Geothermal Energy

Temperature gradients and heat production in two granitic batholiths of New Brunswick

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As part of the programme to assess the geothermal potential of Atlantic Canada, two holes were drilled in granitic batholiths of New Brunswick, near McAdam in the Pokiok batholith at 45° 40.7'N, 67° 18.8'W, and near Welsford in the St. George batholith, at 45° 26.3'N, 66° 26.4'W. The purpose was to obtain accurate geothermal gradient measurements in what were believed to be areas of high radiogenic heat production and hence potential hot dry rock (HDR) resources. The holes were drilled by Hop-Mun Drilling Inc., of Salisbury, N.B., a subsidiary of Logan Drilling Ltd. of Truro, N.S. Management of the drilling operations and data acquisition - temperature logging etc. - were performed by John A. Leslie and Associates, Ltd., (JALA), of Bedford, N.S., who present a detailed description in their final report (Leslie, 1983).

A preliminary report on the drilling and early temperature results was given by Drury (1983). The sites were chosen on the basis of high anticipated radiogenic heat production that could produce high thermal gradients. Fig. 1 is a simplified version of a portion of a map prepared from airborne γ-ray surveys by Chandra and Wallace (1980) of the New Brunswick Department of Natural Resources, that attempts to show in contour form the distribution of surface radiogenic heat production (see Drury, 1983). The St. George and Pokiok batholiths intrude sedimentary and volcanic rocks of the Fredericton Trough, each consisting of several intrusive phases. The particular phases involved in the geothermal investigation were the Mount Douglas granite (McCutcheon, 1981) of the St. George Complex and the Hawkshaw granite (McCutcheon et al., 1981) of the Pokiok complex. The Mount Douglas intrusive is, at the drill site, a pink, equigranular granite. Severe alteration is observed over the entire drilled section, the alteration products including sericitized potassic feldspar, kaolinized plagioclase feldspar and chloritized biotite. The Rb/Sr total-rock age for this intrusive body is 348 $\pm$ 8 Ma. The Hawkshaw intrusive is a grey, medium-grained granite, with some alteration. McCutcheon and Lutes (1981) suggest 390 Ma as the age of crystallization of the Pokiok batholith.

Temperature logs run in both holes 72-84 hours after the end of drilling sugested a gradient of 18 mK/m. The holes were re-logged after approximately 5 months so that equilibrium gradients could be obtained; the results are shown in Figs. 2 and 3. As predicted by Drury (1983) the gradients had increased, as the thermal effect of the drilling operation had dissipated. The gradients after 5 months were 20 mK/m in the Pokiok hole and 19 mK/m in the St. George hole, with surface temperature intercepts of approximately 5.5°C. These gradients compare unfavourably with that measured in the Carnmenellis granite of south-west England, 38 mK/m, which is considered to be economically exploitable for a HDR resource.

Thermal conductivity measurements on core samples from the boreholes are not yet available, but if a conductivity of 3-3.5 W/mK is assumed for the granite, the heat flow at the sites is estimated to be 57 - 70 mW/m^2, uncorrected for climatic effects. The heat flow at Mount Pleasant, just off the northern edge of the St. George batholith (see Fig. 1), was estimated to be 63 $\pm$ 13 mW/m^2 by Hyndman et al. (1979). The assumed heat flow values for the Pokiok and St. George sites do not appear to be abnormally high.

Determinations of radiogenic heat production by measurement of U, Th and K contents were made at the Pacific Geoscience Centre under the direction of Dr. T. J. Lewis. The results are given in Table 1. The mean and standard deviation for the Pokiok hole is 3.6 $\pm$ 0.4 $\mu W/m^3$, and for the St. George hole 7.2 ± 2.8 $\mu W/m^3$ (6.8 ± 1.4 $\mu W/m^3$ if the high value of 21.75 $\mu W/m^3$ is omitted). The agreement between these values and those predicted for the sites from Fig. 1 is poor. The values for the Pokiok hole are approximately twice those that would be predicted, whereas the St. George values are approximately five times the predicted ones. The agreement with values predicted from earlier surface sample measurements was, however, quite good (see data in Leslie, 1982).

