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Meager Creek Geothermal Project —

An exploration case history

by

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Deep drilling and production testing to assess the reservoir as a potential power source will be initiated during 1981.

Introduction

The Meager Creek Geothermal Project area is located 160 km northwest of Vancouver. It is associated with the Pliocene to Recent Meager Mountain Volcanic Complex (Figure 1).

Meager Mountain is the northernmost volcano of the Garibaldi Volcanic Belt (Souther, 1976). The Garibaldi Belt is an extension of the High Cascade volcanos into Canada.

This paper describes the South Reservoir, an area of fractured crystalline and metamorphic

(Editor's Note: The following articles and photographs are a direct result of the Geothermal Resources Council's symposium on the "Geothermal Potential of the Cascade Mountain Range," held in Portland, Oregon May 19-22, 1981.

This highly informative and successful function also featured a field trip to the Meager Creek geothermal project area in British Columbia.)

Abstract

The South Reservoir in the Meager Creek Geothermal Area is within crystalline basement rocks on the southern flank of the Pliocene to Recent Meager Mountain Volcanic Complex.

Geological, geochemical and resistivity surveys were used to determine targets for temperature gradient diamond drilling. Temperature profiles indicate anomalously high temperature gradients in drill holes M2, M3, M4, M6, M7, M8, M10, M11 and M12.

Heat flow values of 105-620 mWm⁻² (2.5-14.8 HFU) have been calculated for drill holes M2, M3, M7, M8, M11 and M12. These values are up to seven times the regional heat flow for the Garibaldi Volcanic Belt.

The main South Reservoir thermal anomaly has been defined over an area about 3 km by 1 km in the Meager Creek valley. The anomaly is open to the north and southeast.

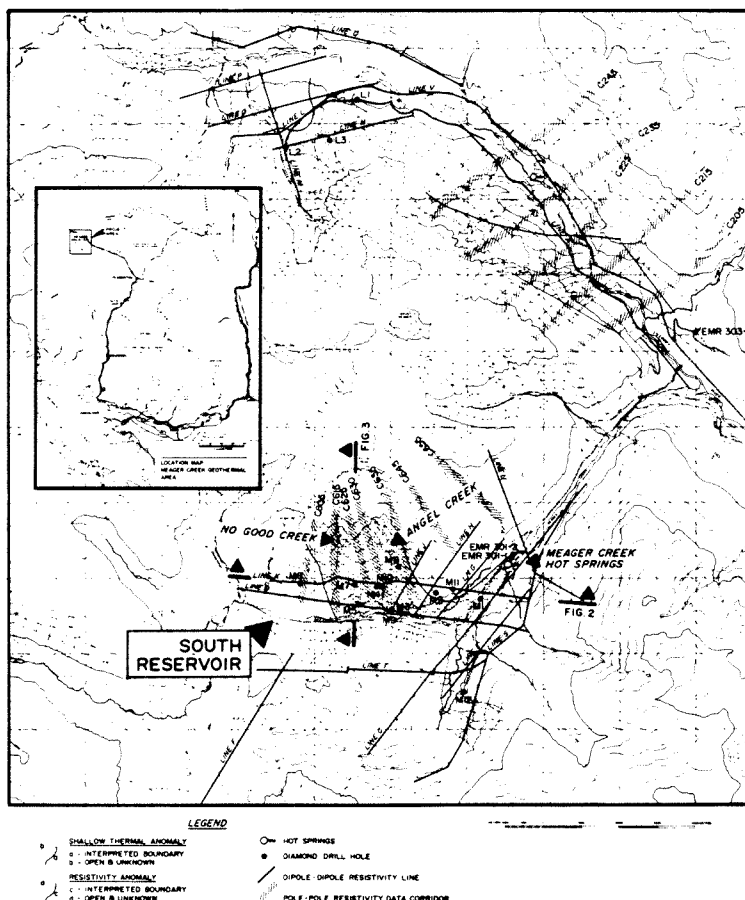


Figure 1. General location map and summary of resistivity and diamond drill coverage

basement rocks on the southern flank of the Meager Volcanic Complex.

