Geothermal Resources Council, TRANSACTIONS, Vol. 8, August 1984

GEOTHERMAL EXPLORATION AT MT. CAYLEY - A QUATERNARY VOLCANO IN SOUTHWESTERN BRITISH COLUMBIA

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Abstract

Mt. Cayley is a deeply dissected multiple plug dome in the Central Garibaldi Belt, 125 kilometres north of Vancouver B.C. Potassium argon dates from the central edifice range from 5.7 to 0.6 Ma whereas peripheral domes give dates as young as 0.11 Ma. The base of the complex and underlying crystalline basement rocks have undergone intense hydrothermal alteration in a zone that contains warm seeps of high Cl - SO_4 water. Resistivity and magnetotelluric surveys have defined a conductive anomaly (< 100 m) beneath the altered zone and diamond drilling has confirmed thermal gradients as high as 105°C/km. Following work by the Geological Survey of Canada beginning in 1979 the area was designated by the Provincial Government as a KGRA and in 1983 O'Brien Resources acquired and began exploration of parcel G3 which includes the principal anomaly.

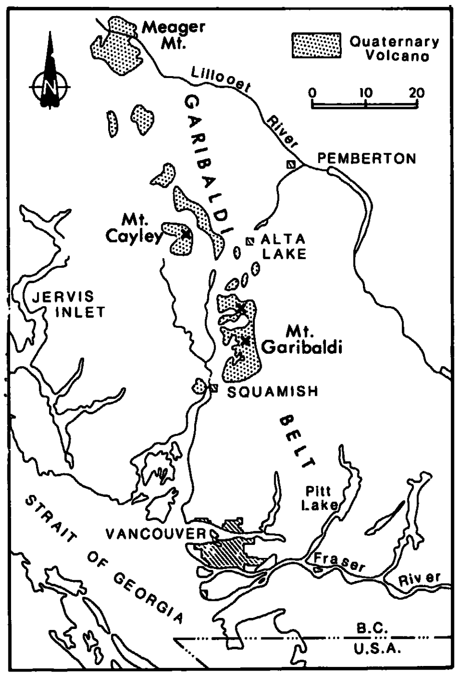

Fig. 1. Index map with locations of Mt. Cayley and other principle volcanoes of the Garibaldi Volcanic Belt.

Introduction:

Geothermal exploration in the Garibaldi Volcanic Belt has focussed mainly on Meager Mtn. (Fairbank et al., 1981) where deep drilling by B.C. Hydro has confirmed the presence of a high temperature (>250°C) hydrothermal system. Examination of other volcanic centres in the central Garibaldi Belt has identified Mt. Cayley as a potential target (Souther 1980). Mapping by the Geological Survey of Canada was followed by the drilling of five thermal gradient holes. In addition contracts, funded by G.S.C. were let to carry out geophysical (Shore, 1981, 1983; Phoenix Geophysics, 1983) and geochemical (Ryder, 1983; Clark et al., 1980) surveys of the area. In 1982 the British Columbia Department of Mines and Petroleum Resources made six parcels available for leasing under the new Geothermal Act. Parcel G3, which includes the main edifice of Mt. Cayley was acquired by O'Brien Resources who conducted additional exploration work during the summer of 1983. This paper presents a summary of data from all sources.

Geology:

The Garibaldi Volcanic Belt can be divided into three north-trending, en echelon segments. The central part, which includes Mt. Cayley lies north and west of Mt. Garibaldi in the southern Coast Mountains (Fig. 1). The belt is underlain by plutonic and metamorphic rocks of the late Mesozoic and early Tertiary Coast Crystalline Complex on which a surface of high relief was eroded prior to eruption of the Garibaldi Belt volcanoes. The basement surface under the Mt. Cayley volcanic pile slopes steeply west from an elevation of more than 1760 meters near its centre to less than 245 metres at the distal end of flows in Squamish Valley.

