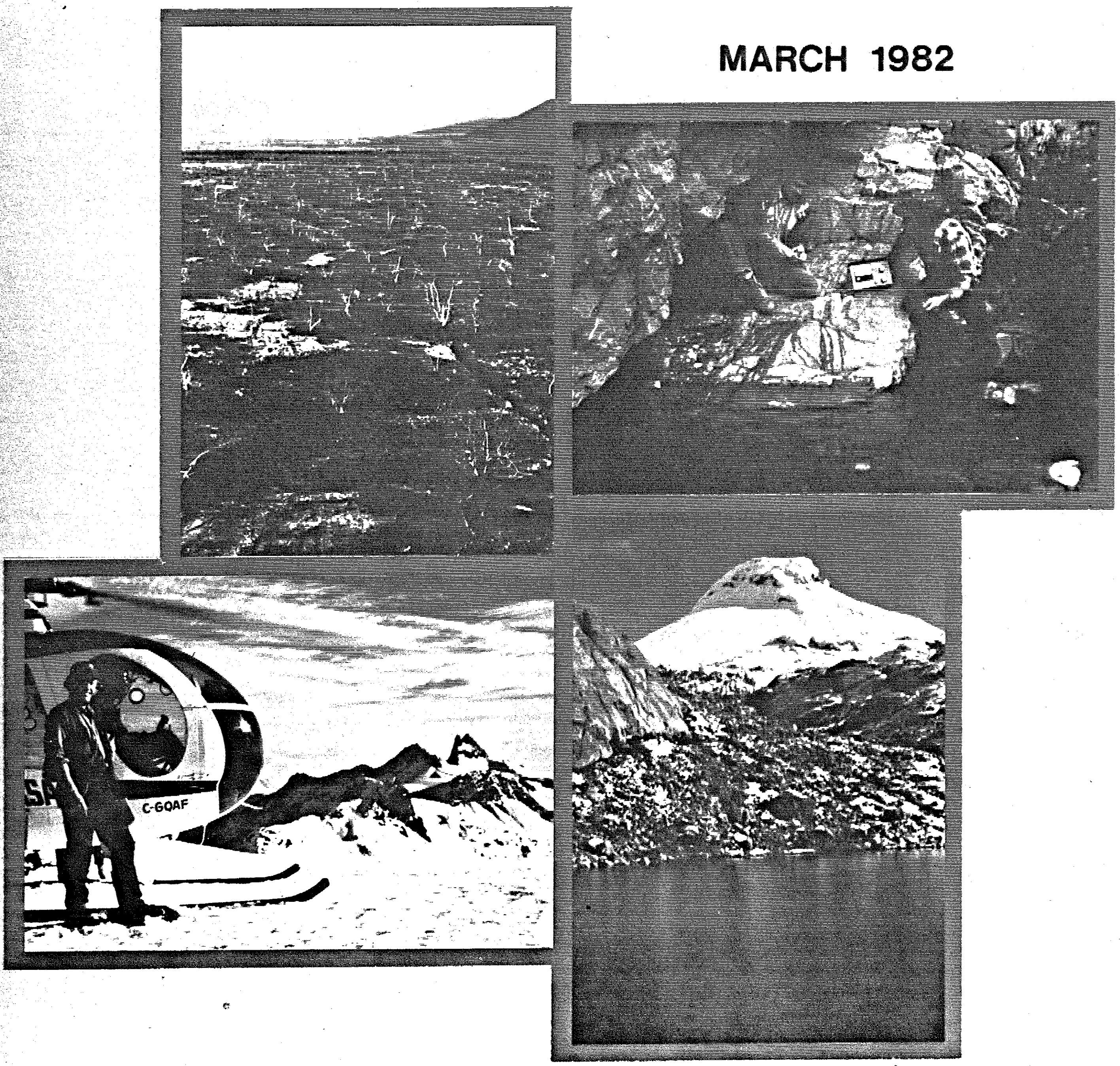
B.C. HYDRO AND POWER AUTHORITY

Report on

GEOTHERMAL RECONNAISSANCE EXPLORATION OF SELECTED AREAS IN SOUTHWESTERN BRITISH COLUMBIA

MARCH 1982



NEVIN | SADLIER-BROWN | GOODBRAND | LTD

B.C. HYDRO AND POWER AUTHORITY

Geothermal Reconnaissance Exploration Of Selected Areas In Southwestern British Columbia

Squamish and Elaho Drainage	J.F. Reader, S.A. Croft
Mt. Garibaldi	J.F. Reader
Pitt River Hot Springs	J.M. Britton
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Aiyansh	R.E. Swintz

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March, 1982

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LIST OF ACCOMPANYING REPORTS ON D.C. RESISTIVITY SURVEYS

1. D.C. Resistivity Survey in the South Meager - Elaho River Valley (Interim Report) September, October, 1981 by Michael G. Schlax and Greg A. Shore for Nevin Sadlier-Brown Goodbrand Ltd. dated January 15, 1982.

2. D.C. Resistivity Survey in the Mt. Cayley - Squamish River Area (Interim Report) September, October, 1981 by Greg A. Shore and Michael G. Schlax for Nevin Sadlier-Brown Goodbrand Ltd. dated January 16, 1982.

3. Report on a D.C. Resistivity Survey in the Pitt River Area, B.C. September, October, 1981 by Greg A. Shore and Michael G. Schlax for Nevin Sadlier-Brown Goodbrand Ltd. dated January 14, 1981.

1.0 SUMMARY

Geothermal reconnaissance exploration, including geological mapping, spring water chemistry, soil geochemistry and, in selected cases, resistivity surveys has been conducted in the Squamish River, Elaho River and Mt. Garibaldi areas of the Garibaldi Volcanic Belt and in the Pitt River Hot Springs, Lower Lillooet River, Lakelse Lake and Aiyansh areas of western British Columbia in the period mid-September-December, 1981. This report represents the first geothermal assessment in each project area with the exception of the Mt. Cayley Volcanic Complex in the Squamish River area (NSBG, 1974; Lewis, 1977; Souther, 1980) and the Skookumchuk and Sloquet Hot Springs in the Lower Lillooet Valley (NSBG, 1974). The objective of the current work was to obtain baseline data in order to identify leading prospects for further assessment and possible development for high temperature geothermal resources.

Project areas were selected due to either the occurrence of hot springs or evidence of Quaternary volcanism or both as outlined in a proposal to B.C. Hydro by Nevin Sadlier-Brown Goodbrand Ltd. dated July 30, 1981. On the basis of data gathered during the 1981 reconnaissance, we consider that there is excellent potential for the occurrence of one or more high temperature geothermal resources within the regions explored that could be developed over the next decade. Areas that require further work are outlined below.

Two targets have been identified as the leading high-temperature resource prospects:

- Mt. Cayley Volcanic Complex (Garibaldi Volcanic Belt)
- Sloquet Hot Springs (Lower Lillooet River)

Specific targets have been interpreted from geological data, thermal spring characteristics, resistivity and soil (Hg, As) anomalies. Further surface exploration to delineate the anomalies and gradient drilling are required.

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Excellent geothermal potential is indicated by the geology at

- Hill 7210
- Aiyansh Hot Springs

Hill 7210 is a complex, differentiated volcanic pile overlying intensely altered, locally pyritiferous granodiorite indicating past or present hydrothermal activity. Only a brief examination of the Aiyansh Hot Springs was made, nevertheless, the spring water chemistry, silica sinter and association with very young volcanic activity (≅200 years old) warrant detailed assessment. Further surface exploration is necessary at both these areas to determine if and where drilling should be done.

In addition, numerous anomalies designated "Interest Areas" require follow-up to determine their geothermal significance. These are:

- Upper Elaho (Garibaldi Volcanic Belt)
- Mt. Garibaldi areas (Garibaldi Volcanic Belt)
- Twin Peaks (Northern Vancouver Island)
- Marble River (Northern Vancouver Island)
- Easy Cove (North Vancouver Island)
- South Lakelse
- Pitt River

Reconnaissance exploration remains to be completed on northern Vancouver Island and in parts of the Elaho drainage of the Garibaldi Volcanic Belt. Winter conditions forced a termination of the field work in the late fall.

The estimated cost of the proposed work is given in the following table:

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TABLE 1.1 ESTIMATE OF COSTS

	Mount Cayley	Hill 7210	Upper Elaho	Mount Garibaldi	Pitt River	Sloquet	Northern[5] Vancouver Island	Lakelse	Aiyansh	TOTALS
Geology and Engineering (includes well site)	77,500	15,500	7,400	14,700	3,700	46,800	24,300	5,200	10,400	205,500
Geochemistry	16,400	4,700	10,900	13,700	6,000	12,000	20,100	3,200	15,800	102,800
Resistivity	80,000	15,000	40,000	23,000	7,000	68,200	40,000	22,000	30,000	325,200
Drilling	276,000[1]	45,000[2]				230,000[3]			34,500[4]	585,500
Other Physical Work (line cutting, roads, pads, etc.)	14,200		2,900			31,500			1,600	50,200
Accomodation & Supplies (including vehicles, mod, demob)	107,800	17,900	5,400	8,600	7,200	85,200	27,800	10,200	10,600	280,700
Helicopter	72,400	19,000	20,000	2,500		40,500	2,500		14,000	170,900
Supervision & Administration	15,000	3,000	1,500	3,000	2,000	16,500	6,500	3,000	2,000	52,500
Analysis & Reporting	27,200	6,900	5,900	4,900	6,600	21,600	14,400	4,400	8,800	100,700
TOTAL	686,500	127,000	94,000	70,400	32,500	552,300	135,600	48,000	127,700	1,874,000

NOTES:

1) Approx. 2400m in 4 holes
2) " 600m in 1 hole
3) " 2000m in 4 holes
4) " 300m in 1 hole
5) Includes work in 3 project areas (Port Alice; Marble River Lineament Zone/Easy Cove; Twin Peaks/Victoria Lake).

2.0 INTRODUCTION

2.1 Terms of Reference

Reconnaissance geothermal exploration of seven separate project areas in southwestern British Columbia was conducted during the period mid-September-December, 1981. The program implemented geological mapping and analysis, spring water chemistry, stream water conductivity, soil geochemistry and resistivity surveys recommended in a proposal to B.C. Hydro and Power Authority by Nevin Sadlier-Brown Goodbrand Ltd. dated July 30, 1981.

Nevin Sadlier-Brown Goodbrand Ltd. (NSBG) was retained by B.C. Hydro as the prime engineering consultant to administer the project, manage logistics, execute and interpret geological and geochemical surveys and plan and manage resistivity surveys. This work was done under the authority of Purchase Order #149885 and Changed Order #149885-01 dated October 6, 1981 and November 18, 1981 respectively. Premier Geophysics Inc. served as consultant and contractor to NSBG for all geophysical work.

2.2 Scope and Organization of Report

This report is a description of field activities and a detailed compilation of results from the 1981 field reconnaissance exploration of seven project areas in western British Columbia. Each project area is discussed separately in Chapters 3.0 - 9.0. Results of resistivity surveys are reported by Premier Geophysics Inc. under a separate cover; only a brief summary is included here. A bibliography of pertinent references for additional background information is given for each area. As exploration was of a reconnaissance nature and is on-going, this report may be considered an interim report.

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In the text, summary maps outline geological features of regional geothermal significance and specific "Interest Areas" for which follow-up work is recommended. Detailed 1:50 000 scale maps of the project area geology, soil geochemistry and stream water conductivity are submitted as supplementary information in a separate folder.

2.3 Project Areas

Geothermal reconnaissance exploration to test the significance of young volcanic complexes, areas of hot spring activity and ~~major~~ crustal structures, was conducted in the following widely separated areas (Figure 1):

- Squamish and Elaho Drainage
- Mt. Garibaldi
- Pitt River Hot Springs
- Lower Lillooet River
- Northern Vancouver Island
- Lakelse Lake
- Aiyansh.

With the exceptions of the Mt. Cayley Volcanic Complex in the Squamish River area (NSBG, 1974; Lewis, 1977; Souther, 1981) and the Skookumchuk and Sloquet Hot Springs in the Lower Lillooet River area, the current work represents the first geothermal exploration in each of the project areas. In addition, hot springs at Frizzell, Sharp Point and Ahousat (Figure 1) were inspected while crews were in the general area. The aerial extent of the various projects varies from tens of km² in and around individual hot springs (e.g. Pitt River, Lakelse, Aiyansh) to over 1,000 km² (Squamish and Elaho Rivers).

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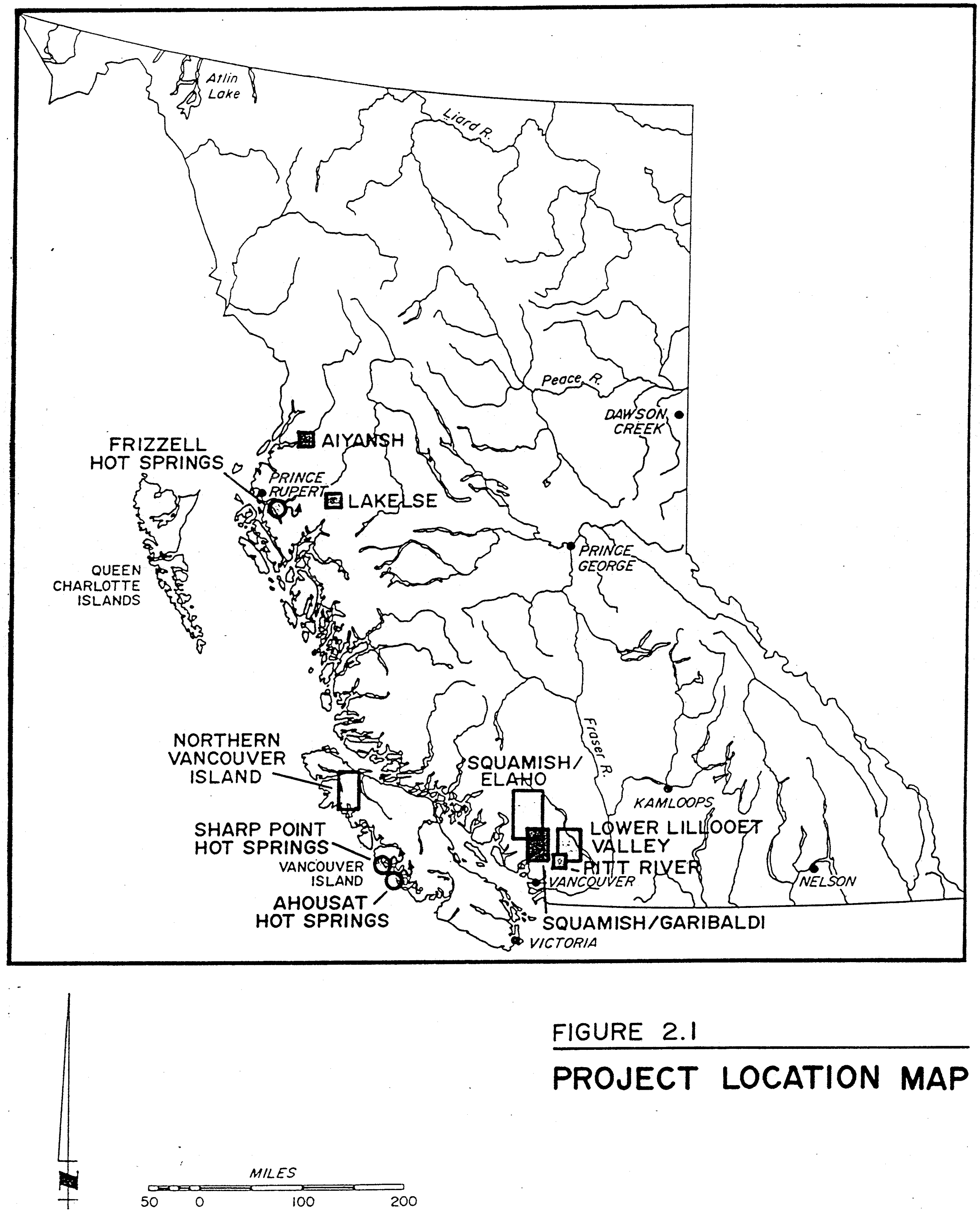

FIGURE 2.1

PROJECT LOCATION MAP

The Elaho River, Squamish River and Mt. Garibaldi projects explore large segments of the Garibaldi Volcanic Belt. High geothermal resource potential along the Garibaldi Volcanic Belt has been demonstrated by past work at Meager Creek (NSBG, 1981) and Mt. Cayley (NSBG, 1974; Lewis, 1977; Souther, 1980). Volcanic complexes between 2,500 and 4,000,000 years old occur at Meager Creek, the Upper Elaho River and Elaho Divide, Hill 7210, Mesa and Crucible Domes, Mt. Cayley, Mt. Fee, Amber Ridge and Mt. Garibaldi. Hot springs occur at Meager Creek and Mt. Cayley.

The Pitt River Hot Springs project is approximately 25km southeast of Mt. Garibaldi. Although the springs are only 50km north of Port Coquitlam, they are not well known because of difficult access and ruggedness of the area.

The Lower Lillooet River area encompasses a series of known and suspected hot springs including Skookumchuk, August Jacob's and Sloquet which occur along the trend of the Lillooet Fault Zone. A volcanic association is not immediately apparent; the line of the hot springs follows the general trend of the Pemberton Volcanic Belt of Souther (1975).

On Northern Vancouver Island, geothermal exploration assesses Quaternary volcanic activity near Port Alice, the Brooks Peninsula Fault Zone, the Marble River lineament, and an area of allunite alteration at Easy Cove.

The Lakelse Lake project area was selected on the basis of an occurrence of high volume, high temperature hot springs close to potential power markets at Terrace and Kitimat. The springs have been used as a resort in the past, however, little information regarding this geothermal resource was available prior to the current program.

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Similarly, the Aiyansh project in west-central B.C. was designed to gather baseline data on little known hot springs in the general area of the recent Aiyansh volcanic flow.

2.4 Reservoir Model and Reconnaissance Exploration Techniques

The project areas have the following common physiographical features:

- potential reservoir formations are inherently impermeable
- permeability is provided soley by fractures and fault structures
- mountainous with extreme local relief and with narrow valleys
- high degree of precipitation
- vigorous surface water run-off
- active groundwater systems

Figure 2 is a general model of the configuration of fracture controlled geothermal reservoirs unique to the physical characteristics described above (NSBG, 1982).

Important elements of the reservoir model are:

- upflow zone (1)
- outflow zone (2)
- recharge zone (3)

As a consequence of the general model, outflow zones (and possibly hot springs) into valleys can be expected from undiscovered geothermal reservoirs. In addition, the upper surface of thermal fluid over the upflow zone will not normally reach the land surface (resulting in hot springs) at high elevations.

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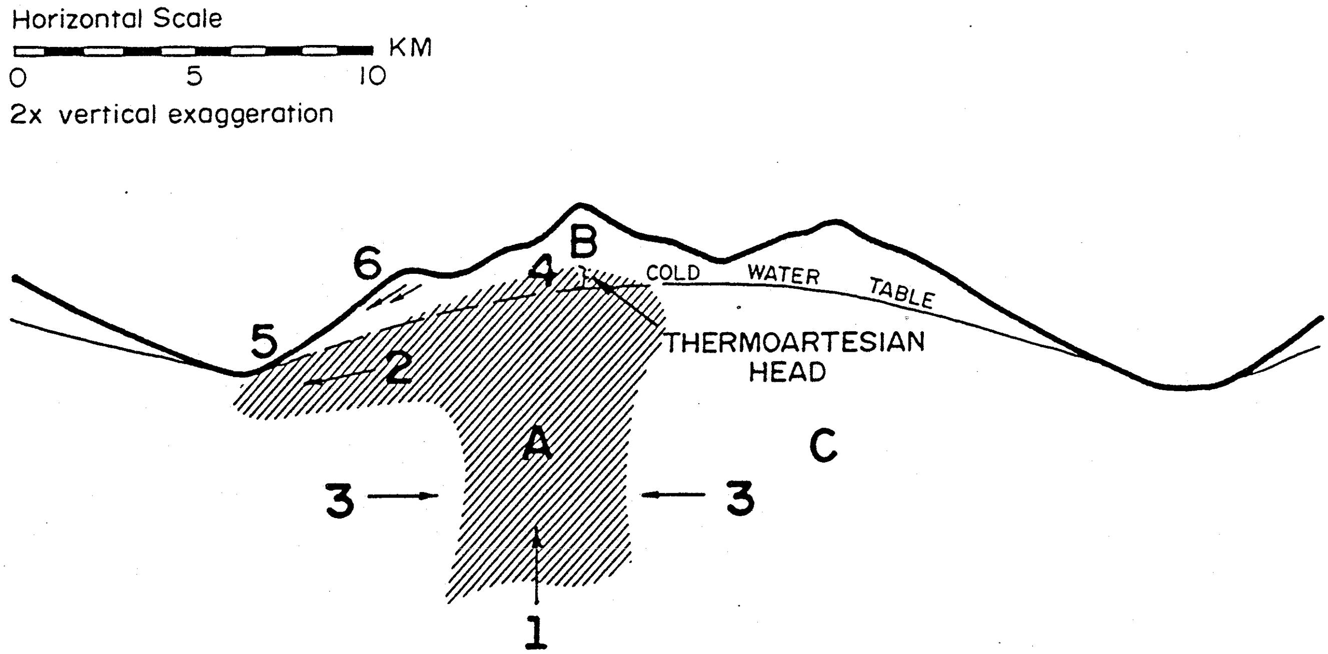

KEY

GEOTHERMAL FLUID ZONE OR GEOTHERMAL "RESERVOIR"

1 UPFLOW ZONE

2 OUTFLOW ZONE

3 RECHARGE ZONE

4 UPPER LIMIT OF THERMAL FLUID

5 ZONE OF SURFACE OR NEAR-SURFACE GEOTHERMAL MANIFESTATIONS (e.g. hot springs, anomalous fluid chemistry, temperature, etc.)

6 GROUND WATER RUN-OFF

A RESERVOIR HOST ROCK, FRACTURE PERMIABILITY

B CAP ROCK, ALTERATION ABOVE RESERVOIR

C COUNTRY ROCK, UNALTERED

FIGURE 2.2

GENERAL MODEL OF GEOTHERMAL SYSTEMS IN THE GARIBALDI VOLCANIC BELT

The conceptual model is used as the basis for the design of the exploration program. Recognition of the existence of outflow zones is important in the reconnaissance exploration stage. Exploration initially aimed at the detection of outflow zones in the valleys can be effectively used to narrow the area of search. Outflow zones or valley upflow zones can be determined from the location of hot springs and a combination of stream water conductivity, soil geochemistry and resistivity surveys. Single line dipole-dipole resistivity surveys along valleys become a rapid reconnaissance technique since the search envelope is to the height of land on either side of the valley. The two-dimensional data and any resistivity anomalies can be interpreted within the context of the general model.

In conjunction with the valley work, geological mapping and geothermal prospecting at high elevations (where outcrop is plentiful) is key to understanding and integrating geochemical and geophysical data as well as being an exploration method in its own right. Surface manifestations of the underlying reservoir may be subtle in the cap rocks. Hydrothermal alteration may be patchy or confined to narrow zones around fracture aquifers. Vigorous run-off and downward ground water percolation may mask or suppress the thermal anomaly and alteration halo above the upflow zone. Thus, an understanding of reservoir configuration is essential for the successful detection of potential resources.

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3.0 ELAHO AND SQUAMISH DRAINAGE

3.1 Location and Access

The project area encompasses an area from approximately 20km north of Squamish 70km northwards to Meager Creek. Most of the field work was conducted in the Squamish River, Elaho River and tributary drainages. Access is afforded by Highway 99 from Vancouver north to Squamish, from whence access to the southern half of the project area is via well maintained, gravel surface logging roads operated by Weldwood of Canada Ltd. Empire Logging Division. Reconnaissance operations were based in Weldwood's dormant logging camp approximately 55km upstream from Squamish near the confluence of the Elaho River and the Squamish River. Logging roads lead from the camp approximately 10km north on the Squamish River and 15km north on the Elaho River to the confluence of the Elaho and Sims Creek. By far the majority of the project area is inaccessible by road or on foot and transportation is practical by helicopter only.

3.2 Topography, Physiography and Vegetation

Elevations in the extremely rugged topography north of Squamish reach in excess of 2500 metres. Valley floors are generally narrow with elevations ranging from sea level at Squamish to over 1000 metres in the upper reaches of the Elaho Valley. The valley walls are very steep and often cliffed. Local relief is up to 2000 metres.

The climate is typical of the British Columbia coast. Precipitation is in excess of 200cm per annum. Snowfall within the mountainous terrain varies from less than 1m to as much as 10m at higher elevations. Heavy precipitation occurs primarily in the late fall, winter, and early spring. Alternate freeze and thaw, particularly in the fall can result in rapid melting and hazardous flash flooding making work in the area difficult. The months from June to September are relatively dry and warm and constitute the best period for exploration in the area.

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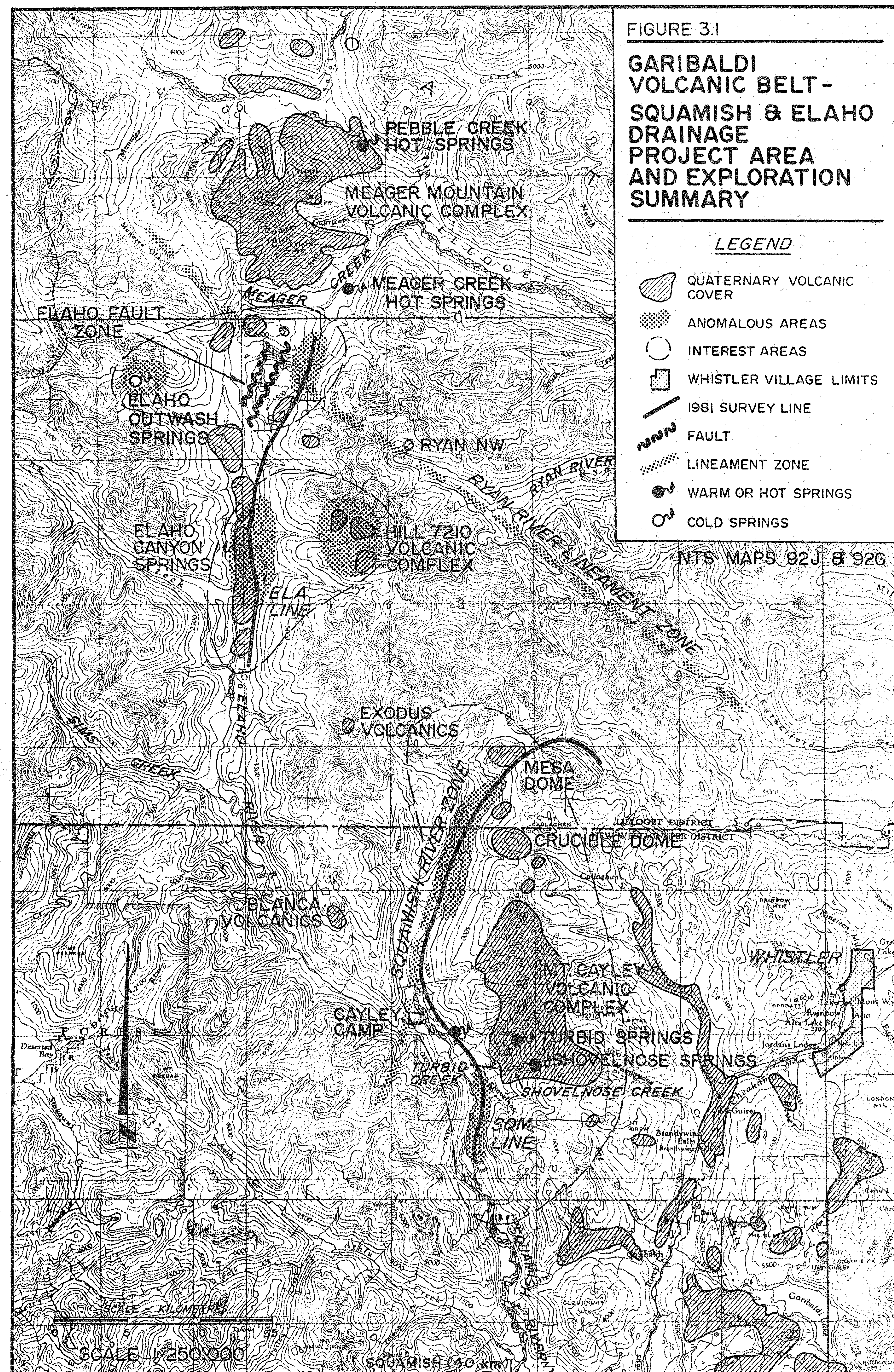

FIGURE 3.1
GARIBALDI VOLCANIC BELT - SQUAMISH & ELAHO DRAINAGE PROJECT AREA AND EXPLORATION SUMMARY
LEGEND
QUATERNARY VOLCANIC COVER
ANOMALOUS AREAS
INTEREST AREAS
WHISTLER VILLAGE LIMITS
1981 SURVEY LINE
FAULT
LINEAMENT ZONE
WARM OR HOT SPRINGS
COLD SPRINGS
NTS MAPS 92J & 92G
PEBBLE CREEK HOT SPRINGS
MEAGER MOUNTAIN VOLCANIC COMPLEX
MEAGER CREEK HOT SPRINGS
MEAGER
CREEK
ELAHO FAULT ZONE
ELAHO OUTWASH SPRINGS
RYAN NW
RYAN RIVER
RYAN RIVER LINEAMENT ZONE
HILL 7210 VOLCANIC COMPLEX
ELAHO CANYON SPRINGS
ELA LINE
ELAHO
RIVER
SIMS
GREEK
EXODUS VOLCANICS
MESA DOME
CRUCIBLE DOME
LILLOOET DISTRICT
SQUAMISH RIVER ZONE
BLANCA VOLCANICS
MT. CAYLEY VOLCANIC COMPLEX
WHISTLER
CAYLEY CAMP
TURBID SPRINGS
SHOVELNOSE SPRINGS
TURBID CREEK
SHOVELNOSE CREEK
SQM LINE
SQUAMISH RIVER
SCALE KILOMETRES
SCALE 1:250,000
SQUAMISH (40 km)

FIGURE 3.1

Uplift of the coastal ranges has produced an immature topography with deeply disected, steep drainages and high levels of erosion and sediment transport. Construction and maintenance of roads is hampered during flood periods.

