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AN ISOTOPIC STUDY OF THE COSO, CALIFORNIA, GEOTHERMAL AREA

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ABSTRACT

Thirty-nine water samples were collected from the Coso geothermal system and vicinity and were analyzed for major chemical constituents and δD and $\delta^{18}O$. Non-thermal ground waters from the Coso Range were found to be isotopically heavier than non-thermal ground waters from the Sierra Nevada to the west. The δD value for the deep thermal water at Coso is similar to that of the Sierra water, suggesting 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 geochemical model previously proposed by Fournier, et al. (1980).

INTRODUCTION

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 that come from the south. Therefore, the isotopic composition of the normal, non-thermal ground water in the vicinity of the Coso geothermal field is slightly lighter than the isotopic composition of nearby Sierran waters. The purposes of the present study were to determine (1) whether the recharge for the Coso geothermal system comes from precipitation on the Sierra Nevada or from local precipitation at Coso, and (2) whether the (1980), the water cannot boil as it moves isotopic data are compatible with the geochemical model for the reservoir fluid proposed by Fournier and others (1980).

SAMPLES STUDIED

A total of 39 samples from 37 different sources were collected and analyzed. Eleven samples are 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. Eight samples are of Sierra Nevada ground water, collected through a 40-km-long region west and northwest of the Coso area; and five samples are from wells in alluvium in Rose Valley, between the Coso Range and the Sierra Nevada. Fournier and others (1980, table 1) previously reported the details of the collection and chemical analyses of two samples of thermal water from the CGEH (Coso Geothermal Exploration Hole) 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. 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 line (Fig. 1), but they have δD values heavier than -100, averaging -94. The 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 water recharge in the two areas, as discussed above.

Water samples from the CGEH No. 1 well, CC77-4 and CF78-1, plot far to the right of the meteoric line (Fig. 1), as do thermal waters 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 the oxygen in the rock becomes lighter. Hydrogen reacts in a similar manner. However, because the rock contains a very large amount of oxygen and only a small amount of hydrogen, the oxygen isotopic composition of the water is changed considerably while the hydrogen isotopic composition is changed only slightly. Therefore, the amount of $\delta^{18}O$ shift away from the meteoric line gives an indication of the relative amount of meteoric water that has reacted with rock, whereas the δD value is indicative of the δD of the meteoric recharge water. The shift in $\delta^{18}O$ of 7°/oo for samples CC77-4 and CF78-1 is very large and indicates that relatively little water has moved through the system.

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 is a mixture of isotopically light Sierra water from parts of the Sierra north of Coso and isotopically heavy locally derived Coso Range water. The isotopic data unambiguously show that recharge for the CGEH No. 1 thermal water is not entirely from locally derived ground water, nor could recharge be from OwensLake, 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 line, but at δD values of -15 and -99, respectively (Fig. 1). The sample from near the top of the water table in this well (CF79-1) at -50 m has about twice the total dissolved solids and is isotopically much heavier than the sample from near the bottom of the well (CF79-2). Evaporation from the top of a free-standing column of water in the well accounts for these differences very nicely.

The relationship of the waters entering the CGEH No. 1 and Coso No. 1 wells is of great interest. On the basis of chemical data obtained from downhole samples, Fournier and others (1980) concluded that a single parental water supplied both wells and that 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 ratio of water to rock are higher 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 reservoir to the 205°C reservoir. If the water had boiled, then the chloride concentration in the downhole samples from the two wells would have been different. The fact that the chlorides are very similar 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 flow could be slow because the permeability within the rock connecting the two reservoirs is very low. Alternatively, the permeability could be high (essentially one reservoir with small vertical extent and a horizontal temperature gradient within it) and convective flow limited by poor permeability on the outflow part of the convection system.

If the model presented by Fournier and others (1980) is correct, the isotopic composition of the water entering the two wells should be about the same prior to any boiling or evaporation during upward movement after leaving the respective local reservoirs (if little water-rock isotopic re-equilibration took place because of very slow reaction rates as the temperature changed from 245°C to 205°C). The slightly different observed isotopic compositions of the downhole sample from the Coso No. 1 well (CF79-2) and of the downhole sample from the CGEH No. 1 well (CF78-1) appears to be the result of slight contamination by evaporated water from the top of the Coso No. 1 well (CF79-1) as shown by the straight-line relationship in Figure 1 among samples from these wells.

CONCLUSIONS

The average meteoric water falling on the Coso Range is isotopically slightly heavier than the average meteoric water 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 located. The large shift in $\delta^{18}O$ of about 7°/oo in the thermal water indicates that the rock-to-water ratio is large, suggesting very slow movement of new water into and 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 passing 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 are found at the surface.

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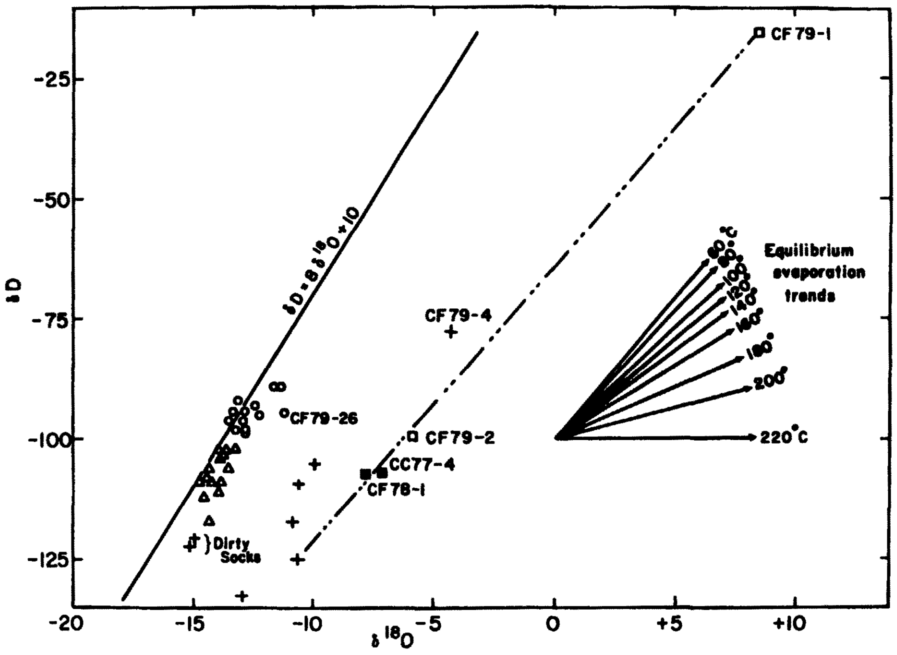

Figure 1. δD versus $\delta^{18}O$ for thermal and nonthermal waters from the Coso geothermal area. Circles, nonthermal waters from the Sierra Nevada and Rose Valley; solid squares, waters from the CEGH No. 1 well; open squares, waters from the Coso No. 1 well; crosses, other thermal waters and steam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