USGS-OFR -- ~~83-455~~

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Temperature profiles from Salt Valley, Utah, thermal conductivity of 10 samples from drill hole DOE 3, and preliminary estimates of heat flow

by

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Open-File Report 83-455

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1983

DISCLAIMER

INTRODUCTION

As part of a thermal study of the Salt Valley anticline, Paradox Basin, Utah, we have obtained temperature profiles in nine wells drilled by the Department of Energy (Figures 1 and 2). We also have measured thermal conductivities on ten samples judged to be representative of the rocks encountered in the deepest hole (DOE 3) (R. J. Hite, personal communication, November 21, 1980). In this interim report, we present the temperature profiles and thermal conductivities, together with some preliminary interpretive remarks and some suggestions for additional work.

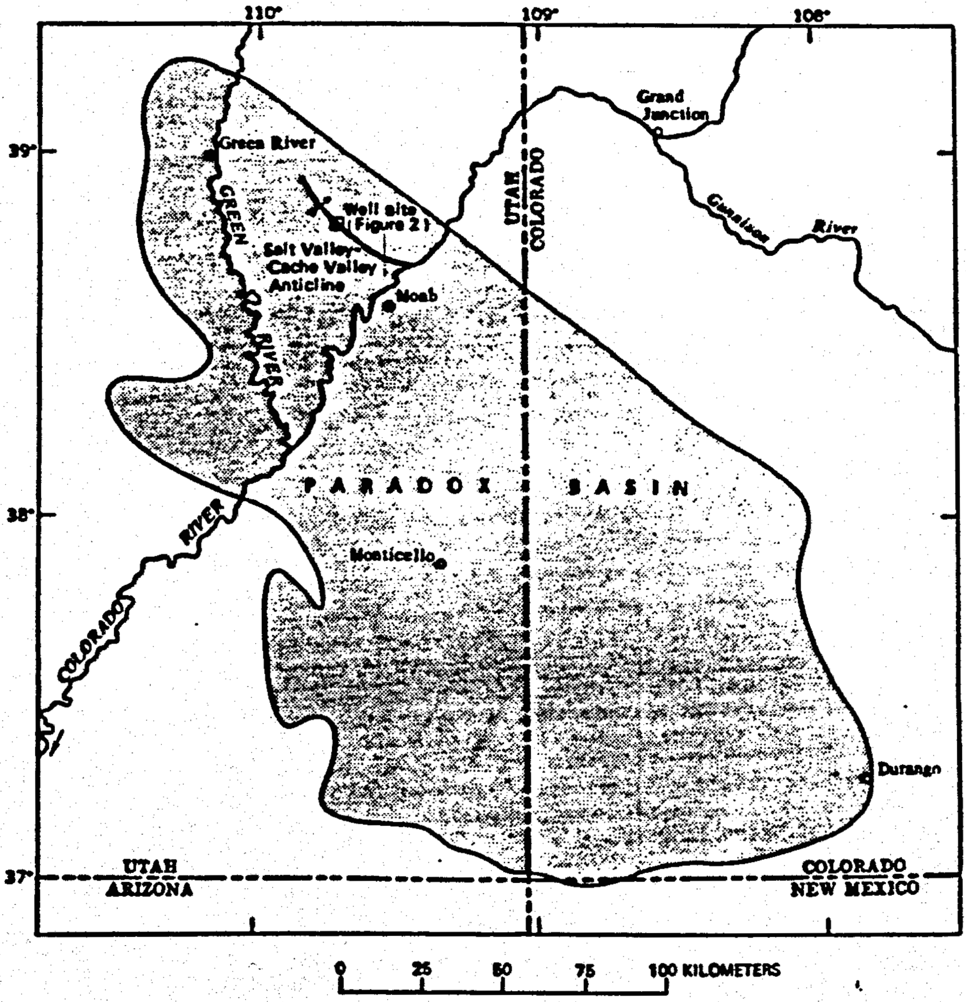


Figure 1. Location of the test-well site in the Paradox Basin of Utah and Colorado (from Rush and others, 1980).

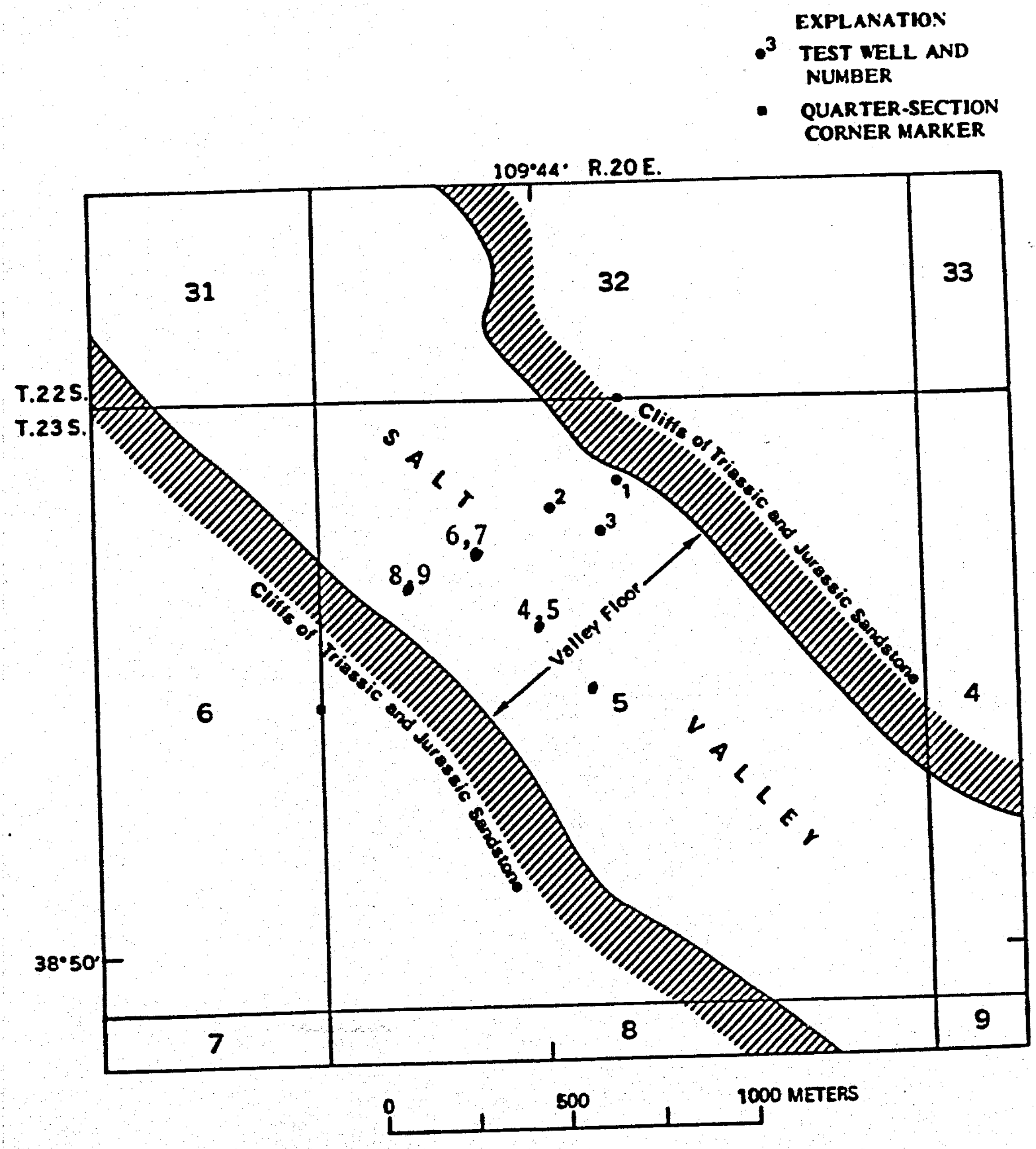


Figure 2. Location of test wells in Salt Valley (from Rush and others, 1980).