Approximately 20% of the project area is covered by glaciers and glacial erosional features predominate at high levels. At lower elevations a lush evergreen forest consists primarily of douglas fir, hemlock and cedar. Open and swampy areas on the forest floor accommodate extremely dense undergrowth. Hardy alpine flora predominate above treeline at 1500m.

Above treeline and in areas of active glaciation outcrop is nearly continuous. Below treeline, however, dense undergrowth and forest floor loam makes continuous mapping of outcrop impossible. Glacial and glaciofluvial deposits form the floors of major valleys. Mapping can be undertaken successfully within the steeply disected drainages throughout the area and along cliff bases which form the valley walls in many areas.

3.3 Previous Work

Work in the Squamish and Elaho drainages of the Garibaldi Volcanic Belt prior to 1981 consisted mainly of 1:250 000 scale geological mapping (Woodsworth, 1977) and several detailed studies of the Mt. Cayley area.

In 1974, Nevin Sadlier-Brown Goodbrand Ltd. (NSBG, 1974) under contract to B.C. Hydro and Power Authority included the central Garibaldi Belt in a geothermal study of southwestern British Columbia. An aerial infrared scan was flown over the Mt. Cayley Complex at this time.

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Geothermal studies focusing on the Mt. Cayley area were conducted by Energy, Mines and Resources, Canada (EMR) during the late 1970's. During the fall of 1977, two shallow diamond drill holes were completed in the Squamish valley on the western flanks of the Mt. Cayley Volcanic Complex. Geothermal gradients of 52.2 and 66.1°C/km were encountered, indicating the potential of a high-temperature thermal regime in this study area (Lewis, 1977). Subsequently, three more holes have been drilled (Souther, personal communication). Two diamond drill holes in the vicinity of Turbid and Shovelnose Creeks (Cayley 1 and Cayley 2) indicate geothermal gradients of about 100°C/km in both Cayley 1 and 2. A fifth hole, drilled during the autumn of 1981 on Brandywine Creek east of the Mt. Fee Complex, shows a gradient of about 50°C/km (Souther, personal communication).

Souther (1980) conducted detailed geological mapping in the central Garibaldi Belt. Several volcanic centres were identified along the north-south trending Squamish-Cheakamus divide. Geological mapping outlined the complex volcanic stratigraphy in the Cayley area. The study discovered two groups of thermal springs within the Mt. Cayley complex ranging in temperature from about 18°C to 40°C. In addition, 12 line-km of dipole-dipole DC resistivity survey was conducted in the higher elevations over plutonic basement rock adjacent to the Mt. Cayley volcanic centres (Souther, personal communication).

3.4 Present Work

Field exploration was initiated on September 15th, 1981. Operations were based in Weldwood of Canada Ltd., Empire Logging Division's dormant logging camp approximately 55km upstream from Squamish near the confluence of the Elaho River and Squamish River. Nevin Sadlier-Brown Goodbrand Ltd. and Premier Geophysics field staff numbered up to twenty-two. A Hughes 500C helicopter was maintained on contract from Quasar Aviation Ltd. for the duration of the program.

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Reconnaissance (1:50,000 scale) geological mapping has resulted in the location and identification of the majority of volcanic centers within the project bounds, and a preliminary evaluation of the basement rocks surrounding these centers. Extensive measurements of surficial water conductivity were made to identify run-off with a high ion content possibly related to thermal fluids. In addition, spring waters of unusual conductivity were sampled for a detailed analysis of their ionic content.

Survey control was initiated with a total of 60km of line cutting. A total of 307 soil samples were taken along the two lines in the project area, the SQM and the ELA lines. These samples were analyzed by Chemex Laboratories Ltd. for arsenic and mercury content. A large array dipole-dipole resistivity survey was performed along the SQM line and the ELA lines.

The exploration camp was demobilized on November 3rd, 1981 after a series of flash floods which cut off road access to the camp and several feet of snow brought effective exploration work to a halt.

3.5 Geology

3.5.1 General Setting

The Squamish-Elaho project concentrated on a number of volcanic centres in the central Garibaldi Volcanic Belt. The area of interest, extending approximately 40km north-northwest from the Mount Cayley Complex in a zone roughly 15km wide, includes a dozen volcanic centres as well as several volcanic flows. The Meager Volcanic Complex marks the northern limit of the Squamish-Elaho project.

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Most of the basement geology in the Squamish-Elaho area consists of various plutonic rocks primarily of quartz diorite composition. Several small pendants of granitoid gneiss and amphibolite possibly correlated to the Twin Islands Group (Roddick, 1965) are located in the Cayley area and along the Squamish-Elaho divide. In addition, an elongate belt of Gambier Group rocks consisting mainly of greenstones and other meta-volcanics borders the eastern flanks of the Cayley Complex.

Tufa deposits and springs were noted throughout the area and include two groups of hot springs on the western flanks of the Cayley Complex. Other possible indicators of near surface geothermal activity include dyke swarms and intense hydrothermal alteration in some basement units.

3.5.2 Squamish Drainage (Refer to Drawing SQM-1)

Volcanic rocks in the Mt. Cayley Complex consist of three distinct stages of intrusive dacite volcanism and associated lava flows, breccia and pyroclastic deposits (Souther, 1980). The earliest "Mount Cayley Stage" consists of a thick wedge of dacite flows and tephra overlying fossil colluvium and basement rock. A separate sequence of porphyritic dacite flows up to 500m in thickness overlies the earlier, hydrothermally altered flow. A third major event forms the main intrusive spine of Mt. Cayley. The "Vulcans Thumb Stage" comprises the vent breccia, massive dacite flows and bedded tephra which form a thick secondary pile on the southwest flanks of the main Cayley edifice. Thick tephra deposits (up to 600m) form the precarious slopes on valleys draining the west sides of the complex. The final "Shovelnose Stage" produced two small porphyritic dacite domes in the upper reach of Shovelnose Creek. Associated lava flows from the lower of the two dome occupies the lower reaches of the Shovelnose valley (Souther, 1980).

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Two sets of thermal springs as well as numerous cold springs have been identified in the Cayley Complex. The thermal springs, issuing from the volcanic-basement contact range in temperature from 15-40°C. Bright orange tufa and silica deposits mark the vents of the hot springs. A number of other seeps stained bright orange were noted in the upper regions of Turbid Creek and orange deposits were noted along the creeks entire length. Because of the hazardous terrain, the upper regions of the creek were not visited.

Two smaller and somewhat older volcanic complexes lie to the south of Mt. Cayley. Considered to be the earliest volcanism in the central Garibaldi Volcanic Belt, the Ember Ridge Complex forms five small patches of porphyritic basalt which appear to have issued from separate vents. Ember Ridge lies slightly to the southwest of Mt. Fee, a narrow exposed neck of intrusive porphyritic rhyodacite. Flows associated with the Fee complex form the sharp crested ridge southwest of Brandywine Creek.

Immediately north of the Mt. Cayley complex are three smaller complexes, Pali Dome, Cauldron Dome and Slag Hill. Pali is considered to be a tuya and is comprised mainly of porphyritic andesite exhibiting peripheral ice contact features. Much of this complex is presently covered by glacial ice. The flat topped Cauldron Dome probably began as a sub-glacial eruption which melted a hole in the glacial ice. Subsequent eruptions ponded inside the hole and eventually breached the ice barrier during later stages of activity. Slag Hill is very similar in morphology to portions of the Ember Ridge Complex. It is considered to be a largely sub-glacial eruption as evidenced by small bulbous masses of the complex which contain small diameter radiating columns of basaltic-andesitic lava.

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The last and northernmost complex described by Souther (1980) is Crucible Dome. This complex, suspected to be another tuya, has been extensively modified by later glaciation and erosion. The flat top surface of the Crucible complex is comprised of oxidized lava and red scoriaceous material of andesitic composition.

Two kilometres north of the Crucible Dome, a small volcanic flow apparently originating in alpine regions extends into the Squamish valley and fills Gestetner Creek valley with dacitic lavas up to 10m thick. Location of the source is uncertain although this small flow may be related to volcanism on the Crucible complex.

The Mesa Dome, at the headwaters of the Soo River is another volcanic edifice exhibiting a tuya structure. Slender chaotic columnar jointing differentiates several basaltic cooling units that have formed the bulk of this volcanic feature. Basement rock in the area consists of pyrite-rich marble and metavolcanics of the Gambier Group to the east and foliated quartz diorite to the west.

The "Exodus" volcanic center located 16km north-northwest of the Mesa Dome comprises basaltic to andesitic lavas exposed in a small area bordered by steep valley walls and glacial ice. Lavas are dark and contain chaotic columnar jointing.

Although the area was not visited, Woodsworth (1977) indicates a small volcanic exposure occurring within a quartz monzonite stock in the vicinity of Blanca Lake approximately 10km northwest of Cayley camp.

As the volcanics of the Mt. Cayley Complex have been mapped in detail by Souther (1980), work in the area concentrated largely on basement rock on the flanks of the complex. The basement is underlain mostly by plutonic rocks exhibiting only minimal alteration.

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One area, slightly northwest of Crucible Dome however, exhibits heavy foliation and extensive epidote flooding. The area is traversed by a number of northeast trending scarps up to 10m in height. The feature may be indicative of collapse-type structures associated with local volcanism and is of particular interest as a significant resistivity anomaly is indicated in the vicinity (near SQM Station 440).

Andesitic to dacitic dykes and associated pervasive argillic alteration occur in foliated quartz diorite exposures immediately west of the Cauldron Dome in the Squamish valley. Hydrothermal activity such as the precipitation of silica and minor sulphides is apparent in some fractures in the area. A large, feldspar-porphyry dacite sill approximately 2m thick occurs in the Squamish Canyon at this vicinity. Associated with this sill is intense hydrothermal alteration along a number of vertical fractures sub-parallel to the canyon and the sill.

Another series of dyke swarms occur uphill (east) from SQM Stations 330N and 370N and intrude the basement quartz diorite. Associated with the intrusions are localized argillic alteration and brecciated wall rock along the volcanic-basement contact. Hints of sulphurous gas were detected in the vicinity of the dykes although the source could not be found.

The Squamish River west of the Cayley Complex is confined in a deep canyon along much of its length. The drainage course is greatly affected by series of vertical fractures trending north-northeast which themselves are off-set by east-west trending transverse faults. It is suspected that this portion of the Squamish River canyon is a reflection of a major north-northeastward trending fault zone. Geothermal activity in the area such as silicification and calcification on shallow dipping fractures immediately west of SQM-367 may be strongly controlled by this "Squamish River Zone" and fracturing associated with volcanism in the Cayley Complex.

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Souther (1980) has mapped a quartz monzonite stock and a metamorphic pendant at high elevations bordering the Cayley Volcanic Complex. Investigation of this area has been minimal due to time constraints and snow in the area during the period of the survey but should be incorporated into future more detailed work.

Evidence for geothermal activity is quite pronounced in the headwaters of the Squamish River immediately southeast of the Exodus volcanics. Several large, north-south trending dyke swarms up to 200m wide cut quartz diorite basement rocks in the vicinity. Pervasive, moderate, argillic alteration occurs in the basement rock and the dykes themselves are intensely altered. Broad zones of basement rock exhibit quartz and massive pyrite veining.

3.5.3 Elaho Drainage (Refer to Drawing ELA-1)

Exposures along the Elaho road consist largely of unaltered quartz diorite locally cut by dacite and andesite dykes. Fluvial and glacio-fluvial sediments fill the Elaho Valley below its junction with Clandenning Creek from which point the Elaho Valley is occupied by basalt flows up to 50m in thickness. The river has cut a canyon to basement through the relatively soft basalt, exposing several separate flows. The dark grey basalt is locally vesicular and forms large, polygonal columns. The lowermost volcanics commonly contain sandy-pebbly debris which has been swept up by the flows from a thin underlying layer of fluvial sediments. The source of the Elaho Valley basalt has not been identified although it is probably near the headwaters of the Elaho River.

A zone of seeps emerges from the base of the Elaho Valley volcanics west of Hill 7210. The seeps, issuing from both sides of the canyon walls, are marked by sinter deposits including red-orange, ferruginous and calcareous encrustations. Limited sampling of the accessible springs indicate they are cold at surface, but geothermometry calculations indicate that the water has possibly equilibrated at higher temperatures at depth (see Section 3.6).

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A line of volcanic centers is located along the height of land east of the Elaho River. Volcanics in the Meager Pass area were also mapped although detailed work in the area was limited. Andesite flows approximately 150m thick overlie sugary-textured quartz diorite. A large waterfall cuts several successive flows, some exhibiting chaotic columnar jointing. Meager Pass volcanics may be related to the pyroclastic deposits and scoria in the vicinity of Hill 5340, 2km to the northeast. Quartz diorite exposures immediately southwest of the Meager Pass are cut by a series of deep fault trenches trending north-northeastward. Dip slip is clearly evident on some of these faults. This zone, referred to as the Elaho Fault Zone, may have a specific relationship to local volcanism as well as that northward, in the vicinity of the Meager Volcanic Complex.

Further volcanic exposures are mapped in the vicinity of Elaho Pass and may be related to volcanics in the Elaho Valley. The volcanics are composed of massive, fine-grained dacite and have been extensively glaciated. Elaho Pass itself appears to be bounded on the east by prominent structures in the Elaho Fault Zone.

7179? - ref ELR map.

Immediately southeast of the Elaho Pass is Hill 7819. Volcanics here are of agglomerates, tuffs, breccias and flows of andesitic composition and appear to be older than and unrelated to the volcanics of the Elaho Pass. Much of the original morphology of the edifice has been modified by glaciation as evidenced by columnar jointing andesites and basalt flows strewn with glacial errata.

To the south-southwest lies the largest volcanic center in the Elaho drainage, Hill 7210, an extensive complex of varied volcanic compositions and textures. The Hill 7210 complex is underlain by quartz diorite on the west and granodiorite on the east, both of which grade southward into granitoid gneiss and vertical dipping metasediments. Volcanism in the area can be divided into two major

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styles. The first is a thick sequence of rhyolite breccia and agglomerate overlying basement rock. The agglomerate contains angular clasts of pyroclastic material in its lower sections and grades upward to contain large clasts of vesicular, porphyritic andesite. This agglomerate is overlain by a thick sequence of columnar jointed andesite flows, up to 50m in thickness. A final stage of light coloured lava flows with fissile and blocky fracturing occurs within the complex.

Portions of the granodiorite basement exposed within the base of the glacial cirque to the south of Hill 7210 have been intruded by a large andesite body which includes basement breccia blocks and extensive hydrothermal alteration. Pyrite occurs in massive blebs and as disseminated grains over much of the cirque floor in the vicinity of the volcanic exposure.

The "Ryan NW" volcanic centre is located on the northern slopes of the upper Ryan Creek valley. Several distinct cooling units of andesite flows display irregular columnar jointing in the steep ice-dammed bluff fronting on the Ryan valley. Foliated quartz diorite underlies the Ryan NW volcanic pile.

The upper reaches of Ryan Creek form a pronounced lineation trending northeastward toward the Meager Volcanic Complex. The Ryan River Lineament Zone (NSBG, 1981) may have structural significance to northern portions of the Garibaldi Volcanic Belt. Mapping along the Ryan lineament indicates extensive shearing in metamorphosed rocks and considerable localized alteration. Further reconnaissance mapping and model development is required in order to accurately assess the significance of the Ryan River Lineament Zone.

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Two areas of crystalline basement rock west of the Elaho River were visited briefly. A large body of homogenous granodiorite in a cirque and glacial valley approximately 10km west of Hill 7210 is considered to be on the eastern edge of the Clandenning Pluton. Little alteration or significant structure was observed in the vicinity. Immediately north of here, at the outwash of Elaho glacier, a number of tufa depositing seeps were located. The host rock for these seeps is a foliated quartz diorite which has been extensively glaciated. Compositional banding in the quartz diorite is strongly pronounced and portions of the rock contain extensive disseminated pyrite and xenoliths of pyritiferous metasediments. Fracturing in the rock is extremely complex and includes several small shear zones.

3.6 Water Chemistry

As a standard exploration procedure, water samples were taken from springs and from creeks indicating anomalous high conductivities. In all, seven samples from the Squamish drainage and two samples from the Elaho drainage were analyzed (see Appendix A).

Two of the three warm springs on Turbid Creek and creek water from near the mouth of Turbid Creek were sampled. Surface temperatures for the springs were measured at 15°C for Turbid N-1 and 25-30°C for Turbid N-2. A pale to bright orange sinter has been deposited at the vents of these springs which occur along the volcanic basement contact. Turbid Creek spring samples indicate that the water has been subjected to temperatures on the order of 120-200°C. Because of poor accessibility the third spring in the Turbid group and the Shovelnose Creek springs were not sampled. Samples of Turbid Creek near its confluence with Squamish River display elevated levels of ions although dilution is strongly evident. Analyses of the sample from Shovelnose Creek near its confluence with Squamish River indicates marginally higher values for most ions although extreme dilution is apparent.

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Three kilometres up the Squamish Valley, a spring issuing from the base of a quartz diorite bluff and an artesian flow from drill hole EMR 304-2 have temperatures of 19°C. At times, the smell of sulphur in the area surrounding the springs is clearly noticeable. Water samples from both sources indicate values in dissolved sodium and chloride comparable to those in the Turbid Creek springs samples although silica values are somewhat lower. Values for both the anions, and cations are slightly higher in the sample vented from the drill hole compared to the surface spring sample indicating less dilution of thermal water in the drill hole. Geothermometry calculations indicate that both waters have been subjected to subsurface temperatures on the order of 40-60°C.

A sample collected from a cold seep in the vicinity of SQM-370 indicates moderate enrichment in carbonate and sulphate ions with slightly anomalous silica. The area is coincident with pronounced conductivity and resistivity anomalies as well as elevated soil mercury values. Geothermometry indicated temperatures are on the order of 70-100°C. It is considered that this sample has been mixed with non-thermal, near-surface water and that the geochemical signature has been affected.

Owing to the difficulty in access to the Elaho springs, the main seep area could not be sampled. Minor effervescent seeps in a cluster on a bench on the valley floor emanate an odourless colourless gas and precipitate a bright red sinter on surrounding rocks. A small amount of carbonate tufa is deposited on the canyon walls above the high water mark. The springs contain very high values in sodium as well as elevated bicarbonate and silica. Although the sampled springs were cold (9.5°C), geothermometry temperatures indicate the water has been subjected to temperatures on the order of 130°C. The springs may

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reflect shallow circulating water confined to an aquifer at the base of the Elaho basalt flow or thermal waters related to the Hill 7210 volcanic complex to the east.

The Elaho Outwash springs, in the headwaters of the Elaho River, originate from extensively fractured, foliated quartz diorite. The seeps issue from small shears up to 5cm in width and precipitate bright orange tufa deposits. The spring water contains high levels of bicarbonate and sulphate as well as elevated calcium, sodium and silica. Geothermometry indicates temperatures in the order of 100°C. Although the source of the Elaho Outwash springs is not apparent, their location is of some significance. It is possible that the body of saline fluid evident in the South Fork (NSBG, 1981) area may have a genetic relationship with the Elaho Outwash springs.

3.7 Water Conductivity Survey (Refer to Drawings SQM-2 and ELA-2)

Water conductivity measurements were taken throughout the project area along hillsides and drainage courses in ponds, lakes, seeps, springs, creeks and rivers.

For orientation purposes, conductivities were measured at the Turbid Creek warm springs and at various locations downstream. The conductivity of Turbid Creek hot springs is 2600-4550 micromhos/cm. Three kilometres downstream from the springs in Turbid Creek, water conductivities were as high as 400 micromhos/cm while at 50 metres downstream of the confluence of Turbid Creek and the Squamish River conductivity values near the bank of the Squamish River had dropped to 80 micromhos/cm. Although the signature is well defined on Turbid Creek, readings taken in themuch larger Squamish River are difficult, if not impossible to interpret without prior knowledge of the source waters. Readings also were taken in the warm spring adjacent to EMR drill hole 304-2. Conductivities here ranged as high as 1700 micromhos/cm indicating that even low temperature thermal springs (19°C) are conductive enough to be distinguished from non-thermal waters.

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A threshold value for anomalies has been chosen in the Squamish area at 50 micromhos/cm. Values for clean run-off water vary between 5 and 25 micromhos/cm and the majority of the background values in the project area coincide with this range of values.

Several conductivity anomalies occur in the Squamish River drainage. In the vicinity of Station 370+00N on the SQM Line, anomalous values were measured in various small creeks draining the hillside below and between the Cayley volcanic pile and the Crucible Dome. This zone coincides with high soil geochemical results (see Section 6) and is adjacent to a major resistivity anomaly (see Section 8). Near the bottom of the Squamish River Canyon at the confluence of one of these minor creeks and the Squamish River, a small deposit of siliceous sinter was located along a shallow dipping fracture on the east bank of the river. Strike/dip direction? → westward

Two clearly defined anomalous zones exist in the headwaters of Callaghan Creek and Brandywine Creek. These are not high magnitude anomalies but they are consistently above background and their proximity to the volcanic centers at Mt. Cayley add significance to their presence. Another small anomaly was located near the south end of SQM Line. The presence of an open resistivity anomaly below this area may be related to these abnormal conductivity values. In addition to the above mentioned anomalies, several sporadic high values of conductivity exist throughout the SQM map area. The local nature of these high values suggests that they are not significant.

3.8 Soil Geochemistry

The SQM and ELA lines were sampled for soil arsenic and mercury concentration. A total of 59.2 km of line was surveyed with samples taken at 200 metre intervals. As preliminary results were returned from the lab, detailed sampling at 50 metre intervals was undertaken over anomalous areas. Where possible samples were recovered from within the B horizon of the soil profile, well below the organic soil layers.

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Arithmetic and log histograms indicate that arsenic and mercury values are lognormally distributed. A standard threshold for anomalous values was taken as the logrithmic mean plus one log standard deviation. The results indicate that this technique adequately separates abnormally high values from the background.

3.8.1 Soil Profile Results

Five soil profiles, consisting of samples taken at regularly increasing depths at the same location, were performed in the project area (Appendix B). These profiles are taken to establish the pattern of element concentrations with depth and with various horizons. The data is used to determine the optimum sampling depth for the soil survey.

The results of the profiles do not show a repeatable pattern. Whereas profiles taken in the Squamish drainage appear to have significant variations with depth, the Elaho profiles are relatively constant with depth. One conclusion that can be drawn is that elevated values of arsenic, and particularly mercury, often exist within the organic loam and A horizon soil layer within a few tens of centimetres of surface. Sampling of the A horizon may give rise to false or spurious anomalies. In one case very high values in both arsenic and mercury occur below 1m depth.

Most sampling on the ELA and SQM Lines was performed at depths between 50 and 80cm. All samples are from well below the organic loam of the forest floor.

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3.8.2 <u>SQM Line</u> (Refer to Drawing SQM-3)

A total of 188 samples were taken on the SQM Line. Several zones of anomalous geochemical values are displayed along the line.

A broad anomalous zone, beginning at the confluence of the Squamish and Elaho Rivers, and continuing northward to approximately station 416N, is defined primarily in mercury. The anomaly is particularly consistent between 354N and 416N. Coincident arsenic and mercury anomalies exist at 356N and 368N. The zone of anomalous values coincides roughly with the location of anomalous conductivity values (see Section 5.2) and a zone of anomalous resistivity values (see Section 8).

Sporadic anomalous arsenic values occur near the southern terminus of the survey line, especially between stations 178N and 252N. The anomaly is best defined in the area of Shovelnose and Turbid Creeks, directly below the Turbid Creek warm spring associated with Mt. Cayley. Lack of coincident anomalous mercury may reflect a former presence of hydrothermal activity (volatile mercury has been driven off). Alternatively, the zone of high arsenic values is roughly coincident with the colluvial fan of Turbid Creek, and the volcanic debris originating near the known thermal springs may be the source of arsenic in these soils.

3.8.3 <u>ELA Line</u> (Refer to Drawing ELA-3)

A total of 119 samples were taken along the ELA Line.

Detailed sampling was done between Stations 62+00S and 74+00S to better define some anomalous values in arsenic. The arsenic anomaly appears to coincide with an older slab of andesitic volcanics which the line crosses in the area. The high arsenic values could reflect the change in rock type or they could be displaying the presence of an active or fossil thermal system.

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A rather broad, spotty anomaly in mercury values exists between Stations 138S and at the end of the line at 196S. These mercury anomalies lie near the valley bottom below Hill 7210, a volcanic centre which displays several geological features of interest (see Section 4). The favourable geological terrain of Hill 7210 and the existence of carbonate springs in the bottom of the Elaho River Canyon below the line, add importance to the anomalous soil results.

3.9 Resistivity

A total of 42km of dipole-dipole resistivity was performed on the SQM (34km) and ELA Lines (8km) during the 1981 field season. The survey was helicopter supported due to the rugged terrain which the lines traverse. The survey utilized 300m dipoles ("a") with measurements taken at dipole separations (na) of n=1 to n=8. Detailed descriptions of the surveys and results is found in reports submitted under separate cover by Premier Geophsyics Inc. (Premier Geophysics Inc., 1982a).