Hyndman et al. (1979) suggested that the relationship between heat flow, Q and surface heat production, A_o for the Atlantic region is approximately: $Q = 32 + 11 A_o$. Applying these values to the present data, and assuming a thermal conductivity of 3.3 W/mK, the predicted gradients at the Pokiok and St. George holes would be approximately 21 mK/m and 33 mK/m respectively. The former is close to that measured, but the latter is considerably higher than the measured equilibrium gradient. It is possible that the true gradient at the St. George hole would be 33 mK/m, but that it is reduced by the effect of flowing groundwater. Flow downward along an inclined fracture or fault zone below the borehole would remove some of the heat flowing upwards from greater depth. This phenomenon has been postulated by Lewis and Beck (1977) and Drury and Lewis (1983) to explain geothermal observations in crystalline rocks. The highly altered nature of the core suggests the existence at some time of large scale water circulation. There is, however, no direct evidence of present groundwater flow that removes heat.

If there is no such flow, the high heat production rock of the St. George must be a relatively thin, near-surface layer that has only a minor contribution to the overall heat generation within the batholith. If the heat flow from below the zone of radiogenic heat production is taken as 32 mW/m^2, from the relationship above, the thickness of the radiogenic layer is estimated to be 4 km if all of the crustal heat is produced in that layer. As this is certainly not the case, the 4 km represents a maximum thickness of the layer. The background heat production of the batholith is not well known. Other granites in Atlantic Canada have an average heat production of approximately 2 $\mu W/m^3$ (Drury, 1983). If this is taken as the background value and the site heat flow is assumed to be 66 mW/m^2, the heat flow in excess of that predicted from the relationship of Hyndman et al. (1979) would be approximately 12 mW/m^2, which could be produced by a uniform layer 1.7 km thick of material of heat production 7.2 $\mu W/m^3$.

As discussed by Drury (1983) the borehole locations were compromises between desirability and practicality. Both were spotted using the airborne γ-ray data heat production map of Chandra and Wallace (1980), coupled with some data of surface sample heat production. In both cases the mean borehole sample heat production was significantly higher than that predicted from the airborne data, but was similar to that obtained from surface samples (Leslie, 1982, Drury, 1983). The latter type of data is clearly the better, but it can be ambiguous, as indicated by the results from the St. George hole.

The results from these two boreholes are not encouraging in terms of HDR potential in New Brunswick. The sites were chosen as the best on the basis of available knowledge, but it was acknowledged that granitic batholiths 300 - 400 Ma old do not have the HDR potential of young intrusives - as, for example, the Tertiary Coryell syenite in British Columbia, which was fully expected to have high heat production and high thermal gradients. The gradients in two holes in that body were 55 mK/m (Lewis et al., 1979).

On-going work, to be discussed in a future report, has indicated high surface heat generation in some of the granitic batholiths of Nova Scotia, in locations that coincide with high U, Th and K contents as deduced from airborne γ-ray spectrometry. In spite of the discouraging results from New Brunswick, consideration will be given to a drilling programme to examine one or more of the anamolous areas in Nova Scotia. Further, it is hoped that a geochemical/mineralogical study of the New Brunswick borehole core can be undertaken in order to determine the nature of the distribution of U, particularly in the St. George core. The aim of the study would be to attempt to estimate the thickness of the layer of high heat generation.

Although neither the Pokiok nor the St. George batholith seems to have a viable HDR potential, the high heat production in the surface layer, particularly of the St. George, might provide a potential for low grade geothermal development in the Fredericton basin, in which the granites are buried by greater than 1500 m of sediments. Here, the blanketing effect of the low conductivity sediments perhaps traps heat generated in the granite. Thermal gradients at Fredericton and Tracy, to the south, are 26 mK/m (Drury, 1981); such gradients could lead to a warm water supply at reasonably shallow depths. Future work in New Brunswick will be concentrated on this area.

