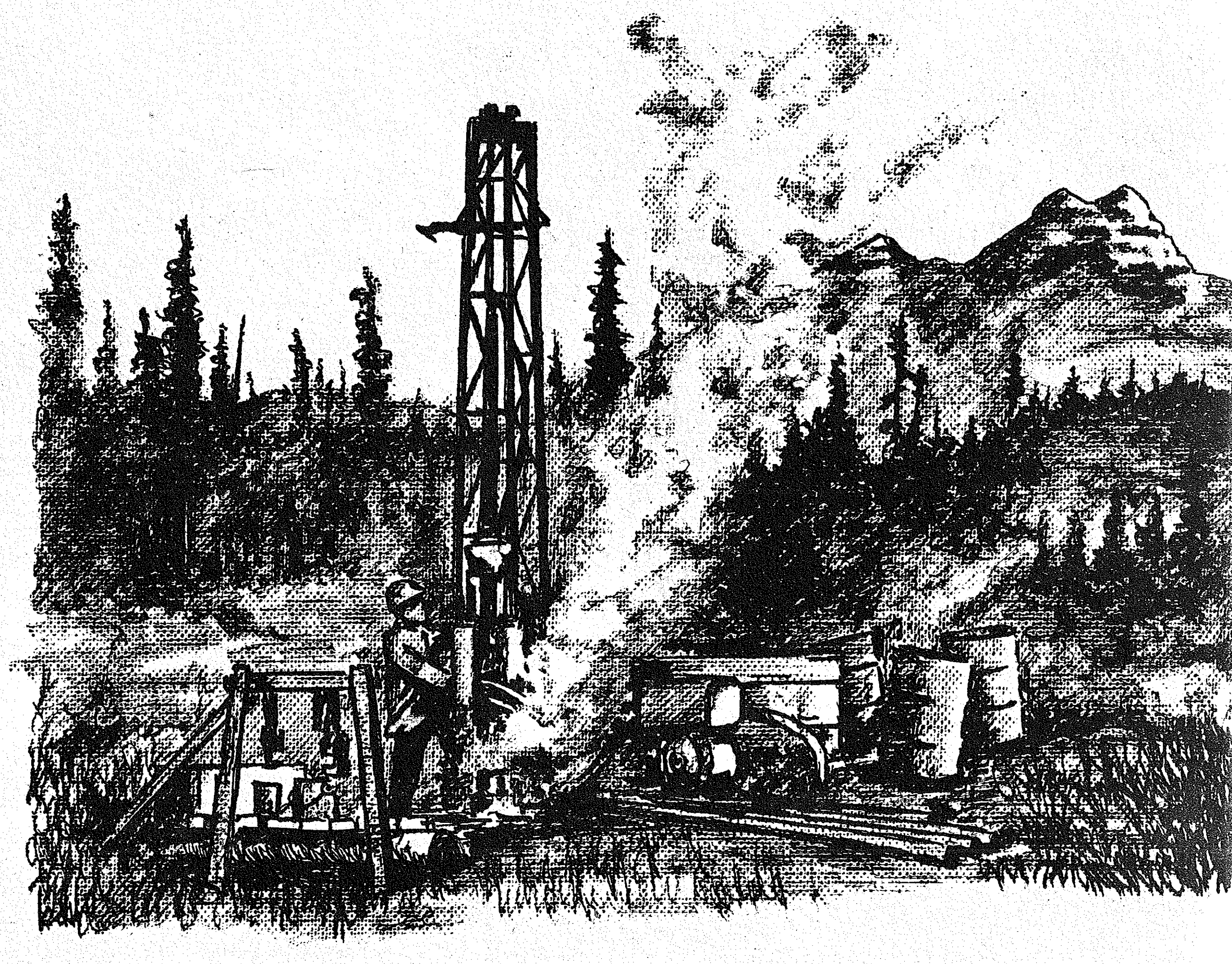
B.C. HYDRO AND POWER AUTHORITY

Report on Detailed Geothermal Investigation at Meager Creek

November, 1975

Volume 1 : Report



REPORT ON DETAILED GEOTHERMAL INVESTIGATION AT MEAGER CREEK

October 1974 Through October 1975

VOLUME 1: REPORT

Submitted to British Columbia Hydro and Power Authority

November 30, 1975

NEVIN SADLIER-BROWN GOODBRAND LTD.
CONSULTING GEOLOGISTS

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1.0. SUMMARY

Within the past few years the Meager Creek area, near Pemberton, has been recognized as the most important geothermal prospect in Canada. The British Columbia Hydro and Power Authority commissioned a geophysical investigation of the area by Nevin Sadlier-Brown Goodbrand Ltd. in late 1974. The investigation made use of standard scientific and exploratory methods, designed to assess those natural properties which correlate with commercial characteristics.

The main operations were electrical resistivity surveys, temperature profiles in four shallow (198 to 1140-foot) wells drilled for that purpose, geochemical analysis of thermal waters from wells and hot springs, application of techniques for estimating sub-surface temperatures from certain trace elements in the waters, and studies of rock types, their distributions and characteristics.

The study discovered and partially outlined the reservoir which feeds the high-volume Meager Creek hot springs. It is at least two square miles in area, although the northern and southern boundaries are presently undetermined, and occupies a fractured quartz diorite host rock. The part inferred to be the hottest and most important is a tabular shaped body, within 4000 feet of the surface and inclined gently downward to the north, under the Meager Mountain volcanic complex. Although the highest temperature measured in a shallow well is 70°C, geochemical data suggest that base temperature exceeds 160°C, and may reach 240°C.

Several hypothetical models of the system have been worked out by interpreting the data in light of similar measurements of the world's productive geothermal systems and the thermodynamics of water and steam. The leading model is that the reservoir is the apex of a hot water system, which reaches commercial requirements down dip under the volcanic complex. (Commercial requirements for a hot water system capable of directly generating electricity are elevated temperatures and pressures, so that a portion of the fluid flashes to steam at the well heads). One of the alternate models, which satisfies many of the observations, is that a saturated steam deposit underlies the hot water reservoir indicated by the electrical resistivity survey.

Estimates of generating capacity or judgements on feasibility of the geothermal system would be premature at this point. The singular test for confirmation of commercial properties is a deep, large-diameter exploratory well. Before locating such a well, however, the geothermal system should be delineated in detail. The needed information is exacting geologic knowledge of the volcanic complex, electrical results around untested parts of the complex, and definition of the northern and southern boundaries of the reservoir by deep-looking resistivity surveys. We suggest programming this work for 1976 and 1977. If results continue to favour a commercial system, the exploratory well could be scheduled.

2.0. INTRODUCTION

2.1. Terms Of Reference

As part of a study of alternative sources of energy, B.C. Hydro and Power Authority instructed Nevin Sadlier-Brown Goodbrand Ltd. to proceed with a detailed investigation of the Meager Creek geothermal area in October, 1974. This project, Phase II of a geothermal investigation, was an outgrowth of the results of Phase I, a reconnaissance study of the Lower Mainland, performed by the firm and reported in June 1974.

The principal objective of the detailed investigation of the Meager Creek area, was to conduct a geophysical program, including resistivity surveys and temperature profiling in shallow drill holes, in order to determine whether or not the area would warrant continued exploration for geothermal power.

2.2. Scope of this Report

This report describes the work conducted and presents the data acquired during the period October 1974 through October 1975. Studies performed in the same area by the federal Department of Energy, Mines and Resources are informally summarized. Known information is interpreted and a hypothetical model of the geothermal system is proposed, along with alternate models. Finally, the report suggests a course along which further work could be pursued.

2.3. Location and Access

The Meager Creek area is located immediately southwest of the Lillooet River, about 35 miles northwest of Pemberton, B.C. The area of interest is centered on latitude 50° 34'N, and longitude 123° 23'W (N.T.S. Map Sheet 92 J).

The existing road along the southwest bank of the Lillooet terminates near South Creek, at a distance of about 6 miles from the confluence of Meager Creek and the Lillooet River. The geothermal prospect is a further six miles up Meager Creek in a southwesterly direction from the confluence. The only practical access from the end of the road at the present time is by helicopter. Projects in the area must therefore be supported by tent camp and every item used in the project transportable by helicopter at a reasonable cost.

2.4. Legal Authority

B.C. Hydro is conducting this program under the Geothermal Resources Act of 1973, which stipulates that geothermal resources of 250°F (121°C) or greater temperatures are to be held for the Crown.