TEMPERATURES

The temperature logs were obtained by Fred Grubb (USGS) on October 12, 1980, using the USGS digital logging system and by John Bodell (University of Utah) on January 7 and 8, 1981, using a portable system similar to that described by Sass and others (1971). Temperatures were measured at 0.3 m intervals in Hole 1 and 2 and 0.6 m below 61 m in Hole 3. In holes 4 through 9, the measurement interval was 10 meters. The overall accuracy of temperature measurement is better than 0.1°C and relative temperatures are accurate to about 1 millidegree (Sass and others, 1971).

Figure 3 shows the profiles for holes 1, 2, and the upper 400 m of hole 3. The entire profile for hole 3 is presented in Figure 4. There are some disturbed zones, both within the salt and the caprock in all profiles; however, the overall thermal regime appears to be conductive. This was confirmed by the measurements in the shallower wells which barely penetrated the caprock (Figures 5 through 10). The temperature disturbances, particularly in the caprock could be the result of localized water movement, but the disturbed zones within the salt are most likely caused by small inflows of gas (R. J. Hite, personal communication, 1981). Temperature gradients in wells 4 through 7 are mutually consistent and average about 38°C/km. Wells 8 and 9 near the western margin of the valley yield temperature gradients of between 25 and 30 °C/km. The systematic difference could be the result of lateral variation of thermal conductivity, structure, vertical water movement or possibly a combination of these. We are presently awaiting conductivity measurements to help resolve this problem.

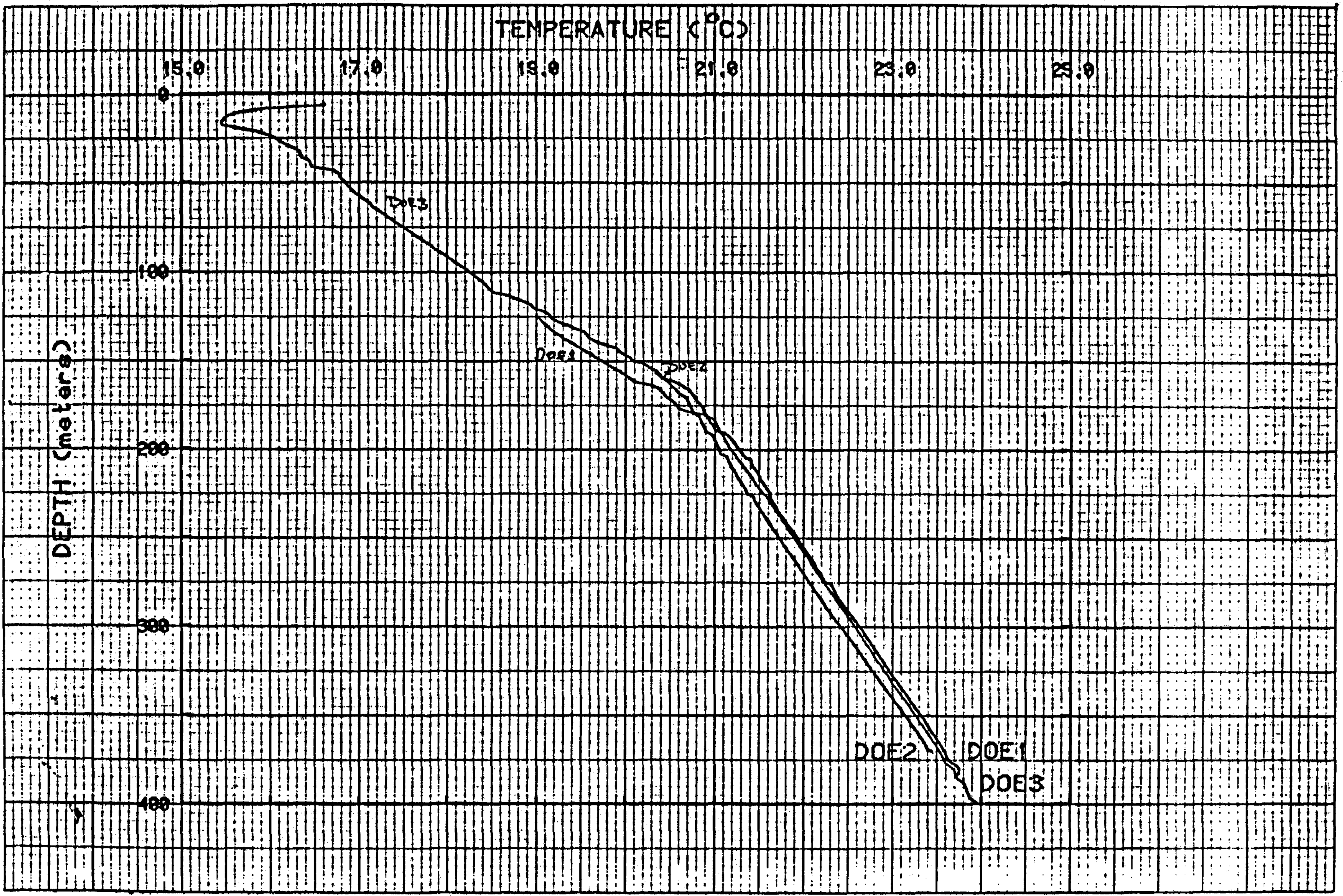


Figure 3. Temperatures in wells DOE 1, 2, and 3, Salt Valley, Utah.

