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GEOLOGICAL SURVEY

Application of Mineral-Solution Equilibria

to the Search for Sandstone-Type Uranium

Deposits in the Beaver Basin, Utah

by

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Abstract

An improved computer modeling program was used to calculate the saturation indexes of 50 waters from the Beaver basin in west-central Utah with respect to uraninite and coffinite. The mineral-solution study showed that the chemical environment of parts of the Beaver basin is favorable for the occurrence of sandstone-type uranium deposits. The ground waters from several areas are supersaturated with respect to uraninite and coffinite. Two areas, in particular, an area west of the town of Beaver and an area near the settlement of Manderfield, have been identified as most favorable for exploration.

The methods described in this study can be utilized to evaluate waters from wells and exploration drill holes as indicators of proximity to possible sandstone-type uranium deposits in other alluvial basins in the western United States.

Introduction

During the summer, 1979, water samples were collected from 38 wells, 7 springs, and 5 streams in the Beaver basin in west-central Utah. The results of the chemical analyses of the 50 water samples can be found in McHugh and others (1980). An interpretation based on mineral-solution equilibria modeling of 34 of the 50 water samples located several areas favorable for the occurrence of sandstone-type uranium deposits (Miller and others, 1980). Recently, an improved computer modeling program has become available (Ball and others, 1981), which has been used to determine the saturation indexes (SI) for uraninite and coffinite of all 50 water samples including improved SI values for the original 34 samples.

Study Area

The Beaver basin is a block-faulted depression along the eastern margin of the Basin-Range province in west-central Utah (fig. 1). The basin is filled largely by Quaternary and Tertiary fluviatile and lacustrine deposits of silt, sand, gravel, and clay probably a kilometer or more in thickness and mostly derived from the surrounding mountains. The basin is bounded on the east by the Tushar Mountains, which contain uranium-bearing volcanic rocks (Cunningham and Steven, 1979), and on the west by the Mineral Mountains, which contain uranium-bearing springs (Miller and others, 1979). Both areas could have served as sources that supplied uranium to the basin fill (Cunningham and Steven, 1979). The flow of most ground water and surface water within the basin is toward the southwest. A hydrologic outlet from the basin is in the southwestern corner, east of Minersville Canyon (Mower, 1978). Ground-water flow in the southern part of the basin is probably northward toward the Beaver River.

Water Geochemistry

Collection and analytical procedures and map plots of the 50 water samples from the Beaver basin, Utah for specific conductances, U, Mo, As, Se, V, Mn, and F can be found in Miller and others (1980). The Beaver basin contains 36 Ca-HCO$_3$, 9 Na-HCO$_3$, and 5 Na-Ca-HCO$_3$-type waters. No central area of high concentration of dissolved salts in water exists in the basin; instead, scattered sites with high concentrations of dissolved salts occur
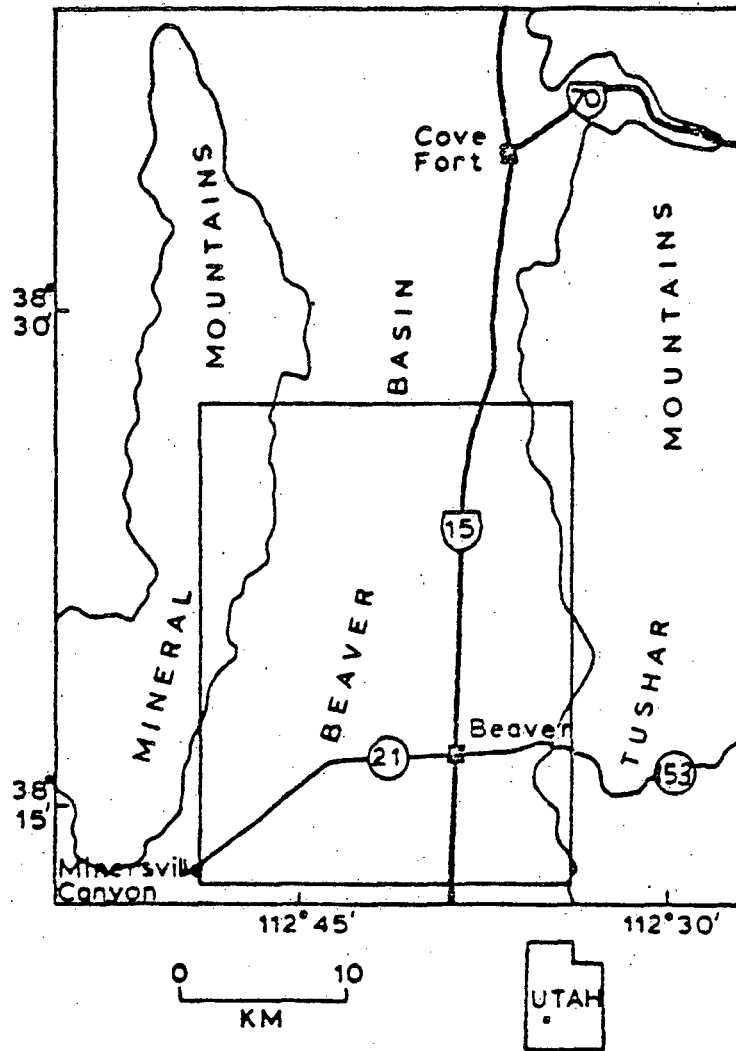
Figure 1.--Location map of Beaver basin,