The precipitous central edifice is a composite, dacite plug dome that was emplaced during at least two stages of volcanic activity (Fig. 2) during which a total of about 20 cubic kilometers of lava and pyroclastic breccia were erupted. The first, or Mt. Cayley stage, includes a lower breccia unit that rests either directly on crystalline basement rocks or is separated from them by a layer of older colluvium and talus. The breccia is overlain by thick dacite flows and the entire lower assemblage is pierced by an

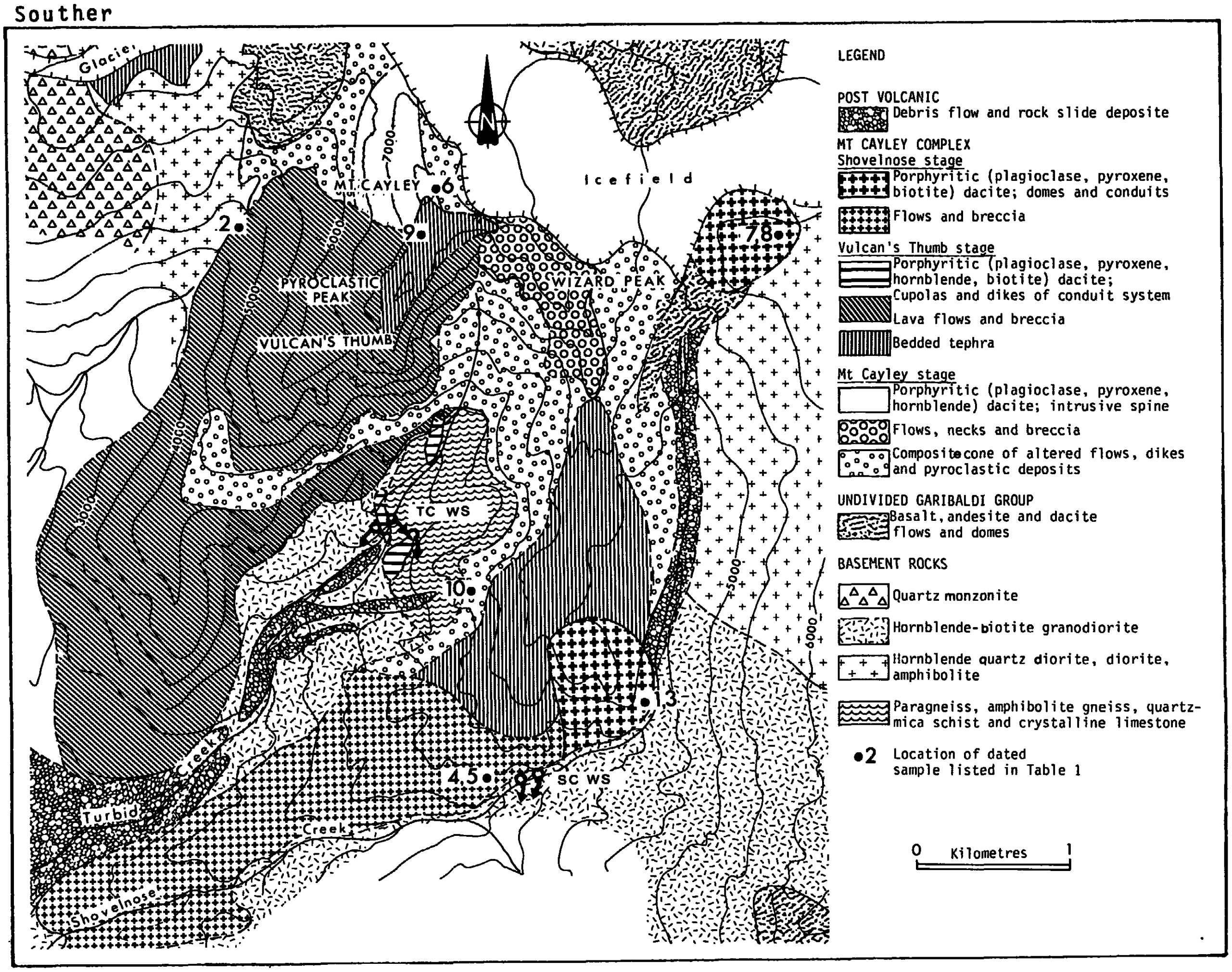

Fig. 2. Geologic map of Mt. Cayley and adjacent basement terrane.

