Geological Survey of Canada

Open File 1337

HEAT FLUX IN THE RAFT BATHOLITH,
CENTRAL BRITISH COLUMBIA

NTS 92P

W.H. Bentkowski and T.J. Lewis
Pacific Geoscience Centre
P.O. Box 6000
Sidney, B.C.
V8L 4B2

Canada

Geological Survey of Canada

Open File 1337

HEAT FLUX IN THE RAFT BATHOLITH,
CENTRAL BRITISH COLUMBIA

NTS 92P

W.H. Bentkowski and T.J. Lewis
Pacific Geoscience Centre
P.O. Box 6000
Sidney, B.C.
V8L 4B2

Canada

HEAT FLUX IN THE RAFT BATHOLITH, CENTRAL BRITISH COLUMBIA

Abstract

Four holes were drilled vertically to depths of 244 m in the Raft Batholith, an early to mid Creataceous body northwest of Clearwater, B.C. Below depths of 107 m the measured temperature gradient in each hole is uniform, with the four gradients ranging from 27 to 36 mK/m. The heat flux, calculated using thermal conductivities measured on core samples, varies from 92 to 114 mW/m^2. The high average heat flux for the batholith of 104 mW/m2 is the result of a high average heat generation of 4.66 $\mu W/m^3$. This shows that the crust in this area was not heated significantly by the processes which produced the Quaternary volcanic eruptions in this region.

Introduction

There has been considerable interest in the geothermal potential of the Anahim Volcanic Belt, where the volcanic activity is believed to be the result of the North American plate moving westward over a hotspot (Bevier et al., 1979; Rogers and Souther, 1983). The Anahim Volcanic Belt was originally defined as extending from the coast to 500 km inland along about latitude 52 N, with decreasing eastward ages (Souther, 1977) (Fig.1). However, recent work has shown that the young volcanic centres near Clearwater, B.C., at the far eastern end of the belt, are probably part of a north-south extensional regime unrelated to the east-west trending belt (Hickson, pers. comm.). It was this eastern area near the young volcanics that was drilled in 1983 within the Takomkane Batholith of Jurassic age. The purpose of drilling was to investigate potential crustal heating associated with a possible hot spot beneath that part of the crust (Bentkowski and Lewis, 1985). The results indicated that there is no significant crustal heating associated with the volcanic activity, regardless of tectonic origin.

Attention was then shifted to younger intrusions with expected high radiogenic heat generation, approximately 50 km to the east of the drill sites (Fig.1). Four holes were drilled in 1984 within the Raft Batholith, a west-northwesterly trending body 65 km long and 16 km wide (Fig.1). The batholith, composed mainly of granodiorite and quartz monzonite, is early to mid Cretaceous in age (Campbell and Tipper, 1971) and straddles the boundary between the Omineca Crystalline Belt and the Intermontane Belt.

This report presents all the temperature, thermal conductivity and heat generation data as well as a heat flux estimate for the area.

