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 1: REPORT

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CONSULTING GEOLOGISTS

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ABSTRACT

A reconnaissance geological and geophysical investigation of the Lillooet River Valley and surrounding region for the purpose of determining the potential for geothermal steam and identifying areas of significant promise has been completed. About 6500 square miles was surveyed to varying degrees by means of geologic mapping in the field and from air photos; 450 line-miles of airborne infrared scanning; chemical analyses of six hot springs and calculation of underlying reservoir temperatures from key elements; and two electrical resistivity profiles.

Characteristics of the region compare favorably with those of the producing geothermal areas of the world. The volume and youthful age of the volcanos provide evidence of the requisite subsurface heat sources; the rocks are fractured enough to provide reservoirs; the ground water system is adequate to feed a hot convection cell; calculated subsurface temperature on one hot spring is in the steam reservoir class; and three other calculated hot spring temperatures and results of one electrical resistivity profile are sufficiently interesting to encourage detailed examination.

Five areas show preliminary evidence of the existence of commercial geothermal resources. The areas totalling 540 square miles (Map B) are:-

(a) Meager Creek, located 35 miles northwest of Pemberton, which is the leading area, centred on a complex Recent volcano 10 miles in diameter and over 5,000 feet high;

(b) Mt.Cayley and the east side of the Elaho River, 15 miles west of Alta Lake;

(c) Bridge River headwaters, 30 miles west of Gold Bridge;

(d) The Lillooet fault zone, a hammer-shaped strip with the head at the north end of Harrison Lake and a long handle extending northwest up the Lillooet River and Billy Goat Creek;

(e) Wasp Creek, an elongate strip 10 miles west of Pemberton.

We recommend that the B.C. Hydro and Power Authority move into a second one-year phase of geothermal investigation, and conduct detailed geophysics on Meager Creek, do preliminary geophysical surveys on the next three areas, and expand the reconnaissance on the Wasp Creek area. Recommended geophysical surveys are mainly about 130 line-miles of electrical resistivity, six 1200-foot drill holes for temperature gradient and heat flow measurements, geological mapping at a scale of 1:25,000, and 2300 line-miles of continued airborne infrared scanning.

We/

We also suggest reconnaissance on a 1,200 square mile strip from Ucluelet to Nootka Sound on western Vancouver Island. This recommendation does not stem from work done in this study, but from the same type of geologic criteria which led to initiating reconnaissance in the Lillooet River region. Two steps are suggested: preliminary geology and hot spring geochemistry, and airborne infrared scanning.

The estimated cost of work on these six independent areas is as follows:-

(a) Meager Creek, detailed geophysics:	
Stage 1 - pilot work	$67,100
Stage 2 - completed survey...............	135,500
(b) Mt.Cayley, preliminary geophysics.............	64,750
(c) Bridge River, preliminary geophysics..........	21,500
(d) Lillooet fault, preliminary geophysics.........	39,750
(e) Wasp Creek, expanded reconnaissance...........	8,900
(f) Vancouver Island, reconnaissance:	
Stage 1 - geochemistry....................	4,500
Stage 2 - infrared........................	30,500
TOTAL -	$372,500

In the context of development of geothermal resources, completion of the recommended program should obtain sufficiently detailed data to justify Canada's first exploratory well in 1975. If B.C. Hydro and Power Authority deems it worthwhile to maintain a steady level of investigation and testing, a confirmed commercial discovery might be anticipated in 1979 and start up of the first 250 Mw of capacity in about 1984.

VOLUME 1: REPORT

Cover Photograph: A 59°C (140°F) vent at the Meager Creek hot spring keeps the snow clear year-round. The water is inferred to be a mixture of cold ground water and water superheated by volcanic action at depth.

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7.0./

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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.

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VOLUME 3: MAPS

Cover Photograph: Earth Resources Technology Satellite image in the 0.6 - 1.1 um wave band - - reflected yellow, red, and "very near" infrared light. Major faults show up as alignments of valleys, snow lines or other tone differences, e.g. from Harrison Lake northwest through Green Lake and on to Meager Creek, at the "cross" in the upper end of the perimeter. The line encloses the study area except for the Bridge River area.

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B.C. HYDRO AND POWER AUTHORITY

REPORT ON INVESTIGATION OF GEOTHERMAL RESOURCES IN SOUTHWESTERN BRITISH COLUMBIA

June 1974

1.0. TERMS OF REFERENCE

Terms of reference for the geothermal steam investigation, Lillooet River region were established by B.C. Hydro and Power Authority in the acceptance of a proposal dated October 15, 1973, from this firm (under the former name Andrew E. Nevin Consultants Ltd.). The region under study was the Lillooet River Valley and its environs, approximately 3,000 square miles extending from the south end of Harrison Lake northwest to the vicinity of Meager Creek, northeast across Anderson Lake and southwest toward Alta Lake. Geologic studies were to be performed aimed at identifying thermal anomalies, such as might be later tested for the presence of commercial geothermal steam. Standard geological and geophysical techniques were to be used, including airborne infrared scanning, air photo and satellite image interpretation, geochemical surveys and on site inspection. Terms of reference included recommending further exploration steps if they appeared warranted and estimating the cost of such steps.

2.0. WORK DONE

2.1. Geology

A geologic map at the scale of 1:100,000 was compiled for the area of interest from existing maps published by the Geological Survey of Canada and B.C. Department of Mines and Petroleum Resources, from air photo interpretation, from E.R.T.S. satellite image interpretation, and from original field work.

2.2. Airborne Infrared Scanning

A low level, high resolution, airborne infrared survey was flown by Integrated Resources Photography Ltd. using an instrument owned by B.C. Hydro. A high altitude survey was ordered from the Canada Centre for Remote Sensing, and has been approved and pending since October 1973.

2.3. Hot Spring Waters and Mineral Precipitates

Water samples from six hot springs within the area of interest were collected and chemically analyzed. Minimum reservoir temperatures were calculated from key chemical constituents. Dr.Peter B. Read, U.B.C., analyzed mineral precipitates from four hot springs by x-ray and microscopic means and compared them to mineral assemblages of producing geothermal areas elsewhere in the world.

2.4./

2.4. Resistivity

Pilot resistivity profiles were run in the vicinities of two hot springs areas by P.P. Nielsen Geophysics Ltd., Vernon, B.C.

2.5. Liaison with Energy, Mines & Resources

Research work conducted by the Geological Survey of Canada and the Earth Physics Branch, both of the Federal Department of Energy, Mines and Resources, was followed with an eye toward utilizing it in this investigation.

2.6. Geothermal Technology

Part of the investigation was concerned with continued contact with geothermal scientists and engineers in other countries in order to make full use of the rapidly growing technology available for this new commodity.

2.7. Regional Extension

As work progressed we extended the perimeter to the south and west to include about 6,500 square miles.

3.0. GEOTHERMAL RESOURCES

3.1. Characteristics

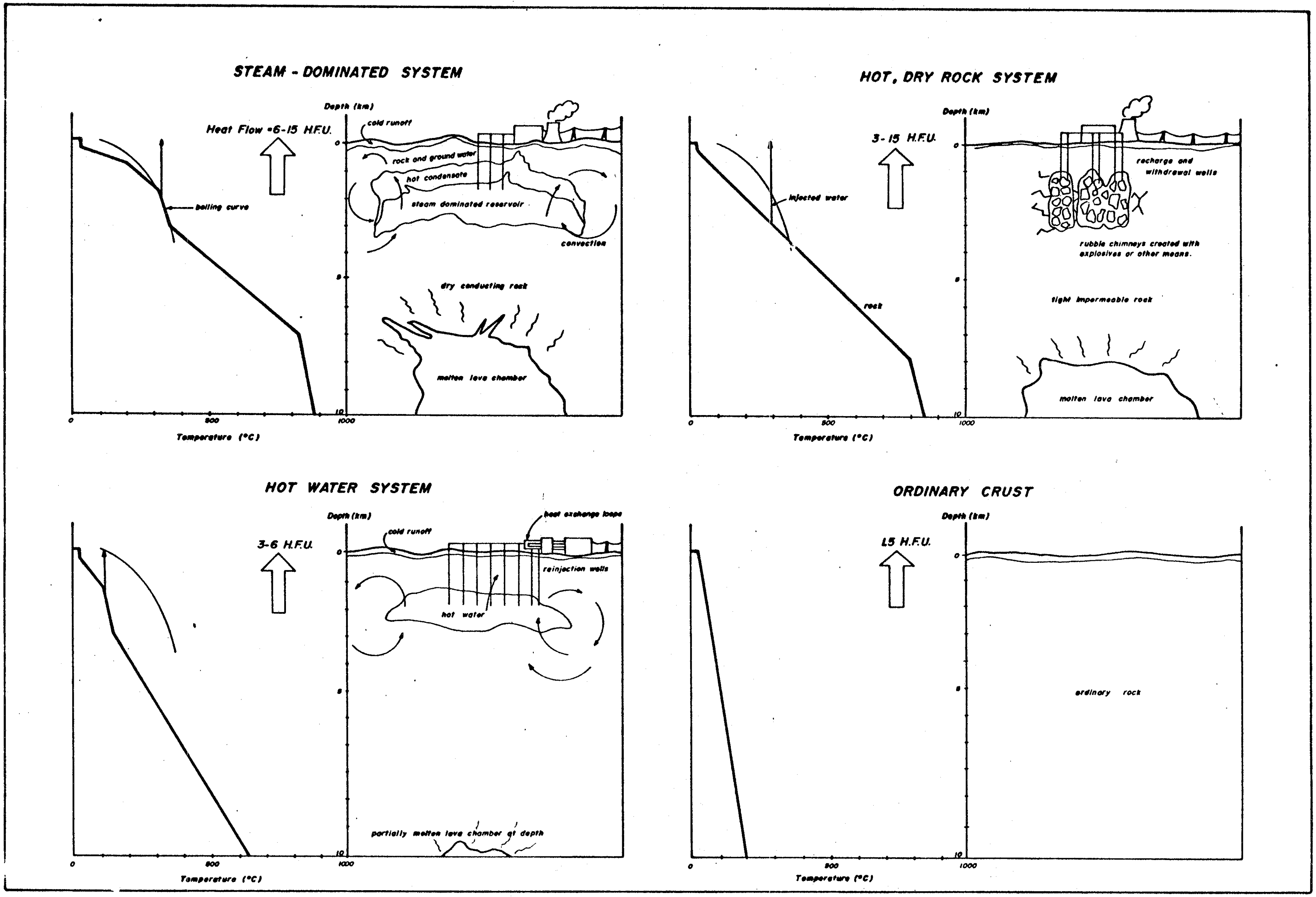
The objects of this investigation are bodies of steam, water, or rock at abnormally high temperatures, high in the earth's crust, as shown in Drawing 1 and reviewed in Appendix C. Slightly anomalous conditions, on or near the earth's surface, accompany geothermal bodies and are used to diagnose their presence. Such conditions include young volcanic rocks, alteration minerals, high fracture densities, hot springs, rocks with high electrical conductivity, high temperature gradients and upward heat flow.