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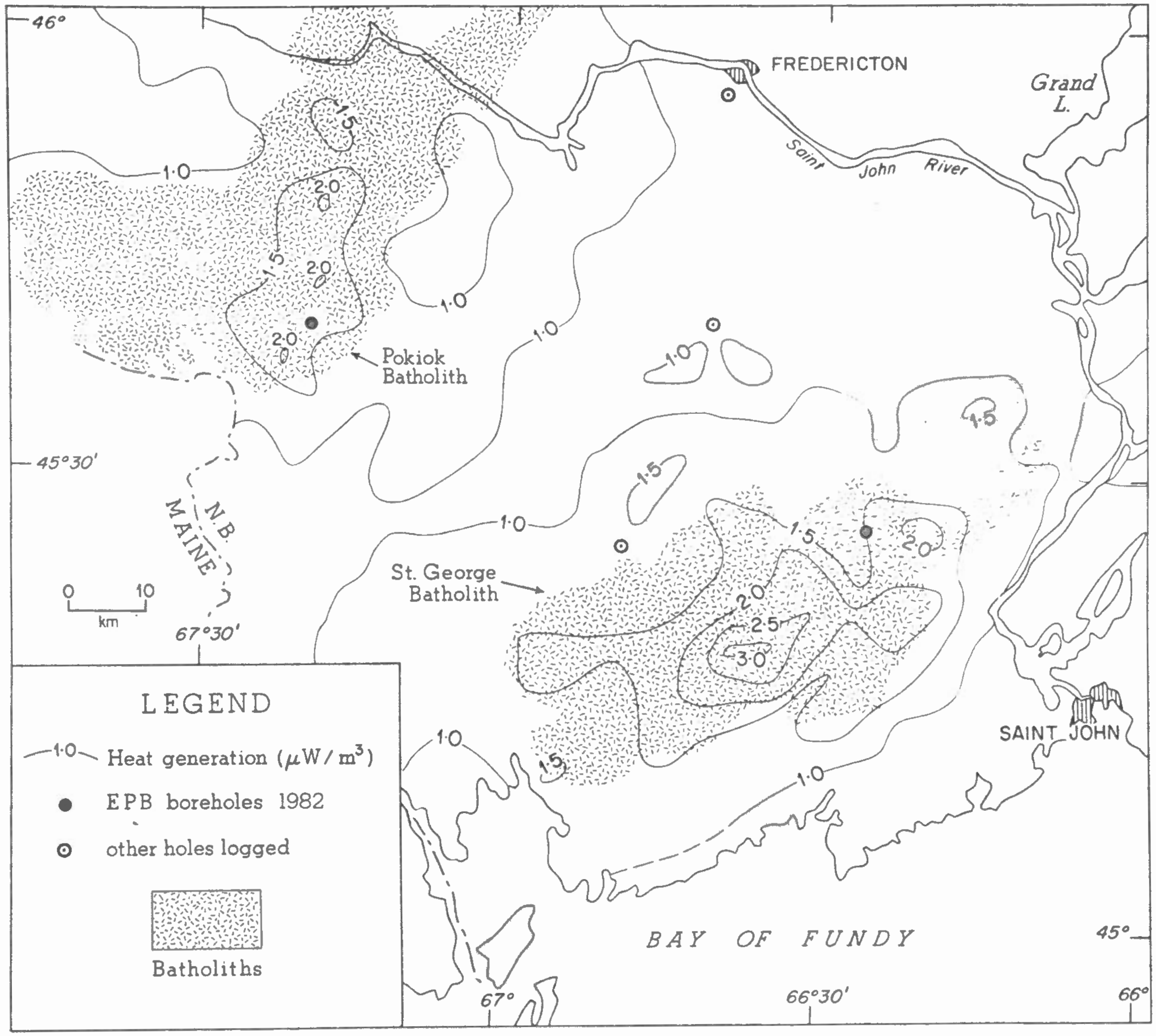
DEPTH (M)	U (PPM)	TH (PPM)	K (%)	HT.GEN. (MICW/M**3)
10.1	7.75	17.70	3.47	3.57
20.3	9.53	17.80	3.78	4.07
30.2	7.99	16.30	3.48	3.54
40.0	6.05	16.50	3.77	3.08
50.2	6.12	16.70	3.52	3.09
60.2	8.25	20.90	3.75	3.95
70.2	7.47	19.20	3.71	3.36
80.2	5.70	11.90	3.70	2.66
90.3	4.43	14.00	3.82	2.49
100.2	9.53	16.00	3.93	3.95
110.2	8.65	16.00	3.81	3.72
120.2	9.16	19.90	3.67	4.11
130.3	8.18	15.80	3.66	3.57
140.3	8.77	19.10	3.44	3.93
150.2	7.93	22.90	3.73	4.01
160.2	9.07	14.10	3.63	3.67
170.2	10.20	13.10	3.37	3.87
180.2	8.43	13.30	3.69	3.46
190.3	8.08	17.80	4.31	3.74
200.2	7.37	20.70	3.77	3.71
210.3	6.79	15.90	4.32	3.28
220.2	8.37	17.50	3.90	3.76
230.2	8.75	17.70	3.36	3.84
240.4	8.47	19.90	3.17	3.88
250.2	8.45	18.20	3.97	3.83
260.2	7.88	21.30	3.62	3.87
270.0	9.12	20.10	2.94	4.04
280.3	10.30	20.40	3.06	4.38
290.2	7.66	13.70	3.89	3.31
300.4	8.23	16.00	3.15	3.54
310.3	7.90	17.00	4.12	3.62
320.3	8.81	18.40	3.17	3.86
330.3	8.19	18.60	4.17	3.82
340.2	7.59	17.10	3.88	3.53
350.2	8.21	15.80	3.48	3.56
360.3	7.82	18.20	3.52	3.63
370.2	8.11	17.00	3.52	3.62
380.3	6.69	17.20	3.13	3.23
390.4	7.40	17.60	3.32	3.46

