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THERMAL MEASUREMENTS IN CORDILLERAN BOREHOLES OF OPPORTUNITY

1984–1987

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ABSTRACT

Most heat flux data in the Cordillera are obtained from suitable mineral exploration boreholes. The distribution of these sites leaves many regions with little or no available data. Heat flux results obtained between 1984 and 1987 are presented here for all areas of the Cordillera including those where insufficient data are available for a regional overview.

In the Queen Charlotte Basin the heat flux is 75 mW m^{-2} on the eastern margin (Lewis et al., 1989) and ranges from 62 to 70 mW m^{-2} on the western margin. The heat flux measured in southwestern British Columbia supports previously published values which reflect the thermal regime due to subduction of the Juan de Fuca plate (Lewis et al., 1988).

INTRODUCTION

Many of the heat flux data in the Cordillera are determined using temperatures measured in mineral exploration boreholes. Relatively few data have been obtained from boreholes drilled specifically to study heat flow for the purpose of geothermal resource evaluation. Because exploration activity is usually concentrated in specific areas or camps the overall distribution of sites is very limited. In large regions of the Cordillera having only sparse or isolated data, there is an ongoing search for new holes. The data accumulate in a database as they are acquired, and when the distribution of heat flux becomes sufficiently well defined in a region, an analysis relating the heat flux to crustal processes, crustal temperatures and tectonic setting is published (eg. Lewis et al., 1988; Lewis et al., 1985; Davis and Lewis, 1984).

This open file is a compilation of all unpublished heat flux data obtained during four field seasons from 1984 to 1987. Locations and the calculated heat fluxes (Fig. 1) as well as thermal conductivities and various other borehole parameters are included for each site in Table 1. For each site a graph of temperature and thermal conductivity as a function of depth is also presented for individual holes. In plotting the temperatures as a function of depth for each hole, the temperature logs are offset with respect to absolute temperature. Consequently the temperature scale is indicated for each site as well as the first temperature measured in each hole. A brief description of the results and preliminary interpretations are given.

Surface temperatures at each hole are defined by extrapolation of the gradient at depth to the surface. Different surface temperatures at a particular site can indicate that water flow is affecting the measured temperatures if the differences are not accounted for by topographic variation or differing overburden thicknesses.

Refraction of heat can have a significant effect on shallow crustal temperatures in a conductive heat flow regime. Corrections were applied to account for effects of topography in areas of mountainous terrain (Table 1). In rugged topography with relatively linear valleys the

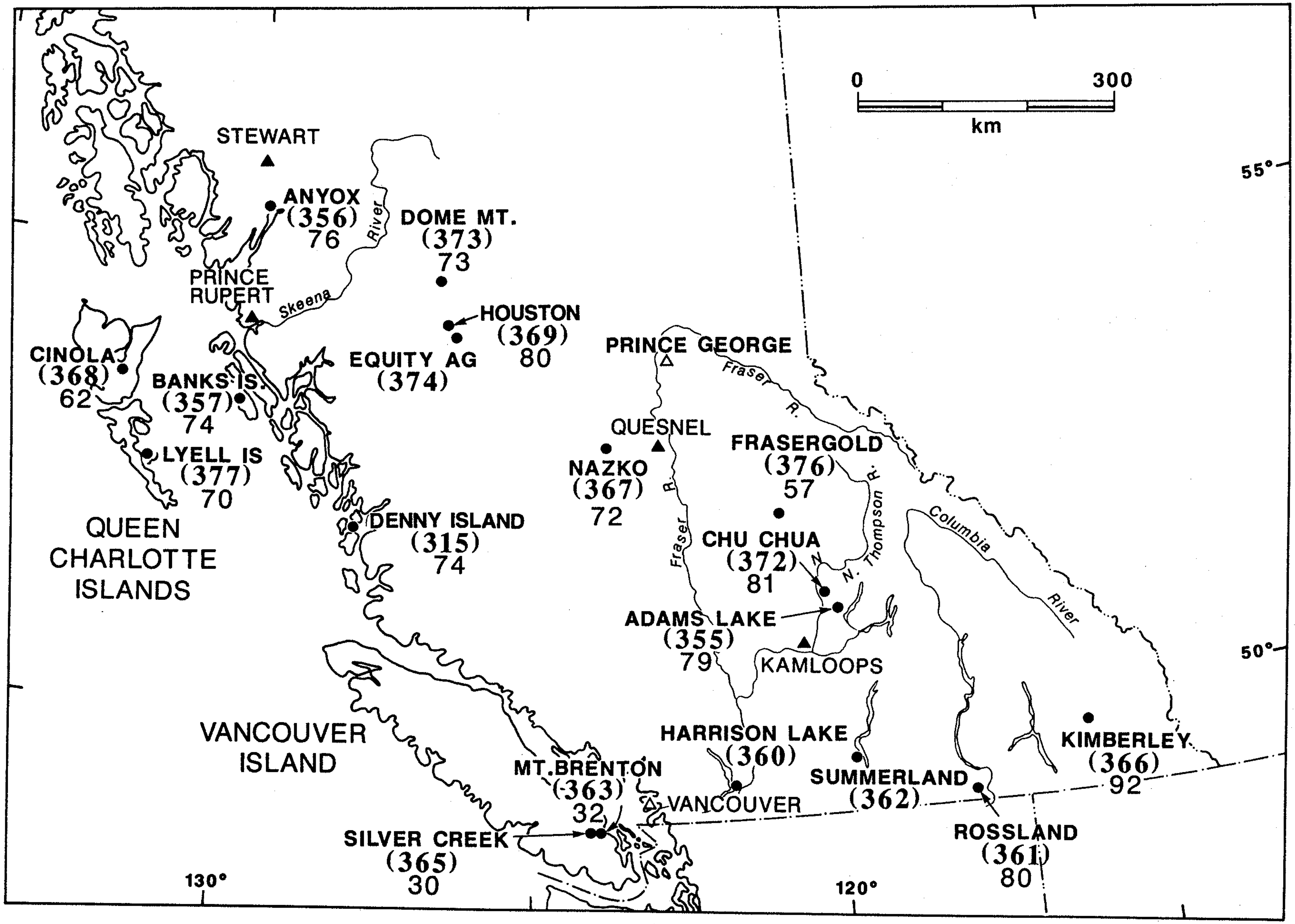

Fig. 1 Location map showing the heat flow sites and the measured heat flux in mW m^{-2}. Site identification numbers are in brackets.

Table 1

SITE	LOCATION			COLLAR ELEVATION	MEASURED INTERVAL	THERMAL CONDUCTIVITY			HEAT FLUX			HEAT GENERATION			ACCEPTED HEAT FLUX
		lat.(N)	long.(W)	(m)	(m)	n	(W/mK)	S.D.	obs.	corr.^{a} (mW/m^{2})	S.D.	n	(uW/m^{3})	S.D.	(mW/m^{2})
315-1	*Denny Island	52°08.1′	128°02.9′	40	50-194	13	2.99	0.29	90.8	-	3.3	^{d}13	2.75	0.86	74
-2		52°08.8′	128°05.7′	40	90-381	24	2.48	0.37	73.7	-	1.6	19	1.95	0.44	
355-1	Adams Lake	51°09.0′	119°49.2′	1502	192-222	17	3.45	0.69	55.7	56.6	0.7				79
-2		51°08.7′	119°48.2′	1524	175-671	23	3.46	0.32	67.4	73.7	0.1				
-3		51°09.0′	119°49.2′	1495	215-425	18	3.85	0.75	82.5	83.8	0.1				
356	*Anyox	55°28.4′	129°49.0′	655	80-292	22	3.94	1.18	65.2	75.5	0.4				76
357-1	*Banks Island	53°21.8′	130°07.5′	33	220-240	16	3.03	0.49	116.6	-	4.7	^{e}2	0.81	0.00	74
-2		53°21.9′	130°07.3′	33	150-389	29	3.06	0.51	76.2	-	0.2				
-4		53°22.0′	130°09.7′	25	50-71	10	3.30	0.77	51.0	-	3.1				
-6		53°22.0′	130°09.7′	25	50-125	15	3.29	0.55	86.9	-	2.8				
-7		53°22.0′	130°09.7′	25	50-89	8	3.11	0.37	75.0	-	1.3				
-8		53°22.0′	130°09.7′	25	50-75	9	3.58	0.24	88.1	-	14.3				
-9		53°21.9′	130°09.5′	25	50-124	16	3.37	0.33	81.0	-	0.3				
-10		53°21.9′	130°09.5′	25	50-137	16	3.24	0.30	71.4	-	1.2				
-12		53°21.9′	130°09.5′	25	50-130	14	3.34	0.50	63.5	-	1.7				
-13		53°21.3′	130°08.9′	10	50-173	24	3.59	0.55	74.9	-	1.0				
-14		53°21.3′	130°08.7′	10	50-116	14	3.59	0.77	75.1	-	2.1				
359-1	Houston	54°13.8′	126°14.0′	1225	75-245	20	1.98	0.18	83.4	82.3	0.1	^{e}2	1.80	0.06	80
-2		54°13.9′	126°14.3′	1225	100-209	10	1.66	0.07	78.5	77.5	0.2				
360-1^{c}	Harrison Lake	49°20.1′	121°44.7′	190	-170	11	2.32	0.29							
-3^{c}		49°20.1′	121°44.6′	250	-167	10	2.28	0.16							
-4^{c}		49°20.0′	121°44.8′	200	-116	5	2.64	0.14							
-5^{b,c}		49°20.1′	121°44.6′	250	-241										
361-1	Rossland	49°05.4′	117°49.5′	1372	230-895	42	2.53	0.39	79.7	79.8	0.2	^{e}11	2.45	1.58	80
-2		49°05.4′	117°49.9′	1201	265-777	30	2.31	0.20	79.1	79.2	0.2				

(cont'd)

Table 1 (cont'd)