2.5. Environment

The selected area is located in the Coast Range of British Columbia in an area of rugged topography with elevations ranging from 1500 feet to 8500 feet above sea level. There are no permanent man made features in the vicinity of the geothermal area. Two Vancouver-based mineral exploration companies hold large blocks of mining claims six to ten miles north of the area of interest. The closest logging operation is about 10 miles downstream in the Lillooet River Valley. Bidding is under way for timber stands in the Meager Creek valley and logging may be expected within the next several years. The timber consists of mature stands of fir, cedar, and hemlock.

Game is not plentiful in the area, but deer, moose, black bear and small fur bearing animals have been observed in the valleys and a small herd of mountain goats is occasionally seen in the high country. The wildlife habitat appears to be adversely affected by heavy snowfalls, which may total in excess of 30 feet, packing down throughout the winter to dense accumulations of 10 feet. The water of Meager Creek and its tributaries is milky from suspended silt, and the nature of the trout or salmon population is not known to us.

Hunters and fishermen do not penetrate the area. A marten trap line through the Meager Creek valley and southward into the Elaho River valley has been abandoned for several decades.

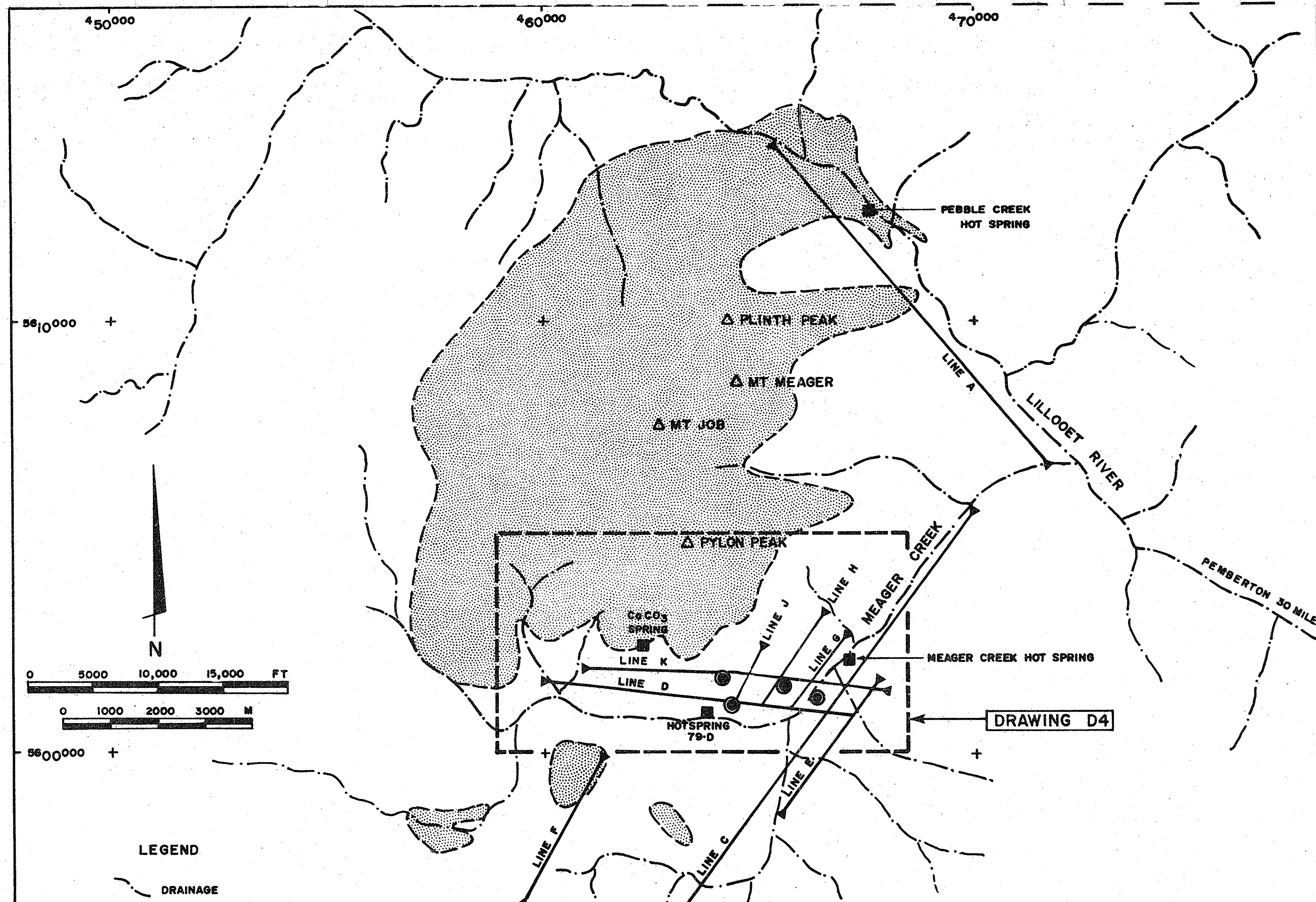
The hot springs at Meager Creek and Pebble Creek, six miles north of the centre of geophysical studies, are occasionally visited by mining, logging, and government personnel who have ready access to helicopter transportation.

Certain unstable volcanic rocks at high altitudes combine with glacial ice and melt water to pose the continuous threat of massive landslides in a few valleys. On July 22, 1975, a 15-million ton slide of mud, rock, and ice took the lives of four crew members in a tributary of Meager Creek which we learned later was named Devastation Creek after a similar slide in 1931.

2.6. General Geology

Quartz diorite of Cretaceous age is the principal older rock in the map area. It includes irregular septa of upper Triassic to lower Cretaceous metavolcanics. This terrain is typical of the Coast Range batholith belt of western Canada.

A Quaternary volcanic complex, 5000 feet in thickness, dominates the area. Composition ranges from rhyodacite through andesite. Modes of occurrence are flows, tuffs, breccias,



NOVEMBER, 1975
DRAWING : C12

B.C. HYDRO AND POWER AUTHORITY

LOCATION MAP

GEOTHERMAL INVESTIGATION

MEAGER CREEK SELECTED AREA B.C.

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ignimbrites, unconsolidated ash blankets, cinder cones, necks and dikes. The volcanics are assigned to the Pleistocene-Recent Garibaldi group (Mathews, 1958). The last recorded event was eruption of an ash unit dated at 2,440 ± 140 years ago (Nasmith et.al., 1967).

Both older and volcanic rocks are cut by sets of widely spaced northwest and northeast-trending faults considered to have minor displacements.

3.0. WORK COMPLETED

3.1. Primary Operations

Two separate electrical resistivity surveys were conducted. The first survey was run by McPhar Geophysics Company in October and November 1974. The second survey was conducted by Deep Grid Analysis Ltd. in July and August 1975. A total of approximately 50 line-miles of resistivity was completed.

Four research wells have been put down as part of the present project. The first and deepest, to 347 metres (1140 feet) was drilled by Kendrick Drilling Co. during the period November 1974 to February 1975. The next three holes were drilled during the month of September and October 1975 to depths of 60-90 metres (198 to 300 feet). The drilling contractor was H.Allen Diamond Drilling of Merritt, B.C. These holes were logged for temperature profiles, geology, water pressures and flows.

As time permitted, geologic mapping at a scale of 1:10,000 was continued.

3.2. Support Operations

In order to perform the primary operations,several other physical and technical steps were completed. Prior to running resistivity, lines were cut and surveyed by compass and chain. Drill sites and helicopter pads were cleared and levelled.

Refraction seismic surveys were conducted at or near anticipated drill sites for the purpose of determining the thickness of unconsolidated overburden.

A "self-potential" electrical survey was conducted concurrent with the second electrical resistivity survey.

Logistics and helicopter transport were given considerable attention since they are cost-sensitive items.

3.3. Energy, Mines and Resources' Program

The Earth Physics Branch and the Geological Survey of Canada, both arms of the Department of Energy, Mines and Resources, have been conducting a research program at Meager Creek, as well as other geothermal areas in western Canada. They are working along four principal lines: regional geologic mapping, temperature gradient and heat flow studies, micro-earthquake studies, and magnetotelluric studies.

Co-operation between the two groups is excellent in regard to sharing equipment, facilities and scientific information with the result that E.M.R's research and B.C. Hydro's commercially oriented program compliment each other. We wish to acknowledge the contributions made to this program by several federal government scientists, in particular, Dr.J.G. Souther, Dr.A.M. Jessop, Dr.Trevor Lewis, Mr. Gary C. Rogers, and Dr.Lorrie K. Law.

