Report on

RESISTIVITY SURVEY IN THE VICINITY OF MT. CAYLEY

AUGUST, 1980

for

Geological Survey of Canada

by

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1.1 Introduction:

A geothermal reconnaissance program has been initiated by the Geological Survey of Canada at Mt. Cayley, British Columbia (Souther, 1980). The program includes geological studies, drill investigations, geophysics and geochemistry in an area centered on Mt. Cayley, the largest volcano in the central Garibaldi belt. Premier Geophysics Inc., under contract to the Geological Survey, has undertaken a reconnaissance D.C. resisitivity survey east and southeast of Mt. Cayley, to test for evidence of geothermal activity in the basement rocks near some eruptive features and recent doming. Dipole-dipole resistivity survey was selected in part because of its successful application in the Meager Creek Geothermal Area, (Shore, 1978; Fairbank et al, 1980) located 60 km to the north-northwest of Mt. Cayley.

The survey consisted of 12 line kilometres of dipole-dipole D.C. resistivity survey using a dipole spacing (a) of 300 metres, and a dipole separation (na) with n equal to 1 through 7,8, or 9. Two lines were completed, line A (9km) and sub-parallel line B (3 km).

1.2 Program Authority:

The survey program was conducted by Premier Geophysics Inc., on behalf of the Geological Survey of Canada. Dr. J. Souther, of the GSC Vancouver office was the immediate client and Scientific Authority for the work which was authorized under a Department of

Supply and Services contract, serial number OSB80-00198, dated August 1, 1980.

2.1 Survey Method:

A conventional dipole-dipole array was used, with dipole separation (a) of 300 metres and a basic required dipole separation (na) of n = 1 to 4. Where possible, data was obtained to n = 5 through 7,8 or 9.

An effective D.C. operating frequency (0.125 hertz reversing polarity square wave, 100% duty cycle) was applied. The receiver recorded the complete observed ground waveform on a chart recorder, with 10 second per centimetre chart speed and 100 microvolt per centimetre maximum resolution. A Premier PG-1A Differential Compensator was used to null out the D.C. component of self-potential, and to provide manual tracking of some low-frequency tellurics. The main receiver was a Hewlett-Packard 7155B microvoltmeter chart recorder.

Transmitter equipment consisted of a Phoenix Geophysics IPT-1 3 kw transmitter operated from 1 kw and 3 kw generators.

Electrodes used were steel rods, for both current and potential measurements.

2.2 Data Processing:

The recorded signal was manually digitized to obtain the peak-to-peak square wave voltage for resistivity calculations. In some cases, severe telluric disturbances impressed a large and variable noise signal onto the square wave, necessitating mechanical filtering to extract the square wave component. Some of the data obtained through glacier ice have been restricted due to uncertainties as to the amount of signal loss at high impedance measurement electrode contacts on the ice. These suspect data are not reported on the pseudosections in this report.

The formula used for the calculations is as follows:

resistivity (ohm-metres) = $\pi a.n(n+1)(n+2)(n+3)Vp/Ig$

where: a = dipole separation in metres
n = dipole separation multiple of "a"
Vp = received signal level in volts
Ig = transmitted current level in amperes (D.C.)

2.3 Data Plotting:

The calculated data are plotted in a pseudosection convention developed by Hallof (1957) and used for most geothermal resistivity results in British Columbia and many induced polarization and resistivity survey results throughout the world. The plot position is explained on the drawings themselves. The observer is reminded that these plots are an organization of data for the convenience of the interpreter, and represent neither the true resistivities at any point relative to another, nor any absolute vertical scale.

Areas of anomalous data are identified by solid or dashed bars at the top of the pseudosections. These bars are reproduced on the plan map (Figure 1) to show the line-to-line spatial relationship of the groups of anomalous data. The actual interpretation, which is more subjective and open to revison with the availability of new information, is reported under the pseudosection plot in the form of a geoelectric section.

An envelope encloses sections of the survey lines on the plan map (Figure 1), to indicate the scope of array sampling along the line. The distance from the line to the edge of the envelope is an estimate of the extent of effective search for the array dimensions used, a value based on the depth of investigation characteristic (D.I.C.) (Roy and Apparao, 1971) of the maximum array dimension used, as modified for pseudosection use by Edwards (1977), who calls it effective penetration, Z_e. In essence, any strongly anomalous conditions at the edge of or within the envelope, to either side or to corresponding depth below, will be apparent in the pseudosection data (provided other local effects do not obscure the results). Thus, where an anomaly is represented by a bar plotted along the line, the observer can use the envelope in conjunction with the pseudosection to identify and evaluate possible geologic or topographic explanations for the anomaly.