intrusive spine of dacite that forms the summit of Mt. Cayley. The adjacent summit of Pyroclastic Peak was formed during the later, Vulcan's Thumb Stage when a thick assymetrical pile of dacite flows, domes and pyroclastic deposits partially buried the southwestern flank of the older Mt. Cayley edifice. This composite central pile was deeply dissected by westerly flowing streams prior to the Shovelnose Stage. This final stage of activity began with the effusion of dacite lava that flowed west into Squamish valley from a vent in upper Shovelnose Creek and culminated with the emplacement of two small satellitic domes, each about 300 m high and slightly less than a kilometer in diameter.

Turbid Creek canyon exposes basement rocks and subvolcanic cupolas close to the central conduit system. In that area rocks in the basal part of the Mt. Cayley pile have undergone intense hydrothermal alteration. The basement gneiss is intruded by glass-rimmed dacite cupolas and cut by north-trending fractures adjacent to which the crystalline rock is altered to clay. Several warm seeps issue from these basement fractures and from glassy selvages of dacite cupolas.

Sample Number	Lithology	Lab	K %	Ar 10^{-6}cc/g	Ar^{40} %	Date Ma
1	dacite	UBC	1.01	0.0072	4.1	0.18 ± 0.05
2	dacite	UBC	1.74	0.0146	13.2	0.21 ± 0.02
3	dacite	UBC	1.19	0.0145	7.7	0.313 ± 0.054
4,5	rhyodacite	TI	1.33	0.028	4.3	0.6 ± 0.4
			1.34	0.032	4.7	0.6 ± 0.4
6	dacite	TI	1.51	0.032	6.6	0.6 ± 0.3
7,8	dacite	TI	1.06	0.045	4.3	0.8 ± 0.4
			1.06	0.033	6.0	1.1 ± 0.3
9	dacite	UBC	1.28	0.1911	5.3	3.8 ± 0.7
10	dacite	UBC	1.66	0.3663	9.7	5.7 ± 0.6

Table 1 Whole rock K-Ar age dates from locations shown on Fig. 2. (constants: $\lambda_\beta = 4.96 \times 10^{-10} yr^{-1}$, $\lambda_\varepsilon = 0.581 \times 10^{-10} yr^{-1}$, $^{40}/K = 1.167 \times 10^{-4}$). Samples listed in order of increasing age regardless of stratigraphic position. UBC (University of British Columbia), TI (Teledyne Isotopes).

Whole rock K-Ar dating by R.L. Armstrong at U.B.C. and Teledyne Isotopes (Table 1) suggest that Mt. Cayley has been episodically active for almost 6 million years. The 5.7 Ma date on dacite near the base of the Mt. Cayley succession is older than the basal Meager Mtn. rocks (ca 3 Ma). A single date from the younger, Vulcan's Thumb succession (3.8 Ma) suggests that it is approximately coeval with early activity at Meager Mountain whereas four dates from flows and domes of the Shovelnose succession, ranging from 0.11 to 1.1 Ma, are approximately the same age as the younger andesite of Meager Mountain.

Geophysics:

The deployment of geophysical surveys on Mt. Cayley has been constrained by precipitous terrane in the central part of the Complex. In 1980 a D.C. resistivity survey, using a conventional dipole-dipole array and 3 kw transmitter, was carried out along two lines parallel to upper Shovelnose Creek (Fig. 3). An electrode spacing of 300 metres was used and, where possible, data were obtained from n = 1 through 8, providing apparent resistivity to a depth of about 600 metres. Pseudosections (Fig. 4) plotted from this data define several conductive zones (< 100 ohm-metres) in rock having a background resistivity of 1000 to 5000 ohm-metres (Shore, 1980).

