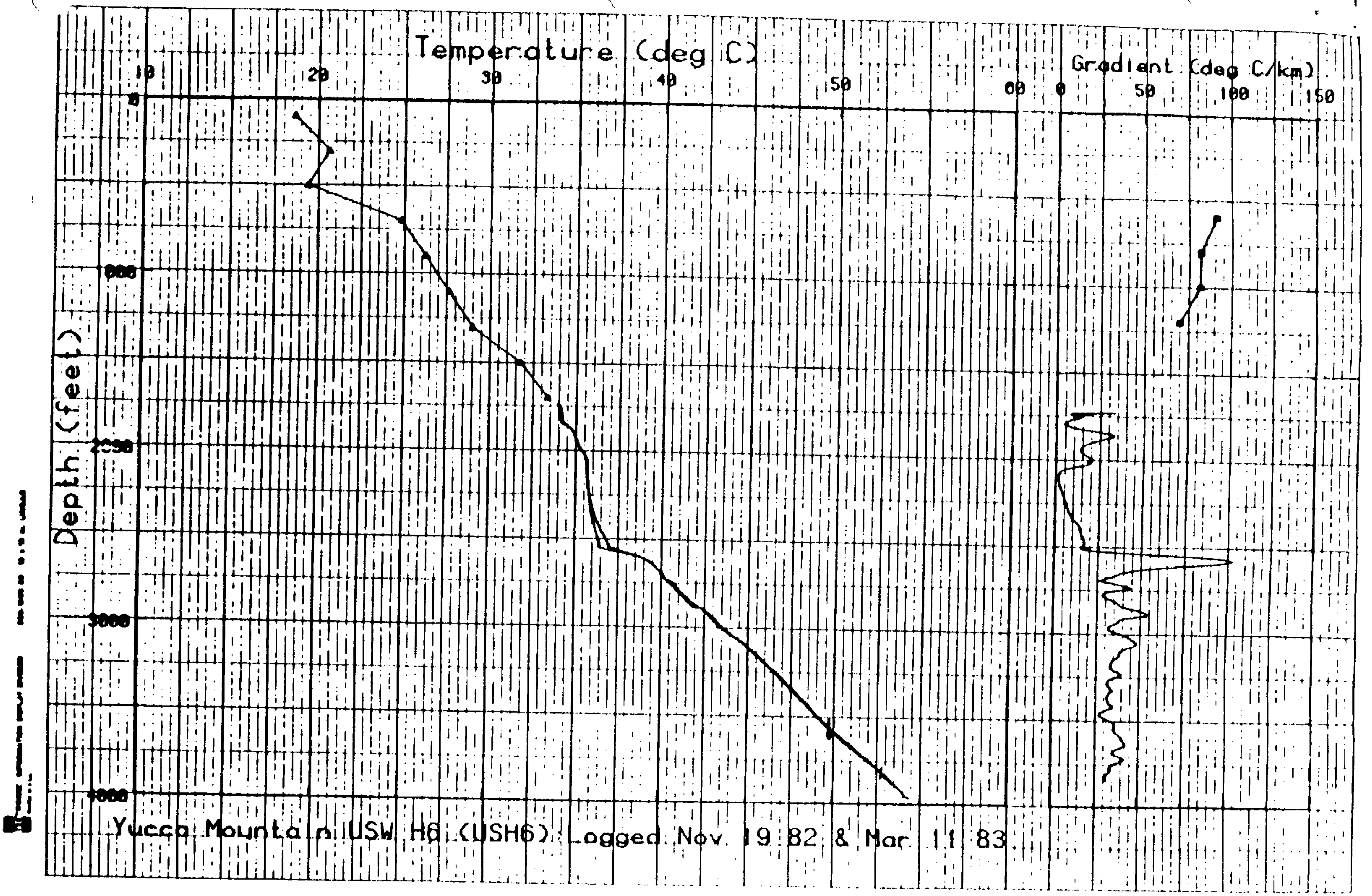

Temperature (deg C)
10
20
30
40
50
60
Gradient (deg C/km)
0
50
100
150
0
1000
2000
3000
4000
Depth (feet)
Yucca Mtn USW H-5 (USH5) Logged Mar 10 83 & Nov 13 82

