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Geochemistry of the Meager Creek Geothermal Field, British Columbia, Canada

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Abstract

The geochemistry and mineralogy of drill core and discharge sinters from the Meager Creek geothermal field suggest that at least two hydrothermal events have affected this area. The earliest of these events is characterized by chalcopyrite mineralization and widespread propylitic alteration of the crystalline rocks which form the geothermal reservoir. A younger event resulted in the deposition of silica, pyrite, clays, carbonate, and hematite in hypabyssal dikes of the Meager Mountain Volcanic Complex and appears to be related to the present geothermal system.

The distributions of Hg + Zn + As, and of Hg and Sr are diagnositic of geothermally altered rocks at Meager Creek and suggest that fractures related to the dikes have been important fluid channels in the past.

Introduction

During the past five years, multielement investigations of geothermally altered rocks have proven to be an effective technique for mapping zones of fluid flow and the temperature distributions in active thermal systems (see for example Bamford and others, 1980; Christensen, 1980; Moore and others, 1982; Christensen and others, in press). These studies have dealt primarily with geothermal systems of the Basin and Range. Similarly detailed investigations of hydrologically complex terraines such as those which characterize the Cascades are, however, lacking.

This paper presents the results of a reconnaissance geochemical investigation of core, discharge precipitates, and thermal waters from the Meager Creek geothermal field, located about 120 km north of Vancouver on the southern flank of Mt. Meager in British Columbia, Canada. The investigation was designed to test the applicability of using trace element distributions in the reservoir rocks at Meager Creek to help guide the ongoing exploration programs. The investigation was funded by the B.C. Hydro and Power Authority and by the DOE/DGE under contract DE-AC07-80ID12079.

Analytical Procedures

The analytical work described here was directed toward documenting trace element distributions developed within rocks of the Meager Creek thermal field. Whole-rock trace element determinations were made on 270 samples of drill core taken at 10 or 20 m intervals from six wells. Each sample represents 0.5 m of core. These data were supplemented by chemical analyses of the thermal waters, well and hot spring deposits and veins contained within the core.

The concentrations of Na, K, Ca, Mg, Fe, Al, Ti, P, Sr, Ba, Cr, Mn, Co, Ni, Cu, Mo, Pb, Zn, Ag, Li, Be, Zr, La, and Ce, were determined in each of the samples by inductively coupled argon plasma (ICP) spectrometry. In addition, the solid samples were analyzed for Hg by gold film detector and As was determined colorimetrically.

Geology

The country rocks of the Meager Creek geothermal system consist predominantly of fractured crystalline and metamorphic rocks of the Mesozoic Coast Range Plutonic Complex. Isolated outcrops of the basement rocks occur in the geothermal area but elsewhere they are overlain by lava flows, breccias and tuffs of the Pliocene to Recent Meager Mountain Volcanic Complex (Fig. 1). The geological relationships have been described by Read (1979) and Fairbank and others (1981). The subsurface geology has been studied and summarized by Read (unpublished data) and Nevin/Sadlier-Brown/Goodbrand Ltd. (unpublished lithologic logs).

To date, fifteen diamond drill holes and three deep rotary wells have tested various portions of the geothermal field. The six diamond drill holes chosen for this study provide an illustrative cross section of the thermal anomaly (Fig. 2). Two of these wells (M7-79D and M10-80D) are located in the central portions of the anomaly, two (M13-81D and M9-80D) are located on the high-temperature margins, and two (M8-79D and M12-80D) are located in the cooler, peripheral portions of the anomaly. Well M7-79D recorded the highest temperature (202°C), and both M7-79D and M12-80D produced small quantities of thermal fluid.

