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MULTIELEMENT GEOCHEMISTRY OF THREE GEOTHERMAL WELLS,
COVE FORT-SULPHURDALE GEOTHERMAL AREA, UTAH

by

Odin D. Christensen

September 1982

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EARTH SCIENCE LABORATORY DIVISION
UNIVERSITY OF UTAH RESEARCH INSTITUTE
420 Chipeta Way, Suite 120
Salt Lake City, UT 84108

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ABSTRACT

Multielement geochemical analysis of drill cuttings from three geothermal wells, Utah State 42-7, Utah State 31-33 and Forminco #1, in the Cove Fort-Sulphurdale KGRA, Utah, demonstrates that the distributions of different elements are the result of different chemical processes operating throughout the geologic history of the area. Statistical analysis of geochemical-data distributions confirm the presence of several distinct element associations.

Of the 36 elements determined on the samples, 12 (V, Mo, Cd, Ag, Au, Sb, Bi, U, Te, Sn, B and Th) were present in concentrations at or below detection levels. Of the remaining 24 elements, only 3 (Ni, Co and Zr) are lognormally distributed. Distributions for the remaining elements are of aggregate populations which represent background, mineralization or other processes.

Pearson correlation coefficients reveal four elemental groupings:

- 1) Na-K-Fe-Al-Ti-P-Sr-Ba-Cr-Ni-Li-Be-Zr-La-Ce
- 2) Ca-Mg
- 3) Mn-Co-Pb-Zn-As-Hg
- 4) Cu

Groups 1 and 2 are related to the lithogeochemistry of the host rocks, the first association representing intervals of volcanic and clastic lithologies and the second association representing carbonates. The third group represents elements associated with hydrothermal enrichment. Cu alone does not correlate significantly with any other element. Lithogeochemistry is the most-significant chemical control both in terms of the number of elements and in terms of the magnitude of the resultant variations.

In the Cove Fort-Sulphurdale system, only the distribution of Hg can be

related to the location of the present geothermal system. Enrichments in other elements, particularly As, Pb, Zn, Mn and Cu are primarily related to older mineralizing events. Frequent spatial coincidence of enrichments of these elements and of Hg are due to control of sequential hydrothermal events by the same structures.

INTRODUCTION

The Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) (Fig. 1) represents one of the largest identified hydrothermal convection systems in the United States (Brook et al., 1978). The area has been the object of a number of recent studies and of significant exploration activity because of its recognized geothermal potential. The geology of the Cove Fort-Sulphurdale KGRA has been mapped and discussed by Moore and Samberg (1979) and Steven and Morris (1981), the geochemistry of temperature gradient hole cuttings interpreted by Bamford and Christensen (1979), resistivity and IP profiles interpreted by Ross (1979), and the geological, geochemical, and geophysical exploration of the area summarized in the integrated exploration case study of the area by Ross et al. (1982).

Previous geochemical studies utilizing cuttings from shallow temperature-gradient drill holes (Bamford and Christensen, 1979; Ross et al., 1982) have demonstrated that As, Hg, Pb and Zn are broadly zoned within the Cove Fort-Sulphurdale area and can be used to distinguish between the effects of several sequential hydrothermal events. Analysis of drill cuttings samples from the three exploration drill holes 42-7, 31-33 and Forminco #1 was initiated in order to confirm the earlier findings and to extend the zoning model to depth.

METHODS

Drill cuttings from the three deep wells were prepared for analysis by compositing individual washed 3 m (10 ft) interval samples over 30 m (100 ft) intervals and pulverizing to -200 mesh in a tungsten carbide shatterbox. All samples were stored in sealed glass vials to avoid sample cross-contamination.

Samples were analyzed for 36 elements by inductively coupled plasma (ICP) emission spectroscopy using an Applied Research Laboratories Model 137 ICP in the ESL geochemical laboratory. Elements determined by ICP were Na, K, Ca, Mg, Fe, Al, Ti, P, Sr, Ba, V, Cr, Mn, Co, Ni, Cu, Mo, Pb, Zn, Cd, Ag, Au, As, Sb, Bi, U, Te, Sn, Li, Be, B, Zr, La, Ce and Th. Specifics of the analytical instrumentation and procedures, as well as an evaluation of the accuracy and precision of analyses are summarized in Christensen et al. (1980). The pulverized samples were dissolved for ICP analysis by a four acid digestion procedure (Christensen et al., 1980). In addition, As was determined on each sample solution by a colorimetric procedure (Fisher Scientific Co., 1960) and Hg was determined on solid samples by gold film Hg detector. Of the elements determined, V, Mo, Cd, Ag, Au, Sb, Bi, U, Te, Sn, B and Th concentrations were at or below detection levels for all or most of the samples. These elements are not considered further.