3.2. Early Exploration

A geothermal exploration program is designed to systematically narrow down a very large area, about which little is initially known, to several relatively small reservoirs. Work generally progresses through a sequence of techniques, from lower to higher cost per unit area covered. As areas which fit diagnostic criteria are identified and successive techniques are applied, information of increasingly higher resolution and value is acquired.

Reconnaissance is aimed at selecting several areas of a hundred square miles, or so, out of thousands of square miles. Techniques commonly used are geologic mapping, airborne infrared, and chemistry of hot springs.

4.0./



DRAWING - I

GENERAL PROPERTIES OF GEOTHERMAL SYSTEMS

4.0. GEOLOGY

4.1. Lillooet River Region

For purposes of this geothermal investigation, the rocks in the Lillooet River region are assigned a two-fold classification: 1) old granites and metamorphics and 2) young volcanics.

The granitic rocks, the crystalline core of the Coast Ranges, were emplaced as slowly cooling bodies of magmas, mainly during the Cretaceous period (136 - 65 million years ago). Subsequently, they were uplifted, overlying rocks were stripped off by erosion, and the present topography was carved into them. The granitic rocks include large pendants and septa of pre-existing rocks, mainly late Paleozoic and Mesozoic submarine volcanics, shales and conglomerates, which have been metamorphosed and deformed. For our purpose these are generally as hard and as crystalline as the granites.

The young volcanics have been called the "Garibaldi group" by previous workers. They were erupted and deposited during the Quaternary period in an episode of volcanic mountain building which began about 1.5 million years ago and has continued to two thousand years ago, in effect, to the present time.

It is 6-10 kilometres under the vents of some of these volcanics that chambers of cooling lava (either remnants of past eruptions or currently forming melts) could provide the abnormal heat flow necessary for commercial geothermal reservoirs.

Faults and fractures in these and the older rocks are also important. They provide the near-surface (down to 3 kilometres) channelways which constitute plumbing and reservoirs for geothermal steam. On a broader scale fractures have served as conduits for volcanism and provide clues as to the locations of zones of abnormal heat flow.

In the following sections 4.2 - 4.7, the geology of six areas is described, five of which have been recommended for additional work.

4.2./

4.2. Meager Creek Selected Area

The Meager Creek selected area, centred on Meager Mountain, Plinth Peak and Mt.Job (Map C1) is a complex, cone-shaped volcanic centre which occupies a circular area 55,000 feet in diameter. The volcanic units, which are assigned to the Garibaldi group, lie unconformably upon Cretaceous granitic and metamorphic rocks. At the east edge of the area, near the confluence of Meager Creek and the Lillooet River, the base of the volcanics is at about 1500 feet elevation; at the west edge the base of the volcanics ranges from 3,000 to 5,000 feet in elevation. The peaks of the cone are in excess of 8,500 feet. Thus depending upon the configuration of the concealed parts of the base of the volcanics,they reach a maximum thickness of 5,000 to 6,000 feet.

The complex contains an estimated 25 cubic miles of volcanic rock. Some of the flows and pyroclastic rocks which were deposited at Meager Mountain have been eroded and redeposited on lower slopes as talus fans or else removed entirely by the Lillooet River drainage system. The geometry of the rocks in place, however, suggests that less than 5 per cent of the original volume has been removed.

The youngest volcanic unit is the Bridge River Ash of dacite composition, which forms snowdrift-like deposits in the high passes, and extends downslope in the form of long talus fans. In some cases it is more than 100 feet thick and contains blocks six or eight feet in diameter. In the immediate complex it consists of white frothy fragments with half the bulk density of ordinary rock. The unit forms a thin discontinuous blanket extending 300 miles northeasterly into western Alberta, where fragment size decreases to fine dust and thickness feathers out to an inch or so. A radiocarbon date by the G.S.C. established its age at 2,330 $\pm$ 140 years.

Immediately underlying the pumice deposit are lobate dacite and andesite flows which moved down the north slope of Plinth Peak. These units, intermediate grey and brown in color, dip 10-20 degrees downslope and range in thickness up to 100 feet.

Underlying the lobate flows in the Lillooet River canyon are one or more welded tuffs of rhyolite to latite composition. The age relationship between these and the bulk of the Meager Mountain complex (described below) is unknown. However, the welded tuffs appear to be among the youngest of the rocks in the complex. They form a flat-topped body which was deposited squarely in the bottom of the existing canyon. This rock is responsible for the broad valley of the Lillooet above Salal Creek, the braided character of the river along this/

this stretch, and the headwall below Salal Creek which forms a spectacular waterfall.

The bulk of the layered rocks in the Meager Mountain complex are flows, breccias, and lahars (hot mud slide deposits) of andesite and dacite composition. Individual flow units have thicknesses between 10 and 200 feet. Attitudes of the various layers are varied, but they do tend to dip as much as 20 degrees away from the central peaks.

Three vents have been positively identified on air photographs and on reconnaissance flights. It is characteristic of this and adjacent volcanic terrains that the vents generally do not take the form of an open crater, but usually stand up as a neck of brecciated lava. In some instances, however, craters are present but partially filled with debris from a subsequent collapse. The only visible evidence of their presence is a circular symmetry in the layering and fracturing of the surrounding rock exposures. The three known vents are large, 500 feet to 3000 feet in diameter, and field work in the area might be expected to turn up 20 or more additional vents and necks down to about 20 feet in diameter.

The complex is cut by numerous steeply dipping faults having small displacements, on the order of 100 feet. Several prominent throughgoing fractures have been identified on satellite imagery and the volcanic centre is located, with almost textbook precision at the junction of two of these, the Lillooet Valley linear and the Elaho Valley linear. This suggests strongly that these fractures are of crustal magnitude, and that they were the conduits which determined the location of the volcanic centre. Several other fractures pass close to the volcano, notably in the valley of Meager Creek. None appear to offset the volcanic rocks to any degree, nor does it appear that any significant regional tilting or adjustment of elevations has taken place in post volcanic time.

Both Meager Creek and Pebble Creek thermal springs issue from Cretaceous granitic rock immediately below the base of the volcanics on the east edge of the complex.

4.3. Mt.Cayley Selected Area

The Mt.Cayley selected area is a zone of discontinuous volcanic cover 88,000 feet from south to north and about 36,000 feet wide at its widest point, in the south (Map C3). The most interesting part of the area is near its southern limit at Mt.Cayley and Mt.Fee, which form the jagged ridge between the Squamish River and the Cheakamus River at Brandywine Falls.

Mount/

Mount Cayley (cover photo, Volume 2 of this report) is a complex volcano very much like the Meager Creek system. The volume of volcanic rock present is estimated at 15 cubic miles. The apparent base of the volcanic pile is asymmetric; it tilts toward the west. The base of the volcanics along their western border is at 1000 to 2000 feet elevation. The peaks in the centre rise to elevations of 10,500 feet, and the base of the pile along the east edge is generally in the high ice fields at about 5,000 - 6,000 feet elevation. Depending upon the configuration of the base, a volcanic pile in excess of 4,000 feet in thickness could be present under the higher peaks.

The Cayley volcanics have been more deeply incised by erosion than those at Meager Creek. Their edges have no doubt been trimmed back slightly since the original deposition, however, their general configuration suggests that they were deposited recently on a surface of relief not very much different than at the present, and that their original lateral extent was not significantly greater than it is now.

The Cayley volcanics range from andesite to dacite in composition and are generally intermediate shades of grey and brown, except where hydrothermal activity has locally altered them to yellow or ochre oxides. Individual flow and ash units have thicknesses ranging up to about 300 feet, although they are generally lens-shaped and in some places as much as 1,000 feet thick. They tend to dip about 10 degrees, generally down the present slope, except in the high peaks and near vents where steep dips are common.

Two of the units at Mt.Cayley contain curious structures of practical value for their enhancement of potential permeability. One of the dacite units at the base of the pile along the west edge is characterized by columnar jointing, and one of the andesite units which flowed down the western slope in an intermediate position within the pile contains several open lava tubes. Ten vents are positively identified in this area, four of which are isolated small volcanos or remnants of pipes north of the discontinuous body of layered volcanics. As at Meager Creek, there is a high probability that field work would turn up at least a dozen more vents and necks.

The adjacent Cretaceous granite, upon which the volcanics rest, is sliced by a high number of major through going faults, which in several cases form conjugate patterns. Very few of these faults displace the volcanic rocks significantly. In two instances volcanics have been down-dropped along a fault against the older rocks 500 to 1000 feet. In four instances major structures mapped from satellite images pass underneath outlying vents. It has not been established yet whether the westward slope of the base of the volcanics is due to tilting concurrent with volcanism, or in post-volcanic time, or if the volcanics were erupted on to the west slope of a range with the configuration more or less like the present range. The/

The latter possibility, however, appears most likely.

