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compiled by

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Geothermal Service of Canada

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Division of Seismology & Geothermal Studies

Earth Physics Branch

Department of Energy, Mines & Resources

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CONTENTS

GEOTHERMAL ENERGY

Programme 4 of Task V - Exploit Renewable Resources Task Force on Energy.

Programme Statement 4 - 'Geothermal Energy' was first prepared as part of Task V - 'Exploit Renewable Sources of Energy' in April 1974, as a result of meetings of Panel A - 'Energy Source' during the winter of 1974. Task V is coordinated by the National Research Council, and by the end of the summer of 1974 a summarising document had been prepared. It is not yet clear whether the financial resources requested in this programme for 1975-76 will be forthcoming, but it is necessary for the scientific personnel involved to keep each other informed of their work and plans, so that they will be ready to make the best use of new resources when they become available.

Those persons who may be concerned with recruiting new staff should maintain an awareness of possible candidates in case funds should suddenly become available during the current (1975-76) financial year.

This collection of statements of activity is the first step in a system of reporting the progress of the Geothermal Energy Programme. When work is financed by the Task Force on Energy it will be necessary to evolve a coordinated system of technical reports so that users may have easy access from a single source and may thus derive the maximum benefit.

The following brief reports on activities related to the search for and assessment of geothermal resources have been prepared under the following format:

1. Work done so far; projects already undertaken and results;
2. Plans for the financial year 1975-76; subdivided into

a) assuming new resources from the Energy Programme are available, on a scale described in the programme proposal for Task V. Exploit Renewable Resources Programme 4. Geothermal Energy; and

b) assuming no new resources will be available.

A research contract is in process of being awarded to a university or other agency to make an initial evaluation of the sedimentary basins of Canada as geothermal resources. To achieve this, all temperature, porosity and other pertinent data will be extracted from the files of oil and gas companies and provincial files. Results will be expressed in maps of temperature distribution, water content of formations, and other relevant parameters. The results of this contract will probably lead to field and laboratory measurements to clarify or complete the resulting information. This contract will be under the supervision of the Geothermal Service of the Earth Physics Branch.

Since the autumn of 1973 there has been a geothermal energy section of the NATO-CCMS (Committee on Challenges to Modern Society) programme. A data collection and exchange system has been set up to deal with growing volumes of information on producing well characteristics and geothermal analyses of thermal waters. Several meetings have been held. Those that were attended by representatives at Department of Energy, Mines and Resources were: 1) Livermore, California, in October 1973 - Preliminary meeting to explore possible projects, attended by J.C. Souther, D. Quinsey, and A.M. Jessop, 2) Wairakei, New Zealand, in April-May 1974 - Mainly concerned with the data exchange system, attended by A.M. Jessop, 3) Los Alamos, New Mexico in September 1974 - on hot dry rock, attended by A.M. Jessop, and

4) San Francisco, California in May 1975 - informal meeting to assist the preparation of report on 'Non-electrical uses of geothermal energy', attended by T.J. Lewis and J.C. Souther. Future important events include a meeting in Paris, France in June 1975 to finalise the report on Non-electrical uses', and a meeting in the Azores in August 1975 on the subject of 'Small power plants'. Department of Energy, Mines and Resources will probably not be represented at these meetings.

The Canadian International Development Agency has made a preliminary investigation of the feasibility of geothermal energy development in certain islands of the British West Indies. A. Jessop accompanied CIDA personnel in a visit to the area in April 1975. A report on the visit will be prepared, and an assessment will be made of how geothermal energy can contribute to the energy needs of the islands to avoid excessive import of hydrocarbon fuels. It is possible that CIDA will request further technical assistance from this Department.

ELECTRICAL RESISTIVITY

L.S. Collett

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Task V: Exploit Renewable Energy Resources

Programme 4: Geothermal Energy

Subprogram/Project Title: Electrical Resistivity

Providing funds from the Energy Programme are available during 1975-76, the Geological Survey of Canada is in a position to conduct, through contract services, ground resistivity surveys for the detection and boundary limits of geothermal sources. The DC resistivity and/or the electromagnetic Geoprobe EMR-14 techniques could be utilized in selected favourable areas in British Columbia or Yukon. The purpose of conducting these surveys is to make an assessment of these techniques for locating geothermal resistivity anomalies.