In order to distinguish between chemical variations resulting from hydrothermal redistribution and the numerical dispersion of analytical values expected in natural background geochemical populations, several statistical procedures were used. These included the graphic display of the cumulative frequency distributions on logarithmic probability paper (Lepeltier, 1969; Sinclair, 1974, 1976) and the calculation of Pearson correlation coefficients (Nie et al., 1975).

GEOLOGIC SETTING

The geology of the Cove Fort-Sulphurdale area has been treated in some detail by Moore and Samberg (1979) and reviewed by Ross et al. (1982). The northern portion of the geothermal area consists primarily of Paleozoic and Mesozoic sedimentary rocks and mid-Tertiary dacitic lava flows. To the south, in the northern Tushar Mountains, these rocks are covered by mid-Tertiary ash-flow tuffs and intruded by latite and quartz-monzonite stocks and dikes.

The geothermal reservoir is situated within fractured Paleozoic carbonate rocks. In the central portion of the thermal area, low-angle normal faults of Tertiary age have moved relatively impermeable volcanic rocks over the reservoir to form an effective thermal and hydrologic cap over the system. Beneath the low-angle faults, heat transfer is primarily by convective flow of thermal fluids within steeply-dipping fractures while, in the upper plate, heat loss occurs primarily by conduction and mixing with cold meteoric water (Nielson and Moore, 1979).

Over much of the area, the thermal water table occurs at depths of approximately 400 meters (Moore and Samberg, 1979) and consequently, principal surface manifestations reflect the effects of degassing and boiling at depth. Hydrogen sulfide gas, presently evolving from the Cove Fort and Sulphurdale areas near the northern and southern margins of the low-angle fault sheets respectively, results in the formation of pyrite and marcasite and the deposition of sulfur. Oxidation of hydrogen sulfide, followed by formation and downward movement of sulfuric acid has reduced the near-surface rocks to porous, siliceous residues. Although the existence of a hot-water reservoir at depth has been confirmed by a deep drilling, surficial features indicative of surface liquid discharges, such as deposits of siliceous or

calcareous sinter, are not present. There is no evidence that the present system has ever discharged liquid to the surface.

A multi-element geochemical survey, utilizing cuttings from 20 90-meter temperature gradient holes from the geothermal area demonstrated that Hg, As, Pb and Zn have distributions clearly related to hydrothermal remobilization. The numerical distributions for these elements suggest that their spatial distributions are related to more than one geochemical event or process. This geochemistry and the known geology provide evidence of the evolution of the Cove Fort-Sulphurdale system.

At least two hydrothermal events affected the area prior to the beginning of the present geothermal activity. During mid-Tertiary time, propylitic alteration of the volcanic rocks and development of fracture-controlled base metal mineralization accompanied intrusion of quartz-monzonite and latite porphyry dikes and stocks. Base metal mineralization is dominated by pyrite but locally includes galena, sphalerite, pyrrhotite, bornite, and chalcopyrite (Moore and Samberg, 1979). Anomalous Pb and Zn concentrations detected in the survey are located within the southeastern portion of the area, especially about the margin of exposed latite stocks and inferred subjacent quartz monzonite. Subsequent to the base metal hydrothermal event, but predating the present sulfur deposition, fluorite mineralization developed during a separate hydrothermal event. The geochemistry of mineralized samples formed during these two events suggests that As was associated with fluids during both the fluorite and base metal mineralization.

The near-surface chemical signature of the present geothermal system is characterized by high concentrations of Hg. Lesser concentrations of the chalcophile elements As, Pb and Zn in some samples probably result from the

scavenging of these elements along with iron from the host rocks during the formation of pyrite. Hg concentrations in drill cuttings are greatest near areas of active hydrogen sulfide discharge and sulfur deposition northwest of Cove Fort and near Sulphurdale.

