EAST MESA GEOTHERMAL ANOMALY, IMPERIAL COUNTY, CALIFORNIA: SIGNIFICANCE OF TEMPERATURES IN A DEEP DRILL HOLE NEAR THERMAL EQUILIBRIUM

T. C. Urban, W. H. Diment and Manuel Nathenson

U. S. Geological Survey
Menlo Park, California 94025

Abstract. Precision temperature logs were obtained in U.S. Bureau of Reclamation drill hole Mesa 31-1 (32°48.6'N,115°15.7'W) at East Mesa to a depth of 1880 m. Comparison of logs taken some two months apart and nearly a year after the production testing suggests the hole is close to thermal equilibrium. The thermal regime of the hole is characterized (1) by high gradients which predominate in the conductive cap (0-840 m) and are affected by hydrologic disturbances to at least 150 m, (2) by a sharp decrease in gradient at the base of the cap (∿ 840 m), (3) by a uniformly low gradient (∿ 40°C/km) below the cap except near the perforated zones (below 1650 m), and (4) by small convective motions within the hole as indicated by temperature-time recordings. The observed low gradient below the cap does not necessarily imply convection in a thick permeable medium. Instead, simple numerical models suggest the gradient could be the result of conductive heating from a hot permeable zone maintained by horizontal water movement near the base of the cap.

Experimental Details. Temperature measurements were made using a glass-enclosed bead thermistor (50,000 ohms at 25°C) attached to a Teflon insulated cable. Resistances and depths were sampled at intervals of 0.6 m and recorded on punch-paper tape for later computer processing. The 20 cm cased hole was logged downward at 6 m/min through a lubricator (well-head pressure 4 bars).

Temperatures. The temperatures plotted in Figure 1 were used to calculate the gradients over 20-m intervals by a linear differencing of the observed data. A second log, taken 72 days later, indicates an average warming of the hole by ∿ 0.2°C. The scatter evident in the temperature differences (Fig. 2) probably reflects variations in conditions both inside and outside the casing.

High gradients (Fig. 1) predominate in the conductive cap and are affected by hydrologic disturbances to at least 150 m and possibly to as great a depth as 400 m (Diment, et al., 1977). The base of the cap (∿ 840 m) is marked by a sudden decrease in the gradient to ∿ 40°C/km. This low gradient persists throughout the remainder of the hole except near the perforated zones below ∿ 1650 m.

Time-temperature recordings at seventeen depths exhibit temperature oscillations of the type illustrated in Figure 3. The range (R) of the oscillation is roughly proportional to the temperature gradient (G) at the depth of recording; and R/G is on the order of 100 cm, a fact first noted by Diment (1967) and Gretener (1967) for holes of nearly the same diameter (∿ 25 cm) but of much lower gradients. Taken as a whole the oscillation data suggests that the principal convective motions in holes near this diameter take place over a vertical dimension on the order of a hole diameter, and that this observation is valid at least in the gradient range 10 to 300°C/km.

The temperature differences in Figure 2 are anomalously large in the interval below the cap and above the perforated zones. Moreover, each of the logs is "noisy" in this interval in the sense that variations of gradient with depth as measured over short intervals are entirely too large to be explained by variation in rock types or convective motions of the type discussed above. Perhaps the "noisy" interval is due to spurious electrical noise. Perhaps it represents a different flow regime within the hole that is caused by ascent of small quantities of gas from the perforated zone below 1650 m. All the deep USBR holes at East Mesa produce some CO_2 at the well head (Mathias, 1976).

Some other features of the difference plot (Fig. 2) may reflect changing conditions outside of the hole, but further speculation is unwarranted in view of the experimental uncertainties. For example, the leakage rate through the lubricator, although small, was not constant when either log was obtained. Thus, some of the differences are a consequence of small differences in the position of the fluid column.