MAGNETO-TELLURIC STUDIES

L.K. Law

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1974-1975 Information on geothermal regions and relevant magneto-telluric techniques was compiled. Plans for a pilot project in southern B.C. were drafted.

1975-1976 (a) Additional funds are not required this year for the pilot study. However, if full scale surveys of potential areas are to be carried out in future years, increased financial resources will be necessary.

The Lillooet Valley geothermal region was selected for the magneto-telluric pilot study. This region is approximately 250 km north of Vancouver in south-western B.C. To determine the broadscale electrical conductivity structure of the N-W trending hot spring belt, along the Lillooet Valley, a perpendicular line of M-T stations will be established. A central station at Pemberton will operate for several months while additional stations will be located at a succession of sites outwards along highway 99. The output from 3-component fluxgate magnetometers and telluric amplifiers will be digitally recorded on cassettes.

A more detailed M-T survey will also be made in the Meager Creek hot-spring area using coil systems recording on F.M. tape. One station will be located at the Meager Creek camp site and the other moved systematically along the creek valley. The development and experiment with the short period call system is a co-operative project with Dr. H. Dragert of U.B.C.

1975-1976 (b) No additional funds have been requested for the pilot study during 1975-1976.

GEOTHERMICS

T. J. Lewis

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Measured terrestrial heat flow and heat production values representing large areas can be combined to indicate temperatures and the structure of the crust and upper mantle. These data, combined with other studies, indicate which regions have the greatest probability of containing geothermal resources and which types of geothermal resources are most likely to be found. With one exception, Meager Creek, the heat flows and heat production referred to in the following are regional in nature and are not measured near a suspected geothermal resource.

1. Existing Projects.

The terrestrial heat flow has been or is being determined at 30 sites on land in the Cordillera; these sites consist of from one to ten individual determinations (Figure 1). Where possible, the heat production of intrusive rocks that are related to the upper crust under each heat flow site is being measured. With the exception of three sites in northern B.C. and the Penticton site, all are associated with company mineral exploration programs, and in many cases a complex or poorly defined geologic structure complicates the determination of a regional heat flow value. As a separate project, not associated with the heat flow sites, the heat production of surficial samples from batholiths is also being measured.

In southern B.C. where the concentration of heat flow sites is highest, regions have different crustal conditions and temperatures (Judge, 1974)