The consistent spatial coincidence of silicification, base metal mineralization, fluorite mineralization, sulfur deposition and the present evolution of hydrogen sulfide along major structures indicates that many of the same geologic structures have remained active or have been reactivated to control fluid movement during the three identified hydrothermal events.

Comparison between the cumulative frequency distribution plots (Figures 16 and 17), the down-hole chemical profiles, and the lithologic log is particularly instructive. Na, K, Fe, Al, Ti, P, Sr, Cr, Li, La and Ce analytical values all belong to two overlapping, non-intersecting populations: a higher population of greater concentration values associated with the volcanic rocks and a lower population associated with the carbonate section. The cumulative frequency curve of Be indicates the presence of three populations representing, in increasing value, the carbonates, the volcanics and an anomalous interval in the upper level of well 31-33. Similarly, Ba values belong to three populations, an upper population associated with volcanics, a lower population associated with carbonates, and an intermediate population associated with clastic sedimentary rocks and intervals of mixed lithology.

The downhole distributions of Ca and Mg are antithetical to those of the 13 elements discussed above. Ca concentrations belong to two populations: a higher population associated with the carbonates and a lower population associated with the other lithologies. Mg concentrations belong to three overlapping populations associated with the carbonates, the volcanic rocks, and the clastic sedimentary rocks in decreasing concentration, respectively.

Thus, of the 24 elements determined which were present in concentrations above detection levels, the distributions of 15 are predominantly lithologically controlled. While some hydrothermal redistribution of these elements undoubtedly has occurred, the effect is masked by lithologic variations.

The associations of elements evident in the down-hole logs are confirmed by correlation analysis of the geochemical data. Pearson parametric

correlation coefficients were computed (Nie et al., 1975) for the geochemical data (Table 2). The absolute values of the correlations obtained are not meaningful because of the inefficiency of the parametric statistic when dealing with non-normal populations. "Indications" rather than "inferences" are drawn from this "quasistatistical" or "pseudostatistical" analysis (Chapman, 1978). Data were not log-transformed in order to effectively weight the analysis in terms of the populations related to hydrothermal enrichment - the delineation of which is a major objective of the analysis.

The correlation coefficients reveal 4 groupings of elements:

- 1) Na-K-Fe-Al-Ti-P-Sr-Ba-Cr-Ni-Li-Be-Zr-La-Ce
- 2) Ca-Mg
- 3) Mn-Co-Pb-An-As-Hg
- 4) Cu

The first group is nearly identical to that identified as representing volcanic and clastic sedimentary lithologies. The second group represents carbonate lithologies. The third group represents elements associated with hydrothermal enrichment. Cu alone does not correlate significantly with any of the other elements.

Pearson correlation coefficients between the elements of the third group are shown in Figure 18. A correlation dendrogram with group correlation coefficients calculated by simple column averaging is shown in Figure 19. If the data were all normally distributed, a coefficient of 0.24 would be significant at the 1% level (double-tailed t-test). Again, because of the non-normality of the data, the values indicate the relative strengths of correlation only.

The association of pyrite, pyrrhotite, bornite, chalcopyrite, galena, and

sphalerite, in places associated with intense quartz veining, has been documented by Moore and Samberg (1979) and attributed to the early mid-Tertiary hydrothermal event. The spatial coincidence of Pb, Zn and Mn concentrations is evident in the well logs. As and Hg are also strongly correlative with these three elements, and Co less strongly so. The highest concentrations do not occur exclusively within any one rock type. The frequency distribution curves for all 6 elements indicate that more than one population are present; at least one population appears to be due to hydrothermal enrichment while the others represent lithologic populations.

The interpretation of the geochemistry of the thermal gradient cuttings indicated that three chemically distinct episodes of hydrothermal metal enrichment could be distinguished: a Pb-Zn event which accompanied intrusion of the quartz monzonite, a fluorite-As event, and the present Hg event. In the drill holes, the chemical enrichments are largely coincident. The close association As with Pb and Zn enrichments may be in large part attributed to movement of different mineralizing hydrothermal fluids through the same structures. The Cove Fort-Sulphurdale area is seismically active, and there is abundant evidence for recurrent movement on several of the major structures (Ross et al., 1982) so that such recurrent and hydrothermal activity is reasonable. Further, some of the carbonate rocks have considerable porosity and permeability which should make them favorable aquifers.