In broader terms, the envelope plot serves as an immediate visual catalog of resistivity data coverage (as opposed to resistivity line location). Where no anomaly exists and no indicators of topographic or stratigraphic masking or distortion are present, the terrain enclosed in the envelope can be considered "explored" to the limits of the Z_e definition of the envelope boundary. Where an anomaly exists, and no firm indication of anomaly source location can be determined (a shallow anomaly at distance "d" to one side may, in pseudosection data, look the same as an anomaly at depth "d" directly under the line) the combination of data envelope and anomaly bar allows the appropriate fitting of follow-up parallel or perpendicular lines to the area terrain. The trial plotting of any proposed detail line and its search envelope provides an opportunity to test the potential effectiveness of the proposed line in clarifying the anomaly source position.

3.1 Resistivity at Mt. Cayley:

The survey targets at Mt. Cayley (and at other B.C. geothermal prospects) are zones of anomalous resistivity caused by one or more of the following factors:

a. increased permeability, particularly in basement rocks, as a result of increased fracture density, fissuring, or intense alteration;

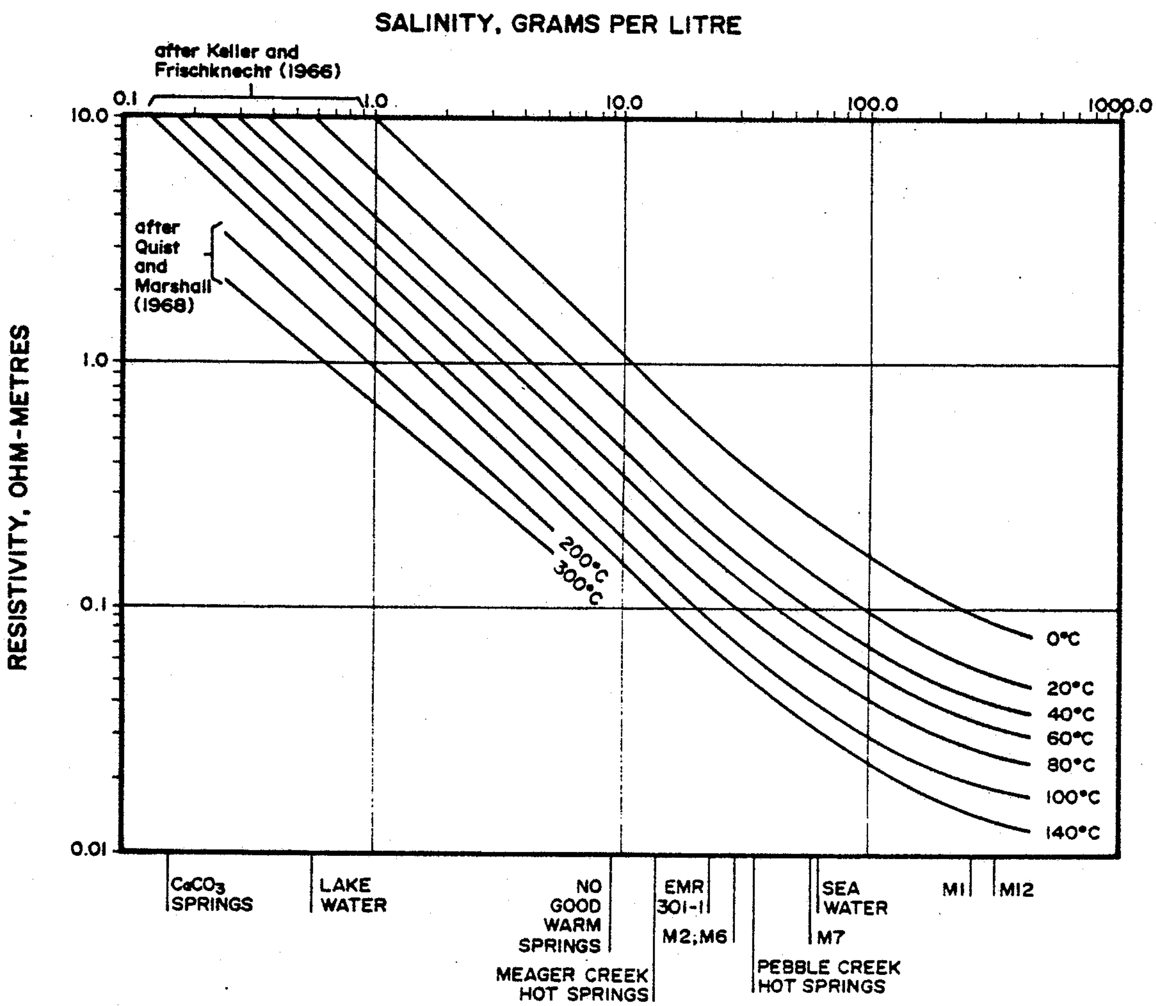
b. elevated fluid temperature, as a result of proximity to a heat source, in any rock types or overburden;

c. elevated fluid salinity, in waters which have concentrated dissolved salts as a result of circulation in a convective cell, as measured in any rock types or overburden.

