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# Temperature Measurements in Boreholes at Chalk River, Ontario

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## Abstract

Subsurface temperature measurements have been made in seven boreholes in the vicinity of Chalk River, Ontario, to maximum depths of 300m. Although the results for most are still partially disturbed by the transient thermal disturbance due to drilling, the temperature logs, as well as yielding equilibrium temperatures and temperature gradients, reveal transient anomalies that can be related to fracture zones and to water flows.

## Temperature Measurements

Subsurface temperature measurements have been made in seven drillholes located as shown in Fig. 1 near Chalk River, Ontario, to maximum depths ranging between 110 and 305m. To date hole CR-1 has been logged on four occasions since completion, holes CR-2 and CR-5 twice and the others only once. A further set of logs is planned once holes CR-8 and CR-9 are both complete. Temperature observations on CR-1 were initially made at 3m intervals although the last log of it and the logs of all other holes were at 8m intervals. All the observations have been made incrementally using a 2.5cm diameter brass probe containing a single thermistor sprung against a 0.06cm stainless steel tip, a lightweight 4-conductor cable, a high sensitivity and precision Wheatstone Bridge and a sensitive electronic galvanometer. Absolute precision of the temperature observations is 0.01°C although differences of several milli-degrees can be resolved. Depths are determined using a pulley counter with divisions every 0.3m and marks on the cable every 8m, thus enabling corrections to be made for both cable stretch and slippage. Logging at 3m intervals the error in the depth interval is about ± 15cm, so in a typical gradient of 10mK/m the typical inaccuracy in the gradient over one interval may be as high as 30%.

## Temperature Results

All drillholes are thermally disturbed by the process of drilling, and particularly by the circulation of drilling fluid. Equilibrium temperatures may be obtained either by waiting for all disturbances to dissipate or by making several logs at intervals and by calculating equilibrium values. Temperature readings from different drillholes may not be compared with confidence until equilibrium values are available. The large disturbance induced by the circulation of drilling fluid is illustrated in Fig. 2 showing successive logs of CR-1 made respectively 44 hrs, 31 days, 164 days and 355 days after completion. The hole took 60 days to drill. During the year of logging the hole has cooled by as much as 1.5°C in the upper section, by 0.25°C near the base, although at bottom-hole the total change is only 0.05°C. At bottom-hole the rock was only very briefly subjected to the drilling process and consequently little disturbance resulted. The final set of temperature results represents values very close to equilibrium and the cooling of the hole has in general fitted the usual logarithmic cooling curves for conductive cooling of a heated cylinder, suggesting little or no convective mass transfer. This rate of cooling can thus be used to determine crudely thermal properties of the wall rock. The individual logs show two very pronounced features;

i Temperature decreases from the surface to a minimum value, the depth of which is at progressively shallower depths on succeeding logs. The minimum temperature is at successively lower values on successive logs.

ii There are several pronounced deviations from an otherwise fairly smooth temperature curve. The magnitude of the deviations is largest on the initial logs and decreases with successive logs.

## Temperature Analysis CR-1

The minimum temperature in the upper section of the hole, with a subsequent normal geothermal gradient, is a common phenomenon attributable to a general trend of warming air temperatures in eastern North America over the past 100 years. Calculated equilibrium temperatures suggest the increase in ground temperature to be approximately 1K and the depth of the inversion at 65m is consistent with observations elsewhere. The presence of a lake nearby at a different temperature from the surrounding land-surface enhances the inversion effect. Successive logs suggest an apparent depth migration of the minimum temperature but this is simply a result of the decrease of the overall temperature gradient as the drilling disturbance dissipates. The gradient below the inversion i.e. between 150 and 260m increases from 7.3mK/m to 10.1mK/m between the initial and final logs. Assuming a logarithmic return to equilibrium to be valid, the final gradient should be 10.3mK/m; the disturbance due to drilling having been 30%. Correcting the gradient for the inclination of the hole, the vertical temperature gradient is 10.7°mK/m.