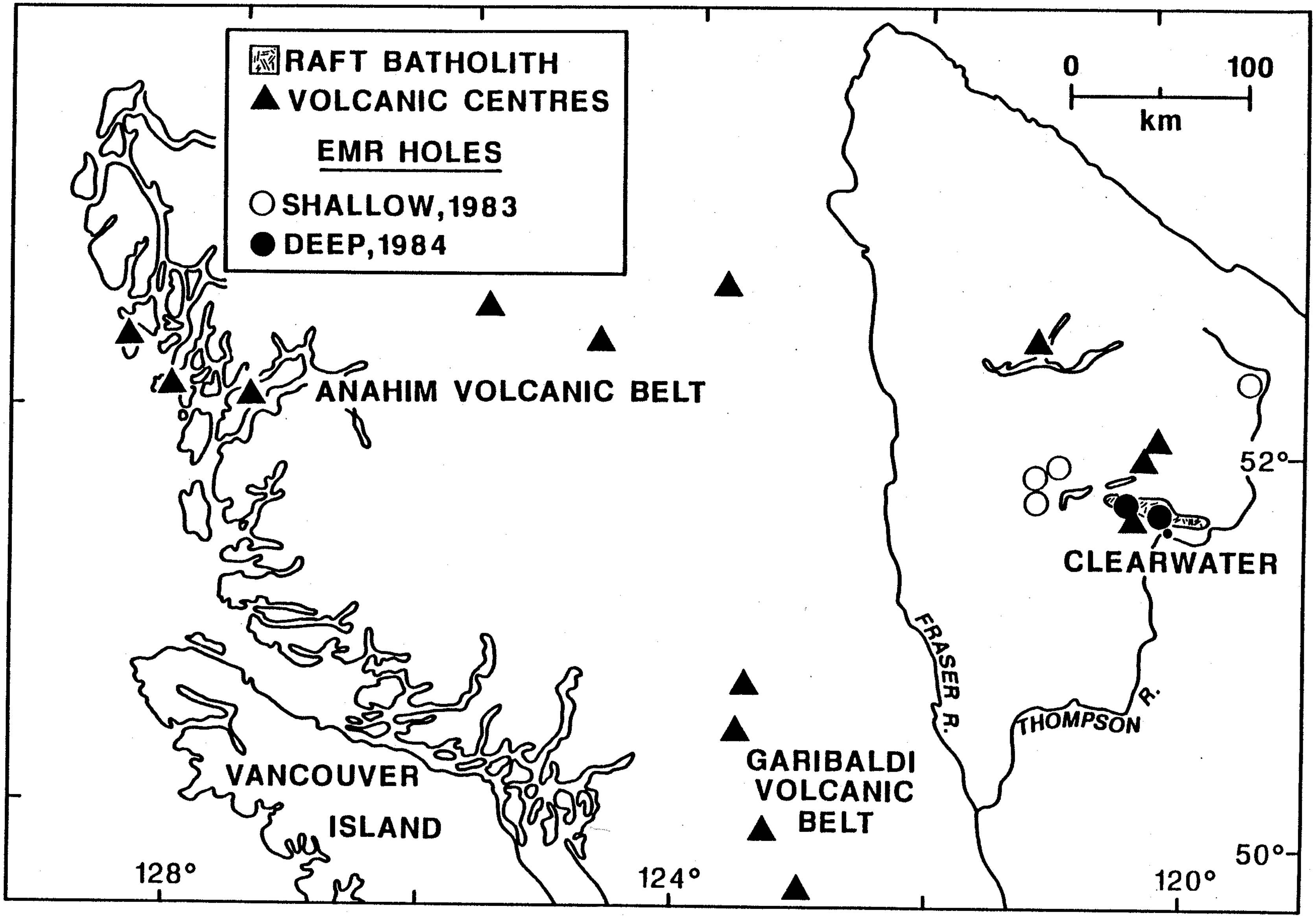

Figure 1 Location map of drill sites with respect to the volcanic belts and other boreholes.

Site Locations

The holes are located between 15 and 44 km northwest of Clearwater along logging roads used by Clearwater Timber Products, so vehicle access is available to each site. The holes are numbered 494-1 to -4 in the order that they were drilled (Fig.2). Locations by latitude and longitude, as well as elevations, are given in Table 1.

Drilling

The drilling contract was awarded to Iron Mountain Drilling Ltd. of Merritt, B.C. A diamond drill was used to drill BQ size (60 mm), vertical holes in the quartz monzonite. Dip tests were done after each hole was drilled to verify the angle. Drilling took place in one 12 hour shift per day, beginning on July 19 and finishing October 7, 1984. This time period included the casing and grouting procedure outlined by Moses and Sass (1979) using 32mm (1 1/4") black iron pipe to case the hole. Hole 494-1 was drilled to a depth of 250 m but was preserved only to 235 m. The latch-down plug did not latch properly in the landing collar and was forced up 15m by the grout before the cement cured. All other holes were preserved to total depth drilled. Drilling times for each hole and the total depths preserved are given in Table 1.

The core recovered was sampled for thermal conductivity approximately every 10 m and for heat generation at about 30 m intervals. The core for each hole was logged and a summary is included in Appendix 1. The core was then abbreviated to 20% and is now stored at the Geological Survey of Canada in Vancouver.