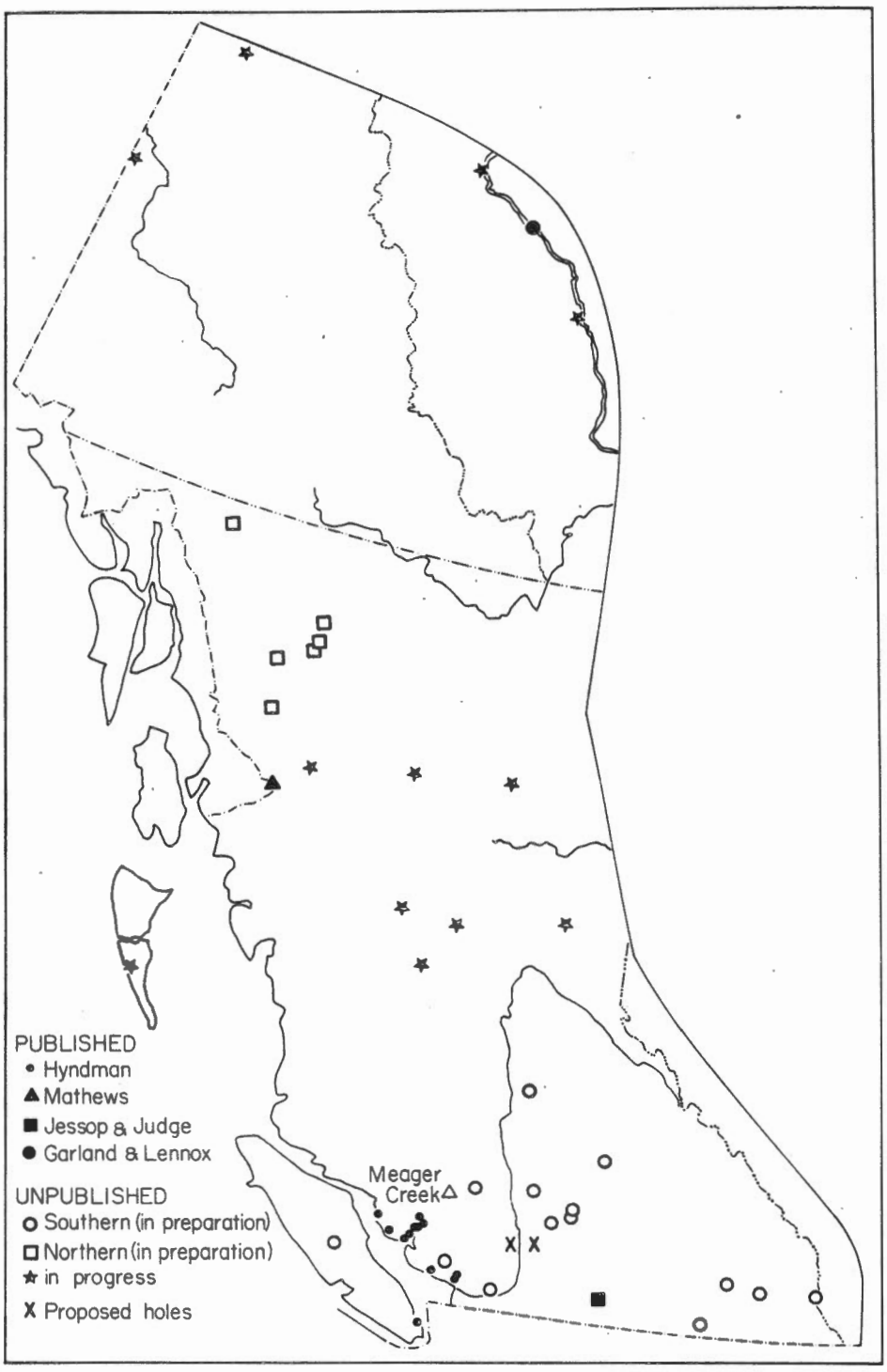

Figure 1. Geothermal measurement sites in the Cordillera.

These data and their interpretation are being prepared for publiction. The value at Penticton has been published previously (Jessop and Judge, 1971). Mathews (1972) has published a heat flow value for the Granduc Area. The analysis of six sites in northern B.C. is being completed. In the sedimentary rocks bordering the Cordillera on the east, Baillie and Vecsey (1967) have reported high temperatures in certain locations near, Fort Nelson, and Garland and Lennox (1962) have reported a high heat flow at Norman Wells. The study of surficial heat production in the Coast Range has indicated exceptionally low values compared with normal values from batholiths to the east (Lewis, 1972). These data are also being prepared for publication.

The analysis of heat flow data at the other sites is either complete or proceeding. Publication awaits a suitable grouping of values for interpretation or acquisition of more sites to provide a regional coverage. The heat production of intrusive rocks from the Chilliwack area is being measured.

A known geothermal area has been investigated in the Meager Creek area. Temperatures have been measured in two short holes in cooperation with the G.S.C. B.C. Hydro has drilled a deeper hole and has measured temperatures by means of equipment on loan from this laboratory. The further development of these data depends on the measurement of the thermal conductivity of samples from the drill core and the assembly of all available maps.

2. Plans for the financial year 1975-76:

a) assuming new resources are available.

In addition to the projects listed in section b) below, two holes will be drilled in batholiths either side of the Fraser fault at about 50°N; the approximate positions are shown on figure 1. The purpose of these holes is to determine the change in heat flow across the Fraser Fault system, to indicate tectonic changes at depth and to demonstrate whether Hyndman's tectonic model (Hyndman, 1975) is applicable. The heat production of surficial samples from the area and borehole samples will be measured. A portable gamma-ray spectrometer will be used, in addition to the laboratory installation.

b) assuming no new resources will be available.

