BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

REPORT ON INVESTIGATION OF GEOTHERMAL RESOURCES IN SOUTHWESTERN BRITISH COLUMBIA

Volume 1: Report

Volume 2: Appendix

Volume 3: Maps

June 1974

VOLUME 2: APPENDIX

NEVIN SADLIER-BROWN GOODBRAND LTD.
CONSULTING GEOLOGISTS

VOLUME 2: APPENDIX

Cover Photograph: The upper 2,500 feet of the thick Mt.Cayley volcano. The blocky spires on the right-hand side are parts of the neck which carried lava from a chamber 5-10 kilometres deep, to spill out on the surface.

CONTENTS

APPENDIX 'A' - REFERENCES AND BIBLIOGRAPHY

David D. Blackwell and Czang-go Baag, Heat Flow in a 'Blind' Geothermal Area near Marysville, Montana, Geophysics, Vol.38, No.5, pp.94-956, October, 1973.

H.H. Bostock, Geological Survey of Canada, Map 42-1963, "Geology, Squamish" 1963.

C.E. Cairnes, Geological Survey of Canada, Map 430A, "Geology Green Lake Area", 1938.

C.E. Cairnes, Geological Survey of Canada, Map 431A, "Geology Cadwallader Creek Area", 1938.

D.D. Campbell, Dolmage Campbell & Associates Ltd. "Geothermal Power in British Columbia", British Columbia Energy Board, Montreal Engineering Company Limited, Vol.7, Appendix X, 10p., 1972.

C. Camsell, Geological Survey of Canada, "Geology P.G.E. Route", 1917.

Jim Combs and L.J.P. Muffler, "Exploration for Geothermal Resources", in Paul Kruger and Carel Otte, "Geothermal Energy: Resources, Production, Stimulation," Stanford University Press, pp.95-128, 1973.

R.T. Elworthy, "Investigation of Mineral Resources and the Mining Industry", Can.Department Mines Publication #669, 1925.

R.O. Fournier and A.H. Truesdell, "An Empirical Na-K-Ca Geothermometer for Natural Waters", Geochimica et Cosmochimica Acta, Vol.37, pp.1255-1275,1973.

R.O. Fournier, D.E. White and A.H. Truesdell, "Geochemical Indicators of Subsurface Temperature, Part I: Basic Assumptions", U.S. Geol.Survey, Journal of Research, Vol.2, No.3, May, 1974, in press.

R.O. Fournier and A.H. Truesdell, "Geochemical Indicators of Subsurface Temperature, Part II: Estimation of Temperature and Fraction of Hot Water Mixed with Cold Water", U.S.G.S., Journal of Research, Vol.2, No.3, May, 1974, in press.

R.O. Fournier and J.J. Rowe, "Estimation of Underground Temperatures from the Silica Content of Water from Hot Springs and Wet-Steam Wells", Amer.Journal Science, Vol.264, pp.685-697, Nov. 1966.

Robert Greider, Chevron Oil Company, "Economic Considerations for Geothermal Exploration in the Western United States", Symposium, Colorado Dept.Natural Resources, Dec.6, 1973; reviewed by Larry H. Axtell, Phillips Petroleum Corp., Geothermal Resources Council, Short Course No.1, Sacramento, Jan.15, 1974.

Stuart S. Holland, "Landforms of British Columbia, A Physiographic Outline", B.C. Dept.Mines & Petroleum Resources, Bull.48, 1964.

Alan M. Jessop, Earth Physics Branch, Dept.Energy, Mines and Resources, Ottawa (personal communication) 1974.

James B. Koenig, "Worldwide Status of Geothermal Resources Development", <u>in</u> Paul Kruger and Carel Otte, "Geothermal Energy: Resources, Production, Stimulation", Stanford University Press, pp.15-58, 1973.

J.W.H. Monger, Geological Survey of Canada, Map 12 - 1969, Paper 69-47, "Geology - Hope West Half", 1969.

Andrew/

Andrew E. Nevin and T.L. Sadlier-Brown, "Exploration and Economic Potential of Geothermal Steam in Western Canada", Canadian Inst.Mining and Metallurgy, Bulletin, 5p., Dec.1973.

J.A. Roddick, "Vancouver North, Coquitlam and Pitt Lake Map Areas, British Columbia", G.S.C., Mem.335, 1965.

J.A. Roddick and W.W. Hutchison, "Pemberton (east half) Map Area, British Columbia", G.S.C. Paper 73-17.

J.A. Roddick and A.V. Okulitch, Geological Survey of Canada, Open File 165, "Geology Southwestern B.C. and Northwestern Washington", July 1973.

L. Skoda and J.C. Robertson, U.B.C., "Water Use, Strait of Georgia - Puget Sound Basin", Environment Canada, Ottawa, Map, 1973.

J.G. Souther, Geol.Survey of Canada, Vancouver (personal communication) 1974.

U.S. Dept.Interior, "Final Environmental Impact Statement for the Geothermal Leasing Program", Four Volumes, approx. 2000 pages, maps, Washington, D.C. 1973.

D.E. White, L.J.P. Muffler and A.H. Truesdell, "Vapor-Dominated Hydrothermal Systems Compared with Hot Water Systems", Economic Geology, Vol.66, pp.75-97, 1971.

Donald E. White, "Characteristics of Geothermal Resources", in Paul Kruger and Carel Otte, "Geothermal Energy: Resources, Production, Stimulation", Stanford University Press, pp.69-94, 1973.

David L. Williams and Richard P. Von Herzen, Woods Hole Oceanographic Inst., "Heat Loss from the Earth: New Estimate", Geol.Soc.America, Abstracts with Programs, p.864, 1973.

A.A.R. Zohdy, L.A. Anderson and L.J.P. Muffler, "Resistivity, Self-Potential, and Induced Polarization Surveys of a Vapor-Dominated Geothermal System", Geophysics, Vol.38, No.6, pp.1130-1144, Dec.1973.

APPENDIX 'B' - GLOSSARY

Geologic Time-Rock Units

Names for time intervals and for the rocks which were formed during those intervals, as used in this report, are defined as follows:-

Era	Period/System	Age/Stage	Millions of yrs. before present
Cenozoic	Quaternary	Recent (post-glacial)	0.007 - 0
		Pleistocene (glacial)	1.5 - .007
	Tertiary		65 - 1.5
Mesozoic	Cretaceous		136 - 65
	Jurassic		195 - 136
	Triassic		225 - 195
Paleozoic			570 - 225
Precambrian			5000 - 570

Definitions (mainly from American Geologic Institute, Glossary).

andesite: a dark-colored, fine-grained extrusive rock that, when porphyritic, contains phenocrysts composed primarily of zoned acid plagioclase (esp.andesine) in the range of An_{35} to An_{70} and one or more of the mafic minerals (e.g. biotite, hornblende, pyroxene) and a groundmass composed generally of the same minerals as the phenocrysts, although the plagioclase may be more acid and quartz is generally present, the extrusive equivalent of diorite. Andesite grades into latite with increasing alkali feldspar content, and into dacite with both more alkali feldspar and more quartz.

alteration: any change in the mineralogic composition of a rock brought about by physical means, esp. by the action of hydrothermal solutions; also, a secondary, i.e. supergene, change in a rock or mineral. Alteration is sometimes considered as a phase of metamorphism, but is usually distinguished from it because of being milder and more localized than metamorphism is generally thought to be.

altered rock: a rock that has undergone changes in its chemical and mineralogic composition since its original deposition.

anomaly: a deviation from uniformity or regularity in geophysical quantities, a difference between observed and computed value.

ash: fine pyroclastic material (under 4.0mm diameter; under 0.25mm diameter for fine ash). The term usually refers to the unconsolidated material but is sometimes also used for its consolidated counterpart, or tuff.

basalt:/

basalt: a dark-to-medium-dark colored, commonly extrusive (locally intrusive, as dikes), mafic igneous rock composed chiefly of calcic plagioclase (usually labradorite) and clinopyroxene in a glassy or fine-grained groundmass, the extrusive equivalent of gabbro.

a term loosely used for dark-colored, fine-grained igneous rocks whether intrusive or extrusive.

breccia: a coarse-grained clastic rock composed of large(greater than sand size or 2 mm in diameter), angular, and broken rock fragments that are cemented together in a finer-grained matrix (which may or may not be similar to the larger fragments) and that can be of any composition, origin, or mode of accumulation, the consolidated equivalent of rubble. Breccia is similar to conglomerate except that most of the fragments have sharp edges and unworn corners; the rock can be formed in many ways, chiefly by sedimentation (sedimentary breccia), igneous activity (igneous breccia), and diastrochism (tectonic breccia).

cinder: an uncemented, juvenile, vitric, and vesicular pyroclastic fragment that has been given various size classifications: 4-32mm diameter, 0.5-5.0cm diameter; so fine that its nature is not discernible to the naked eye.

conglomerate: a coarse-grained, clastic sedimentary rock composed of rounded (to subangular) gragments larger than 2 mm. in diameter (granules, pebbles, cobbles, boulders) set in a fine-grained matrix of sand, silt, or any of the common natural cementing materials.

dacite: a fine-grained extrusive rock with the same general composition as andesite but having a less calcic feldspar.

fault: a surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale.

fracture: a general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fracture includes cracks, joints and faults.

granite,granitic: broadly applied, any holocrystalline, quartz-bearing intrusive rock, including granite, quartz monzonite, granodiorite, quartz diorite and syenite.

interstice: an opening or space between one thing and another, as an opening in a rock or soil that is not occupied by solid matter.

interstitial: said of a mineral deposit in which the minerals fill the pores of the host rock.

interstitial water:/

interstitial water: subsurface water in an interstice.

lava: a general term for a molten extrusive; also, for the rock that is solidified from it.

magma: naturally occurring mobile rock material, generated within the Earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes, it may or may not contain suspended solids (such as crystals and rock fragments) and or gas phases.

metamorphic: pertaining to the process of metamorphism or to its results. n. a metamorphic rock, usually used in the plural, e.g. "the metamorphics" of an area.

metamorphism: the mineralogical and structural adjustment of solid rocks to physical and chemical conditions which have been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which the rocks in question originated.

neck: a vertical, pipelike intrusion that represents a formed volcanic vent. The term is usually applied to the form as an erosional remnant.

permeability: the property or capacity of a porous rock,sediment, or soil for transmitting a fluid without impairment of the structure of the medium; it is a measure of the relative ease of fluid flow under unequal pressure. The customary unit of measurement is the millidarcy.

plate tectonics: global tectonics based on an Earth model characterized by a small number (10-25) of large, broad, thick plates (blocks composed of areas of both continental and oceanic crust and mantle) each of which "floats" on some viscous underlayer in the mantle and moves more or less independently of the others and grinds against them like ice floes in a river, with much of the dynamic activity concentrated along the periphery of the plates which are propelled from the rear by sea-floor spreading. The continents form a part of the plates and move with them, like logs frozen in the ice floes.

porosity: the property of a rock, soil, or other material of containing interstices. It is commonly expressed as a percentage of the bulk volume of material occupied by interstices, whether isolated or connected.

reservoir: a subsurface accumulation of fluid under adequate trap conditions.

rhyolite:/

<u>rhyolite:</u> a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture, with phenocrysts of quartz and alkali feldspar (esp. orthoclase) in a glassy to cryptocrystalline groundmass; also, any rock in that group; the extrusive equivalent of granite. Rhyolite grades into rhyodacite with decreasing alkali feldspar content and into trachyte with a decrease in quartz.

<u>sea-floor spreading</u>: a hypothesis that the oceanic crust is increasing by convective upwelling of magma along the mid-oceanic ridges or world rift system, and a moving away of the new material at a rate of from one to ten centimeters per year. This movement provides the source of power in the hypothesis of plate tectonics. This hypothesis supports the continental displacement hypothesis.

<u>shale:</u> a fine-grained, indurated, detrital sedimentary rock formed by the consolidation (as by compression orcementation) of clay, silt, or mud, and characterized by finely stratified (laminae 0.1-0.4 mm thick) structure and/or fissility that is approximately parallel to the bedding.

<u>subduction zone</u>: an elongate region along which a crustal block descends relative to another crustal block, e.g. the descent of the Pacific plate beneath the Andean plate along the Andean trench.

<u>tectonics:</u> a branch of geology dealing with the broad architecture of the upper part of the Earth's crust, that is the regional assembling of structural or deformational features, study of their mutual relations, their origin, and their historical evolution.

<u>transform fault</u>: a strike-slip fault characteristic of midoceanic ridges and along which the ridges are offset. Analysis of transform faults is based on the concept of sea-floor spreading.

<u>vent:</u> the opening at the Earth's surface through which volcanic materials are extruded; also, the channel or conduit through which they pass. Also used to denote conduit through which thermal water passes to the surface.

<u>volcanic rock:</u> a generally finely crystalline or glassy igneous rock resulting from volcanic action at or near the Earth's surface, either ejected explosively or extruded as lava, e.g. basalt. The term includes near-surface intrusions that form a part of the volcanic structure.

<u>volcanism:</u> the processes by which magma and its associated gases rise into the crust and are extruded onto the Earth's surface and into the atmosphere.