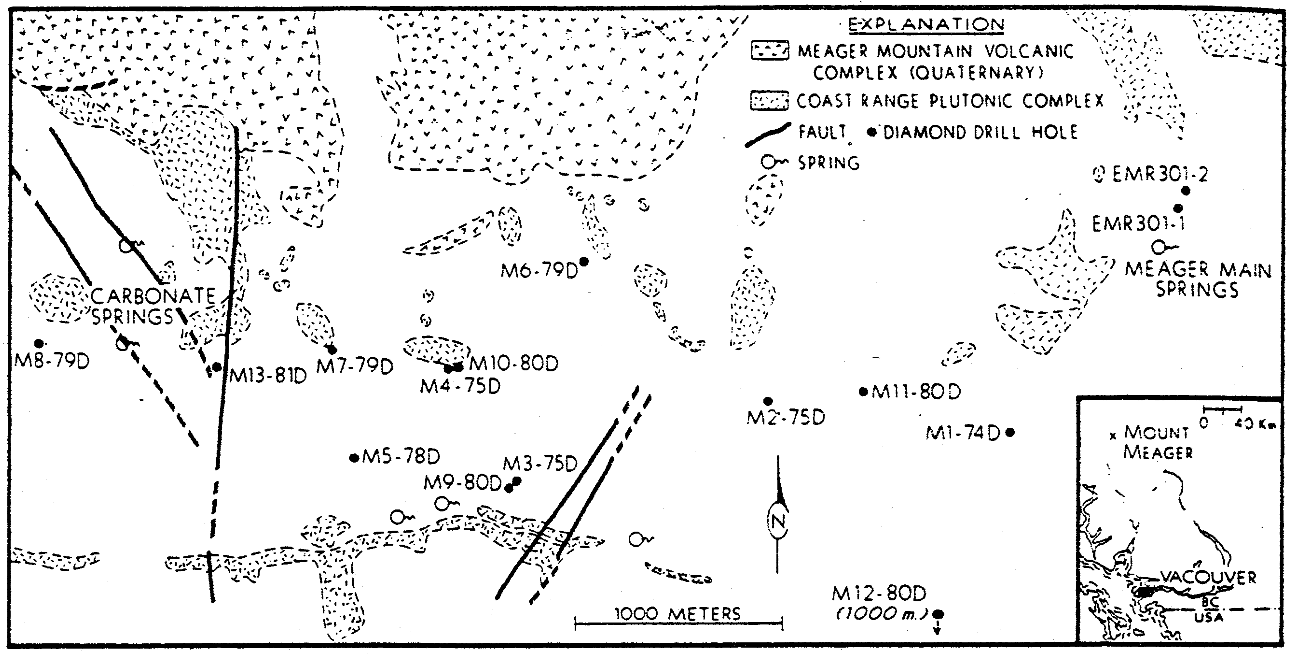

Figure 1. Generalized geology and location of wells and springs in the Meager Creek geothermal field (from Nevin/Sadlier-Brown/Goodbrand Ltd.)

The country rocks penetrated in the wells consist predominantly of variably foliated Cretaceous quartz diorite. Mesozoic metamorphic rocks, intruded by the quartz diorite, comprise the bulk of the samples in well M8-79D, on the western edge of the field, and occur near the base of M9-80D. The lithologies of the chemically analyzed samples are summarized in Figure 2.

The quartz diorite and metamorphic rocks have been intruded by silicic to intermediate composition dikes. These dikes occur widely throughout the field and are probably of several different ages. Fairbank and others (1981) have suggested that dikes of dacite, feldspar porphyry and rhyolite are related to Quaternary volcanism and are correlative with the volcanic rocks on Pylon Peak.

Hydrothermal activity has resulted in widespread propylitic and argillic alteration at depth and the depositon of quartz, clays, anhydrite, epidote, barite, base-metal sulfides, calcite, siderite, dolomite, and hematite in fractures within the reservoir rocks. Detailed investigations of the hydrothermally altered rocks at depth are in progress.

Surface deposits related to the active thermal system at Meager Creek include carbonate and siliceous sinters associated with hot springs located along Meager Creek between Meager Main Springs and well M1-74D, and carbonate deposits formed around the Carbonate Springs (Fig. 1). In particular, the concentrations of Sr, Ba, Mn, Zn, Pb, As and Hg, although variable, are significant (Table 1) and similar in magnitude to the concentrations of these elements found in discharge precipitates from other high-temperature thermal systems.

Thermal Fluids

The thermal fluids sampled from springs and shallow wells in the Meager Creek thermal area are sodium chloride in character. The measured temperatures of these fluids range from about 50° to 60°C. Non-thermal fluids from the Mt. Meager area are calcium to calcium-magnesium bicarbonate in character. TDS values for the thermal waters range from about 1000 to 12,500 ppm, and for non-thermal waters from 50 to 500 ppm (Clark and others, 1982; B. C. Hydro, unpublished data, 1982). The highest temperature fluid yet sampled was encountered in one of the deep (3500 m) rotary wells drilled during 1982. This fluid has a temperature of 190°C and a calculated TDS of 3,573 ppm (B.C. Hydro and Power Authority, unpublished data, 1982).