Perhaps of more interest to the current waste disposal evaluation programme are indications of fracture permeability or of possible water movements, either those up- or down-hole flows induced by the artificial presence of a drillhole or indications of regional water movement through particular formations of rock or along joints or fractured zones. Of particular interest in this context is the pronounced anomaly at a depth of

128m, noticeable on all four logs although progressively reduced in size from 0.45K on the initial log to less than 0.08K on the last. Other zones of similar anomalies occur at depths of 49m, 168m, 198m, 229m and 241m on the first log but these have entirely disappeared by the third. Initially the largest of these anomalous zones at 128m was believed to be related to regional water movement along a fracture. However, the continued diminution in the size of the anomaly with time suggests a passive permeable fracture that filled with drilling fluid at a different temperature from the incipient fluids, and thus the zone was thermally disturbed to a greater extent than the more competent rock on either side. As a consequence the zone is taking rather longer to return to an equilibrium value. Once equilibrium values are established it will be possible to calculate the permeability of the fracture zone and the probable limit of depth penetration of the warm drilling fluid into the fracture. Under these circumstances temperature logs run several days after completion of drilling may prove excellent indicators of open fractures in the wall-rock. Subsequent logs should permit a differentiation between those permeable fracture zones in which water is flowing and those in which it is not.

## Temperature Observations on other drillholes

Since fewer logs have been run on the remainder of the holes, detailed interpretation is unwarranted at this time.

The results of two logs at 30 days and 220 days since completion of CR-5 are shown in Fig. 3. A prominent anomaly at 73m depth is probably not an indicator of fracture permeability alone, because the second log indicates a persistent gradient anomaly and temperature offset to higher values above the zone, usually an excellent indicator of uphole water flow. In this instance water appears to be flowing into the hole at about 80m and out at 55m with some flow to the surface. A further detailed log will be needed to verify this although a water-flow from the collar is readily apparent. The absence of any shallow inversion zone is good additional evidence for the depth of origin of this water. As described in the section on drill-hole CR-1 the entire hole had cooled after hole completion. In the case of CR-5 however, the hole above 200m has cooled while that below has been warmed. Whether the wall-rocks are warmed or cooled by the drilling depends on the relative temperatures of the rock and the circulated fluid. The latter depends on the source of the fluid, the time of the year of the drilling and the depth of drilling; winter drilling for example will normally cool holes to these depths. A further small fracture appears to exist at a depth of 134m.

Fig. 4 shows temperature logs made on CR-2 which was originally drilled in 1977, developed a blockage and was subsequently cleared and reamed out in 1978. Temperature measurements were taken 22 and 210 days after reaming the hole was completed. Again the drilling disturbance, several anomalies and the lack of a shallow inversion are noticeable indicating possible water-movement and fracture zones.

Holes CR-6 and CR-7 have very different drilling histories and have been logged at different times as shown in Fig. 5. It is therefore somewhat surprising to note that although the holes generally are at different temperatures along most of their lengths, at 40m depth the temperatures are very similar. Since the deep gradients are very uniform and the inversions at 70 to 80m are well-developed, no water flows appear to be present through most of the hole, and the zone at 40m appears to represent an interconnecting fracture between the holes which are situated 15m apart.

## Conclusions

This very brief account illustrates the information on natural temperatures, climatic change, rock conditions and water movement that can be deduced from a succession of temperature logs on a borehole. As further logs are taken quantitative calculations of most of these parameters will be possible. Analysis of temperature logs provides important information on the existence of fractures and water flow at depth.

## Recommendations

1. All holes should be logged for temperature. Current incremental logging equipment does not warrant closer spacings than 3m. The continuous logging system will reveal a wealth of additional detailed information particularly on fractures, lithological changes and water movements.

2. The first log of each hole should be made within a day or two of completion.

3. Subsequent logs should be taken periodically, ideally spaced at intervals of 2 weeks, 1 month, 3 months and 1 year after drilling.

4. These requirements for high precision periodic logging suggest that a continuous temperature logging system should be built independently of any multiple parameter logging system and that the hole should be allowed to stabilize for several days after other probes have been running.

5. Pumping tests prior to temperature logging will thermally disturb the drillhole to an unknown extent. If the pumping test conditions are known subsequent temperature logs across such zones may reveal additional information.

6. Detailed analysis of the temperature logs would be enhanced by detailed drilling histories including input and output volumes of drill-fluid circulation, input and output temperatures of the fluid.

