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EVALUATION OF THE GEOTHERMAL RESERVOIR ASSOCIATED WITH AUBURN AND JOHNSON HOT SPRINGS, UPPER STAR VALLEY, WYOMING

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ABSTRACT

Auburn and Johnson Hot Springs are part of a low- to moderate-temperature geothermal resource in western Wyoming. The thermal water is sodium chloride in character, with a dissolved solids content ranging from 5250 to 5962 ppm, and nearly neutral pH. Comparison with other thermal waters from Alpine and Heise Hot Springs, which occur from 45 to 115 km north along the same structural trend, shows them to be chemically very similar and suggests that the mechanisms for generation of these thermal waters are similar. The predicted subsurface temperature and depth of circulation for the thermal waters are on the order of 92°C and 2600 m, respectively. Other sodium chloride waters flow as cold springs from the halite-bearing Preuss sandstone just south of the area. These waters, which range in dissolved solids content from 672 to 270000 ppm, are chemically distinct from the thermal waters and do not appear to have had a thermal origin.

INTRODUCTION

Hot springs and travertine deposits are common along the margin of the north-trending valleys that separate the Caribou Range from the Salt River and Snake River Ranges in Idaho and Wyoming (Fig. 1). Auburn and Johnson Hot Springs, located in Upper Star Valley, mark the southern end of this belt of thermal activity. These springs are sodium chloride in character, and have low to moderate salinities and predicted reservoir temperatures of less than 100°C. Local ground waters are cold and relatively dilute with a chemical character ranging from calcium bicarbonate to calcium sulfate, distinctly different from the character of the thermal water. There are, however, several cold springs south of Auburn that have salinities up to two orders of magnitude higher than the hot springs and are also sodium chloride in character. In contrast to the thermal spring water, this saline cold spring water has low calculated geothermometer temperatures. In this study, the temperature and depth of the thermal reservoir are evaluated along with the interrelationships between the saline cold spring water and that of the hot springs. This study was funded by the U. S. Dept. of Energy under contract DE-AC07-801012079.

GEOLOGY

Upper Star Valley lies near the center of the Wyoming-Idaho thrust belt. The valley is the southern extension of a concave-westward, curvilinear fault-bounded trough. The trough consists of Swan, Grand, and Lower and Upper Star Valleys (Swan-Star Valley trend) (Fig. 1). The Swan-Star Valley trend has been modeled by Stott (1974) as a series of 3000 m deep grabens.

The sedimentary strata along the Swan-Star Valley trend consists of over 15000 m of limestone, sandstone, siltstone, and evaporites. These sedimentary rock units are Paleozoic to Cenozoic in
age (Mansfield, 1927). One of these units, the Jurassic Preuss sandstone, contains locally thick (50 m) accumulations of halite (Mansfield, 1927).

HOT SPRINGS

Auburn Hot Springs consists of over 100 vents covering a 12000 m² area with a total discharge of 2.5 liter/sec and a maximum temperature of 62°C (Hinckley and Breckenridge, 1977). Travertine deposits of gypsum, aragonite, and calcite occur throughout this area and are presently forming around active vents. Previous workers (Hinckley and Breckenridge, 1977) have suggested that native sulfur is deposited as part of the travertine to explain the yellow color. Although hydrogen sulfide evolves from the thermal fluids, X-ray examination of fresh yellow travertine did not confirm the presence of native sulfur.

Johnson Hot Spring, located 1 km south of Auburn Hot Springs, consists of a single spring with a flow of 0.13 liters/sec and a measured temperature of 46°C (Hinckley and Breckenridge, 1977). Travertine surrounds this vent and covers a 225 m² area.

North of the Auburn and Johnson Hot Springs study area there is other evidence of thermal activity along the Swan-Star Valley trend. This includes travertine deposits and two areas containing active hot springs. The travertine occurs sporadically along the western edge of the valley between Johnson Hot Spring and the town of Freedom, 25 km to the north. The vents related to these deposits are presently inactive. Alpine and Heise Hot Springs occur 45 and 115 km north, respectively, of Johnson Hot Spring. Alpine Hot Springs consist of numerous vents that are presently covered by the Palisades Reservoir. The water temperatures ranged from 31°C to 66°C (Mitchell et al., 1978). Bradley (1885, p. 269) reported "calcareous, sulphurous and saline deposits associated with the hot springs. Heise Hot Springs mark the northern limit of the Swan-Star Valley trend. These springs have a maximum measured temperature of 49°C and are surrounded by extensive travertine deposits (Ralston et al., 1981).

WATER CHEMISTRY

Waters from the Swan-Star Valley trend display a broad compositional range. The chemistry of these waters is listed in Table 1 and their chemical character is displayed on Figure 2. Comparison of these water analyses delineates three groups. Group I consists of cold ground water from springs and shallow wells in the vicinity of Lower and Upper Star Valleys. This water is calcium bicarbonate to calcium sulfate in character, with a dissolved solids content of less than 400 ppm, and near-neutral pH. Hydrologic and chemical data from Lines and Glass (1975) indicate that Group I water flows from a variety of Mesozoic and Tertiary sedimentary rocks.

Group II is comprised of cold spring water that discharges exclusively just south of the Swan-Star Valley trend from the Jurassic Preuss sandstone (Fig. 1). Group II water, in contrast to the cold ground water of Group I, is sodium chloride in character and more saline, with dissolved solids content ranging from 672 to 270000 ppm. The relatively high Na and Cl contents of these fluids probably reflect interaction with halite-bearing units within the Preuss sandstone.