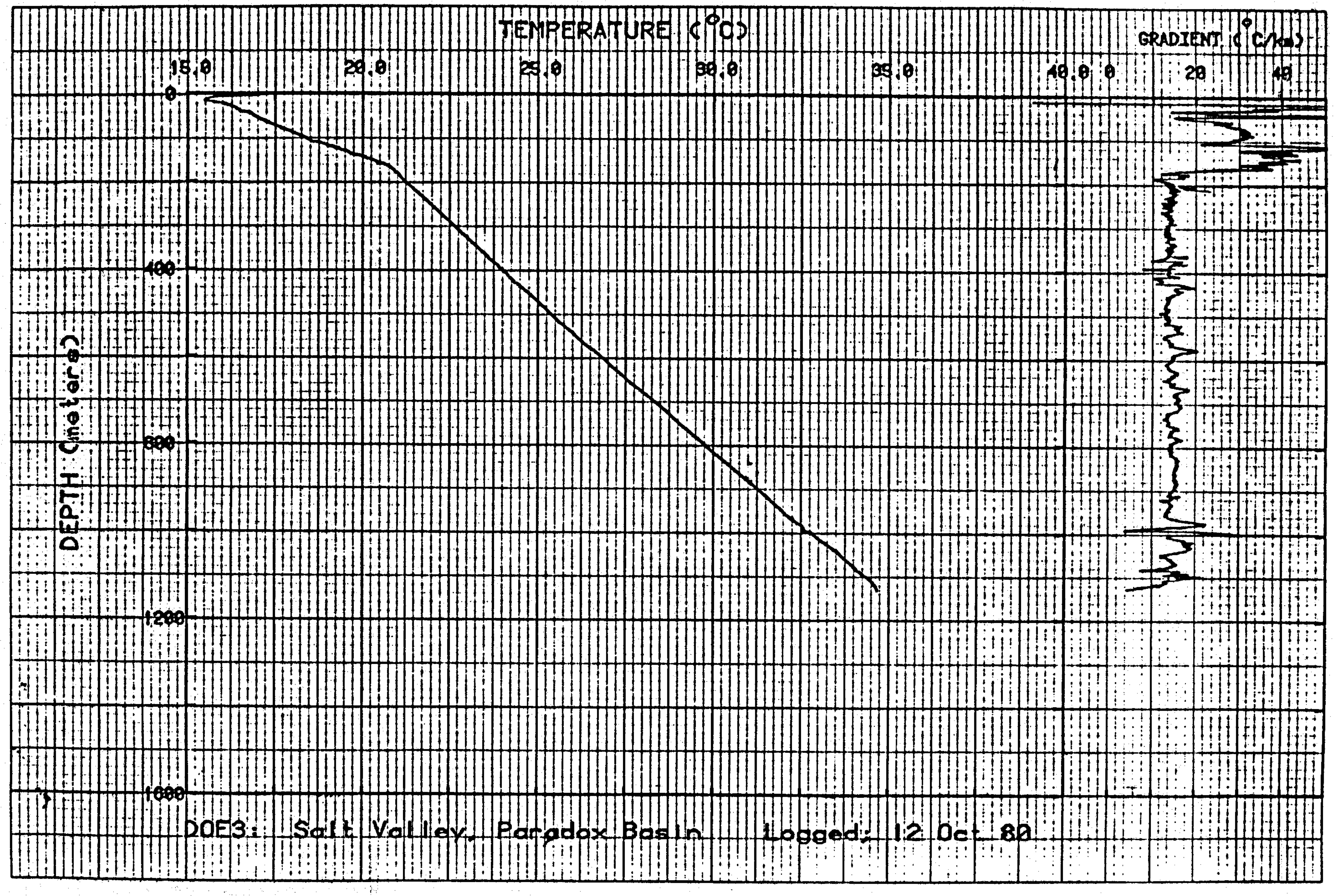


Figure 4. Temperature profile and temperature gradients (sliding average over 5 meters) for well DOE 3, Salt Valley, Utah.

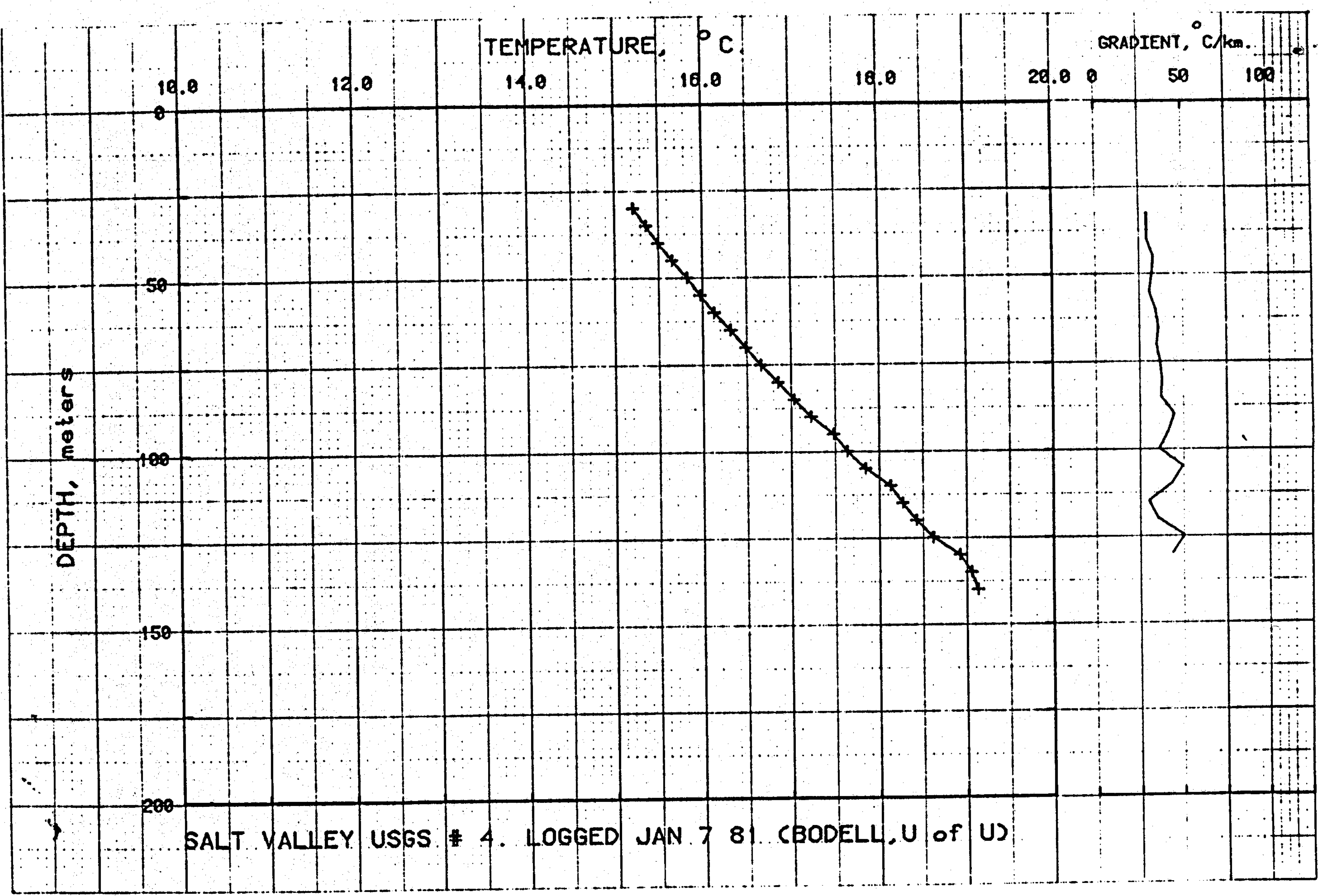


Figure 5. Temperature profile and temperature gradients for well DOE 4, Salt Valley, Utah.