Figure 25



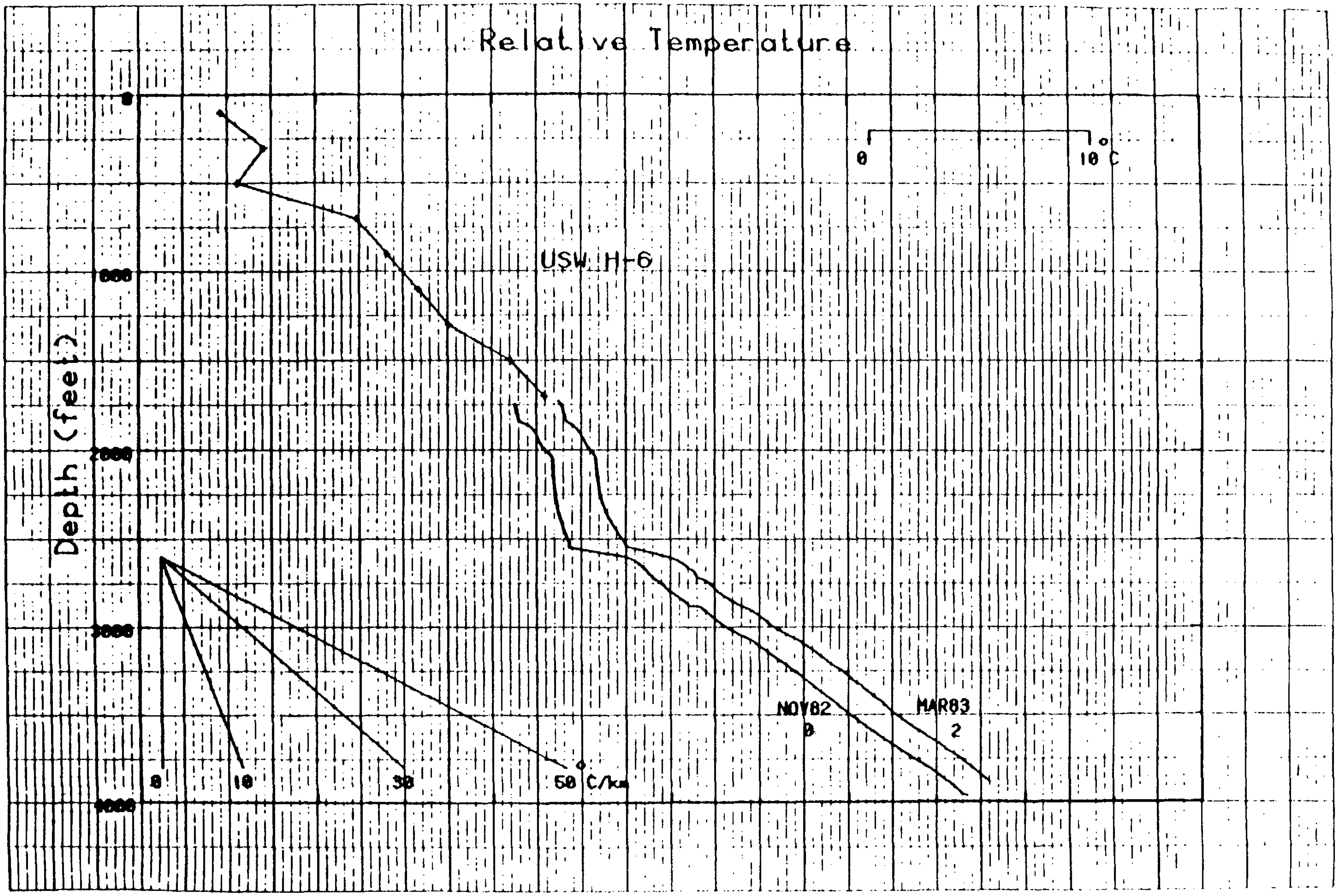
Relative Temperature
0
10 °C
USW H-5
Depth (feet)
1000
2000
3000
4000
MAR88
0
NOV82
-2
0
10
30
50 °C/km