The acquisition of heat flow values at random sites will continue. Two field parties will spend a total of about 4 weeks searching for suitable heat flow sites in the Yukon and B.C.

A graduate summer student will acquire data on the distribution of the heat production of rocks in and near porphyries.

The measurement of the heat production of samples from the Coast Range, Vancouver Island and some other batholiths in central B.C. will proceed. A portable gamma-ray spectrometer is to be acquired and will be used in the Cordillera.

Baillie, A.D., and Vecsey, G.E., 1967, Metamorphism in a middle Devonian reef complex. Internat. Devonian Symposium, Calgary, as reported in: Heise, H., 1968, Hydrothermal trends harbour B.C. gas fields. Oilweek, 12 Feb.1968, 10 - 12.

Garland, G.D. and Lennox, D.H., 1962, Heat flow in Western Canada. Geophys. J.R. Astr. Soc., 6, 245-262.

Hyndman, R.D., 1975. Heat flow measurements in the inlets of southwestern British Columbia. Submitted to Can. J. Earth Sci.

Jessop, A.M. and Judge, A.S., 1971, Five measurements of heat flow in southern Canada. Can. J. Earth Sci., 8, 711-716.

Judge, A.S., 1974, Terrestrial heat flow determinations in the Southern Canadian Cordillera. Amer. Geophys. U. Fall Meeting, San Francisco, Dec.1974.

Lewis, T.J., 1974, A comparison of heat production in the Coast Range complex to values from other areas of B.C. Amer. Geophys.U. Fall Meeting, San Francisco, Dec. 1974.

Mathews, W.H., 1972, Geothermal data from the Granduc area, northern Coast Mountains of British Columbia. Can. J. Earth Sci, 9, 1333-1337.

SEISMIC STUDIES

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Earth Physics Branch

Victoria

1. Activities during 1974-75.

A short period vertical seismograph station was operated in the Meager Creek geothermal area (150 km north of Vancouver) from November 27 to December 17, 1974 and again from January 7 to January 21, 1975. The station was located at the camp of Nevin Sadlier-Brown Goodbrand Limited (consulting geologists). Mr. John Crandall changed records and operated the station. During the first observation period the instrument was recording 96% of the time. The second period was plagued with power supply problems and the instrument was recording only 76% of the time. Total useable recording time in the two periods was about 730 hours.

Snow cover was about 4 feet at the start of the exercise and about 8 feet near the end. Weather experienced included snow, rain and high winds with a temperature range of approximately +5°C to - 15°C encountered.

Instrumentation

The instrument used was a standard regional SPZ helicorder station with 500 ft of cable between the helicorder and Willmore seismometer. The paper speed was 1 mm/sec, the gain setting 18db and the high cut filter 6Hz. The gain setting was adequate through the whole program even though several days of very large microseism activity was experienced at Victoria (230 km south). It is possible that during quiet periods in the summer the gain could be set 6db higher. The high frequency filter was set at 6hz because of previous experience with high frequency wind noise in heavily forested areas.

Nearby Events Recorded

One common event which occurred during times of high winds and/or warm temperatures had the appearance of a few high frequency oscillations. This is thought to be clumps of snow falling from trees in the vicinity of the seismometer. These can usually be distinguished from other seismic events that occur more distant from the seismometer because they lack a Coda or wave train. However very small high frequency seismic events occurring during the times of these snow falls cannot be separated because of their similar appearance.

There were a number of seismic events which may be interpreted as microearthquakes. For discussion they can be divided into 4 groups.

