

TRACE ELEMENT GEOCHEMICAL ZONING IN THE  
ROOSEVELT HOT SPRINGS THERMAL AREA, UTAH

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ABSTRACT

Chemical interaction of thermal brines with reservoir rock in the Roosevelt Hot Springs thermal area has resulted in the development of distinctive trace element signatures. Geochemical analysis of soil samples, shallow temperature-gradient drill hole cuttings and deep drill hole cuttings provides a three-dimensional perspective of trace element distributions within the system. Distributions of As, Hg and Li provide the clearest expression of hydrothermal activity. Comparison of these distributions suggests that Li, followed by As and Hg, are progressively deposited by outward flowing, cooling, thermal fluids. Hg, in contrast to As and Li, is distributed only within the outer portions of the thermal system where temperatures are less than about 225°C. Heating experiments indicate that extensive Hg remobilization in Roosevelt samples occurs at temperatures as low as 200-250°C. This suggests that the distribution of Hg largely reflects the present system thermal configuration and that this distribution may be a useful solid geothermometer.

INTRODUCTION

Although the geochemistry of geothermal fluids and deposits is well-known, little is known about the distribution of trace elements within solids of active geothermal systems. The numerous surface samples and deep drill hole cuttings from the Roosevelt Hot Springs geothermal system provide an unusual opportunity to examine trace element dispersion patterns in three dimensions within a high-temperature hot-water geothermal system. These distributions, formed in response to temperature gradients and fluid flow within the system, place constraints on the geometry of the present system and provide insight into its thermal and convective history.

GEOLOGIC SETTING

The Roosevelt Hot Springs thermal area is located on the western flank of the Mineral Mountains near the eastern margin of the Basin and Range province. The geothermal system is

structurally controlled, primarily by intersections of several principal zones of faulting (Nielson and others, 1978). Reservoir lithologies are predominantly granite, gneiss, and schist. Surface spring and fumarole deposits consist of bedded opaline sinter and minor native sulfur. Alluvium is locally cemented by siliceous sinter and has been altered in varying degrees by downward-moving acid-sulfate waters (Parry and others, 1978). The area is currently being explored for commercial power production. Seven production wells have been drilled with a maximum per-well production capability of  $4.5 \times 10^5$  kg/hr of combined vapor and liquid at a shut-in bottom hole temperature near 260°C (Ward and others, 1978).

Geothermal fluids from the Roosevelt system are relatively dilute, near-neutral, NaCl brines (7000 mg/l TDS). Anomalous concentrations of fluorine, arsenic, lithium, and boron are typical of fluids both from surface discharges and from deep wells in the system.

TRACE ELEMENT DISTRIBUTIONS

Chemical interaction of thermal brine with the reservoir rock has resulted in the development of distinctive trace element signatures. Surficial materials which have been affected by the thermal fluids are characterized by anomalous concentrations of Mn, As, Sb, Li, Be, Hg, and W (Bamford and others, 1980).

At depth within the Roosevelt system, the thermal brines have produced broadly persistent trace element dispersion patterns that are largely consistent with the present thermal regime. The distributions of As, Li, and Hg are, in general, independent of rock type and provide the clearest expression of hydrothermal activity within the field. Although broadly developed, hydrothermal element concentrations are not pervasive throughout the reservoir rock, but rather reflect the geometry of past and present fluid flow channels.

The distribution of temperature and of the elements As, Hg, and Li within the two production wells Thermal Power 14-2 and 72-16 and the nonproducing drill hole Getty Oil Company 52-21 provides an instructive geochemical section

across the southern margin of the geothermal system (Figure 1). Each geochemical data point represents a composite drill cutting sample of a 100-foot interval (Samford, 1978) that has been classified according to statistically distinct geochemical populations (Sinclair, 1974). The anomalous populations are closely associated with fracture zones, locally intense argillic alteration, and deposition of silica, pyrite, and iron oxides. Widespread Hg and As anomalies, distinctive geophysical responses and temperature profiles (Glenn and Hulen, 1979) in the upper portions of wells 14-2 and 72-16, suggest that these fracture zones are steeply-dipping fluid flow channels. Hot water inflow presently occurs at 95 m (312 feet) and 190 m (628 feet) in 72-16

and at 480-550 m (1600-1100 feet) and 870-880 m (2860-2890 feet) in 14-2.