SITE	LOCATION			COLLAR ELEVATION	MEASURED INTERVAL	THERMAL CONDUCTIVITY			HEAT FLUX			HEAT GENERATION			ACCEPTED HEAT FLUX
		lat.(N)	long.(W)	(m)	(m)	n	(W/mK)	S.D.	obs.	corr.[a] (mW/m^2)	S.D.	n	(uW/m^3)	S.D.	(mW/m^2)
362 [c]	Summerland	49°35.3′	119°40.9′	518	-160	22	1.77	0.15							
363-1	Mt. Brenton	48°53.1′	123°52.1′	780	50-100	12	3.15	0.55	20.2	20.3	0.3	[e]3	0.22	0.04	32
-2		48°53.1′	123°52.0′	820	100-123	13	3.38	0.38	19.1	19.1	1.7				
-3		48°53.4′	123°50.7′	960	75-105	11	3.99	0.72	24.8	24.8	1.1				
-4		48°52.7′	123°49.4′	865	150-266	26	3.59	0.62	28.6	31.8	0.1				
365-1	Silver Ck.	49°03.0′	123°54.4′	648	150-198	17	3.61	0.43	30.2	29.6	0.3				30
-2		49°03.1′	123°59.8′	675	45-82	9	3.45	0.25	19.5	19.1	0.3				
366	Kimberley	49°41.2′	115°59.8′	1220	700-893	39	3.50	0.64	94.3	91.9	1.1	[e]20	3.60	0.87	92
367-1	[c]Nazko	52°55.1′	123°37.7′	1160	100-137	6	4.82	0.57							
-2		52°55.1′	123°37.7′	1160	85-137	11	4.66	0.80	74.1	81.5	0.9				72
-6		52°55.0′	123°38.1′	1120	45-100	4	4.91	0.63	71.4	76.6	1.3				
-8		52°54.9′	123°37.5′	1140	108-145	16	3.95	0.51	55.8	58.3	1.6				
368-1	*Cinola	53°31.8′	132°13.1′	198	28-117	11	2.97	0.48	66.2	-	2.1				62
-2		53°31.7′	132°13.0′	193	40-111	10	2.91	0.44	46.0	-	1.4				
-6		53°31.8′	132°13.2′	214	32-69	5	4.08	0.52	75.9	-	2.4				
-7		53°31.7′	132°13.1′	210	30-79	5	4.00	0.59	49.0	-	3.9				
-9		53°31.8′	132°13.1′	210	22-81	8	3.46	0.50	65.8	-	3.9				
-20		53°31.7′	132°13.1′	200	40-68	5	4.06	0.79	68.8	-	2.2				
-22		53°31.9′	132°13.1′	209	30-70	6	3.39	0.34	59.4	-	5.8				
-23		53°31.6′	132°13.1′	182	40-70	3	4.14	0.27	107.3	-	13.3				
-25[b,c]		53°31.2′	132°11.6′	80	-										
-26[b,c]		53°31.0′	132°12.7′	60	-										
-27		53°31.6′	132°13.0′	160	25-87	8	3.47	0.57	69.2	-	6.0				

(cont'd)

Table 1 (cont'd)

SITE	LOCATION			COLLAR ELEVATION	MEASURED INTERVAL	THERMAL CONDUCTIVITY			HEAT FLUX			HEAT GENERATION			ACCEPTED HEAT FLUX
		lat.(N)	long.(W)	(m)	(m)	n	(W/mK)	S.D.	obs.	corr.^{a} (mW/m^{2})	S.D.	n	(uW/m^{3})	S.D.	(mW/m^{2})
372-1	Chu Chua	51°22.8′	120°03.9′	1775	73-386	33	3.22	0.73	70.1	79.6	0.2	^{e}3	4.84	1.12	81
-2		51°22.8′	120°03.9′	1755	50-332	27	2.44	0.35	72.2	81.9	0.3				
-3		51°22.9′	120°03.9′	1790	50-259	29	3.04	0.41	71.0	80.6	0.2				
373-1	Dome Mt.	54°44.6′	126°37.4′	1429	66-228	21	2.72	0.23	68.4	69.3	0.4				73
-2		54°44.6′	126°37.4′	1433	48-178	15	2.96	0.43	69.0	69.9	0.4				
-3		54°44.6′	126°37.3′	1427	57-176	16	3.12	0.45	75.0	76.0	1.3				
-4		54°44.6′	126°37.3′	1419	150-184	17	3.22	0.43	91.1	92.3	1.1				
-5		54°44.6′	126°37.2′	1401	50-98	9	3.60	0.29	73.8	74.8	2.2				
374-1	Equity Silver	54°11.7′	126°15.7′	1314	56-146	20	2.50	0.46	59.5	61.4	1.1	^{e}2	1.80	0.06	
-2		54°10.6′	126°16.4′	1318	99-134	17	3.05	0.57	66.4	68.6	1.3				
-3		54°10.2′	126°16.9′	1107	50-107	12	4.11	1.14	118.6	114.8	1.4				
376-1	Frasergold	52°18.0′	120°34.3′	1553	115-157	14	3.17	0.34	46.4	49.4	2.0	^{e}43	0.93	0.26	57
-2		52°18.2′	120°34.6′	1594	252-284	31	3.24	0.58	60.6	63.8	1.9				
-3^{c}		52°18.2′	120°34.6′	1563	191-223	18	3.54	0.36							
377-1	*Lyell Island	52°43.2′	131°42.9′	118	110-184	10	2.98	0.21	59.7	70.2	1.3	^{d}1	0.48	-	70
-2		52°43.2′	131°42.8′	135	50-111	7	2.86	0.27	48.3	-	0.3				

* - interpretations in Lewis et. al (1989)

a - corrected for topography

b - no thermal conductivities measured

c - no heat flux calculations made

d - heat generation data from Lewis et. al (1989)

e - heat generation data from Lewis and Bentkowski (1988) two-dimensional finite element method of Lee and Henyey (1974), programmed by Finkh (1981), was used. In other cases where topographic variation was not as severe (and not two-dimensional) the method of Jeffreys (1940) was used to model the effects of refraction. Results obviously affected by water flow were not included in the average heat flux calculations for each site.

The preliminary interpretations and graphic results of the sites on the margins of the Queen Charlotte Basin (sites 315, 356, 357, 368 and 377) are contained in Lewis et al. (1989). The borehole parameters are included as part of this report (Table 1).

SITE 355 Adams Lake

The holes are drilled through Late Paleozoic mafic to intermediate pyroclastic rocks of the Eagle Bay Formation which host massive sulfide deposits. Of the three holes in this area, the heat flux in the two deeper holes appears to be conductive, but in the third, shallowest hole slight changes in the temperature gradient down the hole indicate lateral water movement (Fig. 2). The bottom 30 m of the shallow hole is the interval used to calculate the heat flux of 56.6 mW m^{-2}, corrected for topography. The heat flux values in the deeper holes are 73.7 and 83.8 mW m^{-2}, corrected for topographic refraction. For the two conductive holes, an average heat flux is 79 mW m^{-2}.

SITE 359 Houston

The holes penetrate Tertiary volcanic flows and breccias of the Endako Group. The two holes logged are approximately 375 m apart and except for the top of hole 359-2, the heat flux values of 82.3 and 77.5 mW m^{-2} appear to be conductive (Fig. 3). There is a large sudden increase in temperature at about 30 m depth in hole 359-2 and a negative temperature gradient

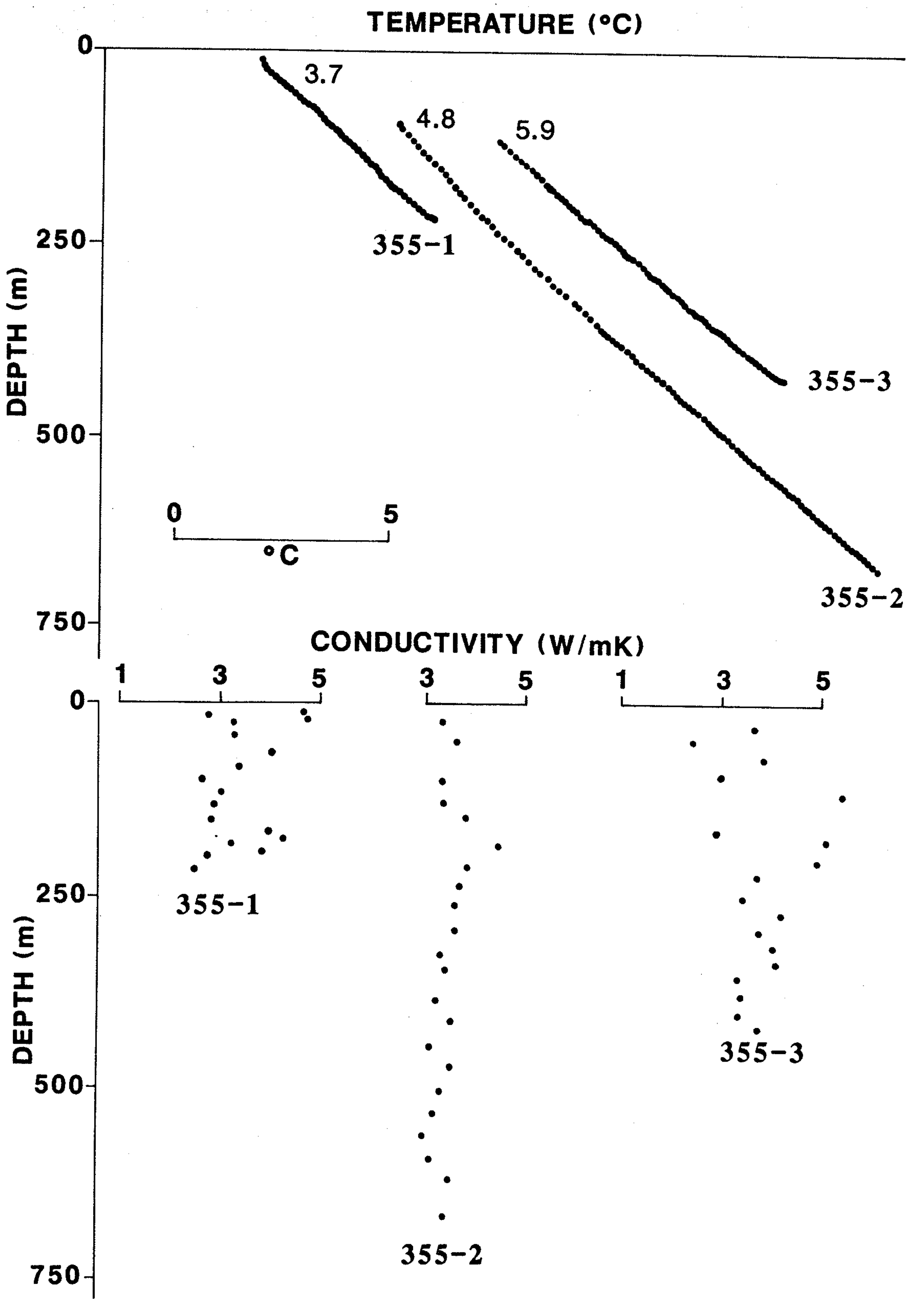

Fig. 2 Measured temperatures and thermal conductivities as a function of depth at Adams Lake, site 355. The first temperature measured in each hole is indicated.

