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THERMAL MEASUREMENTS IN THE FRASER VALLEY, BRITISH COLUMBIA

NTS 92G

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Abstract

Two holes were drilled in the Fraser Valley lowland between Langley and Chilliwack, B.C., to determine the heat flux along the valley axis. An abrupt northeastward increase in heat flux occurs 100 km northwest of this area, caused by subduction of the Juan de Fuca plate. This high heat flux could extend to the lower Fraser Valley, producing a low enthalpy geothermal resource. The transition, based on bottom hole temperatures from old hydrocarbon exploration wells, is expected to be approximately 80 km inland.

The measured heat flux in a 244-m rotary borehole in Tertiary sediments near Langley, and in a 275-m cored hole in mid-Jurassic andesites near Chilliwack is 77 and 85 mW/m^2 respectively. Near Chilliwack corrections, assuming a conductive regime, reduce the value to 65 mW/m^2. These high values do not delineate the expected transition, but indicate that water may be flowing updip in the structural high near Langley, causing the observed high conductive heat flux in the shallow sediments. At this site an observed variation in heat flux with depth may also be attributed to water flows.

Introduction

The variation in heat flux across convergent margins indicates a landward transition from low to high heat flux. This heat flux transition has been observed seaward of the Garibaldi Volcanic Belt about 100 km northwest of the Fraser Valley lowland, where the heat flux increases from 30 to 80 mW/m² over a distance of 20 km (Lewis *et al.*, in prep.[b]). The same pattern has also been measured across the Oregon Cascades to the south (Blackwell *et al.*, 1982). The Fraser Valley lowland, a 30 to 40 km-wide, flat expanse of Quaternary alluvial, marine and glacial deposits, may be underlain by a similar heat flux transition which might provide a low-enthalpy geothermal resource (Fig.1). Two holes were drilled in December, 1984 and January, 1985 to delineate the expected heat flux transition through the valley where the heat flux has not been previously measured.

Initially, a survey was planned to log temperatures in new water wells which penetrated bedrock but no such wells were being drilled. Access to existing wells for measurement of deep temperature gradients was prevented by the presence of well-head equipment and down-hole pumps (Nevin, Sadlier-Brown, Goodbrand, 1985). The bottom hole temperatures from seven hydrocarbon exploration wells drilled during the 1960's were used to estimate geothermal gradients along the valley and thus aid in choosing sites. The gradients were calculated using the difference between the bottom hole temperature and an assumed surface temperature of 9°C over the depth of the well (Table 1). Although the bottom hole temperatures of these wells are of unknown reliability, the gradients indicate that the transition should lie somewhere between Abbotsford and Chilliwack, about 70 to 80 km inland.