3.4. Technical Management

The project was managed and supervised by A.E. Nevin, P.Eng., T.L. Sadlier-Brown, and John T. Crandall. McPhar's resistivity survey was conducted by Albert Wood, and the Deep Grid Analysis resistivity study by Greg Shore.

4.0. ELECTRICAL RESISTIVITY

4.1. Purpose

Electrical resistivity is a leading tool in detailing the outlines of geothermal reservoirs. The resistivity (reciprocal of conductivity) of rock in a geothermal environment is controlled by the proportions and resistivities of materials contained in the pore spaces of the rock. Typical reservoirs have resistivities one-tenth to one-fiftieth of values measured in surrounding rocks, owing to higher porosity, high content of dissolved salts, high proportions of conductive alteration minerals such as clays and iron pyrite, and higher temperature.

4.2. Specifications of Surveys

The linear "dipole-dipole" electrode array was selected for these surveys. (Its geometry is described in detail in Appendices A and B). Electrode spacings of 500, 1000, and 2,000 feet and dipole separations from 500 feet to 14,000 feet were specified, giving effective measurements of resistivity at depths ranging from 500 to 8,000 feet.

McPhar Geophysics used a 2.5 kw transmitter which put out a square wave at a usual frequency of 0.3 Hz. Deep Grid Analysis used a 40 kw transmitter set at 0.0166 Hz.

The nine survey lines were located as shown in Drawings C12 and D4 (and in Appendices A and B), starting with reconnaissance in selected valleys, and progressing toward the discovery and detailing of the anomalous area described below.

4.3. Results

Anomalously low resistivities, signalling the presence of geothermal fluid, were measured on lines C, D, K, J, H, and G. The anomaly is irregularly shaped in plan and extends 12,000 feet in the east-west direction and one mile or more in the north-south direction (see Drawing D4, and the maps and pseudo-sections in Appendices A and B).

The anomaly is defined by resistivity values generally less than 100 ohm-metres*, with a mode on the order of 20 to 30 ohm-metres. The background values for ordinary quartz diorite are generally in excess of 500 ohm-metres, with a mode at 2,000 to 6,000 ohm-metres.

4.4. Interpretation

A strict interpretation of the resistivity data in light of other known factors - - configuration of the hydrologic basin, geology, and drilling results - - suggests that the western portion is the more important area. The linear extension to the east represents flow of hot geothermal fluid down the hydrologic gradient toward the mouth of the Meager Creek basin, ultimately to the surface at the principal Meager Creek hot spring.

The western part of the reservoir appears to be a roughly tabular body, having a base about 2000 - 4000 feet beneath the surface, and inclined gently downward to the north. The western part of the anomaly has an unknown extent to the north and south.

5.0. RESEARCH WELLS

5.1. Purpose

Shallow diamond drill holes are generally put down to confirm the existence of high temperature, to investigate temperature gradients, and to obtain measurements of the flow of heat upward from the geothermal system. They also serve, in areas concealed by overburden, to obtain geological and hydrological information - - rock type, character of mineral alteration, degree of fracturing, orientation of fractures, porosity, permeability, fluid pressure, and fluid composition.

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* Deep Grid Analysis resistivity results are reported in ohm-metres; McPhar's resistivity results in ohm-feet/2 pi. The conversion factor is x ohm-ft/2 pi x 1.91 = y ohm-metres.

5.2. Specifications and Procedure

The first well, 74-H-1,was the deepest drilled, to 347 metres (1140 feet), during the winter of 1974-75 following the McPhar resistivity survey. The contractor was Kendrick Drilling Co. and the machine used was a Longyear 34 diamond drill. The next three wells, labelled 75-H-1, 2 and 3, were drilled during September and October 1975 following the second resistivity survey. The contractor was H.Allen Diamond Drilling Co. and the machine used was a Boyles Bros. BBS-1. All four wells finished with AX or AQ tools, making a hole of 1.9 inches in diameter and a core sample of 1.1 inches in diameter. A thermistor probe was used to measure temperatures. The procedure was to measure the temperature at the bottom of the hole in the morning, after drilling had been shut down for one or more full shifts, in order to obtain an undisturbed "bottom hole temperature" profile. This minimizes the influence on the natural ground temperature by the cold drilling water which is circulated through the hole during the drilling operation. It also minimizes the effects of warm water from fracture zones circulating in the hole or flowing upward under thermo-artesian pressure. Continuous profiles were made periodically to monitor the characteristics of inflowing hot water.

5.3. Summary Logs

Logs of the wells are given in Appendix C, in detailed descriptive form, and are summarized graphically in Drawings D2 and D3. Locations are shown in Drawing D4 in relation to other features. Table 1 summarizes the measurements. It would be useful to refer to the drawings while reading the summary comments below.

In all instances the wells penetrated unconsolidated overburden, made up of soil, sand, clay beds, and boulder beds, and entered quartz diorite bedrock. The quartz diorite is generally fractured and contains hot water. In two wells thermo-artesian pressure and high permeability caused hot water to flow out of the well head.

The wells are widely spaced, covering a distance of 9,000 feet east-to-west and 2,000 feet north-to-south.

Well 74-H-1 is located in the eastern extension of the resistivity anomaly and, as we discovered, in the outflow from the geothermal system. Temperatures increased in overburden to a maximum of 68.9°C at 48 metres (157 feet), then reversed to a low of 35°C at 60 metres (198 feet), before increasing further and entering bedrock. This reversal is diagnostic of lateral flows (rather than upward flows) of hot and cold fluids found on the edges of geothermal reservoirs (White, et.al., 1975).

TABLE 1 - SUMMARY OF RESEARCH WELL DATA.

Research Well	Co-ordinates (metres)	Date Drilled	Total Depth (feet)	Total Depth (metres)	Maximum Temperature(°C)	Gradient at Bottom (°C/km)	Wellhead Pressure (psi.)	Wellhead Pressure (Kg/cm^2)	Flow (gal/min.)	Flow (litres/min.)
74-H-1	601, 440 N 466, 350 E	27 Nov. 74 -5 Feb. 75	1140	347	68.9	27.7	32	2	40	180
75-H-1	601, 610 N 465, 200 E	6 - 11 Sep.75	300	91	15.4	112	2	0.14	7	20
75-H-2	601, 200 N 464, 015 E	13 - 20 Sep.75	287	87	35.0	365	0	0	0	0
75-H-3	601, 770 N 463, 000 E	24 Sep.75 - 5 Oct.75	198	60	20.8	289	0	0	0	0

Well 74-H-1 went on to penetrate bedrock at 124 metres (406 feet), where thermo-artesian pressures, which had been contained beneath the clay in the overburden, forced a strong flow from the well head. The flow persisted, with minor variations in rate and pressure, to the total depth at 347 metres, as the temperature rose to 60.5°C.

This well was the first strong indication that the quartz diorite, not normally a permeable rock, could have interconnected fractures of adequate net permeability to meet commercial requirements.

Well 75-H-1 was the first drilled after detailing of the resistivity anomaly and was located in the central part of the western portion - - that considered most important. It encountered a slight thermo-artesian flow from well-defined fracture sets (as evident in the disparity between the "equilibrium" bottom-hole measurements and the "open-hole flowing" measurements shown in Drawing D3). The gradient recorded was 112°C/km.

Well 75-H-2 had the highest gradient recorded, 365°C/km. Temperatures increased rapidly to 35.0°C over its total depth of 287 feet. It is located on the southern part of the main resistivity anomaly.

Well 75-H-3 is unique in several respects: It was drilled on a -70° angle from the horizontal (to minimize overburden drilling at the site chosen); the upper part of the well recorded cold ground water flowing past the well into the Meager Creek basin; it intersected extensive volcanic dykes in the bedrock quartz diorite; and the lower parts of the well recorded a high temperature gradient of 289°C/vertical km, which approaches that of 75-H-2.

5.4. Temperature Interpretation

The drill hole data merely scratch the surface over the geothermal system. The productive parts of most systems lie at depths on the order of 5,000 feet. Data from the top 300 feet at Meager Creek require interpretation in light of geology, hydrology and geophysics.

High temperature gradients are ambiguous. In this instance interpretation could range between two extremes: (1) that the gradients persist more or less as straight lines downward to commercial threshholds of 180 or 200°C at depths of 1800 feet, or (2) that the gradients are near-surface features meaning simply that a 70°C hot water reservoir (recalling that this is the highest temperature directly measured to date) lies close to the surface at these points, and holds no commercial promise. These alternatives are discussed in light of other data in Section 8 of this report.