Table 1a. U, Th, K and heat production data for Pokiok hole core samples. Density of 2.67 Mg/m^3 assumed.

DEPTH (M)	U (PPM)	TH (PPM)	K (%)	HT.GEN. (MICW/M**3)
10.7	13.50	36.90	4.64	6.51
21.3	15.30	38.40	4.71	7.09
30.6	12.50	35.00	4.67	6.13
40.2	13.30	36.10	4.54	6.40
50.6	15.00	37.70	4.74	6.97
60.2	11.30	41.70	4.76	6.30
70.2	12.30	41.10	4.60	6.50
82.0	12.60	36.40	4.68	6.25
90.4	12.00	37.90	4.64	6.20
100.5	16.70	47.80	4.82	8.12
110.2	18.00	39.00	4.79	7.83
120.7	12.30	36.30	4.81	6.18
130.2	18.20	38.10	4.49	7.79
141.2	10.90	35.60	4.94	5.78
150.2	16.10	35.40	4.82	7.09
160.2	11.90	40.00	4.73	6.33
170.4	14.00	35.70	4.61	6.56
181.6	9.10	29.90	6.34	5.05
191.4	11.40	40.30	4.88	6.24
200.2	8.65	36.50	4.70	5.24
210.0	11.60	35.60	4.66	5.94
220.3	9.11	36.00	4.84	5.34
230.2	9.89	28.10	3.91	4.90
240.2	9.67	28.70	3.91	4.88
250.2	18.30	36.60	4.39	7.70
260.1	17.70	36.20	4.56	7.54
270.5	20.30	41.50	4.93	8.61
280.4	18.00	40.90	4.70	7.96
290.1	18.90	39.50	4.46	8.07
300.0	7.56	16.30	2.58	3.34
310.4	27.30	44.20	4.61	10.57
320.4	12.90	31.90	4.81	6.02
330.1	22.50	46.90	4.32	9.50
339.6	16.20	36.30	4.38	7.14
350.0	18.50	38.80	4.36	7.91
360.2	73.60	33.50	4.87	21.75
369.9	21.80	34.10	4.45	8.43

Table 1b. Data of Table 1a for St. George hole core samples.

Fig. 1. Location map of 1982 boreholes, showing simplified contouring of airborne γ-ray spectrometric data (Chandra and Wallace, 1980).