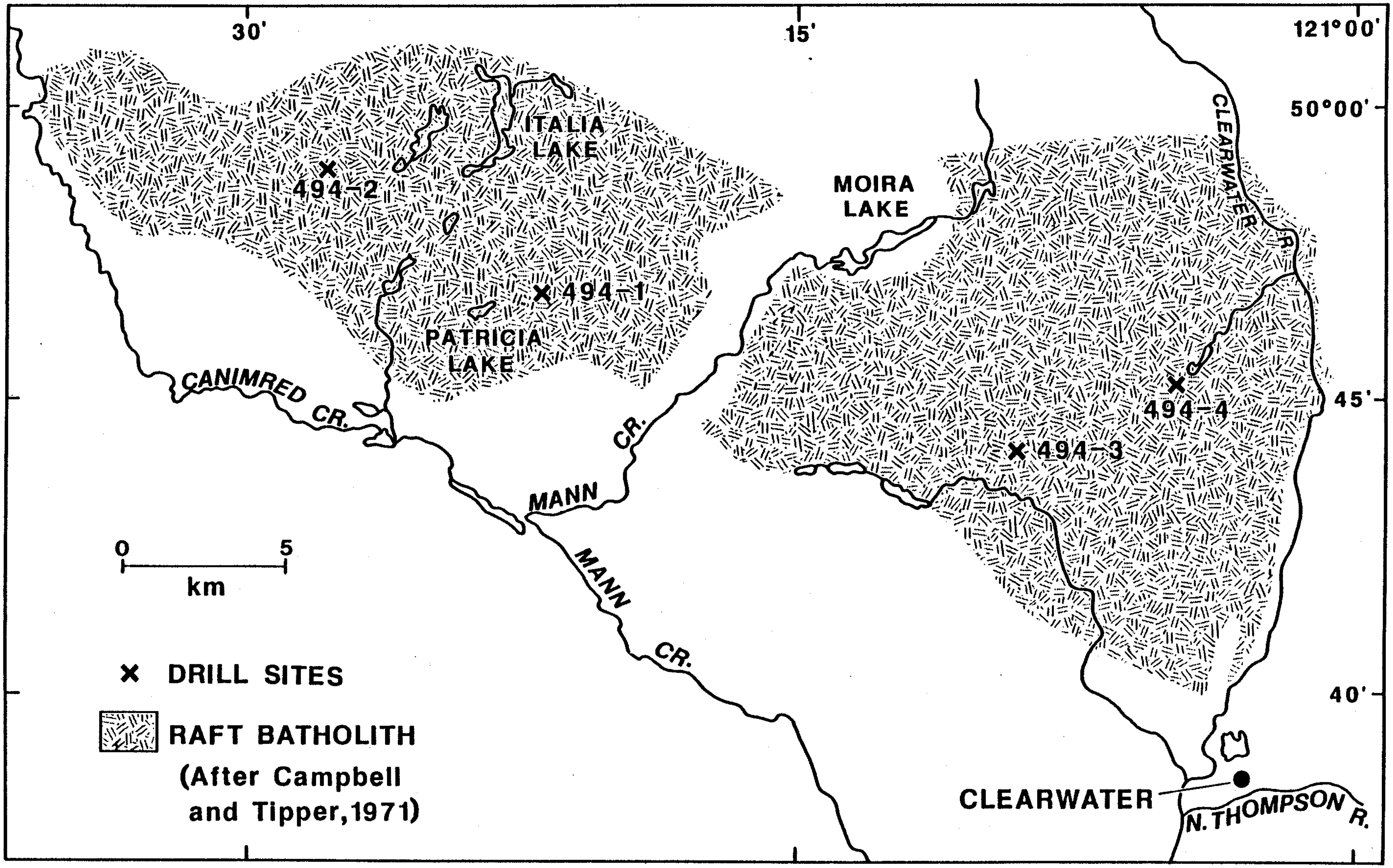

Figure 2 Borehole locations.

TABLE 1

RAFT BATHOLITH - DRILLING 1984

Hole#	Latitude	Longitude	Elev. (m)	T.D (m)	Date of drilling 1984	Final Logging 1985	Extrap. Surf. T (C)
494-1	51 46.95′	120 22.17′	1405	235	July 18 - Aug.1	July 14	3.00
494-2	51 49.0′	120 28.04′	1356	244	Aug.8 - 25	July 13	3.15
494-3	51 44.14′	120 09.04′	1417	244	Sept.1 - 13	July 14	2.80
494-4	51 45.09′	120 04.78′	1311	244	Sept.28 - Oct.6	July 14	3.05

Temperature Measurements

The drilling was done in one 12 hour shift per day so that the temperatures could be measured before the start of drilling each morning. The core barrel was removed at the end of the day shift and the bit was raised about 1 m to allow the probe to reach the bottom of the hole where the temperature disturbance caused by circulation would be minimal.

Temperatures were measured using standard portable logging equipment described in detail by Lewis (1975). The measurements were started at 15 m intervals for the part of the hole that had been drilled previously, but more detailed measurements at 3 m intervals were obtained for the last day's drilling. The temperatures of the hole are the least disturbed at the bottom after a break between the end of circulation and the start of drilling the next morning, usually 12 hours (Lewis et al., 1979). Thus a succession of these bottom hole temperatures would indicate the undisturbed gradient in the rock.

This procedure was followed after each shift for hole 494-1. However drilling progress was very slow due to the hard, competent nature of the quartz monzonite. For the subsequent holes only three bottom hole temperatures were obtained. After the holes were preserved with casing and grout, they were logged at various times as indicated in Table 1.

Geothermal Gradients

The geothermal gradients across the Raft Batholith range from 27.4 to 36.3 mK/m. Except for hole 494-3, all gradients are uniform in an interval from at least 107 m to total depth (Fig. 3). The maximum temperature disturbance, probably due to near-surface ground water flow, occurs between

6 and 9 m in all holes. There are also deeper temperature perturbations which are propagated to depths of 84 to 107 m, but the extent and nature of the disturbance causing these has yet to be determined. The bottom hole temperature gradients, measured in all four holes during drilling, are within 2% of the gradients measured 9½ to 11½ months later.

The gradient in hole 494-3 is calculated below 130 m. Above this depth a disturbance in the gradient is probably caused by colder water flowing laterally at a depth of 130 m resulting in a lower gradient of 23 mK/m. However if lateral water flow was the only effect, both gradients would be uniform. In this case the temperatures between 107 and 130 m decrease more rapidly before the gradient becomes uniform, indicating a small downward component of water movement within or right beside the grouted hole above 130 m.

Thermal Conductivity and Heat Generation

The thermal conductivities were measured on a divided bar apparatus using core samples sliced into 1 cm thick discs. Table 2 lists the results of the conductivity measurements for each hole. Measurements were repeatable to within 3%. Average thermal conductivities for each hole range from 2.82 to 3.50 W/mK. The low conductivity in hole 494-2 reflects the lower quartz content in that part of the batholith.

Heat generation measurements were done by the method outlined by Lewis (1974) using a sample size of 330.0 g. Average heat generation in the Raft Batholith is 4.66 $\mu W/m^3$ (Table 3). As with the thermal conductivity, the heat generation in hole 494-2 was significantly lower than the other three holes. The variation in heat generation is also reflected in the potassium content determined by the measurement, which shows that the less alkalic