3.9.1 SQM Line

Five anomalies were detected along the SQM Line.

A major anomaly occurs between station 438N and 468N with a moderately anomalous extension to 483N. The anomaly is well defined and does not appear to be induced by valley sediments, topography, or other surficial features. There is some correlation between soil anomalies on the line and this resistivity anomaly (see Section 3.8).

A lesser resistivity anomaly between stations 396N and 420N coincides well with a water conductivity and soil mercury anomaly.

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A third anomalous area occurs in the Mud and Turbid Creek area. Unfortunately, poor weather and the close of the 1981 field season left 6km of line in this critical area to be completed in 1982. It is not clear from available data whether the anomaly near Turbid Creek is associated with the hot springs higher on the creek or to the slide debris fan which is an obvious feature of the topography in this area.

From station 155N, a major zone of relatively low resistivities is open to the south. Premier Geophysics Inc. (1982a) consider that the anomaly is not related to valley bottom sediments. This anomaly coincides with a minor stream water conductivity anomaly (Section 3.7). The significance of the anomaly is unclear.

Lastly, a poorly defined anomaly at the extreme north end of the survey line occurs between station 522N and 534N. This anomaly is neither strong nor extensive enough to be considered of immediate interest.

3.9.2 ELA Line

Eight kilometres of survey were performed on the ELA Line in the 1981 field season. An anomaly between station 24S and 55S is correlated with data from previous exploration in the South Fork area (NSBG, 1981). The southern extreme of the anomaly may continue under the pass between the South Fork Meager and the Elaho Valley (below 55S and 80S). The anomaly may reflect a reservoir of warm saline waters as encountered in drill hole M12-80D. The area is along the trend of the north-south No Good Creek Discontinuity and the line of volcanic centres identified by Read (1978) in the Meager Mountain Complex.

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The survey was left uncompleted south of station 105S on the ELA Line with the abrupt termination of the field program. Continued resistivity survey coverage is required in this area due to its proximity to Hill 7210.

3.10 Conclusions

The 1981 reconnaissance program conducted in the Squamish and Elaho Drainage area successfully delineated several areas of geothermal interest. The program provides a positive "first-look" at a large previously unexplored area of the north central Garibaldi Volcanic Belt.

The following areas have been identified as having characteristics consistent with near surface thermal activity (Figure 3.1):

- Squamish Canyon - (in the vicinity of SQM 330N to 440N)
  This is a broad zone of coincident low resistivity values, elevated soil mercury geochemistry, anomalous high conductivity values in surficial waters and positive geological indications of possible geothermal activity.

- Turbid Creek
  The Turbid Creek warm springs and adjacent EMR drill holes (Cayley 1, Cayley 2 and 304-2) prove the existence of at least a warm thermal reservoir on the west flanks of Mt. Cayley. The Turbid and Shovelnose hot springs are unique in the Garibaldi Volcanic Belt because of their high elevation. A reservoir upflow zone is indicated in the vicinity of the hot springs. Soil geochemistry, water conductivity and resistivity data support extensions of this thermal regime.

- Hill 7210
  This volcanic center is the largest in the Elaho drainage. The character of acid volcanism, basal breccia and presence of extensive pyritiferous and altered basement rock are geological indications of the geothermal prospect. Associated soil and spring water anomalies add support to the geological concept.

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* Elaho Pass - South Fork
  Resistivity work confirms and extends a previously discovered area of low resistivities thought to be associated with saline waters. Tension gashes in the Elaho Fault Zone are of Recent age and may provide deep permeability for fluid migration.

3.11 Recommendations

Reconnaissance exploration results of the Garibaldi Volcanic Belt between Mt. Cayley and the Meager Creek Geothermal Area provide an excellent base of data for defining the next stage of exploration. It is convenient to divide the recommended work area into three separate projects as the nature of exploration in all of them will ~~be~~ slightly different.

The Mt. Cayley project area will encompass Mt. Cayley itself and all of its proximal volcanic centres including the Cauldron and Mesa Domes. This area is by far the most advanced in its exploration. Closer investigation of the existing target areas (Squamish Canyon and Turbid Creek) will be complimented by continued reconnaissance throughout the headwaters of the Squamish River and along the flanks of the ridges between Mt. Fee and Mt. Callaghan in the north. The following work is recommended:

* Continued geological mapping at reconnaissance and detailed scales to further define the geological model of the area.
* Approximately 40km of reconnaissance and detailed grid, soil (Hg, As) geochemistry to clarify existing anomalies and to extend coverage to the eastern flanks of the volcanic complex.
* Approximately 40km of dipole-dipole resistivity for lateral delineation of existing anomalies and to extend coverage to the unexplored areas to the east of the Fee-Callaghan height of land. Several deep Schlumberger resistivity soundings should be used to define the vertical resistivity structure in accessible anomalous areas in the valleys and on ridges.

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- Completion of the water conductivity coverage of the area
- Four diamond drill holes to target depths of 600m are recommended for investigating thermal gradients. At present it is possible to target one hole in the vicinity of station 420N on the SQM Line to investigate broadly coincident resistivity, soil geochemical and water conductivity anomalies in the area. Tentative targets for the remaining three drill holes are available.

The second project is referred to as Hill 7210 centered about a large differentiated volcanic pile located between Mt. Cayley and Meager Mountain. The extent and style of volcanism, soil geochemistry in the Elaho Valley below the volcanic center and the presence of highly conductive springs and tufa deposits in the Elaho River Canyon indicate a promising exploration target. The following recommendations are made for 1982:

- Detailed geological mapping should be used to delineate features of the basement-volcanic contacts and basement alteration.
- Approximately 10km of soil geochemistry should be done to delineate the observed soil mercury anomaly.
- Extensive water conductivity measurements should be taken throughout the Hill 7210 area.
- Complete 10km of dipole-dipole resistivity along ELA line.
- Additional resistivity surveys should be conducted in areas to be selected following mapping.

The final project should be a continuation of reconnaissance in the upper Elaho Drainage north of the confluence of the Elaho River and Sims Creek, and south of the Meager Creek Geothermal Area. In addition to completing the reconnaissance work the following is recommended:

- Detailed mapping
- Soil sampling and approximately 10km resistivity across Elaho Fault Zone.

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4.0 MOUNT GARIBALDI PROJECT

4.1 Location and Access

The Mount Garibaldi Volcanic Complex begins immediately northeast of the city of Squamish approximately 45km north of Vancouver (Figure 4.1). The Mount Garibaldi Complex begins with the Ring Creek flow directly east of Squamish at the south end of the complex and continues northward through several well known local peaks, Black Diamond, Mt. Garibaldi, The Table, Castle Towers Mtn., and at the northern end of the complex The Black Tusk. The entire area is about 30km along its north-south axis and 10km wide.

Most of the Mt. Garibaldi Complex is within the confines of Garibaldi Provincial Park. Lands within the park are unlikely to be an exploitable for geothermal resources. The park boundary however, is generally at high elevations on the complex and the surrounding valleys outside of the park boundary are the areas of interest. Exploration was concentrated on the Mamquam River and the Cheakamus River Valleys which flank the mountainous volcanic pile on the south and west.

Access to the southern terminus of the project area at Squamish is approximately 50km north of Vancouver on Highway 99, from whence both Highway 99 and a vast system of logging roads and dirt tracks provide coverage of the areas of interest. To the east and south portions of the project area, access is via MacMillan Bloedel's "Mamquam Main" logging road. This road, although seriously damaged by rain and flood water during the period of investigation in late November of 1981,would normally provide access to many areas of interest along the Ring Creek flow. North of Squamish, access is primarily by the continuation of Highway 99 along the Cheakamus River through the Cheakamus Canyon to the town of Garibaldi and the Daisy

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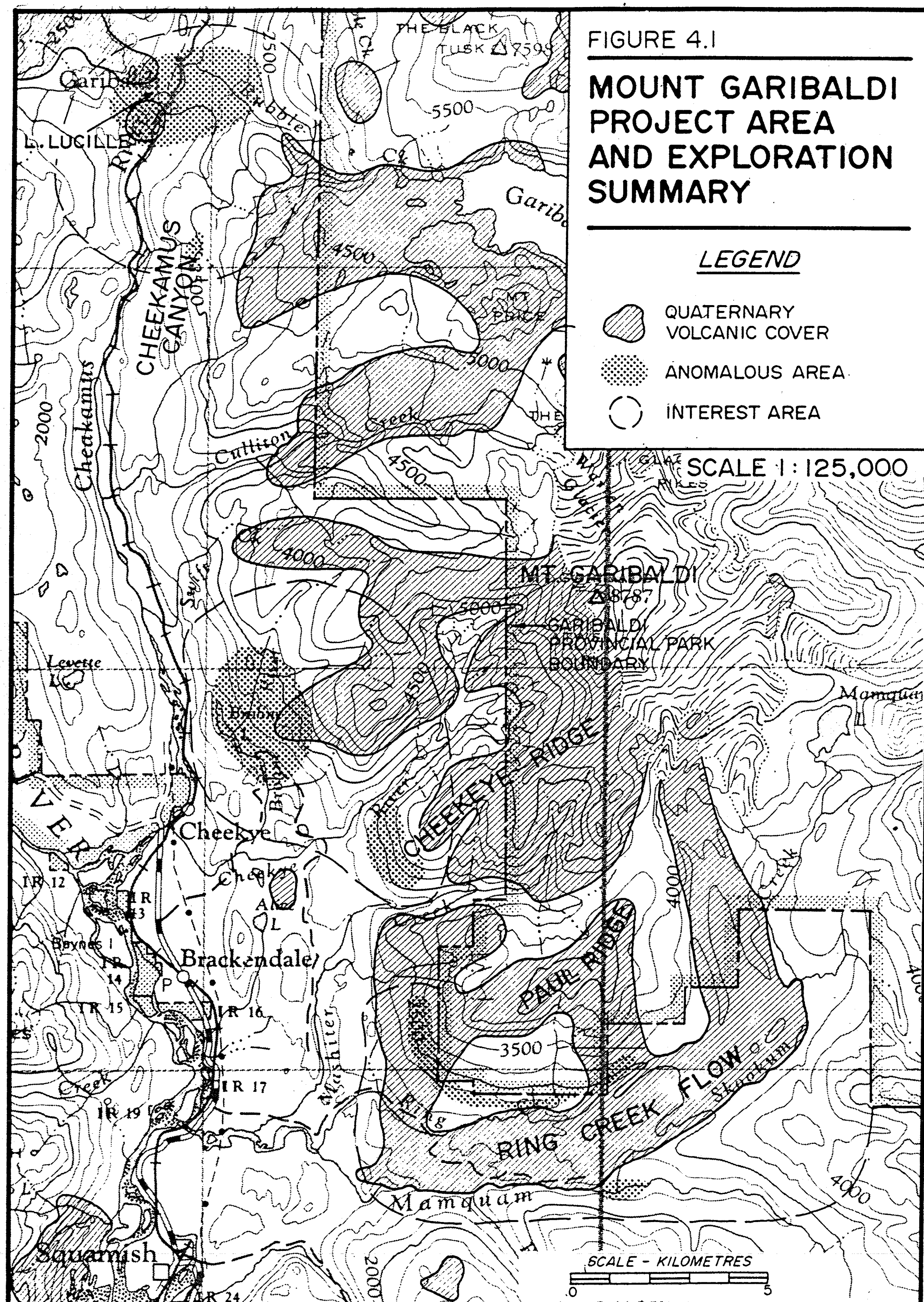

FIGURE 4.1
MOUNT GARIBALDI PROJECT AREA AND EXPLORATION SUMMARY
LEGEND
QUATERNARY VOLCANIC COVER
ANOMALOUS AREA
INTEREST AREA
SCALE 1 : 125,000
SCALE - KILOMETRES
0
5
NTS MAP 92G
CHEEKAMUS CANYON
MT. GARIBALDI
GARIBALDI PROVINCIAL PARK BOUNDARY
CHEEKYE RIDGE
PAUL RIDGE
RING CREEK FLOW
Cheekye
Brackendale
Squamish
L. LUCILLE
THE BLACK TUSK
STAWAMUS CHIEF

Lake reservoir. Many secondary roads in various conditions of repair lead from Highway 99. Most of these roads and tracks require 4-wheel drive vehicles and occasionally wash-outs or overgrowth render them impassable.

The areas to the north and west of the Mt. Garibaldi volcanic pile are within the Garibaldi Provincial Park and are not accessible by road.

4.2 Topography, Physiography and Vegetation

The project area is within the Coastal Plutonic Complex and topography within the area is similar to that of Mt. Cayley and Meager Mountain. The maximum elevation (Mt. Garibaldi) is in excess of 2500m. The elevation of the adjacent Squamish and Cheakamus River valleys nearly sea level. Valley walls are very steep and, along the Cheakamus River drainage, especially through the Cheakamus Canyon, the topography is extremely rugged.

The coastal climate is typically mild throughout the year with high levels of precipitation.

Major drainages are the Cheakamus and Mamquam Rivers. Numerous creeks draining the volanic terrain are tributary to these two major rivers. High elevations combined with relatively high precipitation during the winter produce a large ice-field and glacier system over the top of the complex.

Forests of fir and cedar have been extensively logged since the turn of the century in areas outside the park boundary. The area through the Cheakamus Canyon was burned by a major forest fire approximately 15 years ago which has left the area denuded. As a consequence of heavy logging and forest fires, the basement and volcanic geology is well exposed throughout the project area.

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4.3 Previous Work

Early references in the literature to the project area was made by Leroy (1908), Camsell (1918), and Bell et.al. (1932). A first look at the Garibaldi Mountain Volcanic pile was made by Burwash in 1914 who completed a thesis on the area in 1918. By far the most definitive work on the area is by W.H. Mathews (1958a and b). This study, representing 10 years of work, is in two parts: the igneous and metamorphic geology, and the geomorphology and Quaternary volcanic geology. The only major work since Mathews is a study of the geology and petrology of Quaternary volcanic rocks in the area by Green (1981).

The Mt. Garibaldi project area has not been investigated for its geothermal potential prior to this brief reconnaissance exploration.

4.4 Present Work

A brief reconnaissance investigation, intended to locate zones of geothermal potential, was undertaken in the Mt. Garibaldi area between November 23rd and November 30th, 1981. A field crew of one geologist and two assistants were based out of Squamish. Weather conditions were extremely poor for the duration of the field work. Rain and snow hampered access along secondary roads.

The exploration program consisted primarily of determining access conditions, geologic mapping, soil sampling and water conductivity measurements. 123 soil samples were taken at approximately ½km spacings along roads and water conductivity measurements were obtained from the majority of streams along the perimeter of the volcanic complex.

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4.5 Geology

Although the area surrounding Mount Garibaldi contains no known warm or hot springs, it is thought to have geothermal potential due to the presence of a large volcanic pile of mainly andesitic flows and domes. Some of the volcanism is considered to be post-recession of the Wisconsin Ice Sheet (i.e. less than 10,000 years ago). The basement setting of the Mt. Garibaldi area is typical of the Coastal Mountain range and of the Garibaldi Volcanic Belt itself. The basement consists largely of variably altered and foliated quartz diorite of probably upper Cretaceous age, probable with lesser amounts of younger quartz monzonite and granodiorite stocks of undetermined age. Underlying much of the volcanic complex are several exposures of metasedimentary and metavolcanic pendants of the lower Cretaceous Gambier Group trending in a generally northerly to northwesterly direction.

Volcanic lithologies in the vicinity of Mt. Garibaldi are andesite with lesser quantities of basalt, dacite and rhyodacite. The most distant Garibaldi volcanic outcrop from the main complex occurs at Watts Point approximately 7km south of Squamish on the east side of Howe Sound. Another distinct centre, referred to as the Castle, is directly west across the Squamish River from Squamish. Although several other lesser spires have been observed surrounding Mt. Garibaldi, by far the major volume of volcanic material lies atop an Eocene peneplain in a roughly north-south, oval configuration approximately 10km long with Mt. Garibaldi nearly central to the oval. Much of the complex exhibits features of sub-glacial or partially sub-glacial extrusion (Mathews, 1958). In fact Mathews considers that only two flows, an unnamed flow to the west of Mt. Garibaldi and the Ring Creek flow, show no signs of glacial contact.

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The Cheakamus valley basalt flows occur along Highway 99 and elsewhere. The flow characteristics of these basalts, fluid with well developed columnar jointing, are very difficult than the typical Garibaldi Complex volcanic rock. Green (1981), in a study of the Quaternary volcanic rocks of the Garibaldi Lake area, has determined from the chemical nature of the Cheakamus valley basalts and the Garibaldi Lake rocks that although the two rock types originate from separate magma chambers, these chambers result from different fractionation processes undergone by the same deeper molten rock source.

Rocks from within the Garibaldi Mountain volcanic pile give K/Ar dates from 0.04-1.3 million years ago. The Cheakamus valley basalts are from 34,200 years to 50,000 years old (Harakatol, 1976 cited in Green, 1981; Clague, 1980).

The most recent volcanic rocks belong to the Ring Creek flow. Mathews (1958) determined that there is no evidence of glaciation of the Ring Creek flow, indicating that it is younger than 10,000 years. Its precise age is unknown. The Ring Creek event extruded more than 1 cubic mile of dacite lava.

During the 1981 exploration little regional geological information was added to the work previously accomplished. Mapping shows that much of the basement rock, even at considerable distance from known volcanic centres, was subject to dyking by andesitic and dacitic members of the Garibaldi Group. These dykes and adjacent basement areas were subject to moderately intense alteration.

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4.6 Conductivity Survey (Refer to Drawing GAR-2)

Water conductivities were measured extensively in the project area. An attempt was made to sample all drainages, seeps and springs surrounding the Garibaldi Complex along the Cheakamus River, Ring Creek and Mamquam River. Background values are in the order of 40 micromhos/cm for the area. Zones containing consistent values above 50 micromhos/cm are interpreted as anomalous. Four clearly anomalous areas were determined using this criteria.

To the north of the project area a series of anomalous values occur in the Lake Lucille vicinity. A possible mechanism that might produce this anomaly is ground water drainage through and below an adjacent basalt flow to the west of Lake Lucille. More investigation in this area is required to test this model.

Above the northern end of the Cheakamus Canyon a small group of weakly anomalous values were measured. The lack of coverage in this zone and the marginal nature of the anomaly make interpretation impossible at this time. Coincidental high arsenic values may be related to these waters (see Section 4.7).

Further to the south of the Brohm Lake area the highest conductivity fluids measured in the project area eminate from a series of bedrock fractures on the east side of Highway 99. A large flow of about 1000 L/min issues from a series of springs and creeks all with anomalous water conductivity values. Above background values were identified at Brohm Lake down gradient from the above area. The bedrock source of this relatively conductive water makes the Brohm Lake area the leading area of interest identified in the Mt. Garibaldi area to date.

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Near the southern extremity of the map area a small group of slightly anomalous values was observed near the confluence of the Mamquam River and Skookum Creek. No geologic cause for these high values was observed. A washed out bridge across the Mamquam River at this location precluded further work during 1981.

4.7 Soil Geochemistry (Refer to Drawing GAR-3)

The soil geochemistry survey was intended to sample the perimeter of the Garibaldi Volcanic Complex at roughly 500m intervals using available roads and tracks for access and survey control. Where possible, samples were taken from well within the B soil horizon at depths in the order of 50 to 70cm and away from road right-of-ways.

Below the Barrier in Rubble Creek and Lake Lucille vicinity, several high values of arsenic produce a dispersed anomaly. Whether these values are related to a geothermal feature or result from some other mechanism such as the presence of volcanic debris in the Rubble Creek landslide is unclear. Their coincidence with the location of the slide fan strongly suggests a non-geothermal source.

Above the Cheakamus Canyon, three high values of arsenic are broadly coincident with high conductivity values in the same area. This small anomaly contains the highest arsenic value obtained in the project area. Further investigation is warranted.

A major anomalous zone occurs in the Brohm Lake area where high conductivity values measured in formation waters. The high soil values occur in both mercury and arsenic although not simultaneously. This zone of interest spans an area approximately 4km wide below steep cliffs of quartz diorite. An association of the soil anomaly and conductive waters with a thermal source in this area is suspected.

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Slightly to the south below Cheekye Ridge, a group of four anomalous mercury values appear. The disperse nature of these anomalies and the lack of anomalous conductivity values make this area a low priority target.

Below Paul Ridge and along the northern bank of Ring Creek a group of high arsenic and mercury values produce a significant anomaly spanning approximately 8km. Loamy soil with no substantial B horizon, particularly at stations SGA 12, 13, and 14 may diminish the scale of this anomaly. Regardless, the zone is well established upstream on Ring Creek towards the eruptive centre which produced the Ring Creek flow.

4.8 Conclusions

The results of a brief geothermal investigation in the Mt. Garibaldi area late in 1981 are encouraging. The possibility of the existence of a blind geothermal system, although not proven, is supported by the existence of coincident anomalous water conductivity values and mercury arsenic soil geochemistry. Three interest areas are outlined (Figure 4.1).

4.9 Recommendations

Continued surface exploration in Ring Creek, Cheekye and Cheakamus Canyon interest areas is recommended. Exploration should include:

- Detailed mapping
- Detailed water conductivity surveys
- Detailed soil sampling (mercury and arsenic)
- Resistivity--dipole-dipole survey along roads parallel to valleys and supplementary Schlumberger soundings.

The above outlined work will provide the basis for a decision on drilling or continued exploration in the area.

5.0 PITT RIVER

5.1 Location and Access

The area surveyed covers approximately 40 km² centered on Pitt River hot springs and is located 55 km northeast of Vancouver. (Figure 5.1). Access is by boat or seaplane to the B.C. Forest Products' wharf at the north end of Pitt Lake, thence by private logging roads which extend up the Pitt River Valley to the Garibaldi Provincial Park boundary.

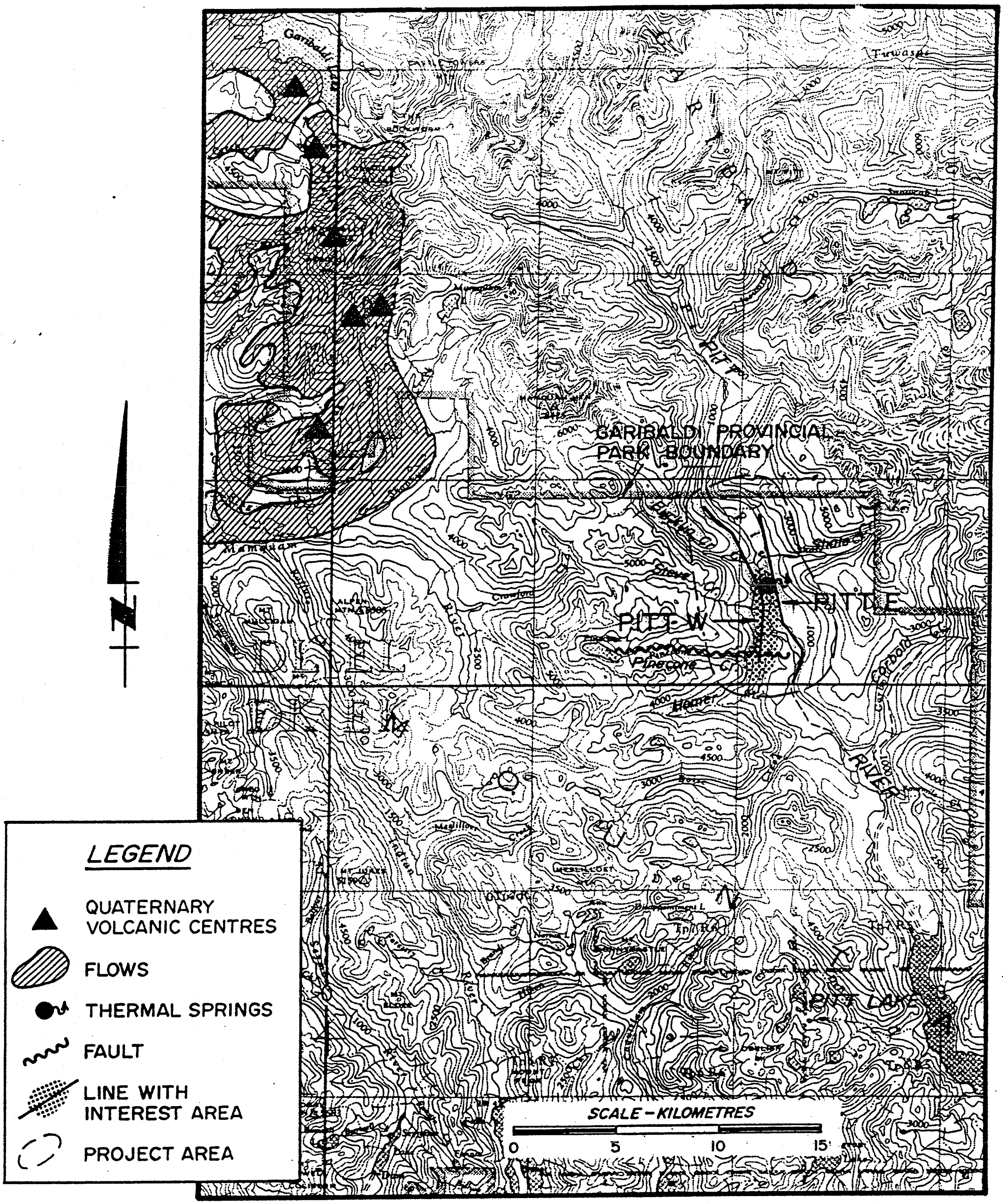
The springs are reached by following a 100m trail from a bridge that crosses Pitt River immediately below "Second Canyon" 21 km north of Pitt Lake. Heavy equipment can be brought in by B.C. Forest Products' barge.

5.2 Topography, Physiography and Vegetation

The area is characterized by deeply incised valleys and increasingly lofty peaks nearer the headwaters of the river. Mountainsides are precipitous, with numerous bald cliffs several tens of metres in breadth and height. Pitt River hot springs occur in the valley bottom at 150m elevation amid shouldered mountains that rise to more than 1550m.

Vegetation is typical of a West Coast rain forest and comprises mixed coniferous, deciduous trees, and dense undergrowth. Extensive logging in the area has provided excellent road access but also large areas of slash and second growth that impedes travel on foot. Exposure is generally good but much of it is inaccessible due to cliffs and waterfalls.

Tributaries to Pitt River include Shale Creek on the east and Bucklin, Stive, Pinecone and Homer Creeks on the west as well as



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NTS MAP 92G

FIGURE 5.1

PITT RIVER PROJECT AREA AND EXPLORATION SUMMARY

dozens of smaller unnamed streams. Creeks are subject to rapid fluctuations in discharge; warm rains induce melting of the principal glacial sources of Pitt River, and can double flow volume within 24 hours. Valley slopes have poor retentive capacity flash floods and washouts are common.

5.3 Previous Work

Apart from regional geologic mapping (1" = 4 mile scale) by the GSC in the late 1940's and early 50's (Roddick, 1966), chemical analysis of the hot springs (Lewis and Souther, 1978), and preliminary geothermal reconnaissance by NSBG (1974), no geologic or geothermal investigations have been conducted in the area. The original discovery of the springs is not on record. A small bathing pool has been created at the upper hot springs by damming the outflow with a low cement wall.

5.4 Present Work

Exploration parties worked out of a tent camp near the hot springs for a total of 19 days in late September and early October, 1981. These crews consisted of an NSBG geologist, and two technicians (Sept. 22 to Oct. 2nd) and a geophysical crew of five (Premier Geophysics Inc.; Sept. 29 to Oct. 10th). The following work was completed (Figure 5.1).

spring water chemistry and sinter analyses
reconnaissance and detailed mapping
soil geochemistry (84 samples along "PITT E" and "PITT W" LINES)
water conductivity measurements
dipole-dipole resistivity (9 line-km along "PITT W" LINE).