Comparison of the trace element distributions suggests that Li, followed by As and Hg, are progressively deposited with decreasing temperature by outward-flowing thermal fluids. Hg is distributed only within the outer portions of the reservoir, conforming closely to the present thermal patterns. We believe these relationships reflect the extreme mobility of Hg within the high-temperature portions of the geothermal system. The absence of Hg at the 870 m hot water entry in well 14-2 suggests that temperatures are presently too high for Hg deposition at this site and, therefore, that fluid

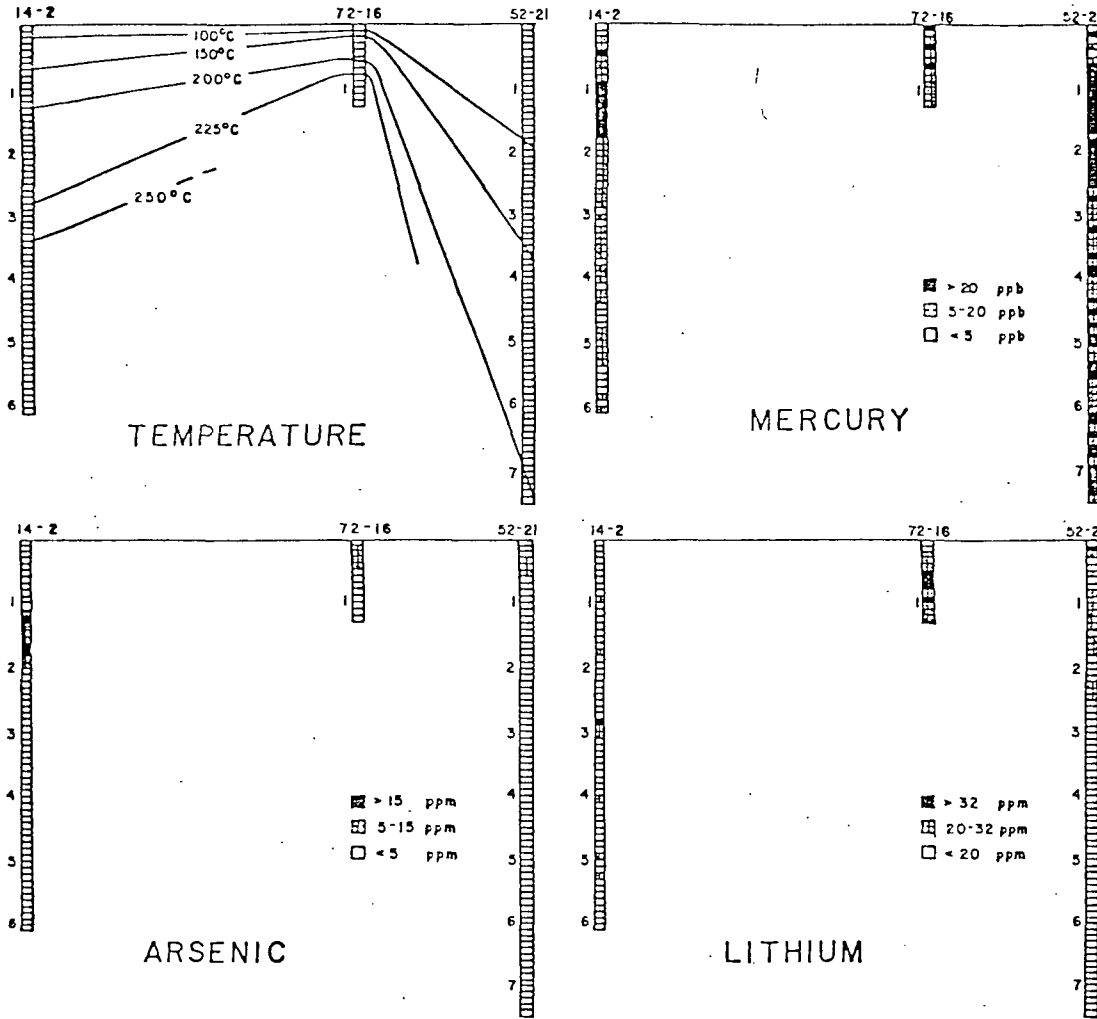


Fig. 1 Distributions of temperature, Hg, As and Li in three drill holes across the Roosevelt Hot Springs thermal area. Concentration ranges presented represent statistically distinguished numerical populations. Depths shown in thousands of feet.