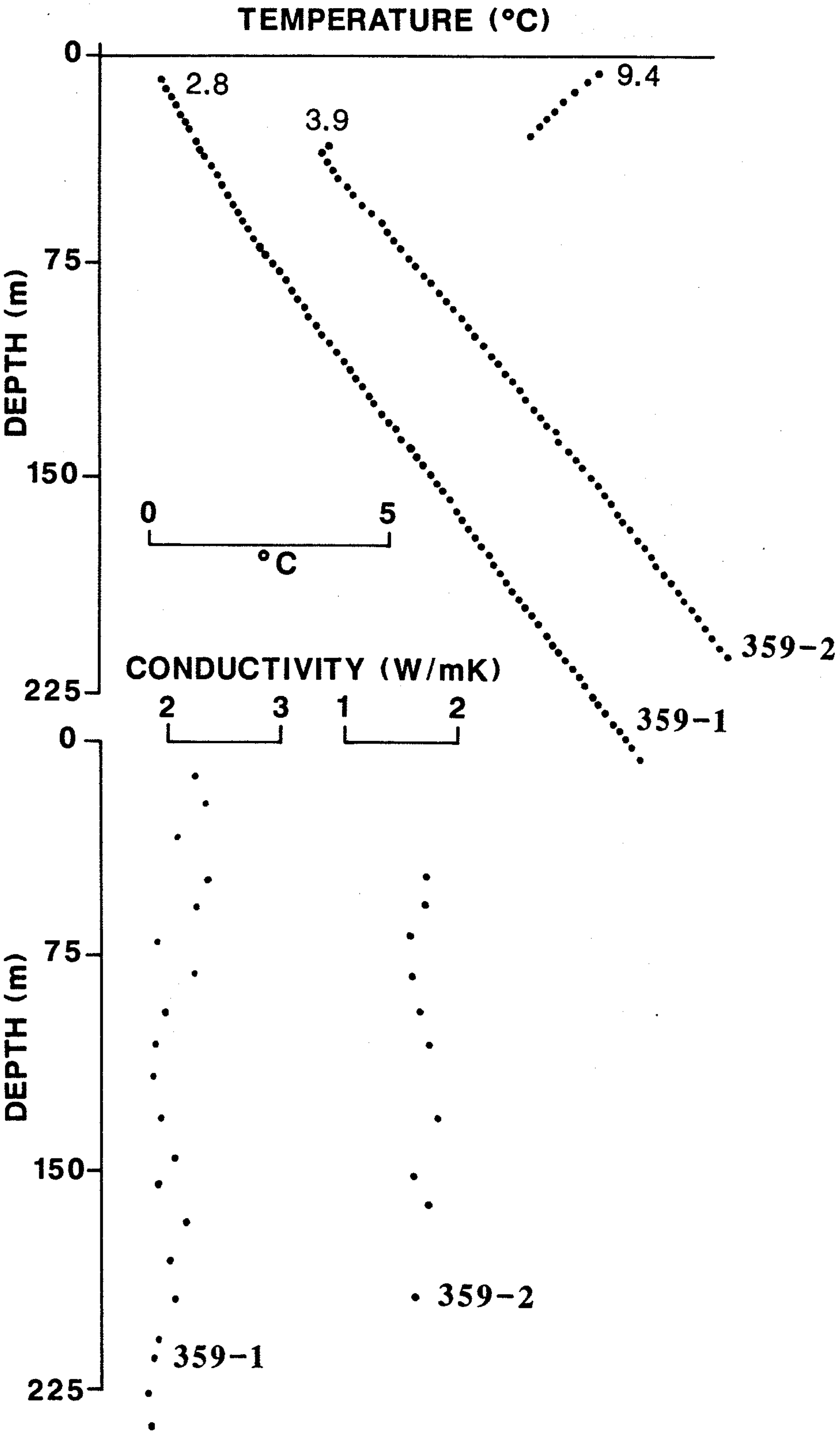

Fig. 3 Measured temperatures and thermal conductivities as a function of depth near Houston, site 359. In hole 359-2 the first measured temperature is shown for the top of the hole as well as the top temperature of the offset at 30 m depth.

to the surface, unlike the relatively undisturbed temperatures of the deeper hole. Warm water must be flowing in at 30 m depth and then flowing upwards where it leaves the hole near the water table, since the top 10 m of the hole are dry, as determined by temperature logging. The holes are on a swampy plateau near the base of a small hill which could provide the hydrologic pressure to drive water through the overburden and up the hole. The holes require only a minor correction for topography. The average heat flux is 80 mW m^{-2}.

SITE 360 Harrison Lake

The holes are located on the side of a steep mountain near the east side of Harrison Lake. There is a large amount of water flowing through the quartz diorite pluton due to the great hydraulic head produced by the local relief. The temperatures in the holes are quite disturbed so that it is impossible to determine a meaningful gradient (Fig. 4).

SITE 361 Rossland

The holes were collared in rocks of the Rossland Group of volcanics and sediments and are surrounded to the north, south and east by the Nelson intrusions of Jurassic age.

The offset of temperatures from a constant gradient in the deeper hole and changes in slope of the gradient in the shallower hole suggest the influence of water flow in the upper parts of the holes (Fig. 5). However the lower sections of each hole are linear and give heat flux values of 79.8 and 79.2 mW m^{-2}. Although the topography is quite rugged, the holes are between two peaks at about the midpoint of 1300 m of relief, so the effects of topographic refraction are minimal and the corrections are insignificant.

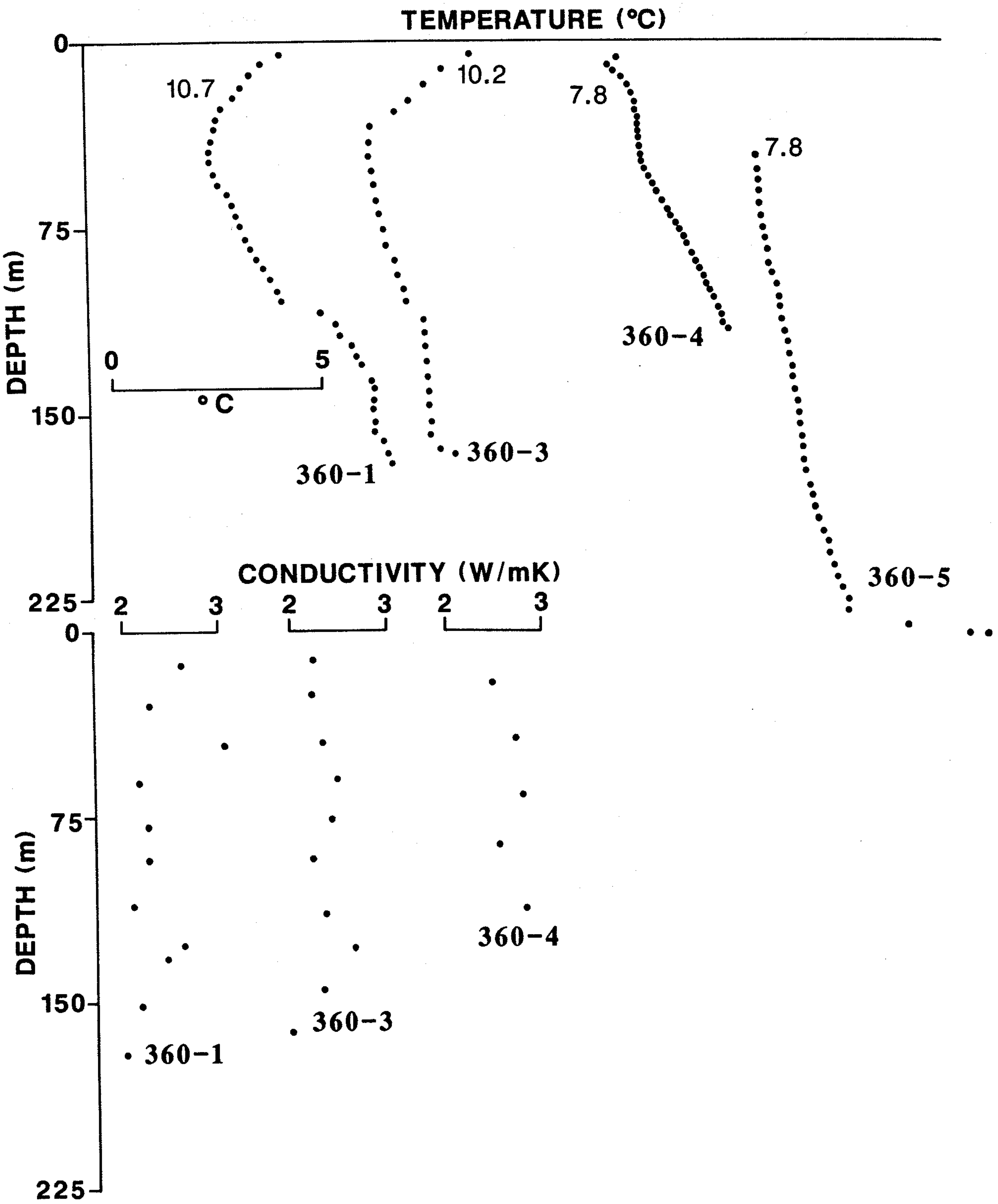

Fig. 4 Measured temperatures and thermal conductivities as a function of depth at Harrison Lake, site 360.