Hg is less closely associated spatially with the Pb-Zn-As-Mn group. The highest concentrations are located immediately beneath the relatively less permeable volcanic section overlying the sedimentary units. In well 42-7, the high concentration of Hg beneath the denudation fault is consistent with the active deposition from convecting hydrothermal fluids confined beneath the

fault. Active deposition of Hg from H₂S-rich gases evolving from about the margins of the glide blocks has been confirmed (Ross et al., 1982).

The nature of the Co enrichment is not known. Hulen and Sibbett (1981) have documented the presence of Co and many other elements as potential contaminants introduced into samples from the degradation of drilling hardware and lubricants. The fact that Co concentrations belong to a single lognormal population suggests that the apparently significant correlation with As (Fig. 18) may be misleading and that the distribution of Co is probably not related to mineralization.

The frequency distribution of Cu suggests multiple populations of values. The highest values (>100 ppm) are associated with recognized chalcopyrite mineralization, while lower values are background. A recognizable lithogeochemical difference exists between the volcanics and the relatively Cu-poor carbonates. The locations of anomalous Cu mineralization are not coincident with Pb-Zn anomalies, suggesting either some difference in the time of the respective mineralizing events or, alternatively, differing chemical controls causing contemporaneous deposition at different locations.

DISCUSSION

Multielement geochemical analysis of drill cuttings from three geothermal exploration wells in the Cove Fort-Sulphurdale KGRA demonstrates that the distributions of different elements result from different geochemical dispersion processes which have operated at different times throughout the history of the rocks. These include the sedimentary and volcanic processes responsible for the formation of the layered rocks, intrusive activity, structural disruption, and several episodes of hydrothermal activity within both hot-water and vapor-dominated portions of geothermal systems.

The lithologic control on chemistry is the most significant both in terms of the number of elements and of the magnitude of the resultant variation. The distributions of Na, K, Fe, Al, Ti, P, Sr, Ba, Cr, Li, Be, La, Ce, Ca and Mg are dominated by rock type, the first 13 being relatively enriched in the volcanic rocks and the latter 2 in the carbonate rocks. Whatever hydrothermal redistribution of these elements has occurred is masked by the dominance of the lithologic control of the chemistry.

The suite of elements Pb, Zn, Mn, As and Hg have distributions evidently affected by hydrothermal redistribution. The correlations between all of these elements is in part a consequence of the superposition of recurrent hydrothermal events. Pb, Zn and Mn are closely associated with an older mineralizing event. Concentrations of Cu, although less strongly correlative, probably formed, if not at exactly the same time, then probably within the same hydrothermal episode. Concentrations of As may have formed during the same event as well as at some later time. Hg is actively moving with the geothermal system today.

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Figure 1. Generalized geology and drill hole locations (after Moore and Samberg, 1979)

DH 42-7

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 4. Al, Ti, P, Sr and Ba in well 42-7

DH 42-7

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 5. Cr, Mn, Co, Ni and Cu in well 42-7

DH 42-7

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 7. Zr, La, Ce, As and Hg in well 42-7

DH 31-33

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 8. Na, K, Ca, Mg and Fe in well 31-33

DH 31-33

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 10. Cr, Mn, Co, Ni and Cu in well 31-33

DH 31-33

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 11. Pb, Zn, Li, and Be in well 31-33

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 1000.0 FT./IN.
(DEPTH SHOWN IN 1000 FT UNITS)

Figure 12. Zr, La, Ce, As and Hg in well 31-33

DH FORMINCO

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 500.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

DH FORMINCO

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 500.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

Figure 13. Na, K, Ca, Mg, Fe, Al, Ti, P, Sr and Ba in well Forminco #1

DH FORMINCO

COVE FORT-SULPHURDALE
MILLARD & BEAVER CO., UTAH

SAMPLE TYPE: WHOLE ROCK
VERT. SCALE: 500.0 FT./IN.
(DEPTH SHOWN IN 100 FT UNITS)

Figure 15. Zr, La, Ce, As and Hg in well Forminco #1

Figure 17. Cumulative frequency distribution plots for Ba, Sr, Co, Li, Cu, Pb, Zn, Ni, Cr, La, Ce and Be. Concentrations of all elements in ppm. Arrows indicate locations of inflection points on curves.

Figure 18. Pearson correlation coefficients for elements associated with hydrothermal enrichment.

Figure 19. Correlation dendrogram. Group correlations calculated by column averaging.

