GEOTHERMAL MEASUREMENTS IN THE DEEP HOLES IN NOVA SCOTIA

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Introduction

The Nova Scotia Department of Mines and Energy (NSDME) is currently engaged in a continental deep drilling programme in the South Mountain batholith (Fig. 1). Four holes are planned, each with a depth of approximately 1700 m. The primary purpose is to obtain deep geological information in a metallogenic batholith, but NSDME has invited other scientists to become involved. Because of my interest in the thermal state of the crust in the Appalachian system of Canada, I have been asked by NSDME to be responsible for making heat flow measurements in the holes. In keeping with my initiative to reintroduce scientific drilling to the Earth Physics Branch, I have readily agreed to do this. The present report, which would be a relevant format for any deep drilling programme, is an indication of the various aspects of geothermics that will bear on the NSDME project. The following sections form an outline, submitted to NSDME at my suggestion, of why and how a geothermal programme would be carried out.

Purpose

The drilling of deep holes in the South Mountain batholith of Nova Scotia will afford an excellent opportunity to obtain high quality geothermal data from an area of great interest to the author. It is proposed that heat flow will be determined, from a combination of thermal logging and measurement of thermal conductivity of core samples. In addition, core samples will be analysed by gamma-ray spectrometry for radiogenic heat production, principally by isotopes of U, Th and K.

There have been some heat flow measurements reported for the

Maritime Provinces of Canada (Jessop, 1968; Jessop and Judge, 1971; Rankin, 1974; Hyndman et al., 1979). The author is currently working on a paper that will report further measurements, derived mainly from his programme to assess the geothermal energy potential of the region. The paper will include a value from a site in the Wedgeport granite of Nova Scotia; a hole was drilled there to a depth of 483m for the author in January 1985, in support of both his scientific interest in the thermal nature of the crust in the Appalachians, and of the Federal geothermal energy programme. The deep drilling will provide an excellent continuation to these studies.

Heat flow studies are of importance in constructing models of the evolution of the earth's crust. Most of the heat flow measured at the surface of the earth is produced from the upper few kilometres of the crust, from the decay of radioactive isotopes. It is possible, for many parts of the world, to define "heat flow provinces", in which there exists a roughly linear relationship between heat flow and heat generation, of the form:

$$Q = Q_o + A_o b$$

in which Q and A_o are the heat flow and heat generation measured near the surface. Q_o is the "reduced heat flow", which represents the heat flowing from the lower crust and deeper, and b is a scale depth for the distribution of radiogenic elements. Q_o and b are constant in any heat flow province. There are several ways in which heat producing elements can be distributed with depth in order that this relationship holds, but it is commonly accepted that the concentration of such elements decays exponentially with depth. For Atlantic Canada the relationship is (Hyndman et al., 1979) Q = 39 +/- 8 mW/m^2 and d = 11 +/- 5 km.

The concept of heat flow provinces is simplistic, and data from deep holes or exposed crustal sections have not verified any particular model (e.g. Lachenbruch and Bunker, 1971; Nicolaysen et al., 1981). Recent work in the region has shown that in some granitic batholiths this relationship does not hold (Drury, 1984); the radiogenic heat production is much higher than would be expected for the measured heat flow. Although heat flow measurements at the Wedgeport site are not yet complete, the same situation appears to hold there. Similar instances from Canadian shield sites have been reported (Jessop and Lewis, 1978; Drury and Lewis, 1983). In each case the interpretation has been that the measured radiogenic heat production was representative of a thin (1-3 km) surface veneer only, and not of the crust to the depth d of the heat flow - heat production relationship. The NSDME drilling programme offers an excellent opportunity to test this idea.

Geothermal studies also afford an opportunity to assess water flow effects in the crust. The flow of water can be an effective mechanism for the redistribution of heat, a phenomenon that has been exploited by the development of analysis methods as part of the Canadian Nuclear Fuel Waste Management Programme. The thermal effects of water flow can be used to detect fractures in crystalline rock, and to delineate flow systems (e.g. Lewis and Beck, 1977; Drury and Lewis, 1983; Drury et al., 1984a). Studies of fluid flow are, of course, of profound significance in exploration geology and geophysics. The redistribution of elements that form economic ore deposits may well be related, in some plutons at least, to the possible redistribution, and concentration near the surface, of radiogenic elements.

If a borehole is free from the thermal effects of water flow, analysis of the temperature gradient can also be used to model past climatic variations (e.g. Cermak, 1971). For this purpose, the deeper the borehole the better, as climatic changes that occurred thousands of years ago would now be indicated by thermal perturbations at several hundred metres depth. A parameter that is necessary in constructing climatic models from down-hole thermal data is thermal diffusivity of the rock. The geothermics laboratory at Earth Physics Branch is the only one known to the investigator to be making measurements of diffusivity of rock core routinely, using a novel technique developed here (Drury et al., 1984b).

The study will also entail physical properties measurements on rock cores, principally thermal conductivity and thermal diffusivity, but also of density and porosity. Such studies are required for the interpretaion of thermal data and for helping construct models of the batholith - density measurements for gravity, for example. The measurements would permit the variation of those properties with depth to be assessed, which aids in developing models of the nature of the crust (e,g, Drury, 1985).

Schedule

The process of drilling a borehole disturbs the thermal gradient in its vicinity. The disturbance dissipates approximately logarithmically, and the pre-drilling thermal gradient is re-established at an elapsed time after the end of drilling of 5-10 times the total drilling time. For this reason, it would be desirable to keep the holes open for one or two years after the completion of drilling. The cost of keeping the necessary surface casing in place could be borne by Earth Physics Branch from its geothermal energy programme; funds have already been marked for this purpose for the current fiscal year, and it would be quite appropriate to use them for the NSDME drilling programme. Consequently, it is recommended that the holes be kept open to permit geothermal logging for at least one year after they are completed. A series of temperature logs would be undertaken; most likely using an EPB wireline thermal probe on a commercial logging truck, in order that the full drilled depth could be logged.

Core material for conductivity and heat generation measurements would also be required. Approximately 5-10 cm of material would be needed for a 1 cm thick disc to be cut, at intervals that would be determined when the lithology was better known, but probably from every 10 m. The material could be returned after analysis, if required, less a minimal loss during sample preparation. For heat generation measurements, approximately 350 g of core would be needed, probably from 30 m intervals. The sampling interval might be reduced if initial analyses indicated a reason to do so; a discernible variation with depth, for example. Such material is crushed, and should therefore be considered as not returnable.

Output

The output will be a detailed study of heat flow in a relatively small area, its variation with depth, the variation with depth of some physical properties of the rock, the variation with depth of radiogenic heat production, possibly an analysis of water flow patterns, and possibly modelling of past climatic variations from their thermal record. It is anticipated that the study would be completed within two years of the last drilling.

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Fig. 1. Location of NSDME deep drilling site, hole 1,currently being drilled, and of hole 2, planned to be drilled this year. Other holes will be in the same area. Location of one other heat-flow site in the South Mountain batholith is also shown. W is the Wedgeport site drilled by EPB in January 1985. SM - South Mountain batholith.