5.5. Temperature Estimating from Geothermal Waters

Waters flowing upward in wells 74-H-1 and 75-H-1 were sampled and analyzed for key elements. These data and analyses of surface thermal and cold waters are presented in Table 2. The reasons for analyzing thermal waters are as follows:-

a) Some trace elements have a memory of the temperature at which the underlying reservoir reached chemical equilibrium with its surroundings.

b) The concentrations and relative amounts of the various chemical constituents in hot spring waters allow the engineer to distinguish families of geologically related waters based on similarities of the chemical fingerprints of those waters.

c) Analyses allow early identification of constituents likely to be deleterious to utilization, e.g. to cause corrosion, scaling, or toxic effects to plant or animal life.

The silica (SiO_2) and sodium-potassium-calcium (Na-K-Ca) geothermometers have been applied to the Meager Creek waters (formulas are given in Appendix E). The results are scattered. However, among 14 values the mode lies between 160° and 167°C and consists of 5 values, three silica and two Na-K-Ca. Five values (mainly silica estimators) are lower and four (all Na-K-Ca) are higher, ranging up to 240°C.

The general application of temperature estimators is subject to a number of assumptions, for example, rapid ascending of the geothermal water without re-equilibration, and minimum or simple mixing with cold ground water.

In this instance waters which should be nearly identical (for example Nos. W 1798 and W 1817, Table 2) show marked divergence in ion concentrations, indicating that re-equilibration or mixing is proceeding independently within a series of relatively small fracture-type reservoirs and conduits.

Since the Na-K-Ca estimator is a ratio it is less sensitive to dilution than the silica estimator, and consequently we assign a higher degree of validity to the higher temperature estimates at Meager Creek. The overall interpretation is to cautiously accept the geothermometers as evidence of commercial temperatures.

All of the thermal waters belong to the same family or derive from a common source. They are characterized by being dilute (less than 5,000 parts-per-million total dissolved solids), slightly acid or neutral, high in chloride (which is also a qualitative high-temperature indicator in this geologic environment), and moderately high in bicarbonate and sulfate.

TABLE 2 - WATER GEOCHEMISTRY AND GEOTHERMOMETERS

Cert. of Analysis	Sample Location	Date Sampled	Est. Flow 1/min.	Measured Temp °C.	p.H.	Analyses in PPM. or Mg/1													Geothermometers	
						SiO_2	Na	K	Ca	Mg	Cl	SO_4	HCO_3	CO_3	Li	Hg	F	Total Diss Solids	SiO_2 °C	Na-K-Ca °C
W 367	Main Vent	5 Jan 74	500	58	6.2	164	450	47	81	25	675	110	468		1.2	0.4	<1.0	1810	167	188
W 416	GSC Drill Hole	29 Mar 74	High	59		151	430	27	85		650		513						162	160
W 1686	Hotspring 79-D	30 Oct 74	Seep	33	6.7	108	150	32	40	7.6	275	76	387	<.01			.245		142	216
W 1686	Meager Creek Water near Hotspring 79-D	30 Oct 74		4		8.3	1.4	0.7	7.8	2										
W 1685	Main Vent	30 Oct 74	500	58	6.6	150	330	54	51	15	600	190	504	<.01			.313		161	213
W 1685	Meager Creek Water near Main Vent	30 Oct 74		4		9.4	5	1.1	6.8	1.8										
W 1798	74-H-1, 406'-877'	31 Jan 75	≥180	55		41.0	910	52.1	150	24.0									93	163
W 1817	74-H-1, 406'-1140'	21 Feb 75	≥180	55	7.34	80.5	2300	90	380			1880	1396	<.1					126	152
W 2034	75-H-1, 65'-300'	18 Sep 75	≥20	10.5		40	20.8	7.8	3.1	14.0	0.3	12	183						92	238
W 2053	$CaCO_3$ Spring	30 Sep 75	>500	8.5	7.96	21.0	3.2	0.16	95.	9.6	0.5	44	278		<.04		.028			

Semiquantitative spectrographic analyses and mercury and fluoride analyses indicate that the thermal waters at Meager Creek are not notably rich in any heavy metal ions, borates, fluoride, or constituents likely to be troublesome or toxic.

A cold mineral spring flows from the base of the volcanic rocks high on the slope of Pylon Peak. This is designated as the "$CaCO_3$ Spring" on maps because it deposits copious calcium carbonate crusts on plant and woody debris and has built up natural ledges and terraces along most of its channel. The relationship of the "$CaCO_3$ Spring" to the geothermal system is not yet known.

5.6. Alteration Minerals

Petrographic studies of core samples by Dr.Peter B. Read (Appendix F) identified products of two periods of regional metamorphism prior to the Meager Creek volcanism, and one assemblage of calcium-rich fracture fillings related to Meager Mountain volcanism and the geothermal system. These fracture fillings consist of calcite and clay minerals, calcium zeolites, and gypsum. In the larger sense these precipitates are low temperature,outer components of a "rind" of plugged fractures around the geothermal system, serving as an impermeable seal.

6.0. GEOLOGIC DATA AND INFERENCES

Geologic mapping, logging, and microscopic study of core samples have been directed toward identifying and assessing the features critical to commercial reservoirs. Reviewing very basic requirements for a geothermal reservoir, they are:-

a) a source of heat at depth,
b) a volume of permeable rock,
c) presence of water in the permeable zones,
d) existence of an impermeable seal around upper parts of the permeable zone.

The heat source clearly exists at Meager Creek. In other volcano-related geothermal fields the heat source is postulated to be a residual chamber of molten or semi-plastic lava at a temperature, for example,of 600°C and a depth of 4 kilometres. At Meager Creek the core of the volcano lies among the mountain peaks (Meager Mountain, Pylon Peak) but the location of the current heat source is not yet known.

Permeability at Meager Creek derives from interconnected, open fracture zones in the quartz diorite. Unlike some other geothermal systems (Yellowstone Park, U.S., Cerro Prieto, Mexico), the observed reservoir rock has no inherent porosity. It is probable, however, that vertical pipes under the volcanic complex or sub-horizontal fragmental units at the base of the volcanic pile provide highly permeable conduits and play an important role.

The quartz diorite reservoir is inferred to be controlled by a wide, east-west trending fracture zone, visible on air photos as projecting through the area concealed by overburden. A similar air photo lineament passes northeast through the eastern part of the anomaly, coinciding with the northeast-flowing part of Meager Creek. Scattered outcrops within the inferred fracture zones show extensive joint sets of more or less random patterns.

Ground water saturates virtually all rocks and unconsolidated deposits in the area. Potential for recharge of the geothermal system is not visualized as a major concern.

The Meager Creek drainage system has a coinciding subsurface hydrologic system which, as inferred to date, also recharges and flows toward the mouth of Meager Creek. We infer that the hydrologic gradient causes the thermal waters to flow south, east, and then northeast through the fractured quartz diorite and overburden toward Well 74-H-1 and the principal hot spring complex.

The outer edge of an impermeable seal is evident in the calcium mineral incrustations in fractures cored by the research wells and in the thick clay beds in the overburden which overlies the reservoir. These are minor components of the sealing system. High temperature quartz fracture fillings might be anticipated at depth.

7.0. OTHER TECHNIQUES

7.1. Refraction Seismic Surveys

Refraction seismic surveys of the type commonly done in civil engineering work were conducted at most of the drill sites in order to ascertain depth to bedrock. Velocities of 10,000-17,500 feet per second were measured in the quartz diorite bedrock, varying inversely with the degree of fracturing.

7.2. Energy, Mines and Resource Passive Seismic Survey

During the time when the camps were being operated Mr.G.C. Rogers, of the Earth Physics Branch, Victoria, installed a seismic recorder to detect earthquakes and micro-earthquakes in the area. Although some micro-earthquakes were recorded, Rogers' study ruled out any association between geothermal activity and micro-earthquakes.

7.3. Energy, Mines and Resources Magnetotelluric Survey

Dr.L.K. Law of the Victoria Geophysical Observatory led a team which conducted magnetotelluric surveys in the Meager Creek, Gold Bridge, Pemberton and Alta Lake regions this past summer. The magnetotelluric method makes use of natural or "telluric" currents in the earth's crust which are generated by magnetic storms. It measures changes in electrical potential and in magnetic fields and by using filters to isolate specific frequencies can provide information on the conductivity at great depth, on the order of 20 kilometres. This type of survey has a very low resolution when compared to the dimensions of a geothermal reservoir. When the results are processed it will, however, provide information on the deep crustal structure through the Lillooet River Valley, but will not pinpoint commercial geothermal features.