The project is operated by B.C. Hydro and Power Authority, a provincial government public utility. Nevin Sadlier-Brown Goodbrand Ltd. has acted as exploration consultants for B.C. Hydro since the work commenced in 1973 (Nevin and Sadlier-Brown, 1972).

The Geological Survey of Canada and Earth Physics Branch of the Department of Energy, Mines and Resources (EMR) have conducted various independent research studies at Meager. These studies generally complement applied exploration by B.C. Hydro.

Standard exploration techniques have been modified to accommodate the rugged terrain, high precipitation and remoteness of the area. Geological mapping, spring water geothermometry, isotope hydrology, radon and soil mercury, airborne infrared scanning, resistivity, self-potential, microseismicity and magnetotelluric techniques have been applied along with temperature gradient drilling utilizing diamond drilling equipment (Nevin et al., 1978).

Emphasis during the initial exploration phase was on geological and geochemical studies. For detailed evaluation of potential target areas, detailed geologic mapping and structural analysis, resistivity surveys, and diamond drilling have proved to be the most useful exploration techniques.

Geology

The volcanic complex and adjacent basement terrane has been mapped by Read (1979).

The basement consists mainly of Mesozoic to early Tertiary crystalline and metamorphic rocks of the Coast Plutonic Complex. It also includes high-level, quartz monzonite plutons as young as late Miocene.

A post-Miocene erosion surface of high relief separates the basement rocks from the overlying volcanic complex. The volcanic edifice itself is a deeply dissected, glacier-covered complex of overlapping andesite, dacite and rhyodacite piles. These piles become progressively younger from south to north.

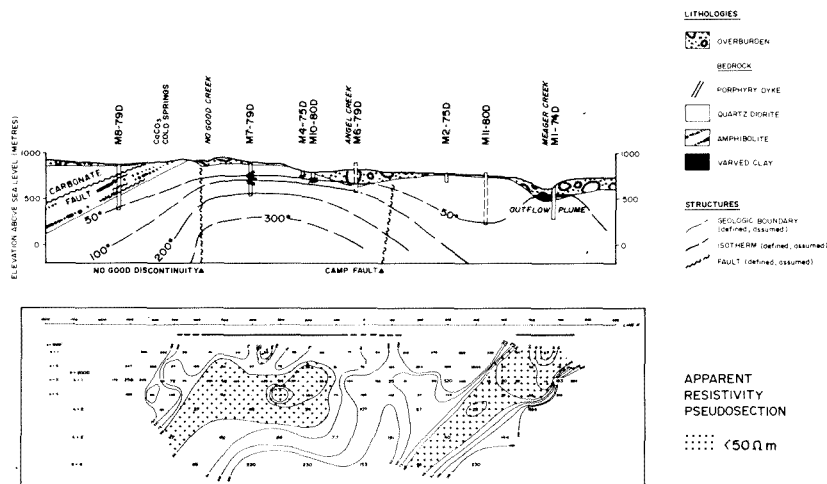


Figure 2. Longitudinal section through South Reservoir

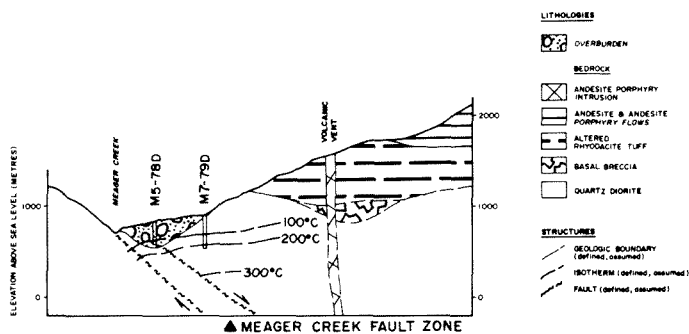


Figure 3. Cross-section through South Reservoir

The earliest (1.0 Ma) episode of volcanism occurred on the south flank of the complex immediately north of current drilling in the South Reservoir. It includes an extensive basal breccia of dominantly plutonic blocks overlain successively by porphyritic andesite flows and breccia, porphyritic dacite flows and breccia, and hydrothermally altered rhyodacite tuff, flows, and breccia (Devastator Assemblage).