Utah; study area is outlined.

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sporadically throughout the basin. The uranium concentration in water from the basin (disregarding site 47, a spring containing 740 μg/L uranium and located in the bedrock area of the Mineral Mountains and discussed in Miller and others (1979) ranged from <0.2 to 52 μg/L, with a geometric mean of 4.0 μg/L. High values for uranium occur at site 5, a well south of Manderfield (52 μg/L), site 25, a well northeast of Beaver, (39 μg/L), and site 17 and site 20, two wells northwest of Beaver (35 and 30 μg/L, respectively) (fig. 2).

Mineral-Solution Equilibria

The chemistry of ground waters can be used in conjunction with thermodynamic data to calculate the state of saturation of ground waters with respect to mineral phases associated with mineralization. This technique has been used to investigate known sandstone-type uranium deposits in Texas, Wyoming, and New Mexico (Langmuir and Chatham, 1980; and Runnells and others, 1981). The potential for sandstone-type uranium deposits in the Beaver basin was evaluated using this technique (Miller and others, 1980). That study determined the saturation indexes (SI) of the ground waters with respect to uraninite and coffinite for 34 of the original 50 water samples. This study reports saturation indexes for all 50 water samples. In addition, an improved computer modeling program, WATEQ3 (Ball and others, 1981), was used to calculate the SI values. The improved program differs from that used in Miller and others (1980) in that for uraninite, all uranium is in the U^{+4} state. Naturally occuring uraninite is usually partially oxidized (Langmuir and Chatham, 1980). Therefore, the results of using an unoxidized uraninite is to be conservative in the calculation of the state of saturation of ground waters with respect to uraninite.

By using thermodynamic data and assuming chemical equilibrium among the dissolved species, the computer program WATEQ3 (Ball and others, 1981) was used to calculate the activities and chemical speciation in waters from the Beaver basin.

The Eh (redox potential) was calculated by assuming equilibrium of the water chemistry with respect to metastable $Fe(OH)_{3(c)}$ and using the measured pH and total dissolved iron, as shown by the couple $Fe(OH)_{3(c)} + 3H^+ + e^- \rightleftharpoons Fe^{2+} + 3H_2O$ (see Garrels and Christ, 1965, for details on calculating Eh values). Fe^{+2} is calculated by using WATEQ3.

The Eh values of waters in the Beaver basin range from -0.137 to 0.225 volts (fig. 3). The lowest Eh occurs at a well (site 46), and other low values occur at sites 7, 44, 42, and 14, with values of -0.051, -0.017, -0.014, and -0.002 volts, respectively. Sites 42 and 46 are irrigation wells, sites 14 and 44 are artesian wells in the southwestern part of the basin, and site 7 is a well near Manderfield. A ground-water environment trending toward reducing conditions decreases the solubility of uranium; therefore, these sites indicate areas favorable for the precipitation of reduced uranium minerals.

