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CHEMICAL AND ISOTOPIC STUDIES OF THE COSO GEOTHERMAL AREA

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ABSTRACT

Wellhead and downhole water samples were collected and analyzed from a 114.3-m well at Coso Hot Springs (Coso No. 1) and a 1477-m well (CGEH No. 1) 3.2 km to the west. The same chloride concentration is present in hot waters entering both wells (about 2350 mg/kg), indicating that a hot-water-dominated geothermal system is present. The maximum measured temperatures are 142°C in the Coso No. 1 well and 195°C in the CGEH No. 1 well. Cation and sulfate isotope geothermometers indicate that the reservoir feeding water to the Coso Hot Spring well has a temperature of about 240-250°C, and the reservoir feeding the CGEH well has a temperature of about 205°C. The variation in the chemical composition of water from the two wells suggests a model in which water-rock chemical equilibrium is maintained as a convecting solution cools from about 245° to 205°C by conductive heat loss.

A total of 39 water samples collected from the Coso geothermal area and vicinity and were analyzed for major chemical constituents, δD and $\delta^{18}O$. Nonthermal ground waters from the Coso Range were found to be isotopically heavier than those from the Sierra Nevada to the west. The similarity of the δD value for the deep thermal water at Coso to that of the Sierra water suggests that the major recharge for the hydrothermal system comes from the Sierra Nevada rather than from local precipitation on the Coso Range. The $\delta^{18}O$ values of the thermal water are about 7°/oo heavier than those of the Sierra water. This shift in $\delta^{18}O$ is the result of water-rock reaction at high temperatures, and the magnitude of the shift indicates that the ratio of rock to total water has been large for the system up to its present stage of development. The isotopic data are compatible with the chemical model.

INTRODUCTION

The Coso Geothermal Area is located in east central California on land included in the U. S. Naval Weapons Center, China Lake. The surface expression of hydrothermal activity at Coso is hot ground, fumaroles, and acid-sulfate springs with low rates of discharge. No chloride-rich springs are present. This type of surface expression is typical of vapor-dominated systems, but is not diagnostic.

In 1978 water samples were collected and analyzed from two wells (Fournier and others, 1980). The first well (Coso No. 1) was drilled in 1967, in altered alluvium and granitic rock to a depth of 114.3 m at Coso Hot Springs. The second well (CGEH) No. 1) is located approximately 3.2 km west of Coso Hot Springs and 1.9 km north of Devil's Kitchen. It was drilled in 1977 to a total depth of 1477 m in granitic and metamorphic rocks. On the basis of chemical data obtained from downhole samples, Fournier and others (1980) concluded that a single parental water supplies both wells and that the compositional variations in the waters collected at the wellheads were the result of (1) different amounts of boiling in the wells during upflow and (2) a higher reservoir temperature in the vicinity of the Coso No. 1 well (245°C) than in the vicinity of the CGEH No. 1 well (205°C). These reservoirs are places in the rock where fracturing is locally more extensive than elsewhere, so that permeability and the water/rock ratio are higher there than in the surrounding rock.

In the model of Fournier and others (1980), the water cannot boil as it moves laterally from the 245°C to the 205°C reservoir; if the water had boiled, then the chloride concentrations in the downhole samples from the two wells would have differed. The fact that these two chloride concentrations are nearly identical indicates very slow natural flow and conductive cooling of thermal water as the water moves from the vicinity of the Coso No. 1 well towards the CGEH No. 1 well. The slowness of the flow could be due to very low permeability within the rock connecting the two reservoirs. Alternatively, the permeability could be high (essentially a single reservoir of small vertical extent and with a horizontal temperature gradient) and the convective flow limited by low permeability in the outflow part of the convection system. A study was then undertaken to determine if the isotopic compositions of the well waters were compatible with the above model, and to determine the recharge area for the hydrothermal system.