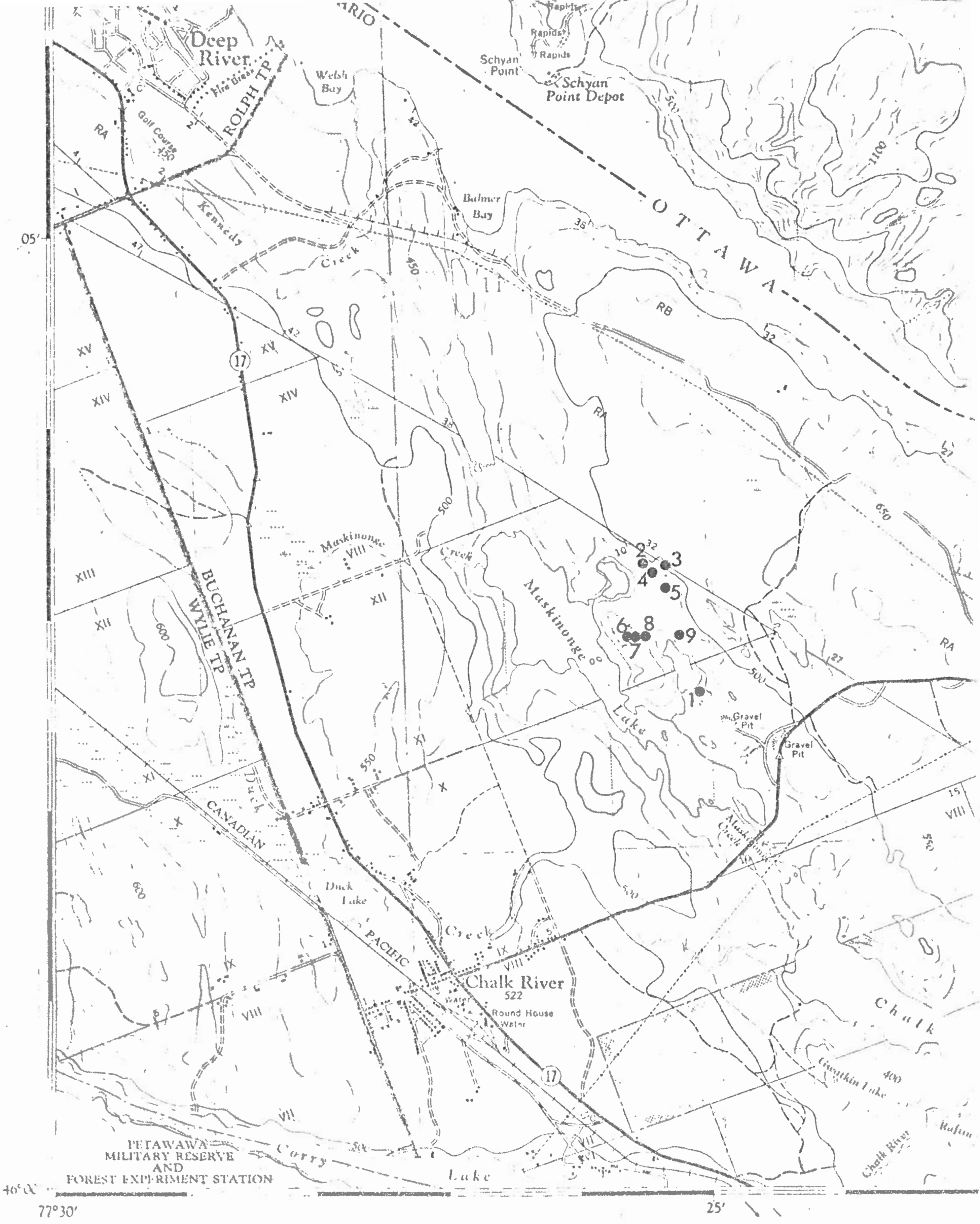

Fig. 1 Localities of boreholes. Scale 1:50,000