APPENDIX 'C' - GEOTHERMAL SYSTEMS

The temperature in the earth's crust normally increases downward at about 1°F per 100 feet or about 2°C per 100 metres. Under these conditions heat flows upward and is lost from the earth's land surface at the rate of about 1.5 heat flow units* (one heat flow unit, HFU, equals one-millionth of a calorie per square centimetre of surface per second).

Depending on objectives and scale of operation there are several classes of geothermal resources, with varying characteristics (Drawing 1, Vol.1). It would be possible to extract and utilize heat from many places in the earth's crust, however, at the present time economic requirements for generating electricity on a large scale are only satisfied by rather unique, steam saturated, hot spots located within the uppermost 3 kilometres of the crust. The principal constraint is the cost of drilling a field of some 50 - 200 production drill holes - - about $40 - $80 per kilowatt capacity - - in order to vent sufficient natural steam. Hot water fields and deep fields of hot, dry rock, which require proportionately larger plants and more numerous drill holes, are resources being exploited on small or pilot-plant scales and are under study elsewhere for future large scale use.

Commercial steam fields depend upon a chamber of molten lava abnormally high in the crust of the earth, say at a depth of only 5-10 kilometres. Such molten rock may have a temperature on the order of 600-1300°C and generates heat upward at the rate of 6-15 HFU as it cools over a period of 10,000 - 50,000 years. It acts as a thermal motor, driving a convection cell of ground water some distance above it. The cell operates in a reservoir, a zone of permeable or fractured rock containing several per cent interconnected pore space. The highest grade natural geothermal reservoirs, called "dry steam" or "steam dominated" systems, have a central steam core enveloped by a blanket of hot condensate. The systems tend to seal themselves off and create super-pressures by depositing mineral precipitates, similar to boiler scale, in the fractures at the interface between hot fluid and cold ground water.

---

* Heat loss from oceans is slightly more, 2.0 HFU, and the total natural heat loss from the surface of the earth is 9-trillion calories per second, or approximately 5 times the rate at which man uses all forms of energy, including fossil fuels (Williams and Von Henzen).

APPENDIX 'D' - PLATE BOUNDARIES.

Following the 1965 proof of sea-floor spreading and continental drifting, considerable work has been done on the break up, evolution, and regrouping of continents. A dozen major plates and a hundred small fragments of crustal plates have been identified in various parts of the world, and the characteristics of several types of plate boundaries have been established. Oceanic ridges such as the Explorer and Juan de Fuca rises (Drawing 2), parts of the East Pacific rise, are zones of spreading and formation of new crust caused by deep seated slowly moving convection cells in the mantle, which are moving apart as would two opposed conveyor belts originating from the same point.

Where plates collide, one is generally shoved over the other to form a "subduction zone". Crustal material is carried downward at a steep angle where it remelts, rises, and erupts inland as a volcanic mountain chain. Another type of plate boundary is a transform fault, brought about where adjacent conveyors move at different rates and the adjacent plates move laterally along the fracture separating them.

Virtually all of the productive geothermal areas in the world lie above plate boundaries, and derive energy from associated igneous rocks. The Geysers, California, overlies a former subduction zone; the Japanese, Kamchatkan and New Zealand fields overlie current subduction zones; Pathe, Mexico, and Yellowstone Park lie on classic transform fault zones where they pass under the continents; Imperial Valley, California - Cerro Prieto, Mexico, the Italian fields, Iceland, and East Africa fields are over spreading zones.

To date nobody is positive about the "plate tectonics" of the continent around southwestern B.C., however the following are elements of the leading thoughts: (1) the Mt.Cayley - Meager Mt. - Bridge River zone is a volcanic mountain chain over a formerly active subduction zone, which possibly originated off the west coast of Vancouver Island (2) the Fraser-Yalakom-Lillooet fault system is probably a manifestation of an underlying transform fault system similar to the Queen Charlotte system, (3) the East Pacific rise either dies out or disappears under the continent in British Columbia. The point is that whatever their geometry and origin, there are several boundary faults of plate fragments in southwestern B.C., and abundant opportunity for centres of abnormal heat flow.

APPENDIX 'E' - AIRBORNE INFRARED SURVEYS

General

Any object at a temperature higher than absolute zero (-273°C) radiates energy in the electromagnetic spectrum. The frequency of this radiation depends upon several factors, but primarily the temperature of the body.

In the range of temperatures found at the earth's surface electromagnetic radiation has a spread of frequencies with a mode in the infrared (0.7 to 1000 um wavelength). In some parts of this spectrum radiation is subject to absorption by atmospheric gases but there are two "windows" or spectral bands which are transmitted by the atmosphere, the 3 to 5 micron (um) band and the 8 to 14 micron band. An airborne sensor equipped to detect radiation in either one of these windows can be used to define variations in the temperature of the earth's surface including geothermal anomalies such as volcanos, hot springs, or fumaroles.

To discriminate between true thermal anomalies and the effects of solar heating or reflection the airborne infrared survey must be flown at night or in the very early hours of the morning. Re-radiated energy from an object in direct sunlight obscures even intense geothermal heat sources in a matter of minutes.

Two types of targets might be sought by airborne infrared surveys. The first is a broad but low amplitude high, i.e. an area of a mile or more across which has a natural surface temperature a few degrees centigrade greater than the surrounding country. The second is a high amplitude spike, such as a hot spring area of a few thousand square feet with a temperature 40 or 50°C above its surroundings. Because of the interference caused by heavy snow in the winter, a pervasive cold blanket of surface and ground water run off in the springtime, and high incidence of direct sunlight in the summer, any attempt to distinguish a broad low amplitude temperature anomaly could only be done in the fall in an area with the climate of British Columbia. Low level, high resolution airborne infrared to identify point sources of heat can be undertaken at almost any time of the year subject, however, to favourable weather, sunlight and run-off conditions. Internationally airborne infrared surveying has encountered both success and failure, but given adequate control it can be used to provide considerable information, particularly in the relatively underdeveloped and rugged terrain of B.C.

Details of Survey

During April 1974 a contract was let to Integrated Resources Photography Ltd. of Vancouver, B.C. to carry out low level infrared scanning of known, rumoured, and inferred geothermal areas. At various times two scanners were used: an AGA Thermovision Model 680 infrared scanner equipped with a 3-5 micron sensing unit on loan from B.C. Hydro and Power Authority, and an AGA 750 on loan from the manufacturer. Infrared/

Infrared imagery from the scanner's video display was photographed with a 35 mm. motor Nikon camera synchronized with a 70 mm. aerial camera which took simultaneous black and white vertical air photographs for ground control. Details of instrumentation follow in a brief by P.Williams of Integrated Resources Photography.

Integrated Resources Photography supplied the pilot, aircraft, and supporting equipment and Nevin Sadlier-Brown Goodbrand provided a geologist familiar with the survey, as camera operator. The scanning was all done in the early morning between 5 and 7 a.m. About 20 hours of flying time were logged and some 450 line miles were scanned at altitudes of between 1000 and 6000 feet above ground level. Each camera took 750 exposures and 213 were selected for printing. The scanner's video display was monitored continuously but the cameras were started at the operator's discretion, only in response to an observed warm spot or other area of interest.

Flight lines followed river and stream valleys for the most part as hot springs tend to occur at or near valley bottoms or to flow into them (see Drawings C1 through C10 for locations). An effort was made to fly all valleys in the vicinity of either known thermal springs or volcanic centres as well as those selected on the basis of air photo and satellite geological interpretation. The survey was suspended after about half of the target terrain had been covered, owing to chronic poor weather and growing solar reflections as the days lengthened.

A summary of the areas covered with the scanner is as follows:-

Shown on Map Sheet	Area
C1	Bridge Glacier Area
C1	Manatee Creek
C1	Salal Creek
C1	Meager Mountain Area
C1	Meager Creek Valley
C1, 4, 8.	Lillooet River Valley northeast bank, parts of southwest bank.
C3	Mount Cayley Area
C3	Ryan River Valley
C3 - 6	Cheakamus River Valley
C4	Green River Valley
C4	Lillooet Lake northeast bank
C6	Mt.Murchison Area (near Squamish)
C7	Tuwasus Creek Valley
C8	Sloquet Valley
C8	Glacial Lake - Snowcap Creek Valley
C9, 10	Harrison Lake shores
C10	Harrison River Valley

In addition to the above parts of the Squamish, Cheakamus and Fraser Valleys were scanned during trips to and from the work area.

After/

After developing, film negatives of the scanners video image were examined and those considered to be of interest were printed along with the corresponding vertical air photographs. Scales were kept approximately the same as an aid in locating and identifying thermal anomalies. In most cases these were rejected as they were found to be sun warmed outcrops, ponds, or gravel bars with several small warm spots attributable to body heat from animals.

Two well known thermal springs, Harrison and Skookumchuck, were flown mainly for the purpose of tuning the scanner and familiarizing the operator with the characteristics of a thermal anomaly. The data were also used to search for new vents which may have gone undetected on the ground. In both of these cases, however, these results were negative.

Results from other thermal spring areas have been compiled and used to determine the location and distribution of spring vents (see figures of Meager and Pebble Creek Hot Springs) and in several cases prospective new springs may have been detected (see section 5.3 for details).

AIRBORNE OPERATION OF AN INFRARED SCANNER

This brief to Nevin, Sadlier-Brown Goodbrand Ltd. describes the airborne use of an AGA Model 680 Thermosvision infrared scanner during May 1974. This brief is restricted to a description of the hardware installation, operational difficulties encountered, and recommended modifications for future operations.

AIRCRAFT:

Cessna 180 on wheels configured into a two seat light remote sensing vehicle.

INSTRUMENT PLATFORM

Vibration isolated platform capable of being oriented in roll, pitch and azimuth.

NAVIGATION

(I) Closed circuit video with camera slaved to the main instrument platform in roll and azimuth, and capable of rotation to view forward or down. The 9" video monitor may be viewed by both the pilot and the navigator/operator.

(II) Vertical looking wide angle optical sight.

SENSOR PACKAGE

Infrared sensor

Aga model 680 Thermovision instrument sensing in the 3 to 5 μm wave band using a 10° field angle lens.

Visual sensor

Vinten 70 mm reconnaissance camera with 20° field angle lens, exposing Kodak Tri-X aerographic film.

Infrared image recording

35 mm Nikon F250 camera.

POWER SUPPLY FOR INFRARED SCANNER

The airborn project was started using a rotary inverter with 115 VAC 250 VA 400 Hz output. During operations, the rotary inverter was replaced with a solid state inverter with 115 VAC 250 VA 400 Hz output. The power supply for the infrared scanner draws from the aircraft's 28 VDC 50 amp power supply.

SENSOR FITMENT AND OPERATION

An adapter was constructed to fit the infrared sensor and the 70 mm reconnaissance camera onto the instrument platform. The infrared sensor and the camera were aligned vertically. Liquid nitrogen was pumped from a one litre thermos reservoir into the instrument's dewar flask.

The operator sits across the aircraft. In this position, he is within reach of camera control console and video navigation monitor by turning to the right, and he can view and control the infrared instrument by turning left.

The system as used is suitable for direct viewing by the user, with cameras to record the heat image and the visual scene.

OPERATIONAL PROBLEMS

Field of view:

The very narrow (10°) field of view of the infrared sensor is a serious constraint. The system is reduced from a tool that can be sent aloft to gather and return data into a device that should be operated in the air by the user of the data.

Power supply

When the infrared instrument was powered by the rotary inverter, the image had highly accentuated video scan lines. When powered by the solid state inverter, the scan lines returned to normal, but a bothersome standing wave density pattern was superimposed on the heat image.

Because both the infrared scanner and the cameras were operated from the 28 VDC aircraft battery, the exposure of the two cameras affected the voltage to the scanner, momentarily altering the heat image as it was being recorded.

Synchronization of the CRT scan with recording camera

Because the exposure time of the camera recording the heat image is similar to the heat image scan rate, lack of synchronization between these devices caused a randomly located light bar to appear diagonally over approximately 20% of the image area.

RECOMMENDATIONS FOR FUTURE OPERATIONS

The recommendations flow from the operational problem described above.

To permit block coverage along predetermined flight lines, the infrared scanner should have a 45° field angle lens. To permit normal level flight while following features such as streams, the scanner should have a 20° field angle lens.

A solid state inverter should be used to power the infrared scanner. It is anticipated that adjustment of the power supply frequency will remove the objectionable standing wave density pattern. The cameras should be powered from a separate battery, or some other isolation technique to prevent interference with the infrared heat image.