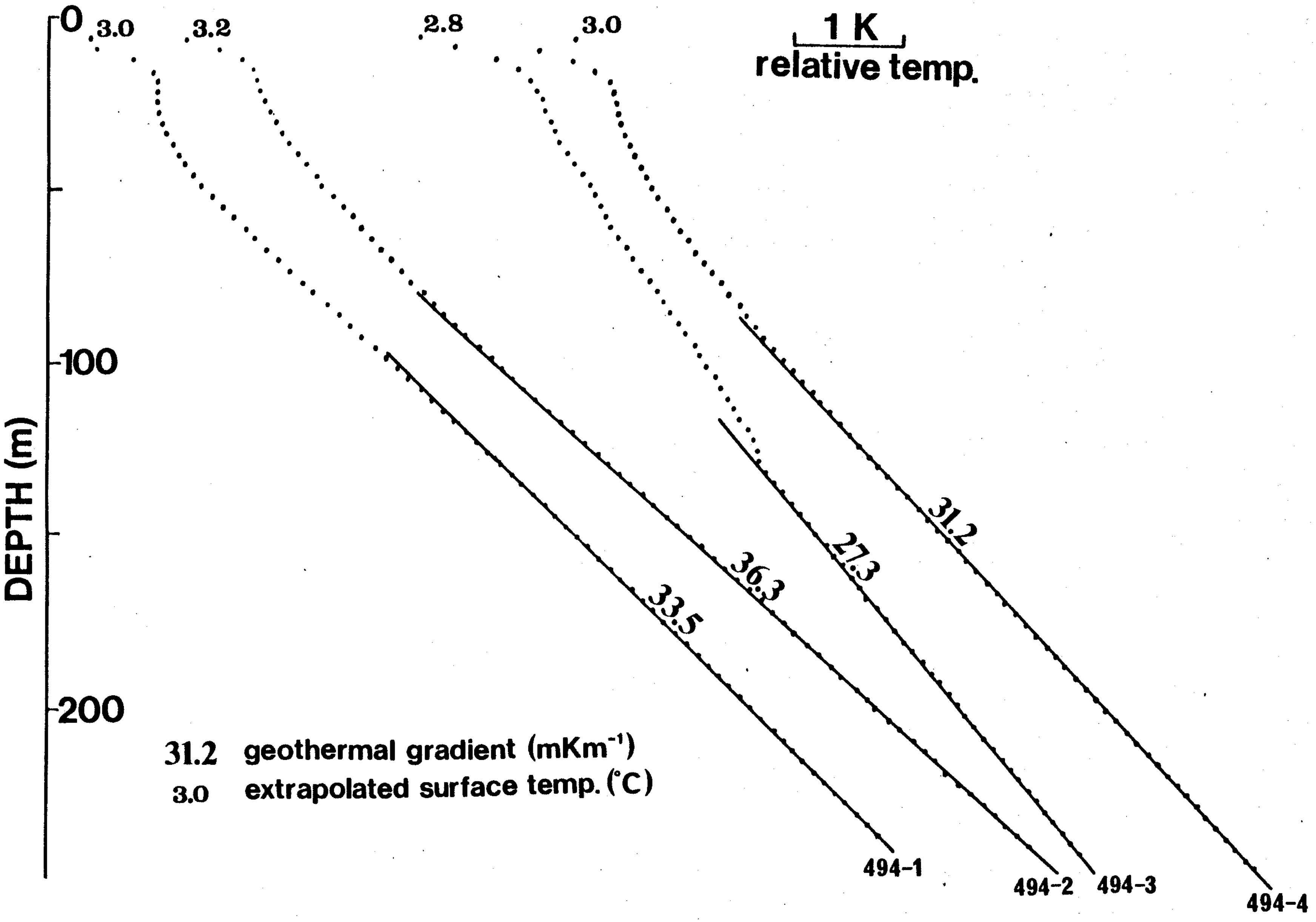

Figure 3 Surface temperatures are extrapolated from best fit line.

TABLE 2

THERMAL CONDUCTIVITY

494-1		494-2		494-3		494-4	
depth (m)	k (W/mK)	depth (m)	k (W/mK)	depth (m)	k (W/mK)	depth (m)	k (W/mK)
5.2	2.66	13.1	2.74	10.1	3.56	6.7	3.65
18.3	2.91	20.4	2.54	14.6	3.42	11.6	3.58
22.9	2.74	31.1	2.55	19.5	3.30	20.7	3.12
37.2	2.73	42.1	2.79	26.8	3.30	29.9	3.81
43.3	3.48	52.7	2.74	33.5	3.36	35.4	3.62
49.4	2.73	60.4	2.69	43.0	3.41	37.2	3.72
54.6	2.86	70.1	2.90	50.6	3.46	40.2	3.54
66.1	3.09	78.3	2.73	51.5	3.19	50.3	3.73
79.9	3.01	87.5	2.86	58.2	2.98	55.8	3.64
87.5	3.53	97.5	2.71	67.1	3.29	64.3	3.66
87.8	2.90	106.1	2.69	76.2	3.46	70.7	3.56
94.5	3.16	119.5	2.76	83.5	3.14	79.2	3.26
96.6	3.30	129.2	2.75	95.7	2.52	90.2	3.40
104.2	3.40	131.7	2.90	106.7	3.18	96.3	3.46
122.5	3.50	146.6	2.86	114.9	3.10	104.9	3.41
136.2	2.87	156.7	2.85	123.4	3.17	112.2	3.30
154.5	3.54	166.4	2.63	132.3	3.21	116.4	3.39
160.6	3.34	171.6	2.86	140.8	3.64	124.4	3.57
175.0	3.54	179.5	2.84	153.6	3.36	132.0	3.47
175.0	3.52	185.0	3.26	160.9	3.29	137.8	3.32
195.4	3.38	193.9	3.36	169.8	3.22	148.1	3.53
207.3	3.46	201.2	3.29	176.5	3.29	154.5	3.53
213.7	3.46	209.7	2.71	180.4	3.42	158.8	3.48
222.5	3.46	219.8	2.72	191.1	3.49	168.2	3.30
229.5	3.22	229.8	2.80	197.2	3.87		
		235.6	2.68	205.4	3.40		
				213.7	3.08		
				221.3	3.13		
				227.7	3.36		
				234.7	3.27		
Avg.	3.19 +/-.30		2.82 +/-.20		3.30 +/-.23		3.50 +/-.16

(and less silica-rich) phase of the batholith also has the lowest heat generation.