To evaluate the saturation of water in the basin with respect to reduced uranium minerals, the saturation indexes (SI) of uraninite (UO_2) and coffinite
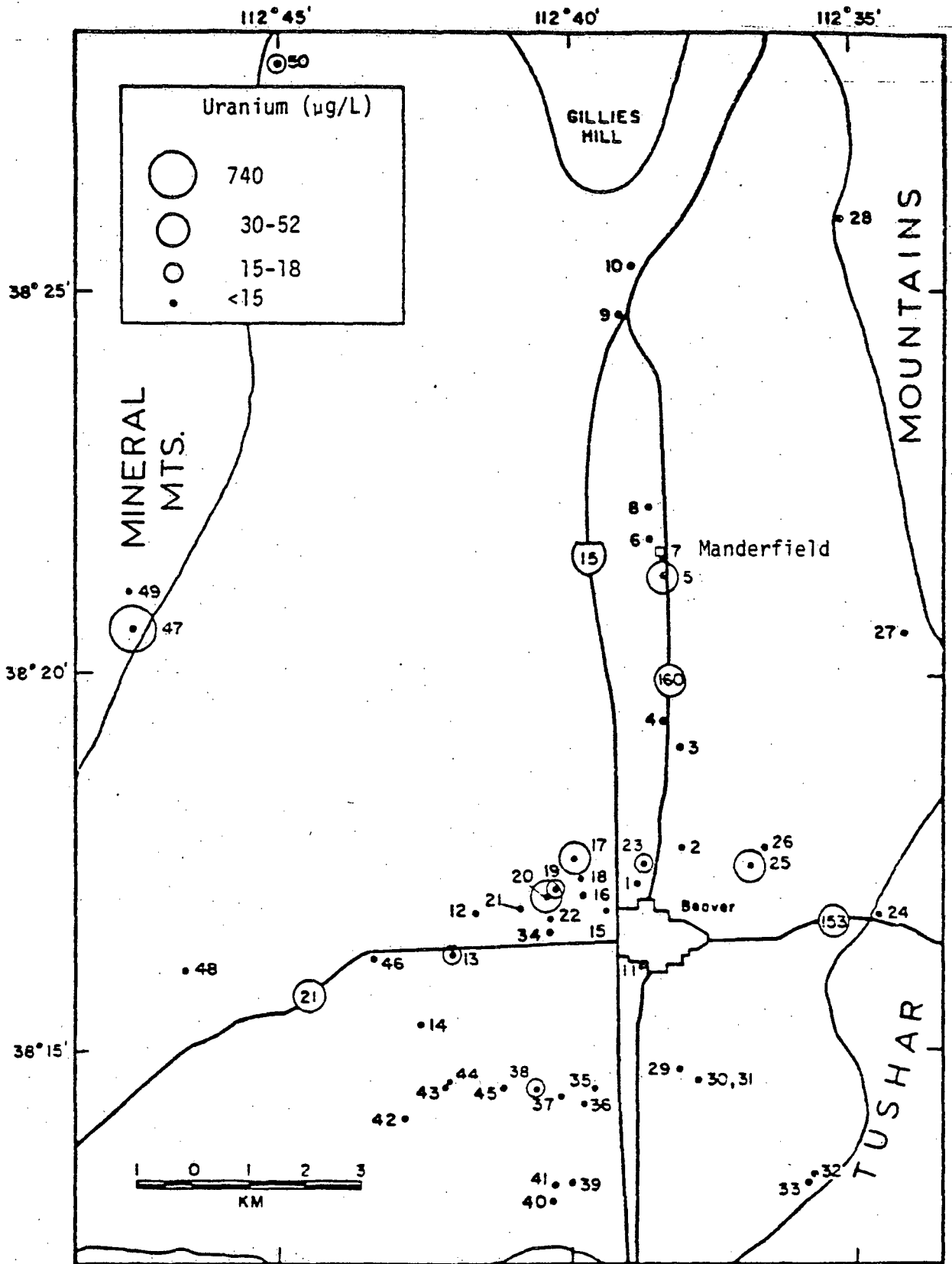
Figure 2.--Distribution of uranium of waters from the Beaver basin,
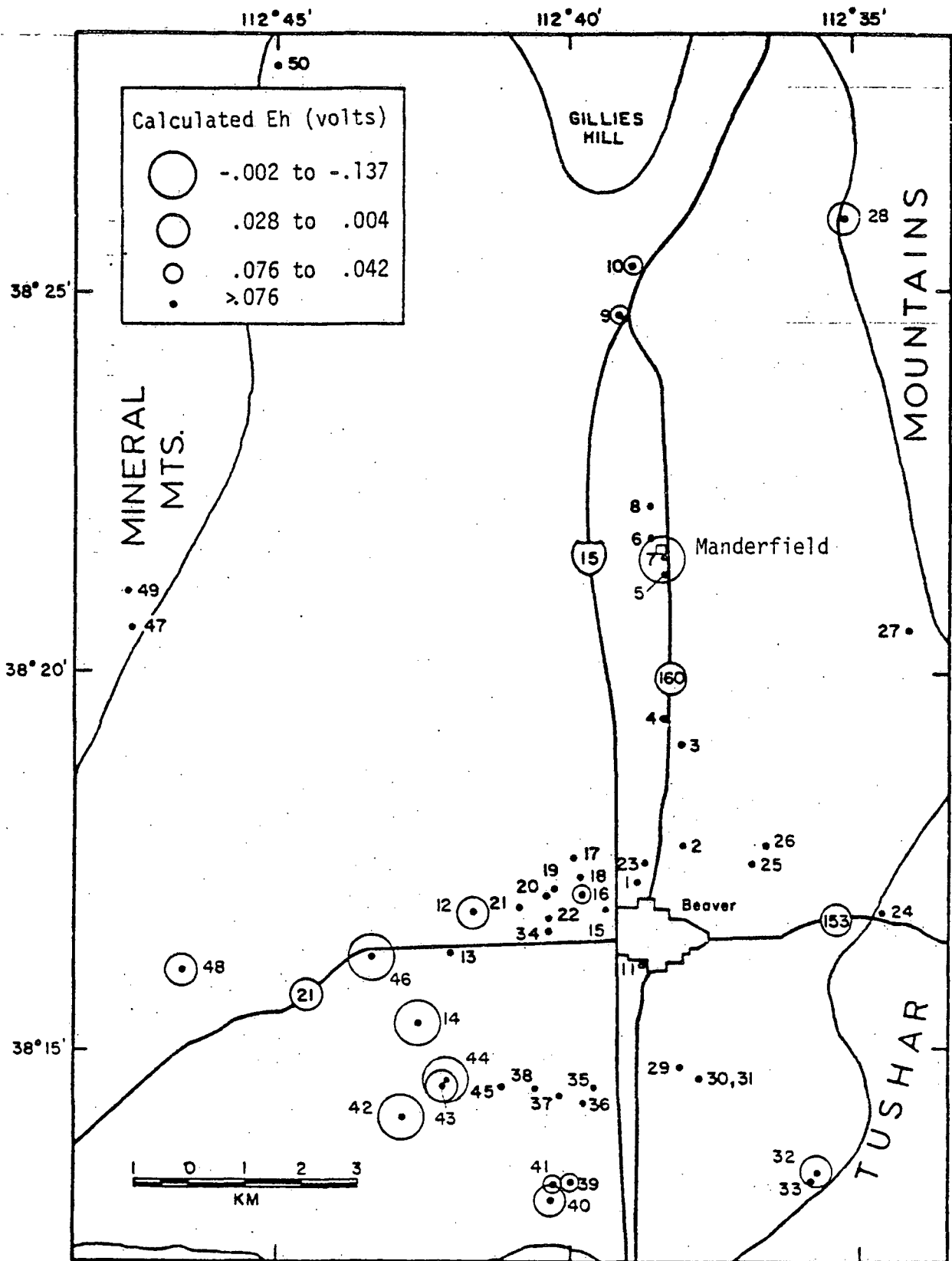Utah (numbers show sites).