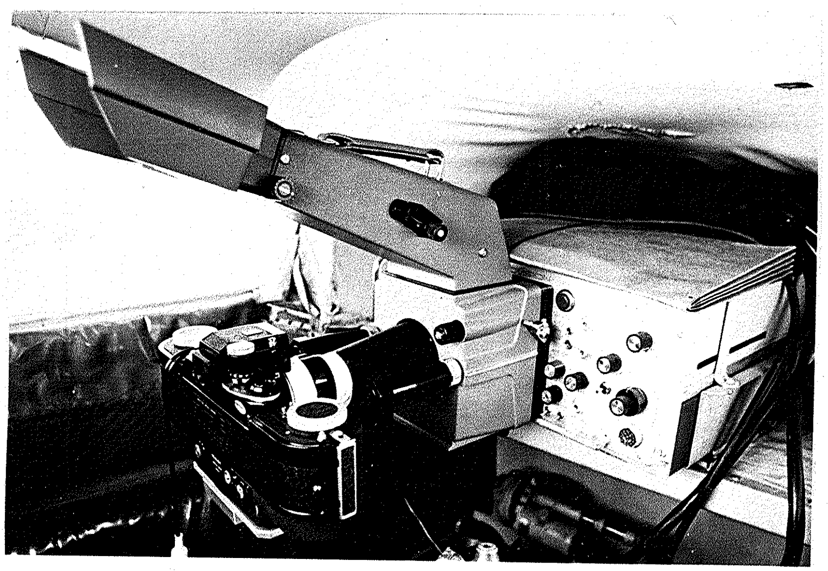
The infrared image recording camera should be synchronized with the scan rate of the infrared cathode ray tube to record a good image.

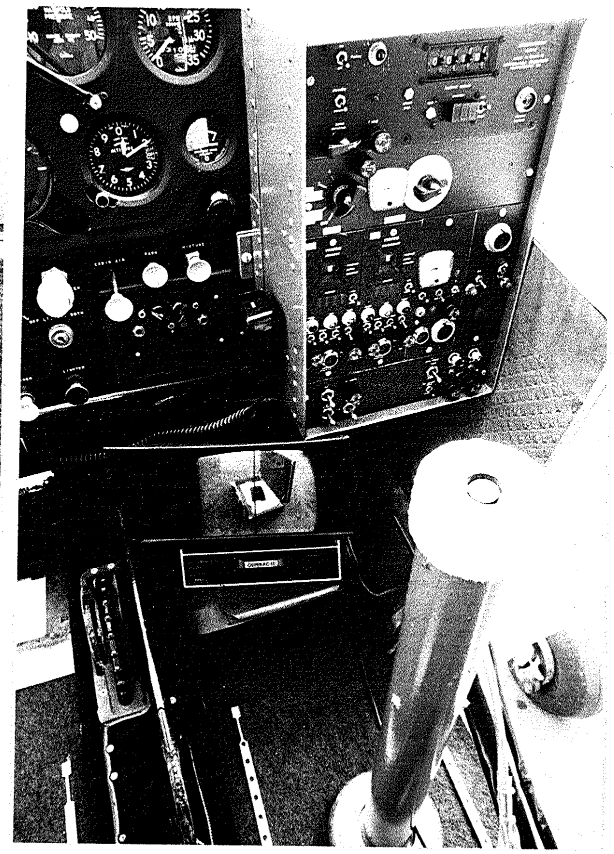
Original Signed by:

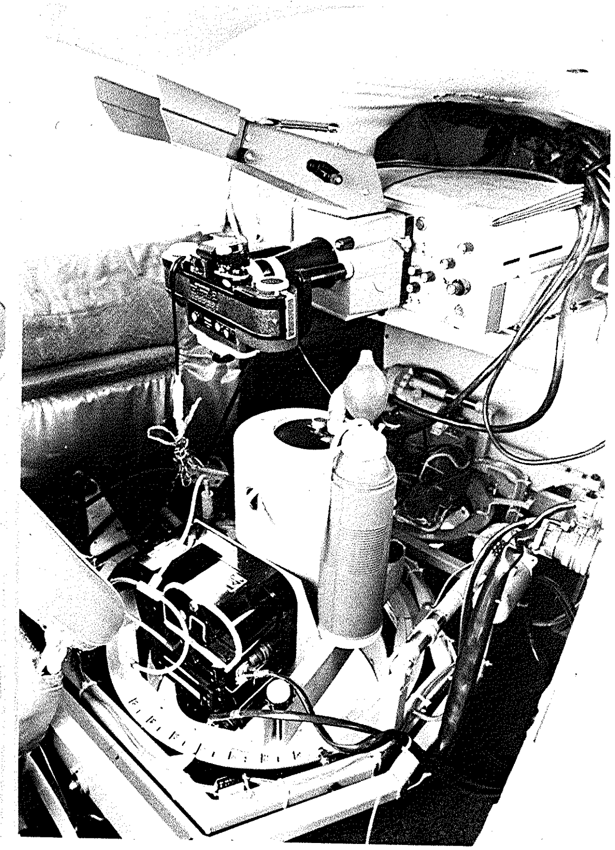
Parker Williams
Integrated Resources Photography Ltd.

26th June, 1974.

AIRBORNE INSTALLATION OF INFRARED SCANNING EQUIPMENT







<u>Top Left</u>: Cessna 180 Survey Aircraft.

<u>Lower Left</u>: Motor Nikon 35mm. Camera Mounted on AGA 680 Scanner Console - Image can be viewed through hood in upper left corner.

<u>Above:</u> Camera Control Console mounted on aircraft instrument panel above Monitor for TV navigation system.

<u>Above right</u>: from top to bottom: Scanner Console and Camera, vertically mounted infrared sensor with thermos of liquid nitrogen, and 70 mm. Vinten Camera, isolated platform holding camera and scanner.

APPENDIX 'F' - GEOCHEMISTRY

1.0. FORMULAS

There are two chemical systems, which can be measured in a hot spring, which have memory of the hottest temperature which the fluid may have reached in an underlying reservoir. The basic formula for the first of these, which makes use of the ratio between sodium, potassium, and calcium, is as follows:-

$$T^{o}C = \frac{1647}{\log \frac{Na}{K} + (B \log \frac{\sqrt{Ca}}{Na}) + 2.24} - 273$$

Where Na,K,Ca = molality of ionic species and where the rational number B = 1/3 for equilibrium temperature above 100°C and 4/3 below 100°C.

This relationship is empirical and it is based on the equilibrium constants between the various feldspars under conditions of high pressure and temperature. Because it is a ratio, it is relatively insensitive to dilution of the hot springs by surface waters.

The second chemical thermometer is the absolute silica content, which is based on the equilibrium of the hot water with quartz (see following drawing). It owes its utility to the fact that upon rapid cooling the reaction which would tend to precipitate excess silica becomes increasingly sluggish. This can lead to an excess amount of silica in meta-stable solution in the hot spring. Absolute silica content is sensitive to dilution of the thermal water by cold surface water, but a "mixing model" can be applied (making certain assumptions), and an estimate of the reservoir's temperature may be obtained.

The principal formula relating silica content to temperature is as follows:-

$$T^{o}C = \frac{1309}{5.19 - (\log SiO_2)} - 273$$

Where SiO_2 = silica content in ppm or mg/l.

This formula translates to the curve shown on Drawing D2.

The mixing model is based on this curve and follows the two formulas as shown below:-

x =/

$$x = \frac{H_{\text{res. water}} - H_{\text{spring}}}{H_{\text{res. water}} - H_{\text{cold water}}}.$$

$$x = \frac{SiO_2 \text{ res. water} - SiO_2 \text{ spring}}{SiO_2 \text{ res. water} - SiO_2 \text{ cold water}}.$$

Where x = fraction of cold water mixed to form hot spring, 1 -x = fraction of hot reservoir water mixed; where H_{spring}, $H_{\text{cold water}}$, SiO_2 spring and SiO_2 cold water are known; and $H_{\text{res. water}}$ and SiO_2 res. water are assumed for unique solution of x.

2.0. SAMPLING PROCEDURE

The following information is noted at each sample location:-

1) An estimate of the flow of the vent or stream.

2) The pH of the sample (measured with a Fisher Accumet battery operated pH meter).

3) The temperature of the stream or vent (measured with a tele-thermometer.

4) The measure of the chloride ion concentration (using a Quantab Chloride Titrator. This is a self acting capillary column which provides colorimetric results).

5) A description of the geology of the area surrounding the hot springs.

6) A sample is taken of any hot spring deposits present.

7) The following samples are taken at each location and are prefixed with a letter denoting the sample location:-

    1) 500 mls. of sample filtered thru a 450 micron filter to remove organic and other debris.

    2) 50 mls. of sample filtered and diluted with 450 mls. of distilled water. The dilution prevents the precipitation of SiO_2 upon cooling which can result in erroneous analyses.

    3) filtered and undiluted, being 495 mls. of sample plus 5 mls. of concentrated HNO_3. The acidification is required to hold the Na, Ca and K in solution thereby preventing precipitation and erroneous analyses.

4)/

4) additional samples:-

one 500 ml. filtered sample is taken of cold surface water at as many locations as possible which might represent mixing water.

8) Analysis:-

Sample # 1 is analyzed for the following ions and complexes:-

HCO_3, Cl, SO_4, CO_3 and Hg. In addition a spectrographic analysis is run on this sample for some 30 additional elements.

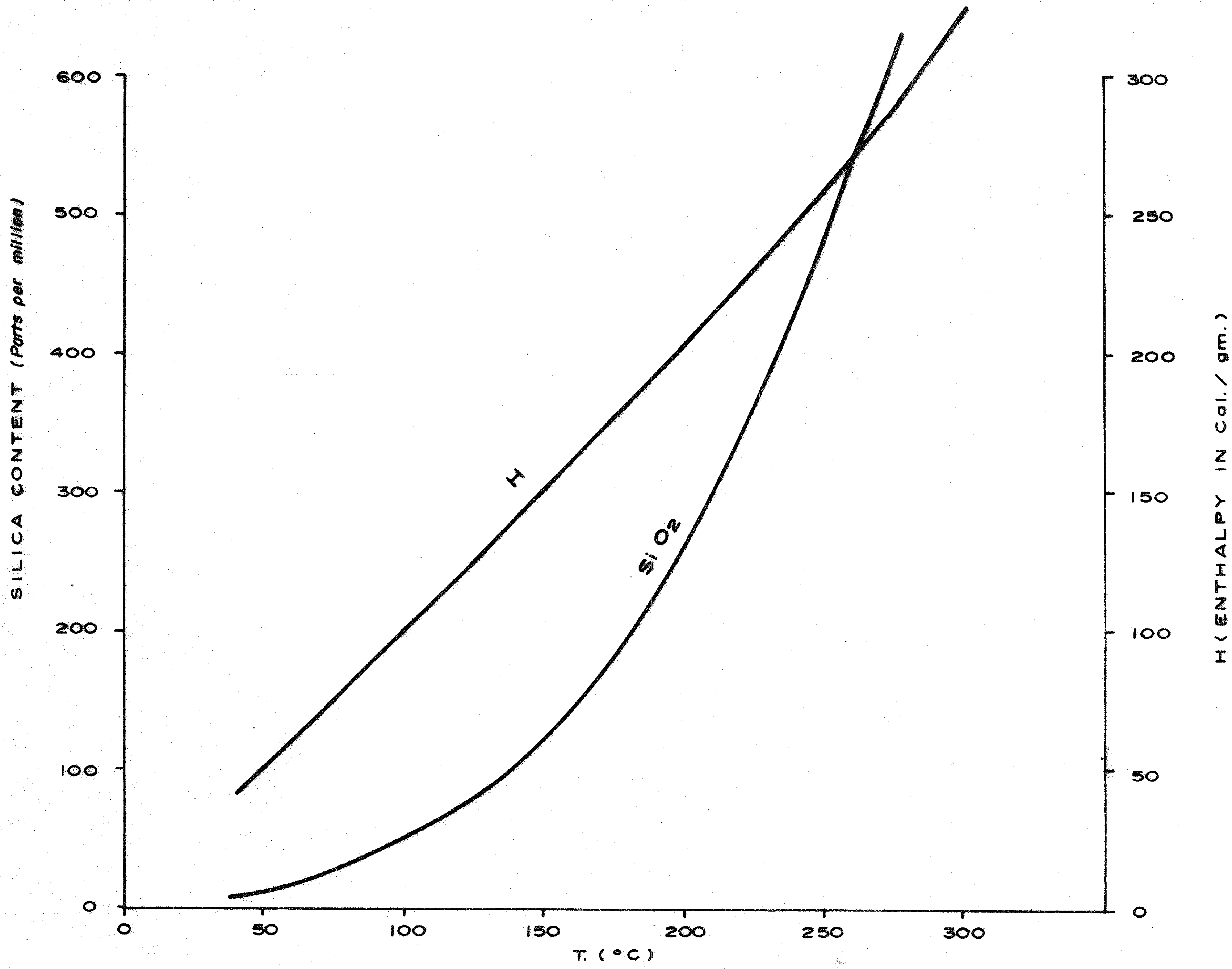
Sample # 2 is analyzed for SiO_2 and calculated back to ppm in the original sample.

Sample # 3 is analyzed for Na,K,Ca and Mg.

Sample # 4 is analyzed for SiO_2, in some instances Na,K, Ca and other elements.

3.0. RESULTS

Quantitative analyses are given in the following Table # 3. Original spectrographic analysis sheets are reproduced directly in this Appendix.