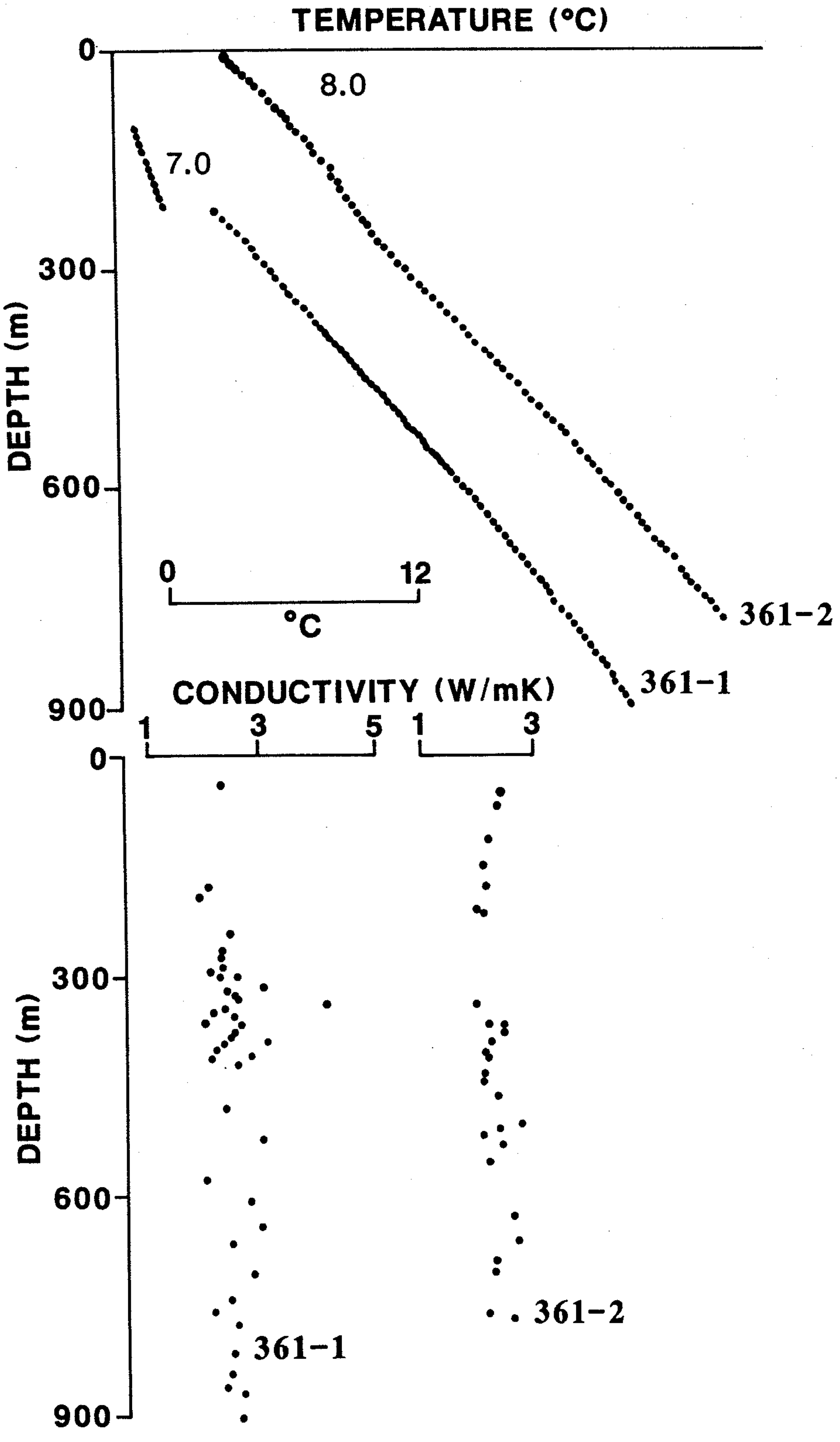

Fig. 5 Measured temperatures and thermal conductivities as a function of depth at Rossland, site 361.

SITE 362 Summerland

This hole is in one of several Tertiary outliers in southern B.C. which may have the potential for producing geothermal energy for space heating (Lewis, 1984).

There is a constant temperature gradient of 35 mK m^{-1} to 155 m depth (Fig. 6). At this depth the hole caved in a shaly unit within a polymictic conglomerate of the White Lake Formation, where the gradient increases dramatically to 87.5 mK m^{-1}. It is unclear whether the increase is due to a change in conductivity or whether water movement at this level is affecting the conductive heat flux above that depth. The heat flux calculated above 155 m depth is 61 mW m^{-2} compared to 86 mW m^{-2} from a hole drilled in granite just outside this Tertiary basin (Davis and Lewis, 1984).

SITE 363 Mt. Brenton

The holes are drilled in volcanic and sedimentary rocks of the Sicker Group, host of many volcanogenic massive sulfide occurrences on Vancouver Island.

The first three holes are relatively shallow with corrected heat flux values of 20.3, 19.1 and 24.8 mW m^{-2}. The fourth hole is much deeper with a higher heat flow of 31.8 mW m^{-2} (Fig. 7). Although the gradients are quite uniform, it is probable that the shallower holes are affected by water flows below the maximum depth measured, resulting in lower temperatures, and are thus not included in the average heat flux for the area. All holes are on the south side of Mt. Brenton where topographic relief in the region is about 1000 m. The three shallow holes are near the midpoint of the total relief where refractive corrections are insignificant, whereas the deep hole is closer to the main valley, 250 m from steep valley walls, resulting in a larger correction.

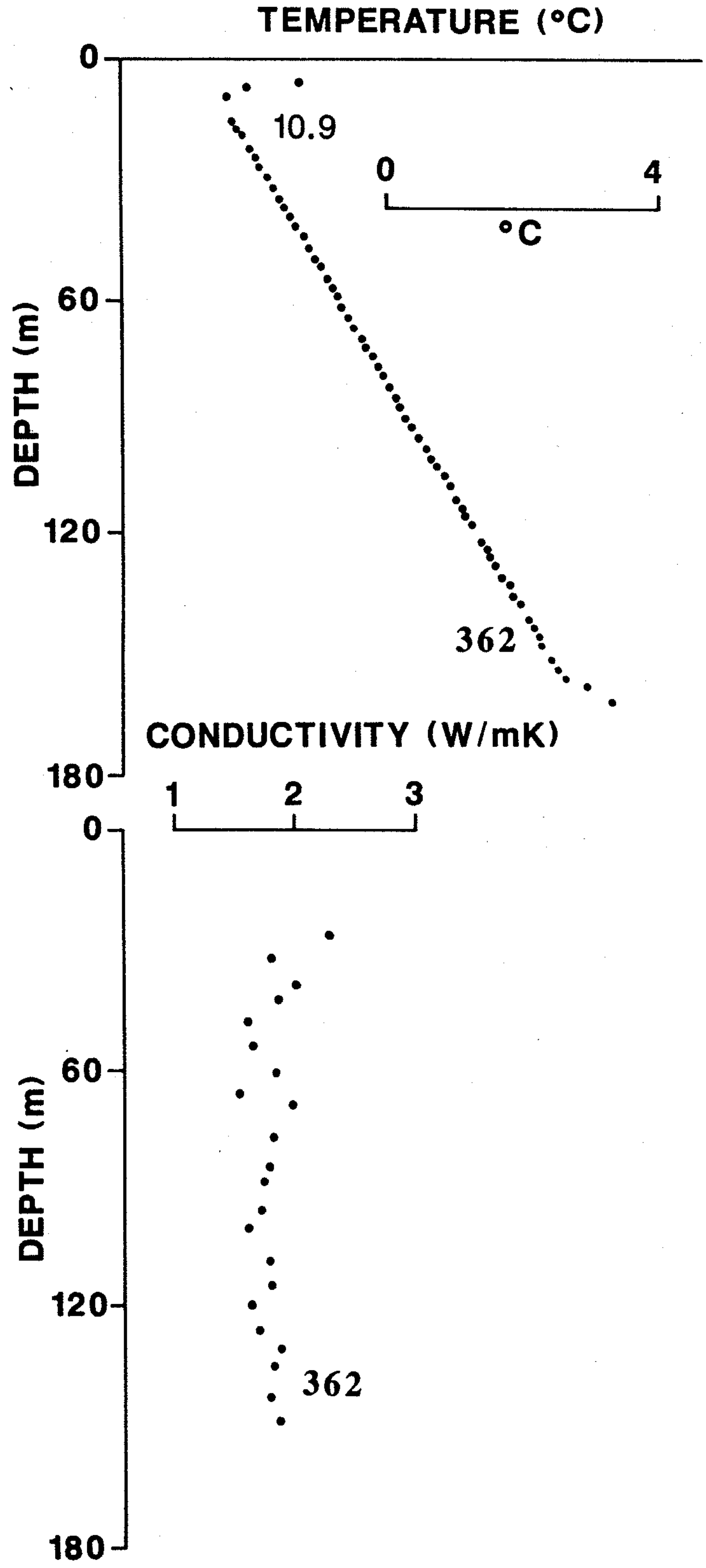

Fig. 6 Measured temperatures and thermal conductivities as a function of depth at Summerland, site 362.