7.4. Energy, Mines and Resources, Temperature Gradients

Dr. Trevor J. Lewis, of the Earth Physics Branch, Ottawa, measured temperature gradients in some wells with different instruments. These results have been incorporated and reported along with our own. He also carried out regional studies which included geothermal gradient determinations from available exploration drill holes in the region.

7.5. Self-Potential Survey

Deep Grid Analysis Ltd. conducted a "self-potential" survey concurrent with the resistivity survey. This method measures natural voltage across two points in the ground. Deep Grid Analysis demonstrated that self-potential correlates well enough with the geothermal system and resistivity results to be considered as a future reconnaissance tool (Appendix B, especially drawing 2).

8.0. CONCLUSIONS

8.1. Techniques

The principal tools used in the detailed examination of the Meager Creek geothermal area were electrical resistivity, temperature profiling in four shallow research wells, geochemical analyses of thermal waters from wells and hot springs, and geologic observations and reasoning.

8.2. Findings

Data and inferences from work at Meager Creek are summarized as follows. The geothermal area lies on the south flank of a large complex Quaternary volcano. The known part of the reservoir occupies pervasive fracture zones in a quartz diorite, a granitic type of rock, at the base of the volcanic system.

Electrical resistivity has established a minimum size of two square miles for the reservoir, and suggests that its top is within 300 metres (1000 feet) of the surface, and its base about 600 - 1200 metres (2000 - 4000 feet). It dips north toward the heat source believed to underlie the volcanic complex. Only the eastern and western limits of the reservoir have been established, leaving the northern and southern boundaries undetermined for the present.

The maximum temperature directly measured is about 70°C, in water-saturated Well 74-H-1. These waters and the hot spring waters are considered to be derived from deeper thermal waters and have been cooled and diluted while flowing toward their points of collection. Indirect chemical estimators of reservoir temperature indicate values grouped at 160-167°C and at 235-240°C, points of thermodynamic significance in that the former approximates the point where quartz ceases to precipitate readily from a cooling fluid, and the latter approximates the natural equilibrium temperature of saturated steam.

Geothermal gradients in the bottoms of the shallow wells (from 60-347 metres, or 198-1140 feet deep) ranged from a minimum of 27.7°C/km, or approximately the normal value, on the edge of the system to as much as 365°C/km at the apparent apex of the reservoir.

The Meager Creek ground water basin is saturated at present and has adequate water available for recharge. Permeability of the near-surface rocks permits thermo-artesian flow from wells and fluid communication between fracture sets. The particular assemblages of mineral crusts deposited in fractures in the reservoir rock offer no firm information on the base temperature of deeper parts of the geothermal system but they do imply a capacity for self-sealing at the margins.

8.3. Leading Hypothetical Model

The leading model interpreted for the geothermal system is illustrated in the cross section, Drawing D5, against a background of the data used to arrive at this hypothesis. This model explains the zone of low resistivity by a reservoir inclined to the north. Temperature gradients from Wells 75-H-2 (365^oC/km) and 75-H-3 (289^oC/km) reflect a gradient increasing down-dip and northward.

For reference purposes the hydrostatic and lithostatic pressures are shown at a depth of 800 metres (2700 feet).

The dip of this tabular reservoir may range between 15^o and 35^o. The threshhold commercial temperatures of 180-200^{o}C (350-390^{o}F) may be reached, as shown, at a depth of some 1100 metres (3,500 feet) beneath the surface, or at a point further north and down dip.

The reservoir is controlled by zones of fractures within the quartz diorite and may comprise an outlet for a primary reservoir in a highly porous volcanic neck, which may be present under Pylon Peak.

The fluid in the reservoir would be at sufficiently elevated temperatures and pressures to flow to the surface through a well and flash, in part, to steam. This hypothesis puts forth a commercial hot-water system of the type utilized for generating electricity in Wairaki, New Zealand, and Cerro Prieto, Mexico.

8.4. Alternate Models

Three additional models appear to satisfy some of the information obtained to date. The first of these is shown as an alternate model inset in Drawing D5. The abrupt cut-off of low resistivity values with depth may be due to the existence of a high-resistivity steam-dominated reservoir underlying an electrically conductive reservoir of hot condensate. This phenomenon has been observed in electrical resistivity studies at Yellowstone Park (see Appendix B for discussion). Under these conditions the underlying steam-dominated reservoir would have a temperature above the boiling point. Because of thermodynamic restrictions (see Section 8.5 and Drawing D6) the top of the steam-dominated reservoir would probably be no deeper than 400 metres (1300 feet).

The steam-dominated model is the best explanation for many data, but does conflict with some. Supporting evidence includes Na-K-Ca temperature estimators from different waters (Table 2), which approach and coincide with the 235^{o}C - 240^{o}C equilibrium point for natural saturated steam reservoirs (as established by White, Muffler and Truesdell, 1971). Conflicting evidence is (1) generally high chloride ion content of the thermal waters, which is inconsistent with condensate from a steam-dominated system and (2) that the position required for the top of a steam-dominated reservoir is within 400 metres of the surface, whereas the electrical resistivity survey appears to indicate its ceiling at a depth on the order of 1,000 metres. None of these lines of evidence, however, is sufficiently precise to prove or disprove its existence.

A second alternate working hypothesis is that some combination of the leading model and alternate exists. This might, for example, take the form of a low-pressure, steam-dominated zone at the base of the volcanic complex, at a higher elevation than the known reservoir.

A third alternate model is that the reservoir consists of fluid at sub-commercial temperatures and has a shape more or less as shown for the leading model. This hypothesis would fail to satisfy the geochemical temperature estimators.

8.5. Role of Confining Pressure

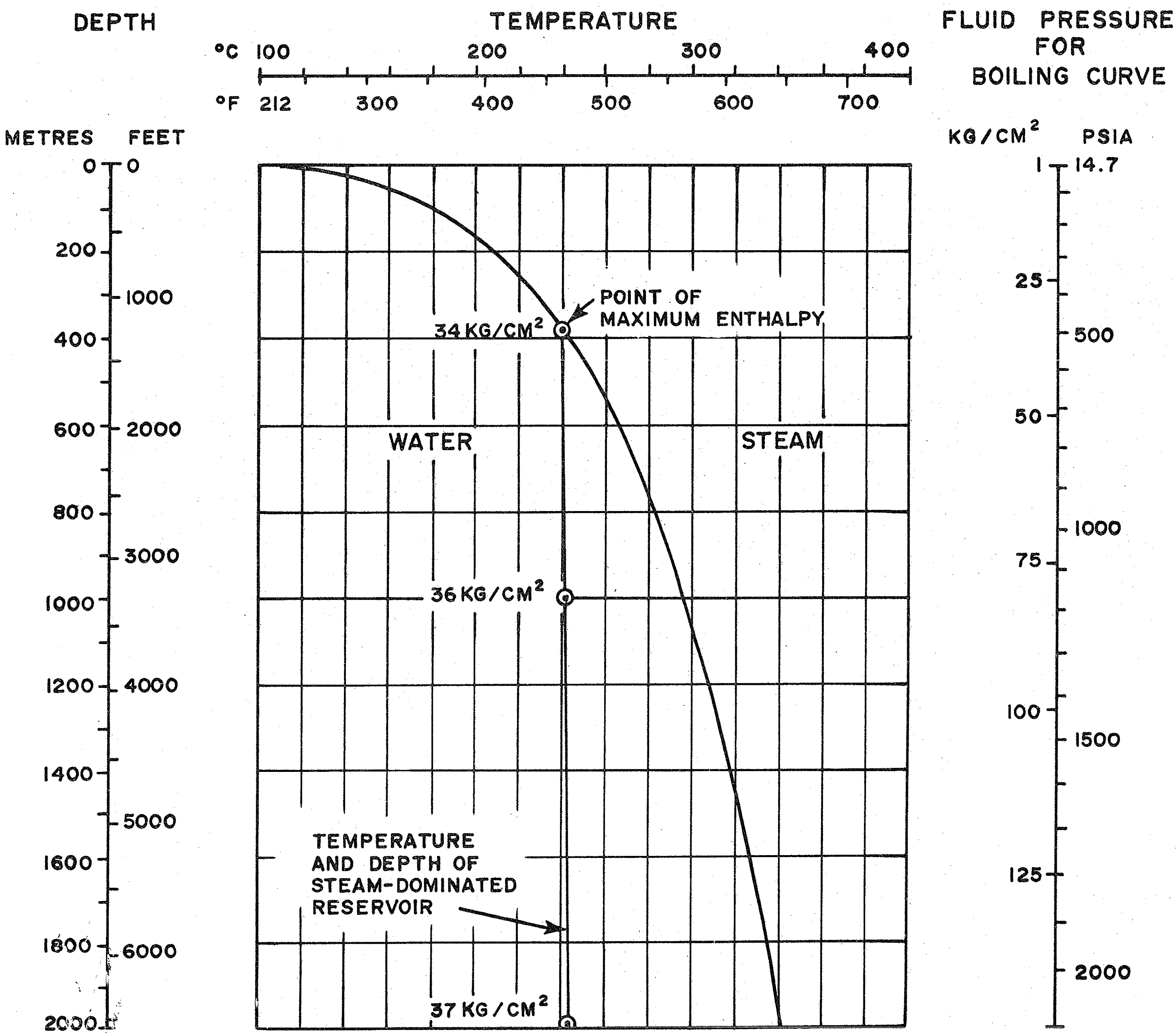
Up to this point our discussion has centred on exploratory considerations, such as the temperature and geometry of the system. We have not discussed the thermodynamics or the commercial implications of the subsurface pressure domains likely to exist in the Meager Creek geothermal system.