RELATIONSHIP BETWEEN SILICA CONTENT OF HOT WATER IN EQUILIBRIUM WITH QUARTZ AT VARYING TEMPERATURES AND ENTHALPY AT VARYING TEMPERATURES

DRAWING - D2

TABLE 3 - SUMMARY OF GEOCHEMICAL ANALYSES

Area	Sample No & Description	Date Taken	Est.Flow litres/min.	Measured Temp °C	pH	Analysis (parts per million)											
						HCO_3	CO_3	SO_4	Cl	SiO_2	Na	K	Ca	Mg	Hg	Li	F
Meager Ck.	Meager Ck. main vent	Jan 5/74	500	59	6.1-6.3	468		110	675	164	450	47	81	25		1.2	<1.0
Meager Ck.	MDH - 1 GSC Drill Hole	Mar. 29/74				513			650		430	27	85				
Meager Ck.	MDH - 2 GSC Drill Hole.	Mar. 29/74									440	27	85				
Meager Ck.	MDH - 3 GSC Drill Hole.	Mar. 29/74								151							
Pebble Ck.	Pebble Ck. main vent.	Jan 5/74	100	60	7.9-8.1	757		<1	100	75.5	425	14.5	30	4.7		.7	5.0
Skookumchuck	Skookumchuck S-1 main vent	Apr. 5/74	40	54	8.4	15.8		420	340						.5		
Skookumchuck	Skookumchuck S-2 main vent	Apr. 5/74								62							
Skookumchuck	Skookumchuck S-3 main vent	Apr. 5/74									240	5	130	<.2			
Skookumchuck	T-1 - Cold Ck. (mixing water).	Apr. 5/74								5.5	3.6	<1	5.0				
Sloquet	Sloquet main vent SL-1.	May 21/74	100	64	8.3-8.5	14.8	14.6	440	40								
Sloquet	Sloquet main vent SL-2	May 21/74								59							
Sloquet	Sloquet main vent SL-3	May 21/74									112	3.4	76	<.2			
Sloquet	Sloquet SL-4(mixing water).	May 21/74		5						5.2	1.0	.6	4.0	.2			
Clear Ck.	Clear Ck. C-1 main vent	Mar 25/74	50	43	-	30.9	2.2	144	60						.6		
Clear Ck.	Clear Ck. C-2 main vent	Mar 25/74								58							
Clear Ck.	Clear Ck. C-3 main vent.	Mar 25/74									70	2	24	<.2			
Clear Ck.	Clear Ck. D-2 small vent	Mar 25/74								46							
Clear Ck.	Clear Ck. D-3 small vent.	Mar 25/74									60	2	23	<.2			
Harrison	Harrison Hot spring H-1 main v.	Feb 20/74	250	63	8.0-8.5	24.8	1.7							<.2		.12	
Harrison	Harrison Hot spring H-2 main v.	Feb. 20/74								54.2							
Harrison	Harrison Hot spring H-3 main v.	Feb. 20/74						506			350	13	83				
Harrison	I-1 Cold Ck. (mixing v.)	Feb 20/74	200	4	6.8-7	7.4								.2		<02	
Harrison	I-2 Cold Ck. (mixing v.)	Feb 20/74								4.41							
Harrison	I-3 Cold Ck. (mixing v.)	Feb 20/74						< 1			.6	.2	1.5				
Harrison	J-1-Harrison Lake	Feb 20/74		7.7	7	17.6								.5		<02	
Harrison	J-2-Harrison Lake	Feb 20/74								4.41							
Harrison	J-3-Harrison Lake	Feb 20/74						<1			1	.5	5.8				

ANALYSES BY CHEMEX LABS LTD., NORTH VANCOUVER, B.C.

CHEMEX LABS LTD.

.12 BROOKSBANK AVE.
NORTH VANCOUVER, B.C.
CANADA
TELEPHONE: 985-0648
AREA CODE: 604

• ANALYTICAL CHEMISTS • GEOCHEMISTS • REGISTERED ASSAYERS

CERTIFICATE OF ANALYSIS

TO: Nevin Sadlier Brown Goodbrand Ltd.,
5th Flr. 134 Abbott St.,
Vancouver, B. C.

ATTN:

CERTIFICATE NO. SP 105
INVOICE NO. 11401
RECEIVED
ANALYSED May 28/74

SAMPLE NO. :	Lower Concentration Limit (PPB)	SLOQUET CREEK. HOT SPRING SL 1
Antimony	50	bcl
Arsenic	20	bcl
Barium	5	5
Beryllium	5	bcl
Bismuth	5	bcl
Boron	20	200
Cadmium	20	bcl
Calcium	0.5ppm-200ppm	20 ppm
Chromium	10	bcl
Cobalt	10	bcl
Copper	1	2
Gallium	2	bcl
Germanium	20	bcl
Iron	0.5ppm-200ppm	0.5 ppm
Lead	5	bcl
Magnesium	0.2ppm-100ppm	0.5 ppm
Manganese	5	5
Molybdenum	10	20
Nickel	5	10
Niobium	50	bcl
Silver	1	bcl
Strontium	20	500
Tantalum	200	bcl
Tellurium	200	bcl
Thorium	100	bcl
Tin	20	bcl
Titanium	5	bcl
Vanadium	10	50
Zinc	50	bcl
Zirconium	20	bcl

Concentration Range

>5000 ppb =>5000 ppb	50 ppb = 25-100 ppb
5000 ppb = 2500-10000 ppb	20 ppb = 10-50 ppb
2000 ppb = 1000-4000 ppb	10 ppb = 5-20 ppb
1000 ppb = 500-2000 ppb	5 ppb = 2-10 ppb
500 ppb = 250-1000 ppb	2 ppb = 1-4 ppb
200 ppb = 100-400 ppb	1 ppb = 0.5-2 ppb
100 ppb = 50-200 ppb	bcl = below concentration limit

Ranges for Iron, Calcium & Magnesium are reported in ppm.

CERTIFIED BY: [signature]

212 BROOKSBANK AVE.
NORTH VANCOUVER, B.C.
CANADA
TELEPHONE: 985-0648
AREA CODE: 604

CHEMEX LABS LTD.

• ANALYTICAL CHEMISTS • GEOCHEMISTS • REGISTERED ASSAYERS

RECEIVED 4.4.74.
A.E.N. ✓
D.W.G. ✓
T.L.S.B. ✓

CERTIFICATE OF ANALYSIS

TO: Nevin Sadler-Brown Goodbrand Ltd.,
5th flr. 134 Abbott St.,
Vancouver, B. C.

ATTN:

CERTIFICATE NO. SP 100
INVOICE NO. 11221
RECEIVED
ANALYSED April 3/74

SAMPLE NO. :	Lower Concentration limit (PPB)	CLEAR CREEK HOT SPRING C-1	SKOOKUMCHUCK HOT SPRING S-1
Antimony	50	bcl	bcl
Arsenic	20	bcl	bcl
Barium	5	5	50 PPB
Beryllium	5	bcl	bcl
Bismuth	5	bcl	bcl
Boron	20	1000	500 PPB (Boro-silicate glassware)
Cadmium	20	bcl	bcl
Calcium	0.5-200 PPM	20 PPM	200 PPM
Chromium	10	bcl	bcl
Cobalt	10	bcl	bcl
Copper	1	5	bcl
Gallium	2	bcl	bcl
Germanium	20	bcl	bcl
Iron	0.5-200 PPM	<0.5 PPM	<0.5 PPM
Lead	5	20	bcl
Magnesium	0.2-100 PPM	<0.2 PPM	<0.2 PPM
Manganese	5	bcl	bcl
Molybdenum	10	50	200 PPB
Nickel	5	10	bcl
Niobium	50	bcl	bcl
Silver	1	bcl	bcl
Strontium	20	500	10,000 PPB
Tantalum	200	bcl	bcl
Tellurium	200	bcl	bcl
Thorium	100	bcl	bcl
Tin	20	bcl	bcl
Titanium	5	bcl	bcl
Vanadium	10	50	500 PPB
Zinc	50	bcl	bcl
Zirconium	20	bcl	bcl

Concentration Ranges Reported

>5000 ppb =>5000 ppb	50 ppb = 25-100 ppb
5000 ppb = 2500-10000 ppb	20 ppb = 10-50 ppb
2000 ppb = 1000-4000 ppb	10 ppb = 5-20 ppb
1000 ppb = 500-2000 ppb	5 ppb = 2-10 ppb
500 ppb = 250-1000 ppb	2 ppb = 1-4 ppb
200 ppb = 100-400 ppb	1 ppb = 0.5-2 ppb
100 ppb = 50-200 ppb	bcl = below concentration limit

Ranges for Iron, Calcium & Magnesium are reported in PPM

CTA MEMBER CANADIAN TESTING ASSOCIATION

CERTIFIED BY: [signature]

212 BROOKSBANK AVE.
NORTH VANCOUVER, B.C.
CANADA
TELEPHONE: 985-0648
AREA CODE: 604

CHEMEX LABS LTD.

• ANALYTICAL CHEMISTS • GEOCHEMISTS • REGISTERED ASSAYERS

CERTIFICATE OF ANALYSIS

CERTIFICATE NO. SP 90
INVOICE NO. 11060
RECEIVED
ANALYSED Jan. 15/74

TO: Nevin Sadler-Brown Goodbrand Ltd.,
5th flr 134 Abbott St.,
Vancouver B. C.
V68 2K4

ATTN:

SAMPLE NO. :	Detection Limit PPB	MEAGER CREEK HOT SPRING. M	PEBBLE CREEK HOT SPRING. P
Antimony	100	bdl	bdl
Arsenic	200	bdl	bdl
Barium	10	100	10
Beryllium	10	bdl	bdl
Bismuth	10	bdl	bdl
Boron	50	2000	1000
Cadmium	50	bdl	bdl
Chromium	20	bdl	bdl
Cobalt	20	bdl	bdl
Copper	1	2	bdl
Gallium	5	bdl	bdl
Germanium	50	bdl	bdl
Hafnium	500	bdl	bdl
Indium	20	bdl	bdl
Lead	10	bdl	bdl
Manganese	10	200	10
Mercury	1000	bdl	bdl
Molybdenum	20	bdl	100
Nickel	10	bdl	bdl
Niobium	100	bdl	bdl
Silver	1	bdl	bdl
Strontium	50	bdl	bdl
Tantalum	500	bdl	bdl
Tellurium	50	bdl	bdl
Thorium	200	bdl	bdl
Tin	50	bdl	bdl
Titanium	10	bdl	bdl
Vanadium	20	50	bdl
Zinc	100	bdl	bdl
Zirconium	50	bdl	bdl

Note: Boron results are probably high due to evaporation of a portion of the solution to dryness in boro silicate glassware.

CONCENTRATION RANGE LEGEND

>5000 PPB	= >5000 PPB	50 PPB	= 25-100 PPB
5000 PPB	= 2500-10000 PPB	20 PPB	= 10-40 PPB
2000 PPB	= 1000-4000 PPB	10 PPB	= 5-20 PPB
1000 PPB	= 500-2000 PPB	5 PPB	= 2.5-10 PPB
500 PPB	= 250-1000 PPB	2 PPB	= 1-4 PPB
200 PPB	= 100-400 PPB	1 PPB	= 0.5-2 PPB
100 PPB	= 50-200 PPB	0.5 PPB	= 0.2-1 PPB
		bdl	= below detection limit

Concentration in filtered water sample.

CTA MEMBER CANADIAN TESTING ASSOCIATION

CERTIFIED BY: R. J. Jones

212 BROOKSBANK AVE.
NORTH VANCOUVER, B.C.
CANADA
TELEPHONE: 985-0648
AREA CODE: 604

RECEIVED 5.3.74
A.E.N.
D.W.G.
T.L.S.B.

CHEMEX LABS LTD.

• ANALYTICAL CHEMISTS • GEOCHEMISTS • REGISTERED ASSAYERS

CERTIFICATE OF ANALYSIS

CERTIFICATE NO. SP 93
INVOICE NO. 11147
RECEIVED
ANALYSED March 1/74

TO: Nevin Sadler-Brown Goodbrand Ltd.,
5th flr. 134 Abbott St.,
Vancouver, B. C.

ATTN:

HARRISON HOT SPRINGS.

SAMPLE NO. :	Lower Concentration Limits PPB	H-3 Water Sample
Antimony	200	bdl
Arsenic	500	bdl
Barium	20	bdl
Beryllium	20	bdl
Bismuth	20	bdl
Boron	100	2000 ppb
Cadmium	100	bdl
Calcium	1 ppm	50 ppm
Chromium	50	bdl
Cobalt	50	bdl
Copper	3	10 ppb
Gallium	10	bdl
Germanium	100	bdl
Iron	1 ppm	<1 ppm
Lead	20	100 ppb
Magnesium	0.5 ppm	<.5 ppm
Manganese	20	bdl
Molybdenum	50	50 ppb
Nickel	20	bdl
Niobium	200	bdl
Silver	2	bdl
Strontium	100	2000 ppb
Tantalum	1000	bdl
Tellurium	100	bdl
Thorium	500	bdl
Tin	100	bdl
Titanium	20	bdl
Vanadium	50	50 ppb
Zinc	200	bdl
Zirconium	100	bdl

"Metal Concentration in water."

duplicate sheet

CONCENTRATION RANGE LEGEND

>5000 PPB =	>5000 PPB	50 PPB =	25-100 PPB
5000 PPB =	2500-10000 PPB	20 PPB =	10-40 PPB
2000 PPB =	1000-4000 PPB	10 PPB =	5-20 PPB
1000 PPB =	500-2000 PPB	5 PPB =	2.5-10 PPB
500 PPB =	250-1000 PPB	2 PPB =	1-4 PPB
200 PPB =	100-400 PPB	1 PPB =	0.52-2 PPB
100 PPB =	50-200 PPB	bcl =	Below concentration limit

Ranges for Calcium, Iron & Magnesium are reported in PPM rather than PPB

CTA MEMBER CANADIAN TESTING ASSOCIATION

CERTIFIED BY: [signature]

APPENDIX 'G'

COMPARATIVE INVESTIGATION OF SURFACE SAMPLES FROM THE GEYSERS AREA, CALIFORNIA AND FOUR HOT SPRING LOCALITIES IN SOUTHWESTERN BRITISH COLUMBIA

Peter B. Read
Department of Geological Sciences,
University of British Columbia, Vancouver 8, B. C.