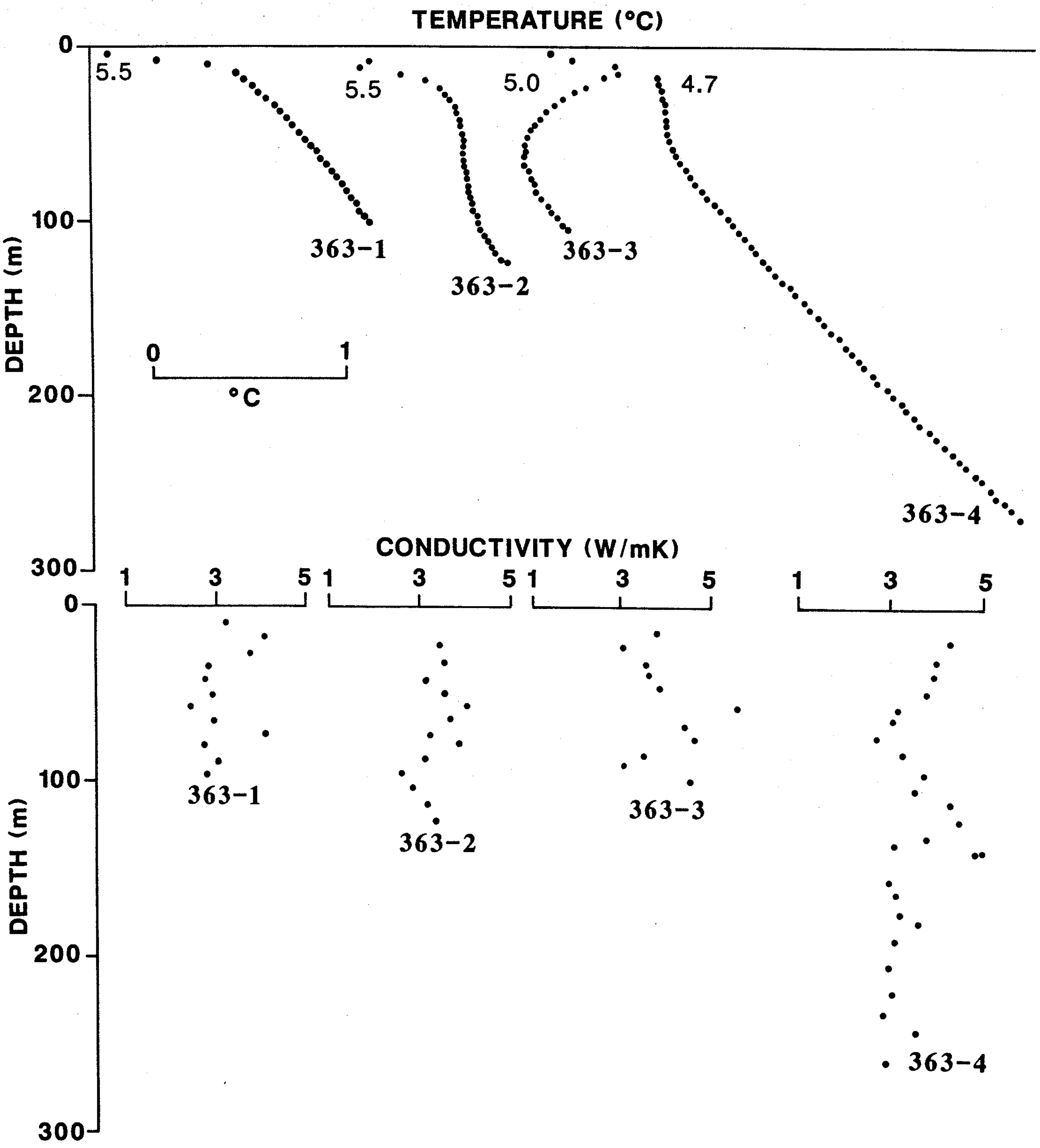

Fig. 7 Measured temperatures and thermal conductivities as a function of depth at Mt. Brenton, site 363.

SITE 365 Silver Creek

These holes penetrate felsic tuffs of the Sicker Group as part of a search for massive sulfides. The temperature gradients are linear in the lower section of each hole (Fig. 8). The upper section of the deeper hole has a lower temperature gradient which gradually increases to an apparent equilibrium gradient at 150 m. The shallow hole does not get beyond this apparent perturbation and therefore the measured heat flux, 19.1 mW m^{-2}, is not used. The deeper hole has a higher heat flux of 29.6 mW m^{-2}. The holes are on the bottom slope of Coronation Mt. so a small topographic correction was applied.

SITE 366 Kimberley

The hole is drilled in the Lower Aldridge Formation comprising thinly bedded argillite, siltstone and quartztite intruded by gabbroic sills and dykes. This Proterozoic formation hosts the nearby Sullivan sulfide orebody. The temperature gradient for the lower 293 m of the hole is relatively uniform yielding a heat flux of 91.9 mW m^{-2} (Fig. 9). Above this depth temperature disturbances are evident, probably caused by subhorizontal water flow. Topography is quite steep in the area but locally the relief is relatively small around the hole, located near the base of a ski hill.

SITE 367 Nazko

The holes are about 35 km northeast of a recent volcanic centre which marks the eastern end of the Anahim Volcanic Belt (Souther, 1986). The heat flux at this site varies from 58.3 to 81.5 mW m^{-2}, corrected for topography, with an average value of 72 mW m^{-2} (Fig. 10). Some of the measured thermal conductivities are high due to the presence of large amounts of quartz

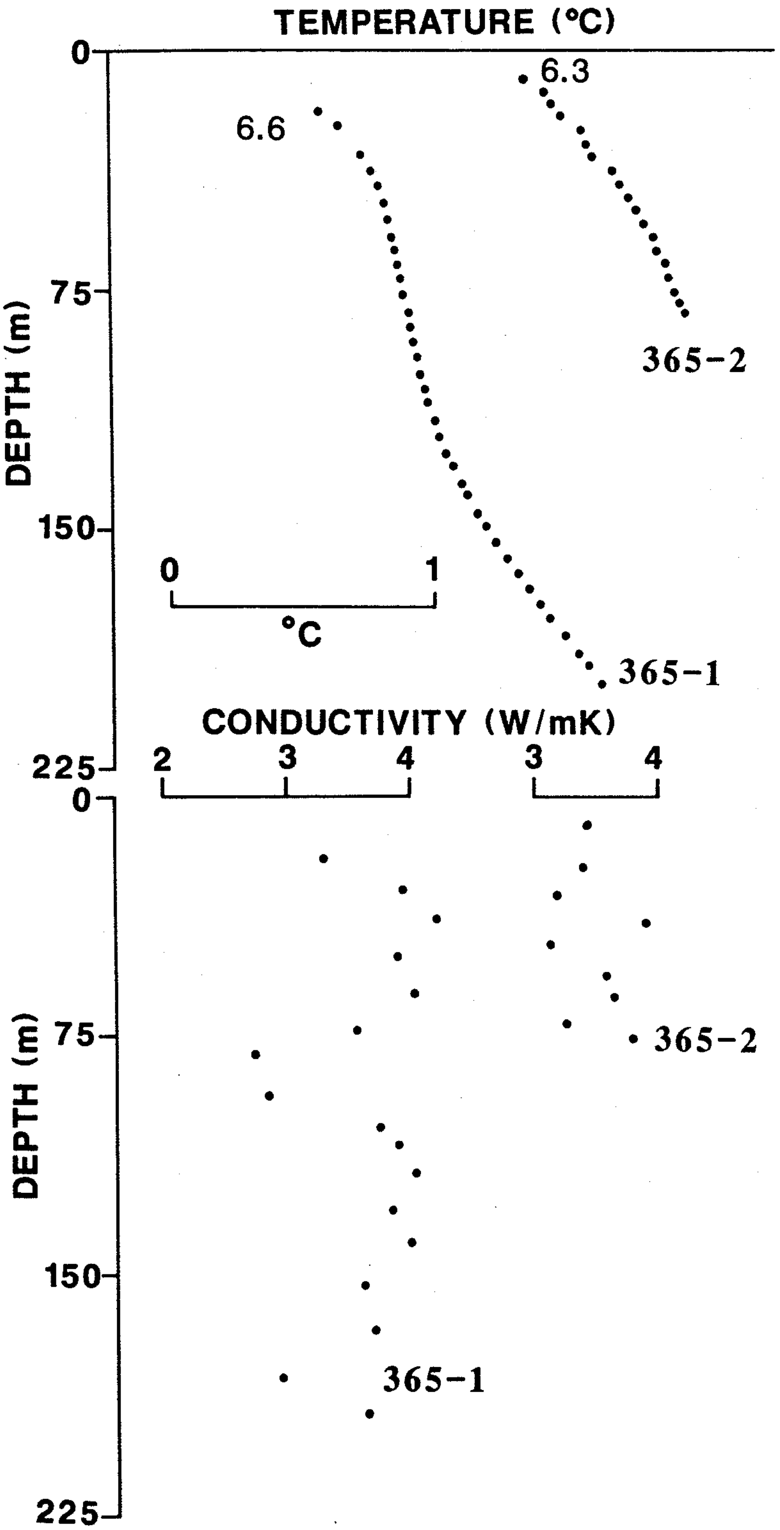

Fig. 8 Measured temperatures and thermal conductivities as a function of depth at Silver Creek, site 365.