Discussion. The temperatures observed in Mesa 31-1 (generalized as curve II in Figure 4) put constraints on the thermal-hydrologic regime in this part of the East Mesa KGRA. The region below 840 m has been referred to as a convective zone below the conductive cap (e.g., Swanberg, 1976). Examination of the geophysical logs made in the hole, however, indicates significant amounts of shale throughout the section below 840 m, which probably would restrict vertical flow to relatively small intervals. However, if it is assumed that vertical convection does occur below ∿ 840 m and that heat transfer is

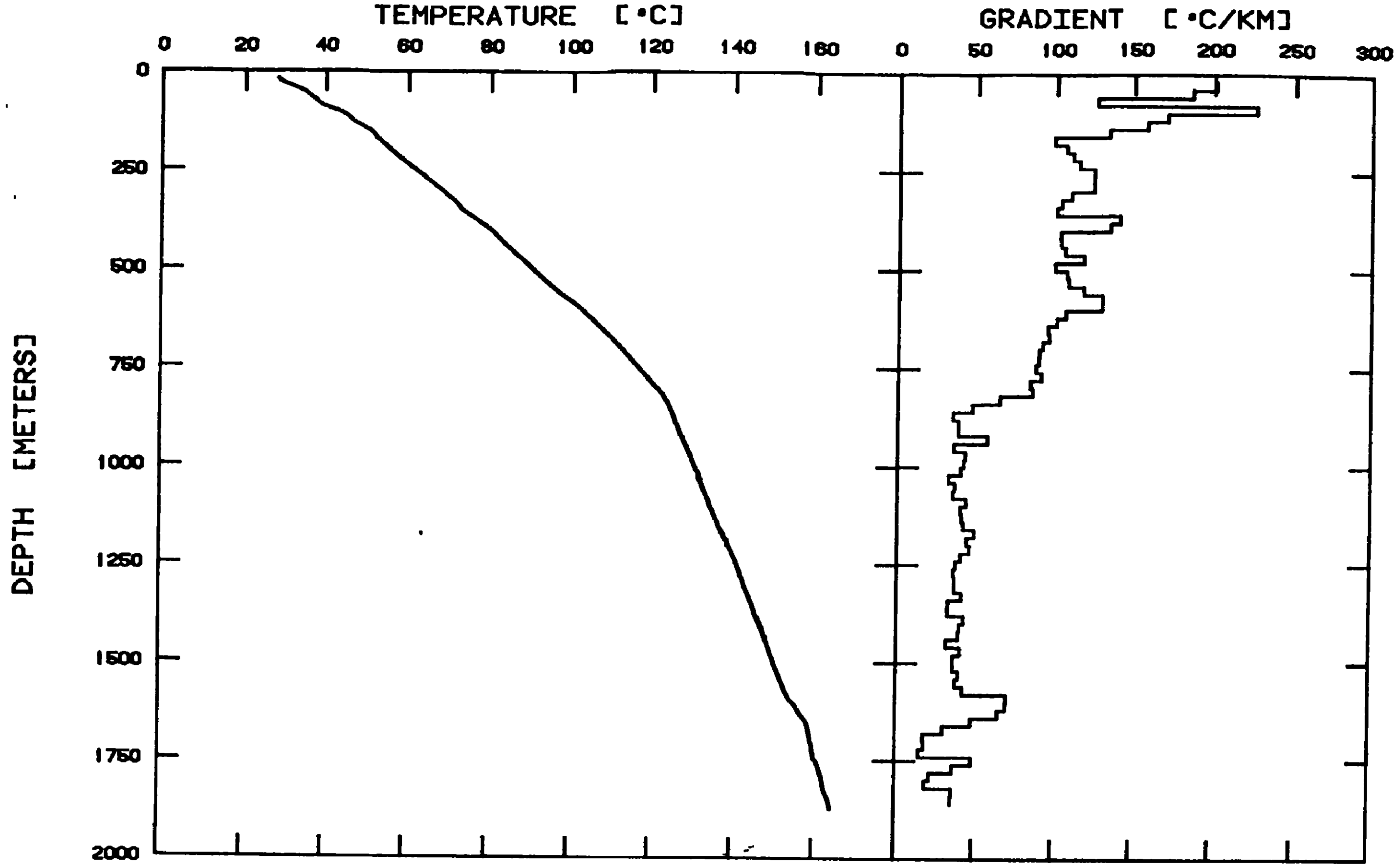

Figure 1. Temperatures and thermal gradients in Mesa 31-1 (April 14, 1977).