Heat Flux

The measured heat flux in the Raft Batholith ranges from 92 to 114 mW/m², averaging 104 mW/m² (Fig.4). Figure 5 shows the Bullard plots that define the heat flux based on the measured gradients and thermal conductivities. This average value of heat flux is relatively high due to the heat produced by the decay of the radiogenic elements in the upper crust. A reduced heat flux of 57 mW/m² is calculated using a depth of 10 km for the heat producing layer, the depth determined for the southern Intermontane and Omineca belts of B.C. (Lewis et al., 1985). This reduced heat flux is only slightly less than the 63 mW/m² reduced heat flux for the region to the south. Thus a normal conductive heat flux is probably present beneath the upper crust.

Acknowledgements

We wish to thank Iron Mountain Drilling Ltd. and George Adam for their effort and cooperation in drilling, as well as Clearwater Timber Products Ltd. for their advice on road conditions and access in the area. We also acknowledge Bill Price and Linda Bedard for drafting some of the figures.

TABLE 3

HEAT GENERATION

494-1		494-2		494-3		494-4	
depth (m)	ht.gen. (uW/m3)	depth (m)	ht.gen. (uW/m3)	depth (m)	ht.gen. (uW/m3)	depth (m)	ht.gen. (uW/m3)
18.3	3.02	30.5	2.89	31.7	5.24	38.7	5.24
49.4	3.25	60.4	3.51	61.0	4.76	60.7	5.12
94.5	3.23	92.0	2.96	88.7	4.67	90.2	5.51
96.6	6.43	119.5	3.04	123.1	6.60	121.3	4.89
122.5	3.81	152.4	3.32	153.3	5.63	154.8	4.12
154.5	5.35	183.5	2.94	182.3	7.19		
188.1	5.16	213.1	3.15	212.8	6.06		
213.4	8.32	243.5	3.26	242.9	5.73		
245.4	4.59						
Avg.	4.79 +/-1.75		3.13 +/-.22		5.74 +/-.87		4.98 +/-.53