The thermal anomaly which was detected by the thermal infrared flight but not confirmed on the ground is located at the base of a lens of ash at a point of its maximum thickness, about 1000 feet.

On the north slope of Brandywine Mountain about 15,000 feet east of Mt.Cayley, a large expanse of Coast Range granite displays an air photo texture characteristic of a friable rock unit. We have inferred that this is due to hydrothermal alteration, and have so indicated the most intense zone on Map C3. This is not confirmed on the ground at the present time, nor is it known whether such alteration would be contemporaneous with the Mt.Cayley volcanism or the earlier episodes of igneous activity.

4.4. Bridge River Selected Area

A series of youthful volcanic centres near the headwaters of the Bridge River (Map C1) represent the northernmost occurrences of Garibaldi group volcanic rocks - - the 90 mile volcanic chain which includes Meager Creek, Mt.Cayley, and Mt.Garibaldi.

A mantle of volcanic deposits and at least four centres of eruption are present just north of the head of the Bridge River and west of Nichols Creek. These rocks cut and overlie crystalline rocks of Mesozoic age and permeable fragmental rocks of the Hurley formation, which become more abundant towards the north and east of the project area. The frequency of highly permeable rock units, with commensurate high reservoir potential, increases northeastward across this part of the Coast Range.

No thermal springs have yet been reported from this area, however, we attribute this to the area's remoteness, difficult access, and essentially unmapped status. (During the course of the infrared survey carried out in the spring several attempts were made to scan the area for hot springs but unbroken bad weather prevented it.).

4.5. Lillooet Fault Zone Selected Area

The lower "Lillooet fault zone" comprises a strip approximately one and one half miles wide extending from the north end of Harrison Lake 40 miles northwest along the Lillooet River to Wedge Pass in Billy Goat Creek. At the southeast end it is wider, including Glacier Lake, Sloquet Creek, and Douglas Creek.

Occupying/

Occupying the centre of this strip is a major fault, with a system of parallel subsidiary breaks, which essentially separates Coast Range granites on the northeast side from metamorphic rocks (predominantly the Fire Lake group, a 15,000-foot thick assemblage of sediments and volcanic-derived strata of upper Mesozoic age) on the southwest side. Much of the movement on the fault is inferred to have taken place in late Cretaceous and early Tertiary time.

In the northwest the zone of major faulting passes through northern Garibaldi Park and dissipates in a "horsetail" of sub-parallel faults in the vicinity of Wasp Creek, the Rutherford and Soo Rivers. To the southeast the lower Lillooet fault zone continues down the valley of Harrison Lake toward an obscure fate under the Fraser Valley alluvium. The fault zone is half of an <u>en echelon</u> system. The other half is the major fracture which controls the upper part of the Lillooet Valley, the emplacement of the Meager Mountain volcanic centre, and its associated thermal springs. The lower fault and its subsidiaries appear to control at least five thermal springs (Harrison, Clear Creek, August Jacobs, Sloquet, and Skookumchuck) and on this basis is tentatively considered to be an important and deep seated crustal feature.

Field and photo geological work to date has failed to turn up any evidence of recent volcanic activity with the possible exception of a few scattered remnants of flows near Billy Goat and Rogers Creeks from 2 to 4 miles on either side of the fault zone. These are given a Pliocene age in the literature, however, and although geologically quite young, are probably too old to be of more than passing interest.

4.6. <u>Wasp Creek Area</u>

The Wasp Creek area is a strip approximately 2½ miles wide, extending south up Wasp Creek from the Lillooet River, to the Rutherford River and on to the Lillooet District boundary. The area is underlain by Coast Range granites, however, in some parts extensive glacial drift and outwash conceal the underlying rocks. Immediately to the west of this region a small cone of Garibaldi volcanics crops out. Included in this complex are at least one vent, one lobate flow and a deposit of ash.

The region is the site of a major structural intersection; the major fault from Squamish north to the Hurley River crosses the "horsetailing" Lillooet fault system.

4.7./

4.7. Mt.Garibaldi Area

The best known examples of Pleistocene volcanism in southwestern B.C. are in the Mt.Garibaldi area just northeast of the town of Squamish. Volcanic rocks of the Garibaldi group, named for the locality, are distributed over an area about 8 miles wide and 20 miles long and consist of flows and pyroclastic rocks composed of basalt, andesite, dacite and rhyodacite. Basalts appear to predominate.

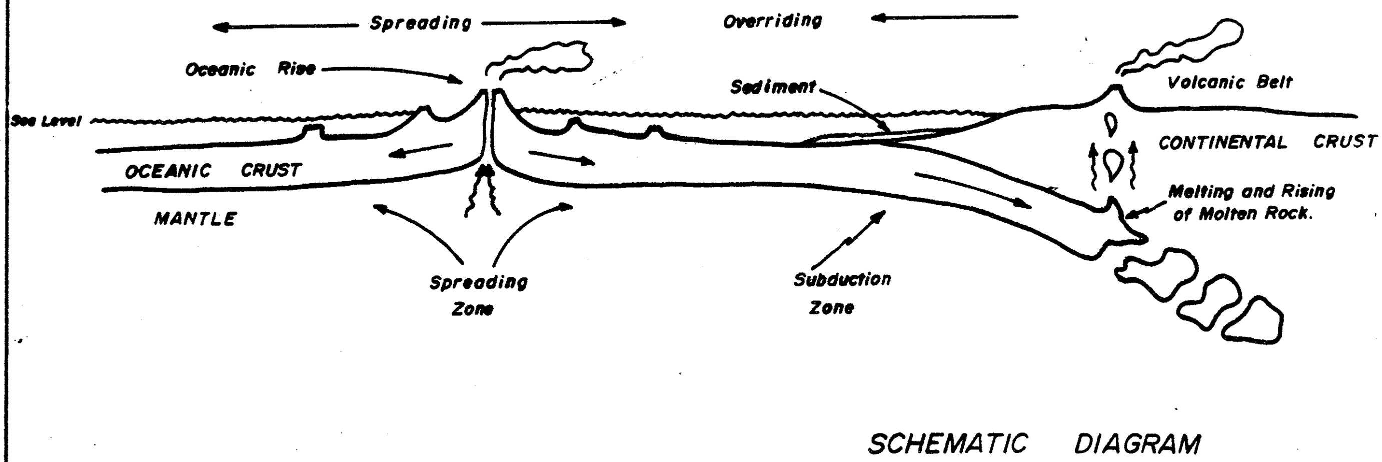
Several volcanic centres including Recent cinder cones and somewhat older (Pleistocene?) necks are present in the area, as are some spectacular lava flows such as those on the slopes of Mt.Price and in the valley of Ring Creek. Roddick and Matthews refer to a 2000-foot thick volcanic pile on Mt.Garibaldi, but the large areal extent of the volcanics is misleading: several units are thin caps or tongue-like flows down valleys. The volcanic rocks here, as elsewhere along the belt, cut and overlie Coast Range crystalline rocks of Mesozoic age.

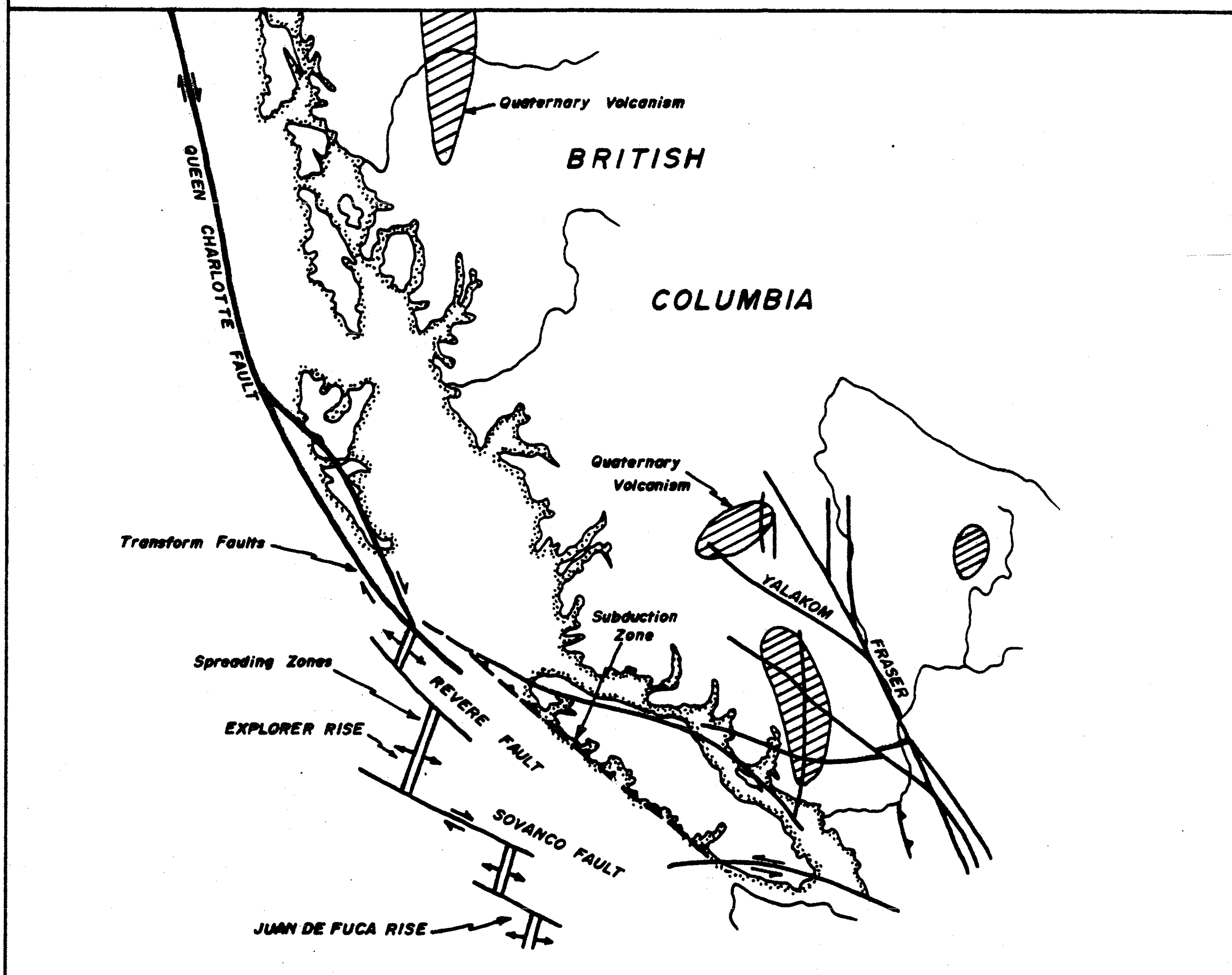
Although the area has been mapped geologically in some detail (Bostock 1963, Roddick 1965, and others) and its proximity to Vancouver makes it a popular area with climbers and hikers, no hot springs or other evidence of current geothermal activity are known.