Chemical and isotope geothermometry indicate that all thermal water, with the exception of the 190°C fluid from the deep well, equilibrated with the country rock at a temperature of 140°C or less (Clark and others, 1982). Chemical geothermometry of the deep rotary well fluid gives temperatures of 185°C and 195°C, both within 5°C of the measured temperature.

Trace Element Geochemistry

The geochemistry of the reservoir rocks and veins indicates that, at depth, the elements enriched in the discharge sinters fall into

Table 1. Geochemistry of Sinters

Element	1	2	3	4	5	6	7
Na_2O (%)			.7	.6	.2	1.4	1.35
K_2O (%)						.6	.5
CaO (%)	60.2	63.0	52.8	58.07	53.8	11.1	24.6
MgO (%)	.2	.2	.2	.1	1.2	2.9	2.1
Fe_2O_3 (%)			6.9	.8		2.6	2.9
Al_2O_3 (%)	.1			.1	.1	8.1	5.5
TiO_2 (%)			.1			.3	.3
P_2O_5 (%)						.1	.1
BaO (%)	.012	.009	.009	.010	.009	.074	.030
MnO (%)	.004		.034	.114	.004	1.58	.076
Sr (ppm)	707	664	13800	14500	5250	1890	2520
Cr (ppm)							6
Co (ppm)					4	24	11
Cu (ppm)						17	9
Pb (ppm)			24				
Zn (ppm)	14	35	58	15		28	28
As (ppm)		5	8750	375	80	100	60
Bi (ppm)	238	252		263	230		
Li (ppm)			6	6	9	17	18
Be (ppm)			3.9			.6	
Zr (ppm)	23	23	68	24	22	11	16
La (ppm)	72	74		71	65		
Hg (ppb)	48	7	7	17	15	77	80

1) Travertine, Carbonate Springs, Meager Creek
2) Travertine, Carbonate Springs, Meager Creek
3) Travertine, discharge precipitate, well M1-74D (74-H-1), Meager Creek
4) Travertine, discharge precipitate, well M1-74D (74-H-1), Meager Creek
5) Travertine, hot spring between Meager Main Springs and 74-H-1 (M1-74D), Meager Creek
6) Siliceous Sinter, Meager Main Springs, Meager Creek
7) Siliceous Sinter, Meager Main Springs, Meager Creek

several distinct geochemical groups. These include:

a) Hg + Cu + Zn + Pb + Ba + K + (Sr depletions)
b) Hg + Zn + As
c) Hg + Zn.

The association Hg + Cu + Zn + Pb + Ba + K + (Sr depletions) is characteristic of the altered quartz diorite and metamorphic rocks which display widespread propylitic and argillic alteration. The alteration is most intense in wells M10-80D and M13-81D where base metal mineralization is common. Similarly altered rocks occur in wells M12-80D and M8-79D on the margins of the thermal field. These observations and the absence of significant Cu enrichments in hypabyssal dikes of the Meager Mountain Volcanic Complex suggests that Cu mineralization preceded emplacement of the dikes. The propylitic alteration bears no apparent relationship to the present thermal system and is interpreted as being pre-geothermal in age.

The trace element distributions in the altered quartz diorite at Meager Creek are similar to those found in the copper porphyry deposits of the Guichon Creek batholith of British Columbia by Olade and Fletcher (1976).

The geochemical association Hg + Zn + As is characteristic of the mineralized hypabyssal dikes. The distribution of these elements is presented in Figure 3. This diagram suggests that these elements are crudely zoned with respect to the present thermal anomaly. Dikes characterized by enrichments in Hg + Zn + As occur in the high-temperature portion of the thermal anomaly in wells M7-79D and M10-80D, whereas dikes enriched only in Zn and Hg occur in well M9-80D. Only two samples of quartz diorite enriched in these elements and containing low concentrations of Cu (<18 ppm) were found. One containing high concentrations of Hg + As + Zn was sampled at a depth of 220 m in M7-79D. The other, from 360 m in M10-80D, is enriched in Hg + Zn. The trace element distributions of these samples is compatible with those of the altered dikes.