A fourth cause of anomalous resistivity may be the presence of concentrations of metallic minerals or graphite. To date such occurrences have not been identified in B.C. geothermal resistivity survey areas.

The relationship of temperature and salinity to resistivity is shown in the plot below. The effects of temperature variation are most pronounced between 0°C and 140°C, which coincides with the principal range of temperatures expected to be encountered in resistivity survey routinely sampling at up to one kilometre penetration. The plot shows a range of salinities obtained from spring and drillhole waters in the Meager Creek Geothermal Area, with lake water (fresh) and sea water plotted for reference.

Both temperature and salinity are seen as the dominant anomaly-causing factors, with net rock permeability controlling principally the amount of connected water volume available to conduct electricity. In extremes of fluid temperature and/or salinity, net permeability variation controls a wide range of effective conductivity (reciprocal of resistivity). Where waters are relatively pure and cool (resistive), the same net permeability variation will provide a much narrower range of effective conductivity, approaching nil variation as water resistivity approaches host rock resistivity.



Variation of water resistivity with temperature and salinity

(from Shore and Schlax, 1981)

4.1 Results:

Anomaly A-1 (Figures 1 and 2)

Anomaly A-1 is a group of isolated low-resistivity values reported from an area of glacial ice cover. The values may result from conductive conditions below or to the sides of the survey line. Part of the anomaly may be caused by severe topographic variability between 40S and 45S. The lack of reliable surrounding data, principally due to potential electrode contact problems on the ice, precludes interpretation beyond the observation that the values are low, and that further investigation with improved instrumentation would be appropriate.

Anomaly A-2/B-2 (Figures 1, 3 and 5)

The line A anomaly A-2 extends from 48S to 61S, over crystalline basement. Due to a lack of parallel line information, it is not possible to determine the position of the source of the anomaly with certainty. Measurements near the exogenous dome at the head of Shovelnose Creek (45S to 51S) show moderate resistivities of about 750 ohm-metres. It is reasonable to expect some fracturing and alteration in the contact area as a result of the forces of dome extrusion. The resistivities reported from near the dome indicate that if fracturing or alteration exist, they are not accompanied by significantly elevated temperature or fluid salinity, either or both of which would result in a stronger anomaly. However, if the area is minimally fractured, the moderate resistivity could reflect elevated temperature or fluid salinity, but not likely a significant combination of these factors, which would produce a stronger response.

Further south, the $n = 1$ low of 373 ohm-metres suggests the near-surface presence of a narrow conductive unit. Its position in line with Mt. Fee to the south-southeast and the dacite dome to the north-northwest suggests a possible major fault/shear axis which could be investigated by mapping and additional resistivity survey across the projected strike to the southeast. Since there is only one survey line, no indication of a structure strike can be obtained directly from the data at present.

The widening of the anomaly signature at increased n-spacings on the pseudosection is in excess of that expected from a narrow vertical structure, but does not exclude the possibility that such a narrow structure exists. The pattern may be caused either by a deep conductive zone connected at depth with anomaly A-3/B-3 or by "side-looking" at the possibly conductive volcanics on the flanks of Wizard Peak. The latter possibility is discounted somewhat, as the "reach" of the array n-spacings reporting the anomalous values falls short of the mapped surface contact between basement and volcanics. A crystalline rock anomaly is therefore logically suggested. As will be the case with anomaly A-3/B-3, there would be value in testing the volcanics directly west of 57S to identify their resistivity characteristic. A high measured value would positively support a crystalline rock anomaly, eliminating any question of "side-look" influence on the anomaly. In addition, a parallel line east of line A would test and define the strike of the anomaly without the possible complication of adjacent volcanics. This would be of particular value if geological proposal and/or a measured conductive response on the volcanics threw the A-2 anomaly into further doubt as to the position of the source materials.

Anomaly A-3/B-3 (Figures 1,3 and 5)

In the area of this anomaly, line A reports from well into the crystalline basement, with its search envelope (Figure 1) just approaching the volcanic contact in Shovelnose Creek. Line B lies lower in the valley, its search envelope (Figure 1) sampling substantial volumes of the volcanics to the west, while testing the basement to the east and below from a lower-altitude advantage.