5.5 Geology

According to regional maps (Roddick, 1966; Roddick, et. al., 1979) the Pitt River area is underlain entirely by rocks of the Coast Plutonic Complex (ranging from diorite to granite and migmatite) with isolated pendants of metamorphic rocks consisting of Late Paleozoic Twin Islands Group and Middle Jurassic Harrison Lake Formation. No Cenozoic volcanic rocks have been reported. Valley bottoms, and to some extent hillsides, are thickly mantled with unconsolidated alluvial and colluvial deposits of Quaternary age.

5.5.1 Lithologies

As a result of this survey bedrock lithology has been divided into 6 units and 17 subunits consisting entirely of different varieties of igneous rocks. These include grey, quartz-poor granitoids of the Coast Plutonic Complex, the Pinecone "pendant" of Harrison Lake Formation (herein referred to as the "Pinecone Igneous Suite"), and various hypabyssal dykes. All units and subunits are defined on the basis of compositional similarity and should not be construed as necessarily having temporal or genetic significance.

The most prevalent lithology in the Pitt River area consists of quartz-poor, medium grey granitoids of the Coast Plutonic Complex (Unit 1). These range in composition from diorite to granodiorite but most are quartz dioritic with either biotite or hornblende or both as mafic phases. As rocks grade into diorite they become more mafic rich and more foliated. Migmatite is reported to underlie the area south of Shale Creek on the east side of Pitt River (Roddick, 1966) however none was found in this survey. All Unit 1 rocks have been subjected to weak, widespread propylitic alteration that is probably not related to present geothermal activity.

The Pinecone "pendant" named for its occurrence near Pinecone Creek is described by Roddick (1966, pg 38) as "greenish-grey porphyritic dacite with phenocrysts of plagioclase and quartz and some porphyritic andesite". The groundmass is aphanitic but completely recrystallized; plagioclase phenocrysts have been albitized but groundmass plagioclase still consists of barely altered sodic oligoclase. Metasomatism is attributed to intrusion by granitoids of the Coast Mountains Plutonic Complex. The rocks are "massive and except for a faint semblance of bedding (northeast strike, gentle southwest dip) no clues to its structure were disclosed." Roddick (1966) correlated this unit with Harrison Lake Formation meta-andesites and meta-dacites which have been assigned a Middle Jurassic age on the basis of fossil evidence and stratigraphic relationships in the type area. Nothing in the Pitt River area has been used as evidence to support this structural interpretation.

Information gained during this survey suggests that a reinterpretation of the Harrison Lake Formation may be in order for the Pitt River area. The Pinecone "pendant" is interpreted from the current work to be a high-level, zoned intrusive complex consisting of two main parts: an epizonal plutonic phase (mainly tonalite, Unit 2) and a hypabyssal phase consisting of strongly porphyritic plugs and dykes ranging in composition from andesite to rhyolite (Units 3a to 6). The Pinecone "pendant" intrudes Coast Mountain plutonic rocks of Unit 1 and is therefore younger. Textural similarities with Tertiary silicic plutons (Fall Creek, Affliction Creek, Salal) elsewhere in the Coast Mountains suggest that this igneous formation herein named the Pinecone Igneous Suite may also be of Tertiary age.

An isolated exposure of gently northwest dipping volcaniclastic textured and layered felsic rocks (Unit 6c), located 1km north of the hot springs, may be related to the Pinecone Igneous Suite or may be the only true remnant of Harrison Lake Formation in the area. The felsic unit was not seen in contact with Unit 1, but if it is related to the Pinecone Igneous Suite, then the contact is unconformable.

A notable feature of Pitt River area is the ubiquitous occurrence of hypabyssal dykes that range in composition from andesite to rhyolite. Typically these are up to a few metres wide, porphyritic and weakly altered. They attest to relatively young intrusive activity that may be the heat source for the hot springs. With the exception of andesite, most dykes can be correlated with massive varieties of the hypabyssal series of the Pinecone Igneous Suite. Texturally they are comparable although phenocryst sizes are usually smaller, and the groundmass finer grained and more recrystallized. Alteration is weak and pervasive. Andesitic dykes are typically medium to dark green, aphanitic to very fine grained, with plagioclase, hornblende or biotite phenocrysts up to 3mm long. Two ages have been identified; the earlier dykes (Unit 3b) are distinguished by more evident metamorphic texture and disseminated granular epidote. These dykes were found cutting Unit 1 on the north end of line Pitt West and are in turn cut by younger andesite dykes (Unit 3a).

One spectacularly mega-porphyritic dacite dyke (exposed south of the south end of line Pitt West) was much fresher than any other dyke and may attest to an even younger magmatic event possibly related to Garibaldi age volcanism.

5.5.2 Structure

Major airphoto lineaments generally parallel northerly to northwesterly striking fractures. Pitt River flows down a valley that, although glacially scoured, has steep walls and a gently zigzagging course apparently controlled by north-northwest and north striking joints. Other regional features are northeast and east striking. Parts of the valley appear to reflect graben-like structures.

The Pitt River area is marked by extensive fracturing both on regional and local scales. Hillside outcrops feature abrupt crevasse-like incisions, up to a few tens of metres long that are a product of glacial action on pre-existing fractures. Although the whole area has abundant fractures, Pinecone Igneous Suite rocks are distinguished by their intensely fractured outcrops. If such conditions are extended to depth these rocks should have adequate fracture permeability to permit reservoir fluid migration.

One major east-striking subvertical fault was discovered in this survey. Since the lower course of Pinecone Creek is controlled by this structure it has been named the Pinecone Creek fault. The fault zone is intensely brecciated and locally filled with clay-like gouge. This feature will likely control the movement of groundwater and may define an aquifer boundary.

5.5.3 Pitt River Hot Springs

The only known geothermal manifestations are the Pitt River hot springs. These consist of two springs about 15m apart issuing from similar fractures (striking northwest, dipping 45° southwest) in granitic rocks (Unit 1) cut by andesitic and dacitic dykes. Each occurs on a cliff wall about 3 to 5km above river level on the ~~west~~ side of the Second Canyon, located about 21km upstream of the north end of Pitt Lake. The springs occur 600m northeast of the intrusive contact between Pinecone Igneous Suite and Coast Plutonic Complex granitoids.

The "upper" and "lower" hot springs are generally similar in appearance. Both springs discharge clear, odourless, almost tasteless hot water, have white sinter deposits near their vents, but lack algae growths. The lower spring has a slightly lower flow rate and temperature but higher conductivity which indicates greater amounts of dissolved constituents.

Another hot spring is alleged to exist further upstream in the vicinity of the Third Canyon, where Pitt River crosses Garibaldi Park boundary. No attempt was made to investigate this due to restriction on time and difficulties of access.

5.6 Water and Sinter Chemistry

Water chemistry is tabulated in Table 5.1. The lower hot spring has slightly lower silica and carbonate but higher boron, calcium, sodium, potassium, lithium, bicarbonate, sulphate, chlorine, and total dissolved solids; other elemental concentrations are similar. The differences in total dissolved solids is in accordance with differences in specific conductivity. Despite similar appearance, the lower hot springs sinter is relatively silica rich and calcium poor whereas upper hot springs sinter has slightly more calcium than silica. Lower hot spring sinter has little calcium relative to the water. This suggests that calcium deposition may be a function of pH or that water chemistry is changing over time, becoming progressively silica enriched.

Predicted reservoir temperatures based on chemical equilibria of Na-K-Ca and SiO_2 indicate maximum temperatures are respectively 77°C and 122°C for lower hot springs and 80°C and 120°C for upper hot spring. The low flow rate of these springs (<20L/min) suggests that mixing with cold groundwater may have occurred which would alter spring temperatures and chemistry. Slow percolation to surface may also have enabled re-equilibration with cooler rocks so that predicted reservoir temperatures may be low.

5.7 Conductivity Survey (Refer to Drawing PITT-2)

Conductivity at the lower hot springs was 2700 micromhos/cm and at the upper hot springs 2300 micromhos/cm. Immediately downstream of both springs Pitt River conductivity was about 300 micromhos/cm; upstream values were about 5 micromhos/cm.

Very few conductivity measurements were made during this survey due to persistent heavy rainfall which flooded all water courses and completely masked any groundwater contribution to run-off. Based on fair-weather measurements, background values appear to range from 5 to 20 micromhos/cm.

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TABLE 5.1

TABLE OF CHEMICAL ANALYSES OF WATER SAMPLES FROM PITT RIVER HOT SPRINGS

Analyses	1	2	3	4	5	6
Date Collected	20/8/81	25/9/81	30/9/81	20/8/81	30/9/81	-
Time	mid-day	1400	1000	mid-day	1100	-
Instantaneous discharge	5-10L/min	20L/min	20L/min	10-20L/min	36L/min	-
Temperature	60°C	55°C	55°C	58°C	57°C	-
Conductivity (umhos/cm)	-	2700	-	-	2300	-
pH**	-	-	-	-	-	-
SiO_2 mg/L	6.4*	75	66	6.8*	72	68.2
B mg/L, ppm	2.56	2.57	2.59	2.17	2.17	-
Fe ppm, dissolved	0.12	0.08	0.04	0.12	0.03	-
Mn ppm, dissolved	0.01	<0.02	<0.02	0.01	<0.02	0.002
As ppm, dissolved	-	-	-	-	-	0.038
Hg ppb, total	5.8	-	0.2	3.6	0.3	-
Mg ppm, dissolved	<0.12	0.25	0.12	<0.12	0.12	0.05
Ca ppm, dissolved	115	120	115	90	95	83.5
Sr ppm, dissolved	-	-	-	-	-	0.440
Na ppm, dissolved	260	260	260	220	210	212.5
K ppm, dissolved	12.0	7.5	7.5	12.0	6.2	8.2
Li ppm, dissolved	-	0.15	0.15	-	0.10	0.145
HCO_3, mg/L $CaCo_3$ ppm, total	16.5	14.5	18.6	16.5	16.6	20.5
CO_3 mg/L, $CaCo_3$	-	2.07	2.07	-	4.14	-
SO_4 ppm, dissolved	470	450	450	380	340	362.0
Cl ppm, dissolved	295	220	220	210	190	196.0
F ppm, dissolved	2.0	1.96	2.00	1.7	1.70	1.460
TDS mg/L	-	800*	1200	-	1000	-
Colour	-	none	none	-	none	-
Turbidity	-	clear	clear	-	clear	-
Odour	none	none	none	-	none	-
Taste	slightly salty	flat	-	-	flat	-
Calculated Temperatures						
T_{SiO_2} Con (°C)	25.7*	121.7	115.2	27.5*	119.6	116.9
$T_{Na-K-Ca}$ (°C)	76.7	61.3	62.2	80.2	58.2	69.3

NOTE:

- not determined or recorded

* probably invalid data

** pH values were measured at 1200 on October 17, 1981. Recorded pH and temperatures were: Lower Hot Springs 7.5, 59°C; Upper Hot Springs 6.8, 56.5°C; Pitt River pH was 5.8

Accompanying notes on following page.

TABLE 5.1 Analyses Pitt River Hot Springs

1. Lower Hot Spring; analyzed 21/8/81 by Chemex Laboratories. Certificate of Analysis No. W5561, Spring #1.

2. Lower Hot Spring; analyzed 28/10/81 by Chemex Laboratories. Certificate of Analysis No. @5660, Pitt 1 sample was acidified 5 days after collection.

3. Lower Hot Spring; analyzed 28/10/81 by Chemex Laboratories. Certificate of Analysis No. @5660, Pitt 2, sample was acidified at time of collection.

4. Upper Hot Spring; analyzed 21/8/81 by Chemex Laboratories. Certificate of Analysis No. W5561, Spring #2.

5. Upper Hot Spring; analyzed 28/10/81 by Chemex Laboratories. Certificate of Analysis No. @5660, Pitt 3.

6. "Pitt River Thermal Spring", Analysis No. 2 in Lewis and Souther, 1978, p6, Table 1. Specific source, date and time of collection or analysis, discharge, temperature conductivity and pH were not reported.

5.8 Soil Survey (Refer to Drawing PITT-3)

Eighty-four soil samples were collected at about 200m intervals, along two control lines (Pitt East and Pitt West) each about 8km long, located along the break-in-slope on both sides of Pitt River Valley. Sixteen soil samples were collected from 3 soil profiles near line Pitt West.

Technical difficulties encountered during this survey included exceptionally dense vegetation and forest floor cover and very thin soil developed on thick glacio-fluvial deposits or bedrock. In many localities road cuts proved to be the most practical source of sample material.

Values of mercury in the Pitt River soil are unusually high when compared to other Coast Mountains project areas. Mean values are around 110 ppb in contrast to about 30 ppb for the Meager Creek area and Garibaldi Volcanic Belt. Arsenic data are less discrepent and have a mean concentration of 5 ppm.

Two interpretations of Pitt River mercury data are possible. First, for whatever reason, the Pitt River may have exceptionally high background mercury concentrations. Under this interpretation, the threshold value for mercury is about 210 ppb. Anomalous mercury values are restricted to the Pitt West line in the immediate vicinity of the hot springs and in a soil profile at the south end of the line.

Secondly, it may be assumed that background mercury concentrations determined at Meager Creek and elsewhere in the Garibaldi Volcanic Belt apply to all Coast Mountains terrain including Pitt River. In this case a threshold of 55 ppb Hg is assumed and all but three line soil samples are anomalous. If the Pitt River area is in fact anomalous with respect to mercury then it is apparent that the present soil lines do not adequately blanket the thermal outflow zone indicated by high mercury values.

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Arsenic soil anomalous are weak and spotty. Three anomalous values towards the south end of Pitt East line straddle the contact between quartz-poor and quartz-rich granitoids (Units 1 and 2, 4, 5, 6) which may be the locus of intense fracturing and movement of thermal fluids. It is noteworthy that at the same contact on the other side of the valley, in close proximity to the hot springs, Hg values are locally about twice those found elsewhere on the line. This also supports the hypothesis that this contact might be an important feature in the control of groundwater.

5.9 Resistivity

Dipole-dipole resistivity survey was conducted along a single 9km long line centered on the hot springs on the west side of Pitt River valley. For a detailed discussion, see the accompanying report by Premier Geophysics Inc. entitled "D.C. Resistivity Survey in the Pitt River Area, B.C.", dated January 14, 1981.

Pitt River is characterized by generally high resistivity except for one symmetrical anomaly located northwest of the hot springs, between the springs and Bucklin Creek.

Part of this anomaly coincides with a steel cable lying partially buried alongside the road. More work is needed to resolve whether the cable has caused the shallow low resistivity signature.

If cables can be discounted then the conductive body detected would appear to be shallow and strongly controlled by structures.

5.10 Conclusions

Work done to date has established that the Pitt River area has geological, geochemical and geophysical anomalies that can be interpreted to indicate a geothermal system.

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Geologic mapping shows the presence of structures (e.g. fractures, faults, contact zones) and lithologies (e.g. probable Tertiary intrusive rocks) consistent with a geothermal reservoir. Soil geochemistry indicates unusually high mercury values throughout the region with the stronger anomaly in the vicinity of the hot springs. A resistivity low slightly to the northwest of the hot springs may be due to hot fluids at depth.

There are however, several mitigrating factors requiring further resolution before detailed investigation can be justified. Included are the cause of the ambiguous resistivity anomaly; the lack of a plausible explanation for regionally elevated mercury values; and a virtual absence of young volcanic rocks typical of Cascade-type geothermal systems.

5.11 Recommendations

In view of the results of this study we recommend that, before a full-scale investigation is designed, further reconnaissance work be done to resolve ambiguities in the soil and resistivity data. In order of priority, this work should entail geophysics, geochemistry, and geological mapping.

Geophysical work involving magnetic or EM methods should conclusively establish whether the anomaly northwest of the hot springs is due to buried cables or natural phenomenon. If the "cable hypothesis" is disproven, resistivity should be conducted on the east side of Pitt River along 10 km of line centered on the hot springs.

Geochemical work should include confirming the high mercury values with detailed sampling in the anomalous area. Pitt West line should be extended south at least 1.5 km in order to close out the exceptionally high mercury value found in soil profile #3. Pitt East line should be extended both northward and southward to close out arsenic anomalies and blanket the mapped extent of Pinecone Igneous Suite whose contacts may be a geothermal fluid migration path.

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Geologic mapping should be directed towards defining the extent of map units, especially the highly fractured Pinecone Igneous Suite, age relationships between quartz-rich and quartz-poor granitoids, andthe extent and relative movement of faulting. Mapping would logically be supplemented by water conductivity measurement throughout the area.

If results of further investigation prove warranted, slim-hole exploratory drilling to test the anomalies would follow in 1983. Such a program would consist of one or two diamond drill holes to approximately 600m depth.

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6.0 LOWER LILLOOET VALLEY

6.1 Location and Access

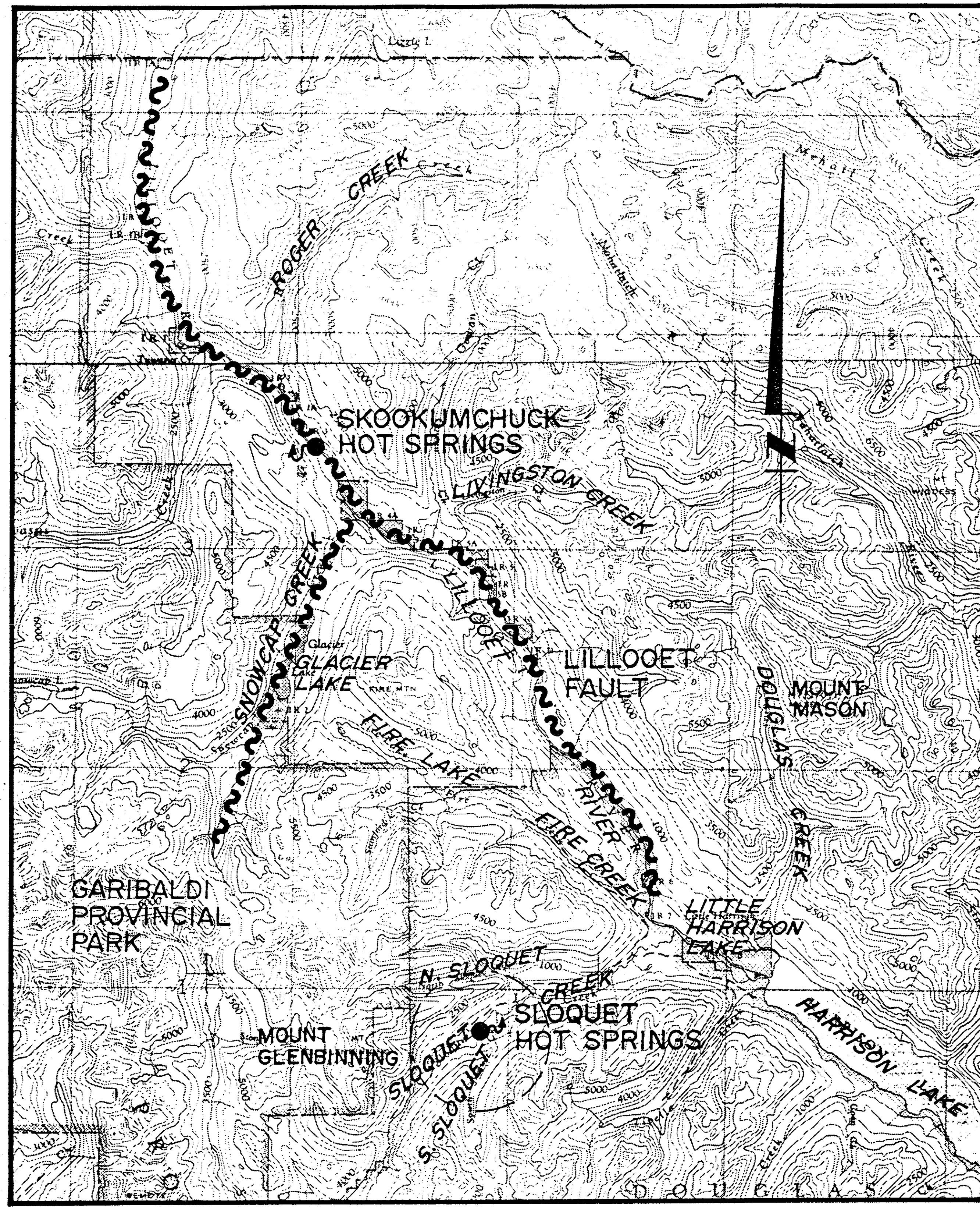
The Lower Lillooet Valley project area is in the Lillooet Valley south of Lillooet Lake and north of Harrison Lake (Figure 6.1). A main logging road leads from Pemberton, B.C. to the north end of Harrison Lake. Secondary logging roads, in many areas in need of repair, provide access up some tributaries to the Lillooet River. Two thermal springs situated in the project area are the Sloquet Creek and Skookumchuk hot springs. Skookumchuk hot spring is located on the northeast side of the Lillooet River roughly midway between Lillooet and Harrison Lakes and approximately 100m southwest of the Hydro transmission line road. Sloquet hot springs are reached by way of a 10km abandoned logging road leading westerly up Sloquet Creek. At the time of our examination a bridge across North Sloquet Creek was washed out.

6.2 Topography, Physiography and Vegetation

Elevations in the project area range between 150m at the base of the Lillooet Valley and 1220m in Roger's Creek and North Sloquet Creek. Relief varies from moderately to steeply dipping slopes (5° to 35°). Peaks rising to 1900m border the Lillooet Valley and are capped by mountain glaciers.

A coastal climate dominates in the region resulting in high annual precipitation and moderate temperatures.

The Lillooet Valley drainage is well developed with the Lillooet River as the main drainage course. The broad U-shaped valley, indicative of recent glaciation, is fed by several major tributaries including Sloquet, Roger's, Gowan, Higher and Snowcap Creeks.



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NTS MAPS 92J & 92G

LEGEND

INTEREST AREA

THERMAL SPRINGS

FAULTS

FIGURE 6.1

LOWER LILLOOET VALLEY PROJECT AREA AND EXPLORATION SUMMARY

Vegetation in the valley reflects a coastal climatic influence with large conifers including fir and spruce extending to treeline at approximately 1300m. Portions of the valley bottom and mountain slopes are covered by deciduous growth with dense underbrush impeding foot travel in these areas.

6.3 Previous Work

Geology within the studied area was mapped at a scale of 1" to 4 miles between 1953 and 1955 by J.A. Roddick of the Geological Survey of Canada (Roddick, 1965). This mapping attributed all granitic rocks within the area to Mesozoic Coast Plutonic Complex intrusions. Later dating of plutons in the Pemberton Belt (Lewis and Souther, 1978) has shown the existence of late Tertiary Plutons intruding Coast Plutonic Complex rocks.

The Skookumchuk springs and Sloquet springs were sampled in 1974, coincident with the surveying of resistivity profiles parallel to the valleys at both springs. The survey was part of a regional reconnaissance survey of geothermally prospective areas in southwest B.C. conducted for B.C. Hydro and Power Authority (NSBG, 1974). The "Lillooet Fault Selected Area "including the Skookumchuk and Sloquet springs was recommended for further work on the basis of geochemical data and geology which resulted in the return to the area in 1981.

6.4 Exploration Synopsis

Current reconnaissance work was conducted by a two man field party between October 7 - 22, 1981. Field studies consisted of conductivity measurements of 128 stream and spring vents; collection, drying, sieving and analysis of 53 soil samples for mercury and arsenic, chemical analysis of thermal spring water and sinter samples from the Sloquet Creek and Skookumchuk Springs, and regional geologic mapping.

6.5 Geology (Refer to Drawing LIL-1)

The distribution of rock types and structures is well documented although new roads south of Sloquet Creek have exposed unmapped bodies of granodiorite of probably Mesozoic age within the large body of metamorphic rock (Roddick's Unit 5, Fire Lake Group). The importance of these exposures lies in the indication that this large body of metamorphic rock may have a substantial component of fractured intrusive rock, and that the metamorphic body is likely a pendant of limited depth.

The biotite granodiorite body south of Sloquet Creek was found to be porphyritic and unlike most Coast Intrusive granodiorites within the area. The rock is similar in appearance to the Salal Creek pluton, and the possibility of a Tertiary age exists. On the south side of Sloquet Creek hot springs, water (64°C) was found flowing at an estimated 15L/min from this porphyritic granodiorite. Most water appeared to be flowing from vertical fractures parallel to the creek, has a sulfurous odour and was accompanied by substantial sinter deposits. Most fractures were sealed with this sinter.

The geology, geochemistry and spring occurrence at Sloquet allow a preliminary model of a geothermal system to be postulated.

6.6 Water Chemistry

Spring water chemistry assays for Skookumchuk and Sloquet hot springs indicate high silica, sodium, calcium, bicarbonate and sulphate ions in the samples (Appendix A). Geothermometry models indicate that geochemical equilibrium has been attained at 100.3 and 51.6°C for SiO^2 and Na-K-Ca geothermometers respectively.

Similar temperatures for the Sloquet springs indicate equilibration at 113.9 and 37.7°C. In these cases, the Na-K-Ca geothermometer is suspect as observed surface temperatures exceed predicted temperatures.

6.7 Conductivity Survey (Refer to Drawing LIL - 2)

Stream temperature and electrical conductivity measurements were taken along Lillooet Valley between Lillooet Lake and Harrison Lake, Gowan Creek, Roger's Creek, Sloquet Creek logging road above and north of the spring vent area and within the Sloquet and Skookumchuk spring systems. A summary of conductivity data is as follows:

No. of Measurements	128	
Mean	43	
Standard Deviation	46	
X + S	89	
No. Samples (X+S)	10	or 7.8%

Of the 10 anomalous readings, 4 are associated with the Skookumchuk springs. The remaining 5 creeks were checked for possible thermal spring sources, but none were found. Three of these 5 anomalous readings were measured near the north end of Little Lillooet Lake; the possibility of a spring system smaller than but similar in nature to Skookumchuk spring exists here. This is approximately 18km north of the Skookumchuk spring.

Conductivities results were markedly different for the two springs tested. Skookumchuk spring with lower temperature (52°C) had a higher conductivity (2880 micromhos/cm) than Sloquet (65°C, 1480 micromhos/cm).

Sloquet Creek conductivity was found to be little affected by the addition of spring flow. Conductivity 5m upstream from the springs was 19 micromhos/cm, and 10m downstream was 23 micromhos/cm. Dilution is therefore extremely thorough and rapid in the turbulent creek water.

The frequency histogram (Figure 6.2) shows that most of the conductivity readings are below 50 micromhos/cm. Many of these readings were obtained along Roger's Creek and Gowan Creek roads, where they pass through Coast Intrusions granodiorite. The indication is that these intrusives are extremely insoluble and no thermal activity exists east of the Lillooet River Valley.

6.8 Soil Geochemical Surveys (Refer to Drawing LIL - 3)

Soil samples were collected along Lillooet River Valley at random locations where good soil conditions were encountered, and at 100m intervals along Sloquet Creek on either side of the spring area. A total of 53 soil samples were collected from the top of the B horizon, immediately under the root zone. Samples were placed in paper sample bags and were dried, sieved and placed in closed vials in the field. Mercury analysis was done with a Jerome Gold Foil Mercury detector, and arsenic analysis by Chemex Laboratories.

The logarithmic threshold value for arsenic is 12.7 ppm. Seven samples are found to be higher than the threshold value. Six samples exceeded the logarithmic threshold value for mercury of 93.4 ppb.