A comparison of surface samples from the Geysers Area, California and four hot spring localities (Meager Creek, Pebble Creek, Skookumchuck, and Sloquet Creek) in southwestern British Columbia indicates:

1. Chemical Precipitates (sinters) differ. Precipitates from the Geysers consists of silica (quartz, cristobalite, opal), alunite, and hematite whereas those from three southwestern British Columbia hot springs are calcite-rich. Sinters from Meager and Sloquet Creeks contain opal.
2. Bedrock alteration involves extensive silicification in the Geysers area but none in the southwestern British Columbia localities.

A cursory comparison of surface alteration from geothermal areas in Italy, Japan, New Zealand, and United States shows opal or cristobalite characterise all and sulphates such as alunite, jarosite and locally anhydrite are present in many geothermal areas.

The absence of silica in the surface precipitates and presence of abundant calcite in the sinters from Skookumchuck and Pebble Creek indicate these springs originate from a hot water rather than a vapour-dominated system. At Sloquet and Meager Creeks, the presence of opal in the sinter and high chloride at Meager Creek hot spring indicate a hot-water dominated system. The combination of water chemistry and siliceous sinters at Meager and Sloquet Creeks support their priority in further investigations of the geothermal potential of the four hot springs examined in southwestern British Columbia.

TABLE OF CONTENTS

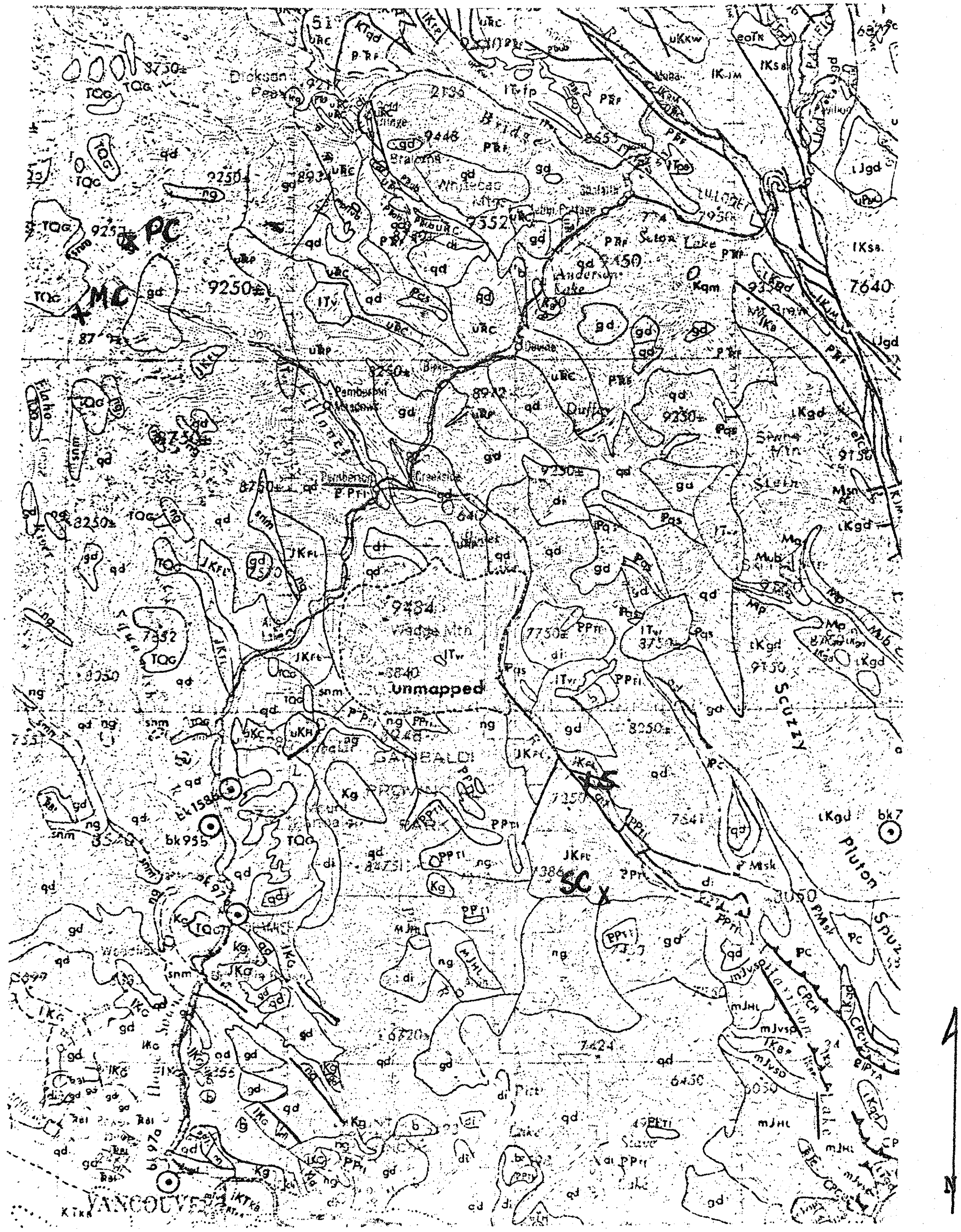
NOTE

Dr.Read's Appendix I is omitted from this final report and Appendix III is reported in Appendix 'F'.

Introduction:

The purpose of this investigation is to compare the surface alteration and mineralogy of the chemical precipitates from an economic geothermal area, The Geysers, California, with the alteration and mineralogy of surface samples from four hot spring areas in southwestern British Columbia. Results of the comparison may yield a quick, inexpensive method for making a preliminary assessment of the geothermal potential of hot spring areas.

Dr. A. Nevin provided eleven surface samples from The Geysers area, California and from southwestern British Columbia areas: 2 samplesfrom Meager Creek, 6 samples from Pebble Creek, 2 samples from Skookumchuck, and 3 samples from Sloquet Creek (Fig. 1). For the Geysers area, Garrison (1972) has summarized the geology of the highly deformed Franciscian and Great Valley Sequences overlain by Pleistocene volcanics and cut by later faults. Roddick (1965) and Okulitch (1973) have summarized the regional geology of an area which includes the four hot springs investigated in southwestern British Columbia (Fig. 1). Northwest of Harrison Lake, Sloquet Creek and Skookumchuck hot springs issue in an area of Mesozoic and older volcanics intruded by Mesozoic granitic rocks. Skookumchuck is close to northwest trending faults of probable mid-Cretaceous age. Northwest of Pemberton, Meager and Pebble Creek hot springs lie in granitic rocks of the Coast Plutonic Complex with small septa of metamorphic rocks. A large volcanic centre of Pleistocene to Recent age lies near the Meager Creek locality.



16 miles

Figure 1

Regional geology map of the four hot spring areas of southwestern British Columbia. (Taken from Okulitch, 1973).

LEGEND

x MC	Meager Creek	TQ_G	(Pliocene & Pleistocene) Garibaldi Group
x PC	Pebble Creek	JK_{FL}	(Cretaceous & Jurassic) Fire Lake Group
x S	Skookumchuck	PP_{TI}	(Pennsylvanian & Permian) Twin Island Gp.
x SC	Sloquet Creek	ng	migmatic complexes of amphibolite grade
		gd	granodiorite

Samples from Hot Spring Areas in Southwestern British Columbia:

Fourteen samples supplied by Dr. A. Nevin came from the following localities:

(a) Mount Cayley (1 specimen):

A porphyritic andesite with 25% plagioclase (An_{34}), and 2% hornblende phenocrysts which are strongly resorbed. There is no indication of hydrothermal alteration.

(b) Meager Creek (2 specimens investigated):

Two fine-grained hornblende diorite pebbles apparently unaltered. Both pebbles have an encrustation of white, powdery sinter up to 15mm thick with embedded plant debris. The sinter consists of calcite and opal with an $R. I._{measured} = 1.455 \pm 0.01$.

(c) Pebble Creek (6 specimens):

The Pebble Creek sinters consist of fine- to coarse-grained (less than 0.5mm to 3mm) calcite ranging in colour from white to buff. The earthy, tile red coatings on sinters from the "Upper Vent" are amorphous, hydrated iron oxides. These chemical precipitates have embedded twigs. The country rock (PC-QM) is a medium-grained (2 to 4mm) quartz monzonite with plagioclase altered to albite with sericite. The timing of alteration is unknown and need not be related to hot spring activity. Appendix I contains X-ray diffractograms on which mineral identifications are based.

(d) Sloquet Creek (3 specimens):

"Altered" rock (sample SC-2) is a fine-grained (less than 0.1mm) unaltered aplite consisting of quartz, andesine and 5% biotite partly altered to chlorite. Sample SC-1 may be an altered aplite consisting of coarse-grained quartz veins to 15mm in width cutting a buff, fine-grained (0.1mm) rock of quartz and potash feldspar with 2% muscovite. Samples SC-1 and SC-2 have a thin (2mm), white encrustation of gypsum and opal with a $R. I._{measured} = 1.455 \pm 0.01$. The timing of alteration of specimen SC-1 is unknown and may not be related to hot spring activity.

(e) Skookumchuck (2 specimens):

Recent pebble conglomerate consisting of 3 to 12mm subrounded pebbles encrusted and cemented by calcite. The calcite forms a partial to complete filling of open spaces between the pebbles. Appendix I contains X-ray diffractograms on which mineral identifications are based.

Samples from The Geysers Area, California:

The following general description is based on a detailed optical and Xray diffraction study of eight surface samples collected in the vicinity of the Geysers geothermal area of California. For descriptions of individual specimens see Appendix II and for supporting X-ray diffractograms see Appendix I.

Most specimens have a porous, earthy texture and are poorly indurated. The rocks range in colour from white through yellow and ochre to tile red. Several of the specimens are silicified "lithic tuffs" but many of the specimens have no primary textures and could be chemical precipitates (Specimens G-3 and G-5 to G-8 inclusive). Silica dominates the mineralogy of these rocks and in the light coloured rocks composes 80% or more of the rock. Quartz is most common, but opal cristobalite and minor tridymite are present. Either quartz or opal form white siliceous sinters. Yellow and ochre coloured specimens contain major silica polymorphs and minor amounts of alunite and jarosite. Tile red specimens contain silica, alunite, jarosite, and hematite. Much of the quartz has recrystallized from chalcedony or tridymite which is pseddomorphs. Clay minerals form less than 15% of the rock and are celadonite or illite.

Comparison of Surface Samples from Geysers Area, California to Some Southwestern British Columbia Hot Spring Areas:

Surface samples from the Geysers Area, California and those from Pebble, Meager, and Sloquet Creeks and Skookumchuck differ in the following aspects:

1. Chemical Precipitates (Sinters):

In the Geysers Area, the principal precipitate is silica in order of decreasing abundance as quartz, cristobalite, opal and minor tridymite. Alunite and hematite are locally important and jarosite is minor. At Pebble Creek and Skookumchuck, calcite and locally amorphous hydrated iron oxides form sinters and cemant debris. At Meager Creek, calcite and minor opal encrust pebbles and at Sloquet Creek, gypsum and minor opal encrust outcrops.

2. Bedrock Alteration:

"Lithic" tuffs from the Geysers Area are extensively silicified which partly destroys the original clastic texture of the tuffs. In contrast, the "altered bedrock" from Sloquet and Pebble Creeks are little altered to unaltered and the development of quartz veins at Sloquet Creek is not necessarily related to hot spring activity.

Important differences among these areas, are the abundance of silica and sulphate precipitates from the Geysers and their limited development in two of the southwestern British Columbia hot spring areas. The abundance of calcite in the southwestern British Columbia localities implies low subsurface temperatures in a hot-water system (White, 1973). The absence of silica in the sinters of Skookumchuck and Pebble Creek substantiates this conclusion for only these two localities.

The lack of bedrock alteration at the surface results from:

1. The low temperature of the hot springs (about 60°C) causing precipitation which prevents bedrock-hot water interaction and rock alteration.

2. Recent glaciation which may have changed hot spring flow patterns within the last several thousand or less years.

3. An absence in southwestern British Columbia areas of glassy to aphanitic, permeable volcanic units which would be unstable and alter readily.