were probably no hotter than about 225°C at the time of Hg deposition at other places in this system. Alteration assemblages associated with the 870 meter entry consist primarily of pyrite and chlorite (Ballantyne, 1978; Glenn and Hulen, 1979) contrasting sharply with the more oxidized, hematite-bearing assemblages present in the upper parts of the drill hole between 250 and 600 meters. Oxidized assemblages are typical of the near-surface alteration zone and may be the result of deposition in a now largely impermeable portion of the fracture zone (Bamford and others, 1980). The mobility of Hg in the temperature range of the geothermal reservoir was experimentally investigated by measuring the temperature dependence of Hg liberation from eight Roosevelt soil and drill cutting samples. Hg release from all samples became significant at about 200°C with maximum Hg loss occurring in the 200-250°C temperature range. Comparison with published decomposition temperatures for various Hg compounds (Koksoy and others, 1967; Landa, 1978) suggests that most of the Hg in the materials investigated exists as adsorbed Hg rather than in sulfide minerals. Results of these simple heating experiments suggest that the distribution of Hg peripheral to the thermal center is largely produced by the present thermal configuration of the system.

Concentrations of As and Li occur throughout the system and are consistently enhanced about present fluid entry points. Li enrichments not associated with present entries are in part coincident with zones of more intense plagioclase alteration, providing evidence of older fluid channels in the lower parts of well 14-2 and upper parts of drill hole 52-21. The absence of present high-temperature fluid flow in 52-21 is evidence of the transience of specific fluid pathway geometries during the life of the system.

Selective analytical extraction experiments designed to identify the trace element locations among mineral components of rocks demonstrate that lithium occurs predominantly in silicate minerals. Arsenic occurs as a trace constituent within pyrite and within crystalline iron oxides formed from the oxidation of arsenical pyrite. Microprobe analysis reveals up to 3.7 weight percent As in pyrite with significant concentration variation between as well as within pyrite grains.

The characteristic trace element zones identified from deep drill hole cuttings intersect the ground surface over the system and are manifest as well in cuttings from shallow drill holes and in soils. Recent studies have demonstrated that cuttings from shallow temperature-gradient holes are a useful medium for the detection of large-scale geochemical enrichments related to shallow fluid flow within geothermal systems (Bamford and others, 1980). Analyses of drill cuttings from 32 shallow temperature-gradient holes drilled over approximately

310 square kilometers reveal a pronounced enrichment of Hg and As in material overlying the known geothermal resource relative to material away from the system.

Anomalous concentrations of Hg and As in soils occur in a series of closely spaced northeast- and northwest-trending zones that reflect the geometry of fluid channels in the uppermost portion of the reservoir (Figure 2). These directions parallel the dominant structural trends mapped by Nielson and others (1978) on the western flank of the Mineral Mountains. Points of fluid discharge, marked by deposits of sinter and arsenic concentrations up to 7 times background values, typically occur at the intersection of the two structural trends. The distributions of As and Hg indicate that structural intersections are of fundamental importance to near-surface fluid flow (Capuano and Moore, 1980). The area of anomalous Hg concentration is more dispersed than that of As, reflecting the greater relative mobility of Hg in the low-temperature environment.

#### CONCLUSIONS

Analysis of solid materials from the Roosevelt Hot Springs thermal area reveals a characteristic distribution of trace elements related to the temperature configuration and fluid flow within the geothermal system. The distributions of As and Li are closely associated with specific fluid pathways, whereas Hg is more broadly distributed within the cooler outer portions of the thermal system and is locally independent of through-going fractures.

Local differences between the known physical geometry of the Roosevelt system and the observed geochemical dispersion patterns suggest that local fluctuations in temperature and fluid convection have occurred in response to fracturing and sealing of reservoir rock. The presence of As and Li anomalies apart from active fluid entry points in drill holes and of As and Hg enrichments in soil over presently inactive fluid discharge points are evidence of the transient nature of specific fluid pathways.

Recognition of this trace element zoning within a geothermal system during exploration may aid definition of the size, shape, and flow pattern of the system. The characteristic spatial distributions and elemental abundances further provide critical constraints necessary for modeling the physical and chemical processes operating within the system.

#### ACKNOWLEDGEMENTS

Funding for this project was provided by the Department of Energy, Division of Geothermal Energy under Contract DE-AC07-80ID12079. We gratefully acknowledge the ESL staff who contributed to this project.