Weak enrichments of both Hg and Sr occur primarily in the outer portion of the thermal field. Although the origin of these enrichments is not yet completely understood, the high concentrations of Hg and Sr in the discharge sinters strongly

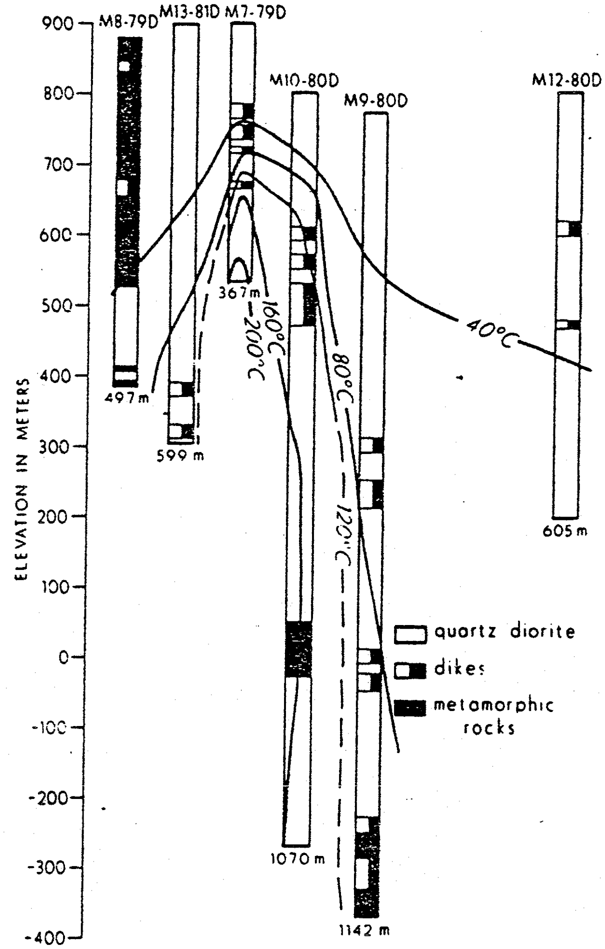

Figure 2. Distribution of lithologies and temperatures in the thermal gradient wells.

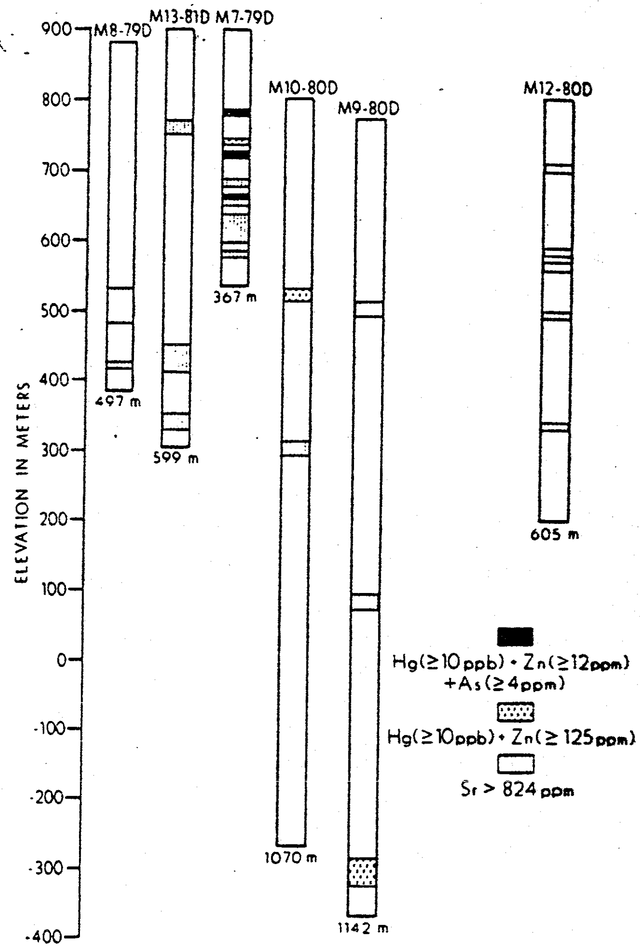

Figure 3. Distribution of Hg + Zn ± As in dikes of the Mt. Meager Volcanic Complex and Sr enrichements in crystalline basement rocks.

suggests that their distributions at depth are at least in part related to geothermal activity. Enrichments in Sr (Fig. 3) occur erratically throughout the thermal field but are most abundant in the weakly altered interval between 190 and 320 m in well M7-79D. Here the Sr appears to be associated with calcite veins, and abundant open fractures.