For these reasons, the lack of bedrock alteration at the surface is not an important difference.

Survey of Surface Alteration from Proven Geothermal Areas:

A cursory survey of surface alteration and mineralogy of sinters from proven geothermal areas in Italy, Japan, New Zealand and United States is given in Table 1. This shows the importance of silica and sulphates in preciptitates of all areas. In the Larderello area, the importance of calcite in the sinter results from the abundance of limestone in the host rocks of the area. The surface alteration of the Geysers, California is typical of proven geothermal areas, and the absence of silica and sulphate precipitates and presence of abundant calcite in southwestern British Columbia localities indicates hot-water systems rather than vapour-dominated systems.

Table 1: Surface Alteration of Known Geothermal Areas

Country and Area	Surface Alteration
Italy, Larderello (1)	anhydrite, ferrous oxides, sulphur, calcite, minor silica, pyrite
Japan, Onikobe (2, 3)	opaline silica, clay, sulphur, pyrite
New Zealand, Ohaki-Broadlands (4)	kaolinite, siliceous sinter
New Zealand, Wairakei (5)	kaolinite, alunite, opal, sulphur
United States, Steamboat Springs Nev. (6, 7, 8)	opaline sinter, beta-cristobalite, pyrite illite, alunite
United States, The Geysers, Calif. (9)	quartz, opal, cristobalite, alunite, jarosite, hematite
United States Upper Geyser Basin, Wyoming (10)	opal, cristobalite

(1) Cataldi, R., G. C. Ferrara, G. Stefani, and E. Tongiorgi (1969)
(2) Seki, Y., H. Onuki, K. Okumura, and I Takashima (1969)
(3) Seki, Y. and K. Okumura (1968)
(4) Browne, P. R. L. and A. J. Ellis (1970)
(5) Steiner, A. (1953)
(6) Sigvaldson, G. E. and D. E. White (1961)
(7) Sigvaldson, G. E. and D. E. White (1962)
(8) Schoen, R. and D. E. White (1965)
(9) This report
(10) Honda, S. and L. J. P. Muffler (1970)

Water Chemistry from Hot Spring Areas in Southwestern British Columbia:

Water chemistry allows an estimate of the last temperature of water-rock interaction assuming rapid ascent of the water from the aquifer to the surface. Data for Meager and Pebble Creek waters, supplied by Dr. A. Nevin (Appendix III) allow two independent temperature estimates of the last temperature of water-rock interaction based on the empirical silica geothermometer (Fournier and Rowe, 1966) and the Na-K-Ca geothermometer (Fournier and Truesdell, 1973). For Pebble Creek estimated T_{SiO_2} = 110°C and $T_{Na-K-Ca}$ = 130°C and for Meager Creek estimated T_{SiO_2} = 160 to 170°C and $T_{Na-K-Ca}$ = 185°C (Appendix III). Although Meager Creek locality has high estimated temperatures, the high chloride content of 675ppm indicates Meager Creek hot spring is part of a hot-water system. The high chloride content of Meager Creek hot springs is less than that of the Wairakei geothermal field of New Zealand with an average value of 1320ppm (Wilson, 1955). White (1973) stated that chloride is the most critical single constituent in distinguishing hot-water systems from vapour-dominated systems. Chloride contents in excess of 50ppm definitely indicate a hot-water system (White, 1973). The source of the chloride content of the southwestern British Columbia localities is unknown but some cold spring and stream water analyses should be made. These analyses would provide data for assessing mixing models of meteoric and magmatic waters. Of the world's geothermal power-generating capacity of 1085Mw at the end of 1973, White estimated 270Mw or about 25% of the power-generating capacity comes from hot-water systems.

Assessment of Surface Alteration and Sinters:

The prominence of calcite sinters in hot-water systems and their absence in vapour-dominated systems which are characterized by siliceous sinters (White, 1973) suggests testing the sinter of a hot spring with dilute HCl for calcite would provide an inexpensive, preliminary field assessment of a hot spring. Because opal is amorphous and will not be detected during X-ray investigation, all sinter should be crushed and checked for opal in an oil immersion of R. I. 1.46. Opal ranges in R. I. from 1.42 to 1.46 depending upon its degree of hydration. Oil immersion would provide a quick, inexpensive office check for silica. Further investigations of alteration and sinters require a combination of X-ray, thin section and oil immersion techniques.

References:

Browne, P. R. L. and A. J. Ellis(1970):
The Ohaki-Broadlands Hydrothermal Area, New Zealand: Mineralogy and Related Geochemistry. Amer. Jour. Sci., vol. 269, p. 97-131.

Cataldi, R., G. C. Ferrara, G. Stefani and E. Tongiorgi (1969):
Contribution to the Knowledge of the Geothermal Field of Larderello (Tuscany - Italy). Remarks on the Carboli Area. Bull. Volcano., vol. 33, p. 29-55.

Fournier, R. O. and J. J. Rowe(1966):
Estimation of Underground Temperatures from the Silica Content of Water from Hot Springs and Wet-Steam Wells. Amer. Jour. Sci., vol. 264, p. 685-697.

__________ and A. H. Truesdell (1973):
An Empirical Na-K-Ca Geothermameter for Natural Waters. Geochim et Cosmochim. Acta, vol. 37, p. 1255-1275.

Garrison, L. E. (1972):
Geothermal Steam in The Geysers-Clear Lake Region, California. Bull. Geol. Soc. America, vol. 83, p. 1449-1468.

Honda, S. and L. J. P. Muffler (1970):
Hydrothermal Alteration in Core from Research Drill Hole Y-1, Upper Geyser Basin, Yellowstone National Park, Wyoming. Amer. Mineral., vol. 55, p. 1714-1737.

Okulitch, A. V. (1973):
Fraser River Map-Sheet (2215) 1:1,000,000. Geology. Geol. Surv. Canada, Open File 165.

Roddick, J. A. (1965):
Vancouver North, Coquitlam, and Pitt Lake Map-Areas, British Columbia. Geol. Surv. Canada, Mem. 335.

Schoen, R. and D. E. White (1965):
Hydrothermal Alteration in GS-3 and GS-4 Drill Holes, Main Terrace, Steamboat Springs, Nevada. Econ. Geol., vol. 60, p. 1411-1421.

Seki, Y and K. Okumura (1968):
Yugawaralite from Onikobe Active Geothermal Area, Northeast Japan. Jour. Japan. Assoc. Min. Pet. Econ. Geol., vol. 60, p. 27-33.

__________, H. Onuki, K. Okumura and I. Takashima (1969):
Zeolite Distribution in the Katayama Geothermal Area, Onikobe, Japan. Japan. Jour. Geol. Geog., vol. 40, p. 63-79.

Sigvaldson, G. E. and D. E. White (1961):
Hydrothermal Alteration of Rocks in Two Drill Holes at Steamboat Springs, Washoe County, Nevada. USGS Prof. Paper 424D, p. D116-D122.

__________ (1962):
Hydrothermal Alteration in Drill Holes GS-5 and GS-7, Steamboat Springs, Nevada. USGS Prof. Paper 450D, p. D113-D117.

Steiner, A. (1953):
Hydrothermal Rock Alteration at Wairakei, New Zealand. *Econ. Geol.*, vol. 48, p. 1-13.

White, D. E. (1973):
Characteristics of Geothermal Resources. in *Geothermal Energy. Resources, Production, Stimulation.* edited by P. Kruger and C. Otte, Stanford Univ. Press., p. 69-94.

Wilson, S. H. (1955):
Chemical Investigations. In Grange, L. I. (Compiler), Geothermal Steam for Power in New Zealand. *N. Z. Dept. Sci. Indust. Res.*, Bull. 117, p. 27-42.

APPENDIX II:

Detailed Petrographic Descriptions of Samples from The Geysers Area, California and Four Hot Spring Localities in Southwestern British Columbia

Geysers Area, California:

Thin Section and X-ray Diffraction

Sample G-1: Yellow-ochre coloured, crumbly "lithic tuff" cut by 2mm wide, white to cream veinlets. The "lithic" fragments consist quartz and some cristobalite and opal partly converted to quartz. The veinlets and matrix surrounding the "lithic" fragments are composed of brownish opal (R. I. = 1.43 ± 0.01) with mats of slightly birefringent fibers. Clear cristobalite (R. I. = 1.48 and uniaxial negative) coats opal and rims cavities. Very fine-grained brownish jarosite has high interference colours.

Sample G-2: Well indurated "lithic" tuff composed of fragments less than 2 mm long which consist of polycrystalline quartz pseudomorphing chalcedony (original fibrous nature of chalcedony still visible), cristobalite and possibly tridymite, and locally brownish, slightly birefringent opal. X-ray diffractogram indicates alunite.

Sample G-3: White porous sinter composed of quartz and local brownish spherules of opal (less than 3% of rock).

Sample G-4: Fine-grained, lithic tuff composed of quartz in a matrix of cristobalite, opal and celadonite

****

X-ray Diffraction

Sample G-5: White earthy material which is poorly indurated. It is pure opal with an R. I. 1.43 ± 0.01.

Sample G-6: Porous and earthy material ranging in colour from yellow through ochre to tile red. X-ray diffraction indicates material is composed of major alunite and jarosite and minor quartz, cristobalite and hematite.

Sample G-7: Porous, tile red material of earthy texture. X-ray diffraction indicates major quartz and minor amounts of alunite, hematite and cristobalite.

Sample G-8: A porous, pale tile red specimen consisting of major quartz, less hematite, and minor alunite.

Hot Spring Areas, Southwestern British Columbia:

Mount Cayley Andesite (MC-1): Light grey, porphyritic (plagioclase and minor hornblende.

Pebble Creek Sinter (Upper Vent):

White to light buff, fine-grained crystalline masses of calcite.

Pebble Creek Sinter - Upper Vent:

Coarse (1 to 3mm), laminated masses of calcite with earthy, brick red coating of amorphous, hydrated iron oxides. Local thin coatings of white fibrous calcite. Twigs are embedded.

Skookumchuck:

Subrounded pebbles, 3 to 12mm in dia.., partly encrusted with calcite cement. Pebbles are unaltered. (X-ray and oil immersion).

Sloquet Creek "Altered" Hand Specimen (SC-1):

Yellow to light buff hand specimen consisting of coarse crystalline quartz in veins 1 to 10mm wide cutting a cream coloured porous groundmass of quartz and untwinned orthoclase ($R.I._{measured} = 1.52$ and small $2V_x$). Thin (2mm), white encrustation of mainly gypsum and minor opal.

Sloquet Creek "Highly altered" hand specimen (SC-2):

Light cream, fine-grained (0.1mm) quartz-plagioclase aplite(?) with 5% biotite partly altered to chlorite. Plagioclase is twinned and strongly zoned with an average composition of An_{45}. Thin (2mm), white encrustation of mainly gypsum and minor opal.

Meager Creek:

Two fine-grained, hornblende diorite pebbles with a thick (up to 15mm) encrustation of dominantly calcite and minor opal. Two other pebbles of medium-grained, gneissic quartz monzonite and quartz diorite are not encrusted. All pebbles are unaltered.

APPENDIX 'H'

REPORT

ON THE

RESISTIVITY TEST SURVEYS

at the

SLOQUET AND SKOOKUMCHUCK HOT SPRINGS, LILLOOET - HARRISON LAKES AREA, B.C.

on behalf of

NEVIN SADLIER-BROWN GOODBRAND LIMITED

by

P. P. NIELSEN, B.Sc., Geophysicist

NIELSEN GEOPHYSICS LTD.

VERNON, B.C.

June 5, 1974

TABLE OF CONTENTS

oOo

INTRODUCTION

During the period May 13 - 19, 1974, test horizontal resistivity profiles were carried out along logging roads at two known hot springs between Harrison and Lillooet Lakes, B.C.

The tests were conducted to explore for geothermal reservoirs in the vicinity of the Sloquet and Skookumchuck Hot Springs and to determine optimum resistivity survey parameters for geothermal exploration in other, less accessible areas. Future survey techniques would be influenced by:

(1) Dimensions and depth of the geothermal reservoir;

(2) Access to the survey area;

(3) Surface conditions including topography, vegetation, snow-cover, water courses, etc.;

(4) Cultural effects such as hydro-transmission lines, logging trucks, railway tracks, and steel fences;

(5) Contact resistances at electrodes;

(6) Resistivity contrasts between country and reservoir rocks;

(7) Communications;

(8) Costs.

A total of 6.6 miles of profiles were run over the two areas in four days of actual surveying. The remainder of the time was spent in mobilization-demobilization, moving camp and overcoming some technical difficulties.

LOCATION AND ACCESS (See accompanying map)

The Sloquet Hot Springs is located on the north bank of Sloquet Creek 6.25 miles from its outlet into the Lillooet River 3 miles northwest of the Tipella Logging Camp which is at the head of Harrison Lake.

Access is via a gravel road from Pemberton to the Sloquet Creek bridge, a distance of approximately 50 miles, and thence by abandonned logging road westerly up Sloquet Creek for 6 miles. The abandonned logging road is shown on topographic map sheet N.T.S. 92G9W "Stave River" and the Sloquet Hot Springs is at the co-ordinates 122°19.5' W. Long. and 49°43.7' N. Lat.