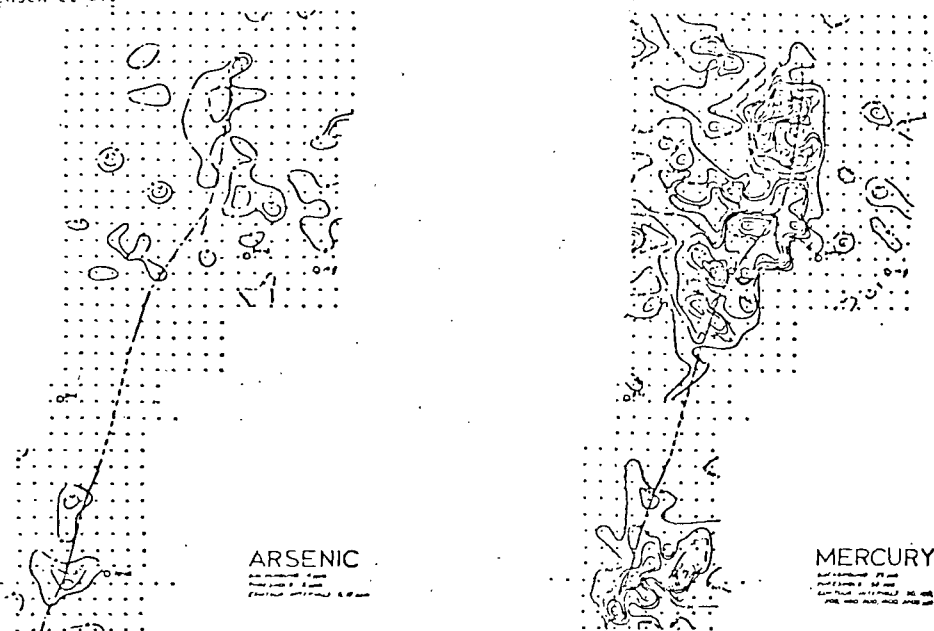


Fig. 2 Distributions of As and Hg in soils over the Roosevelt Hot Springs thermal area. Points mark 500 foot sample grid locations. The positions of wells 14-2 and 72-16 are indicated. (after Bamford and others, 1980).

#### REFERENCES

- Ballantyne, J. M., 1978, Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah: Modal mineralogy and geochemistry of sericite, chlorite, and feldspar from altered rocks, Thermal Power Company Well Utah State 14-2: Univ. Utah, Dept. of Geology and Geophysics, 42p.
- Bamford, R. W., 1978, Geochemistry of solid materials from two U.S. geothermal systems and its application to exploration: Univ. Utah Res. Inst., Earth Science Lab. Report 6, 196p.
- Bamford, R. W., Christensen, O. D., and Capuano, R. M., 1980, Multi-element geochemistry of solid materials in geothermal systems and its applications, Part I: The hot-water system at the Roosevelt Hot Springs KGRA, Utah: Univ. Utah Res. Inst., Earth Science Lab. Report 30, 168p.
- Capuano, R. M., and Moore, J. N., 1980, Hg and As soil geochemistry as a technique for mapping permeable structures over a hot-water geothermal system (Abstract): Rocky Mountain Section, Geological Society of America, Abstracts with Programs, v. 12, p. 269.
- Glenn, W. E., and Hulen, J. B., 1979, Interpretation of well log data from four drill holes at Roosevelt Hot Springs KGRA: Univ. Utah Res. Inst., Earth Science Lab. Report 28, 31p.
- Koksoy, M., Bradshaw, P. M. D., and Tooms, J. S., 1967, Notes on the determination of mercury in geological samples: Inst. Mining Metall. Trans., v. 76, p. B121-124.
- Landa, Edward R., 1978, The retention of mercury vapor by soils: Geochimica et Cosmochimica Acta, v. 42, p. 1407-1411.
- Nielson, D. L., Sibbett, B. S., McKinney, D. B., Hulen, J. B., Moore, J. N., and Samberg, S. M., 1978, Geology of Roosevelt Hot Springs KGRA, Utah: Univ. Utah Res. Inst., Earth Science Lab. Report 12, 120p.
- Parry, W. T., Bryant, N. L., Dedolph, R. E., Ballantyne, J. M., Ballantyne, G. H., Rohrs, D. T., and Mason, J. L., 1978, Hydrothermal alteration at the Roosevelt Hot Springs thermal area: Univ. Utah, Dept. of Geology and Geophysics, 29p.
- Sinclair, A. J., 1974, Selection of threshold values in geochemical data using probability graphs: Jour. Geochem. Explor., v. 3, p. 129-149.
- Ward, S. H., Parry, W. T., Nash, W. P., Sill, W. R., Cook, K. L., Smith, R. B., Chapman, D. S., Brown, F. H., Whelan, J. A., and Bowman, J. R., 1978, A summary of the geology, geochemistry, and geophysics of the Roosevelt Hot Springs thermal area, Utah: Geophysics, v. 43, p. 1515-1542.