4.8. Comparative Geology

Potential reservoirs in the Lillooet River region would occupy fractured granites and metamorphics, or some of the permeable volcanic units - - ash beds, columnar jointed flows, breccia beds or vertical breccia pipes. Granites are noted for having low permeability, however the whole question hangs on the density and distribution of fractures at the particular site. A well fractured granite would have a high permeability. On the whole the reservoir capability of the Lillooet region rocks is inferred to be similar to the median of the world's producing fields. Overall permeability should equal or better the "greenstone" at the Geysers, California, and the Icelandic and Japanese basalts and andesites. The rocks will have less overall permeability than New Zealand's fields and the natural vents at Yellowstone Park which produce from extensive porous volcanic ash beds, Imperial Valley, California, and Cerro Prieto, Mexico, which are in a broad desert valley with alluvium several thousand feet thick as a reservoir, and the Italian fields, where the steam occupies cavernous limestone and dolomite.

The volume and age of the recent volcanic rocks - - evidence of the required heat source - - are comparable to those of the Geysers, Cerro Prieto, Kamchatka Peninsula, East African prospects, Larderello-Monte Amiata, and several prospects under exploration by oil companies and utilities in the western U.S. The Icelandic, Japanese, and New Zealand/





DRAWING – 2

GLOBAL PLATE BOUNDARIES

Scale

100 50 0 100 M.

Zealand fields, and Yellowstone Park all have a larger volume of volcanic rocks, and in some instances these are parts of volcanic belts clearly active in historic time.

The consistent relationship of geothermal fields to major breaks or "plate boundaries" in the earth's crust - - zones of sea-floor spreading, continental rifting, transform faults, or subduction zones - - is reviewed in Appendix D. In this regard southwestern B.C. is imperfectly known, but does appear to have the required deep-seated breaks.(Drawing 2, A2).

Many constituents of ordinary rocks are unstable in geothermal reservoirs, in the presence of hot and slightly acid fluids, and are altered to new mineral suites. These include silica, sulfides and sulfates, clays, and oxide minerals (Appendix G, page 7, Dr.Read's report). Contrary to our expectations, none of these features were found in this investigation. There are several reasons for this: 1) the investigation was of a reconnaissance nature, and presumably further work will establish some outcropping parts of altered zones, 2) the alteration halos around geothermal fields in this region are depressed owing to the heavy rainfall and inflow of cold ground water (see also section 8.4), and 3) the granitic rocks in this region are more chemically stable in the presence of geothermal fluids and less permeable than some of the other geothermal regions.

5.0. AIRBORNE INFRARED SURVEYS

5.1. Principles

Any object at a temperature above absolute zero (-273°C) radiates energy in the infrared spectrum as a function of its temperature. Instruments capable of detecting infrared radiation in the wavelengths 3-5 microns and 8-14 microns* are available and can be used to detect variations in the earth's surface temperature from the air.

Infrared sensing is a reconnaissance technique used to find previously unknown hot springs and abnormally warm areas. It is subject to some constraints. For geothermal reconnaissance, flying must be done at night or in pre-dawn light, because sunlight is composed of infrared as well as visible light, and in a daytime survey spurious reflected infrared radiation masks the signal-to-background contrast. The season makes a difference, too; extensive snow, spring run off and long summer days hamper resolution (Appendix E).

5.2./

* one micron, um, is equal to one-millionth of a metre; visible light has a wavelength of 0.3 - 0.7 um).

5.2. Canada Centre for Remote Sensing

Early in this assignment we had intended to use a service offered by the Federal Department of Energy, Mines and Resources as a primary reconnaissance method. Canada Centre for Remote Sensing was scheduled to conduct a high level infrared survey of 2,000 square miles in the 8-14 micron band at the start of the program in October 1973. With the onset of winter we reduced the number of flight lines and area to be covered. The C.C.R.S. aircraft visited Vancouver several times during the period of this investigation and stood by to conduct the survey, but bad weather, aicraft, and sensor problems at different times forced cancellation of the flights. The survey remains as an active work order and we anticipate it will be completed in the summer or fall of 1974.

5.3. Low Level, High Resolution Survey

About 450 line-miles of selected terrain were scanned with a B.C. Hydro instrument mounted and flown in a Cessna 180 by Integrated Resources Photography Ltd. The instrument displayed the image on a TV screen, which was photographed at will by the operator. Hotter points showed up as white spots and cooler ones as shades of gray and black. Six anomalies of significance were found, as follows:-

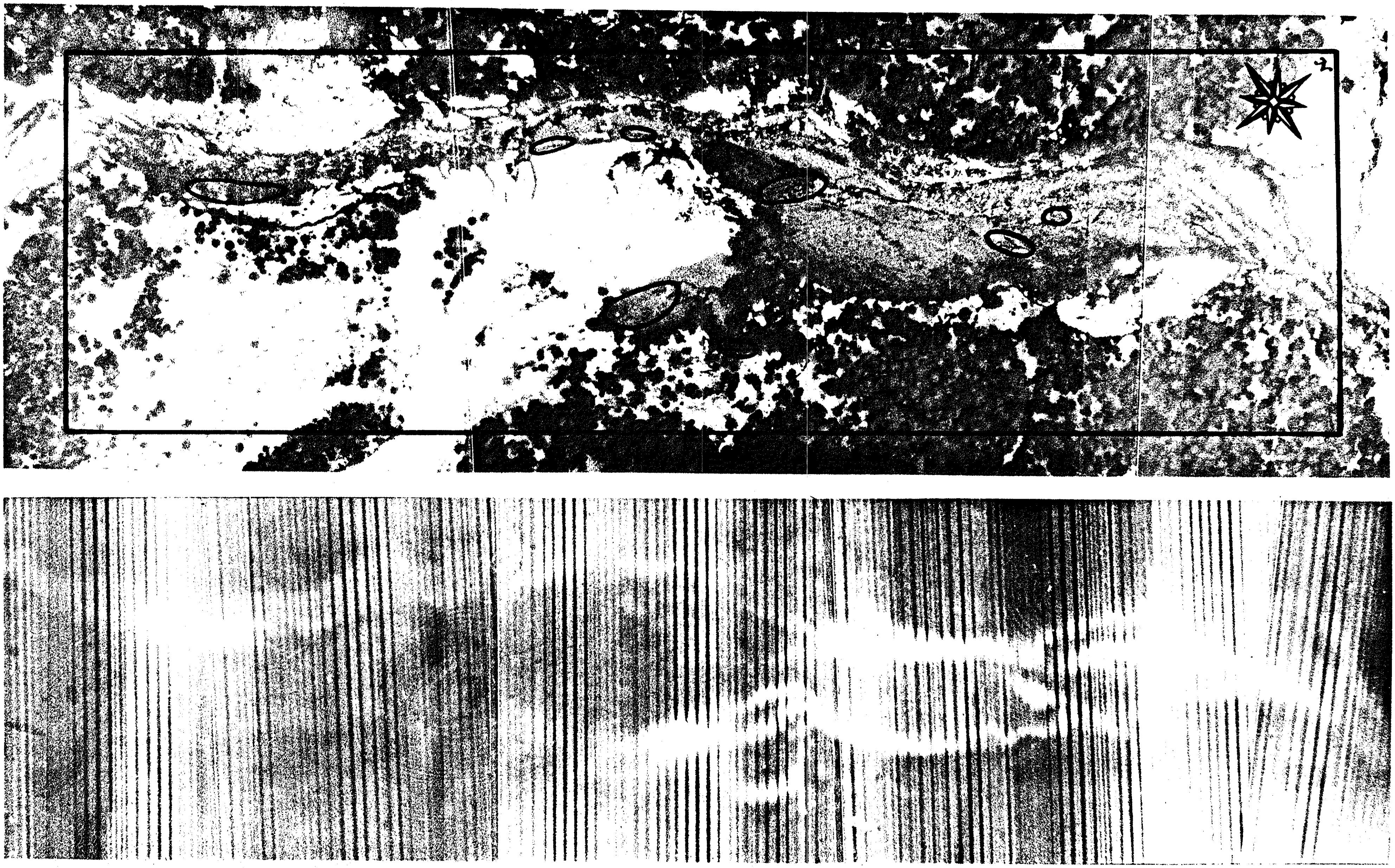
(a) Meager Creek - What was originally assumed to be two hot springs were found to be eight, issuing from a gravel channel over 4,000 feet in length (see following Plate); three small anomalies upstream might be significant or might be from retained solar heat.

(b) Pebble Creek - The scan simply better defined distribution of previously known springs (see second Plate following).

(c) Mt.Cayley - A small anomaly was detected in the gorge of Turbid Creek on the west side of Mt.Cayley; an attempt to inspect this on the ground in early June failed because of high water conditions (Map C3).