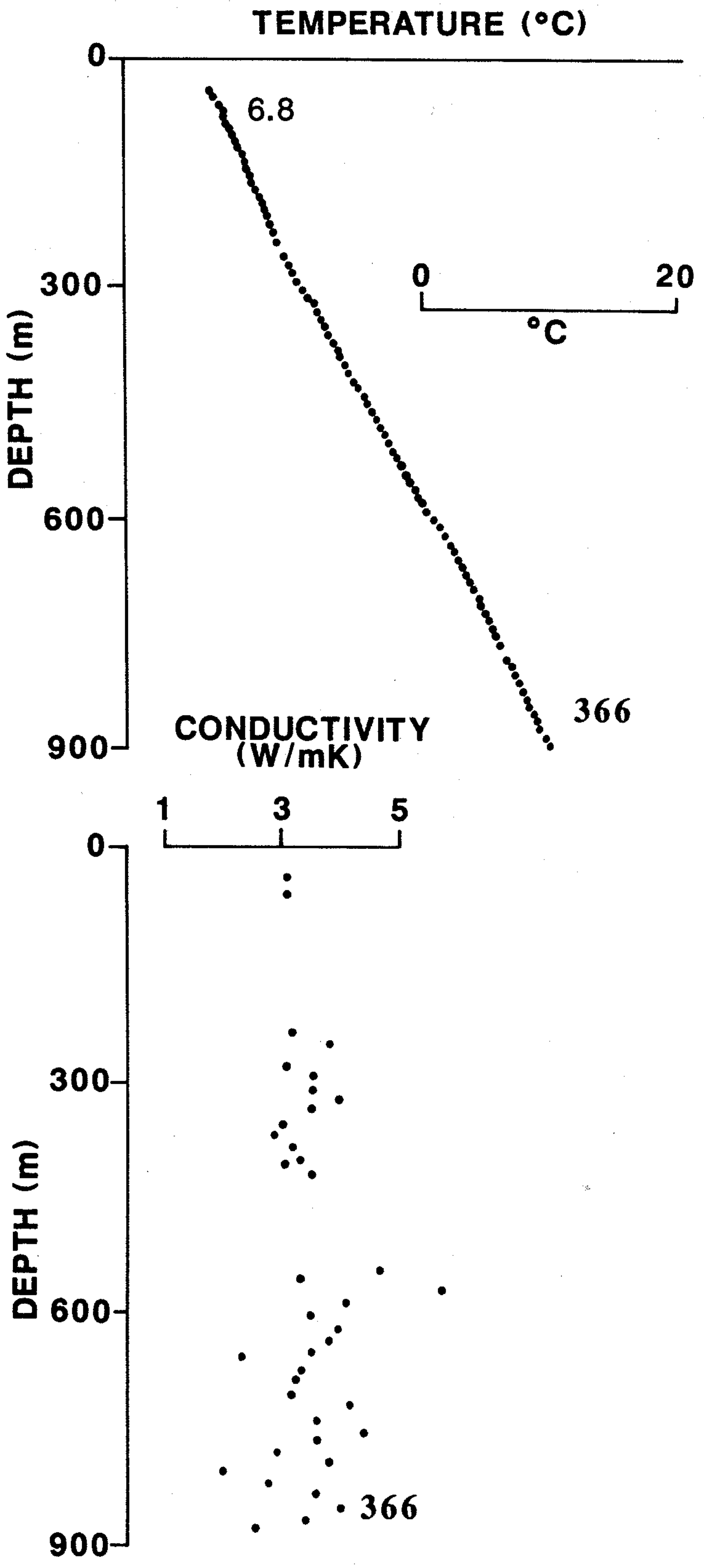

Fig. 9 Measured temperatures and thermal conductivities as a function of depth at Kimberley, site 366.

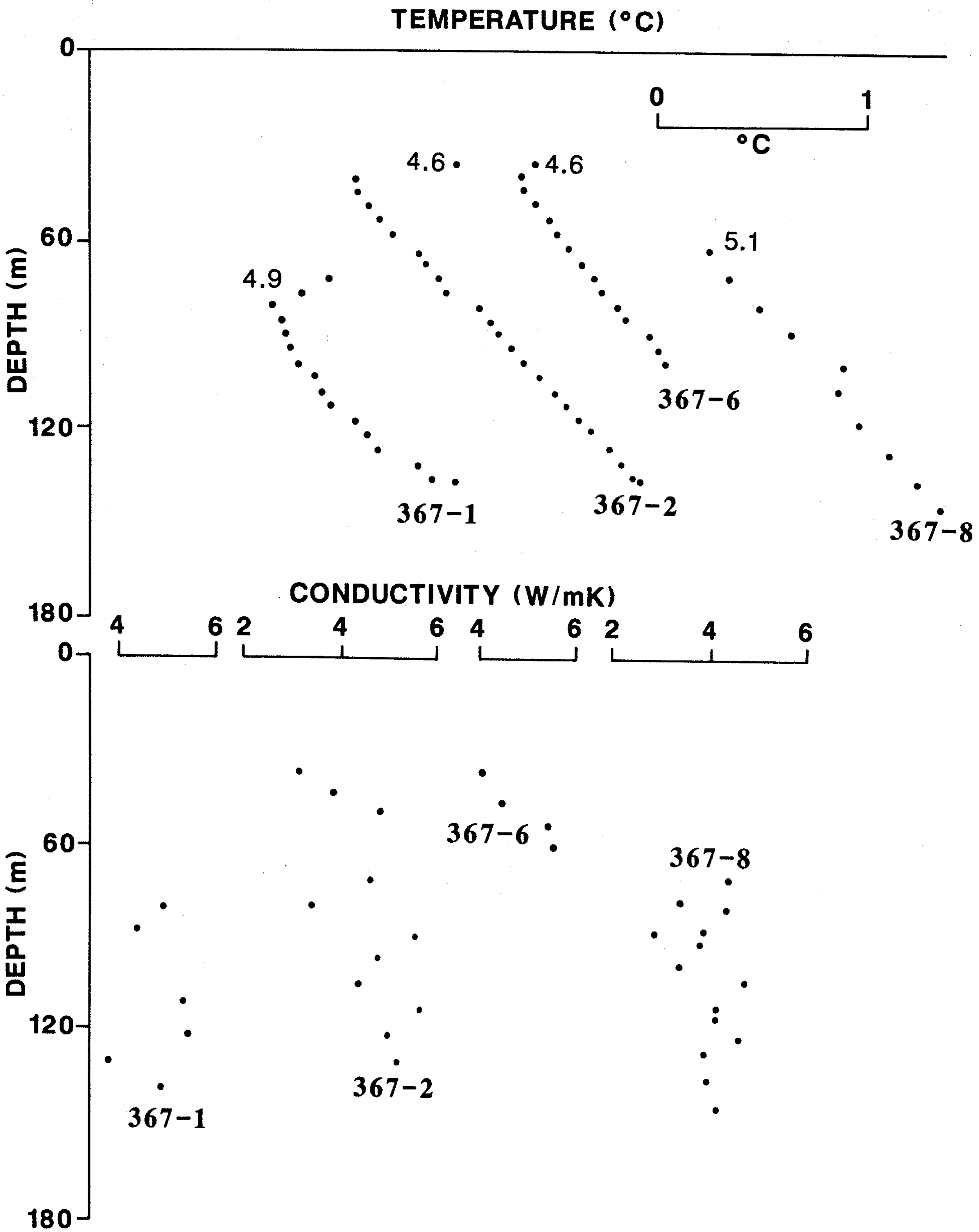

Fig. 10 Measured temperatures and thermal conductivities as a function of depth at Nazko, site 367.

in Late Cretaceous sandstone and quartzite. All holes exhibit some effects of water flow, and the water is probably flowing parallel to bedding. The holes are located near the top of a hill with 180 m of relief with locally steep slopes. The first hole does not have a uniform gradient so is not included in the heat flux average.

SITE 372 Chu Chua

The holes are drilled in basalts of the Fennel Formation, a steeply dipping west-facing assemblage of oceanic rocks. A conductive heat flux regime exists in all three holes (Fig. 11), with values of 79.6, 81.8 and 80.6 mW m^{-2}. The average heat flux is 81 mW m^{-2}, corrected for the effects of topography. The holes are only about 60 m below Chu Chua peak in a relatively subdued saddle, with a gentle slope up to the east to a higher peak and steep slopes to the west down to a creek. Total relief in the area contributing to refraction is about 1700 m so the refractive correction applied is significant.

SITE 373 Dome Mountain

The holes penetrate volcaniclastic rocks and amygdaloidal flows of the Hazelton Group which host many gold-bearing quartz veins. Of the five holes logged on this property, four have conductive heat fluxes of 69.3, 69.9, 76.0 and 74.8 mW m^{-2} and 373-4 is obviously affected by water flow (Fig. 12). A steep slope near the non-conductive hole is probably causing local water flow. The holes are located halfway up the east slope of Dome Mountain with a total relief of about 700 m. The average heat flux for the conductive holes is 73 mW m^{-2} with a slight correction for topography.