Geological Society of America Annual Meeting presentation; November, 1981

FLUID-MINERAL EQUILIBRIA IN A HYDROTHERMAL SYSTEM, ROOSEVELT HOT SPRINGS, UTAH  
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Calculation of the thermodynamic properties of aqueous solution and mineral compositions in the system  $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{CaO}-\text{MgO}-\text{FeO}-\text{Fe}_2\text{O}_3-\text{Al}_2\text{O}_3-\text{H}_2\text{O}-\text{H}_2\text{S}-\text{CO}_2-\text{HCl}$  at temperatures and pressures corresponding to liquid-vapor equilibrium of  $\text{H}_2\text{O}$  permits a quantitative comparison of alteration mineral assemblages observed in a geothermal system with mineral equilibrium relationships calculated for the coexisting reservoir fluid. The composition of the deep reservoir fluid at Roosevelt Hot Springs calculated from analyses of the sampled liquid and steam fractions is a NaCl fluid with 9900 ppm TDS, maximum estimated temperature of  $278^\circ\text{C}$ , and a pressure corresponding to liquid-vapor equilibrium of  $\text{H}_2\text{O}$ . Fluid tapped at  $250^\circ\text{C}$  is computed to have a reservoir  $\text{pH} = 5.6$ ,  $\text{PCO}_2 = 14$  atm,  $\log P\text{O}_2$  between  $-35$  and  $-38$  atm,  $\text{PH}_2\text{S} = .023$  atm, and log activity ratio of  $\text{K}^+/\text{H}^+ = 3.3$ ,  $\text{Ca}^{++}/\text{H}^+ = -0.5$ , and  $\text{Mg}^{++}/\text{H}^+ = -3.9$ .

Theoretical alteration mineral assemblages in equilibrium with the deep reservoir fluid at  $150^\circ$ ,  $200^\circ$ ,  $250^\circ$ , and  $300^\circ\text{C}$  are calculated and compared with observed alteration assemblages in drill cuttings described by Ballantyne (1978, 1980), Parry (1978) and Rohrs and Parry (1978) from geothermal producing wells. Mineral assemblages calculated to be in equilibrium with the reservoir fluid heated to  $300^\circ\text{C}$  include sericite, K-feldspar, quartz, calcite, pyrite and hematite and are in close agreement with those found in higher temperature ( $>225^\circ\text{C}$ ) deep alteration assemblages of producing wells. The addition of montmorillonite and mixed-layer clays to the lower temperature ( $<225^\circ\text{C}$ ) alteration assemblages described at shallower depths in the producing wells corresponds to equilibrium assemblages predicted for a fluid undergoing cooling from  $300^\circ\text{C}$ .

Hg AND As SOIL GEOCHEMISTRY AS A TECHNIQUE FOR MAPPING PERMEABLE STRUCTURES OVER A HOT-WATER GEOTHERMAL SYSTEM: CAPUANO, R.M., MOORE, J.N.  
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A multielement soil geochemical technique has been developed to map fault distributions over active geothermal systems. At the Roosevelt Hot Springs KGRA, Utah, nearly 550 soil samples on a 500 ft grid spacing covering approximately 4 square miles were collected and analyzed for Hg and As using, respectively, gold film and colorimetric techniques. Hg concentrations within the survey area range from 10 to 5,300 ppb with a local threshold value of 58 ppb; As concentrations range from <1 to 41 ppm with a local threshold value of 6 ppm (Bamford, Christensen, and Capuano, in prep.).

Geochemical anomalies occur in a series of closely spaced NE and NW-trending zones that parallel the major fault directions within the geothermal field (Nielson et al., 1978). Portions of these anomalies not associated with mapped faults are believed to reflect concealed faults within the alluvium. Zones of high permeability characterized by extreme enrichment of Hg and As and, in places, hot spring deposits, typically occur at the intersections of these NE and NW structural trends. The distribution of Hg and As suggests that faults are more widespread in the alluvial covered portions of the geothermal field than have been previously mapped and that the intersection of NE and NW-trending structures are of fundamental importance to near-surface fluid flow.

The results of this study suggest that soil geochemistry can be used to map faults that lack surface expressions but have hydrologic importance to the reservoir and can therefore be an effective geothermal exploration tool, particularly in area with alluvial cover.