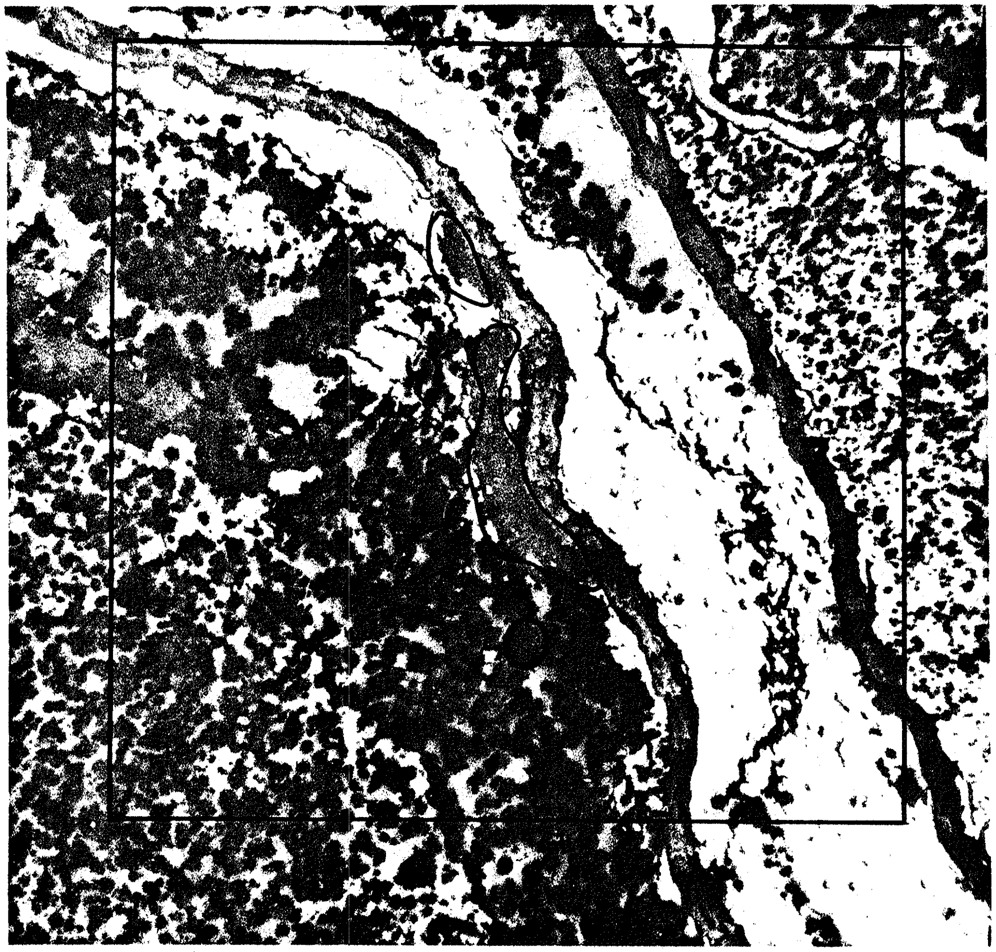
(d) August Jacobs - A hot spring at August Jacobs Creek, northeast bank of the Lillooet River (Map C8) and on the east edge of the Lillooet fault area, was described in 1925 (Elworthy) but has been since "lost". A scan rediscovered it, but high run-off foiled an inspection.

(e)/

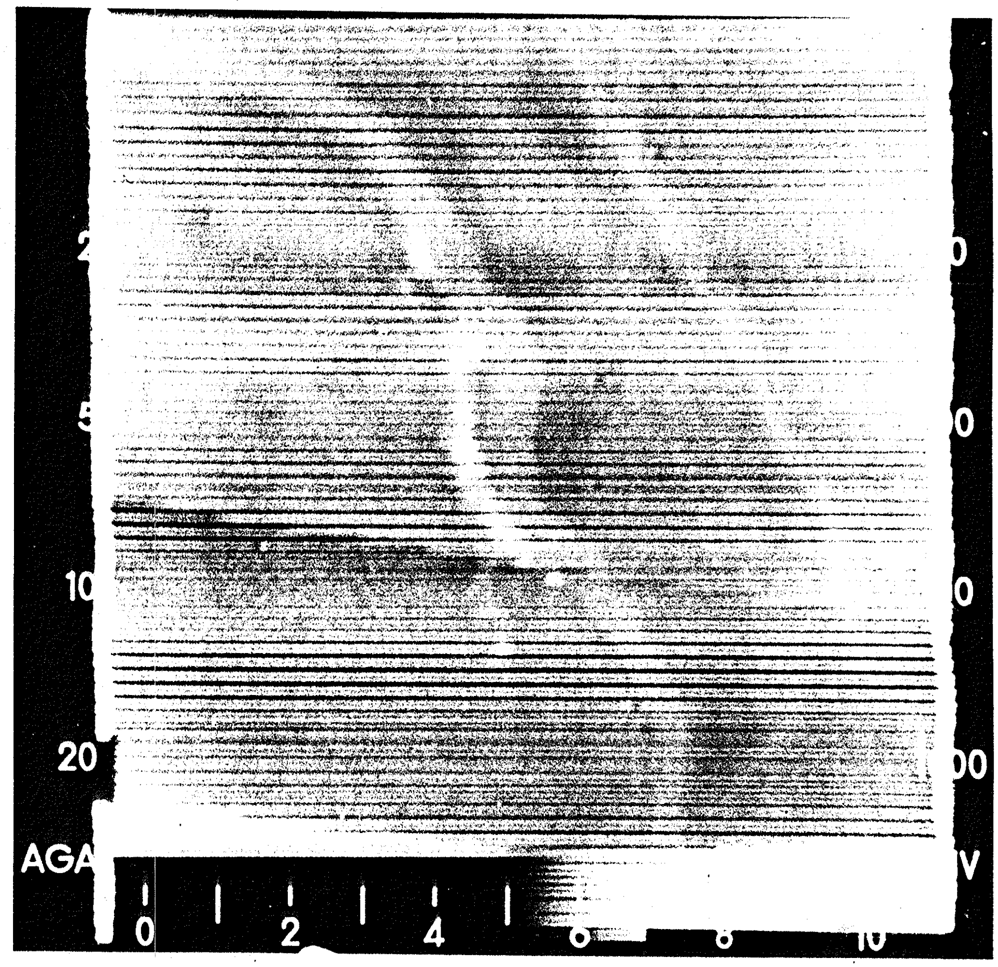


Mosaic of Vertical Air Photographs (top) and Thermal Infrared Scans of part of Meager Creek. Hot Water appears white on the scan. Vent areas and limit of scan are outlined in black on top 'photo. Scale is approximately 600 feet to the inch.

THERMAL SPRINGS ON THE LILLOOET RIVER NEAR PEBBLE CREEK



Vertical Air Photograph with Spring areas outlined.
Scale is approximately 300 feet to the inch.



Infrared Scan showing distribution of
Hot Springs.

(e) Sloquet Creek - Three new vents were added to the two known vents with the infrared scanning, one located 1,200 feet downstream; if the Sloquet Creek part of the Lillooet fault zone selected area becomes important, this information will help in further work (Map C8).

(f) Glacier Lake - An equivocal anomaly, which may be due either to geothermal waters or decaying vegetation, was detected at the south end of Glacier Lake (Map C8) in the Lillooet fault zone selected area; this was not inspected but is included in the proposed program; it is located near an intersection of two important faults.

5.4. Satellites

NASA's Earth Resources Technology Satellite (ERTS) is transmitting images of western Canada every day. These have two "very near" infrared bands (0.7 - 0.8 and 0.8 - 1.1 um), but this radiation behaves just like reflected visible light and has no relation to the temperature of the radiating object. (The images are useful, however, for geologic mapping). At present there is no thermal infrared equipment in any civilian satellite.

5.5. Comments on the Technique

Subject to a few changes, such as focal length of the lens, we feel that infrared scanning has established its utility and should be continued, if continued study is warranted, in the rugged parts of B.C. A more detailed description of the procedure, photographs of the equipment, and a memorandum from Integrated Resources Photography Ltd. are presented in Appendix E.

6.0. GEOCHEMISTRY OF HOT SPRINGS

6.1. Principles

The nature and amount of the dissolved constituents in hot springs are dependent on several factors - - reservoir temperature, host rock composition, physical state at depth, original source of the water, and amount of dilution with near surface waters. Chemical analysis of the thermal water can therefore provide information useful in discriminating between commercial and non-commercial classes of reservoirs. The concentration of silica and the relative proportions of sodium, potassium, and calcium have some memory of the highest temperature reached by the hot spring water in an underlying reservoir or channelway (Appendix F). Basically, the more silica, and the lower the sodium-potassium (Na-K) ratio, the higher/

higher the minimum possible reservoir temperature. Certain other elements also provide clues on the history of the water. Abundant magnesium or chlorine suggests a sub-boiling temperature; high sulfate content, except in a limestone terrain, suggests a hot reservoir.

Hot spring water may be inferred, under some circumstances, to be a mixture of water from a geothermal reservoir and near-surface ground water. Fournier has introduced a formula to unravel the mixing, based on silica content and temperature, to arrive at an estimated reservoir temperature (Appendix F).

6.2. Calculated Geochemical Temperatures

Nine hot springs are known within the region investigated. Six of these were sampled. One (Pitt River) was bypassed and two (Mt.Cayley and August Jacobs) were inaccessible because of high water after their discovery. Temperatures measured and calculated from the SiO_2 and Na-K-Ca thermometers, and other parameters, are given in Table 1.

The Meager Creek hot spring has outstanding properties, based on the estimates of minimum possible reservoir temperatures (166°C, 188°C, and 230-370°C), acidity, opal precipitates, and high rate of flow. Its only chemical drawbacks are the presence of calcite in the sinter and a very high chloride ion content in the water. Both of these are considered indicators of hot water systems rather than steam systems; however, in view of strong chemical and geological evidence to the contrary, it is possible, that these impurities may well be derived from secondary hot water reservoirs, the overlying cold ground water, rocks, or soil.

