Exploration for Uranium Deposits Using Geothermal Methods

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Very rich uranium deposits have been discovered in the Athabasca sandstones of northern Saskatchewan. The geological structure of some of the ore bodies is such that the boundaries are abrupt: core from a drill hole passing within a metre or so of the deposit might not indicate the existance of such a deposit. Consequently down hole geophysical methods of detecting such ore bodies are needed.

A large concentration of uranium (or thorium) in the ground produces a significant amount of heat due to natural radioactivity. If this heat source is large enough, and if the heat moves through the rock only by conduction, then a temperature anomaly will be produced. If this anomaly is large enough, and other causes of temperature anomalies either do not exist or can be predicted, then temperature observations can be used to predict the location of the concentrated heat source. Whether or not such a method is cost efficient is another point which should be considered.

A large rich ore body will create a sizeable temperature anomaly. For example, the Midwest Lake deposit in Canada (Nornern Miner, January 18, 1979) consists of 1 424 000 tons averaging 3.4% $U_3 0_8$, or 97 x 10^6 lb of $U_3 0_8$. This produces 3 600 W of heat. If this body were spherical in shape, its radius, a, would be 48 m, and the temperature anomaly, v, would be given by (Carslaw and Jaeger, p 232):

$$v = A_o a^3 / 3kr \qquad \text{for } r > a \qquad 1$$

where A_o is the constant amount of heat produced per unit time per unit volume, k the thermal conductivity and r, the distance from the centre of the sphere. This is a steady state solution. For this example, A_o is 7.8 mWm^{-3}, and k is 6.0 $Wm^{-1}K^{-1}$ (T. Lewis, unpublished results from Rumpel Lake).

Substituting these values gives:

$$v = 47/r \qquad 2$$

At r = 48 m, the temperature anomaly is approximately 1 K, and at 100 m it drops to about 0.5 K. The heat flux, or temperature gradient at the boundary of the sphere are 2 to 3 times normal.

The sphere is the most compact shape, and produces the largest anomaly outside the ore body. A planar or tablet shaped body would produce the smallest anomaly. If it were 10 m thick and of similar concentration and size, it would produce a temperature gradient anomaly nearly equal to the noraml gradient, perpendicular to the body. One length of the Midwest Lake deposit is reported to be 1500 m. Lewis (1969) showed that at Eldorado the likely heat production from 69 million lb of uranium (including uneconomical reserves) when flowing through the total mine area gave an insignificant anomaly. This is because the mine area is large.

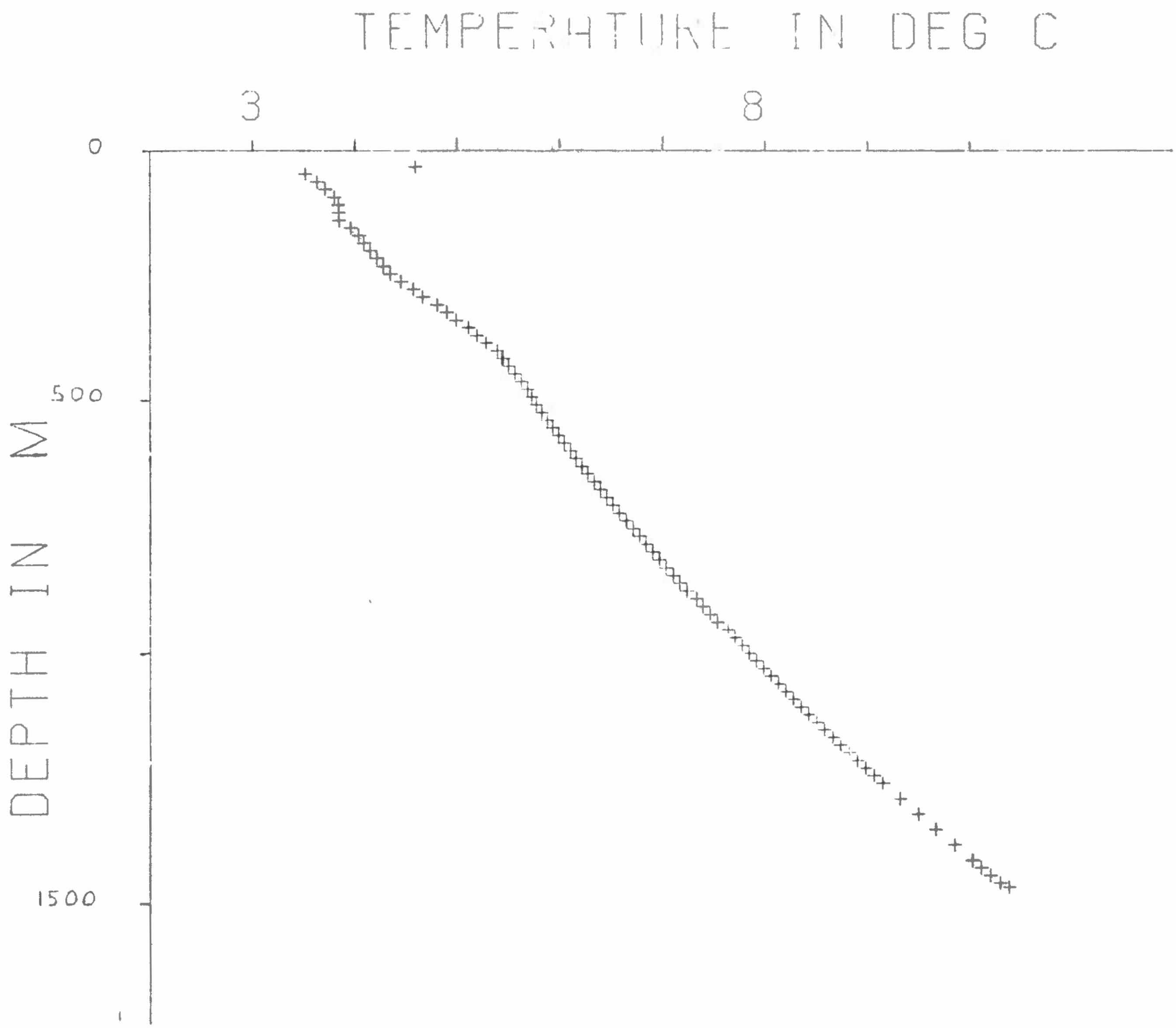
The conductivity of the sandstone is very high; if it were lower, a larger temperature anomaly would be the result.