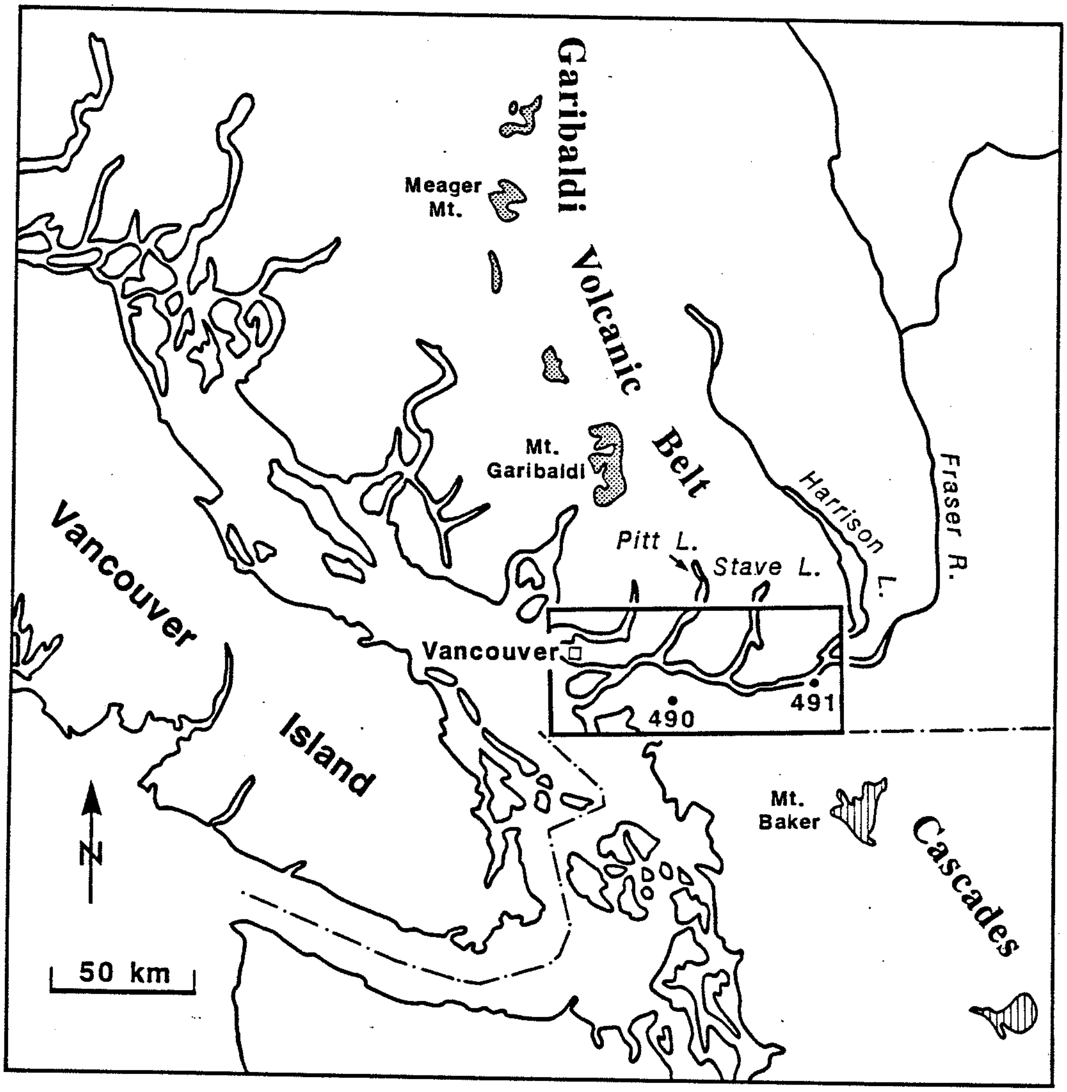

Figure 1. Location Map. The rectangle indicates the area of Figure 2.

TABLE 1

Temperature Gradients in Hydrocarbon Exploration Wells

Map Code	Well	Gradient (mK/m)
A	Richfield Pure Pt. Roberts	16
B	Great Basin #1	18
C	Richfield Pure Sunnyside	17
D	Royal Canadian - Van Tor	16
E	Hercon - Key Evans	17
F	Richfield Pure Abbotsford	17
G	Fraser Valley Chilliwack	28

Site Locations

The first hole drilled (hole 490) is 6 km southeast of Langley where low heat flux on the seaward side of the transition was expected (Fig. 2). The main consideration in choosing the site was the shallow depth of bedrock over a structural high, determined from an isopach map for the base of the Quaternary (C. Halstead, pers. comm.). The hole is at the edge of a private airstrip, the only accessible location in this part of the valley which was solid enough to support all the drilling equipment during the wet season.

The second site (hole 491) is 5 km west of Chilliwack at the southern base of Chilliwack Mountain, about 45 km east of hole 490 (Fig. 2). The site is easily accessible along a dirt road at the edge of a swampy field and less than 100 m from the main road.

Drilling

Different methods of drilling were used at each site. Hole 490 required some form of rotary drilling through the Tertiary sediments. Longyear Canada Inc. was awarded the contract, and used a modified diamond drill to "tri-cone" the entire hole to a depth of 244 m with a diameter of 108 mm (4 1/4 in). Drilling began on December 5, 1984. Quaternary overburden was 47.5 m deep. Chip samples for thermal conductivity measurements were collected approximately every 10 m.