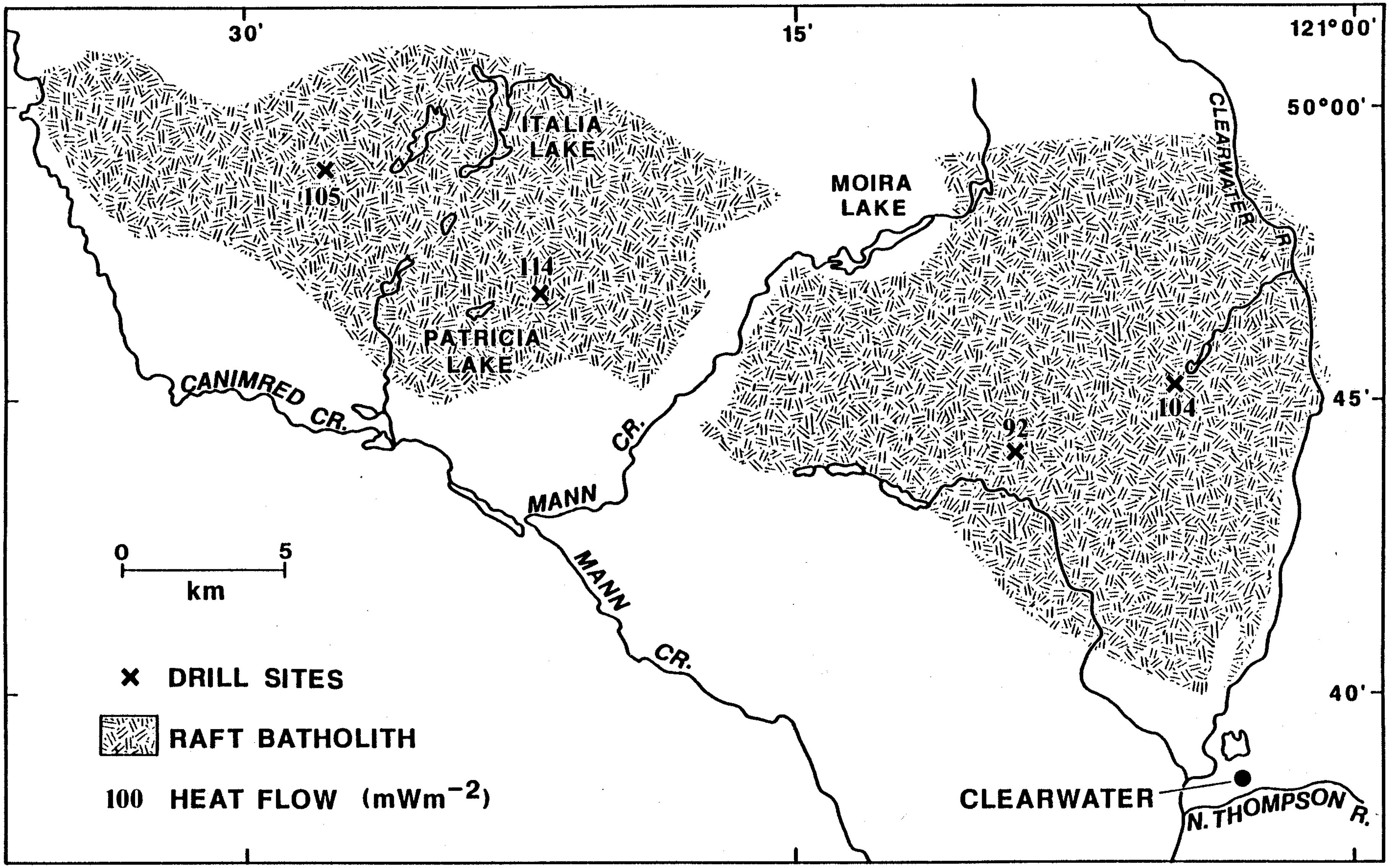

Figure 4 Distribution of calculated heat flux.

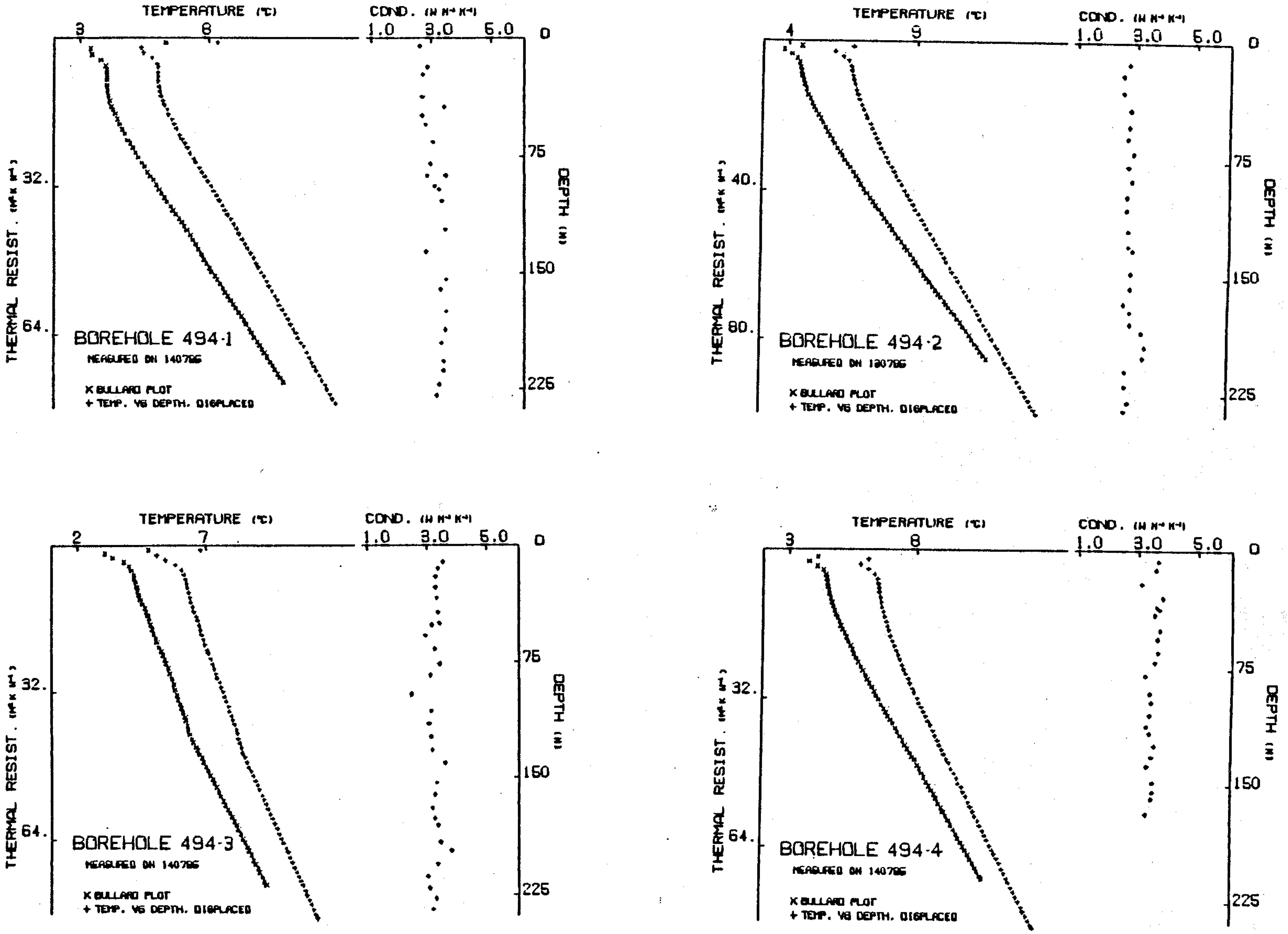

Figure 5 Bullard plots.

References

Bentkowski, W.H. and Lewis, T.J. 1985. Preliminary results from shallow drilling in the Anahim Volcanic Belt, B.C. Earth Physics Branch Open File 85-9, 19 p.

Bevier, M.L., Armstrong,R.L. and Souther,J.G. 1979. Miocene peralkaline volcanism in west-central British Columbia - its temporal and plate tectonics setting. Geology, 7, pp. 389-392.