Figure 26



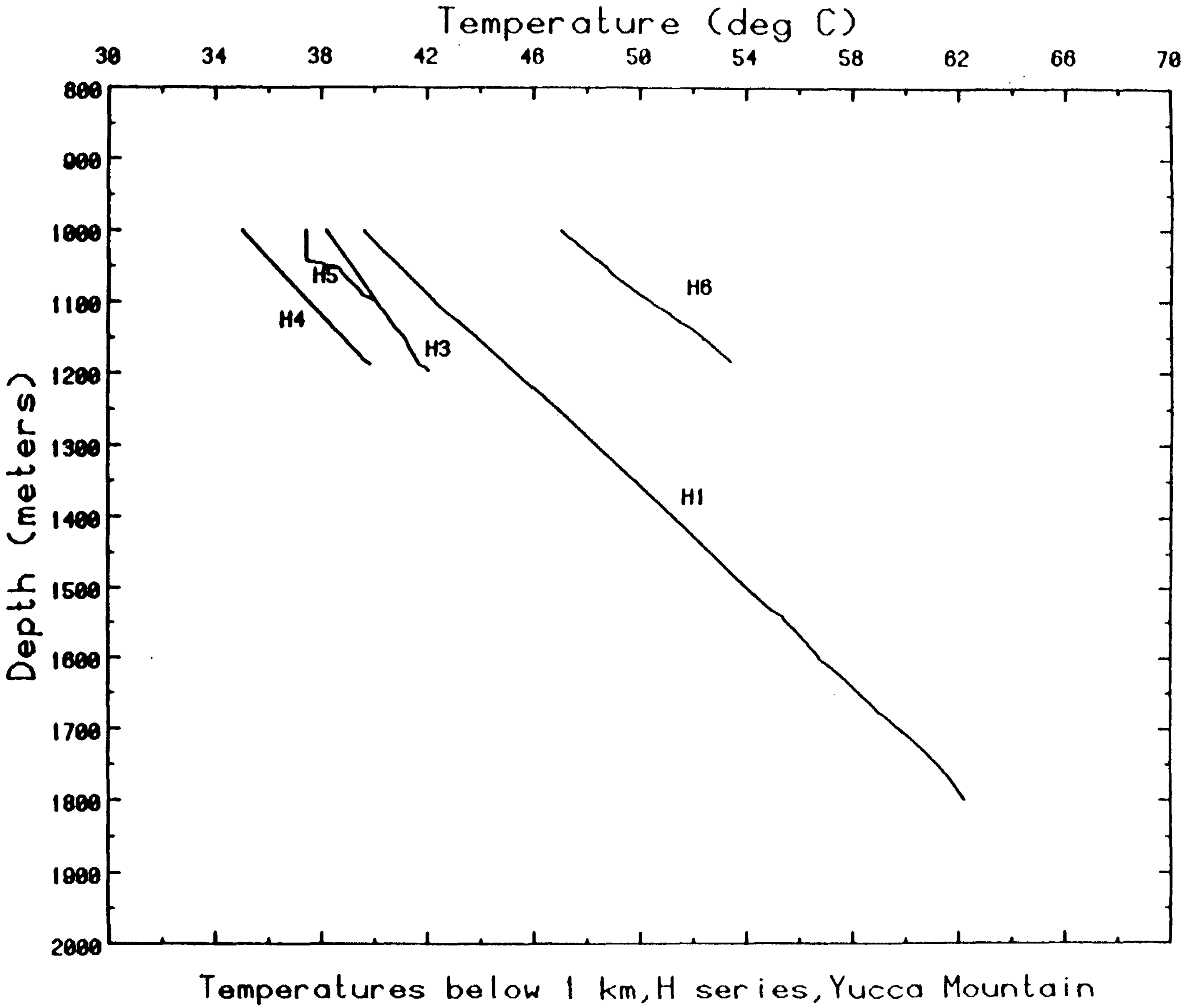
Temperature (deg C)
10
20
30
40
50
60
Gradient (deg C/km)
0
50
100
150
Depth (feet)
0
1000
2000
3000
4000
Yucca Mountain USW H6 (USH6) Logged Nov 19 82 & Mar 11 83