On the weight of geochemistry alone, Skookumchuck, Sloquet, and Harrison hot springs have given up only "permissive" evidence and we are using other criteria to evaluate these areas. Pebble Creek is rather bland chemically, but we are including it in with the Meager Creek system on the basis of proximity and geology. Clear Creek is of no further interest.

6.3. Comments

The Geological Survey of Canada conducted similar geochemical studies province-wide in the summer of 1973, under the direction of Dr.J.G. Souther. Their analyses are currently being completed and these data should be placed in open file status within a few weeks.

The value of geochemistry in reconnaissance has been established by U.S. Geological Survey researchers (Fournier, White, Muffler and others), and unlike our pilot work in infrared and resistivity, we have simply followed their lead.

7.0./

TABLE 1 - CALCULATED TEMPERATURES OF HOT SPRINGS

Spring	Map No	Flow (litres/min)	Temperatures (°C) Observed	Na-K-Ca	SiO_2	Mixing Model	Comments
Meager Creek	C-1	500	59	188	166	230 - 370	600 ppm.Cl, pH 6 opal, calcite.
Pebble Creek	C-1	100	60	140	120	not calculated.	100 ppm.Cl. - calcite, iron oxide.
Skookumchuck	C-8	40	54	N/A	112	160 - 230	300 ppm.Cl. - calcite.
Sloquet Creek	C-8	100	64	135	110	135 - 185	440 ppm. SO_4 - opal, gypsum.
Harrison Hot Spring	C-10	250	63	132	106	125 - 175	High SO_4
Clear Creek	C-9	50	43	N/A	109	not calculated.	

7.0. ELECTRICAL RESISTIVITY

7.1. Principles

Electrical resistivity is the single most diagnostic geophysical tool used in the search for geothermal reservoirs and in detailing their outlines. The specific resistivity (the reciprocal of specific conductivity) of rock in a geothermal environment is controlled by the proportions and resistivities of interstitial materials contained within it. Typical reservoirs have resistivities one-tenth to one-fiftieth of surrounding rocks, owing to higher porosity, high content of dissolved salts, high proportions of conductive alteration minerals such as clays and iron pyrite, and higher temperature.

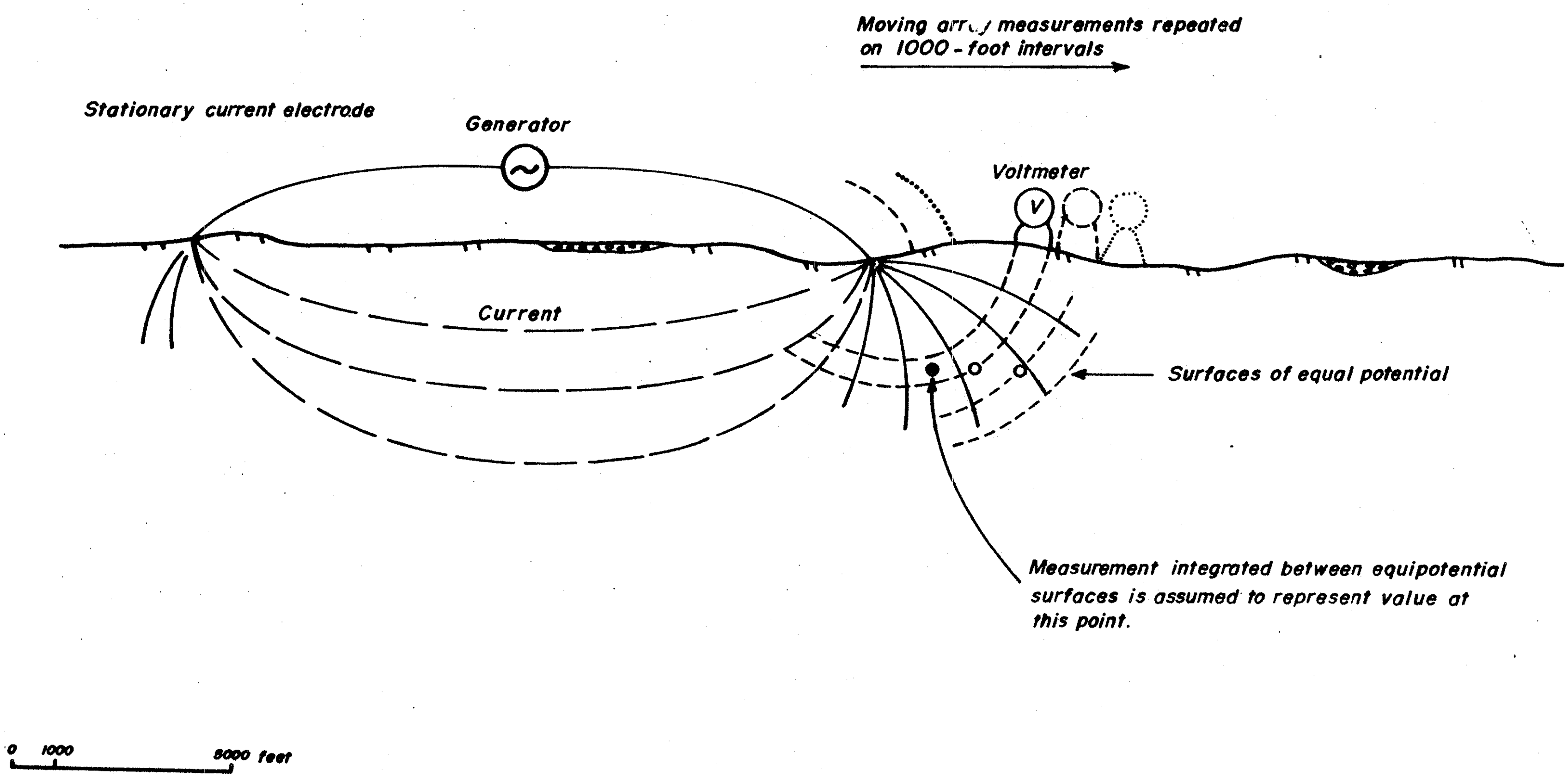
7.2. Profiles

Resistivity is primarily a tool for detailing known or suspected reservoirs. It is usually conducted on a widely spaced grid over an area of several square miles. We ran two pilot profiles in the course of this reconnaissance investigation for two reasons: to test the adaptability of the method to the ground water and crystalline rock conditions in this region, and to further investigate the two areas.

The survey described in detail in Nielsen's report (Appendix H) consisted of transmitting a current between two electrodes placed in the ground at least 15,000 feet apart, and measuring the voltage across a nearby interval with two other electrodes, as shown in Drawing 3. Part of the electrode array is moved along the line, the operation is repeated, and a profile is constructed.

Meager Creek and Skookumchuck hot springs were originally selected for test resistivity profiling, the latter largely because of its ready access and Meager Creek because it is considered the leading commercial candidate. The persistent snow pack there, however, rendered geophysical work impossible and forced the substitution of the Sloquet Creek hot spring.

The four mile profile at Skookumchuck was run on the southwest side of the Lillooet River, across from the hot spring and a 360kV transmission line. Resistivities varied from 7540 ohm-metres to 870 ohm-metres. Background resistivity of the ordinary granitic rocks is 5000 to 7000 ohm-metres. A broad 1000 - 2000 ohm-metre resistivity low (with two humps in the middle) is present in the centre of the profile. (Map and Profile, D1). Using electric and geologic criteria, we interpret this low as the apex or fringe of a conductive zone, perhaps a reservoir, centred under or adjacent to station 2+50S, which is located 3000 feet south-southeast of the Skookumchuck hot spring. More parallel survey lines on the/



DRAWING — 3

Cross Section of Electrical Resistivity Method

Pole - Dipole Electrode Array

the opposite side of the river would better define the low.

At Sloquet Creek the resistivity readings varied from 2000 to 5600 ohm-metres over a profile of 2.8 miles. There is little contrast along the profile and nothing of interest was detected.

7.3. Comments on the Method

As anticipated from other electrical exploration, the general abundance and purity of run off and near-surface ground water in the region forms a resistive blanket between the surface and the subject rocks at depths of 3000 feet or 1 kilometre. Apparent (measured) resistivities are thus higher than in geothermal regions elsewhere in the world, where ordinary rocks measure 100 - 1000 ohm-metres and geothermal reservoirs measure 10 - 20 ohm-metres. We believe, however, that the validity of the electrical resistivity holds, although an expanded survey might install larger and deeper current electrodes, repeat readings at various electrode spacings, and use, in part, another electrode array, the dipole-dipole array.

8.0. OTHER DATA

8.1. Energy, Mines and Resources Work

The Geological Survey of Canada and Earth Physics Branch of E.M.R., conducted a study of the Meager Creek hot spring in March-April, 1974, which included two drill holes to depths of 155 and 200 feet. Both hit artesian hot water at 59°C, the same temperature as the natural flow, one in the gravel stream channel and the other in fractures in the granitic rock (Dr.J.G. Souther, personal communication).

The G.S.C. is scheduled to map the geology of the Pemberton map sheet (C1-C5 of this report) in the summer of 1974, which will be an invaluable adjunct to our reconnaissance mapping.

8.2. Earthquakes

Epicentres of all recorded earthquakes in southwestern B.C. of greater than Richter magnitude 3 were plotted with an eye toward establishing deep seated faults. They are too scattered to form a distinct pattern, but they do cluster around major faults outside the region of interest, and a few lie along and confirm recent activity on major faults at the west edge of the Lillooet River region of this report (Map A2).