Smith and others (1979) measured the deuterium concentrations in rain and snow collected at 26 stations in California and Nevada during the exceptionally wet 1968-69 season. Their results showed that the winter precipitation upon the Sierra Nevada was isotopically slightly lighter than the summer and fall precipitation on the nearby Mojave Desert; most of the Sierra ground-water recharge comes from winter storms moving generally from west to east. These winter storms drop most of their moisture before reaching the Coso Range, which is directly east of the Sierra Nevada. In contrast, most of the Coso Range recharge is from large but infrequent tropical storms moving from south to north. Therefore, the isotopic composition of normal, nonthermal ground water in the vicinity of the Coso geothermal field is slightly lighter than that of nearby Sierra waters.

SAMPLES STUDIED

A total of 39 samples from 37 different sources were collected and analyzed. Of these samples 11 were of cold ground waters flowing from springs and wells in the Coso Range, north and east of Coso Hot Springs within the China Lake Naval Weapons Center; 8 were of Sierra Nevada ground water, collected through a 40-km-long region west and northwest of the Coso area; and 5 were from wells in alluvium of Rose Valley, between the Coso Range and the Sierra Nevada. Fournier and others (1980, table 1) previously reported on the details of the collection and chemical analyses of two samples of thermal water from the CGEH No. 1 well (CC77-4 and CF78-1). Two downhole samples from the Coso No. 1 well (CF79-1 at -50 m and CF79-2 at -95 m) were collected for the present study using a modified version of the Fournier and Morganstern (1971) sampling tool designed for use on wireline equipment.

RESULTS AND DISCUSSION

A plot of δD versus $\delta^{18}O$ (Fig. 1) shows that cold ground waters flowing from the Sierra Nevada and the well waters from Rose Valley all plot near the average meteoric water line of Craig (1961) and have δD values less (more negative) than -100°/oo. The δD values of the Sierra waters generally become more negative to the north (Smith and others, 1979). The cold ground waters collected from springs and wells within the Coso Range also plot near the meteoric-water line (Fig. 1) but have δD values larger (more positive) than -100°/oo, averaging -94°/oo. This difference in isotopic composition between the Sierra ground water and that of the Coso Range reflects the different types of storm systems contributing the major recharge in these two areas, as discussed above.

The two water samples from the CGEH No. 1 well, CC77-4 and CF78-1, plot far to the right of the meteoric-water line (Fig. 1), as do the thermal waters from most geothermal systems throughout the world (White, 1970). As meteoric water flows into a geothermal system and becomes heated, its oxygen exchanges with the isotopically heavy oxygen in the surrounding rock, so that the oxygen in the water becomes isotopically heavier and that in the rock becomes lighter. Hydrogen reacts similarly. However, because the rock contains abundant oxygen and only a small amount of hydrogen, the oxygen-isotopic composition of the water changes considerably while the hydrogen isotopic composition changes only slightly. Therefore, the degree of ^{18}O shift away from the meteoric-water line indicates the relative amount of meteoric water that has reacted with rock, whereas the δD value indicates the δD of the meteoric recharge water. The very large shift in ^{18}O of 7°/oo for samples CC77-4 and CF78-1 indicates that relatively little water has moved through the system (Fig. 1).

The δD value of the CGEH No. 1 water suggests that recharge for the hydrothermal system comes predominantly from the Sierra Nevada to the west with little or no component of recharge from the Coso Range. However, the data do not rule out the possibility that recharge may be a mixture of isotopically light water from parts of the Sierra Nevada north of Coso and isotopically heavy locally derived Coso Range water. The isotopic data unambiguously indicate that recharge for the CGEH No. 1 thermal water is not entirely from locally derived ground water, nor could recharge be from Owens Lake, which is isotopically very heavy because of extensive evaporation (Friedman and others, 1976).

The two samples from the shallow Coso No. 1 well (CF79-1 and CF79-2) also plot far to the right of the meteoric-water line (Fig. 1), but at δD values of -15 and -99°/oo, respectively. The sample from near the top of the water table in this well (CF79-1 at -50 m) contains about twice the total dissolved solids and is isotopically much heavier than the sample from near the bottom of the well (CF79-2 at -95 m). Evaporation from the top of a freestanding column of water in the well accounts for these differences very nicely.