Because the water table in the Meager Creek valley is close to the surface, hydrostatic pressure (also called fluid or pore pressure) will increase downward from the surface at a rate equal to that of a column of water corrected for slightly decreasing density with higher temperatures. This rate is approximately 0.09-0.1 Kg/cm^2 per metre (0.39 - 0.43 psi/foot) as shown in the boiling curve, Drawing D6. Thus at a depth of 800 metres (2700 feet) the pressure is about 70 Kg/cm^2 (1000 p.s.i.) as in Drawing D5.

If upper margins of the reservoir are capped by an impermeable or semi-permeable seal, an additional component will be added to the confining pressure from the weight of the overlying rock. (The thermo-artesian flow of water from Wells 74-H-1 and 75-H-1 illustrates this phenomenon in the near-surface environment: total confining pressure exceeds the hydrostatic pressure to a minor degree, and the column of fluid is forced upward). This excess, or "lithostatic" pressure, could approach a value of about 2.7 times the normal hydrostatic pressure.

In a hot-water system, the fluid exists in the liquid state in the reservoir at temperatures ranging from 180°C to 300°C or more and at pressures which can exceed 100 Kg/cm^2.

TEMPERATURE—DEPTH RELATIONS OF GEOTHERMAL SYSTEMS



Adapted from (1) California Division of Oil and Gas
(2) White, Muffler, Truesdell.

DRAWING D6

In general a lithostatic pressure component derived from a seal is needed to lift the column of hot water up the well bore, where the delivery pressure is reduced mechanically and a portion of the fluid boils, or "flashes" to steam.

The steam-dominated system is subject to a peculiarity in the thermodynamics of low temperature steam. The point at which a saturated steam (or water and steam coexisting in equilibrium) has maximum heat content is 240°C and 34 Kg/cm^2 (460°F and 460 p.s.i.). It stands to reason that a natural system would exist as a saturated steam, rather than a superheated steam, and it has been observed (White, Muffler and Truesdell, 1971) that the steam-dominated reservoirs at the Geysers, California, and Larderello, Italy, lie at this point. This means that the steam reservoir cannot exist at a pressure substantially more than 34 Kg/cm^2, or, in other words at a depth of more than 400 metres below the water table. Reservoir temperature, pressure and depth relations are indicated in Drawing D6.

Applying this to the Meager Creek geothermal system, where the observed water table is near surface, the top of a steam-dominated system, should one exist, could occur no deeper than about 400 metres. The thermal profile of a drill hole approaching this depth should then increase from about 15°C at the collar to 240°C at 400 metres, or along an overall gradient of about 560°C/km.

8.6. Suggestions for Continued Work

The evidence available at the present time strongly suggests the existence of a geothermal reservoir in the commercial class which warrants a deep, large-diameter, exploratory well. At the present time, however, not enough information is available on the geothermal system to pinpoint the exact site for the exploratory well, nor to anticipate the depth of a productive zone. To obtain this information more indirect testing or geophysical work is required.

We suggest the following steps:

1) Detailed geologic mapping of the entire Meager Mountain volcanic complex and subjacent quartz diorite;

2) Self-potential and follow-up resistivity surveys on a reconnaissance basis to scout the east, north, and west sides of the Meager Mountain volcanic centre for obscure extensions of the geothermal system;

3) A deep-looking resistivity survey to inspect the subsurface north and south of the main geothermal reservoir and test for direct extensions, tentatively using an unusual electrode array - - the "gradient array" - - to accommodate steep and rugged topography;

4) Approximately 1000 feet of new thermal research wells, on sites which have not been identified, but anticipated to lie high on the mountain in the floors of cirques;

5) A provision for evaluation and demonstration of geophysical methods not yet employed at Meager Creek, such as an electromagnetic method now being refined by Energy, Mines and Resources under private research contract, or a similar method tested successfully in American geothermal areas by the U.S. Geological Survey.

We would anticipate completion of indirect testing in the summer of 1977. At that time, should the evidence continue to favour a commercial system, appropriate steps would include:

1) Locating and drawing up specification for a deep exploratory well;

2) Inviting tenders and scheduling a rotary drill;

3) Designing and constructing an access and service road;

4) Drilling and logging the well.

8.7. Ultimate Potential

Estimates of the ultimate potential capacity and judgements on the commercial feasibility will require more information. Capacity depends on factors unknown at present: temperature, pressure and heat content of the fluid, depths of productive zones, permeability of the reservoir rock, and the areal extent of the reservoir. We would guess that if the base temperature of the reservoir is found to exceed 180°C, the capacity might be in multiples of hundreds of megawatts. Feasibility would depend, of course, on specific engineering studies conducted in the future, when all aspects of the geothermal system are understood.

Respectfully Submitted:

NEVIN SADLIER-BROWN GOODBRAND LTD.

November 30, 1975.