8.3./

8.3. Airborne Magnetic Maps

Energy, Mines and Resources released airborne magnetic maps of the region between Hope and Lytton during this study. The area covered by these extends far enough west to include the Harrison and Clear Creek hot springs, and Lillooet Lake, but stops short of most of the region of geothermal interest. Some information on geology of minor value was obtained from these maps.

8.4. Annual Precipitation

The Lillooet River region has annual precipitation measured at about 40 - 50 inches in the valleys to more than 150 inches (rainfall equivalent) in the high mountains (Skoda and Robertson). This is an order of magnitude greater than that of geothermal areas in temperate and desert climates, and is comparable only to rainfall in tropical regions. Thus the region is unique in several respects in comparison to the well-studied temperate and desert geothermal deposits:

(a) Tendencies to form hot springs and natural geysers are likely to be suppressed by cold ground water. These phenomena are disproportionately rare and estimates of geothermal potential based on hot springs alone are erroneously low.

(b) Where hot springs occur they are mixed and contain a high proportion of fresh ground water; temperatures are lowered and temperature indicators are diluted.

(c) As mentioned (section 7.3) the fresh ground water contains few ions and forms an electrical insulating blanket.

(d) The availability of water for a geothermal convection cell is high and would not be a limiting factor in natural recharge ability.

(e) Salinities of reservoirs could be expected to be low, unlike the deleterious 30 per cent brines of the Imperial Valley - Cerro Prieto desert basin.

9.0. RECOMMENDATIONS

9.1. Existence of Commercial Geothermal Reservoirs

Exploration is premised on the concepts that one or more commercial reservoirs exist and that the explorer has the ability to find one, identify it and develop it. This program has confirmed these concepts in our minds for the following reasons:-

(a)/

(a) Geology - - mainly faults and volcanics - - are comparable to producing geothermal areas elsewhere.

(b) Geochemical temperature calculations on one hot spring are outstanding; those on four others constitute permissive evidence.

(c) The technology for discovery is available.

9.2. <u>Selected Areas</u>

On the basis of the foregoing data we suggest areas of continued interest as defined on the Summary and Recommendations Map (Drawing B) and outlined in Table 2. The areas are ranked in order of attraction. Volcanos and volcanic rocks are given greatest weight; major faults are second; and hot spring temperature calculations third.

9.3. <u>"Geophysical" Techniques</u>

Reconnaissance, as noted in foregoing sections, makes use of airborne infrared, preliminary geology, and hot spring chemistry. Detailed evaluation (the geothermal industry inherited the term "geophysics" from the oil industry to describe this stage) makes use of more specific tools:-

(a) Resistivity - parallel lines spaced 3000 - 5000 feet apart, taking measurements at depths of 1500, 3000, 5000 feet, etc.

(b) Shallow drill holes - to below the influence of cold ground water, say at least 1000 feet in this region, for the purpose of obtaining a temperature gradient and heat flow measurements. (Heat flow must be measured in several non-fractured impermeable sections of the drill hole, since total heat flow is made up of conductive and convective components, and only the former can be measured <u>in situ</u>). Such drill holes are used for preliminary permeability tests as warranted.

(c) Detailed geologic mapping - at a scale of about 1:25,000.

(d) Microseismic survey - a spread of stationary geophones records micro-earthquakes of Richter magnitude -4 to 1, the same order of seismic events as noise from a train several miles away. This information is processed to pin-point the location and geometry of the major fractures controlling the convection cell. (Application of microseismicity to geothermal investigations is in its infancy, and the method should be used cautiously).

We recommend combinations of these techniques and expansion of some of the reconnaissance techniques on the selected areas.

TABLE 2 - SELECTED AREAS

Rank	Area	Square Miles	Favorable Features	Proposed Work
1	Meager Creek (incl. Pebble Creek)	90	Large layered volcano, several large craters and lava vents; hot spring chemistry and temperature calculations; abundant volcanic ash beds; major faults.	1. Resistivity survey, 80 line miles. 2. 4 1200' drill holes for heat flow measurements. 3. Detailed geologic mapping 4. (Possible) microseismic survey.
2	Mt.Cayley and east side Elaho River.	100	Large layered volcanos, several vents.	1. Airborne infrared 2. Hot spring sampling 3. Detailed geologic mapping 4. Resistivity profiles, 25 line miles. 5. 1 1200' drill hole, heat flow.
3.	Bridge River	60	4 prominent and young volcanic vents.	1. Airborne infrared 2. Detailed geologic mapping 3. Resistivity profile.
4.	Lillooet fault zone	170	Major fault systems; two permissive hot springs; one resistivity anomaly.	1. 1 1200' drill hole, heat flow. 2. Resistivity profiling, 20 miles.
5.	Wasp Creek	120	Intersection of two major fault systems.	1. Airborne I.R. 2. Ground inspection of geology.

9.4. Timing and Sequence

The proposed work could be scheduled to run from July 1974 and be completed by June 1975 at Meager Creek and mid-August 1975 for other areas (Appendix J). Work on Meager Creek should start immediately upon approval, beginning with geology and resistivity. We visualize that if Meager Creek continues to remain interesting, resistivity and detailed geology should be followed by heat flow drilling. There is no road access to Meager Creek and a helicopter must be used to transport people, equipment and supplies. The Meager Creek work could proceed in stages as indicated in section 9.6.

Concurrent with the work on Meager Creek, preliminary "geophysics" should be done in sequence on Mt.Cayley, Bridge River and Lillooet fault areas (as generalized in Drawing 4 and scheduled in Appendix J). An expanded reconnaissance is proposed to follow in sequence for the Wasp Creek area.

There is a reason for a multi-faceted approach to several independent areas. Experience elsewhere (and in the oil and mineral industries) holds that in order to finish with one producer, several areas must be examined closely. Hence in deciding how and where to proceed, each prospective area is weighed against an ideal model of parameters at that stage of exploration, and against each other area under consideration. The leading area, in this case Meager Creek, is subjected to the most scrutiny in the next stage, but in order to optimize the program, work in a few other independent areas should be brought along tentatively.

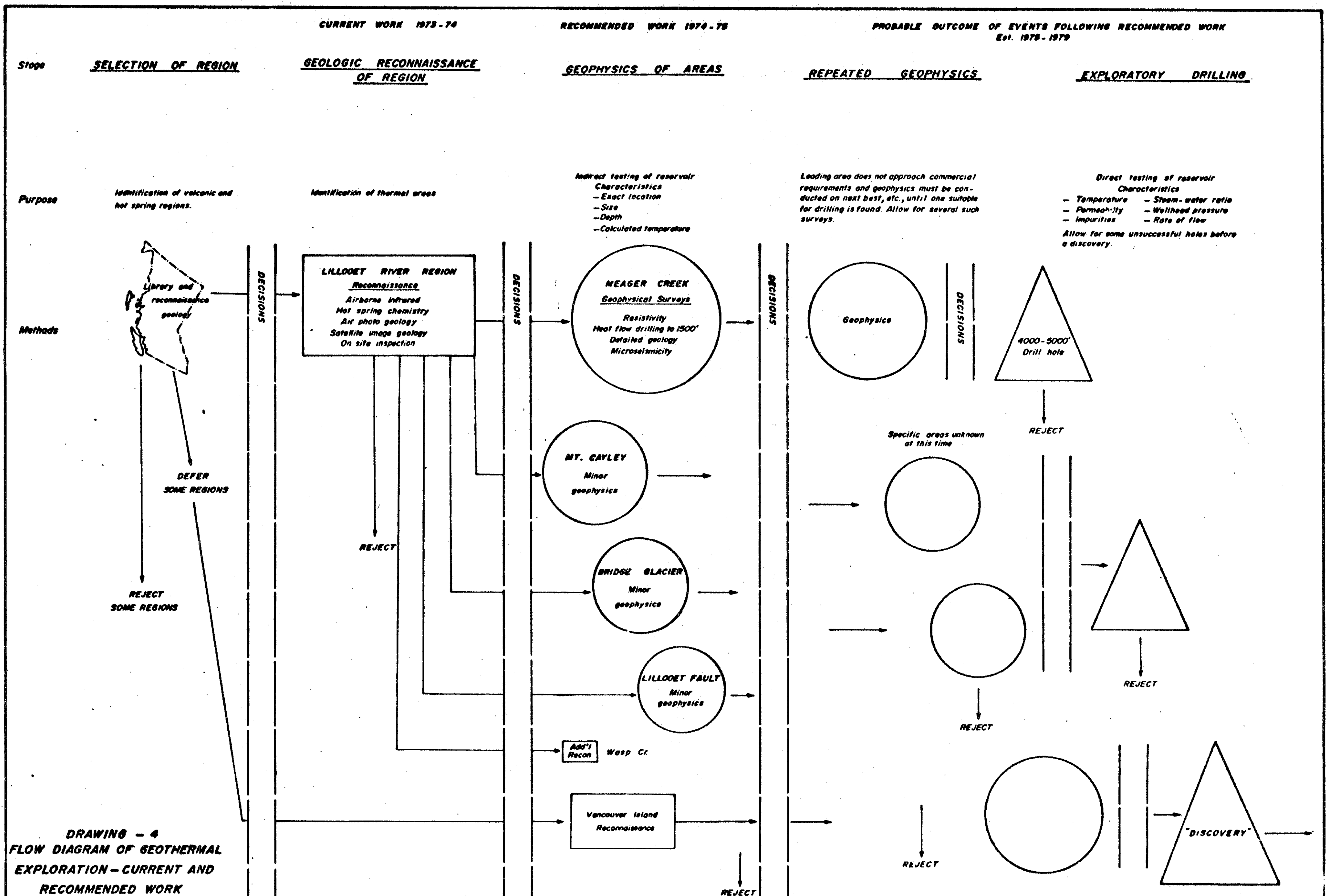
9.5. Western Vancouver Island

Vancouver Island is outside the scope of this assignment and was not studied. However, the same geologic criteria which led to the selection of the Lillooet River region suggest strongly that anomalous heat flows and commercial geothermal resources could be present along a major fault zone on the west coast of the Island.

