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Possible Geothermal Resources in the Coast Plutonic Complex of Southern British Columbia, Canada[1]

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Abstract – In southern British Columbia the terrestrial heat flow is low (44 mW m^{-2}) to the west of the Coast Plutonic Complex (CPC), average in CPC (50–60 mW m^{-2}), and high to the east (80–90 mW m^{-2}). The average heat flow in CPC and the low heat generation (less than 1 $\mu W\ m^{-3}$) indicate that a relatively large amount of heat flows upwards into the crust which is generally quite cool. Until two million years ago the Explorer plate underthrust this part of the American plate, carrying crustal material into the mantle. Melted crustal rocks have produced the inland Pemberton and Garibaldi volcanic belts in the CPC.

Meager Mountain, a volcanic complex in the CPC 150 km north of Vancouver, is a possible geothermal energy resource. It is the product of intermittent activity over a period of 4 My, the most recent eruption being the Bridge River Ash 2440 y B.P. The original explosive eruption produced extensive fracturing in the granitic basement, and a basal explosion breccia from the surface of a cold brittle crust. This breccia may be a geothermal reservoir. Other volcanic complexes in the CPC have a similar potential for geothermal energy.

Key words: Coast Plutonic Complex; Quaternary volcanism; Plate tectonics; Heat flow; Heat production

Introduction

Regions within Canada having quite different thermal characteristics are being evaluated for potential to produce geothermal energy (Souther, 1976). From deep sedimentary basins the production of large volumes of hot water could yield large amounts of space heat and process heat in the Prairies (Jessop, 1976). In southern British Columbia the area west of the Rocky Mountain Trench has geothermal characteristics similar to the Basin and Range province (Judge, 1976; Judge *et al.*, in prep.) and could have a similar potential for geothermal energy production. In this paper we examine the type of geothermal resource to be expected in the Coast Plutonic Complex of southern British Columbia (see Fig. 1).

The Coast Plutonic Complex (CPC) is a belt extending along the coast of British Columbia from approximately 49°N into the Yukon, north of 60°N (Roddick and

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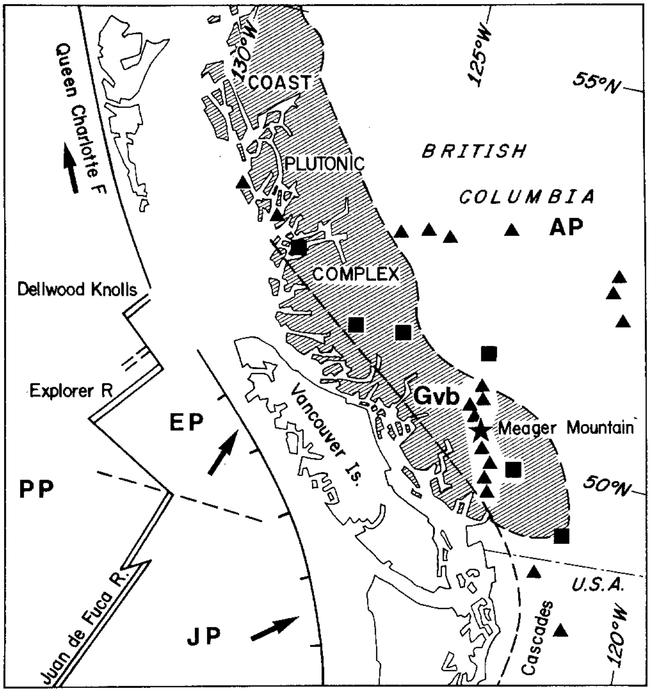

Figure 1
Tectonics near the Coast Plutonic Complex: AP – American Plate, EP – Explorer Plate, JP – Juan de Fuca Plate, and PP – Pacific Plate, GVB – Garibaldi Volcanic Belt. Arrows indicate plate movements relative to AP. Square symbols indicate Miocene volcanic centres, and the star which is Meager Mountain and triangles indicate Quaternary volcanics. The dashed line is the western limit of volcanism and the buried trench is indicated west of Vancouver Island. (After RIDDIHOUGH and HYNDMAN, 1976.)