Figure 3.--Distribution of calculated redox potentials (Eh) of waters from the Beaver basin, Utah (numbers show sites).

($USiO_4$), the most common ore minerals containing reduced uranium, were calculated. The saturation index is the logarithm of the ratio of the apparent ion activity product (Kap) to the equilibrium solubility product (Kt). An SI>0 indicates that the water is supersaturated with respect to a mineral phase, and that the mineral phase should precipitate. An SI<0 indicates that the water is undersaturated (see Runnells and others (1981) for details).

The two equations used for the calculation of the apparent ion activity products for uraninite and coffinite are:

$$UO_2 + 4 H^+ \rightleftharpoons U^{4+} + 2 H_2O$$
and
$$USiO_4 + 4H^+ \rightleftharpoons U^{4+} + H_4SiO_4.$$
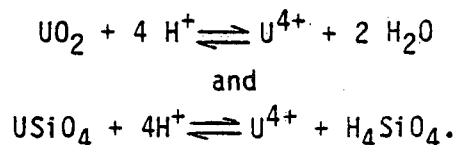
Therefore, the log Kap for UO_2 = log $a_{U^{4+}}$ + 4 pH and log Kap for $USiO_4$ = log $a_{U^{4+}}$ + log $a_{H_4SiO_4}$ + 4 pH. The activities for U^{+4} and H_4SiO_4 were calculated using WATEQ3, and the pH was measured in the field.

The pH, specific conductance, water type, uranium concentration, dominant uranium species present in water, the Eh, and the degree of saturation of the water with respect to uraninite and coffinite for the 50 sites in the Beaver basin are shown in table 1. The dominant uranium species present in waters from the Beaver basin are $UO_2(CO_3)_2^{2-}$ and $UO_2(CO_3)_3^{4-}$.

The saturation indexes for uraninite ranged from +0.789 to -6.52 (fig. 4). The most anomalous samples were from sites 46 and 7 with SI values of 0.789 and 0.196 respectively, which indicates supersaturation with respect to uraninite. Site 46 is a well approximately 440 feet deep (Mower, 1978). Site 7 is from a 500-foot-deep well that supplies the Manderfield town water system; the upper 300 feet of this well is sealed (C. Bradshaw, oral commun., 1981). The supersaturation of the waters from these sites constitute the most favorable indication for deposition of uraninite found so far in Beaver basin. Water from site 28 is only slightly undersaturated with respect to uraninite, which may indicate proximity to a saturation front.

The distribution of saturation indexes for coffinite ranged from +2.25 to -4.69 (fig. 5). The most anomalous sites are 46, 7, 28, 44, 32, and 42 with values of 2.25, 1.72, 1.34, 0.413, 0.088, and 0.020 respectively. Waters from these sites are supersatuated with respect to coffinite. Waters from sites 48 and 16 are slightly undersaturated with respect to coffinite. All these sites are wells except for site 28 and 32 which are located along Indian and Birch Creek. These sites mark the most favorable sampled areas in the Beaver basin for the precipitation of coffinite. Other favorable areas in the basin correspond to the remaining anomalous values shown in Figure 5. As noted, waters from sites 28 and 32 are supersaturated with respect to coffinite and are slightly undersaturated with respect to uraninite. These sites are Indian Creek and Birch Creek which are draining areas of uraniferrous bedrock. The

Table 1.--Chemistry, calculated Eh values, and saturation indexes (SI) for uraninite and coffinite for waters from the Beaver Basin, Utah