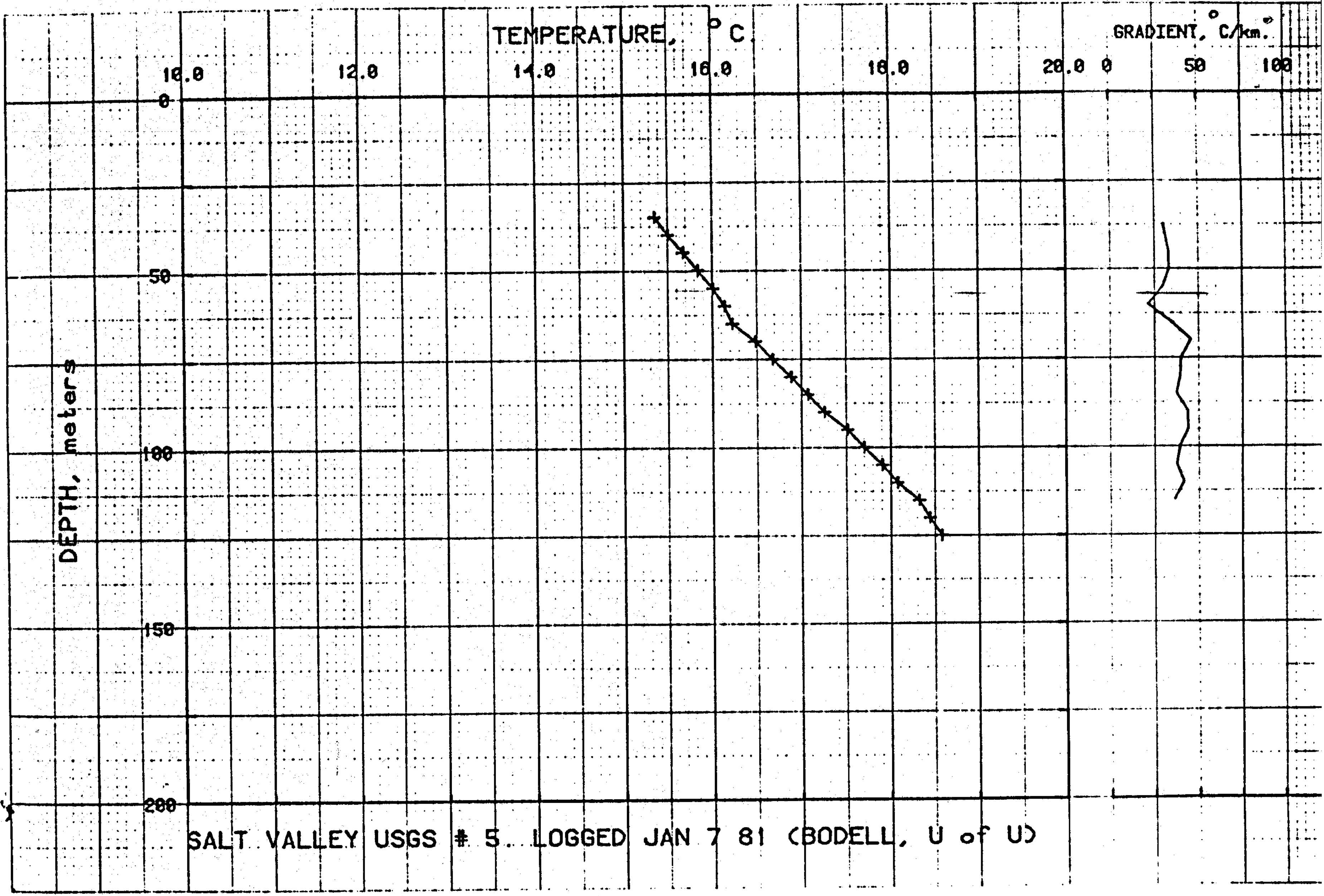


Figure 6. Temperature profile and temperature gradients for well DOE 5, Salt Valley, Utah.

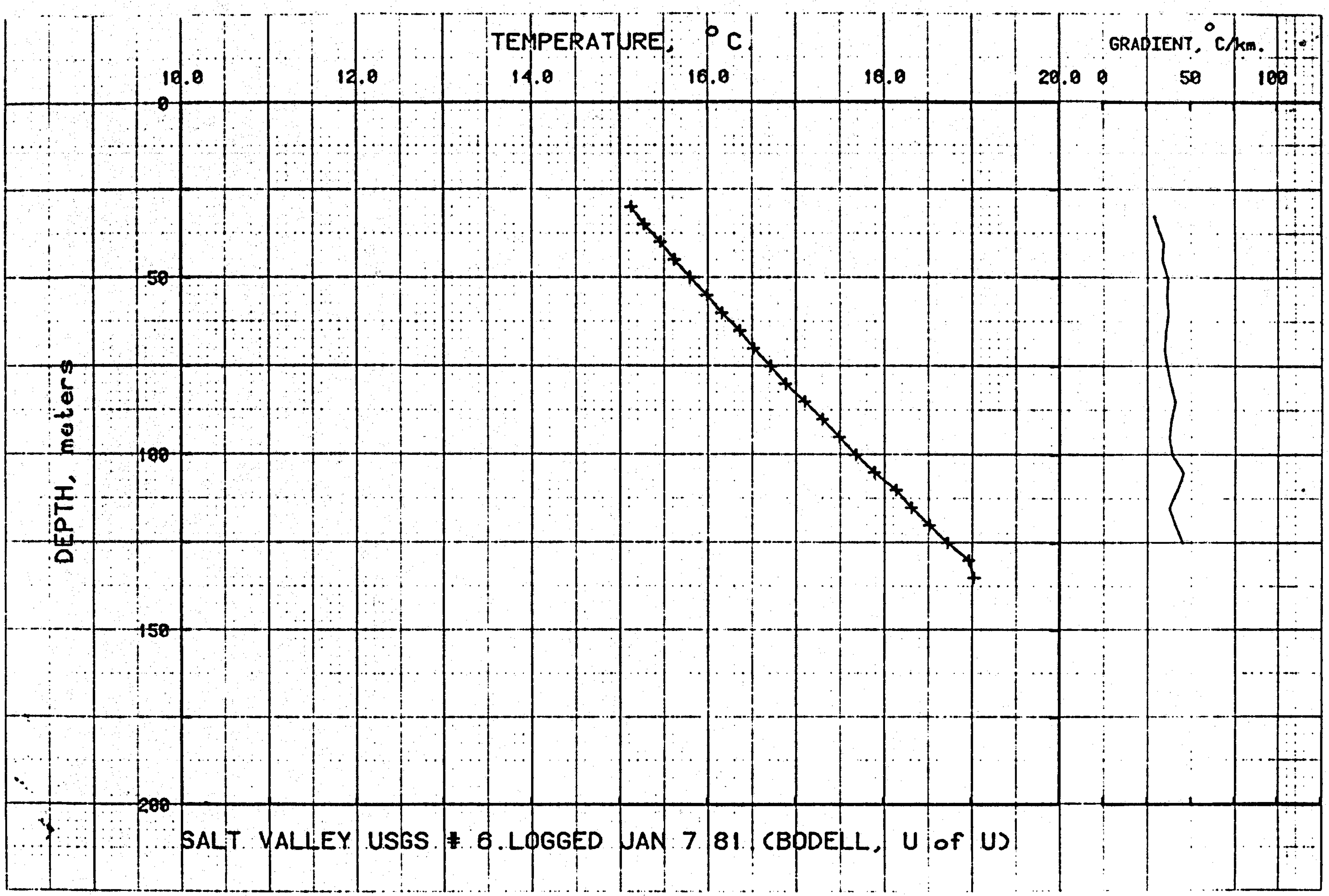


Figure 7. Temperature profile and temperature gradients for well DOE 6, Salt Valley, Utah.