Hole 491, started on January 28, 1985, was diamond-drilled also

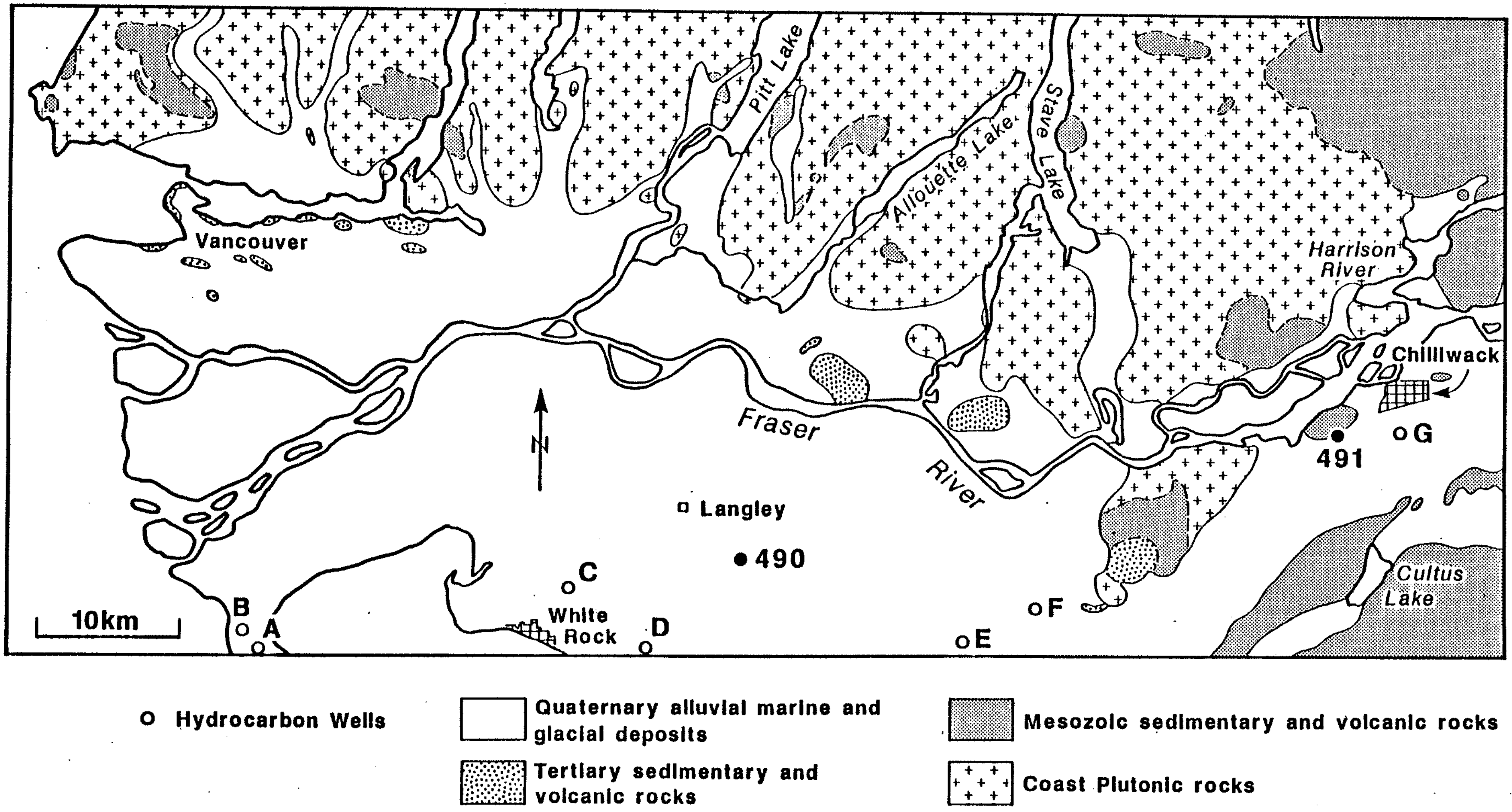

Figure 2. Site locations and regional geology.

by Longyear Canada Inc. with BQ diameter bit (60 mm) to a depth of 275 m through andesite and andesite porphyry of the mid-Jurassic Harrison Lake Formation (Roddick, 1965). The core was logged (Appendix 1), sampled at 10 m intervals for thermal conductivity, abbreviated by 80% and stored at the Geological Survey of Canada warehouse in Vancouver.

Both holes were cased with 32 mm (1 1/4 in) black iron pipe and grouted according to the procedure outlined by Moses and Sass (1979). Hole 490 was preserved to a depth of only 231 m due to the malfunction of the latch-down plug which was pushed up the hole by the grout. After casing hole 491, the grouting operation was hampered by sand at the bottom of the hole which plugged the string of pipe as the grout was pumped down. The bottom 209 m of the hole were cemented in and not available for subsequent temperature logging.