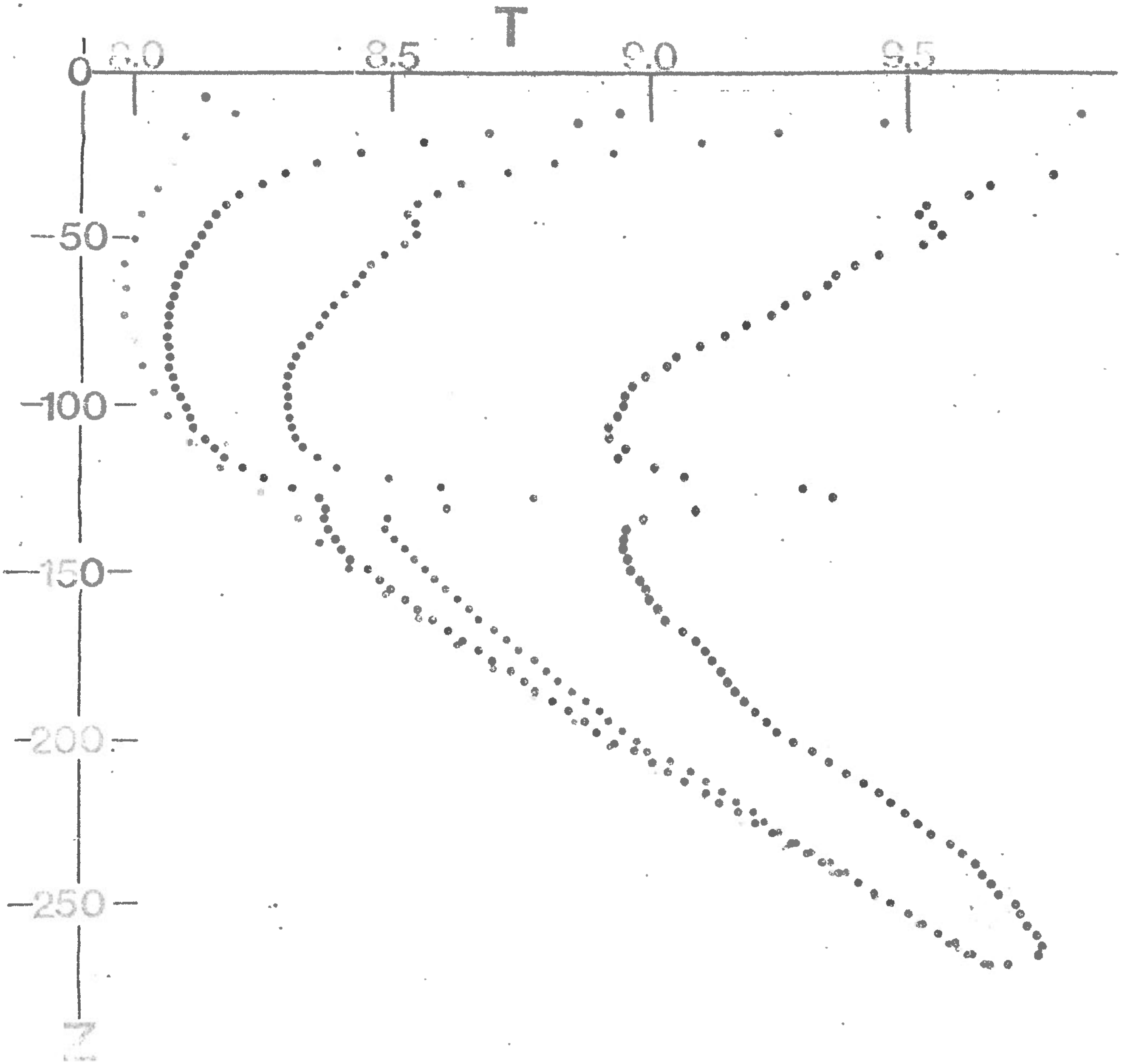

Fig. 2 Temperatures in CR-1

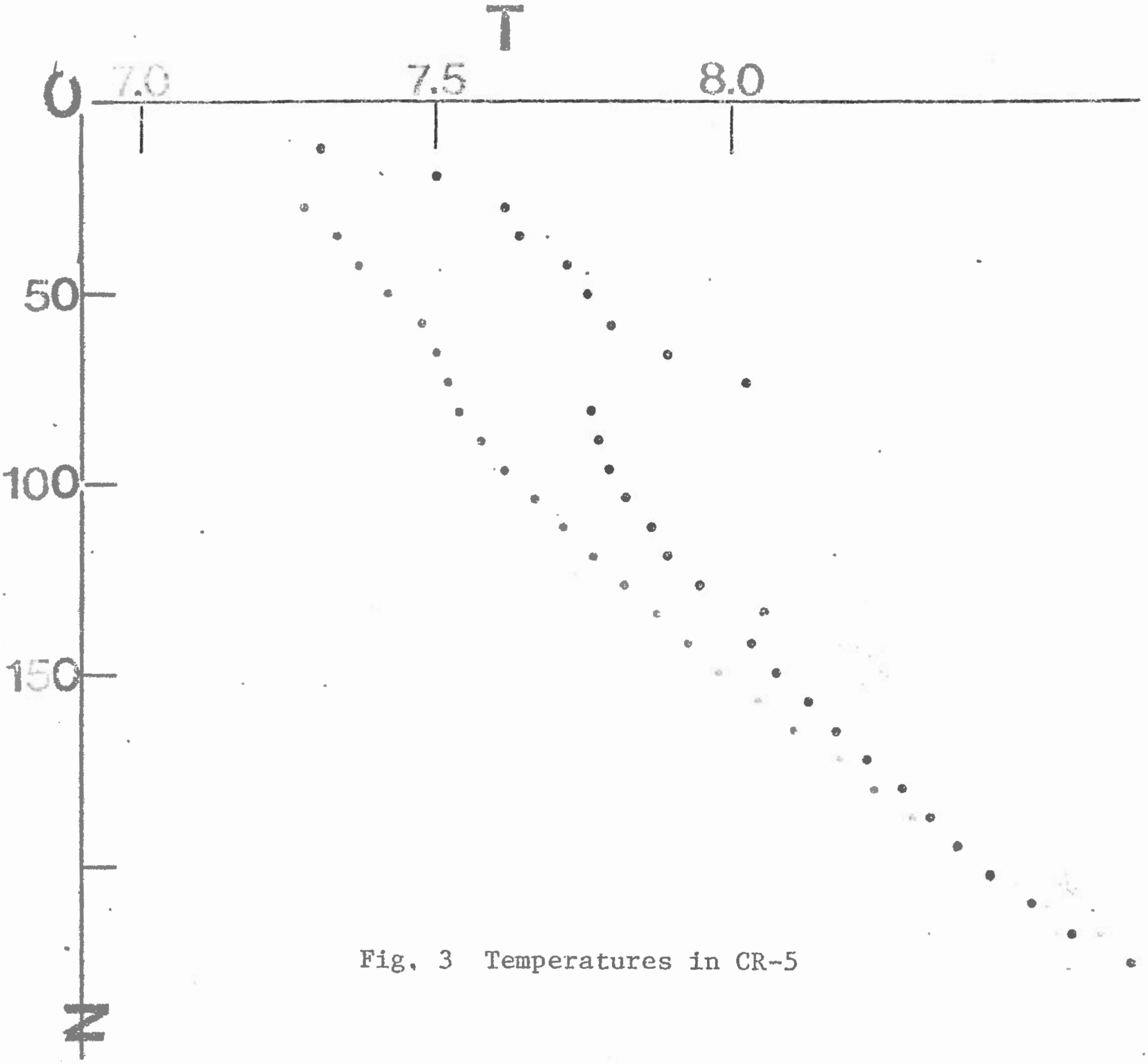