The line of samples collected along Sloquet Creek detected a major mercury anomaly coincident with the Sloquet springs, even though most samples were collected from extremely poor soil. Mercury and arsenic values from this line are shown in Figure 6.3. The coincidence of anomalous readings from both elements over 600m

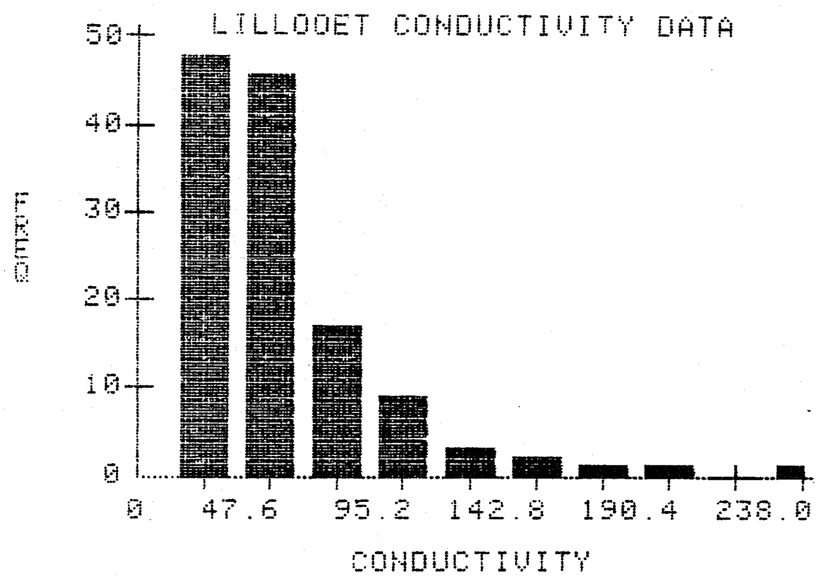


Figure 6.2
Frequency Histogram of
Lower Lillooet Valley Conductivity Data

suggests the existence of a geothermal system of substantial size within the area of the springs.

No anomalous soil mercury values were detected in samples collected along the Lillooet River.

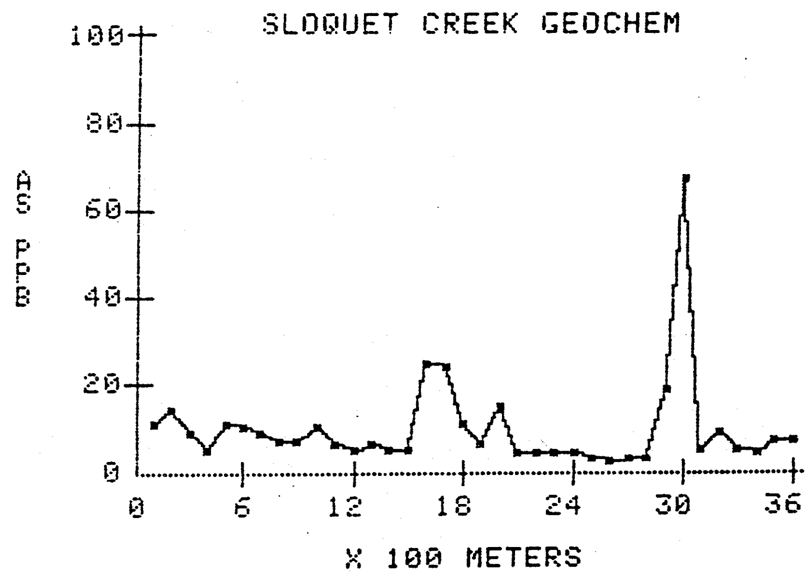
6.9 Conclusions

Conductivity measurements taken in the project area have produced three anomalous areas which have measurements over the threshold value of 80 micromhos/cm. The Skookumchuk springs area has five anomalous readings with a maximum reading of 2800 micromhos/cm.

From the results of the soil geochemical survey, one anomaly with elevated values in both arsenic and mercury has been identified at the Sloquet springs area. These results support the existence of a geothermal system in the Sloquet spring vicinity.

The field studies conducted in 1981 indicate that the Sloquet Creek spring area is the most favourable exploration target. The porphyritic granodiorite body to the immediate south is expected to be the geothermal source, and any hot fluid reservoir is expected to be related to and likely within this body. Exploration should be conducted so as to detect the location and extent of such a reservoir.

Petrographic comparisons of rock samples from the Sloquet area with samples from The Geysers geothermal area, California, provide further encouragement. Studies by Read (1974) indicate sinter samples from the two areas are comparable although bedrock alteration is somewhat different. Opal and gypsum deposits at the Sloquet



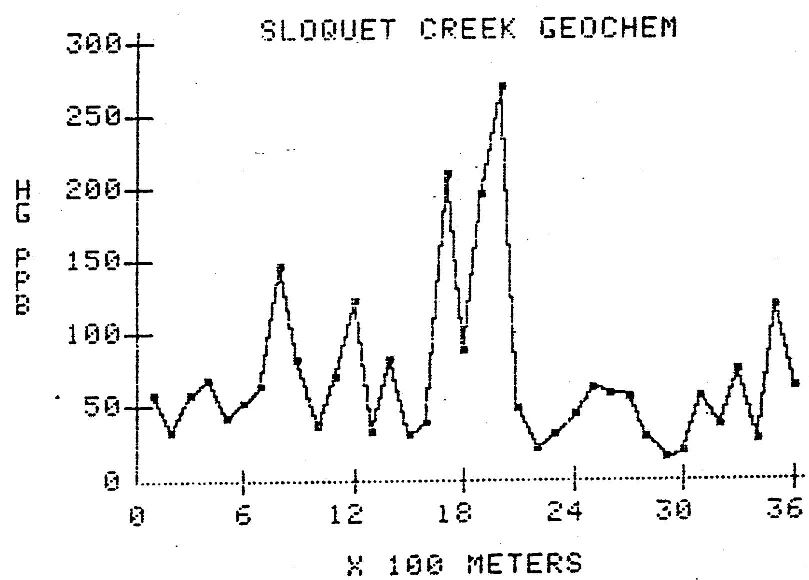


Figure 6.3

Soil Geochemistry Over Sloquet Hot Springs hot spring vent indicate high subsurface temperatures and, in view of this and other supporting evidence, the area is considered a high priority target.

6.10 Recommendations

Preliminary investigations indicate excellent geothermal potential for the Sloquet Creek region and a detailed follow-up study in the vicinity is strongly recommended. As the area of interest is relatively small, we propose that a program involving detailed geological mapping, soil sampling and conductivity measurement be focused on the Sloquet Valley.

The success of soil mercury analysis indicates that this technique should be expanded in the Sloquet Valley. Additional lines of samples parallel to the valley should be collected to verify the anomalies in mercury and arsenic detected in 1981. This should provide data necessary to design a soil grid suitable for detecting a geothermal system as postulated for Sloquet Creek.

In conjunction with geological work, we recommend that a dipole-dipole resistivity survey be performed. The inadequate resolution hindering earlier geophysical surveys would be overcome by use of this technique.

A drilling program is recommended and would involve up to four gradient holes. The first priority should be the drilling of a 600m well in porphyritic granodiorite on the south side of Sloquet Creek to provide initial geothermal gradient data for the region. This hole should intersect the hot fluid flow between the postulated source and spring vents. Contingent upon geological, geophysical and drilling results, provision for up to three more holes should be made.

7.0 NORTHERN VANCOUVER ISLAND

7.1 Location and Access of Project Area

Northern Vancouver Island reconnaissance focused mainly on the region between Port McNeill and Port Alice (Figure 7.1). This area lies approximately 400km by road northwest of Nanaimo.

Access to the area is by way of either aircraft to Port Hardy or by vehicle to Port McNeill or Port Alice (see Figure 7.1). Daily scheduled flights from Vancouver service Port Hardy, itself an active seaplane and helicopter base for remote logging camps on the north island. Road access is by way of the recently completed Island Highway (Highway 19) to Port McNeill and then southwestward to Port Alice. An extensive network of active logging roads traverses much of the region and affords excellent access to many areas.

Larger settlements in the area include Port McNeill, Port Hardy and Port Alice (Rumble Beach). These provides a variety of accommodations, restaurants, stores and garages.

The Island Copper ore body, operated by Utah Mines, is located slightly northwest of the project area.

7.2 Topography, Physiography and Vegetation

Most of the project area is typified by rugged mountainous terrain with moderate to extreme relief. This is especially true of areas east of Port Alice although the terrain becomes more subdued northwards.

The climate is typical of most coastal areas in British Columbia with moderate temperatures and high precipitation. Although minimal in the lower coastal areas, snowfall may be heavy

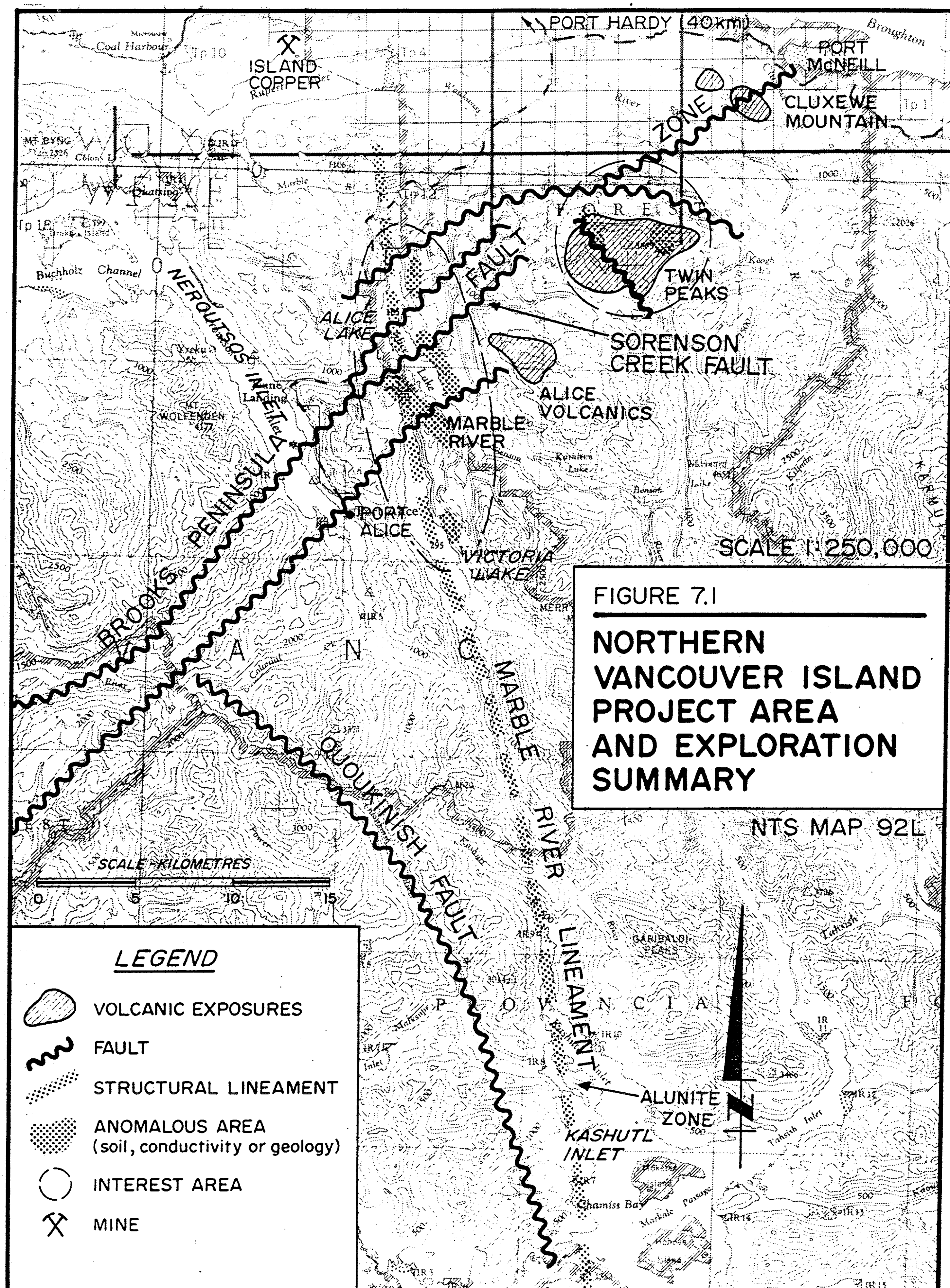


FIGURE 7.1

NORTHERN VANCOUVER ISLAND PROJECT AREA AND EXPLORATION SUMMARY

over much of the northern island during winter. Low cloud and fog are very common and often hamper air and marine traffic.

Drainages in the area typically exhibit a deep V-shaped profile. Elongate troughs cut the topography producing strong lineaments such as Alice and Victoria Lakes and Neroutsos Inlet. Drainage patterns are strongly controlled by underlying fault systems. Outcrop is sparse owing to dense vegetation however, small rock quarries (for road surfacing material) and road cuts provide good outcrop exposure.

Vegetation in the area is typical West Coast rain forest with large conifers (mainly cedar and fir) providing a dense canopy over thick moss and fern growth at ground level. In many areas logging has stripped much of the original growth now replaced by a virtually impassable blanket of second growth fir and hemlock.

7.3 History

The northern end of Vancouver Island supports an active mineral exploration industry and as such, much of the area has been extensively mapped. A comprehensive report on the geology and mineral depostis of the Alert Bay-Cape Scott map area (Muller, et. al., 1974) mentions an investigation by Clapp (1915) reporting on the occurrence of rocks bearing high temperature alteration in the vicinity of Kashutl Inlet, south of Port Alice. An attempt by Nevin Sadlier-Brown Goodbrand Ltd. (1975) to locate the source of this thermal deposit as well as to investigate alleged hot springs in the Fair Harbour area failed to locate any positive evidence of hot springs activity using an airborne infrared survey technique.

Mineral exploration in the area has been quite extensive and has identified two large and several small ore deposits. Although the possibility has not been investigated, the body of information produced on the exploration of the mineral showings may contain significant information regarding geothermal activity.

7.4 Exploration Synopsis

A three man crew consisting of a geologist and two technicians was mobilized to Port Alice by truck on November 21, 1981. Soil sampling and conductivity measurements were collected and regional geological mapping was initiated. Snow at higher elevations and poor weather hampered the progress of the survey in early December and the crew was demobilized on December 3. 146 soil samples and substantial geological and conductivity data were collected over much of the regions (Tertiary volcanic terrains, Marble River Lineament) of primary interest. The "Alunite Zone" south of Port Alice was not inspected due to deteriorating weather conditions.

7.5 Geology (Refer to Drawing NVI-1)

7.5.1 General Setting

Recent investigation in the Port Alice-Port McNeill region focused mainly of crustal structures in areas surrounding exposures of Tertiary volcanic rock. The Marble River Lineament in particular was investigated for evidence of geothermal acitivity. Except for rumoured hot springs at Fair Harbour, no hot springs are known to exist in the project area. However, localized high temperature alunite alteration of outcrop along the lineament and the geological setting with respect to various crustal features present a prime geothermal exploration target.

Most of the project map area is underlain by rocks of the Vancouver Group with later plutonic intrusives and Quaternary volcanic flows of limited extent. The lowest member of the Vancouver Group exposed in the map area is the Triassic Karmutsen Formation. Karmusten volcanics are comprised of a thick sequence of pillow lavas overlain by basalt flows, pillow breccias, and aquagene tuff and breccia. The Karmutsen in overlain by upper Triassic Quatsino limestone and clastic sediments of the Parson Bay Formation. These in turn are overlain by the upper member of the Vancouver Group, the lower Jurassic Bonanza Volcanics. Water lain tuff breccia and volcanic conglomerate overlies the Parson Bay Formation in the map area. Jurassic granodiorite and quartz diorite of the Island Intrusives intrude Vancouver Group stratigraphy at five localities in the project area. Finally, Tertiary volcanic rocks of andesitic to basaltic composition are laid down in the area between Port Alice and Port McNeill.

The area is traversed by several faults that form deep clefts in the topography. Of particular interest is the Brooks Peninsula Fault Zone which corsses Vancouver Island southwestwards starting from Port McNeill and extending to Brooks Peninsula. Tertiary volcanic centres align themselves along this zone and may be coincident with fault activity. Other major lineaments in the area of interest trend northwestward and include structures such as the Ououkinsh Fault and the Marble River Lineament. The latter extends north-northwest from Kyuquot Sound for approximately 70km and includes Victoria and Alice Lakes.

7.5.2 Detailed Observations

Exposures of Tertiary volcanic rock occur approximately 8km west of Port McNeill. The largest, Cluxewe Peak, is comprised of fine-grained dacite with well developed vertical jointing. The rock is remarkably intact and massive; only indistinct flow banding and rare feldspar crystals distinguish it from sandstone. A smaller hill slightly to the northwest consists of a volcanic breccia and conglomerate containing angular blocks of altered basalts indicating that this is a vent area. (Muller et. al. 1974) Basement rock in the vicinity of the vent is obscured by thick vegetation and glacial till and, as such, the degree of hydrothermal alteration is impossible to determine from surface mapping.

To the southwest at Twin Peaks, extensive exposures of dark grey dacite and basalt flows overlie a thick section of Karmutsen volcanics. Volcanic flows exhibiting chaotic columnar jointing and conglomerate with dacitic to basaltic clasts 2-50 cm in diameter are particularly well exposed southwest of Waukwaas Creek. The contorted morphology of the exposures suggests considerable post-volcanic re-working. Limited evidence suggests that a large part of the Twin Peaks edifice may have been eroded. Contacts between pillow basalts of the Karmutsen Formation and the overlying Tertiary volcanics are indistinct. However Karmutsen exposures in the area do not exhibit pronounced hydrothermal alteration that could be associated with the Twin Peaks volcanic activity.

A smaller area of Tertiary volcanic outcrop 2 km east of Alice Lake consists mainly of basaltic to dacitic flows and breccia. In some places flow banding imparts a foliated texture to the rock. Hypabyssal dykes contain porphyritic feldspar crystals up to 3mm in length. Patchy dacite flows on the northwest rim of the "Alice volcanics" exhibit slender columnar jointed columns up to 20 cm in diameter. Vesicles in the flows are present but uncommon. Fine grained pyrite is disseminated throughout much of the rock.

Several small occurrences of subvolcanic rock appear between Alice and Victoria Lakes near the intersection between the Marble River Lineament and the "Sorenson Creek Fault". The dykes and sills could conceivably be related to major structures in this vicinity. The best exposure of volcanics occurs in a road cut on the "Alice Lake Main" road where purple to green andesite has forcefully intruded Quatsino limestone. Although located close to the "Alice Volcanics" textural and compositional differences suggest that the two events are unrelated. At the contact of the intrusions, limestone is brecciated and in places, has been recrystallized to marble. Stringers of kaolinite commonly form the matrix between breccia fragments. The dyke, possibly 20m in width, exhibits several phases of intrusion and is well brecciated. Porphyritic feldspar is kaolinized and dyke walls have been encrusted with pyrophyllite or gypsum, indicating the presence of high temperature alteration.

At a similar locality on the west side of Alice Lake near the inflow of the Marble River, dacite and andesite intrudes limestone in a band approximately 150m in width. The brecciated limestone volcanic contact dips almost vertically. The volcanics have been traced in spotty outcrop for approximately 3 km up Sorenson Creek. In places, the dacite has been completely leached by hydrothermal action and contains disseminated fine-grained pyrite. Basalt near the shore of Alice Lake is locally vesicular suggesting that the volcanism was near or at surface. It is unknown if this zone is an extension of the altered brecciated volcanic zone on the eastern side of Alice Lake.

7.6 Water Chemistry

Only one sample was collected during the recent survey (BPR-W01). The sample was taken from a small anomalously conductive seep approximately 2 km northwest of Marble River.

Geothermometry calculations based on different ionic constituents do not give consistent groundwater temperature predictions. Silica is not present in significant levels however the sample is not considered representative of any geothermal waters in the area.

7.7 Conductivity Survey

Water conductivities were measured in conjunction with soil sampling in the primary interest areas. Background conductivities averaged 20 micromhos/cm. Conductivities are considered anomalous above 75 micromhos/cm. Readings did not show significant variation with meteorological conditions.

Three areas of anomalous stream conductivities measured in the vicinity of Marble River between Alice and Victoria Lakes and on the southeastern shore of Alice Lake. Elevated values occur near the mouth of Sorenson Creek and upstream in small tributaries for approximately 3 km. Conductivities of stream water upslope on a small knob immediately south of Sorenson Creek are anomalous and probably affected by dilution by surface run-off. The largest conductivity anomaly coincides well with a major altered andesitic to dacitic dyke and mapped structures cutting the Quatsino Formation limestone. Higher background stream conductivities might be expected in limestone terrain relative to volcanic or plutonic areas. Stream conductivities along the Benson River valley immediately southeast of Alice Lake (underlain by the Quatsino Formation) should be measured in order to determine the effects of ions from the dissolution of limestone on conductivities. Anomalous areas northwest of Marble River on the west side of Alice Lake in the vicinity of Station "VM-50 S" are coincident with anomalous arsenic values in soil samples.

Two other anomalous areas occur on the "Alice Lake Main" logging road east of Alice Lake. Conductivities 4 to 5 times the background value were detected near Benson River and slightly northwards of Pinch Creek. The highest conductivity measured was 250 micromhos, occurring in a bright orange cold seep from a dry creek bed near AL-30 N.

Conductivity measurements elsewhere in the project area did not yield significant anomalous values. Stream conductivities in the Alice volcanics, Twin Peaks, and Cluxewe areas show low values although sampling of these and other drainages is far from complete.

7.8 Soil Geochemical Surveys (Refer to Drawing NVI-3)

Soil samples were selected at 500m intervals along the logging reads extending along the Marble River Lineament and across areas of Tertiary volcanism. Samples were collected from a depth of approximately 70 cm, placed in plastic jars, lidded tightly and analyzed for arsenic and mercury. Results of the geochemical survey are plotted on Drawing NVI-3.

Values for arsenic throughout the area average approximately 5 ppm and ranged from below the detectable limit of 1 ppm to a high of 440 ppm. Background values appear to vary to some extent with geological terrane. Results are log-normally distributed with a threshold value for anomalous arsenic of approximately 20 ppm. Logarithmic treatment of mercury soil data indicates an average of approximately 35 ppb and a threshold for anomalous mercury values of 70 ppb. Although the magnitude of the soil mercury anomalies was considerably less than that for arsenic, a greater number of anomalous values were identified.

Areas of coincident anomalous mercury and arsenic results are considered to be the most significant in defining geothermal interest areas. Seven such anomalies have been identified. In general, anomalies are considered to be a reflection of underlying structural geology.

Anomaly A, situated on the east side of Victoria Lake, is coincident with fault structures splaying off the Marble River Lineament. "A" is a broad, low profile anomaly with elevated values in both arsenic and mercury. Anomaly B, also on the east side of Victoria Lake, is a relatively narrow anomaly although arsenic values in the area are remarkably high.

Anomaly C, located between Alice and Victoria Lakes contains high values in arsenic and is supported by elevated stream conductivity readings and mercury. The anomalous area is coincident with the intersection of the Marble River Lineament and the Sorenson Creek Fault. Geochemical values could conceivably be a reflection of these structures and associated volcanism, or alternatively, may be related to small stream deposits in the immediate area.

An extension of the Sorenson Creek Fault across Alice Lake is detected by anomaly D in the vicinity of Station AL-70. High mercury values in this area are strong indicators of the presence of hydrothermal activity. Anomaly E located approximately 3 km north also exhibits elevated mercury values although this anomaly appears related to the geological terrane rather than mapped geological structure.

In the Twin Peaks area, Anomaly F is located in the Waukwaas Creek Fault, and Anomaly G occurs near the base of the volcanics over a fault crossing the eastern side of the complex. Anomalies F and G are anomalous in mercury only, and are considered positive indicators of juvenile geothermal fluid circulation in the area. Permeable structures displace the Twin Peak volcanics and have thus been recently active. By contrast, virtually no anomalous areas were located on either of the Alice volcanics or in the vicinity of Cluxewe Mountain.

7.9 Conclusions

The study conducted during November and December, 1981, has identified three broad geothermal interest areas requiring further geothermal exploration.

The "Marble River Area" (Figure 7.1) encompasses local areas of Quaternary volcanic activity and several geochemical anomalies along the Marble River Lineament. Along Sorenson Creek, andesitic to basaltic flows exhibit brecciated limestone contacts and extensive hydrothermal alteration. Coincident stream conductivity anomalies and elevated values in both soil mercury and arsenic indicate that the area has considerable geothermal potential. The interest area is extended north and south from Sorenson Creek based on observed areas of hydrothermal alteration, areas of conductive surface waters and mercury and arsenic soil anomalies.

The "Twin Peaks Zone" is indicated by geochemical anomalies each coincident with faults traversing the volcanic complex. Elevated mercury values may be indicative of sub-surface geothermal activity.

Although no significant areas of interest were noted on either of Alice volcanics or of those near Cluxewe Mountain exploration here and elsewhere is in the preliminary stages and should be supplemented by further reconnaissance.

7.10 Recommendations

Preliminary results of the 1981 survey are promising in the area of investigation, however much of the project area was not explored because of time constraints and stormy winter weather. Therefore it is strongly advised that reconnaissance scale work be completed both in the Brooks Peninsula Fault Zone and on southward extensions of the Marble River Lineament. Past geothermal activity in these areas is indicated by hydrothermal alteration of surface outcrops. In particular a marine-based survey of geological mapping, soil sampling and conductivity measurements should be conducted in the Kashutl Arm region. The alunite showings, considered to be key indicators of geothermal activity, are of particular interest in this area.

Detailed follow up and further reconnaissance scale work is required in the "Marble River" and "Twin Peaks" interest areas. The survey would entail continued geological mapping, detailed soil sampling and detailed conductivity measurements followed by DC resistivity surveys along logging roads. In lieu of shallow gradient drilling, it is proposed that the locations of existing mineral exploration drillholes be compiled and temperature traverses run in accessible holes to determine the regional and local geothermal gradient.

7.11 Sharp Point and Ahousat Hot Springs

A single day, November 18, 1981, was spent by J. Taylor Crandall of Nevin Sadlier-Brown Goodbrand Ltd. and Colin Harvey of KRTA sampling the Sharp Point and Ahousat hot springs on the west coast of Vancouver Island. Both springs are reached by float plane from Vancouver. The springs were originally sampled by B.C. Hydro in 1975 (NSBG, 1975). Apart from the 1981 data (see Table A-1) no new findings or conclusions can be drawn.

Sharp Point is located near the south end of the Openit Peninsula west of Flores Island. The thermal waters issue from the base of a diorite outcrop at a temperature of 50.5°C. The SiO^2 geothermometer estimate is 91°C and the Na-K-Ca geothermometer is 47.5°C.

The Ahousat spring is located on the beach at the head of Matilda Inlet 1.6 km south of Ahousat on Flores Island. Water issues from the bottom of a concrete walled pool at 24°C. The SiO^2 geothermometer temperature is 91°C and the Na-K-Ca geothermometer temperature is 18.5°C.