Temperature Measurements

The temperatures in hole 490 were logged after the hole was cased and grouted. However in hole 491, three bottom hole temperatures between 213 and 275 m were measured just before drilling began each day. The temperatures were measured using standard portable logging equipment described by Lewis (1975). Temperature logs in both holes were also done up to five months after drilling (Table 2).

Geothermal Gradients

The temperatures in hole 490 define a uniform gradient of 25.1

TABLE 2

Borehole Parameters

Hole #	Latitude (N)	Longitude (W)	Elevation (m)	Depth drilled; preserved	Dates drilled	Dates logged
490	49 04.27′	122 35.90	61	244;231	Dec. 5 - Dec. 22 Jan. 2 - Jan. 14	Jan. 14, 28 Feb. 18 May 31
491	49 08.73	122 01.35	20	275;63	Jan. 28 - Feb. 7	Feb. 4, 5, 6 May 31

mK/m for the lower 60 m of the hole (Fig. 3). Above this depth, intervals from 96 to 131 m and 152 to 171 m have lower gradients of 14.1 and 13.9 mK/m respectively, and are separated by an interval with a higher gradient of 36.0 mK/m. A temperature reversal is present to 61 m depth, approximately 15 m below the base of the unconsolidated Quaternary sediments, indicating either a deep temperature perturbation or water flowing in the unconsolidated sediments. It is unlikely that the different temperature gradients over 20 m depths represent different thermal conductivities, given the measured conductivity values. The decay of the temperatures from the effects of drilling was calculated from the three successive temperature logs (see Table 2). It is evident that water flow controls the temperatures at horizons where the gradient changes.

The bottom hole temperature gradient measured in hole 491 is 30.9 mK/m (Fig. 3). Although no other temperature logs at depth could be obtained due to the unsuccessful grouting attempt, the temperatures in the top 66 m were logged again after drilling (Table 2). Generally there is good agreement with the gradient defined by the bottom hole temperatures but some water movement is likely affecting the temperatures in the top 50 m of the hole (Fig. 3).

Thermal Conductivity

The thermal conductivity of the chip samples from hole 490 was measured by two methods. The first method (Lewis *et al.*, in prep.[a]) monitored the temperature decay of a vacuum-saturated sample following the input of a known heat pulse from a needle probe. A geometric