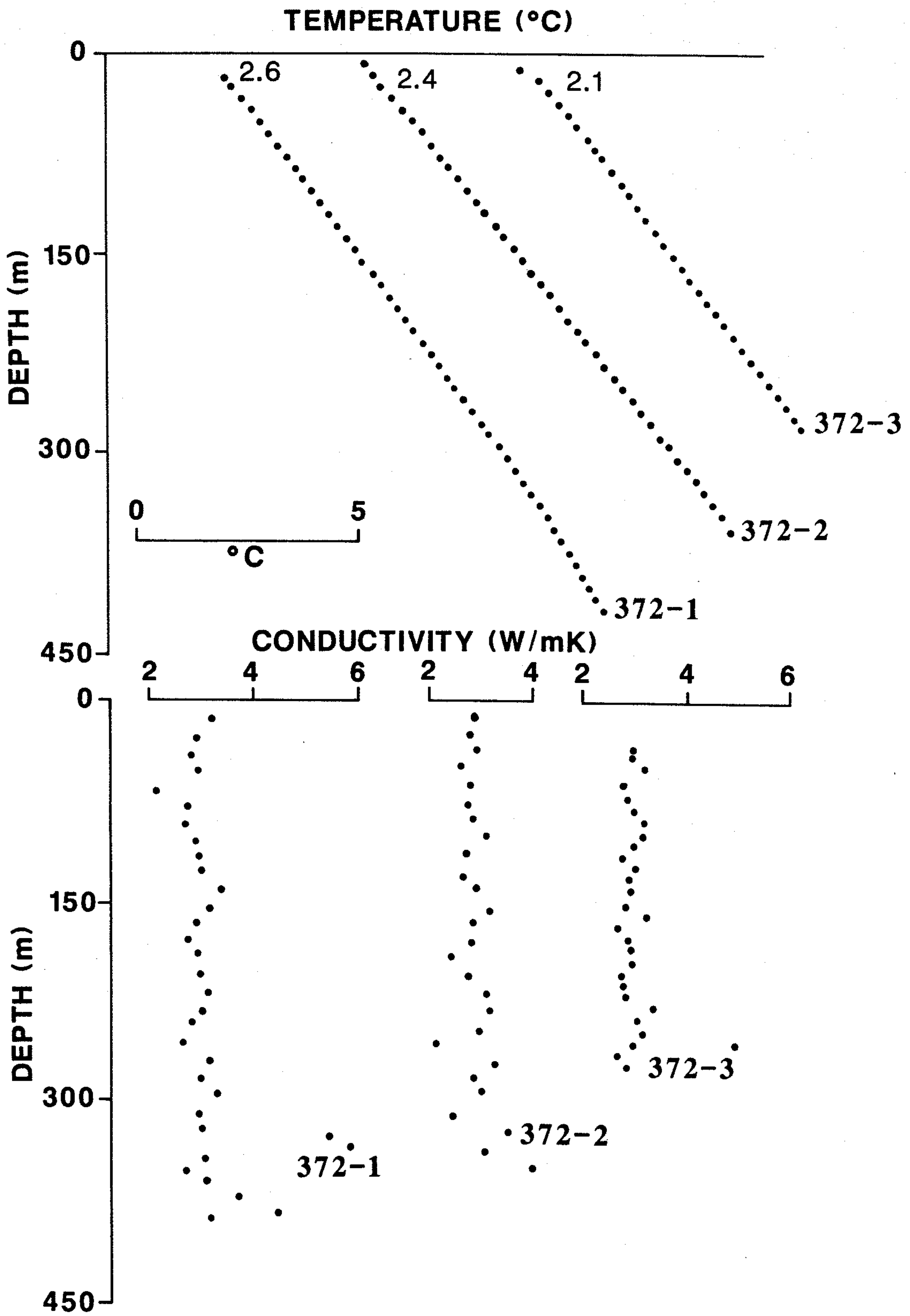

Fig. 11 Measured temperatures and thermal conductivities as a function of depth at Chu Chua, site 372.

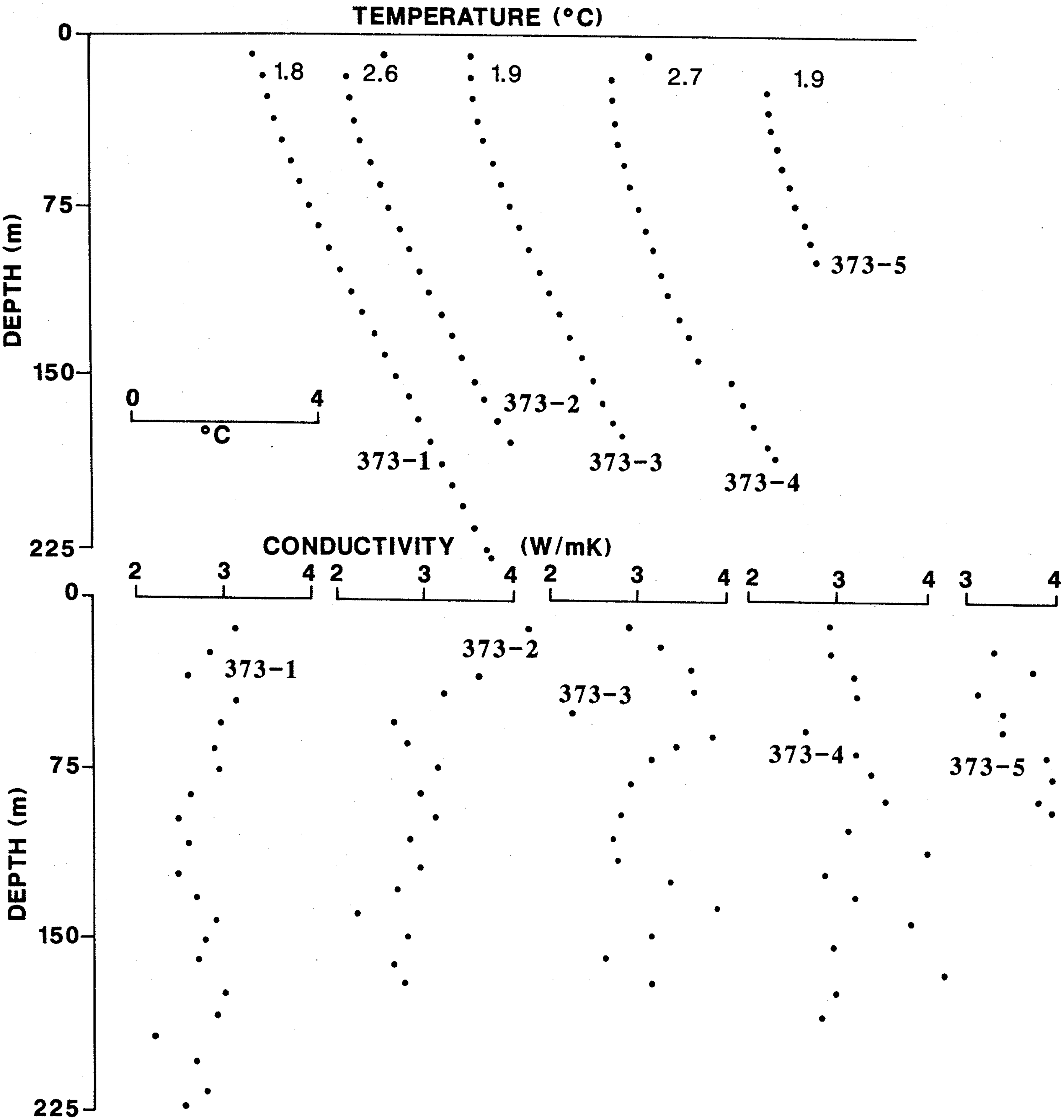

Fig. 12 Measured temperatures and thermal conductivities as a function of depth at Dome Mountain, site 373.

SITE 374 Equity Silver

The holes penetrate an inlier of Upper Jurassic to Cretaceous sedimentary, pyroclastic and volcanic rocks intruded by a quartz monzonite stock. The heat flux in three holes in this area is quite variable ranging from 61.4 to 114.8 mW m^{-2}, taking into account topographic corrections (Fig. 13). The shallowest hole is producing water at the surface but appears to be conductive for the lower 50 m where the heat flux is very high. The high thermal conductivies in the upper 50 m of this hole are due to silicified tuff and agglomerate overlying mafic volcanics with lower conductivities. It is probable that the temperatures in the hole are being influenced by water flow beneath it. The next deeper hole is also producing a small amount of water at the collar and such flow is evident in the temperature log by the changes in the gradient down the hole. The deepest hole, although not producing water at the surface, also seems to be influenced by water flow.

The topography in the area is generally not steep with about 625 m of relief, but locally steep slopes are driving water flows that affect the temperatures. Compared to the nearby apparently conductive heat flow of nearly 80 mW m^{-2} at site 359, it is probable that water flow significantly affects the temperatures at this site and the measured heat flux is not necessarily representative of the average heat flux deeper in the crust.

SITE 376 Frasergold

The holes are drilled in Triassic black phyllites with interbedded siliceous sediments and chert. All three holes exhibit signs of water flow with obvious breaks in the temperature gradients (Fig. 14). Although the steep topography contributes to the water flow problem, the topographic correction is small because the holes are located part way up the slope about 300 m above the main valley. The corrected heat flux from the shallowest and deepest holes is 49.4

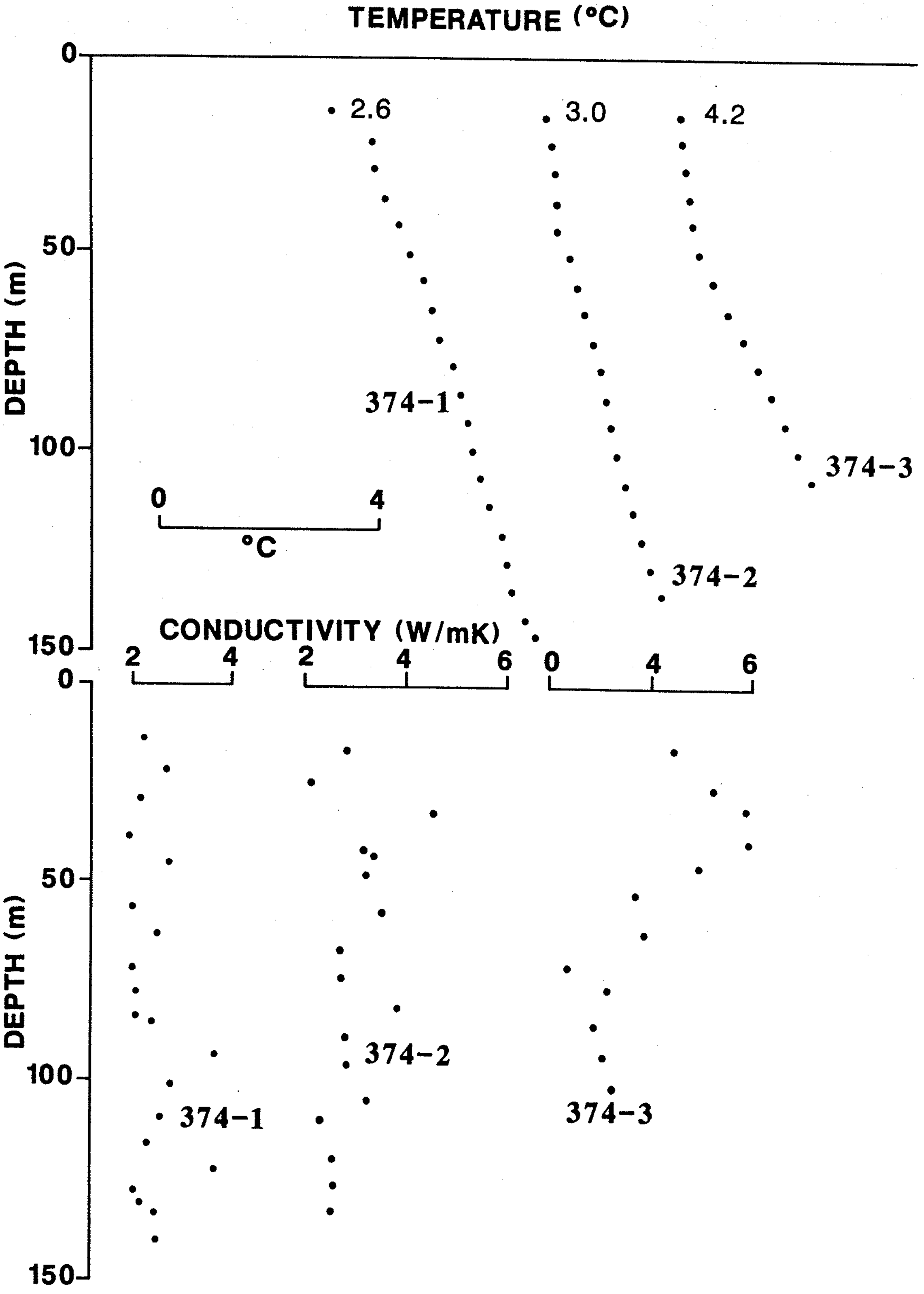

Fig. 13 Measured temperatures and thermal conductivities as a function of depth at Equity Silver, site 374.