Fig. 3 Temperatures in CR-5

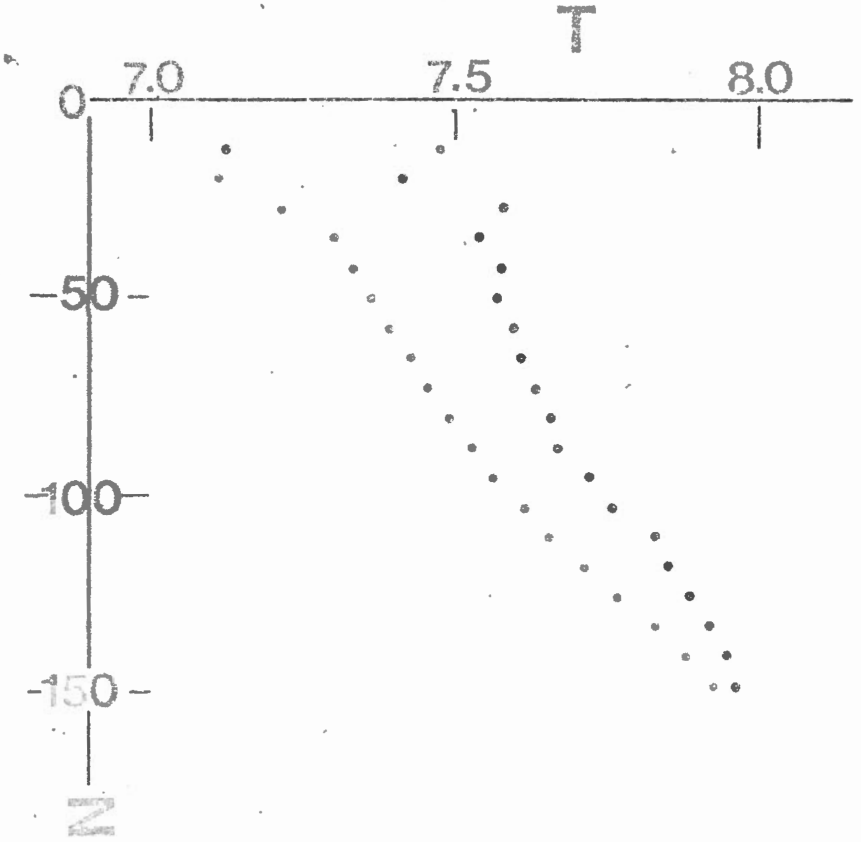