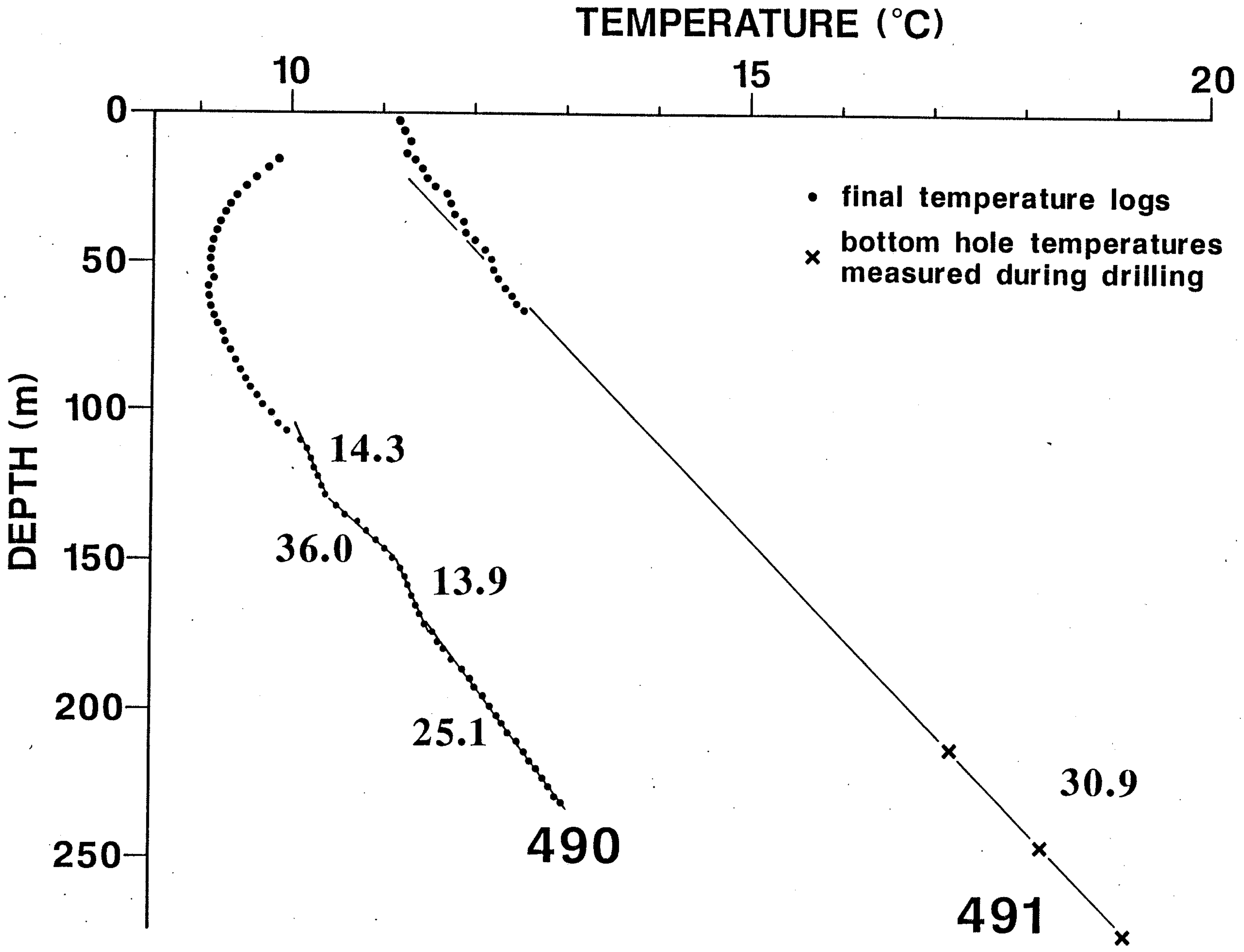

Figure 3. Temperatures in boreholes 490 and 491 as a function of depth. The temperature gradients are given in mK/m.

model was used to calculate the conductivity of the rock matrix, and the *in situ* rock porosity was taken to be the amount of water in excess of 40% in the wet sample.

The second method required the rock fragments to be vacuum-saturated and packed in perspex cells for measurement on a divided bar apparatus. The conductivity of the entire cell was measured and a geometric model was used to obtain the rock matrix conductivity (Sass *et al*., 1971).

The cell method does not account for the *in situ* rock porosity. Thus in order to directly compare the results from both the needle probe and the cell methods, the average differences in the rock matrix conductivities were calculated. The needle probe measurements are systematically higher than the cell results by an average of 17.2%. However, this includes differences of over 45% in samples with a thermal conductivity greater than 4.0 W/mK (see Lewis *et al*., in prep.[a] for discussion). Without these biased values, the average difference is 10.8%. The *in situ* rock porosity can be obtained from the needle probe method, and is used to calculate the *in situ* conductivity using the rock matrix results from each method.

The *in situ* conductivity results from these two methods are averaged (Table 3). The conductivity values for each depth may be uncertain because of the probability of contamination of any sample from higher zones.

Discs one cm thick were cut from the core obtained from hole 491 and measured on a divided bar apparatus. Measurements were repeatable to within 3%. The average thermal conductivity is 2.93 W/mK (Table 4).

TABLE 3

Average thermal conductivity results from Hole 490

Depth (m)	k (W/mK)
118.9	2.92
128.0	4.31
137.2	3.23
146.3	2.75
155.4	2.81
164.6	2.32
173.7	3.68
182.9	3.62
192.0	4.65
201.2	3.04
210.3	3.47
219.5	2.92
228.6	2.15
Average k for lower 60 m	3.36 +/- 0.78

TABLE 4

Thermal conductivity results from Hole 491

Depth (m)	k (W/mK)
14.6	3.24
24.1	3.26
35.4	3.15
45.1	3.18
57.6	2.80
62.2	3.07
72.5	2.62
165.8	2.68
172.2	2.30
181.1	3.26
188.7	3.30
195.4	3.09
201.5	2.26
209.4	2.64
235.0	2.42
239.6	2.93
246.3	2.74
257.6	2.36
261.2	3.49
266.4	3.45
Average k	2.93 +/- 0.38

Heat flux

The measured heat flux for holes 490 and 491 is 77 and 85 mW/m^2 respectively. Because the valley narrows near hole 491, a correction for a conductive heat flow regime was applied to account for the effects of the steep topography and refraction in the thick sediments of the valley. The corrected heat flux is 65 mW/m^2. No such corrections are required for hole 490.