Group III includes all hot springs occurring along the Swan-Star Valley trend. The thermal waters are sodium chloride in character, have dissolved solids contents ranging from 5250 to 6495 ppm, and pH values ranging from slightly acidic to
neutral. The similar chemical compositions and geothermometer temperatures for all four of the hot springs suggest that waters discharging from these springs have equilibrated under similar physical and chemical conditions, despite their geographic separation. In addition, this suggestion of a similar evolutionary history is further supported by the close spatial association of the springs with the faults bounding the Swan-Star Valley trend.

Groups II and III are similar in that they are both sodium chloride in character. However, they differ considerably in their element concentrations and temperatures. Group II has a wider range in dissolved solids (672 to 27000 ppm) than the relatively narrow range of Group III (5250 to 6495 ppm). Na/K and Cl/SO₄ ratios are generally higher for Group II, ranging from 56 to 1300 and 0.76 to 7600, respectively, whereas Group III Na/K and Cl/SO₄ ratios range, respectively, from 7.88 to 10.0 and from 1.3 to 3.2. The measured and predicted temperatures of Group II waters, less than 16°C and 45°C, respectively, are distinctly lower than those of Group III (Table 1). Group III has measured temperatures ranging from 49°C to 62°C, and geothermometer temperatures ranging from 75°C to 101°C.

It is suggested by Mansfield (1927) that thermal waters of this area have derived their sodium chloride character from the halite beds in the Preuss formation. Nonthermal spring water flowing from the Preuss formation (Group II) is significantly enriched in Na and Cl relative to all other element concentrations in the samples. The thick halite beds present in the Preuss are the probable source for the high Na and Cl in this water and the relatively slight enrichment of the other elements. In contrast, the thermal water (Group III) is not only enriched in Na and Cl, but relative to Group II water, the thermal water is also enriched in most other elements. It is therefore suggested that Na and Cl enrichment in the thermal water is the result of interaction of this water at elevated temperatures, on the order of 100°C, with the other Mesozoic and Cenozoic lithologies at depth. This does not preclude the possibility that some component of the Na and Cl in the thermal water is derived from interaction with the Preuss at depth.

**SUBSURFACE TEMPERATURE**

The reservoir temperatures for the hot springs occurring along the Swan-Star Valley trend were estimated using the quartz (Fournier, 1981) and the Na-K-Ca (Fournier and Truesdell, 1973) with Mg correction (Fournier and Potter, 1979) geothermometers. The temperatures derived using the two methods were concordant, ranging from 75°C to 95°C for the quartz geothermometer and 79°C to 101°C for the Na-K-Ca (-Mg) geothermometer.

The silica equilibrium temperatures were calculated assuming saturation with quartz rather than its polymorph, chalcedony. Frequently the chalcedony geothermometer is used to give a minimum temperature of silica equilibrium.
similar manner, halite in the Preuss formation may provide the absolute abundance of sodium, while feldspar equilibrium dictates the ion ratios. This would be true only if the temperature is high enough or the residence time long enough for feldspar base exchange to compensate for possible sodium influx. This assumption is supported by the considerably higher Na/K ratios in waters that have interacted with halite-bearing lithologies (Group II) in comparison with the thermal waters (Group III).

The accuracy of the Na-K-Ca (-Mg) geothermometer is also affected by deposition of travertine at the surface. The hot springs along the Swan-Star Valley trend actively deposit calcium-bearing minerals around their vents. Precipitation of these minerals lowers the calcium concentration in the water, raising the derived Na-K-Ca temperature. Conversely, the magnesium correction factor is increased by calcium loss, resulting in an overall decrease in the Na-K-Ca (-Mg) geothermometer temperature. Thus the Na-K-Ca (-Mg) geothermometer temperatures for these hot springs are a minimum estimate with respect to mineral deposition.

SOURCE OF THERMAL WATER

The depth of the thermal reservoir was calculated using a one-dimensional conductive heat flow equation \[ \frac{(T_d-T_s)}{x} (Q/K_i) = X \] (Gretener, 1981). For this study, \( T_d \) is the estimated reservoir temperature, 92°C, \( T_s \) is the average surface temperature, estimated at 10°C, \( Q \) is the heat flow, 1.59 \( \mu \) cal/cm sec, derived from a thermal gradient hole near Auburn Hot Springs (H. Hesslar, pers. comm.), \( K_i \) is the summation of the thermal conductivities estimated from average conductivities for specific lithologies and \( X \) is the depth to the reservoir temperature. Based on thermal conductivity of 4 to 6 mcal/cm sec, the reservoir depth for the thermal fluids is 2100 to 3100 m. Gravity data (Stott, 1974) suggests that this depth coincides with the base of the deep graben that runs the length of the Swan-Star Valley trend.

CONCLUSIONS

Auburn and Johnson Hot Springs have an estimated reservoir temperature of approximately 90°C. Their chemical compositions and geothermometer temperatures were very similar to the Heise and Alpine Hot Springs and indicate a similar evolutionary history for the fluids at depth. All of these hot springs lie along faults that bound the continuous 150 km long Swan-Star Valley trend, which consists of a series of graben structures. The depth to basement based on gravity modeling suggests that the graben are 2300 to 3400 m deep. Heat flow calculations show that the maximum temperatures recorded by the geothermometers could be reached at these depths.

REFERENCES