Fig. 4 Temperatures in CR-2

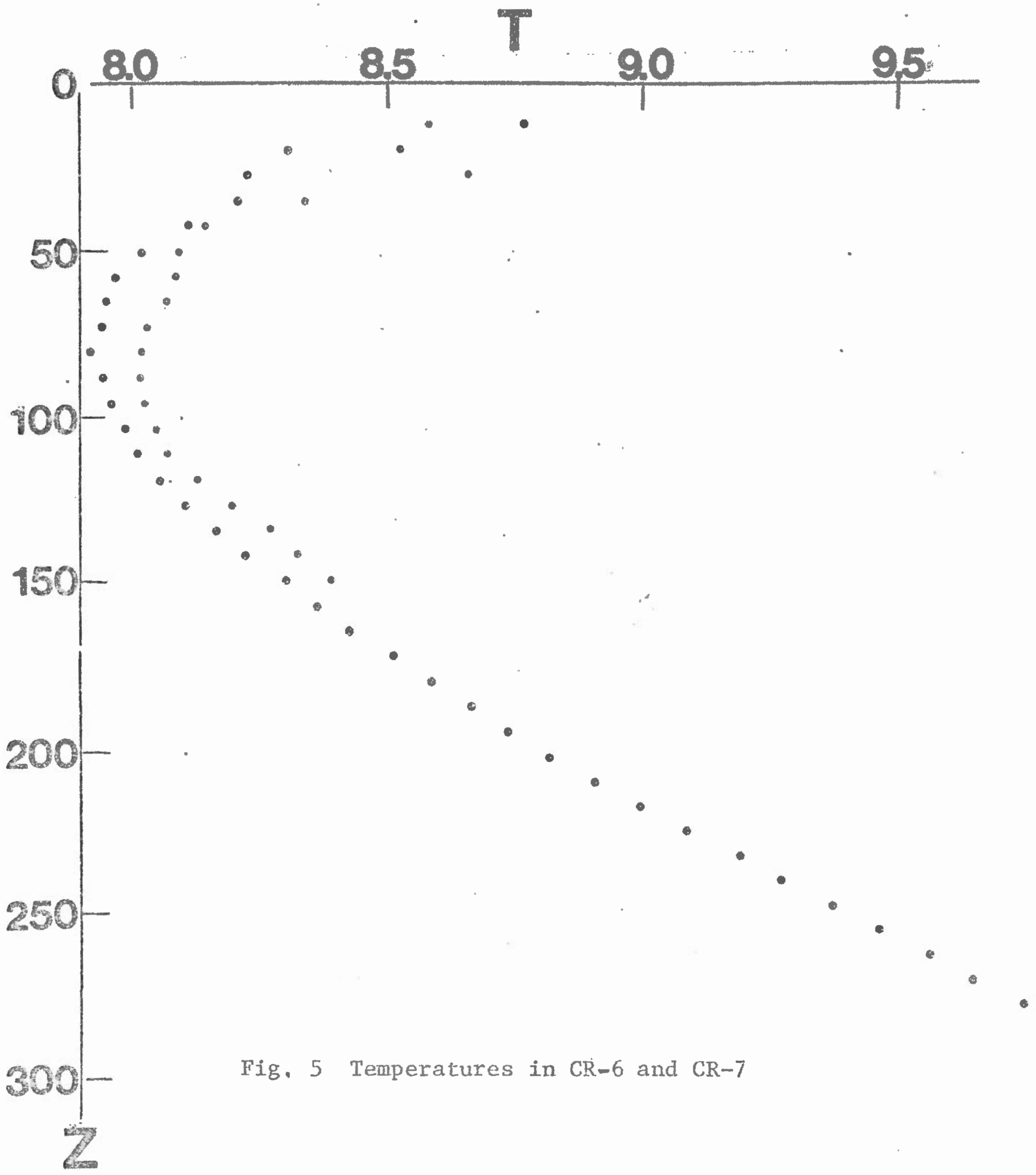

Fig. 5 Temperatures in CR-6 and CR-7