HUTCHISON, 1974). The Insular belt to the west of CPC is represented by Vancouver Island, and the Intermontane and Hinterland belts lie to the east. The rugged CPC consists mainly of granodiorite, diorite and quartz diorite with associated gneiss. Potassium–argon ages indicate a linear zonation: the oldest rocks, up to 146 My, are on the western side, and the youngest rocks, as young as 40 My, are on the eastern side. HUTCHISON (1970) suggested that successive uplift and unroofing from west to east produced this pattern of ages. MONGER *et al.* (1972) incorporated this process in a plate tectonic synthesis for the Cordillera.

Much younger epizonal plutons and volcanics cover a much smaller part of this area. A row of Quaternary volcanic centres forming the Garibaldi volcanic belt is shown in Figs. 1 and 2 extending north through CPC. In the Meager Creek area this belt is intersected by the older, north-westerly trending belt of late Tertiary and Quaternary high-level plutons, the Pemberton belt. Both belts are thought to be related to subduction of the Juan de Fuca Plate, now much less extensive than in the late Miocene when the Pemberton belt was active. RIDDIHOUGH and HYNDMAN

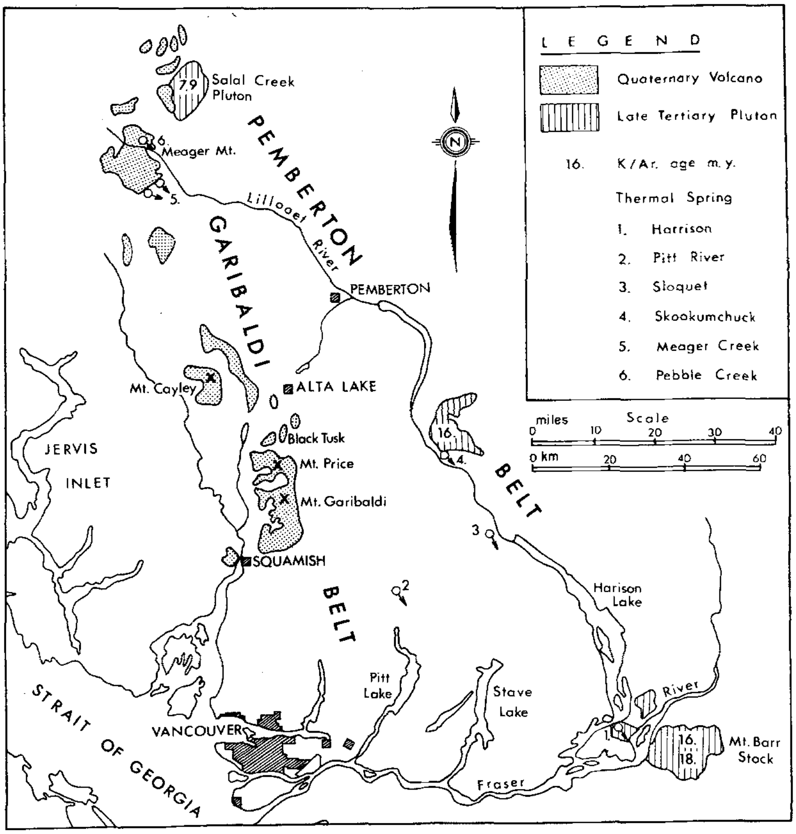

Figure 2
The Pemberton and Garibaldi volcanic belts.

(1976) studied the ocean floor magnetic lineaments and concluded that subduction of the small Explorer plate under CPC may still be happening, but at a relatively slow speed.

Heat flow and heat production

HYNDMAN (1976) measured heat flow in coastal inlets of southern British Columbia using oceanic techniques. Corrections to such measured heat flows are required to remove the effects of temperature changes of the bottom waters, sedimentation, thermal refraction by bottom sediments, topography, microclimatic effects, uplift and erosion. Unfortunately the parameters for calculating these corrections are not well known, and the corrections can be large. After making the necessary corrections, Hyndman obtained low heat flows, increasing towards the east, as shown in Fig. 3. JESSOP and JUDGE (1971) measured a high heat flow at Penticton, east of the CPC. More recent heat flow determinations (LEWIS, 1977) in and near the southern CPC