8.0 LAKELSE HOT SPRINGS

8.1 Location and Access

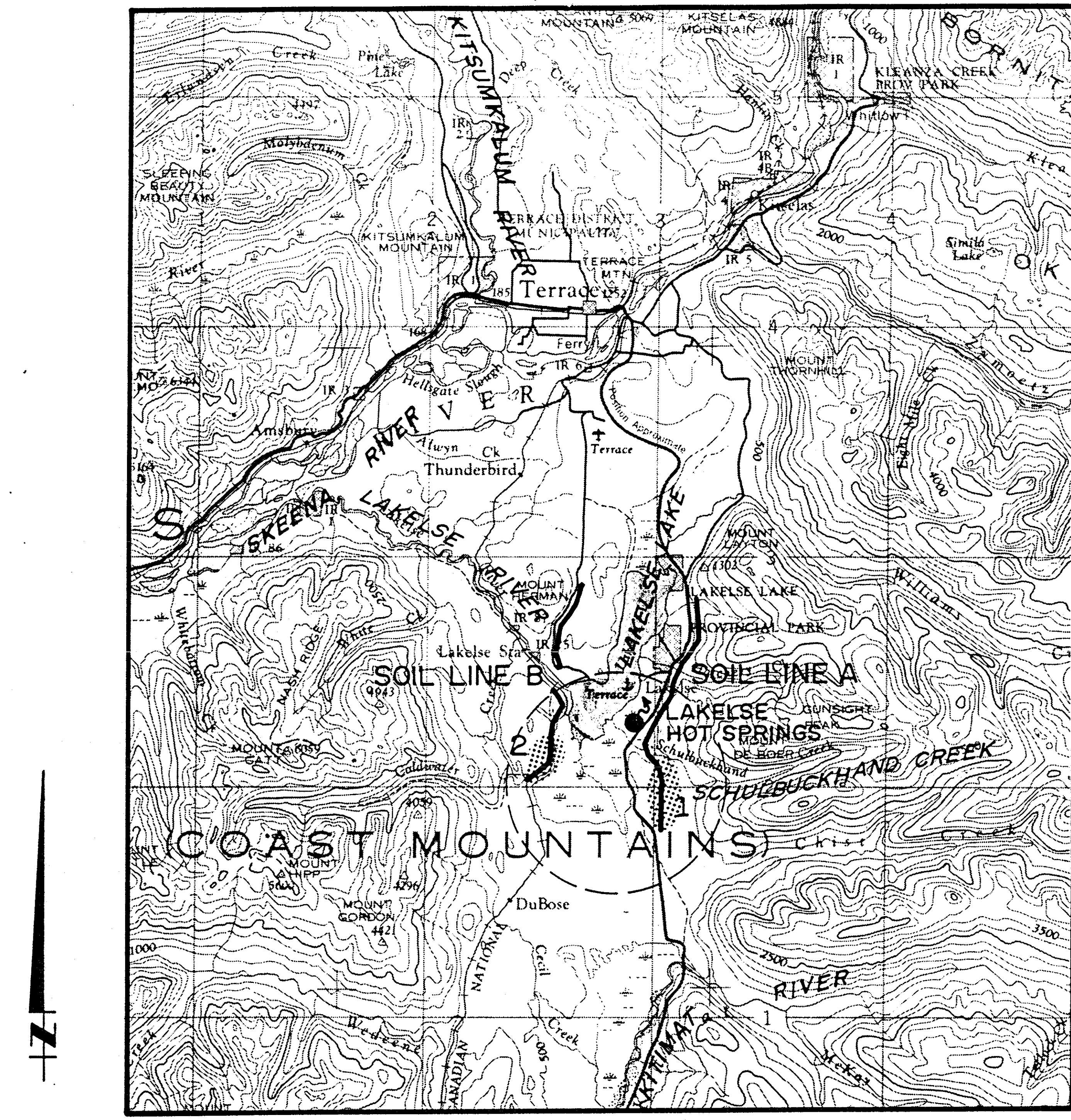
The Lakelse hot springs are located on the eastern edge of the Coast Mountains of British Columbia, 120 km inland from Prince Rupert. Hot springs occur on both sides of the Terrace-Kitimat highway near Lakelse Lake, 20 km south of the town of Terrace. The project area covers 1200 km² enveloping the hot springs and centered over a 4 km wide portion of the broad, north-south, Kitimat-Kitsumkalum valley (see Figure 8.1).

The western margin of the area of interest is accessed by a branch of the Prince Rupert line of the Canadian National Railways that runs from Terrace to Kitimat. A paved highway along the eastern side of the valley connects Kitimat with Terrace. Well maintained logging roads provide excellent access to both the areas south of Lakelse Lake and the area along its northwest shore.

Except for a few logged areas in the southeastern portion of the project area, roads on the valley slopes do not exist. Travel by foot is impeded somewhat by extensive swamp lands on the valley floor and heavy forest on the mountain slopes. Access in the immediate vicinity of the hot springs is excellent due to their proximity to the Terrace-Kitimat highway and a newly constructed dirt road.

8.2 Topography, Physiography and Vegetation

The Lakelse area is characterized by high mountain peaks and deeply incised, glacial valleys. Local relief ranges from Lakelse Lake, at an elevation of 70 m above sea level, to 1850 m at the summit of Mount Catt 10 km to the west. Most of the area of interest however, lies below 300 m in elevation.



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LEGEND

INTEREST AREA

THERMAL SPRINGS

SOIL LINES

ANOMALOUS AREAS

FIGURE 8.1

LAKELSE PROJECT AREA AND EXPLORATION SUMMARY

The climate of this area is typical of that of coastal British Columbia with Terrace receiving an average annual rainfall of about 127cm. Consequently, valley sides are heavily vegetated with thick, mature stands of cedar, hemlock, fir and spruce. Undergrowth is continuously damp and consists of thick mosses, devil's club, and common broad leafed plants. The valley floor is covered dominantly by stagnant swamp areas connected by small meandering streams, with cedar stands on some of the topographically higher areas.

Major drainages in the area are the southwest flowing Skeena River and the Kitimat River flowing southward from near Lakelse Lake to the Kitimat Arm. The Lakelse River drains Lakelse Lake and flows northwestward into the Skeena River. Most of the project area is drained by this system.

Outcropping of the local bedrock in the valley floor is rare due to extensive glacial deposits. Bedrock exposures on the valley slopes are abundant in the form of cliffs and short ridges. Also, good road and railroad cuts are common at the break-in-slope along the valley sides.

8.3 History and Previous Work

The Lakelse Hot Springs were first developed as a health resort around the turn of the century. During the first years of its use, spring waters were piped through a gravity feed system to a pool and hotel complex 900 m to the northwest on the shores of Lakelse Lake. The motel, pools and surrounding buildings that exist on the property today were built and operated after a change of ownership in 1958 (Lloyd Johnston, pers. comm.). This resort has not been in operation for a number of years and is now owned by the B.C. Ministry of Lands, Parks and Housing. At present, proposals are being solicited from private industry for the development, lease and operation of a tourism and recreational resort at the site.

Early accounts of the geology were exploratory or general in nature (Richardson, 1876; Cambie, 1878; Dawson, 1880; and McConnell, 1914; Hanson, 1925, Marshall, 1926; Kindle, 1937, a, b). The most recent work has been done by Duffell and Souther (1964) and includes a 1:253,440 scale geologic map. This latest work describes the detailed geology of the Lakelse Lake area. Although considerable geological mapping has been conducted in the area, the hot springs themselves were not dealt with specifically until 1951, in a report prepared for the Department of Lands and Forest, Water Rights Branch (Odynsky, 1951). This work was done to explore the springs and assess their potential for recreational development. It includes water chemistry data, flow estimates, and a brief description of each spring group.

8.4 Exploration Synopsis

Field work was done over a period of eight days during the last half of November, 1981. Based in Terrace, the field crew consisted of a geologist and an assistant. The project included reconnaissance geologic observations, water sampling of the hot springs, soil geochemistry and water conductivity measurement. All of the work was conducted on or within hiking distance of the main roads.

8.5 Geology (Refer to Drawing LAK-1)

8.5.1 General Geology

The Lakelse area lies at the eastern edge of the Cretaceous or younger Coast Range batholith, where the batholith comes in contact with Paleozoic to early Cretaceous volcanic and sedimentary rocks. The stratigraphy of the sedimentary rocks is not completely known due to difficulties in correlation from one area to another. Total thickness has been estimated to be 4 600 to 6 100 m (Duffell, Souther, 1964). The batholith occurs as many different phases and was probably emplaced over a long span of geologic time.

Paleozoic limestones and associated greenstones occur as pendants in the batholith. Unconformably overlying these Paleozoic rocks and boulder limestone conglomerates, greywackes, and cherts, probably of Triassic age. The Jurassic Hazelton Group comprised dominantly andesite flows with minor basalt, dacite, rhyolite, greywacke, and argillite, conformably overlies these Triassic rocks. Above the Hazelton Group lie upper Jurassic and Cretaceous marine and continental sediemtns referred to as the Bowser Group.

The actual age of the Coast Intrusions is unknown but earlier writers refer to it as upper Cretaceous or younger. The bulk of the Coast Intrusions in the Terrace region is granodiorite or quartz diorite although diorite, syenite, and gabbro occur as small stocks (Duffell, Souther, 1964). The variety of compositions suggest a series of distinctly different intrusive pulses.

Numerous dykes intrude all rock types and vary widely in composition. Some of the more common dyke rocks are granite, diorite, aplite, lamprophyre, and basalt. Many of the economic mineral deposits of the area are associated with these dykes.

A complex glacial history has created deep valleys blanketed with glacial sediments. A series of glacial advances and retreats, and associated sea transgressions up the Kitimat Arm, has resulted in an intricate bedding of tills, pitted outwash plains, and extensive marine clays throughout the Kitimat-Kitsumkalum valley.

The only significant rock unit in the project area is a leucocratic granodiorite, exposed along the valley sides. Unconsolidated glacial and marine deposits are extensive and deep in the Kitimat-Kitsumkalum valley. Work to date suggests that the north-south linear nature of the valley is an expression of a major underlying structure.

The grey, medium-to-coarse-grained, leucocratic biotite-hornblende granodiorite is a phase of the Cretaceous or younger Coast Intrusions. In a general sense, mineralogy varies only in the amounts of mafic minerals, ranging from 5-10% of the whole rock composition. Biotite predominates, however, minor amounts of hornblende and magnetite are usually present. Quartz occurs in fresh anhedral blebs throughout the rock and feldspars usually exhibit a euhedral nature. Two texturally different phases exist, a coarse grained phase and a medium grained phase occurring on the western and eastern sides of the valley respectively. The contact between these two units, whether sharp, gradational, or faulted, lies beneath the glacial and marine sediments that cover the valley floor.

The granodiorite is well fractured and has a regular near vertical jointing pattern on a localized scale. Fracture surfaces are generally coated with epidote, hematite, and less are commonly slickensided. No major alteration zones were found within the basement rocks, although alteration of the biotite to chlorite is common throughout the area. No evidence has been found as yet that would suggest hydrothermal alteration of the basement rocks by the present thermal regime.

Minor occurrences of Paleozoic greenstones and limestones as roof pendants in the Coast Intrusion are present just northwest of Lakelse Lake. Mesozoic strata of the Hazelton and Bowser Group are not found within the project area.

Numerous granodiorite, quartz diorite, and andesite dykes intrude the basement rocks. Generally, they are less than one meter in thickness, but range up to 15 metres. Usually, the intrusion of the dykes is along near vertical, east-west and northwest-southeast jointing systems, but randon orientations do exist. Emplacement probably occurred during the later stages of the Coast Intrusions.

The Kitimat-Kitsumkalum valley in interpreted to be a result of erosion along a major fault in the basement. Evidence for this lies in the fact that the major contacts between sedimentary rocks and the Coast Intrusion are displaced across the valley in the area of Kitsumkalum Lake, north of Terrace (Duffell and Souther, 1964 a). Within the project area, the presence of two different phases (i.e. medium and coarse grained) of the Coast Intrusion, one on each side of the valley supports this observation.

Two minor faults striking nearly east-west, were found along the railroad grade west of Lakelse Lake. Here, shearing has taken place along zones about 3 metres wide in a vertical plane. Direction and amount of displacement is unknown.

A complex deposit of unconsolidated, Pleistocene and Recent glacial and marine sediments forms the valley floor. Coincident with the initial retreat of glacial ice in the Kitimat-Kitsumkalum valley, sea waters moved up the Kitimat Arm to near the present townsite of Terrace. Marine clays were deposited in an estuary environment that probably covered the entire area around Lakelse Lake. A pair of glacial advances and ice retreats produced two pitted outwash planes, one south of Lakelse Lake and the second near the town of Terrace (Duffell, Souther, 1964 a).

8.5.2 Lakelse Hot Springs

Lakelse hot springs consist of a series of six groups of hot springs/seeps and one main spring scattered over an area of roughly 1600 m^2 (Figure 8.2). Total flow of the system is

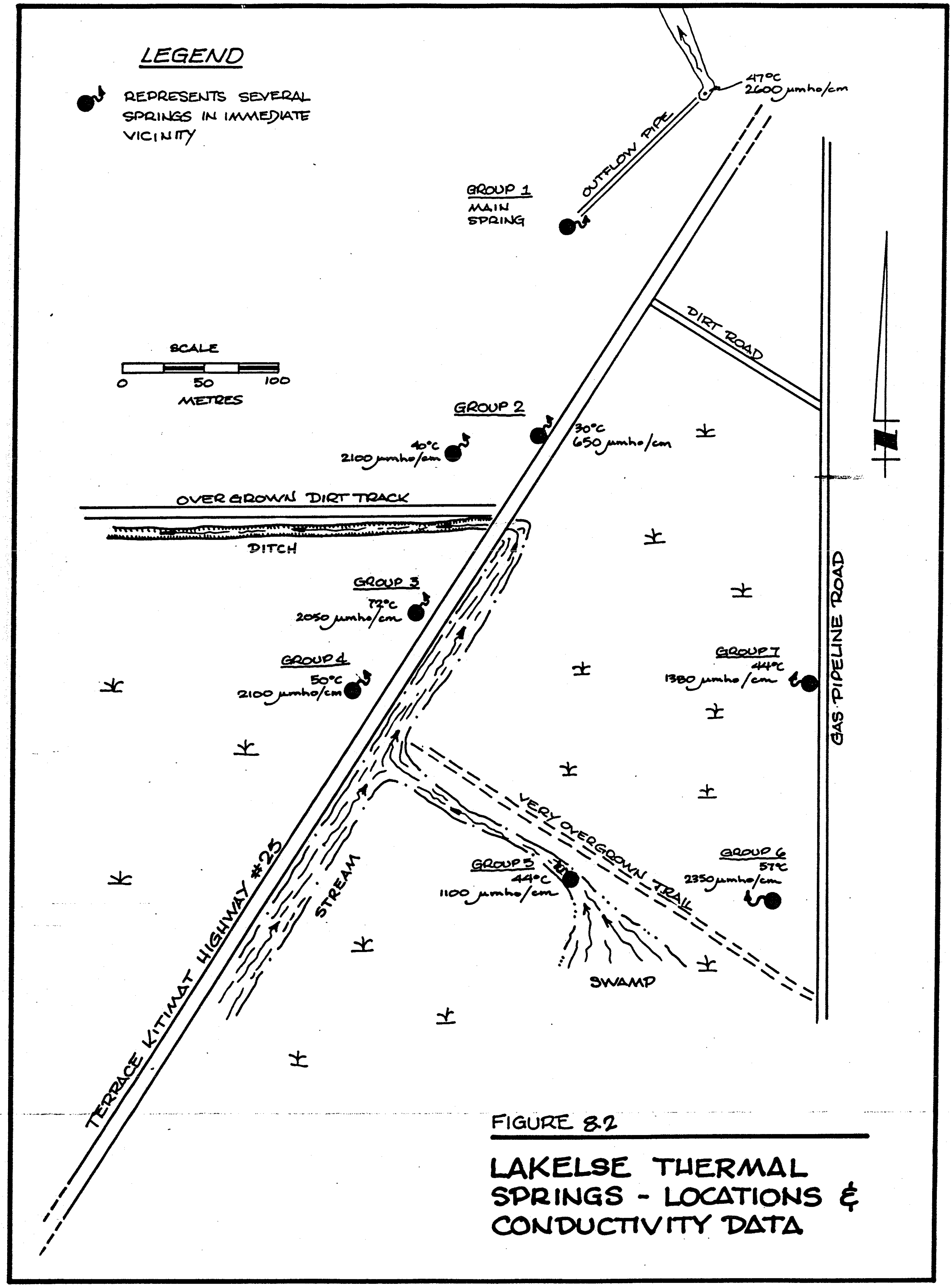


FIGURE 8.2

LAKELSE THERMAL SPRINGS - LOCATIONS & CONDUCTIVITY DATA

estimated to be nearly 600 L/minute. All of the springs issue from glacial material into small mud lined ponds in a marshy area of the valley floor. The main spring (Group 1) vents to a 12 m wide pool at an estimated flow-rate of 250 L/minute. Temperatures at the margin of the pool reach 47°C but undoubtedly are hotter near its center.

The hottest springs, a member of Group 5, is 15 cm across and has a temperature of 72°C. Flow of this spring is much less than one L/second. Thermal waters from all the springs are colourless, odourless and tasteless, and no mineral precipitates are present.

The nature of the source of the thermal fluids is not known at this time. If the Kitimat-Kitsumkalum valley is a major fault system it is very likely that the thermal waters are migrating upwards along this fault(s). Independent of this, the actual surface exposure of the thermal fluids is effected by extensive impermeable marine clays, undoubtedly causing some migration of the fluids laterally from their bedrock source.

8.6 Water Chemistry

A single sample was taken from the hottest spring on each group (Appendix A). For thermal waters, the Lakelse springs contain only moderate amounts of the major cations, anions and silica. Silica geothermometry assuming adiabatic cooling (Truesdell, 1975) predicts source temperatures as high as 115°C, while temperature estimates from a Na-K-Ca geothermometer (Fournier, Truesdell; 1973) reach up to 79°C. Subsurface temperature estimates from silica geothermometry are consistently higher than those from the Na-K-Ca formula.

Sampling of cold surface waters at three locations was done in an attempt to determine the background compositions of those waters in the area around the hot springs. Concentration of all ions, as expected, are very low relative to hot spring waters and fairly similar from one sample to the next. Four samples were taken of anomalously conductive cold surface water in the area of the hot springs to determine their compositions and correlate their relative conductivities. From this work, chloride, sulphate, and sodium concentrations are considerably higher than those of background surface waters and enrichment in these ions tends to be reflected by increased water conductivity. These three ions are not the only factors however, that determine relative conductivities (i.e., Fe, Mn, and K also appear to have a pronounced effect), and merely general trends are implied.

Subsurface temperature estimates of the thermal fluids of the Lakelse hot springs are probably affected by surface water dilution because of their location in a swamp area. The effect of this dilution would be a false depression of the SiO_2 and Na-K-Ca geothermometer temperature estimates.

Another factor that might influence the geothermometers to an unknown extent, is that of lateral migration of thermal fluids due to the impermeable marine clays in the valley floor. If the amount of lateral migration is large, chances of cooling and subsequent precipitation of major ions below the surface increases.

The Na-K-Ca geothermometer appears to reveal inaccurate results at Lakelse. The temperature estimate from spring group #3 (70°C), for example, is less than the measured temperature at the surface (72°C).

8.7 Conductivity Survey (Refer to Drawing LAK-2)

Water conductivity measurements were taken of all the hot springs (see Table A-1) and of surface waters throughout the project area. Conductivity measurements of most cold surface waters were less than 50 micromhos/cm. Measurements taken along the entire shore of Lakelse Lake of streams flowing into the lake were similarly low. Conductivity of the hot springs ranged from 1100 to 2600 micromhos/cm. Cold seeps from the base of the slope near the hot springs have values up to 900 micromhos/cm.

Except for the area directly adjacent to the hot springs, no other anomalous areas were discovered from this work. Cold surface waters elsewhere have conductivities generally lower than 20. Values would have to reach upwards to near 75-80 micromhos/cm to be considered anomalous. A number of anomalies occur in the swamps lying adjacent to the southeast shores of Lakelse Lake where organic material may be affecting the conductivity of stagnant water.

The fact that no new areas of interest were discovered by measuring surface water conductivities in the Lakelse Lake area is significant. The absence of high conductivities of streams and seeps from the valley slopes implies that thermal fluids do not originate from there. Rather, they probably come from somewhere below the valley floor along a fault or fracture system in the basement rocks. Any amount of the thermal fluids that reaches the surface, other than those of the hot springs, most likely cannot be detected, due to their low volumes and mixing with low temperature surface waters.

8.8 Soil Geochemistry (Refer to Drawing LAK-3)

Ninety-six soil samples were taken along two north-south lines, one on each side of the valley (Figure 8.1). Samples were spaced at

200 m and an attempt was made to keep the lines as close as possible to the break-in-slope. Two soil profiles were sampled in an attempt to determine the vertical distribution of Hg and As in the soil horizons (Appendix B). Both profiles indicate that the highest concentrations are in the A2 horizon and that arsenic is concentrated in the B horizon.

Soil mercury values range from 10 ppb to 300 ppb. Statistical analysis of the data has established an anomalous threshold concentration of 170 ppb. A pair of anomalies (i.e. 200 and 210 ppb) exist 400 m apart on the southern portion of Line A. They are bracketed on both sides by non-anomalous, but elevated mercury results. Four other anomalies exist evenly spaced along soil Line B, about 2 km apart.

Values for arsenic in soils range from 1 ppm to 14 ppm. The anomalous threshold value for arsenic is 12 ppm. Six anomalies exist, five of them occurring on the southern portion of Line A.

As a result of this work two broadly anomalous areas are apparent. The first (anomalous area #1) occurs along the eastern margin of the valley bottom in two, one kilometre long sections of Line A south of Lakelse Lake where Schulbuckhand Creek flows onto a glacial outwash plane, from the east (Figure 8.1). The two Hg anomalies, one coincident with an As anomaly, are bracketed to the south with elevated Hg values and to the north by an As anomaly. One kilometre to the south, three consecutive As anomalies are open to the south. Low conductivity measurements of Schulbuckhand Creek and other water draining the valley slope in that area infer that the anomalous mercury and arsenic amounts in soils are most probably due to their upward migration from below the present valley floor, and not downward from somewhere on the valley sides.

The second anomalous area (anomaly #2: Figure 8.1) on Line B is smaller in magnitude than anomaly #1. Spotty, isolated anomalous mercury values in soil occur along a 4 km line interval.

It is possible that the two anomalous areas are related to the same geothermal system, even though they lie 5 km apart. Consequently, they and the area between them has been designated as a new interest area (see Figure 8.1).

8.9 Conclusions

Two anomalous areas, apart from the hot springs themselves, have been identified by work done to date. The highest priority anomaly is located 3 km south of the hot springs and consists of two smaller areas, each 1 km across. The second anomaly is of lesser priority and consists of a 3 km long segment of the southern end of soil line B. Discovery of both areas was a result of soil geochemistry anomalies. It is possible that these two anomalies may be associated with one another and are a result of a single thermal system located below the center of the valley floor.

It appears as if the Kitimat-Kitsumkalum valley may be an expression of a major fault in the basement rocks. If this is so, the fault would act as a conduit for upward migration of thermal waters from depth.

Water chemistry of the Lakelse hot springs is only moderately encouraging. The Na-K-Ca geothermometer appears to be not applicable, while the SiO_2 geothermometer reveals subsurface temperatures of up to 115^oC, although estimates are probably somewhat depressed by surface water dilution. More definative estimates of the potential for the existence for high-temperature resources must be based on gradient drilling. Moderately high temperatures ($\simeq$100^oC) certainly exist which combined with the high apparent flow rates (600 L/min.) of clean spring water could prove to be adequate for direct use applications. Local uses could include space heating in the town of Terrace, and industrial use by lumber and fisheries developments.

8.10 Recommendations

Recommendations for follow-up work are listed below:

- 10 km of close spaced soil sampling, in an 8 km segment on each side of anomalous area #1.
- Orientation resistivity survey of anomalous area #1.
- Detailed geological work in hot springs area and in anomalous area #1.
- 5 km of close spaced soil sampling in anomalous area #2.
- Detailed geological work around anomalous area #2.

8.11 Frizzell Hot Springs

A single day was spent at the Frizzell Hot Springs, located near the junction of the Extall and Skeena Rivers near Prince Rupert. Water chemistry and soil geochemistry samples were collected to help extend the knowledge of known thermal systems of this region in British Columbia.

The springs are located 2 km east of the mouth of the Extall River on the southern bank of the Skeena River. They consist of 3 springs with a total estimated flow of 200 L/min, and temperatures reaching up to $39^{o}C$. Thermal waters seep from fractures in a quartz diorite phase of the Coast Plutonic Complex. No obvious alteration zones were discovered in the immediate area of the hot springs.

Two of the three springs were sampled. SiO_2 geothermometer estimates were 93°C and 100°C while Na-K-Ca geothermometer estimates were both 20°C (Appendix A). The springs are located only 20 m above the Skeena River and very near its banks. At this point in the river there is a tidal influence and an unknown amount of salt water/fresh water mixing. The effect of this water on the chemistry of the geothermal fluids is not known.

Five soil samples taken at the site of the hot springs reveal anomalous concentrations of mercury. Values ranged from 40 ppb to 380 ppb. Arsenic values were all very low.

The Frizzell Hot Springs does not present a priority target at this time for geothermal exploration. Surface temperatures of thermal waters and geothermometer estimates are both low and total flow of the system is very small.

9.0 AIYANSH

9.1 Location and Access

The project area is located 70 km north of the town of Terrace along the Nass Road that connects Terrace and the Nass logging camp. It is divided into two smaller portions, the vent area of the Aiyansh lava flow and the Aiyansh hot springs along the Nass River, 30 km to the west (Figure 9.1). The lava vent is located 5 km up a tributary valley of the Tseax River near the northern end of Lava Lake. The hot springs are just south of the logging road to Greenville along Ansedagan Creek.

Easy access to each area is by means of well used logging roads. Travel by foot from the Nass Road up the lava flow to the vent is possible but made very difficult by the rugged surface of the flow. The vent is best visited by helicopter.

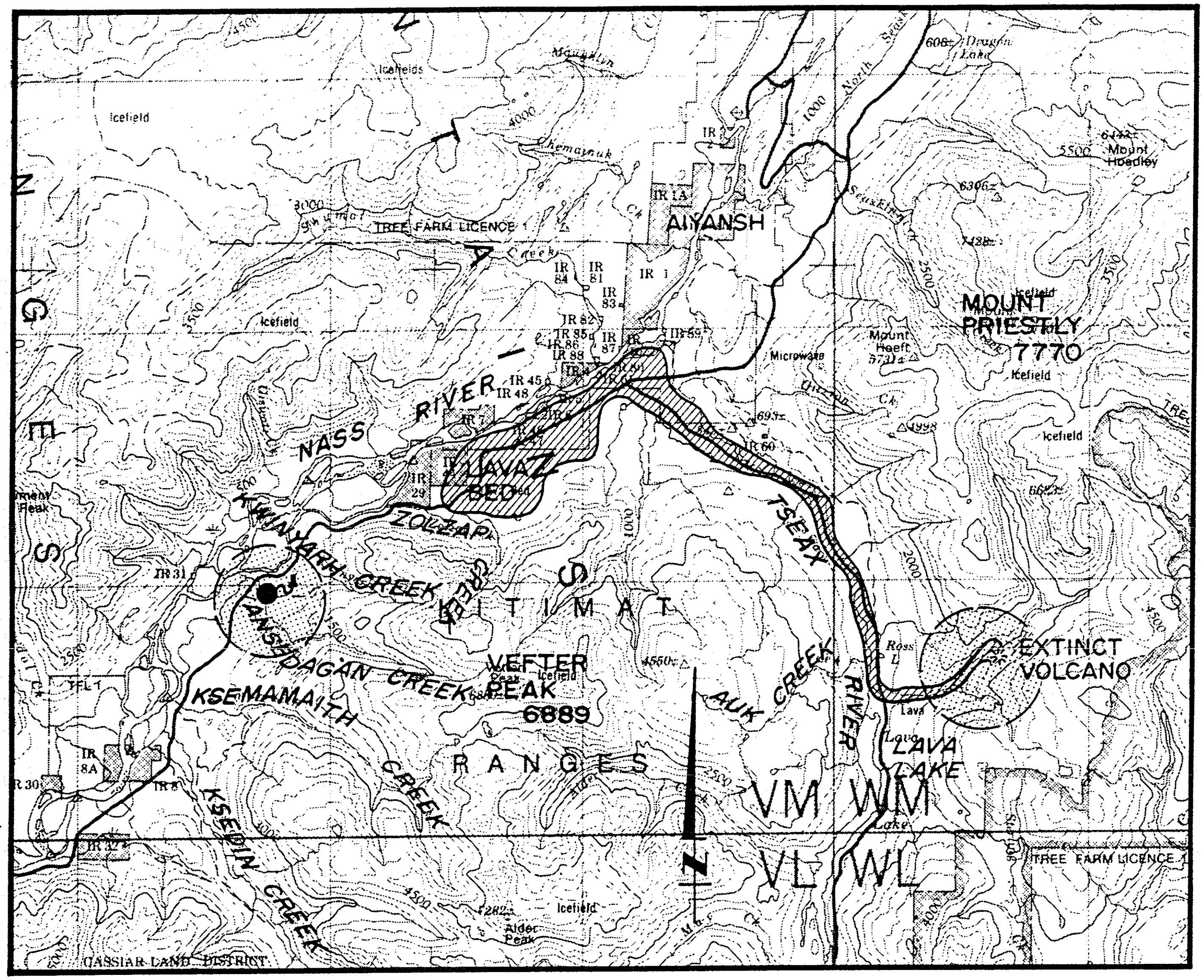
The hot springs can be reached through heavy underbrush by walking roughly 500 m from the east-west logging road along the Nass River.