Usually a geological structure is associated with any ore body. The thermal conductivity of the rocks in this structure are usually different, and movement of water in the structure is a possibility. At Eldorado (Lewis, 1969) the thermal conductivity of the structure was modelled, to account at least partially for the differences in thermal conductivity. However this can only be done accurately if the structure is well sampled.

The effect of water movements cannot be accurately calculated. These effects can be large or small; a small systematic water flow can cause large anomalies (Lewis and Beck, 1977). And even in shield rocks having very little surface topography, these flows exist; for example, they exist near Whiteshell, northwest of Winnipeg.

Our unpublished results in the Athabasca Sandstones are from Rumpel Lake (58° 19.5'N, 106° 32.5' W). The average thermal conductivity for 50 samples between depths of 433 and 1448 m is 6.45 Wm^{-1} K^{-1}, a very high value. The average temperature gradient measured in the borehole over the same interval is 4.7 mKm^{-1}, yielding a measured conductive heat flow of 30 mWm^{-1}. In comparison, results from the Superior Province (Jessop and Lewis, 1978) include gradients from 9 to 17 mKm^{-1}. The higher temperature gradient (see enclosed graph of Rumpel Lake temperature log) between approximately 245 and 395 m is the result of a much lower thermal conductivity in this interval. Above 135 m the isothermal section is probably caused by a small, constant water flow in the borehole. Two temperature logs measured a year apart give identical temperatures, except in the top 30 m where a larger amount of water is flowing downwards.

The curvature, or increase in temperature gradient towards the bottom of the hole could be considered a temperature anomaly since it does not appear to be related to a change in thermal conductivity, nor to water flows! The core log shows relatively more porosity in the upper hundred meters and in the lowest (conglomeratic) zones. The slight changes in gradient at 855 m and 945 m are unexplained.



TEMPERATURE IN DEG C
3
8
0
500
1500
DEPTH IN M

In order to measure temperatures accurately in boreholes it is necessary to measure either a) bottom hole temperatures at the end of one-half day pauses in the drilling, or b) to measure the holes a long time after the drilling has finished. Option a) produces equilibrium temperatures even if afterwards the hole intersects faults to which, or from which water flows up or down the hole. The disadvantages are: temperatures must be measured all during the drill program, such measurements may slow down the drilling, and temperatures are obtained only at depths where the drilling was stopped for a shift. Option b) is much preferred if water is not expected to flow up or down the hole. However to be successful the holes must be saved, surface casing must be left, plugged, and this necessitates the interest of the mining company in the operation. When mining companies inform us that they have preserved boreholes in which we may make measurements, 90% of the time the holes are either blocked near the surface, or there is not even surface casing left in place. Company personnel can easily check holes by lowering a weight on a fishing line down the first 50 m of the hole.

Our standard borehole logging equipment (Lewis, 1975) is portable (two men can carry everything), can go to 900 m depth, can resolve temperature differences of .002 K, and is accurate to .01C. It is used mainly by ourselves for research, and is not suitable for every person to use. A geologist or geophysicist who is careful, and who has been shown how, can use it himself. It is best in holes at 45^{o} or deeper dip angles. The HP quartz thermometer is by comparison much more expensive, much less portable, much less reliable, and needs calibration (i.e. constant temperature baths and calibrated platinum thermometer).

Discs from whole core samples are best used to determine the thermal conductivity (e.g. Lewis, 1975). This data is most necessary in determining if changes in thermal gradients are due to anomalies, or to a change in the rock's thermal conductivity. For crustal studies, we often measure the heat generated in the rock, using a laboratory gamma-ray spectrometer with a Ge (Li) detector (Lewis, 1974).

References

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