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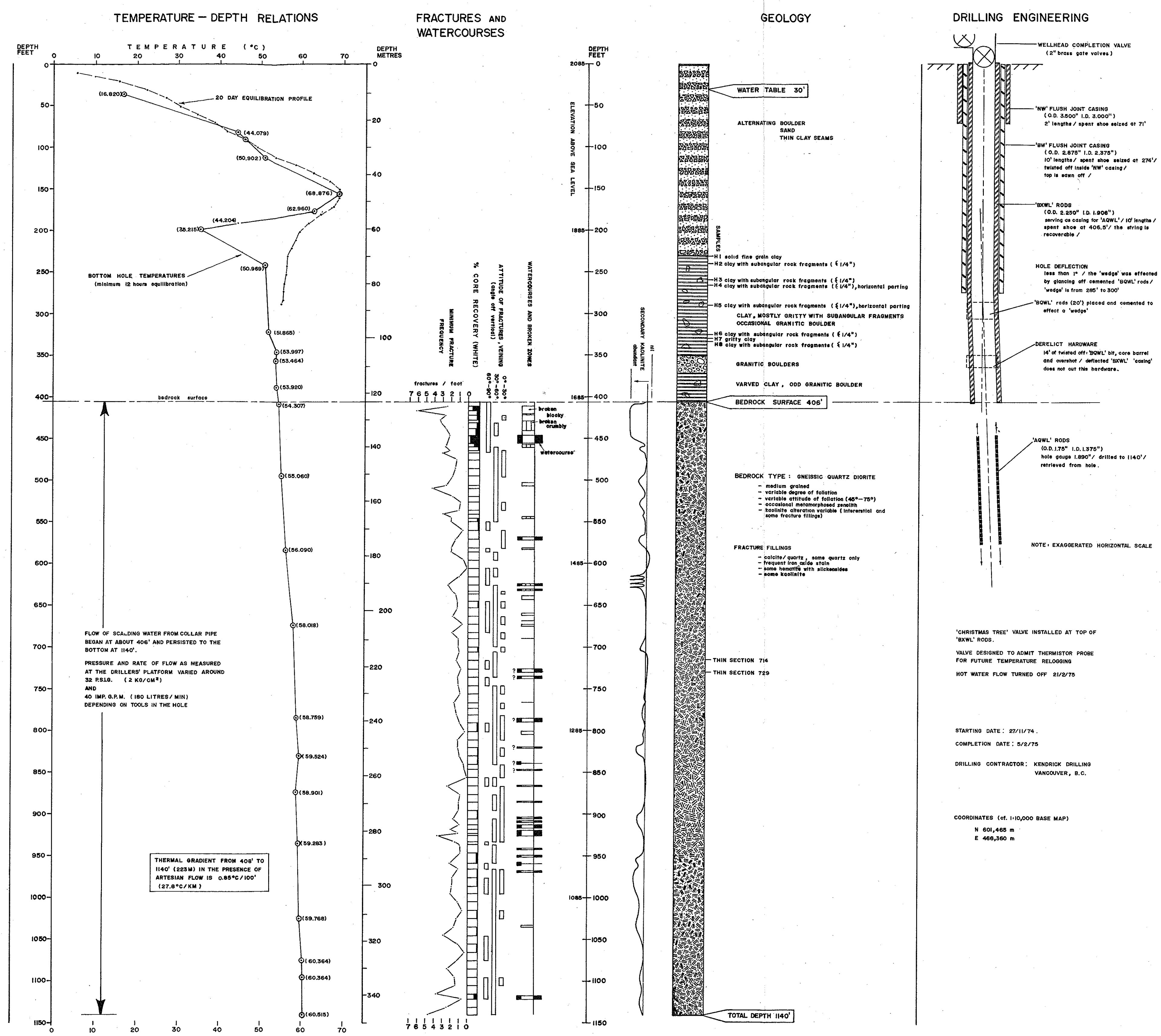
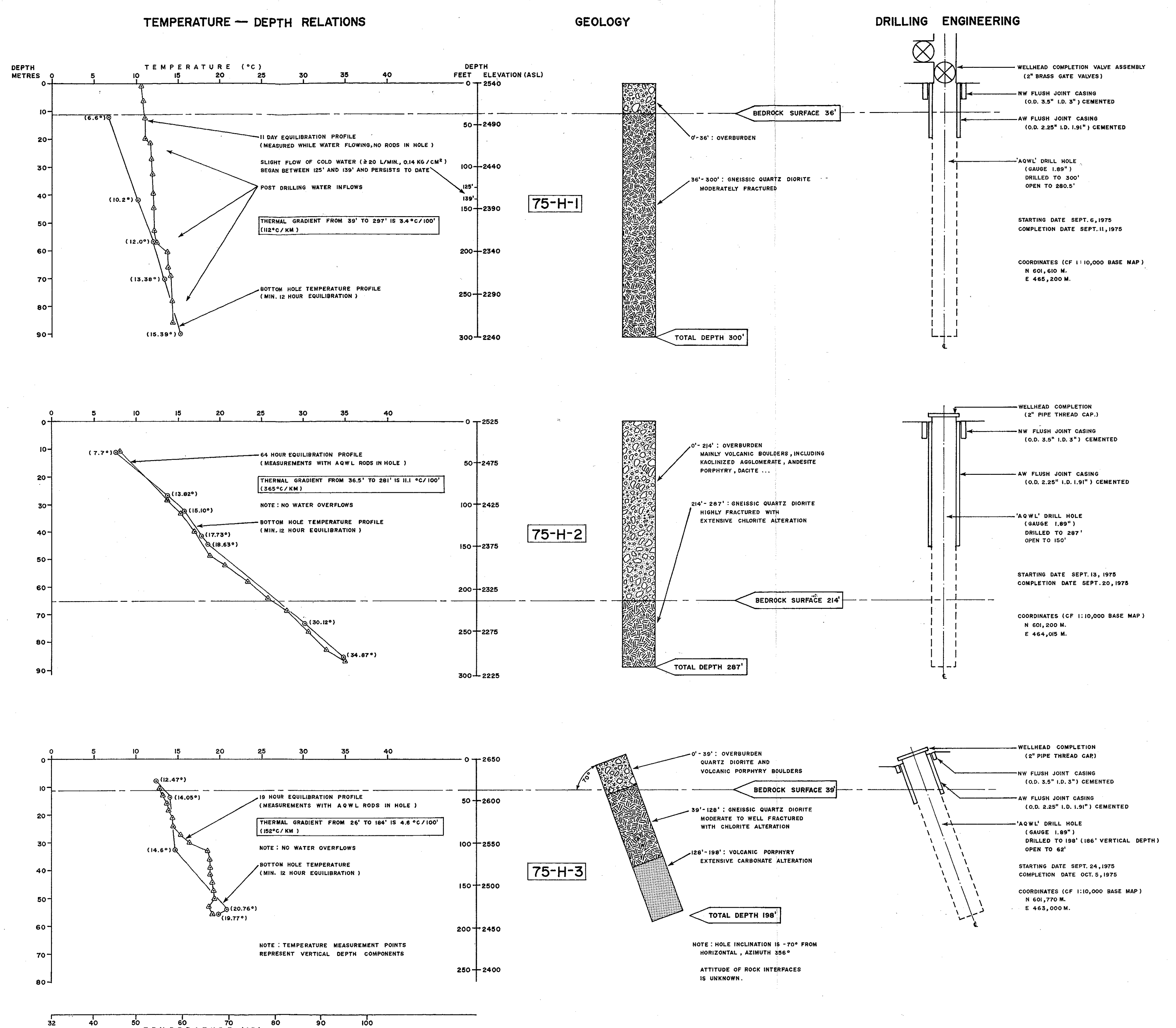
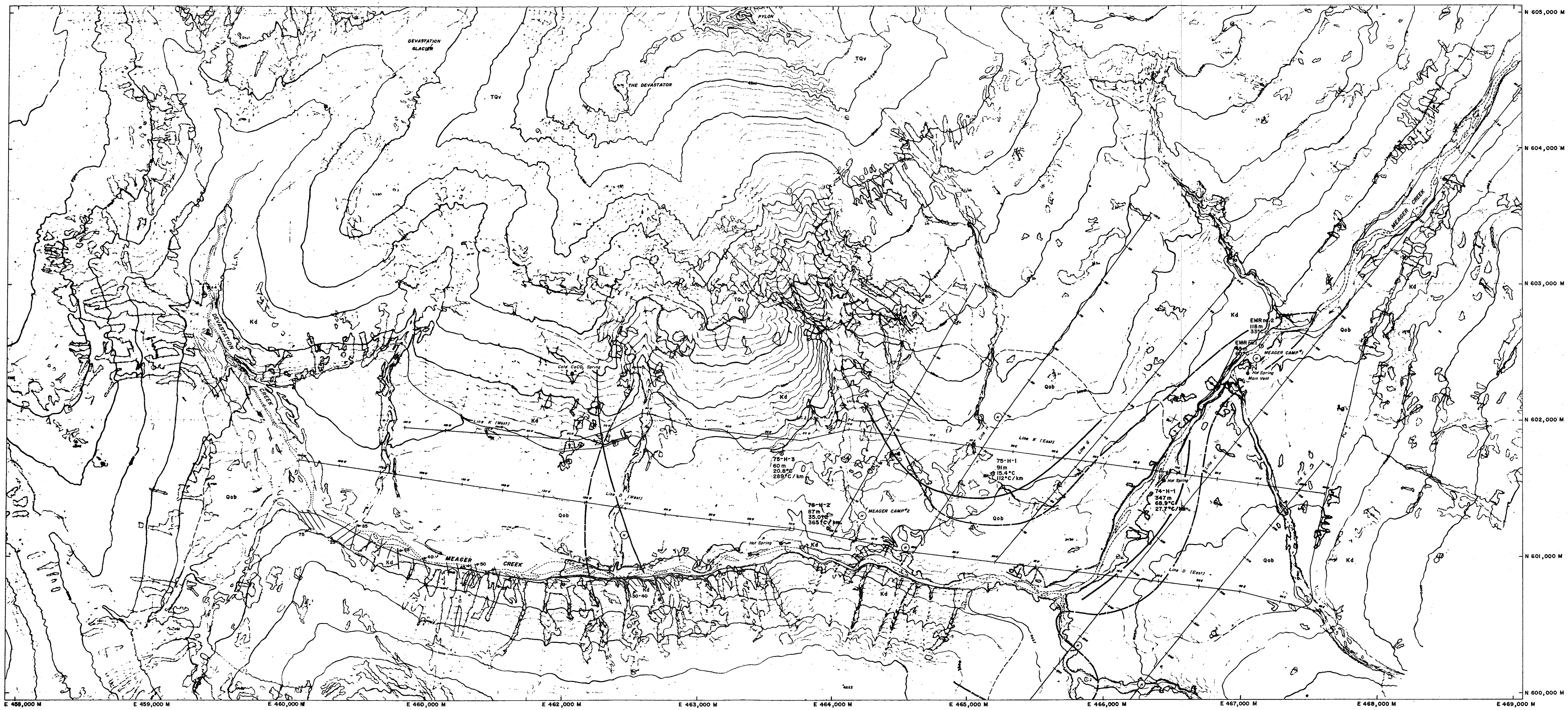
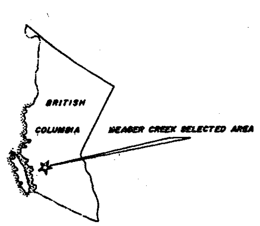