The A-3 portion of the anomaly appears to lie entirely within crystalline basement and may constitute a narrow (400 to 800 metres) steeply dipping structure, for which a strike of northwest is suggested by B-3 anomaly data. A steep dip to the north (northeast, if a strike of northwest is accepted) is suggested in the A-3 anomaly pseudosection, and is neither supported nor denied in the B-3 pseudosection.

Line B data (72S to 81S) sample the endogenous dacite dome at the main bend of Shovelnose Creek and report resistive values. The pseudosection pattern on line B from 69S to 75S is consistent with a vertical contact between a resistive unit to the south (the dacite dome) and a conductive unit to the north. The mapped altered flows and pyroclastics of the Mt. Cayley stage vulcanism (Souther, 1980) could be conductive and therefore at least partially responsible for the B-3 anomaly. Thus, while the line A anomaly appears to be "safely" within crystalline basement, the line B data are intimately involved with volcanics of unknown conductivity. A quantitative sampling of the resistivity of the volcanics would have one of two results:

a. a resistive signature, which would remove suspicion of volcanic rock contribution to the B-3 anomaly and would support the northwest strike proposed for the A-3 anomaly portion, or

b. a conductive signature, which would leave the further interpretation of the A-3 anomaly extent and strike to the west of line A in its presently ambiguous state.

In summary, a strong resistivity anomaly (A-3) of potential geothermal significance has been identified within crystalline basement under or near line A between 66S and 72S, with possible west or northwest extension at least to the volcanics, possible connection at depth (greater than 400 metres) with anomaly A-2 to the north, a clearly indicated boundary to the south, and an untested easterly extent.

Anomaly A-4 (Figures 1 and 4)

Anomaly A-4 is a large-n anomaly plotted with its center at 88S. The origins of the data (Figure 1) are well within the mapped granodiorite basement (Souther, 1980) in an area of satisfactory topographic regularity. The "quick look" at the pseudosection character yields a two-zone interpretation showing 1800 to 4000 ohm-metre granodiorite lying within 200 to 400 metres of the line location, and a kilometre-thick zone of 100 to 250 ohm-metre material beyond that, extending to an undefined depth or distance from the line. A two-dimensional forward modelling technique should be applied here to attempt to fit a reasonable structure, either vertically layered or rotated to fit an eastward "side look".

The eastward look is warranted by the presence of a massive tower of extruded basalt, part of the Ember Ridge complex (Souther, 1980) about 400 metres east of 91S, line A. The volume of extruded basalt itself cannot begin to justify the anomaly, whatever its possible electrical conductivity. The anomaly may relate to basement rock fracturing and/or alteration associated with the venting, or to fracturing, fissuring or alteration associated with the magma source plumbing at depth. The presumed presence of a broad, intensely fractured (permeable) zone will require an additional factor of elevated fluid temperature, elevated fluid salinity, or both to satisfy the measured anomalous response.

The results of this single line of data consistently point to probable geothermal activity near A-4. This single line, however, is far from definitive in pinning down the nature and geometry of the anomaly source structure. Additional resistivity survey should be undertaken to allow logical confirmation of the anomaly source structure geometry relative to the ground surface. The present line data provide only a radial distance (from the line at surface) to the nearest anomalous material, to the best estimate available from polar measurements derived from successive, potentially directionally variable electric fields. With little room for additional parallel or perpendicular dipole-dipole lines, a case can be made for a blanket (3 km by 3 km) survey network of multiple pole-pole survey which would yield a greater density of data coverage (in otherwise inaccessible terrain) while providing reliable vector mapping of a blanket potential field encircling the basalt vent.

In summary, a strong resistivity anomaly is identified in data plotted near 84S to 93S of line A. Follow-up resistivity survey should be applied to further define the nature and geometry of the anomaly source materials, prior to or coincident with the application of geological mapping and available geochemical methods, and certainly prior to consideration of a drilling test.

Anomaly A-5 (Figures 1 and 4)

Anomaly A-5 lies entirely within granodiorite basement rocks near 98S on line A. The pattern generated on the pseudosection plot is ambiguous, containing some elements suggesting narrow conductive structures near surface at 91.5S and 103.5S, yet lacking the consistent follow-through in the patterns that would allow a reasonably confident qualitative interpretation. Certainly no layered case is present here - a layered interpretation would demand a true resistivity, in the vertical position represented by n = 3, 141 ohm-metres (Figure 4), of a value close to zero ohm-metres. A more structure-sensitive survey could be undertaken here if mapping and other considerations fail to yield a satisfactory explanation for the anomaly.

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