The intense brecciation and alteration indicate that the initial eruption was explosive and that it was followed by prolonged hydrothermal activity. Subsequent, successively younger eruptions form a stratavolcano of andesite, dacite and rhyodacite flows, breccias and subvolcanic intrusions 12 km across.

The last volcanic eruption of welded block and ash flows occurred approximately 2550 years ago. This eruption was from

a vent on the north side of the complex. Ash from this eruption (airfall tephra, the Bridge River Ash) is similar in morphology and extent to the May 18th, 1980 St. Helen's Ash.

The South Reservoir area is underlain by weakly foliated Cretaceous quartz diorite. This contains tabular and wedge-shaped pendants of banded amphibolite, migmatite, greenstone and quartzofeldspathic gneiss.

Intrusive contacts are gradational. Quartz diorite and metamorphic rocks are affected by pervasive propylitic (chlorite, epidote, carbonate and albite) alteration and local silification.

Hypabyssal dikes of light-green, dacitic, feldspar porphyry and milky-white aphanitic rhyolite correlated with volcanics on Pylon Peak cut basement rocks. Most of them display a strong pervasive clay-carbonate-

quartz-chlorite alteration that partially obscures original textures.

Mineral precipitates in fractures include silica, kaolinite and other clays, calcite, dolomite, gypsum and barite. A crude zoning of precipitated minerals upward and outward from the near-surface thermal anomaly appears to exist.

Silica precipitates occupy a central position. They are surrounded by peripheral zones of clay-carbonate, carbonate and gypsum.

Structural control of the reservoir configuration is provided mainly by faults and fractures along which hydrothermal fluids are localized.

Of particular importance are the Carbonate Fault (Figure 3) and the Meager Creek Fault (Figure 4). The Carbonate Fault strikes 160° and dips 60° southwest near the western boundary of the near-surface thermal anomaly. The Meager Creek Fault strikes east-west along Meager Creek and dips approximately 40° north.

The Meager Creek Fault is a relatively young extensional

feature. It has about 500 m of normal dip-slip movement possibly related to subsidence.

In addition, young volcanic dikes (intersected in drill holes) are commonly emplaced along faults and/or zones of weakness with evidence of post-dike movement. Faulted and/or broken, permeable zones associated with hypabyssal dikes are up to 20 m wide.

The dominant joint attitudes in the South Reservoir area are $130^\circ/60^\circ$ SW (parallel to foliation attitudes and the Carbonate Fault) and 020° /vertical. Various other attitudes are important over smaller areas within the South Reservoir area.

Fractures striking east-west and dipping 40° N (parallel to the Meager Creek Fault) occur in exposures along Meager Creek. They also occur on the slope of the Meager Creek valley between No Good and Angel Creek. These fractures are of particular interest with respect to the reservoir configuration (see **Reservoir Model**).

The generally regular joint pattern breaks down and becomes random in the area of the north-south trending No Good Discontinuity (Figure 3). Here one set of north-south near-vertical fractures is prevalent.

Geochemistry

In early assessment work, spring water chemistry was used to obtain reservoir temperature estimates. These estimates were $59\text{--}166^\circ\text{C}$ using the silica geothermometer (Fournier and Rowe, 1966) and $96\text{--}250^\circ\text{C}$ using the Na-K-Ca geothermometer (Fournier and Truesdell, 1973).

A stable isotopes study of oxygen isotope fractionation between SO_4 in solution and water similarly indicates a low temperature ($< 150^\circ\text{C}$) shallow origin for most of the waters studied (Fritz *et al.*, 1980). A study at Meager by Hammerstrom and Brown (1978) determined that the spring waters are in equilibrium with near-surface rock alteration assemblages.

Water chemistry is complicated by mixing relationships between reservoir fluids and voluminous but variable surface runoff. Thermal water at the Meager Creek main hot springs is believed to have migrated up to 5

km from the source area within crudely stratified colluvium greater than 250 m deep in the Meager Creek channel. Thus the calculated temperatures must be viewed with discretion.

The stable isotopes study also indicates that the water samples have a residence time of at least 25 years (Fritz *et al.*, 1980).