9.2 Topography, Physiography and Vegetation

This area is typical in all aspects of that of coastal British Columbia. Local relief ranges from numerous snow capped peaks over 2200 m to near sea level in the Nass River Valley. Precipitation is high and vegetation is extremely thick.

Two major valleys drain the region. The Tseax River flows north from near Lava Lake to the northeast-southwest trending Nass River valley. The Nass River flows southwest to the Portland Inlet, in a classic steep sided, broad floored, glacially carved valley.

Exposure of the local bedrock is good along the valley sides and in road cuts. The lava flow itself is virtually unvegetated and exposure is excellent throughout its course.



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NTS MAP 103P & 103O

LEGEND

AIYANSH LAVA FLOW

THERMAL SPRINGS

INTEREST AREA

FIGURE 9.1

AIYANSH PROJECT AREA AND EXPLORATION SUMMARY

9.3 Previous Work

Early geological investigations in the area were reconnaissance in nature and detailed work was limited exclusively to localized sulphide mineral deposits. A geologic map compiled by Carter and Grove (1971) from these earlier works is the best source for regional geological information. Detailed work on the Aiyansh lava flow by Sutherland-Brown (1969) includes descriptions of its surface morphology and petrology.

9.4 Exploration Synopsis

Three days (November 25th, 29th, and December 1st) were spent by a two man crew based out of Terrace on the Aiyansh project. The crew located the hot springs and sampled 4 of them, collected three soil samples, and made preliminary geologic observations at the springs and the Aiyansh lava flow. Due to heavy snow cover, the lava vent was not visited. All work was accomplished within hiking distance from good logging roads.

9.5 Geology (Refer to Drawing AIY-1)

In a regional sense, the project area lies at the eastern margin of the Coast Plutonic Complex near its contact with Mesozoic metasediments. This basic setting is very similar to that of the Lakelse area, 90 km to the south.

9.5.1 Lava Flow

The Aiyansh lava flow is an alkali basalt, age dated to be about 230 years old (Sutherland-Brown, 1969). The flow is about 30 km in length and its surface texture varies widely, ranging from a flat plain that it forms in the Nass Valley, to sharp angular blocks up to a few metres across near the vent area. Final stages of the eruption comprised a series of lava fountains and explosions at the vent leaving a small volcanic cone nearly 100 m high

(Sutherland-Brown, 1969). The uniform basaltic composition and the fluid nature of the flow suggests a deep mantle origin for the lava.

The vent area occurs in a small valley eroded in a siltstone-sandstone sequence of the Bowser Group. No major alteration zones were found in the country rock along the margins of the flow below the vent. Along the north side of the valley, 1 km down-flow from the vent, two subhorizontal basalt lava flows exist, roughly 20 - 30 m above the surface of the lava flow. They are probably members of the Pleistocene and older plateau basalts that have been mapped by earlier writers 5 km to the northeast.

9.5.2 Hot Springs

Eight hot springs flow from fractures in an outcrop of a highly altered quartz monzonite stock or plug of the Eocene, Alice Arm Intrusions. Three others flow from swampy soil along an assumed contact between the intrusion and the metasediments. The actual location of this contact is covered by overburden. The quartz monzonite is very coarse grained and composed primarily of quartz and K-feldspar. The outcrop is very friable due to a high degree of alteration and precipitation of Fe-oxides along fractures and grain boundaries. The size and extent of this quartz monzonite intrusion is not known.

The thermal springs occur in a small tributary drainage roughly 20 m above the Nass River (Figure 9.2). Temperatures range from $36^{o}C$ to $55^{o}C$. The most interesting aspect of the Aiyansh hot springs is the presence of a white siliceous sinter along the margins of the pools/seepages and in some fractures in the quartz monzonite outcrop. This precipitate is a result of high concentrations of SiO_2 dissolved in high temperature thermal waters at depth. Semiquantitative spectrographic analysis of sinter (Table 9.1) show a high concentration of elemental silicon with lesser but substantial amounts of potassium, aluminum, sodium, calcium, and

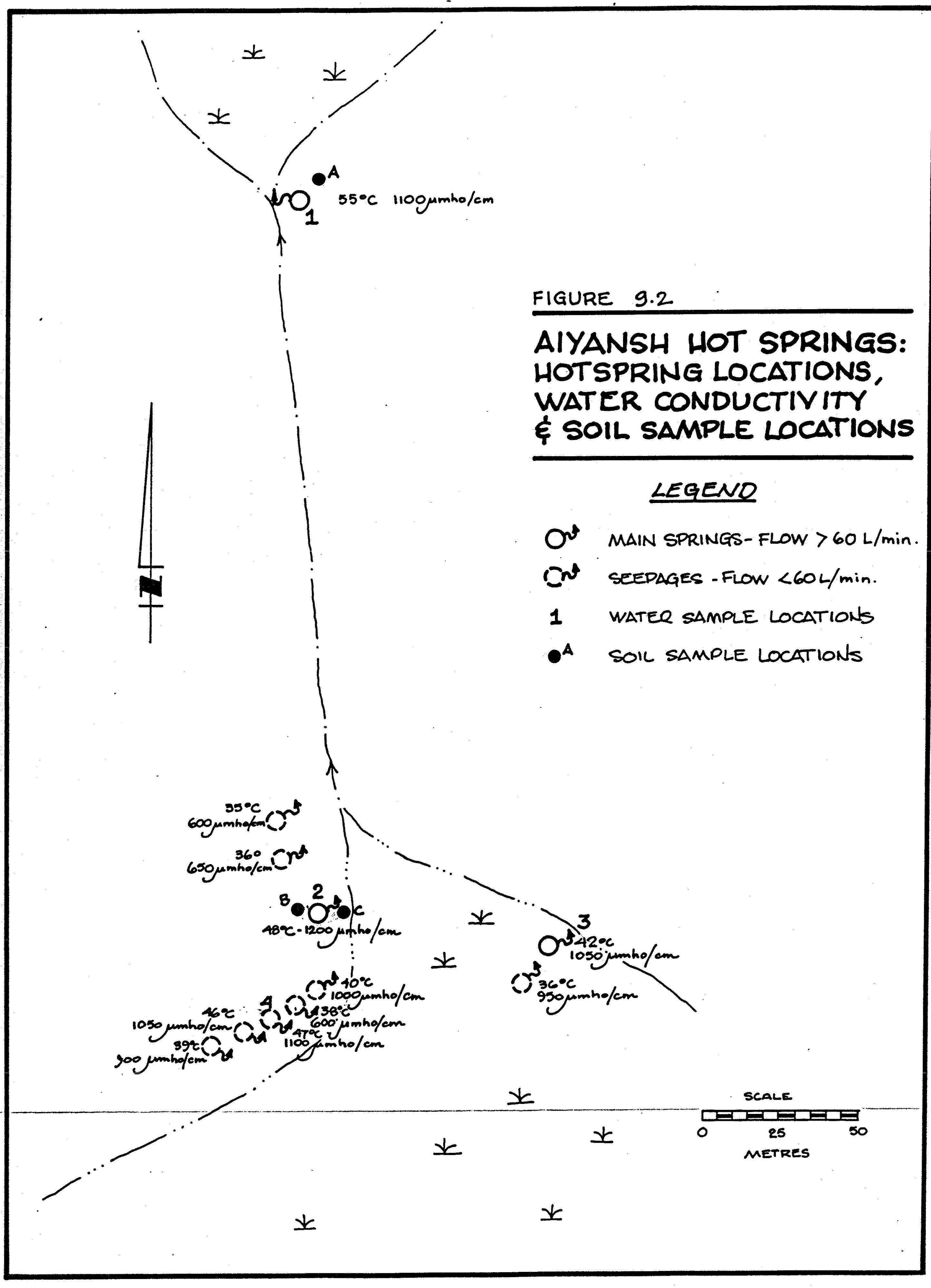

FIGURE 9.2

AIYANSH HOT SPRINGS: HOTSPRING LOCATIONS, WATER CONDUCTIVITY & SOIL SAMPLE LOCATIONS

magnesium such that a sinter is considered indicative of subsurface temperatures in excess of 180°C (White, 1973).

9.6 Water Chemistry

Of the eleven springs located in the Aiyansh hot springs, the three main pools and one small seep were sampled. Results are similar to those of typical thermal waters, with high concentrations of SiO_2 , K, Na, Ca, SO_4, and Cl. The SiO_2 geothermometer (assumes adiabatic cooling) produces very consistent results, ranging from 138°C to 147°C. The Na-K-Ca geothermometer temperatures are likewise consistent 79°C - 91°C but are in poor agreement with the SiO_2 results. Both geothermometry models indicate temperatures lower than 180°C, the minimum source temperature associated with siliceous sinter depositing springs (White, 1973). This disparity indicates that one (or all) of the models is not applicable to the Aiyansh hot springs.

9.7 Conductivity Survey (Refer to Drawing AIY-2)

Water conductivity was used to help locate the springs and to measure them directly. Of the springs located, the conductivity ranged from 600 micromhos/cm to 1200 micromhos/cm. All of the main springs (i.e. springs with the greatest flow) have conductivities greater than 1000 micromhos/cm.

9.8 Soil Geochemical Survey (Refer to Drawing AIY-3)

Three soil samples were taken at the springs to help determine the chemical signature of the soil there. Results from these samples revealed elevated mercury values in two of the samples and high arsenic in the third sample. Not enough data was collected however to determine any general trend in the results.

TABLE 9.1

Thirty Element Semiquantitative Analysis of the Aiyansh Sinter

Element	Concentration (ppm)
Aluminum	0.3%
Antimony	<100
Arsenic	<50
Barium	300
Beryllium	<2
Bismuth	<2
Boron	50
Cadmium	<20
Calcium	0.2%
Chromium	100
Cobalt	<20
Copper	7
Germanium	30
Iron	0.2%
Lead	<5
Magnesium	0.02%
Manganese	15
Molybdenum	<100
Nickel	<20
Niobium	<200
Potassium	<0.5%
Silicon	15%
Silver	<2
Sodium	0.2%
Thorium	<500
Tin	<10
Titanium	300
Vanadium	<200
Zinc	<10
Zirconium	<50

9.9 Conclusion

The Aiyansh area has good potential for the occurrence of a high temperature geothermal resource. The hot spring area consists of a series of eleven springs and seep with a total estimated flow of 450 L/min and temperatures up to 48^{o}C. The presence of a siliceous sinter at the springs and the water chemistry suggest high subsurface temperatures. Detailed geology of the spring location is not known, however it appears that the thermal waters might be migrating upwards along the contact between Upper Jurassic-Lower Cretaceous metasediments and a stock of the Tertiary Coast Plutonic Complex.

The Aiyansh lava flow is a black alkaline basalt that varies little in composition. It is one of the youngest volcanic occurrences in British Columbia, about 230 years old. From its vent area it flowed 23 km down the Tseax River valley and spread out in a broad lava plane in the Nass River valley. Due to poor weather the vent area was not visited this season and soil geochemistry samples not collected. It is important that this work be done in order to make an accurate assessment of the potential of this area.

The actual relationship between the thermal activity of the Aiyansh hot springs and the Aiyansh lava flow vent area is not known at this time. Because of the relative young age of the lava flow, its thermal origin may be in some way related to the present thermal activity at the hot spring.

9.10 Recommendations

Further work should be carried out in two stages. First, reconnaissance work at the volcanic vent from a fly camp, and secondly, follow-up work at the hot springs from a tent camp.

Work in the vent area should include preliminary geologic mapping of the volcanics and surrounding country rock. Specific attention would be given to the identification and extent of any alteration zones within the country rocks. Geochemical surveys would include a close-spaced soil sampling along lines that would surround the entire vent area.

Follow-up work at the hot springs would include preliminary geologic mapping, soil geochemistry, and an orientation resistivity survey. Geologic mapping would be focused on the extent of the quartz monzonitic intrusion and its contact with the metasediments. Concurrently a geochemical survey could be conducted across the entire hot springs area. A follow-up dipole-dipole resistivity survey would logically augment geochemical coverage or be used to characterize geochemically anomalous areas.

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APPENDIX A

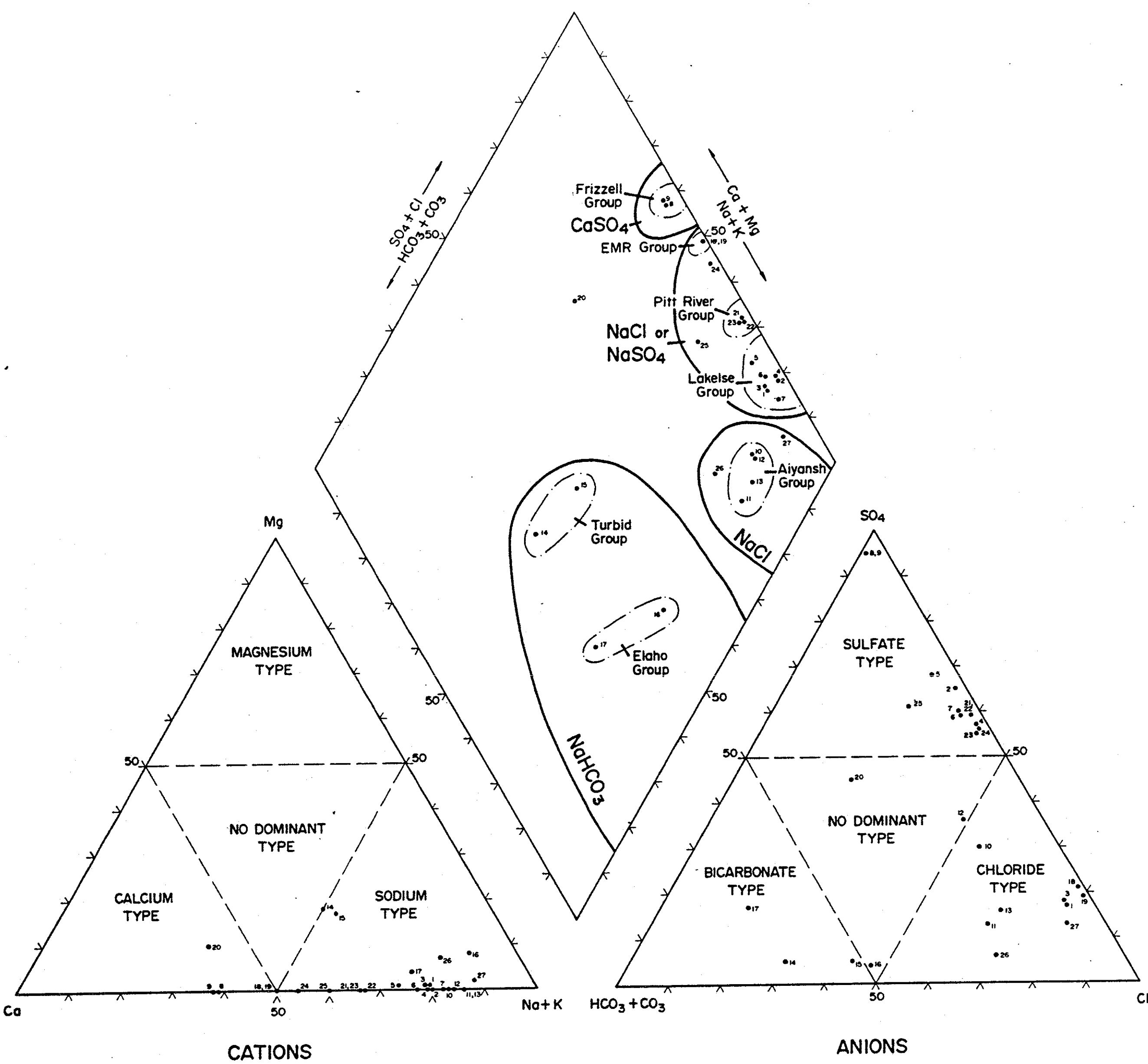
SPRING WATER GEOCHEMISTRY

Appendix A

TABLE A-1 SPRING WATER CHEMISTRY

Spring	Date	T°C	pH	TDS ppm	SiO_2	Na	K	Ca	Mg	Fe	Mn	Li	Hg	CO_3	HCO_3	SO_4	Cl	F	B	Rb	Sr	Spring Type*	T_{SiO_2} °C	$T_{Na-K-Ca}$ °C	Conductivity umhos/cm
LAKELSE																									
Main Vent	11/81	47	6.5		48.0	270.00	6.00	60.0	1.0	0.350	0.005	<0.05	0.3	0.0	18.6	54.00	180.0	51.00	0.12	1.20	-	Na-Cl	102	69	2600
Group 2	11/81	40	5.7		64.0	300.00	7.00	65.0	0.1	0.080	0.020	0.10	0.6	0.0	17.3	538.00	200.0	50.00	0.12	0.10	3.00	$Na-SO_4$	114	73	2100
Group 3	11/81	72	6.5		52.0	275.00	6.50	64.0	2.5	0.300	0.100	<0.03	0.4	0.2	16.6	50.00	160.0	48.00	0.11	1.20	-	Na-Cl	105	70	2050
Group 4	11/81	50	5.9		56.0	275.00	6.30	63.0	0.3	0.220	0.040	0.10	1.2	0.0	18.3	375.00	195.0	46.00	0.12	0.10	3.00	$Na-SO_4$	108	70	2100
Group 5	11/81	44	-		40.0	120.00	3.20	38.0	0.3	0.260	0.020	0.05	0.5	0.0	17.8	210.00	63.0	29.00	0.04	0.15	1.40	$Na-SO_4$	95	52	1100
Group 6	11/81	57	5.8		62.0	220.00	6.30	58.0	0.5	0.200	0.800	0.10	0.4	0.0	26.5	338.00	154.0	43.00	0.08	0.15	2.50	$Na-SO_4$	113	69	2350
Group 7	11/81	44	-		66.0	290.00	7.50	55.0	0.3	0.400	0.330	0.10	0.5	0.0	37.7	400.00	180.0	53.00	0.10	0.15	2.80	$Na-SO_4$	115	79	1380
FRIZZELL																									
Vent 1	12/81	38	5.5		38.0	74.00	2.10	103.0	0.8	0.180	0.020	<0.05	0.3	0.0	23.4	410.00	2.0	8.40	0.01	1.60	1.60	$Ca-SO_4$	93	20	1250
Vent 2	12/81	39	5.5		46.0	72.00	2.10	105.0	0.8	0.040	<0.010	<0.05	0.3	0.0	19.4	400.00	2.0	6.30	0.02	0.10	1.60	$Ca-SO_4$	100	20	1150
AIYANSH																									
Vent 1	11/81	55	8.1		110.0	150.00	6.00	28.0	0.1	0.070	0.010	0.25	0.7	0.0	57.0	90.00	120.0	17.00	0.50	0.20	0.25	Na-Cl	138	79	1100
Vent 2	11/81	48	7.6		130.0	160.00	7.30	23.0	0.1	0.040	<0.010	0.25	1.1	0.0	80.0	40.00	140.0	16.00	0.01	0.20	0.28	Na-Cl	147	91	1200
Vent 3	11/81	42	7.0		120.0	150.00	7.00	25.0	0.1	0.080	0.010	0.25	0.6	0.0	57.0	110.00	110.0	18.00	0.46	0.20	0.25	Na-Cl	143	87	1050
Vent 4	11/81	47	7.8		130.0	170.00	7.50	25.0	0.1	0.040	0.010	0.25	0.5	0.0	56.0	40.00	120.0	17.00	0.50	0.20	0.28	Na-Cl	147	90	1100
TURBID																									
T-N1	10/81	15	6.3		62.0	650.00	52.00	380.0	130.0	5.900	1.400	1.00	-	0.0	1760.0	97.00	490.0	1.10	3.14			$Na-HCO_3$	112	166	2600
T-N2	10/81	27			76.0	870.00	62.00	450.0	150.0	2.400	0.980	1.40	-	0.0	1600.0	120.00	780.0	1.60	3.95			$Na-HCO_3$	121	164	4550
ELAHO																									
Canyon	10/81	9			86.0	1650.00	42.00	160.0	85.0	6.200	0.250	1.20	-	0.0	1600.0	95.00	880.0	4.60	13.90			$Na-HCO_3$	129	134	1850
Outwash	10/81	10			40.0	690.00	31.00	180.0	21.0	7.600	0.660	0.85	0.3	0.0	1350.0	280.00	200.0	4.00	11.60			$Na-HCO_3$	92	145	
EMR Spring	10/81	19	6.5		6.0	460.00	5.50	410.0	1.5	0.120	0.005	0.10	-	0.0	12.0	140.00	380.0	25.00	3.63			Na-Cl	24	36	1700
EMR 304-2	10/81	19			18.0	620.00	6.50	540.0	2.0	0.055	0.010	<0.05	0.3	0.0	12.0	190.00	600.0	25.00	4.24			Na-Cl			
SQM 370	10/81	7.9			26.0	22.00	1.60	36.0	4.0	0.060	<0.005	<0.05	0.4	0.0	48.0	55.00	20.0	0.48	0.12	-	-	None	74	20	210
PITT RIVER																									
Lower Spring	25/9/81	55.0	-	800	75.0	260.00	7.5	120.0	0.25	0.08	<0.02	0.15	-	2.07	14.5	450.00	220.0	1.96	2.57	-	-	$Na-SO_4$	121.7	61.3	2700
Lower Spring	30/9/81	55.0	7.5	1200	66.0	260.00	7.5	115.0	0.12	0.04	<0.02	0.15	0.2	2.07	18.6	450.00	220.0	2.00	2.59	-	-	$Na-SO_4$	115.2 –	62.2	-
Upper Spring	30/9/81	57.0	6.8	1000	72.0	210.00	6.2	95.0	0.12	0.03	<0.02	0.10	0.3	4.14	16.6	340.00	190.0	1.70	2.17	-	-	$Na-SO_4$	119.6	58.2	2300
LILLOOET VALLEY																									
Skookumchuck		52.0	-		46.0	260.00	7.5	200.0	<0.1	0.060	0.015	<0.05	1.4	0.0	20.7	496.00	280.0	20.00	0.41	-	-	$Na-SO_4$	100.3	51.6	2800
Sloquet		65.0	-		64.0	120.00	2.9	71.3	<0.0	0.010	<0.005	0.15	2.0	10.3	14.5	138.00	42.0	7.00	0.18	-	-	$Na-SO_4$	113.9	37.7	1480
AHOUSAT	11/81	24.0	-	150	36.0	30.00	0.35	5.0	1.5	0.080	<0.010	0.05	0.2	1.8	51.0	12.00	93.0	10.00	0.45	1.20	-	Na-Cl	91.0	19.0	
SHARP POINT	11/81	50.5	-	-	36.0	150.00	1.50	17.0	1.5	0.060	0.010	<0.05	0.3	0.5	21.7	33.00	150.0	11.00	2.20	1.20	-	Na-Cl	91.0	48.0	

* From Piper Trilinear Plot, Figure A-1, this Appendix.



SPRING KEY

LAKELSE
1 MAIN SPRING
2 GROUP 2
3 GROUP 3
4 GROUP 4
5 GROUP 5
6 GROUP 6
7 GROUP 7

FRIZZELL
8 VENT 1
9 VENT 2

AIYANSH
10 VENT 1
11 VENT 2
12 VENT 3
13 VENT 4

TURBID
14 T-N1
15 T-N2

ELAHO
16 CANYON
17 OUTWASH

EMR
18 SPRING
19 #304-2 (DRILL HOLE)

SQUAMISH
20 #370 (COLD SPRING)

PITT RIVER
21 LOWER SPRING
22 LOWER SPRING
23 UPPER SPRING

LILLOOET VALLEY
24 SKOOKUMCHUCK
25 SLOQUET

AHOUSAT
26 SPRING

SHARP POINT
27 SPRING

Note: See discussion on trilinear plots and data tabulation, this appendix

PIPER TRILINEAR PLOT OF WESTERN B.C. THERMAL SPRINGS

Piper Trilinear Plots - Discussion

The Piper diagram is a graphic representation of relative equivalents of major ions used to identify different groundwater types. For both cations and anions, three major ionic constituents of the water sample are plotted as a single point on a ternary graph (the triangles) according to their relative molecular percentages. For anions these constituents are CO_3^{-2} + HCO_3^{-1} , Cl^{-1}, and SO_4^{-2}; and for cations, Na^{+1} + K^{+1} , Ca^{+2} , and Mg^{+2}. The cation and anion plot points are then projected upwards on lines parallel to the outer side of their respective triangles, with the intersection plotted as a point on the diamond shaped portion of the Piper diagram. Plots represent "relative equivalents" of major ions; absolute amounts are not involved. In other words, a hot spring water with high amounts of dissolved solids would plot identically to that of a cold spring with much lesser amounts of dissolved solids if the relative amounts of the major ions are similar.

Of the British Columbian springs plotted and tabulated in this appendix, four groups have been identified by water chemistry; Na-Cl, Na-HCO_3, Ca-SO_4, and Na-SO_4. Interestingly, Na-Cl and Na-SO_4 type springs are the most common in western B.C. To understand how this grouping is determined, refer to the area labelled "Types" in the two ternary portions of the Piper plot and notice that each sample is represented in an anionic "type" and a cationic "type". By combining these two labels, the springs are catagorized into groups.