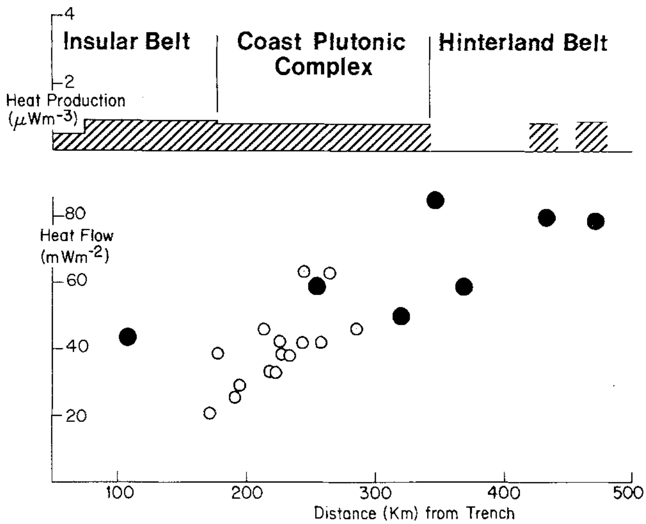

Figure 3
Profiles of heat flow and surficial heat production across the Coast Plutonic Complex, as a function of distance east of the buried trench off Vancouver Island. Open circles indicate measurements made in the inlets and solid circles indicate land measurements.

are also shown in Fig. 3, details of these measurements will be published elsewhere (LEWIS *et al.*, in prep). None of these measurements is near the younger plutons or volcanics. Therefore, the regional heat flow increases from west to east across CPC from about 40 mW m^{-2} in the Insular belt to 80 mW m^{-2} in the Intermontane and Hinterland belts.

Heat production measurements have been made on fresh looking, representative surface samples of bedrock using a gamma-ray spectrometer. Published values (LEWIS, 1976) and new results show a low heat production ranging from 0.5 to 1.0 μW m^{-3}. Average values are shown in Fig. 3. There is no apparent variation in potassium content nor heat production across CPC. The amount of heat generated in the upper crust, 10 mW m^{-2}, is small, and thus the majority of the measured heat flow is coming from beneath the upper crust. In most areas of CPC where there is no mass movement within the crust the crustal temperatures will be normal: approximately 240°C at 10 km depth. However, of the total area, the small proportion formed by young plutons and volcanics probably has much higher temperatures.

Meager Mountain

The initial assessment of the geothermal resource potential of western Canada, including the compilation of data on locations and ages of Quaternary volcanoes and young, high-level plutons and a geochemical survey of thermal springs, led to the selection of the Meager Creek area for more detailed investigation. Meager Creek, near which hot surface springs were found, is located at the upper end of the Lillooet Valley approximately 150 km north of Vancouver in moderately well foliated quartz diorite and granodiorite typical of CPC (RODDICK and WOODSWORTH, 1975). Meager Mountain lies on a rugged surface of typical CPC basement, and partially on one of several small satellitic bodies of quartz monzonite similar to the nearby Salal Creek pluton. The Salal Creek pluton is a small epizonal pluton dated at 7.9 My.

Meager Mountain itself is a complex of several closely related dacite and andesite lava domes and associated pyroclastic deposits (READ, 1977; ANDERSON, 1975). A basal breccia, exposed on the south side of the complex contains jumbled blocks of quartz diorite of dimensions up to 20 metres in a tuffaceous matrix. The initial eruption was an explosive discharge of gas-rich magma accompanied by extensive fracturing of the granitic basement. This was followed successively by dacite flows, the deposition of up to 500 metres of acid tuff, and the events forming the main mass of the complex, a porphyritic andesite (LEWIS and SOUTHER, 1978). Potassium–argon ages of 4.2 My and 2.1 My indicate that this main second phase was the product of a long episode of intermittent volcanism. The dacites of the third phase were deeply dissected prior to eruption of the Bridge River Ash, suggesting that the complex was dormant for a period prior to the most recent eruption. The Bridge River Ash is younger than 2240 y. The centres of the phases of activity moved progressively northwards with time.

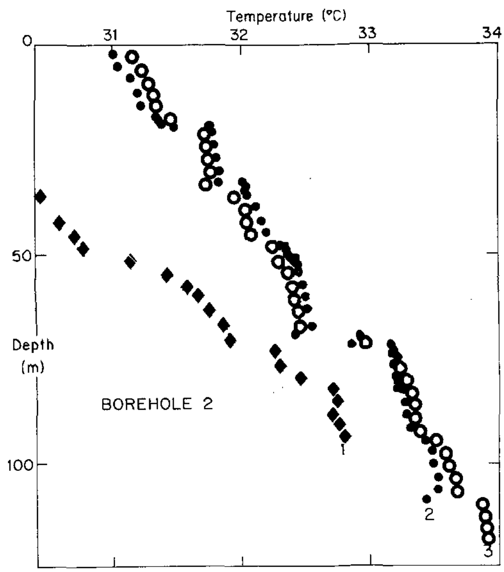

Figure 4
Temperature logs of a shallow borehole near Meager Creek. The logs were taken on successive days before drilling started, following a night in which no drilling nor circulation took place.