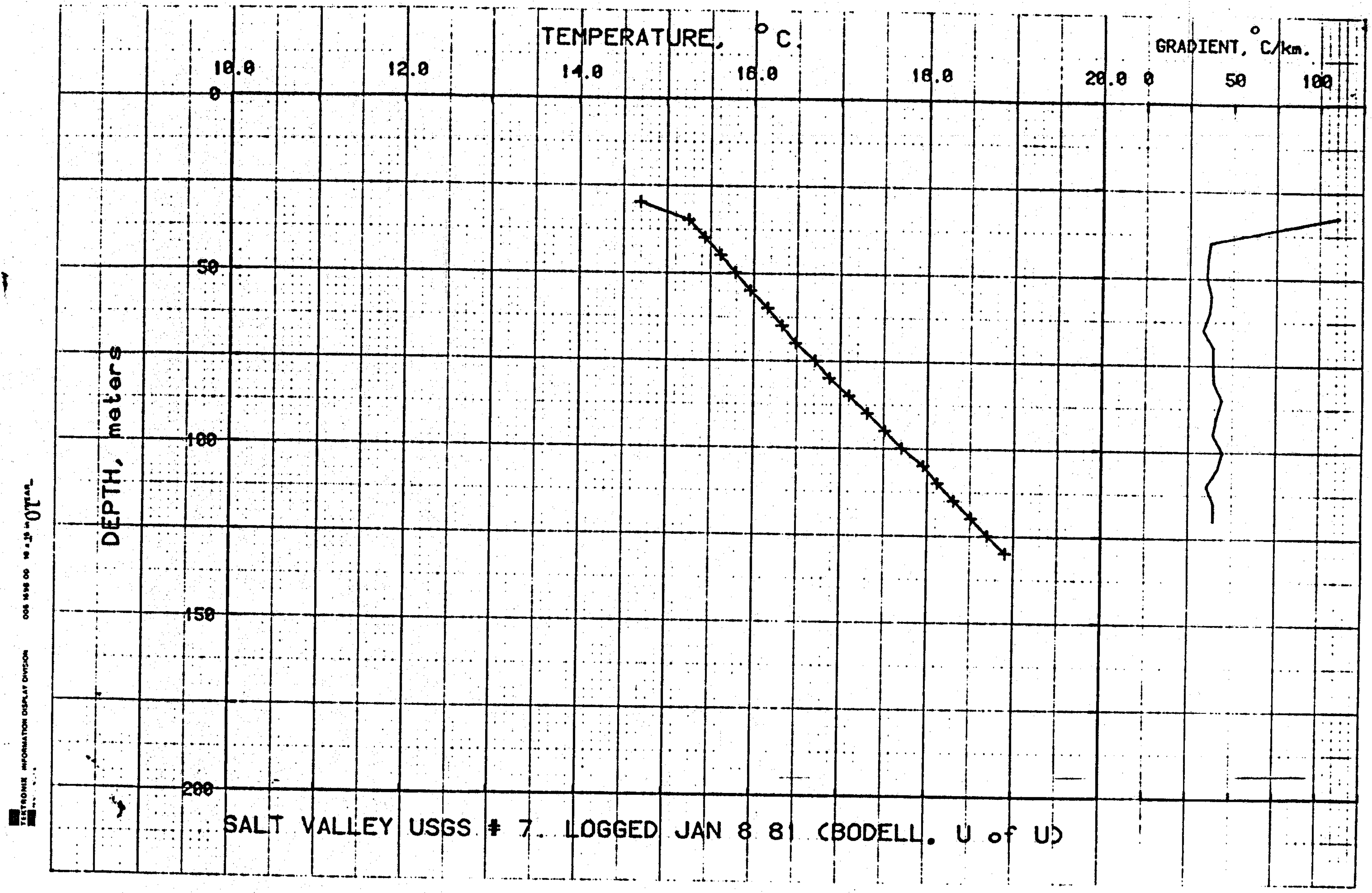


Figure 8. Temperature profile and temperature gradients for well DOE 7, Salt Valley, Utah.

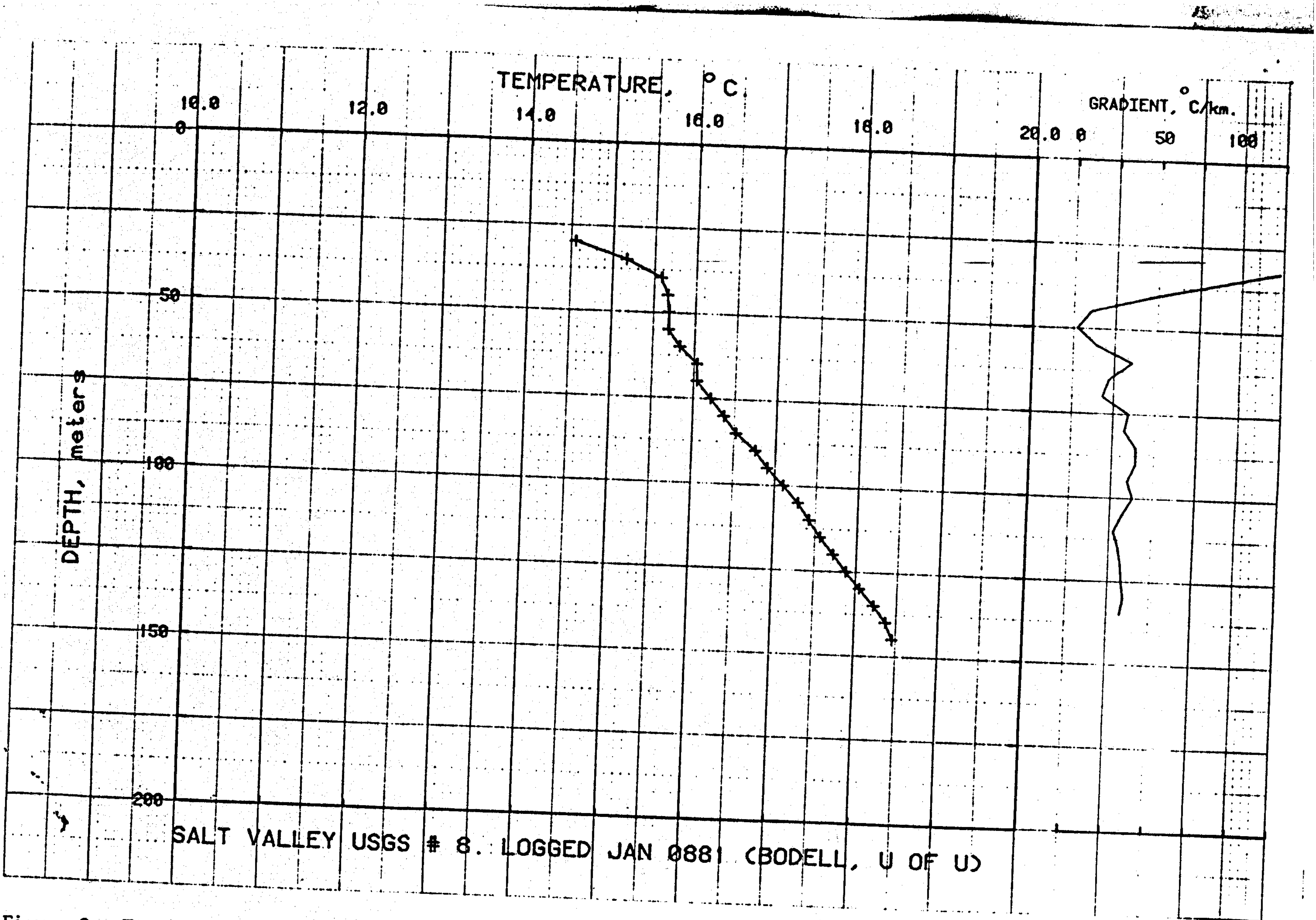


Figure 9. Temperature profile and temperature gradients for well DOE 8, Salt Valley, Utah.