The Skookumchuck Hot Spring is located on the northeast side of the Lillooet River roughly midway between Lillooet and Harrison Lakes and is less than 100 yards off the hydro transmission line road which is the same access road used to reach Sloquet. Due to the possible physical danger and high noise interference from the hydro transmission line immediately adjacent to the public road, it was necessary to set up camp across the river and to conduct the survey along a private logging road. Permission to use this road was granted at the Tipella Logging Camp from which the survey vehicles were allowed to follow a logging truck to a point opposite the Skookumchuck Hot Spring. Extreme caution was taken during the survey due to heavy and unpredictable logging truck traffic.

The Skookumchuck survey area is located on topographic map sheet N.T.S. 92G16 "Glacier Lake" and is at co-ordinates 122°26' W. Long. and 49°52.7' N. Lat.

TOPOGRAPHY AND GROUND CONDITIONS

Sloquet Area

Although the terrain is extremely rugged with the Sloquet Hot Spring occurring in a narrow creek valley, the resistivity traverse was conveniently run along the abandonned logging road which parallels the creek and passes within 500 feet of the hot spring. Elevations varied from 550 feet A.S.L. at the eastern and to 900 feet A.S.L. at the western end of the traverse for a total relief of 350 feet.

Overburden thicknesses were generally less than 200 feet and electrical ground contact resistances were less than 6 K-ohms due primarily to snow melt water run-off. The western end of the traverse was terminated at Station 6 W due to the road being washed out with thick growths of willows and underbrush making it impossible to pull the potential wire further in that direction.

Skookumchuck Area

The active logging road, although somewhat hazardous due to heavy traffic proved to be an excellent traverse paralleling the south-west wide of the Lillooet River on the opposite bank of the Skookumchuck Hot Spring and hydro transmission line. Elevations varied from 500 feet A.S.L. at the southerly end to 600 feet A.S.L. at the northerly end for a total relief of only 100 feet along the entire traverse.

Overburden thicknesses and type were quite variable. From Station 1 N to 4 S, a distance of 5,000 feet, the sub-surface consisted of a 50 foot cover of unconsolidated, coarse river gravels underlain by a more extensive and thicker mantle of glacial overburden and river silts. The area covered by the coarse river gravels was devoid of top-soil and was extremely dry resulting in electrical contact problems. Readings were finally obtained by offsetting the moving current electrode to the northeast where the terrace gravels had been eroded down to the level of glacial overburden which was more moist and of higher electrical conductivity.

Contact problems were also encountered at the north end of the survey line due to talus slopes. A combination of high contact resistance (low current input) and very close proximity to the hydro transmission line (noise interference) made it impossible to take two readings in this area.

Survey stations were installed along the logging roads every 1,000 feet using the 1,000 foot potential wire as a chain. Stations were indicated by tying marked flagging to trees along the roadside.

GENERAL GEOLOGY

The Sloquet and Skookumchuck Hot Springs occur along or adjacent to what appears to be a major northwesterly trending structural lineament which includes Harrison Hot Springs to the southeast and possibly other hot springs to the northwest.

Observed rocks are mainly Coast Range granodiorites to diorites with local occurrences of metamorphic rocks. Valleys are filled with river gravels and glacial alluvium of varying thicknesses and lateral extent.

A detailed geological description of the survey areas is included in the accompanying report by Nevin Sadlier-Brown Goodbrand Ltd.

THE RESISTIVITY SURVEYS

1. Application of Resistivity Surveys to Geothermal Exploration

Resistivity surveys of geothermal areas have been used extensively in several parts of the world and, to date, it is the single, most diagnostic geophysical tool used in the search for steam reservoirs.

Although an extensive drilling program is the most reliable way to explore for and to assess the potential of a geothermal reservoir, much valuable yet relatively inexpensive information can be derived from preliminary and concurrent resistivity studies. Both hot-water systems and vapour-dominated systems have been successfully surveyed by resistivity methods using reconnaissance horizonal profiling, total field mapping and depth-sounding techniques.

The resistivity of a rock in a geothermal environment is controlled by the proportions and resistivities of interstitial materials contained within it. Typically, the reservoir consists of highly porous rocks with a low resistivity due to high temperature porewater and high content of dissolved salts. The rocks can also contain appreciable amounts of conductive minerals such as clays, zeolites and sulphides.

Resistivities of reservoir rocks encountered in most presently explored geothermal areas exhibit resistivities of less than 10 ohm-meters which is in the order of 10 to 50 times smaller than the resistivities of the surrounding country rocks. The Mud Volcano area in Yellowstone Park, for example, has undergone extensive drilling, geological and geophysical surveys and the results indicate the presence of a vapour-dominated reservoir at a depth of only 300 feet with a lateral diameter of about one mile. The resistivity data indicates that the vapour-dominated layer has a resistivity of about 75 - 130 ohm-meters and is overlain by a very low resistivity layer of from 2 - 7 ohm-meters and is laterally confined by a layer of 30 ohm-meters. This latter layer is believed to be due to hot-water circulating in low-porosity rocks.

Induced polarization (apparent chargeability) measurements were also taken at Yellowstone with the anomalies being attributed to high concentrations of pyrite adjacent to the reservoir.

Although geoelectric properties of rock-types and the general geomorphology could be somewhat different from reservoir environments in other parts of the world, resistivity surveys in British Columbia will, in all probability, yield obvious resistivity lows over geothermal reservoirs. Resistivity profiling with broad electrode spacings followed by detailed depth soundings appears to be a relatively inexpensive and viable exploration tool prior to drilling for geothermal reservoirs.

2. Theory of Method Used

Induced Polarization equipment is commonly used to carry out a resistivity survey and the chargeability readings are usually taken as the additional time involved is minimal and because the chargeability data can assist in the interpretation of the resistivity results. This is particularly important where polarizable material may be present in a geothermal environment such as disseminated sulphides, conductive overburden, graphite, magnetite and the host of clay minerals including montmorillonite, vermiculite, saponite, and bentonite.

A discussion of the Induced Polarization phenomenon is therefore made, although chargeability data is not embodied in this report.

Induced Polarization refers to the polarized distribution of electrical charges throughout a medium to which an electric field has been applied. When current is passed across an interface between an electrolyte and a metallicly conducting body, double layers of charge build up at the interface creating the phenomenon known as "overvoltage" or the "I.P. effect". This effect can be used to detect conducting materials as mentioned above.

The time-domain (Pulse) equipment used for the test surveys consists of a motor-generator driven transmitter which injects an alternating square wave signal into the ground at two electrodes C_1 and C_2. The signal seen by remote sensing receiver at two other electrodes P_1 and P_2 provides an indication of the apparent chargeability (M_a). By observing the input current (I) and primary "on-time" voltage, (V_p) the apparent resistivity ρ_a is calculated using Ohm's Law and a geometric factor dependent upon the electrode array used and the units (ohm-meters or ohm-feet) desired. The "apparent resistivity" (ρ_a) is the product of the geometric factor calculated for a homogenous medium and the resistance actually measured in the non-homogenous environment encountered in the field. To determine the actual or true resistivities of a layered half-space, various electrode separations or "depth-soundings" must be made and the results either graphed and matched to type-curves or interpreted with the aid of a computer.

With the pole-dipole array resistivity lows (or highs) are assymetrical with the anomaly troughs or peaks not necessarily falling directly over the center of the causative source. The maximum anomaly is obtained for the electrode spacing equal to the depth to the center of a buried idealized sphere, although spacings of 3/4 to 1½ times the depth give at least 90% of the maximum likely anomaly.

The distinct advantagesof the pole-dipole or three electrode array are that they require only three men on the survey line, they have good depth penetration, they respond well to both flat-lying and steeply-dipping bodies and they maintain high resolution. The pole-dipole array can also be conveniently employed in "depth-soundings" by keeping the distance "b" (between the two potential electrodes) constant, say 1000 feet, and increasing the distance "a" (between the moving current electrode (C_1) and the nearest potential electrode (P_1)) from say, 1000 feet to 2000 feet, 3000 feet, 4000 feet, etc. Under normal field conditions the pole-dipole array is the most convenient and inexpensive array for horizontal profiling with possible follow-up depth-sounding using a high-powered, fixed transmitter power source.

In certain circumstances, other profiling arrays such as the dipole-dipole array can be effectively employed. An example would be where a very long traverse was being run along a road and the amount of wire to be strung out was to be kept to a minimum. A truck could be used to transport the motor-generator and transmitter along to each set-up position. In rough, mountainous terrain and in areas of poor or no road access the power source is fixed and the pole-dipole array is then preferred.

For the present tests, the pole-dipole array was used because, in the case of Sloquet, the entire traverse could be run from one central transmitter location and, at Skookumchuck, the heavy logging truck traffic made the presence of a survey truck somewhat dangerous. A moving current electrode (C_1) and two potential electrodes (P_1 and P_2) were moved in unison along the roads keeping "a" at 3000 feet and "b" at 1000 feet. The second current electrode (C_2) was fixed at "infinity" (∞) which is usually a minimum of 5 times the distance "a"from the nearest station being measured. The station location is midway between C_1 and P_1, (see map in pocket). The station interval was 1000 feet resulting in a high degree of overlap or resolution. In retrospect, a station interval of 2000 feet would have been quite adequate when one considers the size of the target sought. Depth of penetration is roughly equal to the electrode separation "a" used.

3. Data Presentation

The apparent resistivity ρ_a in ohm-meters was calculated from the equation:

$$\rho_a = \frac{Vp}{Ia} K$$

where Vp = primary "on-time" voltage measured by the remote sensing receiver at position P_1

Ia = input current in amps measured at the transmitter site

K = form factor = $1.92a \frac{a + b}{b}$

where a = distance from C_1 to P_1 in feet

b = distance from P_1 to P_2 in feet.

The calculated results ρ_a were then plotted on semi-logarithmic paper in profile form relative to the stations flagged along the roads at 1000 foot intervals.

4. Discussion of Results and Interpretation

(a) Skookumchuck Hot Springs Area

The apparent resistivity readings varied from 7540 ohm-meters at station 5+50N to a low of 870 ohm-meters at station 5+50S for a total relief of 6670 ohm-meters along the four mile traverse.

Background resistivity of the granodiorite or diorite country rocks is interpreted to be 5000 to 7000 ohm-meters. A broad resistivity low occurs between station 2N and 7S with two local high resistivity peaks superimposed on this low.

The local peak of 4630 ohm-meters at station 3+50S is coincident with coarse highly resistive river gravels about 50 feet thick but they are not likely causing this local high peak due to the very small volume of gravels being sampled at the wide electrode separation used. Although other electrode separations would be required to determine the cause of this feature and the other smaller local high ρ_a peak at station 0+50N they are tentatively interpreted as being due to two steeply dipping faults crossing the survey line at station 4+50S and 1+00N respectively.

The removal of the influence of these interpreted faults would result in a broad pronounced resistivity low, negatively peaking at 500 ohm-meters, with the causative source being 7000 feet wide centered at station 2+50S. This position is approximately 3000 feet SSE of and on the opposite side of the Lillooet river from the Skookumchuck Hot Spring. It is possible that a parallel survey line on the opposite side (NE) of the river might yield a more pronounced low and that the present results represent the northwestern margin of lower resistivity rocks related to a potential geothermal reservoir.

A high degree of self-potential or inductive interference from the live hydro transmission line across the Lillooet River was encountered, making it extremely difficult for the remote sensing receiver to "lock-on" to the transmitter signal. The low signal-to-noise ratio was greatly improved by using a 60 Hz filter across the input terminals of the receiver, and by increasing the number of samples received at each station thus allowing the S.P. or noise "buck-out" circuitry to function to its maximum. The time spent taking a reading at Skookumchuck was 3 to 4 times longer than that required at Sloquet and the noise interference experienced is directly attributable to the hydro transmission line. The distance of the hydro line away from the survey line varied from 700 feet at the north end to about 2000 feet in the central portion of the traverse.

Any further surveying near similar live transmission lines should be no closer than 1500 feet to the line unless the power to these lines is shut off during the entire survey.

No appreciable electrical interference was observed from the frequently passing logging trucks along the survey road.

A few apparent chargeability (M_a) readings were attempted but the high noise level, which is particularly significant during the "current-off" time when M_a is measured, prevented the receiver from "locking-on" and therefore reliably measuring the Induced Polarization effect.

(b) Sloquet Hot Springs Area

The resistivity readings varied from5600 ohm-meters at station 5+50W to 1965 ohm-meters at station 6+50E for a total relief of 3635 ohm-meters over the entire traverse of 2.8 miles.

The profile illustrates deviations of about 1500 ohm-meters from a mean or background value of 4000 ohm-meters. Although there is a subtle resistivity depression from station 2+50E to station 2+00W centered very close to the Sloquet Hot Spring, the high levels of resistivities are not indicative of any interesting geothermal rock-types.