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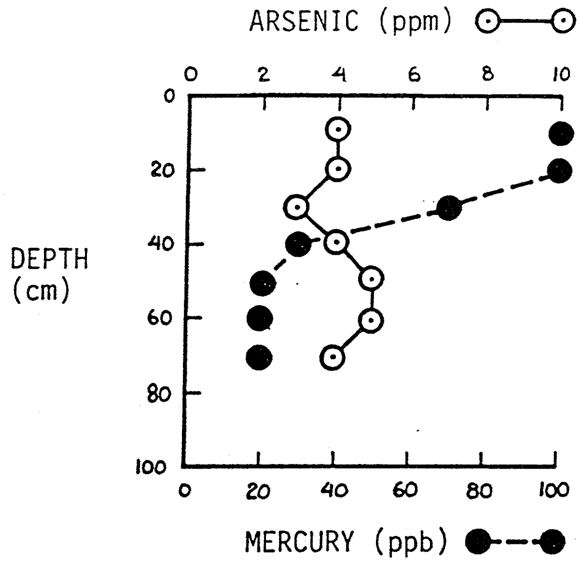
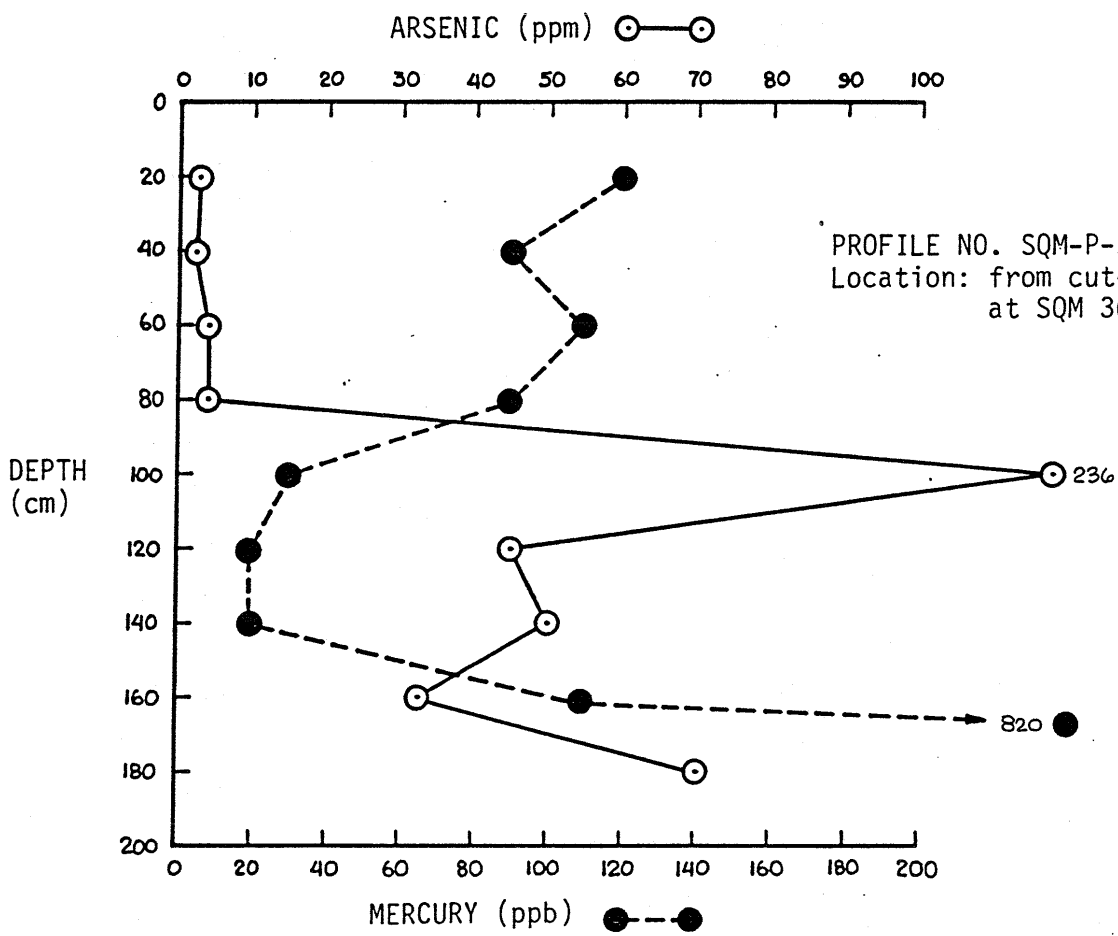
APPENDIX B

SOIL PROFILES (Hg and As GEOCHEMISTRY)



PROFILE NO. SQM-P-1
Location: 6m East of
cut-bank on road
at SQM 364+00N

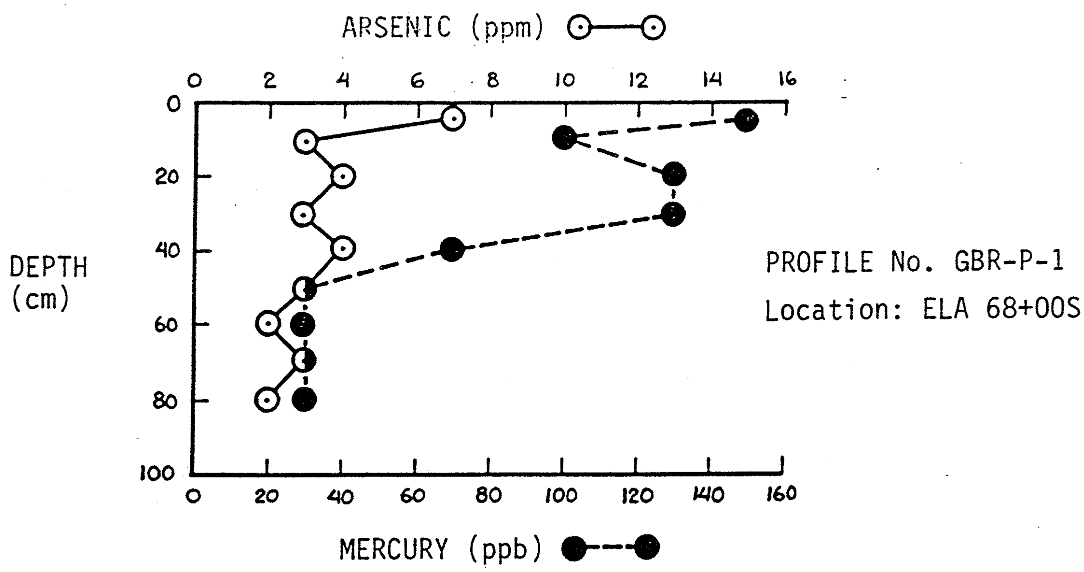


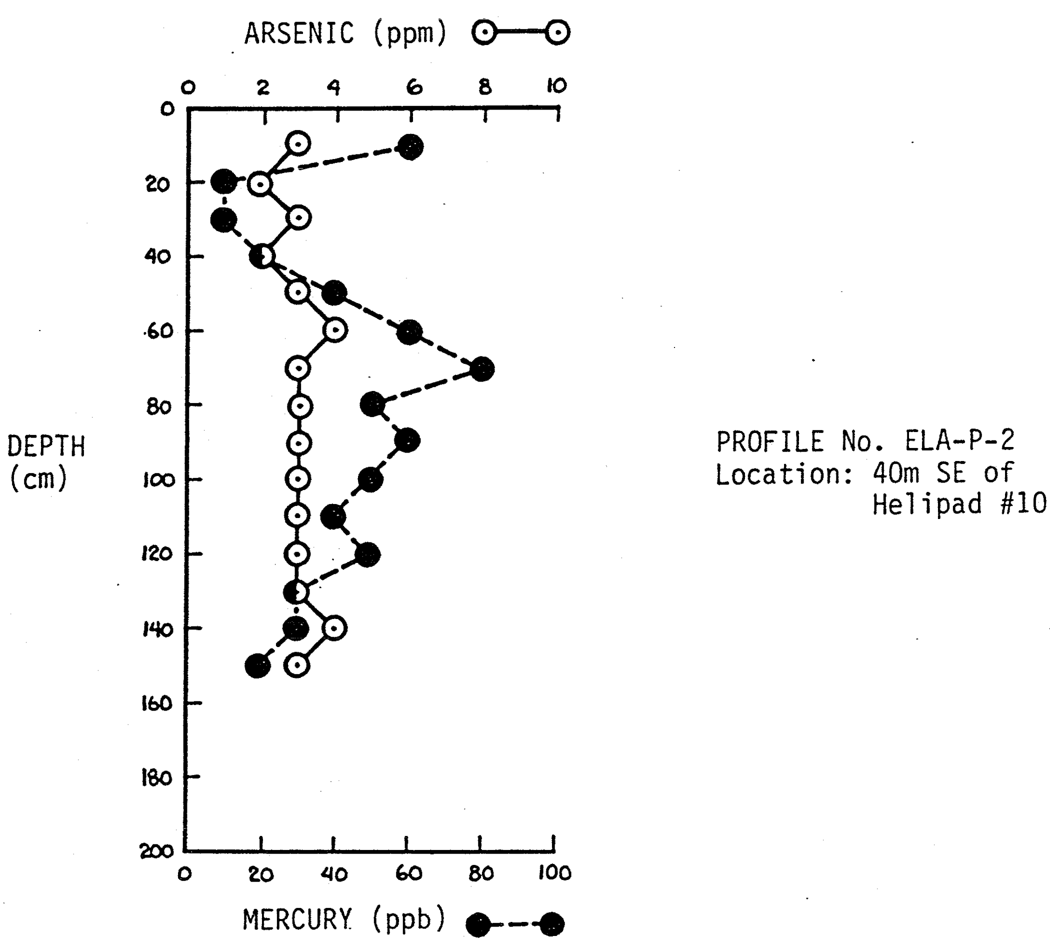
PROFILE NO. SQM-P-2
Location: from cut-bank
at SQM 364+00N

SOIL PROFILES

GARIBALDI VOLCANIC BELT SQUAMISH DRAINAGE

(refer to Dwg. SQM-3 for location key)

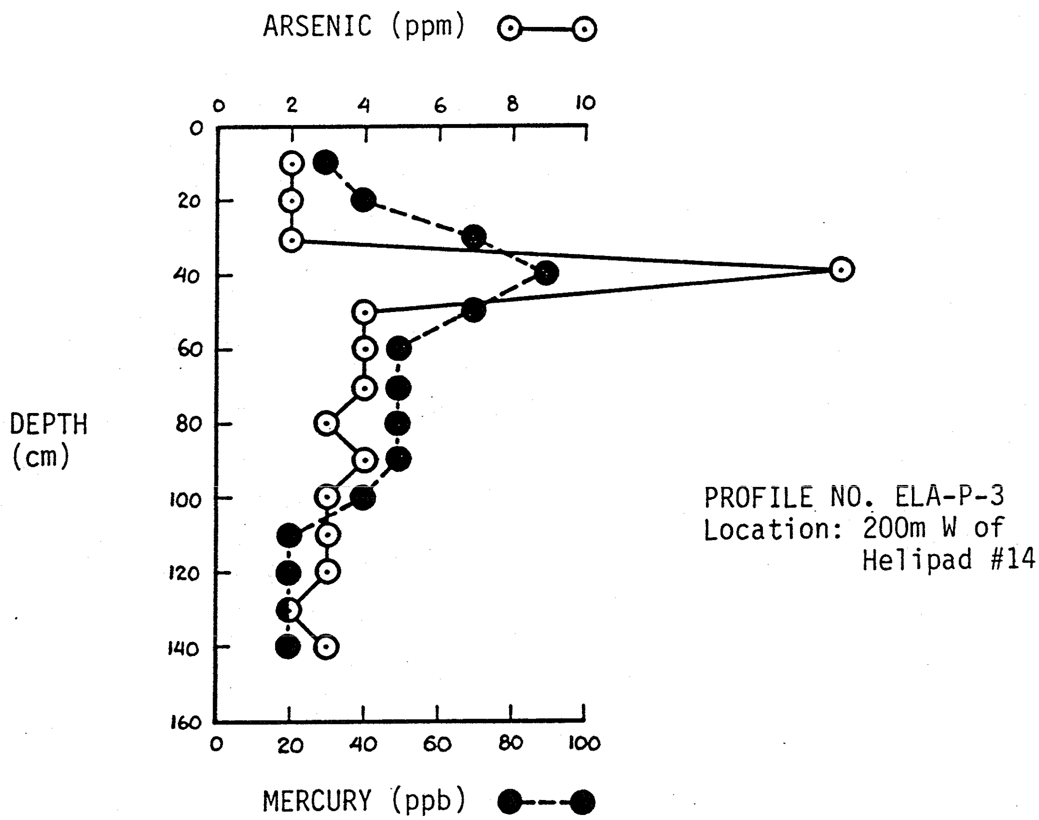




SOIL PROFILES

GARIBALDI VOLCANIC BELT ELAHO DRAINAGE

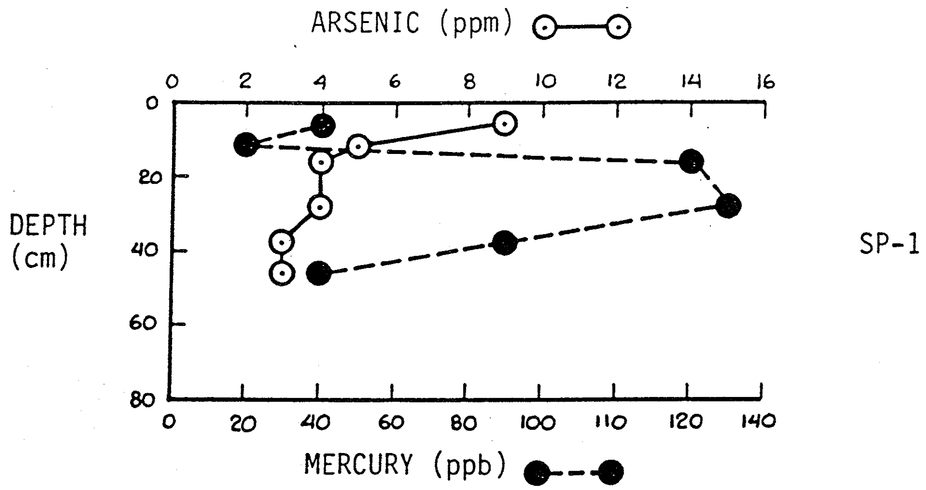
(refer to Dwg. ELA-3 for location key)

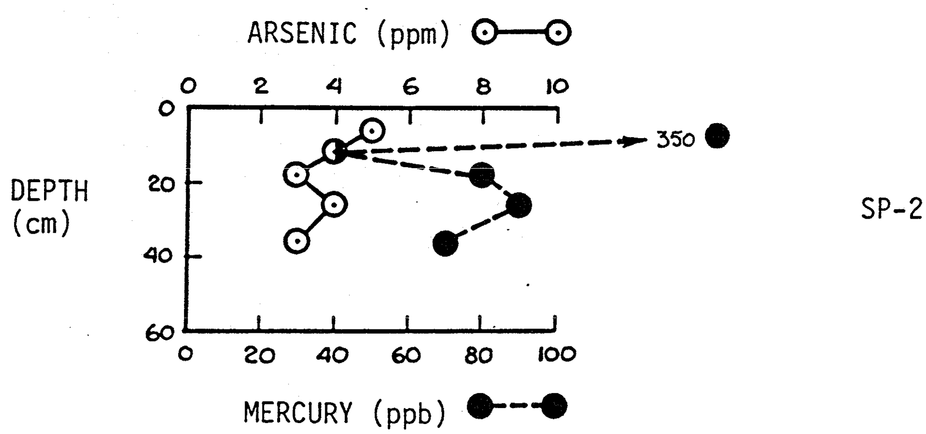


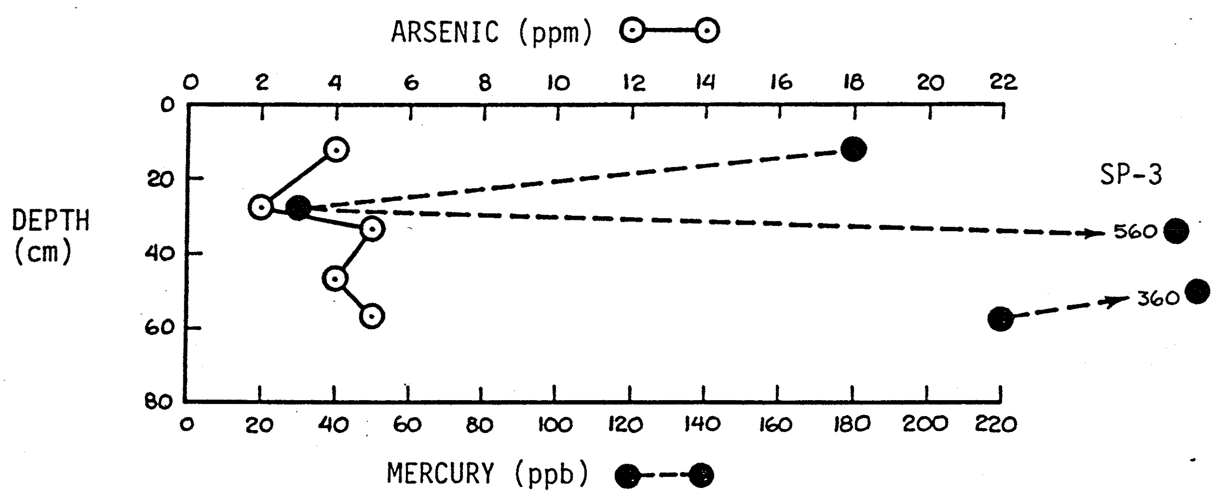
SOIL PROFILE

GARIBALDI VOLCANIC BELT ELAHO DRAINAGE

(refer to Dwg. ELA-3 for location key)



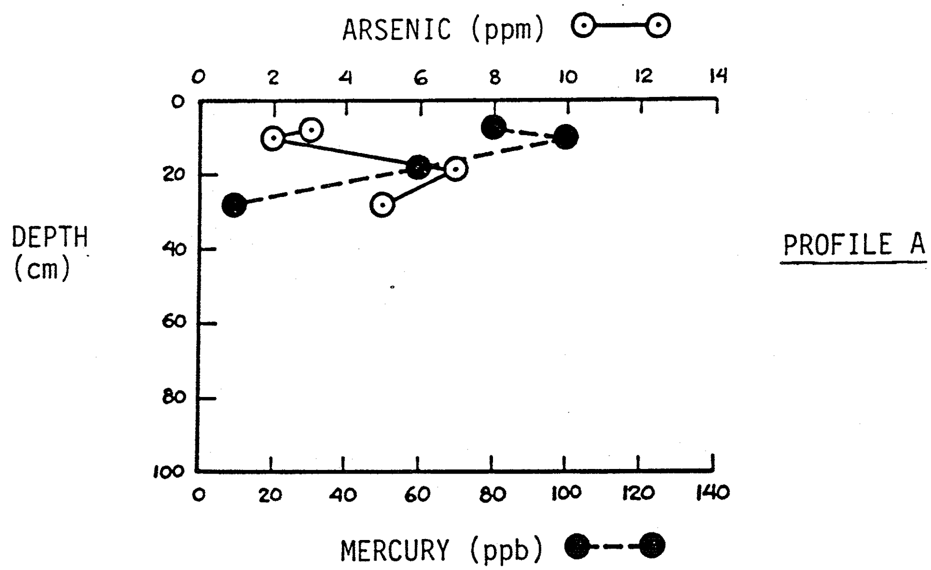


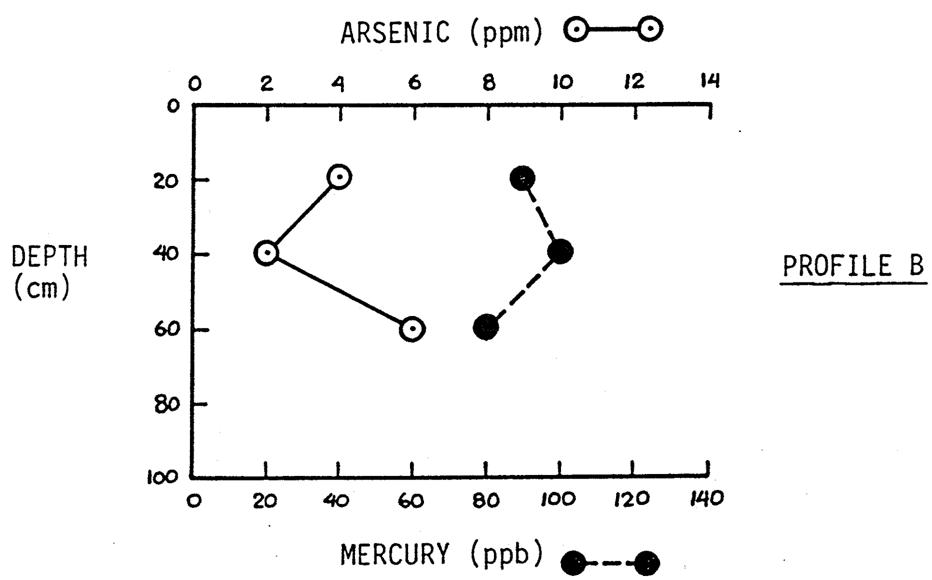


SOIL PROFILES

PITT RIVER

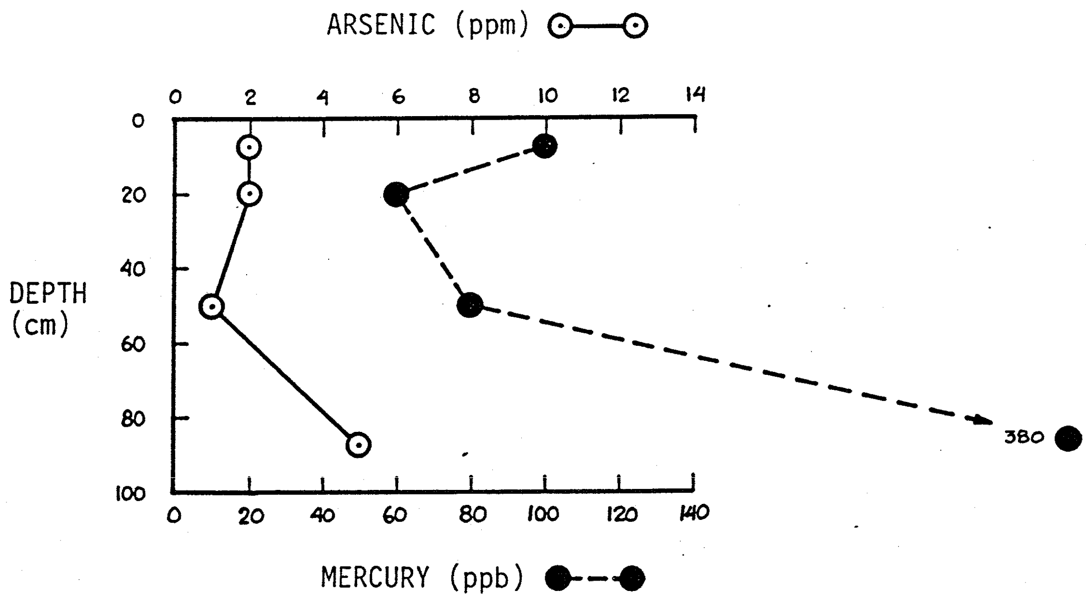
(refer to Dwg. PITT-3 for location key)





SOIL PROFILES

(refer to Dwg. LAK-3 for location key)



SOIL PROFILES

FRIZZELL HOT SPRINGS

APPENDIX C

GARIBALDI VOLCANIC BELT

History

The Garibaldi Volcanic Belt consists of a line of at least 32 volcanic centers of primarily andesitic and dacitic composition (Souther, 1976) trending north-northwest in the southwestern corner of the British Columbia mainland. These centers lie within the Coast Plutonic Complex, a long belt (1600km) of rugged terrain consisting largely of granitic plutons of various ages, but also containing pendants of older metamorphic sediments. The formation of the Coast Plutonic Complex began possibly as early as the Precambrian although it is considered to have been largely emplaced during the late Cretaceous and early Jurassic.

The general setting of southwestern British Columbia has been one of active tectonic plate subduction with well developed off-shore trench, forearc basin, magmatic arc (i.e. the Coast Plutonic Complex) and foreland basin east of the Rocky Mountains. The present geologic environment is a result of the subduction of the Juan de Fuca Plate beneath the continental North American Plate. Geophysical data, including off-shore seismic and magnetic studies, indicate that the subduction of the Juan de Fuca Plate is continuing at the present time although at a lesser rate than in the past. Evidence for a relationship between the Garibaldi Belt Volcanics and the subduction of the Juan de Fuca Plate is the calc-alkaline nature of the volcanic rocks (Souther, 1976; Green, 1981) throughout the belt which is typical of arc volcanism related to subducting tectonic plates elsewhere in the world. The recent discovery of an active fault zone off Vancouver Island (Keen and Hyndman, 1979), named the Nootka Fault Zone, has clarified the relationship of the Garibaldi Volcanic Belt and the Juan de Fuca Plate.

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The abrupt northerly termination of the Garibaldi Volcanic Belt eruptive centers coincides closely with the intersection of a line along the belt and the northeastward projection of the Nootka Fault Zone through Vancouver Island and the mainland (Green, 1981; Roddick, et.al., 1979). As such, these northernmost centers are considered to coincide with the northern edge of the Juan de Fuca Plate.

Present Setting

From the north shore of the Burrard Inlet northward to the Bridge River area the land is extremely rugged and composed of deeply disected plutonic rock. Most of the intrusions belong to the Coast Plutonic Complex of quartz diorite, granodiorite, diorite, quartz monzonite and various gneisses and migmatite complexes. Foliation in these rocks varies from non-existent to gneissic; alteration is commonly regionally propylitic or stronger. By far the majority of plutonic masses and the bulk composition of the Coast Plutonic intrusions are quartz diorite (Roddick and Hutchinson, 1974; Roddick, 1965). Epizonal plutons of late Tertiary age as young as 8-million years are felt to represent the unroofed parent intrusions which were the magmatic source of a late Miocene volcanic arc sequence. This sequence has been referred to as the Pemberton Volcanic Belt and was probably related to the early stages of the Juan de Fuca Plate subduction (Souther, 1975).

Elongate pendants of metasediments and metavolcanics of various ages are common (less than 10% by volume) throughout the Coast Plutonic Complex (Roddick and Hutchinson, 1974). In the Garibaldi Volcanic Belt area these pendants trend generally north-northwest and appear to be steeply dipping. At least two distinct types of metamorphic pendants are commonly encountered. The older of these is primarily sedimentary in origin and generally displays complex contact relationships with older plutons. More recent, lower Cretaceous Gambier Group submarine volcanic rocks and lesser sedimentary horizons is more continuous and forms larger pendants than older metamorphic units.

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Volcanic centers of the Garibaldi Volcanic Belt trend north-northwest. The southernmost exposure of these volcanics occurs at Watts Point in Howe Sound. The volcanics continue to the north with the major centers occurring at Mount Garibaldi, Mt. Cayley, and Meager Mountain which is about 55km northwest of Pemberton, B.C. Various smaller centers occur north of Meager Mountain towards the Bridge River area. Volcanism began at least 4-million years with the Bridge River event at Meager Mountain (Read, 1977). Most of the centers take the form of flows and domes of andesitic to dacitic compositions although some relatively fluid basalt flows have occurred. Several include more acidic rhyodacite and rhyolite compositions and evidence for explosive eruptive events exists. Tuffaceous flows, lahars and ash-plumes have been identified particularly with the more recently active centers. Almost all volcanic piles in the belt exhibit features associated with partial or complete sub-glacial intrusion.

Geothermal Potential

Several features are clear indicators of the geothermal potential of the Garibaldi Volcanic Belt. The recently active volcanism with its associated hot and warm springs and basement alteration are the most obvious manifestations of near-surface thermal activity. Less obvious is the development of a classic tectonic plate subduction zone in the southwest corner of British Columbia and the Coastal Plutonic Complex (Riddihough and Hyndman, 1976). Results of magnetotelluric surveys within the Garibaldi Belt indicate the possible existence of molten rock at depths as shallow as 15-20km (Dragert, et.al., 1980). The data suggest active emplacement of molten plutonic masses to relatively shallow depths and provide evidence for continuing subduction-arc, near surface thermal activity. Mechanisms for enhanced heat flow are likely provided by large scale fracturing and block faulting related to the emplacement of shallow plutons, differential uplift and the subduction of the Juan de Fuca Plate. Such large scale fracturing is a mechanism suspected of providing for deep migration, heating and storage of water.