The majority of springs are dilute Cl-dominated waters with 200-2000 ppm total dissolved solids (TDS). Two drill holes yielded artesian flows which had TDS of 6000-10,400 ppm and high boron contents of 22-28 ppm. These two samples were obtained from the deepest part of the system. They are the best candidates obtained to date for a representative geothermal fluid.

Pilot radon gas (Track-Etch) and mercury soil surveys conducted in 1978 detected local anomalies. However, deep groundwater-saturated overburden effectively suppresses response over most of the area. This reduces the applicability of these surveys as a reconnaissance tool in the Meager environment.

Mercury content was found to be dependent on soil type, proportional to organic content. However, soils are extremely variable and consistent sampling becomes a limited factor in survey design.

Radon is associated with thermal water at the Meager Creek main springs.

Resistivity

Resistivity surveys of two types, dipole-dipole and pole-pole, have been conducted (Figure 1; Shore, 1975, 1978).

For dipole-dipole surveys, dipole surveys, dipole spacings ("A") of 300 m and dipole separations ("NA") of N=1 to 8 are currently used.

Because of the rugged terrain and inability to lay out straight lines of suitable lengths, dipole-dipole work was confined mainly to the valleys or to slopes parallel to valleys.

The pole-pole resistivity technique has been used to overcome terrain restrictions (Shore, 1978). This technique has one each of the current and potential electrode pairs placed at electrical infinity and corresponding active current and

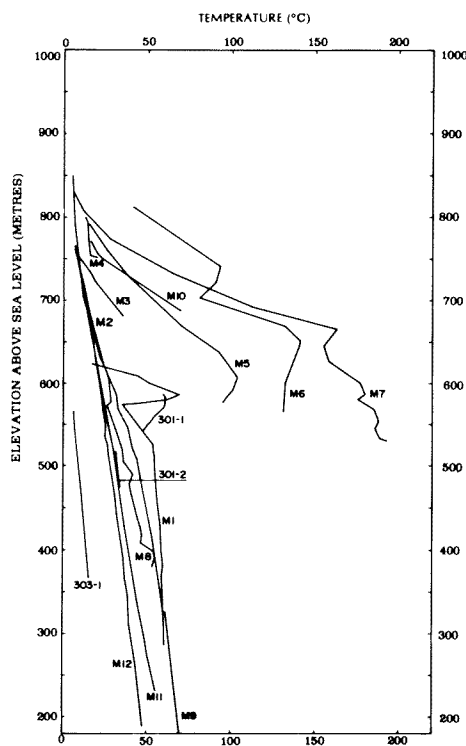


Figure 4. Temperature profiles, South Reservoir

potential electrodes positioned in the survey area.

Interpretation of resistivity data must take into account water-saturated conductive overburden and significant topographic effects.

The coincidence of resistivity anomalies along lines K and D with the high-temperature zone determined by drilling (Figures 1 and 3) is striking. Apparent resistivities between 14 and 50 $\Omega \cdot m$ are measured across the thermal anomaly against a background of 250-1000 $\Omega \cdot m$. Absolute resistivity values of 50 $\Omega \cdot m$ in the anomalous zone and 500 $\Omega \cdot m$ background (10:1 ratio) are interpreted from apparent values.

Pole-pole results confirm that the resistivity anomaly extends northward toward Pylon Peak up to the point where deep response is masked by conductive volcanic units at surface. East and west of the shallow thermal anomaly shown in Figure 1, the subsurface is relatively non-conductive ($>500 \Omega \cdot m$).

Drilling

Fourteen diamond drill holes have been drilled in the South Reservoir area (Lewis and Souther, 1978; NSBG 1974-1981). Helicopters were used for mobilization and camp support until road access was established in late 1978.

Holes are drilled with HQ and/or NQ bits for a hole diameter of 96 and/or 76 mm respectively. Depths are routinely 300-600 m. Blowout-prevention equipment is installed whenever temperatures are encountered over 100°C.

Holes are drilled primarily for temperature profiles. Temperatures are measured daily on bottom following an eight-hour static period between shifts. Additional temperature traverses are run following hole completion.

The continuous core sample recovered in diamond drilling is extremely useful in determining lithological distribution, interpreting, alteration and mineral precipitate patterns, and in obtaining rock samples for geochemical and other studies.