Overburden is not thought to have affected the resistivity readings to any significant degree. One short electrode spread with a 200 foot separation yielded a resistivity of 1500 ohm-meters which is interpreted to be caused by water saturated clayey gravels up to 150 feet thick at Station 0 nearest the Hot Spring. The chargeability (M_a) value for this reading was 15 milliseconds (msecs.)

M_a readings were taken at a few stations using the 3000 foot electrode separation. There was a general increase in values from a low of 18 msecs. at the west end of the line to 30 msecs. at station 0 to a very high reading of 60 msecs. at station 4+50E. East of this point M_a values decreased again to below 25 msecs. The M_a's are considered anomalous from station 0+50E to 9+50E and are interpreted as being caused by up to 5% by volume disseminated and/or fracture filling sulphides. A "gossan" (rust-stained area) is present just north of station 4+00E where the highest M_a was measured, which strongly implies that the cause of the anomalous chargeabilities is due to pyrite and, possibly, other associated sulphides.

CONCLUSIONS AND RECOMMENDATIONS

The resistivity tests recently carried out over the Skookumchuck and the Sloquet Hot Springs areas have proven to be informative and very worthwhile.

The profile across the Sloquet Hot Spring failed to discover any low resistivity rocks which might be related to a significant geothermal reservoir within the immediate vicinity of the hot spring. The chargeability readings indicated a broad zone of sulphides thought to be pyrite east of the spring on the north side of Sloquet Creek.

The traverse on the opposite side of the Lillooet River from the Skookumchuck Hot Spring indicated the presence of a broad moderately low resistivity anomaly which could be the margin of a more pronounced low to the northeast of the traverse or southeast of the Hot Spring. Further resistivity investigations are warranted along the northeast bank of Lillooet River in this area but would require that the hydro transmission line be turned off during this work. Should a significant resistivity low be discovered by horizontal profiling, another parallel survey line should be attempted approximately 2000 feet to the northeast of the public road at about the 1500 feet elevation level. The results of this work would determine if and where depth soundings should be carried out.

The test surveys have assisted in determining survey parameters for future geothermal exploration. It is now apparent that the Coast Range granitic rocks exhibit relatively high resistivities in the order of from 4000 to 4500 ohm-meters.

The tests have also shown that the output power (7,500 watts) of the instrument used is more than adequate for electrode separations up to 3000 feet, and provided that the contact resistance at the current electrodes is kept low, the I.P. - resistivity system with the very sensitive receiver should be capable of measuring valid, stable readings with electrode separations up to 5000 feet.

It was also concluded during the course of the surveys that communications between the crew-men could break down in areas of variable topography and thick vegetation. Walkie-talkies were used but reception between the crew-men on the line and the transmitter operator was marginal over a distance greater than 2 miles. Higher powered walkie-talkies should be used for future horizontal profiling and the feasability of using a telephone system between the moving current man and the transmitter operator is being studied.

Although each survey area has its own peculiar logistics problems it is generally recommended that future resistivity investigations should be carried out as follows:

(1) Long horizontal profiles using the pole-dipole or dipole-dipole electrode array configuration with two electrode separations of 1500 and 3000 feet should be initially run along roads, trails or cut-lines in the vicinity of known, interesting hot springs with geothermal potential.

(2) Portions of the reconnaissance traverse yielding significant resistivity lows should be gridded with parallel and, possibly,

perpendicular lines and surveyed to produce a contour map of lateral variations in resistivity.

(3) Areas of lowest resistivity should then be subjected to depth soundings to determine optimum drill targets.

The cost of executing the above will be quite variable depending upon accessibility, the time of year that the work is being done, the amount and quality of line-cutting required, the total line-mileage of surveying carried out and a host of other variables. Line-cutting costs could vary from $100 to $300 per line-mile.

The cost of horizontal resistivity profiling using two electrode separations could vary from approximately $450 per line-mile along roads to $700 per mile over rough terrain in helicopter supported areas.

Depth soundings could cost up to $2,000 per station if carried out concurrently with the preliminary work.

Respectfully submitted,

P. P. Nielsen, B.Sc.
Geophysicist

NIELSEN GEOPHYSICS LTD.
VERNON, B.C.

EQUIPMENT DESCRIPTION AND SPECIFICATIONS

1. Receiver

The Huntec MKIII Receiver is a portable, remote sensing pulse-type instrument incorporating the following features:

- Adjustable timing cycle
- Up to 56 distinct sample points measured on the decay curve
- Automatic S.P. buck-out
- Direct digital read out of Vp and M factors including sign
- High noise rejection allows operation in Vp levels down to 30 micro volts with 0.1 micro volt resolution
- Greater than 10 megohm input impedance

Specifications

- Sensitivity: Vp = 10^{-7} to 10^{-6} volts for low noise 1% resolution
  Vp = 10^{-6} to 10 volts for 0.1% resolution
  Total Range 30 x 10^{-6} volts to 10 volts in 11 ranges
- Self Potential: MAXIMUM ± 1 volt
- Power consumption: 0.7 ampere at 12 volts
- Dimensions: 16" x 9" x 5.3/4"
- Weight: 12.5 lbs. (without battery pack).

2. Transmitter - Alternator

The Huntec Pulse type transmitter alternator is a high-powered, 7.5 Kilowatt system utilizing the following:

- Solid state power control and switching mechanism
- Produces high currents into low resistance loads
- Accurate and adjustable timing using Crystal Clock
- Voltage regulator with push-button field energizer

- Dummy load
- 2 cylinder ONAN engine driving a Bendix alternator.

Specifications

1. Transmitter
   - Output: 100 to 3,250 volts in 10 steps
     16 amps maximum
   - Cycling Rates: Normally 2 sec. ON, 2 sec. OFF
   - Dimensions: 21" x 12" x 17"
   - Weight: 75 lbs.

2. Alternator
   - Output: 18 K.V.A. 120/208 volts 3 phase 400 Hz.
     52 amps/phase
   - Engine: 2 cylinder, 4 cycle, air-cooled 16.5 H.P.
     ONAN at 3,600 R.P.M.
   - Alternator: 3,600 R.P.M. direct driven Bendix with
     sealed bearings and rotating field
   - Dimensions: 42" x 17" x 26"
   - Weight: 225 lbs.

APPENDIX 'I' - PERSONNEL

Nevin Sadlier-Brown Goodbrand Ltd:

Andrew E. Nevin	-	Geologist.
Timothy L. Sadlier-Brown	-	Geologist.
Douglas W. Goodbrand	-	Geologist.
Mrs.J.R. Hobden	-	Secretary.
Mr.T.R. Drews	-	Draughtsman.

Principal Consultants and Contractors:

Integrated Resources Photography Ltd. - Mr.Parker Williams and staff.
2nd Floor - 310 Water Street, Vancouver, B.C.

P.P. Nielsen Geophysics Ltd. - Mr.P.P. Nielsen and crew.
2603 - 25th Street, Vernon, B.C., VIT 4P6.

Dr.P.B. Read, University of British Columbia, Dept. of Geology.

Minor Services:

Altair Drafting - No.5 - 821 West Pender Street, Vancouver, 1, B.C.

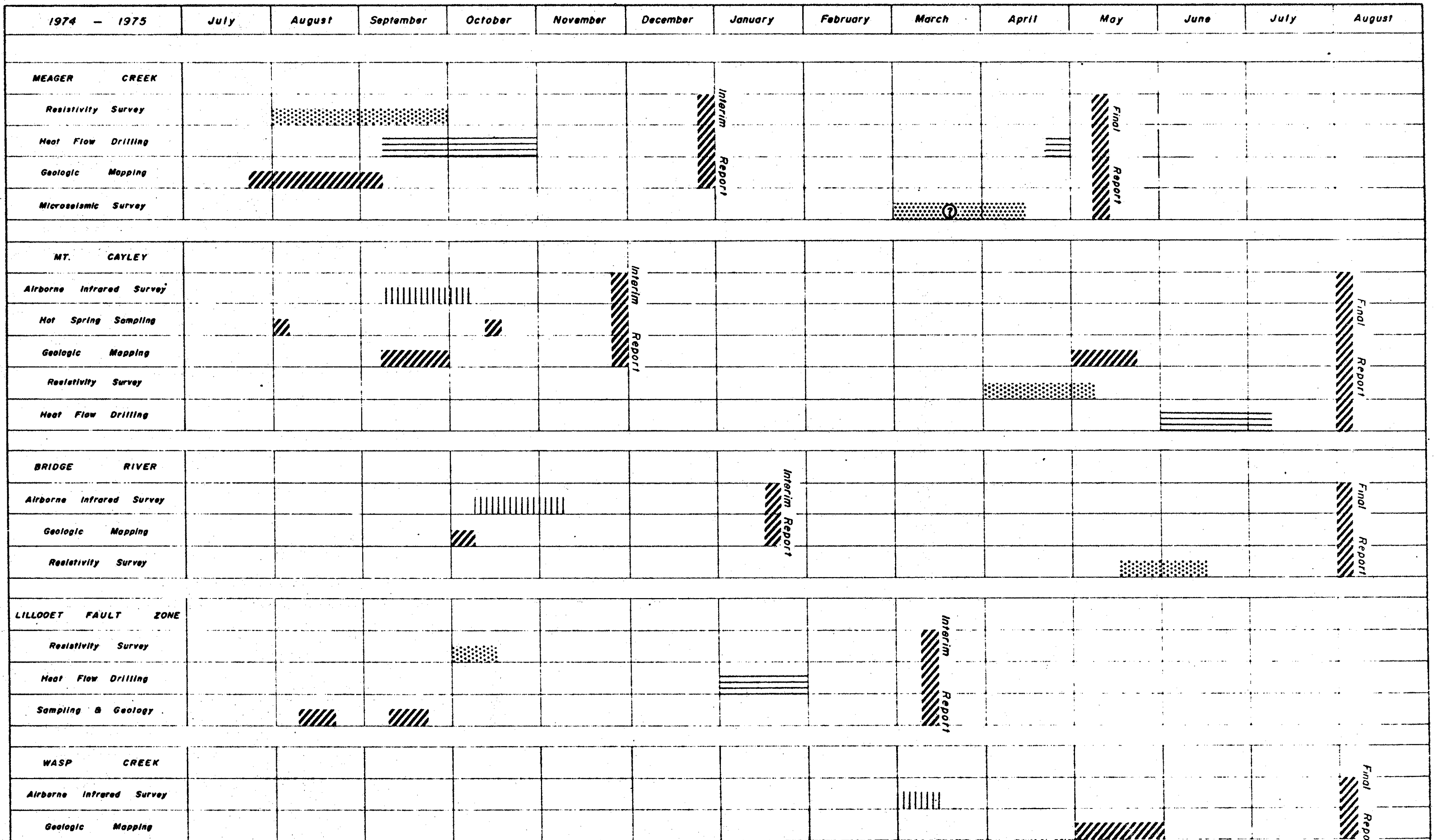
Chemex Labs. Ltd. - 212 Brooksbank Avenue, North Vancouver, B.C.

CX Film Processing Laboratories Ltd. - 933 West Pender St. Vancouver 1, B.C.

Fisher Scientific Co. Ltd. - P.O. Box 6082, Montreal 101, Quebec.

Okanagan Helicopters - 439 Agar Drive, International Airport South, Vancouver, B.C.

Van Cal Reproductions - 1777 West 3rd Avenue, Vancouver, B.C.



APPENDIX - J

TIME TABLE — PROPOSED WORK

APPENDIX 'K'

CHAPTER 117

Geothermal Resources Act

[Assented to 7th November, 1973.]

HER MAJESTY, by and with the advice and consent of the Legislative Assembly of the Province of British Columbia, enacts as follows:

Interpretation.

1. In this Act, unless the context otherwise requires,

"geothermal resource" means the natural underground reservoirs of heat that may be exploited, developed, or used for the production of heat energy, including, without limiting the generality of the foregoing, any minerals that may be obtained by means of a geothermal resource or by a natural or artificial injection of fluid, brine, gas, or steam in any form; but does not include petroleum resources, or water that is less than two hundred and fifty degrees Fahrenheit measured at its lowest location underground.

Crown property in geothermal resources.

2. Unless otherwise provided in any other Act, the right, title, and interest in all the geothermal resources in the Province is vested in and reserved to the Crown in right of the Province.

Printed by K. M. MacDonald, Printer to the Queen's Most Excellent Majesty
in right of the Province of British Columbia.
1973

APPENDIX 'L' - WORLD GEOTHERMAL FIELDS*

Country	Field	Installed Capacity (Mw).
Iceland	Namafjall	3 +
Italy	Larderello	360
	Monte Amiata	26
Japan	Matsukawa	20
	Otake	13
	Akita	10 +
Mexico	Cerro Prieto	75
	Pathé	4
New Zealand	Wairakei	160
	Kawerau	10
United States * *	Geysers	522 +
U.S.S.R.	Pauzhetsk	5
	Paratunka	1
		1209

* Exploration and development, some under the auspices of the UN, is in progress in El Salvador, Chile, Kenya, Tanzania and about 15 other countries.

* *

In addition six other massive fields have been identified: studies are in progress to overcome salinity or low temperature in 4; 2 are active steam prospects, the latest discovered by Union Oil in Sandoval Co., N.M., with the discovery well alone reporting 6.5 Mw capability.