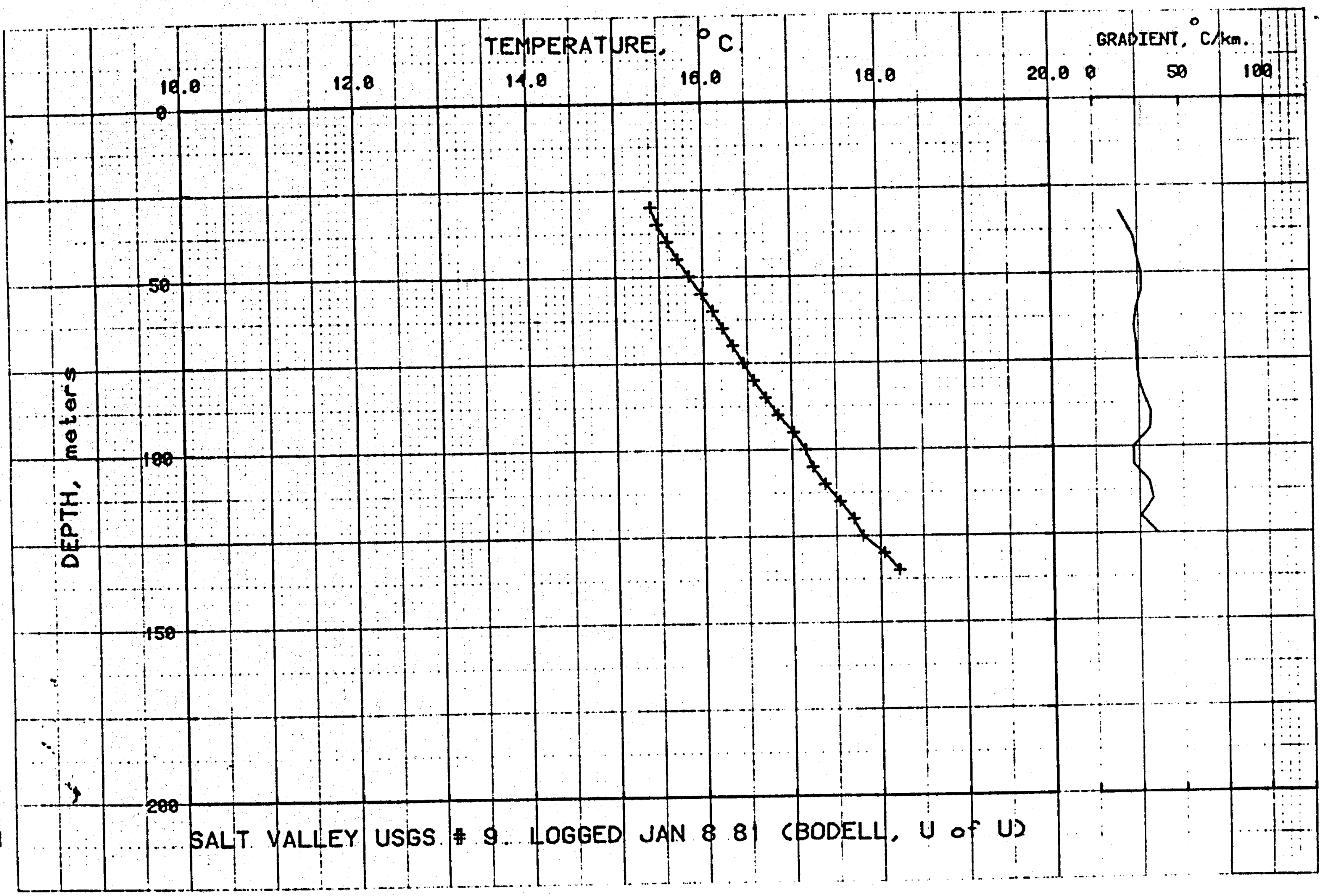


Figure 10. Temperature profile and temperature gradients for well DOE 9, Salt Valley, Utah.

THERMAL CONDUCTIVITIES

Thermal conductivities were measured using an updated version of the needle probe system described by Lachenbruch and Marshall (1966). Probe calibrations are checked periodically against fused silica standards so that all values are relative to Ratcliffe's (1959) values for fused silica. The procedure for solid core involves drilling 1 mm diameter holes 36.5 mm long both axially and radially into the core. These holes provided a snug fit for the needle probe (which has the same dimensions) and no contact resistance effects were apparent in the curves of temperature versus logarithm of time used to obtain values of thermal conductivity. The thermal conductivities are reproducible and precise to better than ±3%.

Results of thermal conductivity measurements at the sites indicated on the sketches of Figures 11 and 12 are presented in Table 1. The needle probe method is based on the theory of a line source of heat in an infinite medium. Thus, the conductivity measured is in a direction perpendicular to the orientation of the probe. Hence, for example, the sites with "A" (axial) orientation yield the mean thermal conductivity in a radial direction. No anisotropy is apparent in any of the cores tested (Table 1) so that, for our purposes, the probe orientation is not important. The values for evaporites, Table 1a, fall well within the range of values tabulated in the literature but are higher than those reported by Spicer (1964). Clark's (1966) summary of previously reported (room-temperature) values shows a range of 12.8 to 17.2 TCU (1 TCU = 10^{-3} cal cm^{-1} s^{-1} $°C^{-1}$) for natural rocksalt and a value of 21.3 TCU for synthetic halite, as compared with our values of between 14.4 and 15.4 TCU at 22°C. Literature values for anhydrite fall between 11.7 and 13.4 TCU (Clark, 1966) as compared with our mean value of 12.7. Our value of 7.4 TCU for dolomite is more characteristic of a dolomitic limestone than of typical dolomites which have conductivities in the range 10 to 12 TCU. Finally, our high value (9.1 TCU) for black shale probably reflects admixtures of salt and a high degree of silicification of the shale.

The agreement with literature values from Table 1a was encouraging; however, the discrepancies between our values and those of Spicer (1964) prompted us to obtain more conductivity values. The rocksalt intervals in DOE 3 are composed primarily of very pure halite (R. J. Hite, personal communication, 1980). To examine the influence of impurities and cracks, we obtained an additional five samples of rocksalt which had some cracks and minor anhydrite banding (not conspicuous at a hand sample scale). The results show more scatter and a slightly (but not significantly) lower mean.

The suggestion has also been made (G. E. Raines, written communication, December 22, 1980) that the large discrepancy (~50%) between our values and some obtained by J. F. Lagedrost (unpublished ONWI report, 1980) might be the result of our small-diameter probe's not sampling intergranular contact resistances. An extensive comparison of measurements on small and large samples (Sass, 1964; Sass and Beck, 1966) indicates that such effects are considerably smaller than the aforementioned discrepancy.

Table 1a. Thermal conductivities, Hole DOE 3, Salt Valley, Utah
(Conductivities measured at ∼22°C)

Depth (m)	Material	Site*	Orientation[†]	K W m^{-1} K^{-1}	K mcal cm^{-1}sec^{-1}°C^{-1}
365	Halite	A	A	6.26	14.98
		B	R	6.24	14.94
			Mean	6.25	14.96
438	Black shale	A	A	3.58	8.57
		B	R	4.07	9.75
		C	R	3.75	8.97
			Mean	3.80	9.07
453	Anhydrite	A	A	5.33	12.74
		B	R	5.12	12.26
		C	R	5.58	13.35
		D	A	5.19	12.42
			Mean	5.30	12.69
528	Dolomite	A	A	3.04	7.27
		B	R	3.12	7.46
			Mean	3.08	7.36
892	Halite	A	A	6.22	14.88
		B	R	6.03	14.42
			Mean	6.12	14.65

* See sketch identifying measurement sites (Figure 11).

[†] A Needle probe oriented along core axis.
R Needle probe oriented along a radius (perpendicular to core axis).

Table 1b. Thermal conductivities, Hole DOE 3, Salt Valley, Utah
(Conductivities measured at ~22°C)

Depth (m)	Material	Site*	Orientation†	K	
				W m^{-1} K^{-1}	mcal $cm^{-1}sec^{-1}{}^{\circ}C^{-1}$
595	Halite**	A	A	6.55	15.67
		B	R	6.29	15.04
		C	A	6.49	15.52
			Mean	6.44	15.41
660	Halite**	A	A	6.22	14.87
		B	R	6.21	14.84
		C	A	6.25	14.96
			Mean	6.23	14.90
767	Halite**	A	A	5.99	14.34
		B	R	5.98	14.32
			Mean	5.98	14.33
945	Halite**	A	A	5.88	14.07
		B	R	5.71	13.67
		C	A	5.75	13.76
			Mean	5.78	13.83
1242	Halite††	A	A	5.78	13.82
		B	R	5.71	13.66
		C	A	5.67	13.55
			Mean	5.72	13.68

* See sketch identifying measurement sites (Figure 12).