A near-surface thermal anomaly has been detected by drilling as shown in Figure 1. The eastern "tail" of the anomaly is

interpreted as an outflow plume from the main reservoir.

Temperature profiles (Figure 2) indicate anomalously high temperature gradients in M2, M3, M4, M6, M7, M8, M10, M11 and M12. Heat-flow values of 105-620 mWm⁻² (2.5-14.8 HFU) have been calculated for M2, M3, M7, M8, M11 and M12 (NSBG, 1981). These values are up to seven times the regional heat flow determined for the Garibaldi Volcanic Belt (Lewis and Jessop, 1981). Calculated heat-flow values of 1150 and 1730 mWm⁻² (27.5-41.3 HFU) for M6 and the upper part of M7 are considered to be strongly influenced by convective heat transfer.

Drill holes M5 (entirely in overburden) and M1 have temperature inversions due to lateral hot fluid movement within the overburden. At M1, hot water is produced under artesian conditions from a confined aquifer between two varved clay horizons.

The highest temperature recorded to date is from hole M7 (Figure 5). A temperature of 192.7°C was recorded at a total depth of 367 m eight hours after completion and 202.2°C following a two-week static period.

Minor hot-water inflows are suggested by the temperature profile. It also suggests rock alteration at depths of 230 m, 295 m and 330 m corresponding to temperatures of 160°C, 175°C and 185°C respectively. These zones are coincident with fractured and broken intervals as indicated on the rock quality log (Figure 5).

Temperatures in the bottom section of M7 are increasing at a rate of 330°C/km.

In the fall of 1980, an attempt was made to flow the well. Although it flashed, production was not sustained. Efforts were further thwarted by cold water inflows below the casing in the upper part of the hole.

Reservoir Model

A shallow thermal anomaly has been defined by drilling over an accessible area of about 3 km by 1 km in the Meager Creek valley.

The west boundary of the thermal anomaly and possibly the reservoir is coincident with and influenced by the Carbonate Fault (Hole M8, Figure 3) and/or the No Good structural discontinuity (Figure 3). The nature of the east boundary is unknown. The north boundary is open into the mountain.

Work is currently under way to assess areas southeast of the known shallow thermal anomaly (Figure 3).

The South Reservoir is believed to be roughly tabular and dipping into the mountain towards Pylon Peak. Meager Creek Fault and parallel fractures act as major controls (Figure 4). This general pattern may be distorted by other dominant fracture directions and/or major faults.

In conclusion, temperatures adequate for electric power generation from a water-dominated reservoir are apparent. However, the degree of fracture permeability at depth and recharge to enable sustained production are yet to be determined.

At shallow depths penetrated so far by drilling, permeable zones

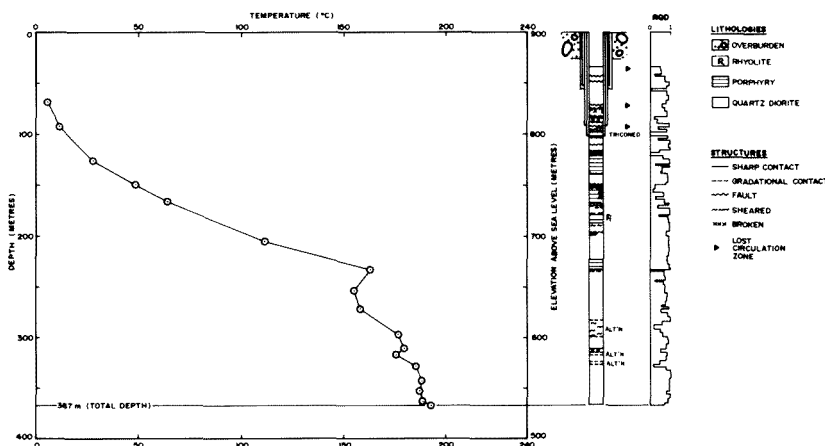


Figure 5. Temperature profile and graphic log - M7-79D

associated with volcanic dikes, fractures, and faults are common.

Warm and hot fluid migration along discrete structural zones and convective heat transport on a larger scale have been documented by the temperature profiles and geologic logs in drill holes.

Deep drilling and production testing to assess the reservoir as a potential power source will be initiated during 1981.

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