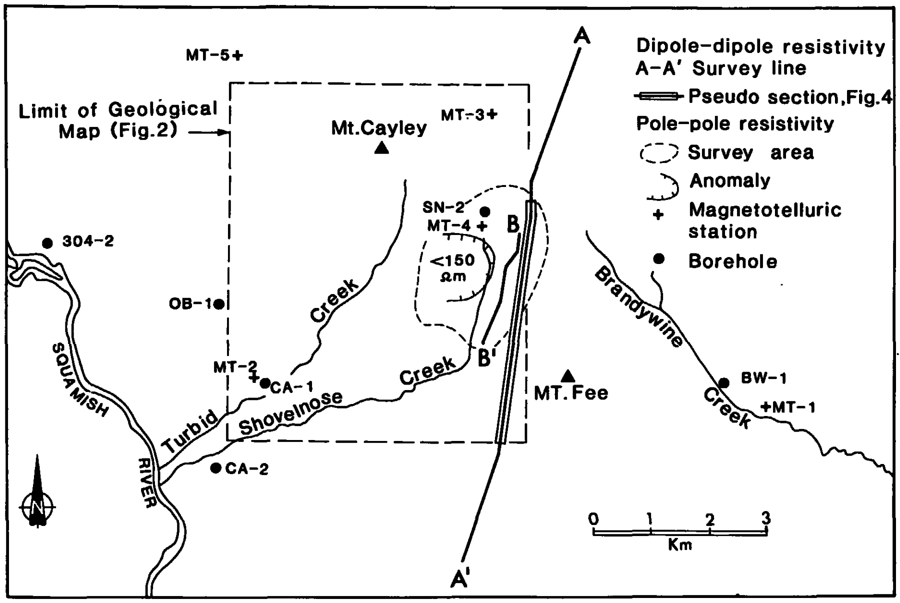

Fig. 3. Map with locations of dipole-dipole and pole-pole resistivity arrays, magneto-telluric stations and thermal gradient boreholes

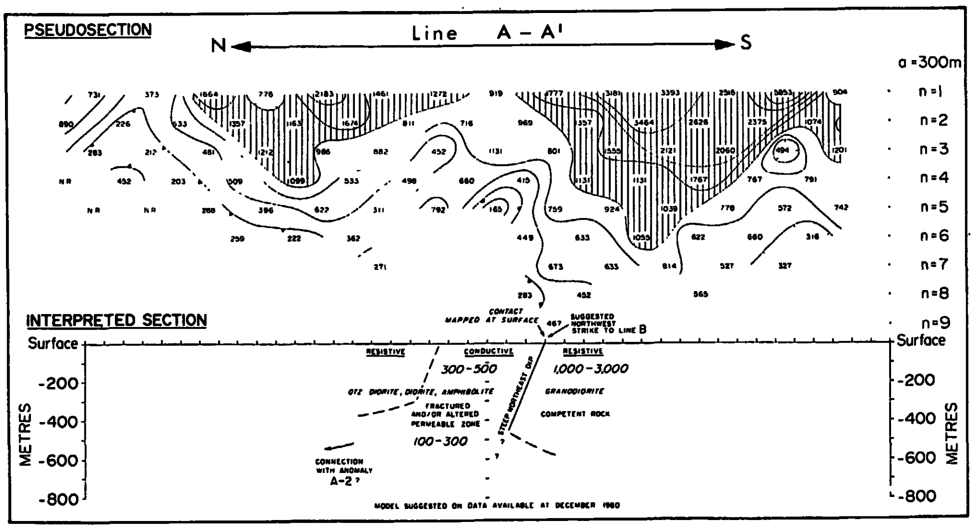

Fig. 4. Pseudosection and interpretation of the central part of dipole-dipole line A-A' (location shown on Fig. 3) (from Shore, 1981).

In order to unambiguously define the location of these resistivity anomalies relative to the dipole lines the Geological Survey conducted a more detailed survey (Shore 1983) using a multiple pole-pole (E-Scan) array. This survey defined the eastern edge of a conductive anomaly (<150 ohm-meters) that is open westward, toward the zone of intense alteration surrounding the Turbid Creek warm springs (Fig. 3).

Magnetotelluric data collected by Phoenix Geophysics Ltd. under contract to the Geological Survey in 1983 provides additional data on the deep thermal structure. A Phoenix Model MT-1 magnetotelluric system was installed and run overnight at five locations on and around Mt. Cayley (Fig. 3). The data from stations 3 and 4 (Fig. 5) suggests that restivity at depth is an order of magnitude lower beneath the central part of the complex as compared with data from stations 1, 2, and 5 located around its periphery.