If the model of Fournier and others (1980) is correct, the isotopic composition of the water entering the two wells should be about

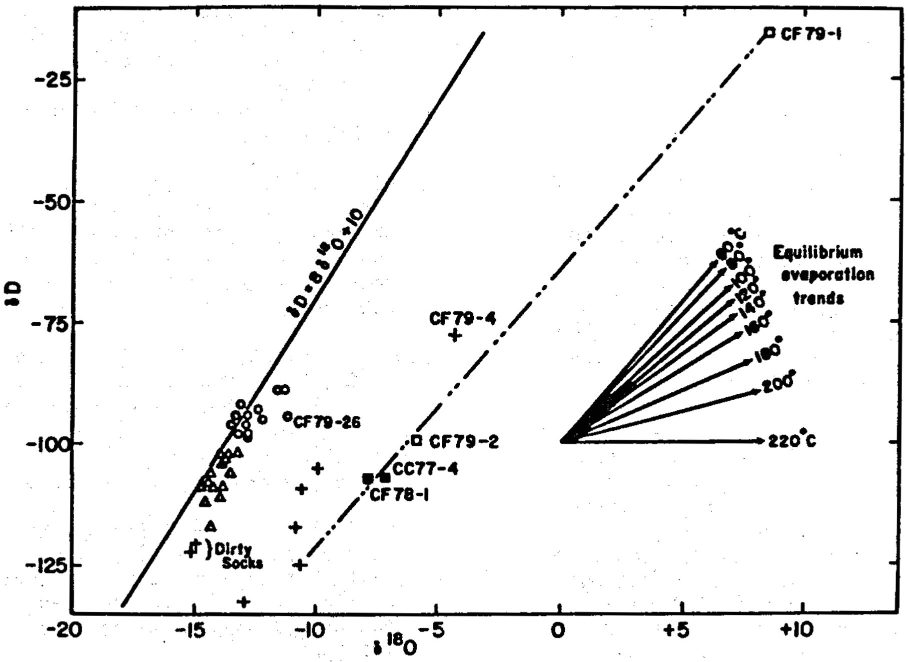

Figure 1. δD versus $\delta^{18}O$ for thermal and nonthermal waters from Coso geothermal area. Circles, nonthermal waters from Sierra Nevada and Rose Valley; solid squares, waters from CGEH No. 1 well; squares, waters from Coso No. 1 well; crosses, other thermal waters and steam condensates..

the same before any boiling or evaporation during upward movement after leaving the respective local reservoirs (if little water-rock isotopic reequilibration takes place because of very slow reaction rates as the temperature changes from 245° to 205°C). The slight difference in the observed isotopic compositions of the downhole samples from the Coso No. 1 well (CF79-2) and the CGEH No. 1 well (CF78-1) appears to reflect slight contamination by evaporated water from the top of the Coso No. 1 well (CF79-1), as shown by the straight-line relation in Fig. 1 for samples from these wells.

CONCLUSIONS

The average meteoric water falling on the Coso Range is isotopically slightly heavier than that falling on the Sierra Nevada to the west. The deuterium concentration in the deep geothermal water is similar to that in the Sierra Nevada ground water and is different from that in the Coso Range water. Therefore, recharge into the deep part of the geothermal system probably comes predominantly from the Sierra Nevada. The main upflow in the hydrothermal system appears to be along a north-northeast-trending fault zone along which Coso Hot Springs is situated. The large shift in ^{18}O of about 7°/oo in the thermal water indicates that the rock/water ratio is large and suggests very slow movement of new water into and of old water out of the convection system. The isotopic data are compatible with the geochemical model of Fournier and others (1980), in which some of the chloride-rich hot water ascending along faults that pass through the Coso Hot Springs area encounters other permeable zones and flows laterally toward the CGEH No. 1 well, cooling conductively and reacting chemically with the surrounding rock as it travels. The top of the chloride-rich water remains below ground, and, where underground boiling occurs, fumaroles, acid-sulfate pools, and acid-altered rock occur at the surface.

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