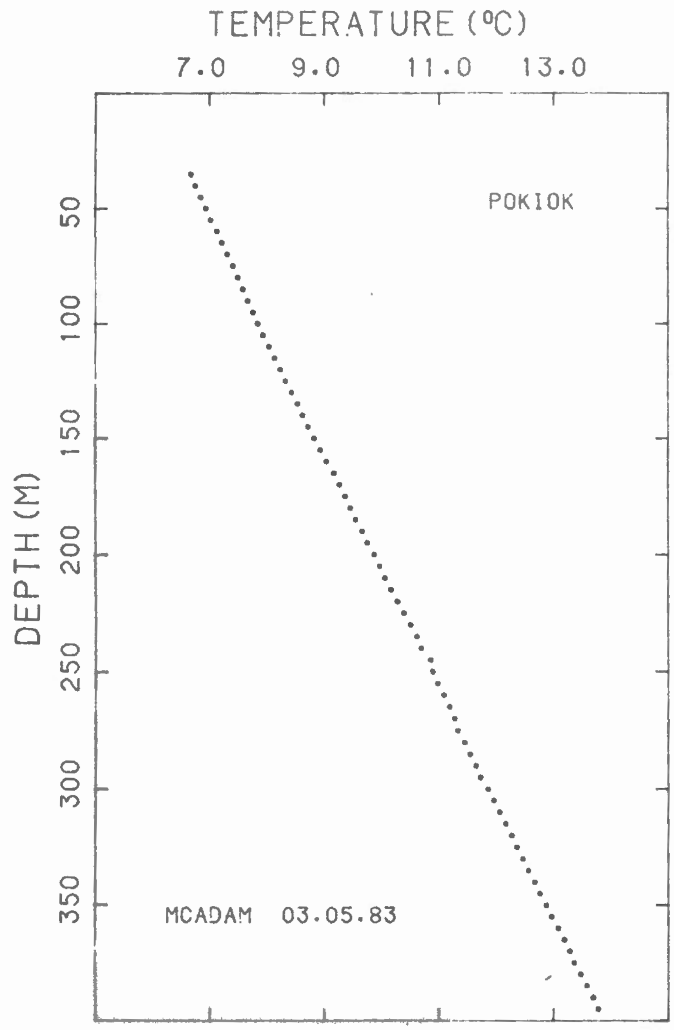


Fig. 2. Temperature log of Pokiok hole, 5 months after the end of drilling. Gradient is 20 mK/m.

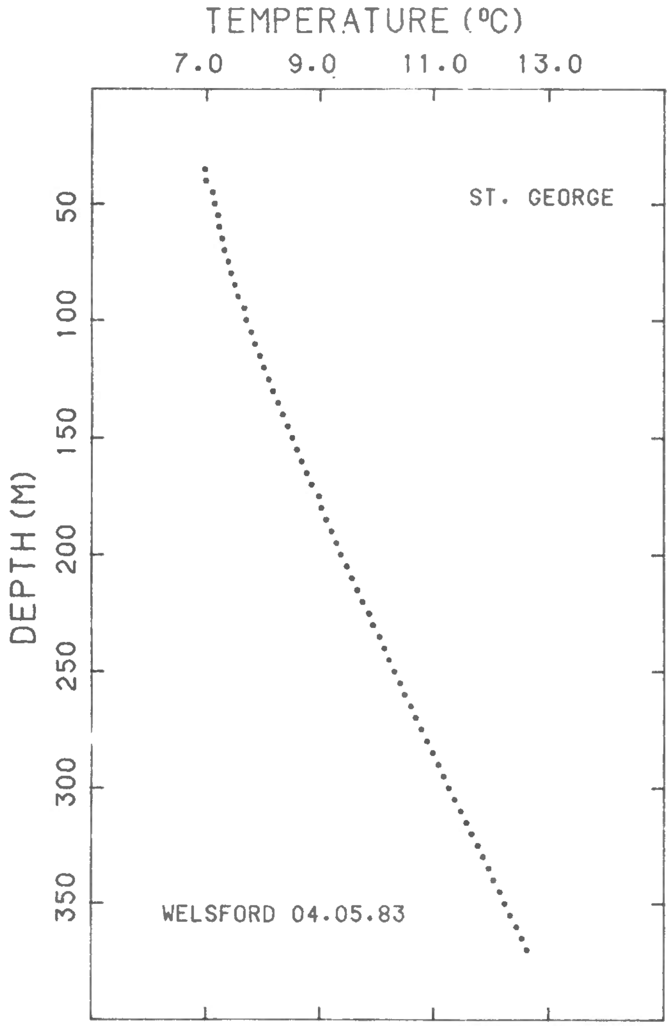


Fig. 3. Temperature log of St. George hole, 5 months after the end of drilling. Gradient is 19 mK/m.