Campbell, R.B. and Tipper, H.W. 1971. Geology of Bonaparte Lake map area, British Columbia. Geological Survey of Canada, Memoir 363, 100 p.

Lewis, T.J. 1974. Heat production measurement in rocks using a gamma ray spectrometer with a solid state detector. Canadian Journal of Earth Sciences, 11, pp. 526-532.

Lewis, T.J. 1975. A geothermal survey at Lake Dufault, Quebec. Ph.D thesis, University of Western Ontario, London, Ontario, 349 p.

Lewis, T.J., Allen, V.S., Taylor, A.E. and Jessop, A.M. 1979. Temperature observations during drilling of two 400 m wells in the Coryell intrusives north of Grand Forks, British Columbia, 1978. Earth Physics Branch Open File 79-4, 16 p.

Lewis, T.J., Jessop, A.M. and Judge, A.S. 1985. Heat flux measurements in southwestern British Columbia: the thermal consequences of plate tectonics. Canadia Journal of Earth Sciences, 22, pp. 1262-1273.

Moses, T.H. and Sass, J.H. 1979. Drilling techniques presently in use by the geothermal studies project, United States Geological Survey. U.S. Department of the Interior, Geological Survey, Menlo Park, CA. Open File Report 79-763, 26 p.

Rogers, G.C. and Souther, J.G. 1983. Hotspots trace plate movements. GEOS, 12, pp. 10-13.

Souther,J.G. 1977. Volcanism and tectonic environments in the Canadian Cordillera - a second look. In: Volcanic regimes of Canada. Edited by W.R.A. Baragar, L.D. Coleman and J.M. Hall. Geological Association of Canada, Special Paper 16, pp. 3-24.

APPENDIX 1

CORE LOG SUMMARIES

HOLE 494-1

0-1.2 Overburden

1.2-39.0 Medium to coarse grained equigranular quartz monzonite relatively homogeneous in composition, although the mafic content varies from 0 - 20% in places. Anhedral alkali feldspar can be quite coarse, and subhedral plagioclase has a slight sericitic alteration. Qtz commonly 20 - 30%. Biotite is the mafic mineral with magnetite < 1%. Alteration is quite minor and only affects the plagioclase.

39.0-46.9 Grades into finer grained quartz monzonite i.e. contact has a mix of grain size and iron oxide veining associated with it. Mafic content is very low (< 1%). Alteration is variable in intensity but mainly weakly propylitic.

46.9-115.2 Grades into coarse to medium grained qtz monz., relatively homogeneous, with chalky plagioclase alteration from 59.7 - 61.3 and associated qtz - chlorite veinlets with disseminated pyrite. Aplite dykes from 6 to 50 cm wide commonly at 45° to core axis and with some qtz monz fragments incorporated. Density of dykes up to several per foot of core and contacts generally sharp and even. Dykes vary from aphanitic, cherty, buff to rusty coloured with occasional anhedral qtz microphenocrysts.

115.2-144.5 Gradational contact with fine to medium grained qtz monz. Variable distribition of mafics (biotite) from 1 - 30%. Pegmatitic zone 9 cm wide at 118.9. This part of core characterized by coarse equigranular zones within finer grained uniform rock. Aplite dykes present but less common. Alteration is minor along 45° to subvertical fractures and veinlets. Some minor chalky alteration in isolated zones throughout, partly associated with mafic clots.

144.5-152.1 Long gradational contact with more homogeneous fine grained qtz monz and evenly distributed mafics (2%). Very minor chalky alteration.

152.1-169.8 Zone of variability in grain size and distribution. Pegmatitic patches becoming common, up to 23 cm zone of very coarse qtz and feldspar. Mafics occurring in clusters and patches irregularly distributed, and more abundant in association with coarser sections, throughout the finer grained rock. Aplite dykes 10 - 20 cm wide at 45° still present, as well as fractures and irregular qtz stringers from 45° to subvertical. Sericitic alteration of feldspars pervasive in places.

169.8-224.0 Becoming less variable fine to medium grained qtz monz with increased homogeneity with depth. Mafic content is <1% commonly.

224.0-T.D. Grading to mainly medium to coarse grained qtz monz. Chalky alteration in some zones and low mafic content increasing to 5% at depth.

Hole 494-2

0-9.4 Overburden

9.4-109.7 Relatively homogeneous medium grained quartz monzonite varying to granodiorite in composition, with lower quartz content (10 - 15%) than 494-1. Plagioclase/alkali feldspar ratio much higher (>1) than in other holes, hence the borderline compositional classification between qtz monz and granodior. Also the mafic content is significantly higher at 20 - 30% with both biotite and hornblende, and minor magnetite. Slight chalky alteration associated with white qtz - albite veins and fractures at ~45°.

109.7-112.2 Basalt dyke with black aphanitic groundmass, and feldspar and pyroxene phenocrysts. Randomly fractured throughout entire length in sharp upper contact with fresh qtz monz. Basalt has only a 1 cm wide chloritized zone at this contact. Lower contact however has a much wider and more intense zone of alteration with the basalt becoming friable and losing all phenocryst development. Contact with qtz monz is sharp but q.m. has pervasive Fe oxide stain and minor propylitic alteration, especially along fractures, decreasing with depth.