Type 1 (S-P 3/4 second)

These appear to be small microearthquakes with very sharp P and S phases and a definite seismic coda. If a near surface velocity of 5 km/second and a Poissons's ratio of 1/4 are assumed then the S-P interval is equivalent to 5 km distance. These events occurred in 3 groups, about 25 in a 6 hour period on Dec. 11, ten in an hour on Dec. 13 and a single event, the largest ($M_L \sim$ 1-1/2) on Dec. 15. Most events are between $M_L = 0$ and $M_L = 1$. The only thing suspicious about these events is that they all occurred during daylight hours when temperature was hovering near freezing and dropping below freezing at night. This introduces the possibility that they may be related to a freezing thawing cycle. However, they appear to be microearthquakes which ultimately must be related to some active faulting process.

Type II (S-P 1-1/2 - 2 sec).

There were about 10 events on Dec. 14, one on Dec. 17 and one on Jan. 13. These events vary in character and are probably not all related. Because of their unusual appearance, they may not be microearthquakes, but if they are not, their cause is unknown. Their P wave is much lower in amplitude and in frequency content than the S wave arrivals which have sharp onsets, high frequency (10 Hz or greater) and very short coda length. They are all in the 0 to 1 magnitude range and occurred both in daylight hours and at night. All occurred when the temperature was below freezing.

Type III (S-P < 1/2 sec).

These are the most dubious of the possible microearthquakes, and they may be related to some phenomena close to the seismometer such as snow falling or water dripping. They all occurred during a warm spell starting in the afternoon of Dec. 2 at a rate of several per hour and continuing at a rate of about one per hour for 2 days. The events have a high frequency content (5Hz or greater), are impulsive and are short in duration. The smaller ones cannot be distinguished from snow falls. The larger ones have a slight coda (which is the main reason to think that they may be microearthquakes) and appear to have a secondary smaller phase about 1/2 second after the first phase, as if there was a large P and a very small S. All events would be between magnitude -1 and +1.

Type IV (S-P 4 seconds)

One microearthquake ($M_L \sim$ 1-1/2) was observed on Dec. 5 with a S-P of 4 seconds (distance about 30 kilometers).

Summary

Of the 730 hours of recording, only 35 hours contained microearthquakes or suspected microearthquakes. The possible microearthquakes can be divided into 4 types on the basis of their apparent S-P intervals. Two types (S-P 3/4 sec and S-P 4 sec) are thought to be genuine microearthquakes while the other two types cannot be positively identified as such at this time.

2. Plans for 1975-76 - Based on regular manpower and financial resources.

Microseismicity study.

Three short period vertical seismograph stations will be deployed near Pemberton, near Gold Bridge and near the Meager Creek campsite, forming an equilateral triangle approximately sixty kilometers to a side. At the Meager Creek site an additional short period vertical station will be deployed so that one seismometer is located on each side of the valley, and both recorders are in the camp. This should enable the sorting of microearthquakes from phenomena near the seismometer. The instruments will be maintained in place from mid-June to mid-August subject to the time a camp is located in the Meager Creek area.

Expected operating gains should allow location of all events greater than magnitude 1-1/2 in or near the triangle. Detection of much smaller events will be possible in the vicinity of each of the stations. Data analysis will consist of microearthquake counts of any events in the immedate vicinity of each station and the location of all events possible in the vicinity of the triangle. If the microearthquake activity recorded during the winter of 74/75 persists or if other significant activity found in the Meager Creek area (i.e. a rate of one or more events per day) attempts will be made to identify the local source of activity through the deployment of 2 additional Sprengnether portable siesmographs. These seismographs may be deployed as individual stations or channelled into a single tape recorder to form a small array if this seems feasible.

Gold Bridge Station: This will be a SPZ helicorder station run from A.C. power. The station will be operated by B.C. Hydro personnel or on a contract basis with a local resident.

Pemberton Station: This will be a Sprengnether system also recording on analogue tape. The tape recorder will be that used in the Geomagnetism Division/U.B.C. short period equipment. This station will probably be deployed before the G.D./U.B.C. short period is ready to start, but after their long period experiment is underway. Tapes will be changed mainly by G.D. or U.B.C. personnel.

Meager Creek Station: This will be two Sprengnether systems each with about 1000 feet of cable between seismometer and recorder. One system will also record on analogue tape during the time of the G.D./U.B.C. short period experiment. Tapes will be changed mainly by G.D./U.B.C. personnel and hopefully paper records will be changed mainly by Meager Creek camp personnel.