For this reason, contingent upon B.C. Hydro's plans for future energy supplies, we recommend a two-stage reconnaissance be conducted on a 1200 square mile strip from Ucluelet to Nootka Sound. The first stage would sample the four hot springs in the region and inspect the geology, and the second consist of airborne infrared scanning and geological reconnaissance.

This work (not scheduled in Appendix J nor shown on the Map B, Recommendations) could be scheduled any time, noting that fall is the most efficient season for infrared surveys.

9.6./



DRAWING – 4
FLOW DIAGRAM OF GEOTHERMAL EXPLORATION – CURRENT AND RECOMMENDED WORK

9.6. Estimated Cost of Recommendations

(a) Meager Creek Selected Area

Stage 1.

Geologic mapping at 1:25,000	$ 15,000
Resistivity survey, 20 line-miles @ $650/line-mile	13,000
One 1200' heat flow drill hole at $18/foot	21,600
Helicopter support, transportation	8,000
Camp costs	3,500
Administration, supervision, reporting	6,000
	67,100

Stage 2.

Resistivity survey, 60 line-miles	39,000
3 - 1200' heat flow drill holes @ $15/foot	54,000
Field Supervision	5,500
Helicopter support, transportation	10,000
Camp costs	6,000
Administration	12,000
Road and well cost estimate and specifications	4,000
Reporting and contingencies	5,000
	135,500
SUB TOTAL -	$202,600

(b) Mt.Cayley Selected Area.

Geology, geochemistry	8,000
Airborne I.R., 1000 line-miles	8,000
Resistivity, 25 line-miles @ $550/line-mile	13,750
Heat flow hole - 1200' @ $15/ft	18,000
Transportation, camp costs, supervision	8,000
Administration, reporting	9,000
	$ 64,750

SUB TOTAL c/f -	$267,350

SUB TOTAL b/f -$267,350

(c) Bridge River Selected Area

Geology	3,000
Airborne I.R., 500 line-miles	4,000
Resistivity, 10 line-miles	5,500
Helicopter support	4,000
Camp, supervision, administration, reporting.	5,000
	$21,500

(d) Lillooet Fault Zone Selected Area

Geology and geochemistry	5,500
Resistivity, 15 line-miles	8,250
Heat flow hole - 1200' @ 15/ft	18,000
Transportation, camp, supervision, administration, reporting	8,000
	39,750

(e) Wasp Creek Reconnaissance Area

Airborne I.R. - 800 line-miles @ $8/line mile.	6,400
Geology, geochemistry, interpretation, report.	2,500
	$8,900

(g) West Vancouver Island Region

Stage 1

Preliminary geochemistry and geology	4,500

Stage 2

Airborne I.R., 3000 line-miles	24,000
Geology, administration, support, reporting	6,500
	35,000

TOTAL OF RECOMMENDATIONS........ $372,500

9.7./

9.7. Possible Outcome

Execution of the proposed work should carry the geothermal investigation to the point where Canada's first exploratory geothermal well, a 4000 - 5000 foot hole, can justifiably be drilled; or it should carry it very close to that point, lacking only some additional geophysics, as shown schematically in Drawing 4.

10.0. REVIEW OF DEVELOPMENT AND PRODUCTION

10.1. Exploration Objectives

The objective of exploration is to discover a deposit which can be developed and produced at an economic cost, and it is appropriate to be thinking ahead during an exploration program.

10.2. General Exploration, Development, Production

Early stages of exploration have an ethereal quality. There is no guarantee that an expenditure of "X" dollars will result in a discovery of commercial steam. However, as exploration progresses and knowledge of a region or area is augmented, two things happen: the probability of a discovery increases, and a clearer picture unfolds as to the location and physical properties of the target geothermal field(s), the timing of development, costs, problems, and capacity. If the probability does not increase fast enough, in the judgement of knowledgeable managers, and the economic picture does not come into focus, the program should be re-evaluated or terminated. (The probability concept is diagrammed in Drawing 5).

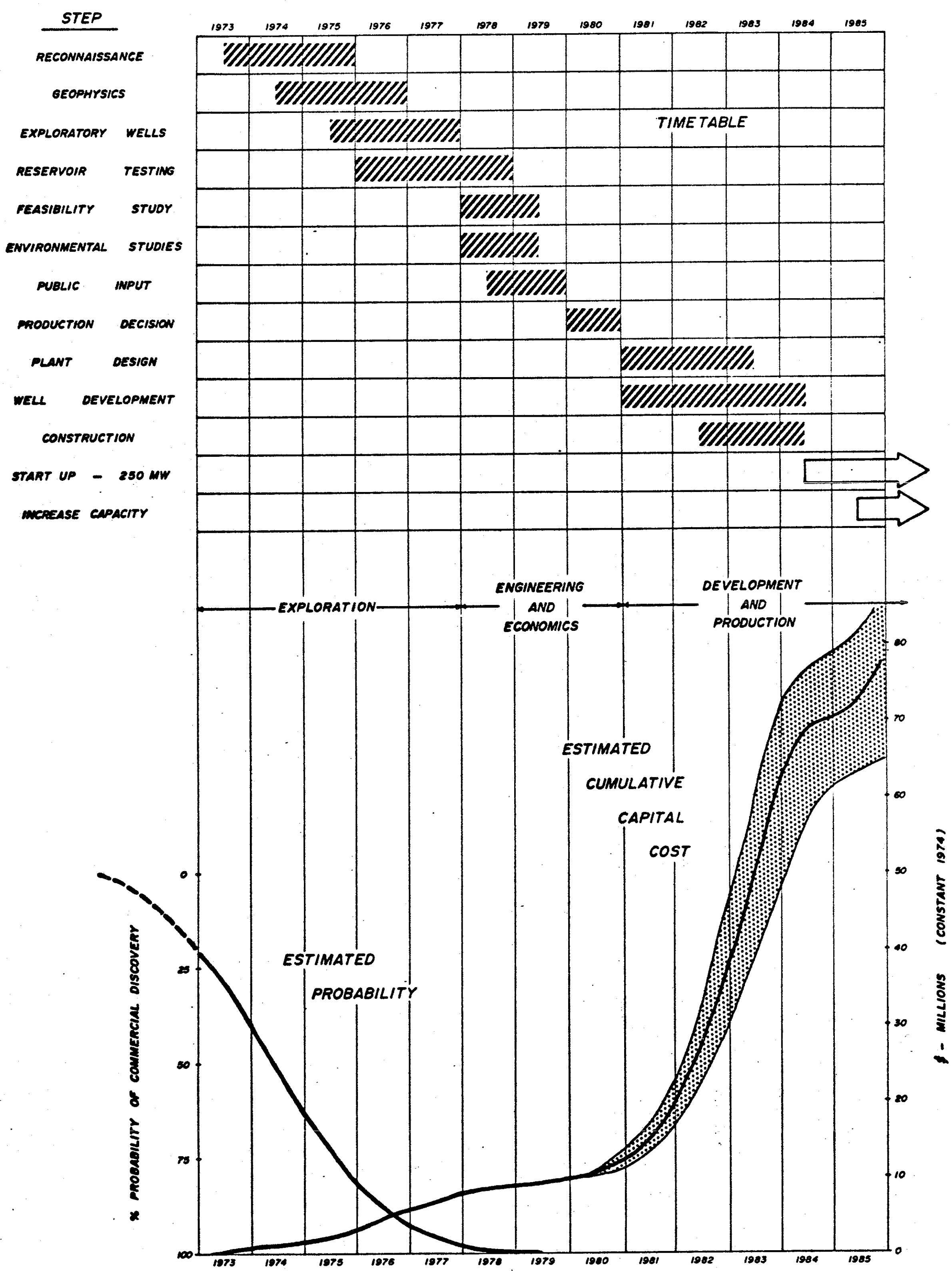
In the absence of a large statistical base the success ratios and cumulative costs of a commercial discovery can only be estimated. When viewed against the value of a substantial geothermal field, however, most estimates yield odds in favor of the explorer. Greider and Axtell estimate a total exploration and testing cost of about $8-million (1974 dollars) for one producer.

An approximate timetable of steps and rough estimate of cumulative capital cost, based on industry-wide experience, is shown schematically in Drawing 5, along with the probability concept in perspective. We suggest that work initiated in 1973 could lead to a confirmed commercial field in 1979, and a start up of the first 250 Mw in 1984.

Timing depends on the effort put forth. An optimum level of activity would be as diagrammed, and could be accelerated by one or two years or stretched out over several more years without wasteful spending or delays.

10.3./

APPROXIMATE TIMETABLE FOR GEOTHERMAL DEVELOPMENT



DRAWING 5

10.3. Environmental Considerations

The recommended exploration would include cutting lines, placing electrodes, and building tent camps and small drill sites, all totalling less than one affected acre. We foresee no threat of damage to water quality, fisheries, marketable timber, soil stability, aesthetics or other environmental values. We suggest, however, that guidelines of the B.C. Fish and Wildlife Branch, Forest Service, and Department of Mines and Petroleum Resources be observed.

Edges of the Lillooet fault selected area touch or extend into Garibaldi Park at three points. We recommend that work within the park be limited to geologic mapping and hot spring sampling.

Later stages of exploration would involve pioneer roads and large drill sites, affecting more than one acre. We suggest detailed plans to protect streams and restore land in conjunction with the appropriate Provincial government agencies.

Environmental aspects of development and producing plants are beyond the scope of this report. Considerable research has been done on this, and a leading reference is a recent Environmental Impact Statement by the U.S. Department of the Interior.

10.4. Tenure

The provincial Geothermal Resources Act received Royal assent November 7, 1973. It defines the resource and states that unless otherwise provided title is reserved to the Crown (Appendix K).

Respectfully Submitted:

NEVIN SADLIER-BROWN GOODBRAND LTD.

June 30, 1974.