Figure 27



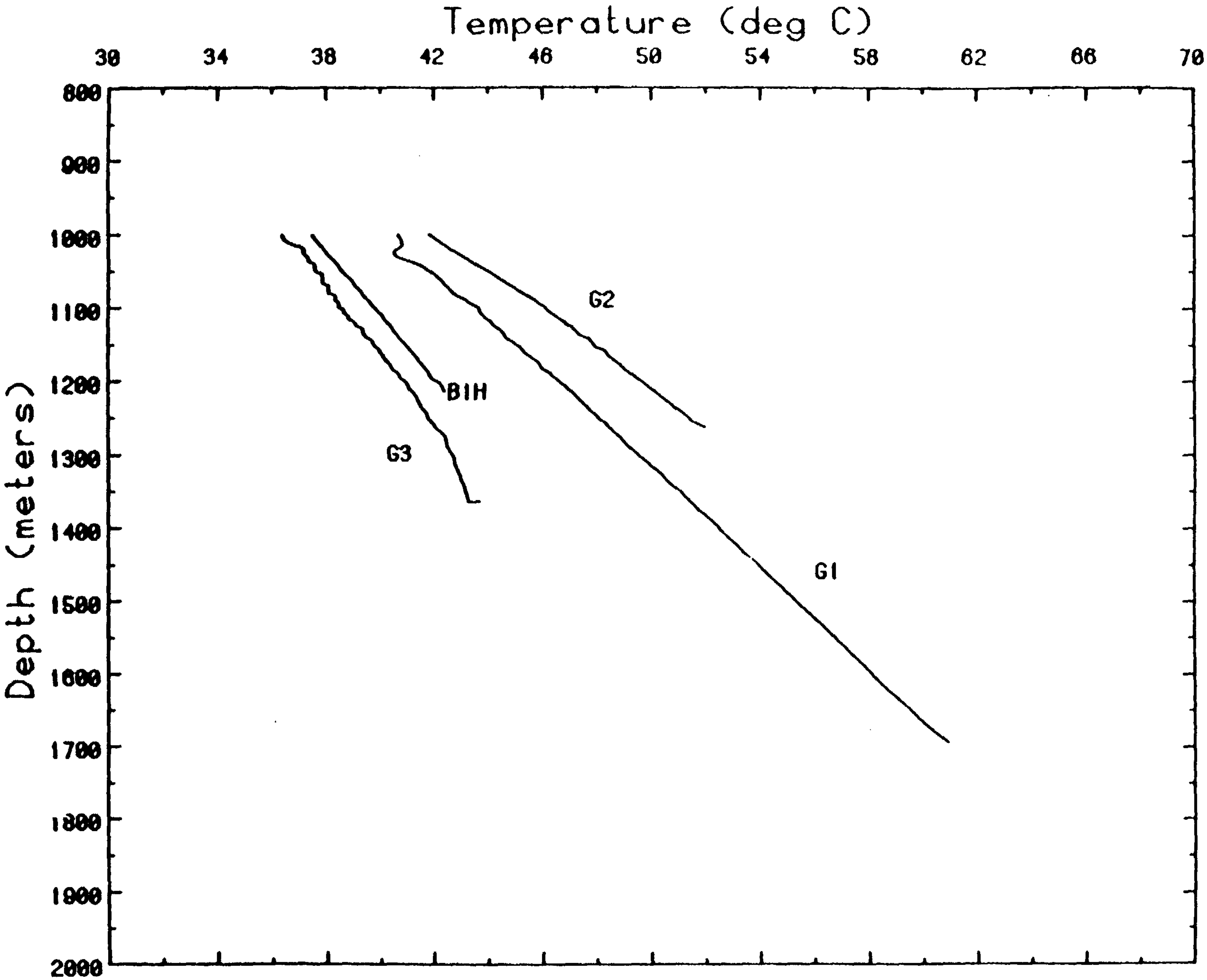
Relative Temperature
0
10 °C
USW H-6
Depth (feet)
1000
2000
3000
4000
NOV82
0
MAR83
2
0
10
30
50 C/km

Figure 28



Temperature (deg C)
30
34
38
42
46
50
54
58
62
66
70
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Depth (meters)
H5
H6
H4
H3
H1
Temperatures below 1 km, H series, Yucca Mountain

Figure 29



Temperatures below 1 km in G series Wells & Ue25 B1H.

Figure 30