Ground noise study

This will be done in conjunction with the G.D./U.B.C. short period experiment. During the summer, between 10 and 20 stations are expected to be established in the vicinity of Meager Creek during periods of high magnetic activity for a duration of a few hours for telluric work. A Sprengnether seismograph will be set up at each telluric station and be recorded on the analogue tape of the short period telluric system. Simultaneous sections from this mobile station, the Meager Creek station and the Pemberton station will be digitized and their spectra compared for spectral anomalies. If this spectral analysis shows differing or higher noise levels in some areas then a more detailed grid of measurements will be run near the end of the summer to define the character of any ground noise anomaly.

b) No additional resources have been requested for microseismicity studies during 1975-76.


Seismograph stations
Summer 1975

GEOCHEMISTRY, VOLCANOLOGY and HYDROLOGY

J.G. Souther
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Geological Survey of Canada
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1. Activities during 1974-75

(a) Cordilleran Volcanic Project

An ongoing study of volcanic and related phenomena in the Canadian Cordillera was initiated in 1973. The age, distribution, chemistry and tectonic setting of late Tertiary and Quaternary volcanoes and subvolcanic plutons provides basic data on the thermal history and present thermal structure of the region. Five belts of young volcanoes have been defined and several individual volcanoes in each belt have been investigated. During the 1974-75 field season an extensive reconnaissance of the Wrangell volcanic belt in southwestern Yukon was completed (Souther and Stanciu, 1975). A synthesis of Cordilleran volcanism and its relationship to plate tectonic models was prepared for the G.A.C. Symposium on Volcanic Regimes in Canada (Souther, 1975a).

(b) Cordilleran Geothermal Project

This continuing project was initiated in 1973 for the purpose of compiling an inventory of thermal data on the Cordillera to serve as a basis for assessing the geothermal resource potential of the region. The first phase of the study was completed in 1975 with the collection and analysis

of water from most of the known thermal springs of Western Canada. The analytical data have been used to classify Canadian Thermal springs into three major types of which only one appears to have any connection with high temperature flow systems. The latter are spatially related to belts of Quaternary volcanoes and those springs for which geochemical thermometers indicate the highest subsurface temperatures issue from volcanoes which have erupted acid pumice within the past 2,000 years. A synthesis of this data was presented at the 2nd U.N. Conference on Geothermal Energy and will be published in the proceedings of that meeting (Souther, 1975b).

The second phase of the Geothermal Project was initiated in 1974 with the drilling of two shallow holes at Meager Mountain where high silica springs (> 200 ppm) are associated with young pumice eruptions. Both holes encountered artesian flows of $\pm$ 55°C water from a self sealed reservoir within both fractured quartz diorite gneiss and a thick overlying deposit of gravel and sand. Flow rates and temperatures of all natural springs in the vicinity have been measured and an attempt is being made to estimate the heat and water balance of the system. This preliminary hydrological study is being accompanied by detailed geological mapping of Meager Mountain volcano and subvolcanic structures that may control the size and shape of the hot water reservoir.

(c) "Watching Brief"

Progress in geothermal R and D has been monitored for the past three years and reports on new developments circulated to interested groups within E.M.R. J. Souther has attended and reported on the following meetings:

(i) N.A.T.O. Planning Meeting on Geothermal Energy; Livermore, El Centro, San Diego; Oct. 1-5, 1973

(ii) Geothermal Resources Council, Symposium on Geothermal Energy; Boise Idaho; Oct. 15-18, 1974

(iii) 2nd United Nationa Conference on Geothermal Energy; San Francisco; May 20 - June 3, 1975

(iv) Alaska Geothermal and Wind Planning Conference; Anchorage; July 8-9, 1975

In addition J. Souther has maintained close liaison with B.C. Hydro and Power Authority and their consultants who are investigating the Meager Mountain site north of Vancouver. Co-operation and free exchange of data between B.C. Hydro and E.M.R. has ensured the funding of complimentary programs and avoided duplication.