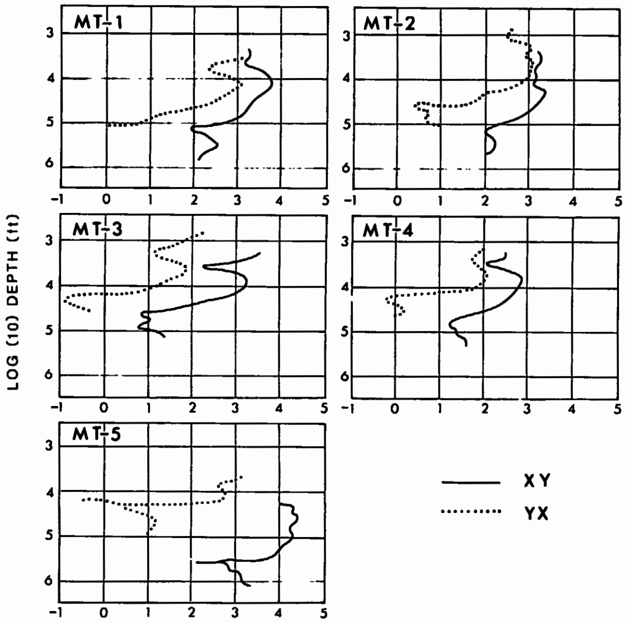

Fig. 5. Bostick 1-D inversion, showing log depth vs log resistivity for the five magnetotelluric stations plotted on Fig. 3.

Water Chemistry:

Preliminary study of the hydrogeochemistry and geothermometry of spring, surface and borehole waters (Ryder, 1983) and isotope hydrology of the Turbid Creek thermal water (Clark et al., 1980, 1982; Clark and Fritz, 1984) confirm the presence of a chemically distinctive hydrothermal fluid leaking from the Mt. Cayley reservoir (Fig. 6). Non-thermal waters contain Na^+ and NCO_3^- as principle ions and generally have less than 50 mg/l of dissolved solids. Thermal waters (Table 2) typically contain Na^+ and Cl^- as principle ions along with elevated Ca^{++} and Mg^{+2} concentrations. The Turbid Creek spring water has a higher sulfate content than water issuing from the SN-2 borehole but is otherwise similar.

	Turbid Creek Warm Spring	Shovelnose Creek Warm Spring	304-2 Warm Well	SN-2 Warm Well
T °C	29.1	27.3	20.5	31
pH	8.1	6.8	8.4	6.5
Cl	1190	787	489	685
F	0.5	0.5	1.7	0.36
HCO_3	1400	199	13	2317
CO_3	0	0	2	
SO_4	1130	60	1260	88.3
SiO_2	89	45	18	66.6
Na	911	402	489	
K	73	75	8	32.4
Ca	474	83	402	272
Mg	168	13	1	105
Li	1.3	1.3	0.2	1.06
B	3.9	3.5	2.1	
T qtz °C	131	97	60	
T chal °C	103	67	27	85.3
T Na/K-Ca °C	123	166	47	140.6
T Na/K-Ca-Mg °C	45	106	-	37.5
T SO_4-H_2O °C	78*	-	-	
Na/Li				97.6

Table 2 Chemical analyses and geothermometry of thermal waters, Mt Cayley. Units are mg/l unless otherwise noted. (*Clark et al., 1984), (**Reader 1983)

Estimates of subsurface temperature based on several chemical geothermometers (Table 2) exhibit considerable scatter. According to Clark (1980) and Clark and Fritz (1984) the high Mg content of the Turbid Creek spring waters suggests that they are part of a shallow, low temperature flow system as indicated by the Na-K-Ca-Mg, Mg-K, and SO_4-H_2O geothermometers. The relatively high temperatures indicated by the Qtz-H_2O geothermometer are considered to be erroneous - the result of near surface equilibration with chalcedony.