† A Needle probe oriented along core axis.
R Needle probe oriented along a radius (perpendicular to core axis).

** Minor anhydrite banding.

†† Extensively fractured

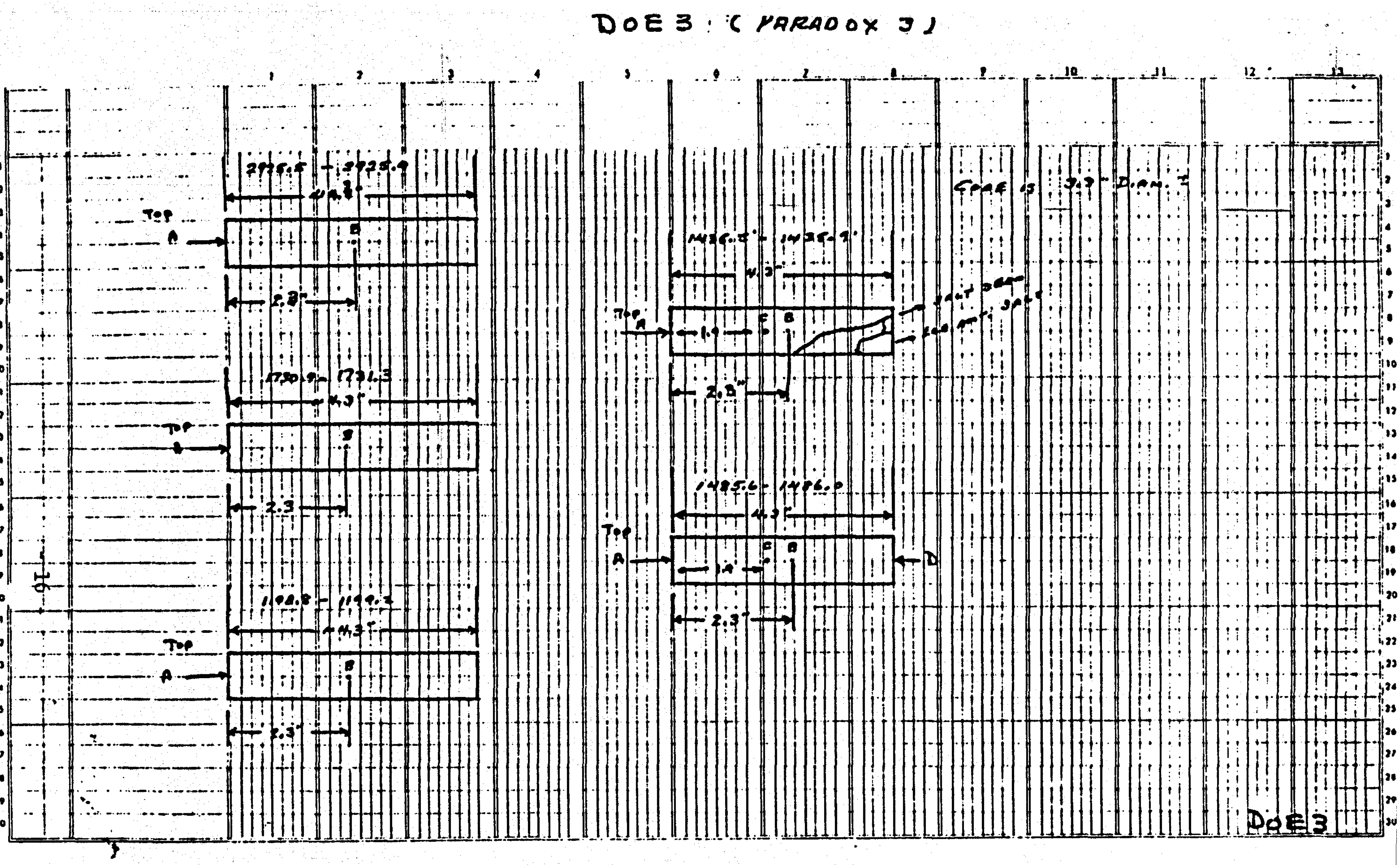
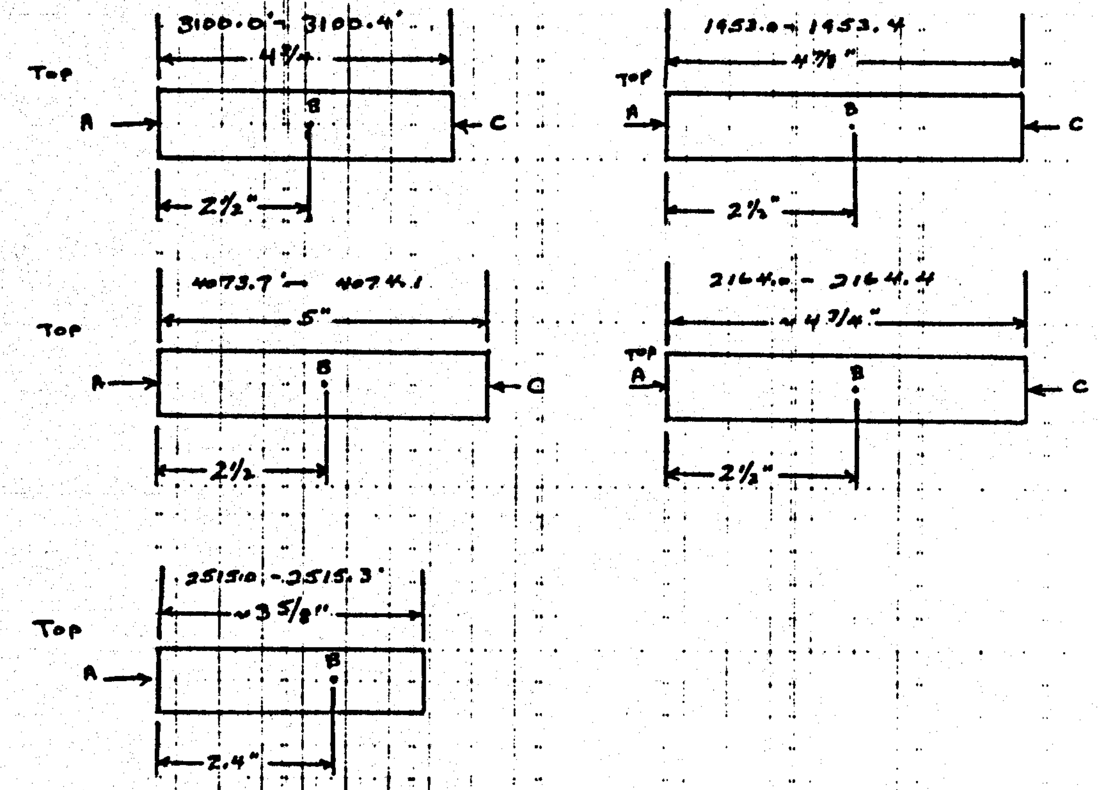


Figure 11. Sketch indicating locations of holes for needle probe determinations of thermal conductivity summarized in Table 1a. Depths are in feet. Distances along core are in inches measured from top of core.

DOE3 (PARADOX-3)



(DOE3)

Figure 12. Sketch indicating locations of holes for needle probe determinations of thermal conductivity summarized in Table 1b. Depths are in feet. Distances along core are in inches measured from top of core.