Temperatures were measured in six shallow boreholes drilled in the granodiorite and quartz diorite of the Meager Creek area. The holes were uncased, and water flowed through some portion of each hole. Figure 4 shows three temperature logs run to the bottom of a hole at three different pauses in the drilling. The sudden changes in temperature at many depths indicate where water is entering this hole. Using bottom hole temperatures it was possible to calculate the original conductive heat flows at four of the six sites before water started flowing through the holes. The conductive heat flow varied from 100 to 930 mW m^{-2} (LEWIS and SOUTHER, 1979), or 2 to 16 times the world average heat flow.

The results from other geophysical surveys support the claim that this area contains a geothermal reservoir. The excess silica in the Meager Creek hot springs might indicate that the water has been at a much higher temperature (HAMMERSTROM and BROWN, 1977). A deep resistivity survey indicated a large anomaly extending downwards and northwestwards from Meager Creek (NEVIN SADLIER-BROWN GOODBRAND LTD., 1975). The present observations suggest that hot water is available in the brecciated basement rocks, and these rocks may form a reservoir which can be economically exploited.

The type of geothermal resource

In this tectonic setting, it is expected that steam or hot water may be available to form an economical energy source. The cool, brittle crust overlying a slowly subducting oceanic crust has been subjected to vertical forces, causing block faulting. Lack of seismicity indicates no movement at present. Although in general crustal temperatures may be low, heat is brought to or near the surface from great depth by magma moving along major crustal faults. The magma is generated from material with a low melting point which previously was part of the oceanic crust. The volcanic belts are the surface indication of intrusions formed by the ascending magma solidifying before it reached the surface.

To remove heat economically from rock requires a hydrological system which will absorb the heat at high temperatures from a large mass of hot rock, and carry it at a useful temperature to a transfer point on the surface. If such a system operated naturally, it may have already dissipated most of the energy. Usually large amounts of water flow through the contacts of volcanic flows in young rocks (e.g. PALMASON, 1967), and these rocks are quickly cooled, and chemically altered.

At Meager Mountain the first explosive eruption has formed a large volume of coarsely brecciated rock, part of which may form a reservoir (see Fig. 5). Erosional debris and further lava flows have covered parts of this unit. Later eruptions have emplaced other hot rock in contact with parts of the breccia, increasing the probability that it contains hot water. Therefore, parts of this breccia unit may form an economic geothermal energy resource.

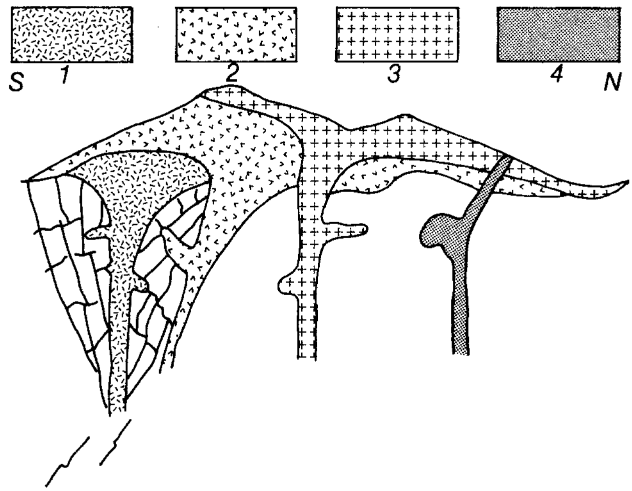

Figure 5
Cartoon showing the four successive phases of eruptions which formed Meager Mountain. The initial phase, 1, produced the large volume of breccia; the following phases erupted progressively northwards.

Meager Mountain is an example of the type of geothermal occurrence to be expected in the Coast Plutonic Complex. Other similar volcanic complexes in CPC such as Mt. Cayley, the Franklin Glacier and Silverthrone complexes are being studied since they have a similar potential for producing geothermal energy.

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