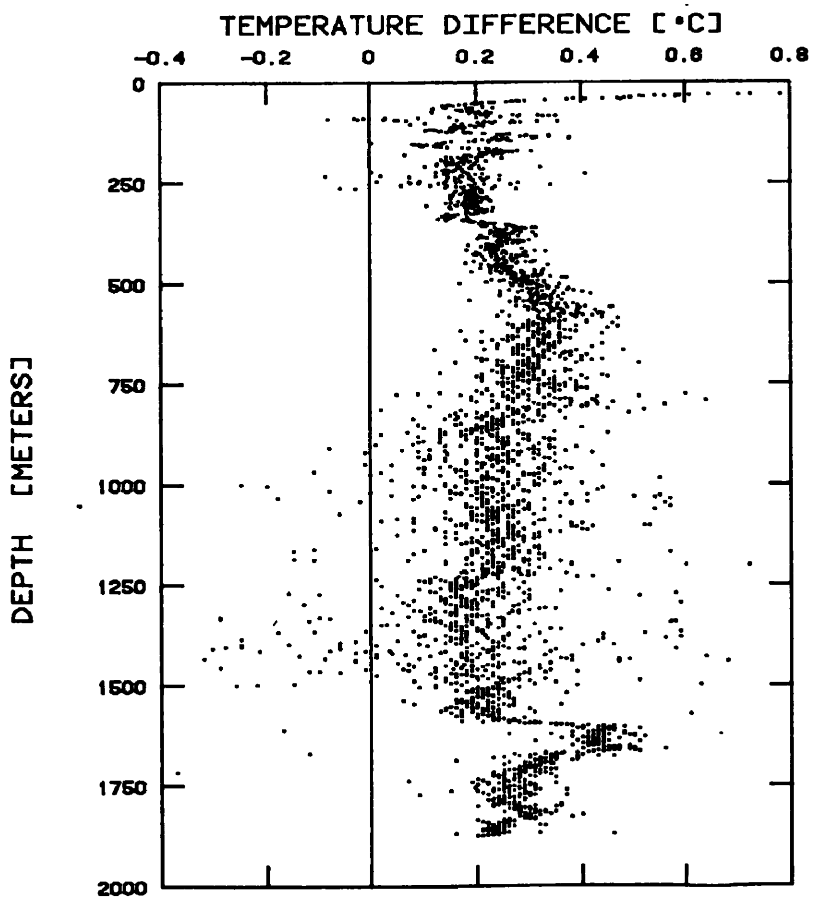

Figure 2. Temperature increase in Mesa 31-1 from April 14 to June 25, 1977. The apparent vertical alignment of the points below 600 m is due to rounding of the temperatures to 0.001°C above 600 m and to 0.01°C below 600 m.