A heat flux transition seaward of the Garibaldi Volcanic Belt defined by Lewis *et al*. (in prep.[b]) was not detected in the lower Fraser Valley. The high observed heat flux in the western hole may be due to water flowing updip in the structural high.

APPENDIX 1

Core log summary - Hole 491

0 - 6.7 Overburden

6.7 - 29.3 Andesite porphyry with 5 - 25% phenocrysts of qtz eyes (1-5%) and light buff rounded feldspar (4-20%), 2 - 6 mm in diameter. Very fine-grained light green to grey groundmass. Narrow irregular subhorizontal to subvertical with albite(?) veining. Decrease in feldspar phenocrysts and variable qtz eye distribution toward breccia zone at 29.3.

29.3 - 33.8 Vertical, locally -stained fractures from 29.3 - 29.5. Gradational breccia, vein fracturing with epidote groundmass and andesite porphyry fragments. Silicification and development of qtz crystals around breccia zones. Fe oxide staining in breccia zones occurs with clots of epidote.

33.8 - 36.9 Sharp vein contact with andesite porphyry at 33.8. At 36.9 hematite veinlets at 45° to vertical mark beginning of friable, altered zone.

36.9 - 93.0 Intense alteration, chloritization of groundmass and argillic alteration of feldspar. Ductile deformation with "birds-eye" folding patterns developed in places. Subvertical shear zones and disharmonic convolute folding, graphitic layers in places, as well as later(?) more brittle deformation in the form of brecciation and small scale faulting in sheared zones. Chlorite and Fe oxide - stained layers, or dark grey layers folded and subvertically sheared. Irregular, locally en echelon, albite veinlets 45° to subvertical. Intense clayey alteration from 84.1 - 87.2. Less altered massive andesite near contact at 93.0 with irregular veinlets of albite.

93.0 - 147.5 Sharp intrusive contact with black fine-grained basalt. Pervasive random irregular veinlets of albite and qtz(?) throughout (about 50% density). Locally fractured, friable and clayey. Disseminated pyrite along fractures. From 129.5 - 132.9 zones of massive andesite with brecciated contacts, in both andesite and basalt. Some small scale faulting in basalt. Gradational increase in deformation ie. sheared and friable toward lower contact.

147.5 - 175.6 Sharp contact with recrystallized andesite tuff(?). Fine grained chlorite groundmass with random irregular albite veinlets and minor faulting. Grades into fine-grained more massive, light green andesite. Disseminated pyrite along fractures and in veins. Vein breccias, 1-10 cm wide, with matrix of fine-grained albite and qtz and hematite-stained, occur throughout the andesite fragments.

175.6 - 198.4 Gradual increase in feldspar phenocrysts to about 7% but as much as 35% in isolated zones. Feldspars are euhedral laths rather than rounded anhedral grains. Development of foliation 45°, parallel to some veins. Towards contact, shearing and minor brecciation occur, grading to massive andesite.

198.4 - 221.6 Non-porphyritic andesite with some breccia zones 5-20 cm wide with white albite - qtz matrix and angular andesite fragments. Pyrite is abundant (up to 10%) in association with the breccia zones and within the veins, occuring as fine crystals and disseminated. Bands of hematite stain in the matrix of the breccia.

221.6 - 233.5 Gradational contact with andesite tuff. Change in colour from light green to darker green - chlorite alteration. Vein fracturing in places with hematite stain. Two types of breccia zones: some gradational breccia zones, unlike vein breccias with sharp boundaries in previous zone, with dark green or black matrix; and vein breccias with white or hematite-stained albite-qtz matrix. Commonly oriented at 45°. Pyrite is less abundant, but it occurs disseminated through the andesite, not just in association with veining and brecciation.

233.5 - EOH Gradual increase in pervasive alteration. Epidote is common in veins with bleached haloes. Anhedral epidote phenocrysts to

30% in patches, with coalescing blebs of epidote with bleached haloes. Mix of random epidote and albite-qtz veins.

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