Reader (1983) disagrees, pointing out that no chalcedony was observed in core from the Shovelnose 2 borehole and thus the SiO_2-H_2O geothermometer is probably a more reliable indicator in the quartz-rich, granitic basement rocks from which the water is issuing. He also points out that Mg appears to be in equilibrium with rock in the bore and should not be used to correct the relatively high maximum temperatures indicated by the Na-K-Ca geothermometer.

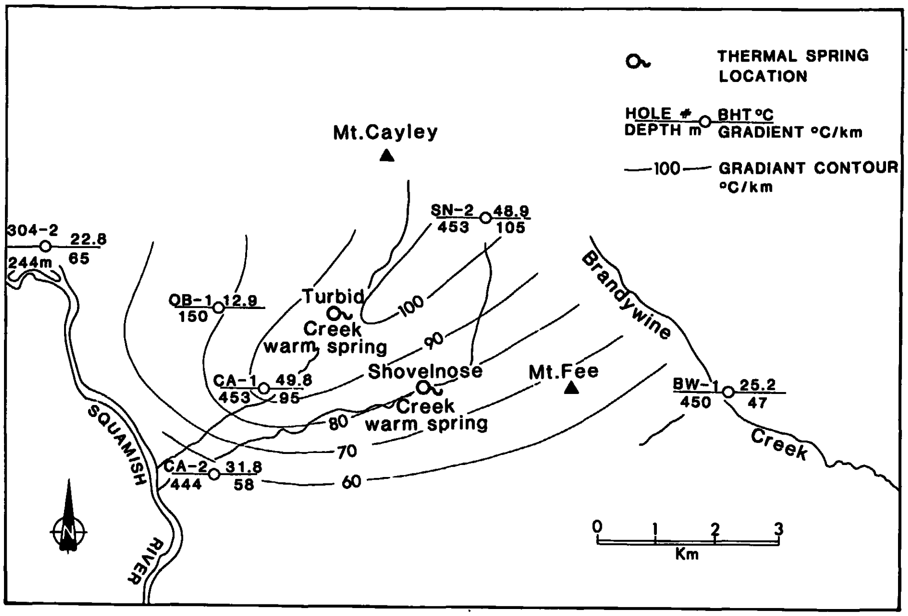

Fig. 6. Map with locations of thermal springs and boreholes, borehole temperature data and thermal gradient contours.

A hydrogeochemical reconnaisance (Ryder, 1983) indicates that the unique chemistry of the thermal water can be detected in surface water and seeps over a wide area on the southwest side of Mt. Cayley. Most of the drainages show a progressive downstream decrease in both anions and cations due to progressive dilution. However, in Turbid Creek the mineralization remains remarkably constant over an interval of 1.5 km below the warm springs, and the concentrations of Cl^- and HCO_3^- show a slight downstream increase, suggesting that an outflow plume of thermal water is entering the drainage at several points below the springs. The concentration of both anions and cations in the Shovelnose drainage is considerably less than in Turbid Creek. Near the head of Shovelnose Creek about 400 m above the warm springs are acid-sulfate-carbonate seeps with high calcium and magnesium concentrations. The chemistry of the seeps may result from steam and gas introduction into surface waters (Ryder, 1983).

Drilling:

Six thermal gradient holes have been drilled on and around Mt. Cayley (Figs. 3,6). Temperatures were taken with a thermister probe having a precision of 0.02° C. Bottom hole measurements were made after a twelve hour equilibration period following each shift throughout the drilling process and continuous temperature traverses were run on the completed holes after at least seven days of thermal equilibration. Data from this work (Fig. 7) support the geophysical and geochemical evidence for a thermal anomaly in the central part of the complex. Borehole SN-2, at the head of Shovelnose Creek, is on the eastern edge of the pole-pole resistivity anomaly and near small seeps of water having anomously high SO_4^{--} and HCO^{3-}. Its gradient (105°C/km) and bottom hole temperature (48.9°C) are the highest recorded.

Borehole CA-1, in lower Turbid Creek, has a relatively high gradient 95°C/k and has a bottom hole temperature 49.8°C. It is approximately 1500 feet below and directly down slope from the Turbid Creek hot springs, in an area where the surface water is strongly contaminated with chloride and other constituents of the geothermal fluid. Small water flows were intercepted in the borehole and the gradient is probably influenced by the westerly outflow of a hot water plume from the vicinity of the springs.