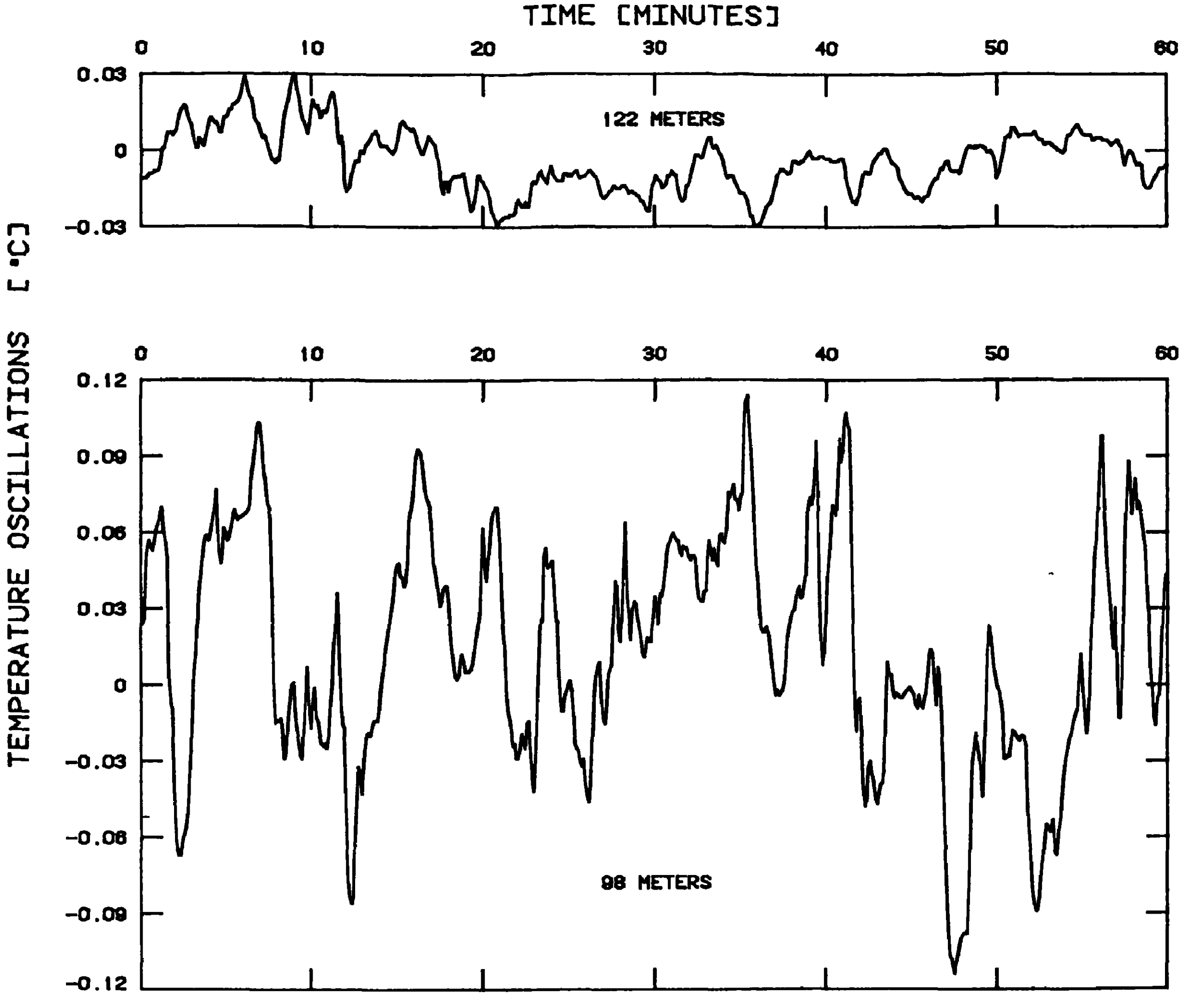

Figure 3. Temperature oscillations in Mesa 31-1. The gradient is 315°C/km at 98 m and 87°C/km at 122m.

by conduction above, then by balancing the energy flows in the "conductive" (curve IIb) and "convective" regions and applying the analysis of Bredehoeft and Papadopulos (1965), curve III in Figure 4 is obtained. The calculated temperatures (curve III) exhibit far more curvature than is observed (curve IIc) in Mesa 31-1. The calculations suggest that no vertical convection takes place at Mesa 31-1 but at the same time tell us nothing about the rest of the field. Indeed, convection could take place in a fault zone a few kilometers away and no curvature would probably be observed in Mesa 31-1.