NEVIN SADLIER-BROWN GOODBRAND LTD. CONSULTING GEOLOGISTS · VANCOUVER, B.C.	B.C. HYDRO AND POWER AUTHORITY
TYPE/DATE SURVEY-	LOG OF RESEARCH WELL 74—H—1
TO ACCOMPANY REPORT: INTERIM PROGRESS REPORT MARCH 31, 1975	GEOTHERMAL INVESTIGATION
BY: JTC / DATE: MAR 1975	MEAGER CREEK SELECTED AREA, B.C.
REVISED: 11/75	SCALE: AS INDICATED / DWG. NO. D2



NEVIN SADLIER-BROWN GOODBRAND LTD. CONSULTING GEOLOGISTS VANCOUVER, B.C.	B.C. HYDRO AND POWER AUTHORITY
TYPE/DATE SURVEY-	LOG OF RESEARCH WELLS 75-H-1,2,3
TO ACCOMPANY REPORT: NOVEMBER, 1975	GEOTHERMAL INVESTIGATION
BY: J.T.C, A.E.N. DATE: 11/75	MEAGER CREEK SELECTED AREA, B.C.
	SCALE: AS INDICATED DWG. NO. D3





DRILLING

B.C. HYDRO RESEARCH WELL

- ⊙ — location of well
- 74-H-1 — designation of well
- 347 m — total depth in metres
- 68.9°C — maximum temperature
- 27.7°C/km — thermal gradient at bottom

ENERGY, MINES AND RESOURCES WELL

- ⊙ — location of well
- EMR no. 1 — designation of well
- 45 m — total depth in metres
- 60°C — maximum temperature

NOTE: Wells 75-H-3, EMR no. 1 and no. 2 were drilled at angles

ELECTRICAL RESISTIVITY

80W — 60W, LINE D — SURVEY LINE AND STATIONS

OUTLINE OF KNOWN GEOTHERMAL (LOW RESISTIVITY) ZONES:

- at shallow depths — less than 2000 ft. (610 m)
- at greater depths — 2000–8000 ft. (610 m – 2440 m) where surveyed on lines D and K

L E G E N D

GEOLOGY

- Qob — OVERBURDEN — glacial gravels and clays colluvium, alluvium. Quaternary
- TQv — VOLCANIC ROCKS — rhyodacite to andesite in composition; flows and fragmental units. Tertiary? & Quaternary.
- Kd — QUARTZ DIORITE — and undifferentiated lamprophyre dykes and metavolcanic pendants. Cretaceous.

NOTE: Unmapped areas are blank.

- 20 — contact with dip
- inferred contact
- 85 — fracture zone with dip
- fault

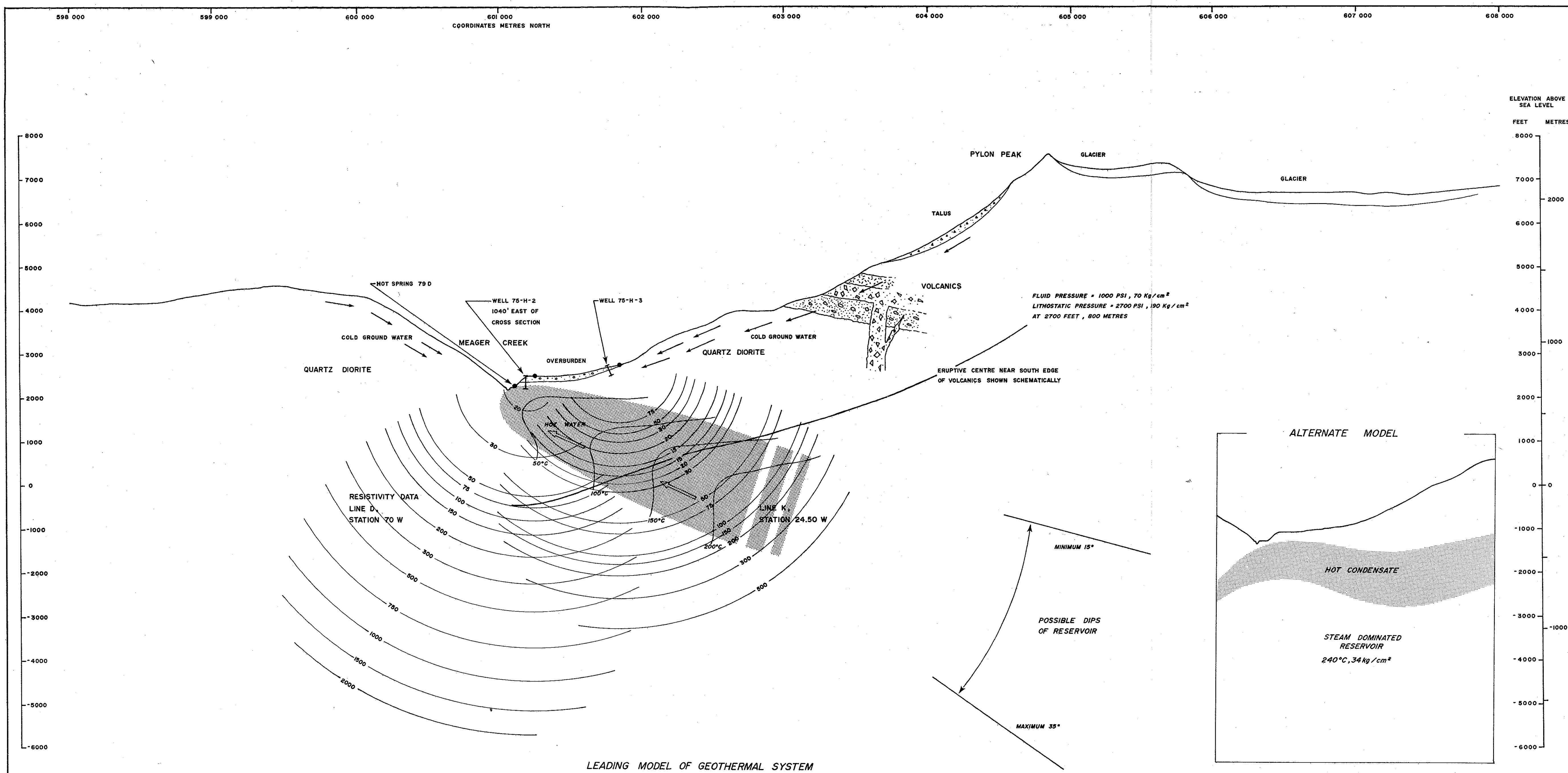
CONTOUR INTERVAL 100 FT.

SCALE

0 — 1000 — 2000 — 3000 — 4000 Feet

(H) HELICOPTER PAD

NEVIN SADLIER-BROWN GOODBRAND LTD. CONSULTING GEOLOGISTS · VANCOUVER, B.C.		B.C. HYDRO AND POWER AUTHORITY
	TYPE/DATE SURVEY-	SUMMARY MAP
	TO ACCOMPANY REPORT: NOVEMBER, 1975	GEOTHERMAL INVESTIGATION
	BY: AEN, JTC / DATE: NOV. 1975	MEAGER CREEK SELECTED AREA B.C.
		SCALE: HORIZ. AS INDICATED / DWG. NO. D4



LEADING MODEL OF GEOTHERMAL SYSTEM

TEMPERATURE GRADIENTS ADAPTED FROM WELLS

CROSS-SECTION LOOKING WEST NEAR
COORDINATES 464,000 E

NEVIN SADLIER-BROWN GOODBRAND LTD. CONSULTING GEOLOGISTS VANCOUVER, B.C.		B.C. HYDRO AND POWER AUTHORITY
	TYPE/DATE SURVEY: TO ACCOMPANY REPORT: NOVEMBER, 1975	MODEL OF GEOTHERMAL SYSTEM IN CROSS-SECTION
		GEOTHERMAL INVESTIGATION
	BY: A.E.N. DATE: 11/75	MEAGER CREEK SELECTED AREA B.C.
		SCALE: AS INDICATED DWG. NO. D5