Borehole OB-1, on the west flank of Pyroclastic Peak, encountered glacial gravel to total depth at 150 m. The apparent thermal gradient is a manifestation of 7°C lateral water flow in glacial debris.

The remaining 3 bedrock holes, 304-2 and CA-2 in Squamish Valley, and BW-1 in Brandywine Creek valley, are peripheral to the volcanic complex. Their moderate bottom hole temperatures (22.8°C to 31.8°C) and gradients (48°C/km to 65°C/km), reflect a broad, regional thermal high that appears to underlie the entire Garibaldi Volcanic Belt.

The contoured thermal gradient distribution (Fig. 6) shows an apparent maximum near the Squamish River. It is likely that the strong westerly flow of cold groundwater has displaced the near surface thermal regime and surface water geochemistry to the west. The actual peak of the deep thermal gradient isotherm is probably further east, beneath the profound alteration zone of Turbid Creek.

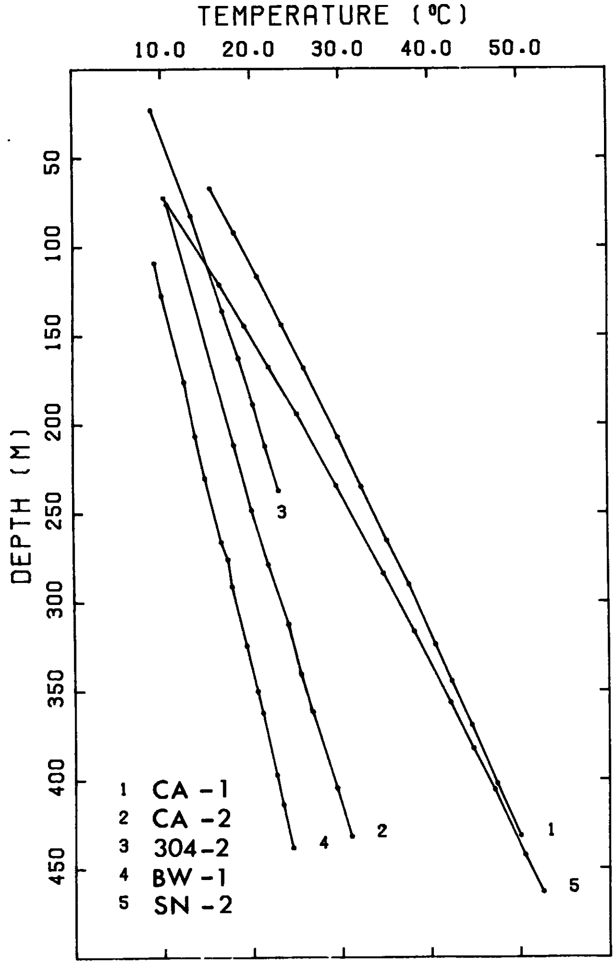

Fig. 7. Temperature vs depth for five boreholes on and adjacent to Mt. Cayley (locations shown on Figs. 3 and 6).

Discussion:

Geological, geochemical, and geophysical data suggest that an active hydrothermal system is associated with the young volcanic edifice of Mt. Cayley and diamond drilling has confirmed the presence of anomalously high temperature gradients. The similar age, structure, composition and tectonic setting of the Mt. Cayley and Meager Mountain composite volcanoes suggests that the associated hydrothermal systems may also be comparable. At Meager Mt. deep drilling has confirmed temperatures in excess of 250° C. but, as at Mt. Cayley, the only natural surface manifestations are relatively small warm springs. The chemistry of the Mt. Cayley thermal water sugests that it has been greatly diluted by surface water. It is noteworthy that the spring vents are on steep terrane, over 600 metres above the adjacent valley floor, in an area where cold recharge would be expected to depress the regional isotherms. Thus the presence of thermal seeps and high thermal gradients in upper Turbid creek suggests the presence of a convective hydrothermal system having sufficient size and vigor to displace a substantial column of cold groundwater.

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