PRELIMINARY ESTIMATES OF HEAT FLOW

Spicer (1964) reported heat-flow values from oil tests in the same general area: 3 wells within the anticline ~10 km to the northwest, 1 well (Balsley #1) about 10 km to the southeast and a single well (Hyde #1) lying off the structure about 20 km to the east. Spicer's thermal conductivities are suspect as he used values from "dry" specimens. Spicer also made no attempt to correct his heat-flow values for the effects of structure. Studies now under way at University of Utah (John M. Bodell and D. S. Chapman, personal communication, 1980) should provide improved values of thermal conductivities from which Spicer's (1964) values (particularly for Hyde #1) can be improved. Our preliminary summary of heat flow from DOE 3 is presented in Table 2. In the caprock, we obtained a gradient of 39.2 ± 0.3 °C km^{-1} between 107 and 162 meters. This compares well with Spicer's (1964) gradients within 10 km which range (with one exception) from 37 to 39 °C km^{-1}. Our gradients in the Paradox salt also are comparable with Spicer's, his ranging from 12.3 to 15.7°C km^{-1} and ours, from 13.1 to 14.7 °C km^{-1} (Table 2). We have as yet no samples from which to estimate caprock conductivities. Our values for salt, however (Table 1), are more than 50% higher than Spicer's values for what appears to be the same formation. In the estimates of Table 2, the thermal conductivity of salt was corrected for the effects of temperature by averaging the rate of increase per °C of thermal resistivity with temperature from Birch and Clark (1940) (0.3 cm sec cal^{-1}) and that from McCarthy and Ballard (1960) (0.2 cm sec cal^{-1}). The 3 salt intervals yield internally consistent values of heat flow averaging 84 ± 2 kW km^{-2}. We attribute the lower value for the shale interval to the strong probability that the shale layer is steeply dipping and/or laterally discontinuous. The value of 84 kW km^{-2} would require a thermal conductivity of ~2.1 W m^{-1} K^{-1} (~5 TCU) in the lowermost 55 m of caprock as compared with values of ~3.5 TCU (~1.5 W m^{-1} k^{-1}) used by Spicer.

The hole is only ~200 meters from a sandstone cliff ~100 meters high. The effect of this topography will not be important at the depths of our heat-flow estimates. What will affect our interpretation is the presumed conductivity contrast between salt and sandstone across a dipping contact extending to depths of several kilometers. The total thickness of salt at this site is not known precisely, but from nearby wells it most probably extends to depths of between 2 and 3 km (Spicer, 1964; Hite and Lohman, 1973; Rush and others, 1980).

Because of the present uncertainties in sensitive parameters, we shall attempt only a crude analysis of the refraction effects to provide a basis for further measurements. Application of simple two-dimensional models for bodies approximating the geometry of Figure 13 (Lachenbruch, 1968; Lachenbruch and Marshall, 1966; Jaeger, 1965) assuming a conductivity contrast of 2 between halite and country rocks result in corrections of $30\%\pm15\%$ to the observed heat flux. Our best estimate of regional heat flux is thus 59 ± 12 kWkm^{-2}. Fortuitously, Spicer arrived at a comparable mean value using underestimates of conductivity and ignoring the thermal conductivity structure. More refined estimates of regional heat flow must await more precise determinations of country rock thermal conductivity and perhaps a more detailed picture of the structure. They also must take account of the layer of caprock overlying the salt.

TABLE 2. Estimates of heat flow from Hole DOE 3

Depth interval (m)	Material	Gradient °C km^{-1} (SE)	Conductivity W m^{-1} K^{-1} (SE)	Heat flow kW km^{-2} (SE)
198-366	Salt	13.69 (0.01)	6.19 (0.05)	85 (1)
430-448	Shale	16.45 (0.4)	3.79 (0.14)	62 (3)
457-488	Salt	13.14 (0.03)	6.10 (0.1)	80 (1)
677-966	Salt (95%) Anhydrite (3%) Shale (2%)	14.69 (0.1)	5.90† (0.1)	87 (2)

†Harmonic mean of component conductivities (Table 1) with corrections for in situ temperature.

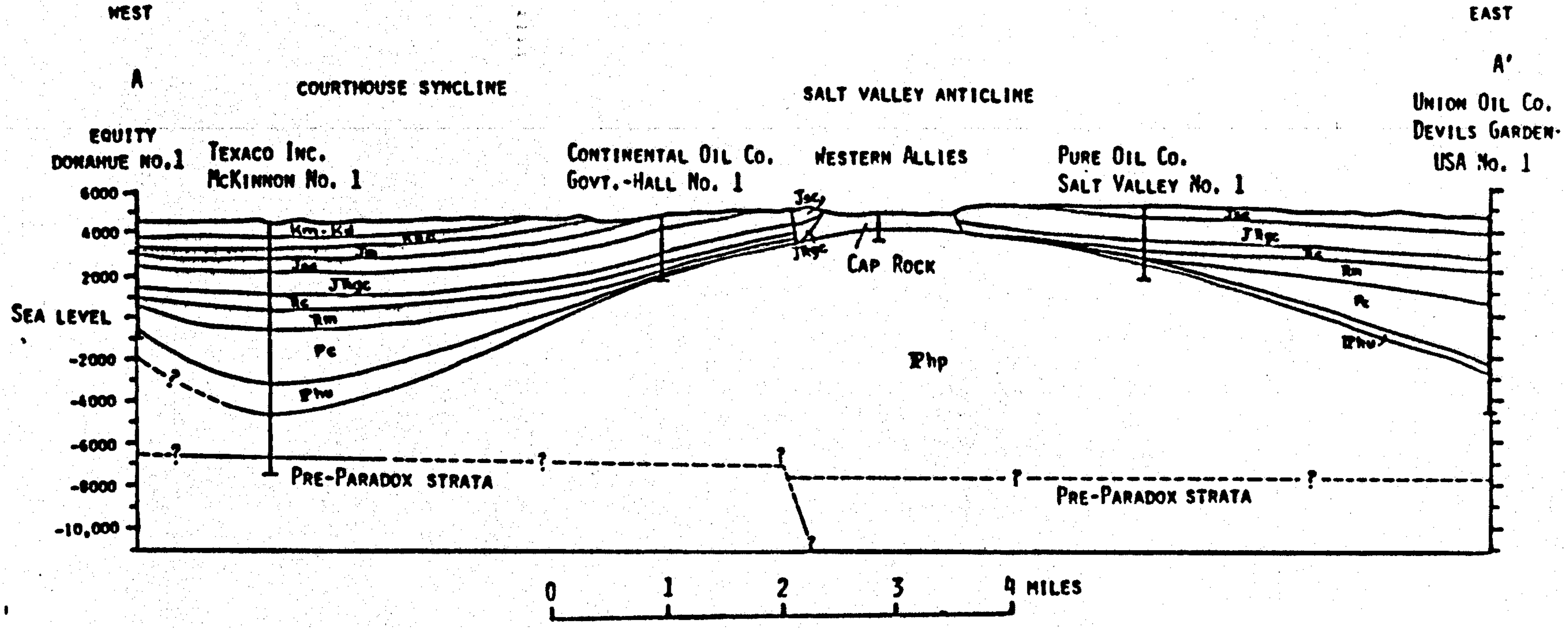


Figure 13. Cross section through Salt Valley anticline (from Hite and Lohman (1973)).

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AUGMENTATION:

SPLIT	DESCRIPTORS	FLAGS
	Utah	T3
	geothermal wells	T1 Q3
	temperature ~~well~~ logging	Q2 Q1
	thermal conductivity	
	well temperature	
	geothermal gradients	
	drill cores	T2

FORM TI-70 (9-83)