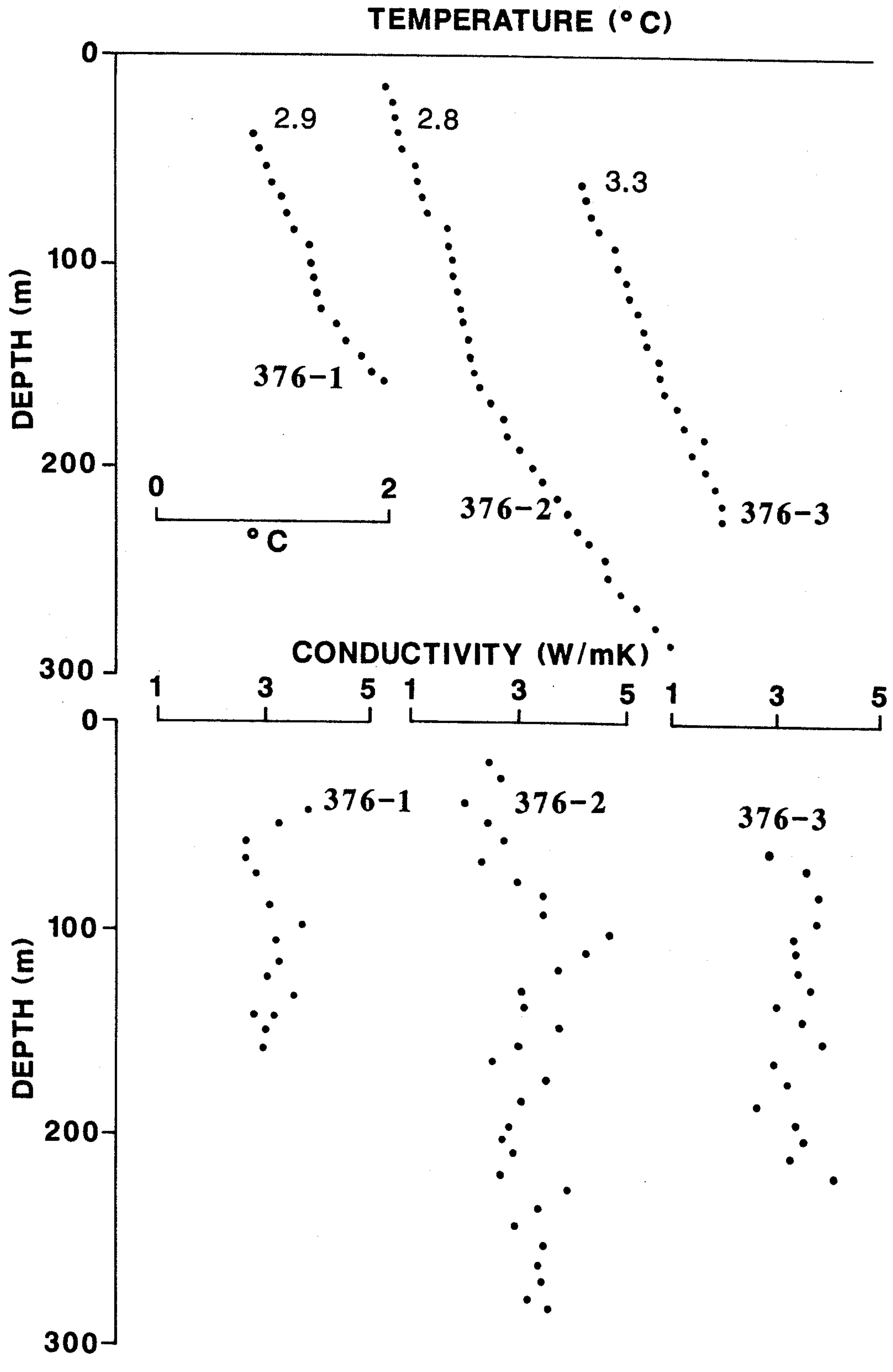

Fig. 14 Measured temperatures and thermal conductivities as a function of depth at Frasergold, site 376.

and 63.8 mW m^{-2} respectively, calculated from the lower 30 m linear temperature gradient of both holes. The gradient in the third hole is non-linear so heat flux was not calculated. The average heat flux for the two holes is 57 mW m^{-2}.

DISCUSSION

The results presented in this report are mostly isolated heat flux values for each site (Fig. 1). However data from 5 sites on the margins of Queen Charlotte Basin show that heat flux is 75 mW m^{-2} on the eastern side of the basin (Lewis et al., 1989) and ranges from 62 to 70 mW m^{-2} on the western margin. Hyndman et al. (1982) reported a heat flux of 47 mW m^{-2} at Tasu, and Yorath and Hyndman (1983) reported values from offshore wells in the basin ranging from 45 to 78 mW m^{-2}. Additional oceanic data from the basin are yet to be analysed.

The two sites on Vancouver Island (363 and 365) lie near the LITHOPROBE profile which crosses the convergent continental margin beneath Vancouver Island (see Clowes et al., 1984). Heat flux has been defined along this profile (Lewis et al., 1988) showing relatively low heat flux at this position over the subducting oceanic plate, with an average value of 36 mW m^{-2} near these two sites. The results presented in this report show a slightly lower average value of 31 mW m^{-2}.

The heat flux of 81 mW m^{-2} at Chu Chua (site 372) agrees with that from Adams Lake (site 355) which is 79 mW m^{-2}. The high heat generation from the Baldy Batholith (Table 1, site 372) to the north does not seem to influence the heat flux at either of these two sites. These results also compare with heat flux to the south near Kamloops where values of 78 to 82 mW m^{-2} are reported (Lewis et al., 1985).

Heat flux to the southwest of Frasergold (site 376) in the Takomkane Batholith ranges from 60 to 65 mW m^{-2} (Bentkowski and Lewis, 1985), comparable to the 57 mW m^{-2} at Frasergold.

At most sites the extrapolated surface temperatures are approximately the same if the holes are not affected by water flow. At Adams Lake (site 355) the surface temperature of the non-conductive hole is much higher than the other two even though the elevation differences are small so the result is not included in the average for the site. However at Rossland (site 361), the large differences in the surface temperatures are expected because of the differences in elevation between the two holes.

Corrections for the effects of uplift and erosion or glacial surface temperature changes were not made and are probably not required.

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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 Report 85-9, 19 p.

Clowes, R.M., Green, A.G, Yorath, C.J., Kanasewich, E.R., West, G.F., and Garland, G.D.

1984: Lithoprobe - A national program for studying the third dimension of geology; Journal of the Canadian Society for Exploration Geophysics, v. 20, p. 23-29.

Davis, E.E. and Lewis, T.J.

1984: Heat flow in a back-arc environment: Intermontane and Omineca Crystalline belts, southern Canadian Cordillera; Canadian Journal of Earth Sciences, v. 21, p. 715-726.

Finkh, P.

1981: Heat flow measurements in 17 perialpine lakes; Geological Society of America Bulletin, part 2, v. 92, p. 452-514.

Hyndman, R.D., Lewis,T.J., Wright,J.A., Burgess, M.M., Chapman, D.S., and Yamano, M.

1982: Queen Charlotte Fault Zone: heat flow measurements; Canadian Journal of Earth Sciences, V. 19, p. 1657-1669.

Jeffreys, H.

1940: The disturbance of the temperature gradient in the Earth's crust by inequalities of height; Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, v. 4, p. 309-312.

Lee, T-C. and Henyey, T.L.

1974: Heat flow refraction across dissimilar media; Geophysical Journal of the Royal Astronomical Society, v. 39, p. 319-333.

Lewis, T.J.

1984: Geothermal energy from Penticton Tertiary outlier, British Columbia: an initial assessment; Canadian Journal of Earth Sciences, v. 21, p. 181-188.

Lewis, T.J., Jessop, A.M. and Judge, A.S.

1985: Heat flux measurements in southwestern British Columbia: the thermal consequences of plate tectonics; Canadian Journal of Earth Sciences, v. 22, p. 1262-1273.

Lewis, T.J. and Bentkowski, W.H.

1988: Potassium, uranium and thorium concentrations of crustal rocks: a data file; Geological Survey of Canada, Open File Report 1744, 165 p.

Lewis, T.J., Bentkowski, W.H., Davis, E.E., Hyndman, R.D., Souther, J.G. and Wright, J.A.

1988: Subduction of the Juan de Fuca Plate: thermal consequences; Journal of Geophysical Research, v. 93, no. B12, p. 15207-15225.

Lewis, T.J., Bentkowski, W.H., Bone, M. and Wright, J.A.

1989: Note on the thermal structure of Queen Charlotte Basin, British Columbia; in Current Research Part H, Geological Survey of Canada, Paper 89-1H, p. 121-125.

Souther, J.G.

1986: The western Anahim Belt: root zone of a peralkaline magma system; Canadian Journal of Earth Sciences, v. 23, p. 895-908.

Yorath, C.J. and Hyndman, R.D.

1983: Subsidence and thermal history of Queen Charlotte Basin; Canadian Journal of Earth Sciences, v. 20, p. 135-159.