Table 2

Cove Fort-Sulphurdale Geothermal Wells
Pearson Correlation Coefficients

	Na	K	Ca	Mg	Fe	Al	Ti	P	Sr	Ba	Cr	Mn	Co	Ni	Cu	Pb	Zn	Li	Be	Zr	La	Ce	As	Hg
Na	1.00																							
K	.89	1.00																						
Ca	-.73	-.79	1.00																					
Mg	-.56	-.66	.57	1.00																				
Fe	.85	.89	-.81	-.59	1.00																			
Al	.93	.93	-.83	-.60	.97	1.00																		
Ti	.89	.93	-.83	-.59	.96	.98	1.00																	
P	.44	.50	-.40	-.47	.54	.53	.55	1.00																
Sr	.75	.72	-.55	-.55	.79	.82	.77	.37	1.00															
Ba	.91	.85	-.72	-.49	.81	.88	.83	.27	.62	1.00														
Cr	.32	.49	-.48	-.50	.51	.46	.52	.49	.31	.13	1.00													
Mn	-.06	.05	-.12	-.12	.09	.05	.05	.21	.04	-.02	.10	1.00												
Co	-.08	.05	-.35	-.34	.03	.00	.01	-.17	-.07	-.06	.07	.05	1.00											
Ni	.08	.22	-.36	-.16	.38	.26	.33	.20	.13	-.03	.60	-.01	.21	1.00										
Cu	-.03	-.14	.20	.08	-.11	-.14	-.15	.18	-.09	-.14	-.12	-.08	.00	-.12	1.00									
Pb	-.26	-.03	-.05	-.08	-.05	-.11	-.12	-.17	-.19	-.07	-.03	.86	.13	-.17	.00	1.00								
Zn	-.19	-.17	.09	.13	-.19	-.19	-.20	-.09	-.18	-.05	.03	.24	-.02	-.04	-.04	.56	1.00							
Li	.41	.52	-.46	-.11	.58	.57	.55	.33	.46	.33	.12	.22	-.06	.26	-.15	.09	-.07	1.00						
Be	.77	.84	-.57	-.49	.65	.73	.75	.41	.47	.64	.22	-.07	-.31	.08	.07	-.25	-.28	.31	1.00					
Zr	.33	.36	-.23	-.35	.32	.29	.34	.35	.21	.25	.31	-.07	-.09	.13	-.06	-.15	.14	-.05	.39	1.00				
La	.77	.78	-.67	-.45	.71	.76	.80	.45	.41	.70	.49	-.21	-.25	.14	.12	-.32	-.20	-.08	.74	.50	1.00			
Ce	.22	.32	-.43	-.35	.07	.09	.31	.00	-.21	.09	.40	-.29	.03	.29	-.17	-.48	-.17	-.59	.48	.78	.74	1.00		
As	-.33	-.14	-.02	-.18	-.12	-.21	-.21	-.14	-.23	-.25	-.07	.32	.39	-.11	-.02	.47	.17	-.16	-.43	-.10	-.39	-.13	1.00	
Hg	-.22	-.18	.06	-.12	-.11	-.18	-.18	.04	-.14	-.20	.01	.02	.13	.01	-.01	.12	.28	-.26	-.29	.55	-.19	.18	.37	1.00

analytical values less than detection level omitted in the calculation of correlation coefficients
total sample size = 119

MINERAL MTN SWARM, 1981

MAGNITUDE SCALE (ML) :

△ SEISMOGRAPH STATION

A

NEGRO MAG FAULT

14-2
1500' to WNW

No Vertical Exaggeration

SCALE .61 km/in $\rightarrow$ 1:24,000

PLATE II

4

DEPTH, KM ($\times 10^{-1}$)

.00 6.10 12.20 18.30 24.40 30.50 36.60 42.70 48.80 54.90 61.00 67.10 73.20 79.30 85.40 91.50

B

13-10
1650' South of Section
OPAL MOUND FAULT

9-1
1600' South of Section

B

DEPTH, KM ($\times 10^{-1}$)

.00 6.10 12.20 18.30 24.40 30.50 36.60 42.70 48.80 54.90 61.00 67.10 73.20 79.30 85.40 91.50

No Vertical Exaggeration

SCALE .61km/in $\rightarrow$ 1=24,000

PLATE III