The evolution of the system to the observed data may be modeled by conductive heating from two hot permeable zones maintained by horizontal water movement. The initial temperature distribution (curve I) is T = 25°C + 74.5Z, where Z is in kilometers. The initial gradient (74.5°C/km) is obtained from the observed surface intercept and bottom hole temperature. Depending upon the thermal conductivity assumed for the section, this would correspond to a heat flow of 2 to 4 μcal/cm^2 s. The curves shown in Figure 4 were calculated assuming plane heat sources at 610 and 840 m (Carslaw and Jaeger, 1959, p. 100). Temperatures very close to those observed can be obtained with such a hypothetical model in about 10,000 years. Although the details of this model are probably incorrect, the important point is that many features of the temperature distribution in this and other wells can be produced by conduction from a hot zone near the base of the cap.

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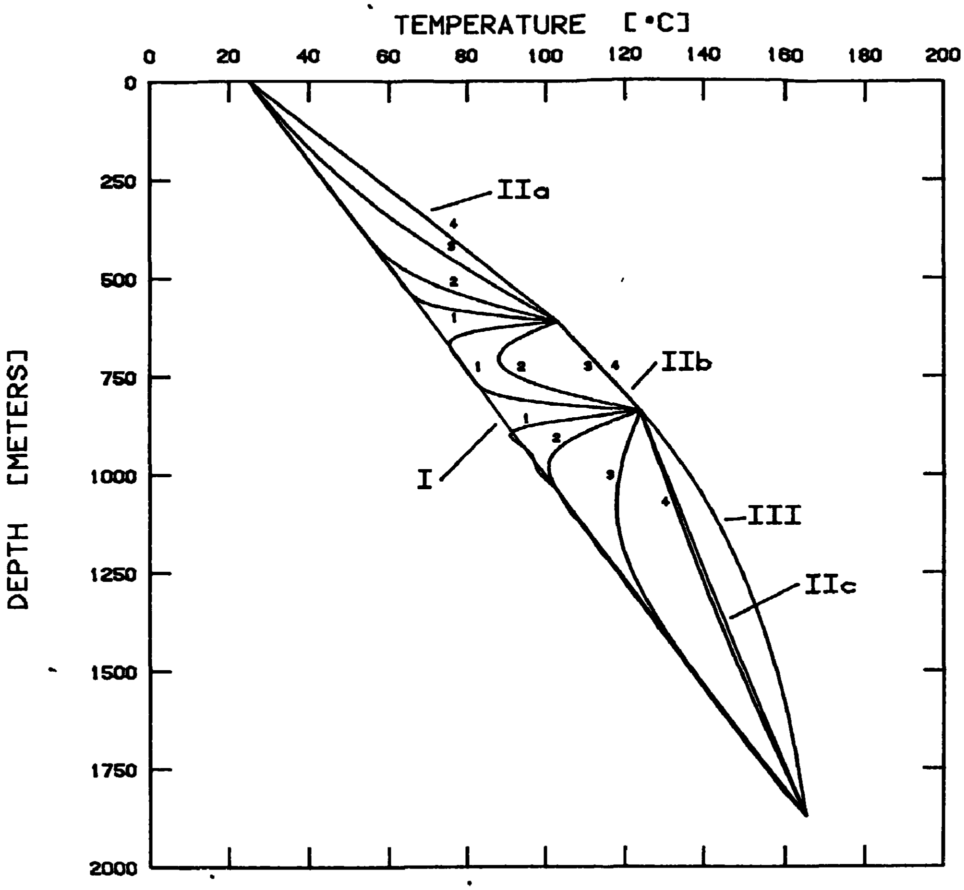

Figure 4. Graphs showing hypothetical evolution from an assumed initial temperature (I) to an approximation of the observed profile (II), assuming conductive heating from two hot, permeable zones near the base of the cap whose temperatures are maintained at constant values by horizontal water movement. The numbers represent the log 10 of the elapsed time in years since the formation of the hot zones. The surface and bottom temperatures were held constant at their observed values. The thermal diffusivity is 0.01 cm^2/s. Curve III represents the temperatures that should result if convection occurred.

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