112.2-118.6 Qtz monz has pervasive Fe oxide stain and minor propylitic alteration, especially along fractures, generally decreasing with depth. Coarse rusty felspar surrounds albite - epidote veins toward 118.6.

118.6-140.2 3 cm thick qtz - albite vein, in part brecciated, with a few qtz phenocrysts, marks transition to mixed zone of varying degrees of alteration of qtz monz/granodior. Pervasive green rock in places where plagioclase almost totally sericitized, with minor clusters of very fine epidote. Euhedral to subhedral crystals of calcite rim the subhedral plagioclase grains, and also occur within the plagioclase and chlorite. Fine magnetite associated with the chlorite. Calcite makes up only 5% of rock, equal to proportion of chlorite. Qtz and alkali feldspar remain relatively unaltered, with only minor sericite in the feldspar. This extremely altered rock is mixed with zones of less altered rock crosscut by random albite- epidote veins which have alteration halos on either side of finer grained and lighter coloured minerals. The different alteration zones are in places separated by discontinuous bands of scattered chalky plagioclase.

140.2-181.1 Grading to less altered qtz monz. which is generally not homogeneous in composition or grain size ie. coarse alkali feldspar occurs variably fron 20 - 60% associated with mafic clots of biotite and amphibole (some of which is altered to chlorite). Increased chloritization and friability to 181.1.

181.1-203.0 Sharp vein contact with QFP (Qtz-feldspar porphyry) at 45°. Brown - grey aphanitic groundmass of mainly sericite with rounded qtz and rusty coloured alkali feldspar phenocrysts with minor sericite alteration. Chlorite - rich in places and along random fractures. Lower contact lost although pervasive chloritization occurs in contact zone on both sides.

203.0-T.D. Medium grained qtz monz with decreasing intensity of alteration with depth. Some friable zones of chloritized rock as well as chlorite filled fractures 45 - 70°.

HOLE 494-3

0-8.5	Overburden

8.5-11.9 Coarse grained equigranular qtz monzonite with qtz 30 - 40% and about equal proportions of plagioclase to alkali feldspar. Mafic content (biotite) is generally 5 - 10%. Minor sericitic alteration.

11.9-17.7 Sharp, irregular contact with fine grained qtz monz. Slightly porphyritic with plagioclase phenocrysts and some coarser grained sections.

17.7-126.5 Upper contact with mainly medium to coarse grained qtz monz. is quite sharp. Grain size and mafic mineral distribution is variable and irregular. Qtz up to 40%, and plagioclase is approximately equal to alkali feldspar in content. Mafics are low at 2 - 5%. At 34.1 grades into a zone of biotite - rich fine grained q.m. and at 35.4 rapidly grades to a coarse pegmatite with graphic texture about 10 cm wide. Below this zone qtz monz continues to be quite variable in grain size and mineral distribution. Porphyritic in sections with qtz and sometimes plagioclase phenocrysts. Alteration confined to chalky or argillic alteration, and chloritization and brecciation at shear zones which span 4 - 9 cm. Pegmatite zones at 84.1, 105.5, 124.7 with spectacular crystal development and graphic textures. Varying intense propylitic alteration and shearing between 90.5 and 110.3.

126.5-185.0 Slowly grades into medium grained qtz monz with mainly argillic alteration. Pegmatite zones occur at 134.7, 142.6, 150.6, 178.9 and 182.6.

Low mafic content and variable distribution. More equigranular texture but with some patches of variable grain size.

185.0-T.D. Increase in shearing and fracturing. Fine grained grey cherty dykes from a few cm to 45 cm in width with sharp but irregular contacts. Some with fragments of sheared qtz monz. At 188.1 a 45 cm shear zone of Fe oxide stained vein system brecciating the qtz monz. Argillic alteration pervasive in the more homogeneous unsheared parts of core. Pegmatite zone at 214.6 with very coarse (3 - 5 cm) crystals of pyrite with the quartz and feldspar. At 222.2 a brecciated grey cherty dyke? broken by white veinlets in a light brown aphanitic matrix. Composition of the qtz monz. relatively invariable in unaltered sections.

HOLE 494-4

0-1.5 Overburden

1.5-140.2 Medium grained qtz monz with pervasive argillic and propylitic alteration, with pitted and friable chloritic zones. Some breccia and shear zones. Dominantly the same proportions throughout the various alteration zones - qtz 30%, alkali feldspar $\geq$ 35%, biotite and magnetite 3%, muscovite 2%. Fractures are variable filled with chlorite, epidote, and/or qtz. The alteration zones are gradational but the texture remains relatively homogeneous. Fe oxide stain associated with vein systems and disseminated pyrite occurs with some of these.

140.2-217.0 Continuing variable alteration with a change in the feldspar ratio ie. plagioclase varies in content from 0 - 40% and in alteration from sericitic to chalky argillic alteration.

171.6-T.D. Remaining core has not been logged nor abbreviated and is at the GSC in Vancouver.

217.0-233.8 Locally minor propylitic alteration, with epidote associated with minor deformation. Fine, dark grey irregular veins and veinlets associated with shearing. Below 223.7 a few sheared zones completely enclose undeformed qtz monzonite. At 224.9 shearing less intense and plagioclase content < 10%. Locally iron oxide replacing feldspars.

233.8-T.D. At 233.8 sharp shear contact with zone of hematite replacement of K feldspar(?) within undeformed qtrz monzonite. Below 235.3 hematite is less ubiqitous and alteration of plagioclase is variably argillic.