Mercury concentrations in the reservoir rocks range from less than 10 ppb to 1,000 ppb. In general, the highest concentrations of Hg occur in the central portion of the thermal anomaly. Wells located on the margins of the field are, in contrast, characterized by relatively low concentrations of Hg. For example, samples from well M12-80D contain less than 40 ppb Hg, whereas only one sample from well M8-79D has a Hg concentration that exceeds 10 ppb.

Minor concentrations of Hg characterize intervals of the country rock containing fluid channels in well M7-79D (220-240 m) and M12-80D (420-450 m). The fluid channels in these zones occur at a depth of 233 m in M7-79D and at 441 m in M12-80D. The rocks in wells M9-80D and M10-80D are unproductive but charactrized by relatively high temperatures. The limited distribution of Hg in these wells is consistent with their low permeabilities. Well M13-81D is also dry but characterized by Hg enrichments throughout its length, suggesting that this portion of the reservoir may have been more permeable in the past.

Summary and Conclusions

Water-rock interactions between the reservoir rocks of the Meager Creek geothermal field and high temperature thermal fluids have produced distinctive geochemical anomalies which reflect the patterns of fluid flow and temperature distributions of two different hydrothermal systems. Three multielement geochemical associations in addition to the distributions of Hg and Sr have been mapped within the reservoir based on chemical analyses of thermal waters, discharge precipitates and core from six shallow to intermediate depth wells. These associations include: Hg + Cu + Pb + Zn + K + Ba + (Sr depletions), Hg + As + Zn and Hg + Zn.

The association Hg + Cu + Pb + Zn + K + Ba + (Sr depletions) is restricted to propylitically altered crystalline and metamorphic rocks of the Coast Range Plutonic Complex, which underlies the volcanic rocks of Mt. Meager. This alteration assemblage bears no apparent relationship to the present temperature distribution of the thermal field and is interpreted as resulting from circulation of high temperature fluids generated during emplacement of the Cretaceous stocks of the plutonic complex.

Hydrothermal alteration related to the active geothermal system followed intrusion of Pliocene to Recent dikes belonging to the Meager Mountain Volcanic Complex. Within the high temperature portion of the field, the dikes are enriched in Hg + As + Zn and Hg + Zn. In contrast, enrichments in Hg and Sr occur sporadically in the fractured crystalline rocks. Although it is not yet possible to unequivocably assign an age to the enrichments in Hg and Sr, both elements are important trace constituents of the geothermal fluids, and discharge deposits. Thus it appears likely that the enrichments of these elements in the reservoir rocks is at least in part produced by the active thermal system.

The geochemical distributions suggest that two chemically different fluids have been responsible for the trace element patterns present in the rocks altered by the geothermal fluids: one related to the deposition of Hg + As + Zn and the second to the enrichments in Sr and perhaps Hg. Although wells containing rocks enriched in Hg + As + Zn did not encounter high temperature fluids some inferences can nevertheless be made based on data from other high temperature systems. For example, at Broadlands, deposition of base metals are associated with high temperature (greater than 200°C) NaCl brines (Weisberg and others, 1979). We suggest that similar, higher temperature, fluids may be present in a deeper (but yet untapped) thermal reservoir at Meager Creek. The association between the dikes and the distribution of Hg + As + Zn suggests that fractures along the dike margins may have provided conduits which allowed the fluids to migrate upward into the shallow portions of the field.

On the other hand, fluids which are actively depositing calcium carbonate enriched in Sr vary from thermal (<60°C) NaCl brines (<9000 ppm TDS) to cold (<10°C) $CaHCO_3$ (<600 ppm) dilute springs. These fluids have been examined by Clark and others (1982). They concluded from chemical and isotope geothermometry that the thermal springs and well waters from the shallow wells in the Meager Creek area equilibrated with the reservoir rocks at a temperature of 140°C or less. Recent deep drilling conducted during 1982 has encountered fluid with a temperature of approximately 190°C. This fluid is compositionally similar but more dilute than some of the fluids discharged from some of the shallow wells. Variations in the chemistry of the fluids tapped by the wells and springs suggests that some of these fluids could have been derived from a high temperature portion of the thermal system and subsequently reequilibrated in a lower temperature, low permeability reservoir.

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