2. Plans for 1975-76 based on existing manpower and funding

(a) Detailed mapping of Meager Mountain thermal area will be started by J.G. Souther as part to the Cordilleran Volcanic Project. In addition, J. Souther is thesis advisor to two PhD students doing detailed volcanological studies on Garibaldi Peak and Level Mountain respectively.

(b) Water samples will be collected from the few remaining springs not sampled in phase 1 of the Geothermal Project.

(c) Test blanks of various metal alloys used in the fabrication of pipe will be installed in several hot springs to determine relative rates of corrosion and hence provide some advanced metallurgical data for possible future non power development.

(d) The feasibility of using natural acid thermal water for recovering metals from disseminated ore bodies will be

investigated by means of a small scale leaching experiment.

(e) Investigation of a "fossil" hydrothermal system, initiated in 1974, is continuing. An attempt is being made to use fluid inclusions in quartz to determine the temperature and composition of fluids deep in the hydrothermal system.

3. Plans for 1975-76 based on availability of new resources as proposed for Task V

(a) Exploration for geothermal reservoirs employs three principal disciplines of earth science: geology, geophysics and hydrology. In order to maintain a balanced program it is necessary to recognize some fundamental differences in the implementation of studies within these different disciplines. Geology and Hydrology tend to be labour-intensive whereas geophysics tends to be cost-intensive. In any given region the rate of data-gathering is much slower for geological and hydrological surveys than it is for most geophysical surveys. Moreover geophysical surveys can usually be accelerated with increased rates of expenditure relative to manpower but this is not true of geological and hydrological surveys. Thus in a recently defined geothermal target-area such as Meager Creek there is a tendency for geophysical surveys to "get ahead" of geological and hydrological investigations. Since the latter provide the basic framework on which interpretation of geophysical data depends it is essential to maintain the maximum possible level of geological and hydrological data-gathering. Present resources for work at Meager Creek provide for continued geophysical work (E.M.R., U.B.C., B.C. Hydro) and drilling (B.C. Hydro), no hydrological work, and only token geological mapping (G.S.C.).

If the additional resources requested for fiscal 1975-76 under the task V proposal are forthcoming they will be used as follows:

(i) Detailed mapping (1/25,000) of Meager Mountain volcano and the lineament on which it is situated. (2 man years, volcanologist).

(ii) Hydrological study of upper Pemberton Valley and the Meager Creek geothermal reservoir with emphasis on potential low temperature utilization (2 man years, hydrologist-geochemist).

(iii) Detailed study of alteration and other hydrothermal phenomena in and around late Miocene sub-volcanic stocks in the Anehim Volcanic Belt of Central B.C. (1 man year, volcanologist-mineralogist).

Publications during 1974-75

Souther and Stanciu (1975)

Operation St. Elias, Yukon Territory: Tertiary Volcanic Rocks, Geol. Surv. Can., Paper 75-1, Pt. A., pp. 63-70.

Souther (1975a)

Volcanism and Volcanic Environments in the Canadian Cordillera - A Second Look, G.A.C. Volcanology Division Symposium, G.S.A. Abstracts with Programs Vol. 7, No. 6, p. 862.

Souther (1975b)

Geothermal Potential of Western Canada, Abstracts, Second Uniter Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, p. I-35.

(b) The search for and development of a Geothermal Resource in Canada will require an extremely broad multidisciplinary approach with input not only from earth scientists and engineers but also from the legal, political and economic sphere. Although the latter are beyond the scope of this report their importance cannot be overemphasized.. Government funding of geothermal R and D programs must be guided by sound economic as well as scientific data. An economic appraisal of geothermal energy and its relation to alternate energy sources should be undertaken immediately. It should take into account such things as relative environmental impact, capital cost, markets, and the savings that might accrue from utilization of low temperature geothermal fluids in place of high quality fuels for process heat and district space heating. It should form the basis for formulating a legal framework with clearly stated policies of ownership, leasing practices, royalties and environmental controls. Without such a legal framework private investors are unable to make feasibility studies of geothermal enterprises in Canada.