Site number	Source	pH	Specific conductance	Water type	Uranium µg/L	Dominant uranium species	Calculated Eh, volts	SI for uraninite	SI for coffinite
1	irrig. well	7.61	440	Ca, HCO_3	14	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.165	-5.080	-3.435
2	irrig. well	7.45	265	---do---	6.0	----------do---------	.121	-3.085	-1.539
3	irrig. well	7.37	395	---do---	5.2	$UO_2(CO_3)_2^{2-}$-UO_2CO_3	.161	-4.415	-2.854
4	domestic well	7.50	320	---do---	1.7	----------do---------	.103	-3.275	-1.891
5	irrig. well	7.35	570	---do---	52	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.176	-4.689	-3.060
6	irrig. well	7.71	450	---do---	12	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.080	-2.298	-0.718
7	town water well	8.54	195	---do---	5.6	----------do---------	-.051	0.196	1.719
8	irrig. well	7.30	460	---do---	10	----------do---------	.187	-5.282	-3.730
9	irrig. well	8.02	560	---do---	13	----------do---------	.062	-3.247	-1.710
10	irrig. well	7.85	820	---do---	11	----------do---------	.075	-3.726	-2.191
11	spring	7.12	295	---do---	3.4	$UO_2(CO_3)_2^{2-}$-UO_2CO_3	.172	-4.746	-3.169
12	irrig. well	8.21	530	Na, HCO_3	<.20	$UO_2(CO_3)_3^{4-}$-$UO_2(CO_3)_2^{2-}$	.016	-3.343	-1.500
13	irrig. well	7.38	800	---do---	17	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.112	-3.242	-1.371
14	artesian well	8.22	320	Ca, Na, HCO_3	<.20	----------do---------	-.002	-2.364	-0.403
15	domestic well	6.98	320	Ca, HCO_3	7.4	$UO_2(CO_3)_2^{2-}$-UO_2CO_3	.124	-2.748	-1.438
16	domestic well	7.24	315	---do---	6.2	----------do---------	.076	-1.488	-0.085
17	domestic well	6.98	500	---do---	35	----------do---------	.204	-5.132	-3.800
18	domestic well	7.20	400	---do---	9.6	----------do---------	.104	-2.278	-0.658
19	domestic well	6.84	355	---do---	18	----------do---------	.225	-5.395	-3.849
20	irrig. well	7.05	440	---do---	30	----------do---------	.212	-5.374	-3.791
21	irrig. well	7.72	320	Ca, Na, HCO_3	11	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.110	-3.201	-1.443
22	domestic well	6.98	400	Ca, HCO_3	6.4	$UO_2(CO_3)_2^{2-}$-UO_2CO_3	.179	-4.750	-3.423
23	town water supply	7.70	360	---do-----	17	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.117	-3.731	-2.330
24	stream, Beaver Ck.	7.57	143	---do-----	<.20	$UO_2(CO_3)_2^{2-}$-UO_2CO_3	.080	-3.178	-1.685
25	domestic well	7.42	620	---do-----	39	$UO_2(CO_3)_2^{2-}$-$UO_2(CO_3)_3^{4-}$	.126	-3.375	-1.898

Table 1.--Chemistry, calculated Eh values, and saturation indexes (SI) for uraninite and coffinite for waters from the Beaver Basin, Utah

| Site number	Source	pH	Specific conductance	Water type	Uranium μg/L	Dominant uranium species	Calculated Eh, volts	SI for uraninite	SI for coffinite
26	irrig. well	7.76	420	Ca, HCO$_3$	12	$UO_2(CO_3)_2^{2-}$–$UO_2(CO_3)_3^{4-}$	.098	-3.041	-1.496
27	stream, North Ck.	7.32	145	---do---	1.4	$UO_2(CO_3)_2^{2-}$–UO_2CO_3	.136	-3.293	-1.893
28	stream, Indian Ck.	7.96	92	---do---	1.2	----------do---------	.021	-0.078	1.338
29	irrig. well	7.60	275	---do---	1.2	$UO_2(CO_3)_2^{2-}$–$UO_2(CO_3)_3^{4-}$	.158	-5.677	-3.837
30	spring	7.33	410	---do---	2.1	----------do---------	.144	-5.240	-3.505
31	domestic well	7.09	450	---do---	5.2	$UO_2(CO_3)_2^{2-}$–UO_2CO_3	.159	-4.339	-2.544
32	stream, Birch Ck.	8.13	122	---do---	<.20	$UO_2(CO_3)_2^{2-}$–$UO_2(CO_3)_3^{4-}$	.004	-1.617	0.088
33	stream, South Ck.	7.26	138	---do---	.20	$UO_2(CO_3)_2^{2-}$–UO_2CO_3	.150	-4.680	-2.972
34	irrig. well	7.63	320	---do---	6.0	$UO_2(CO_3)_2^{2-}$–$UO_2(CO_3)_3^{4-}$	.156	-4.820	-2.988
35	irrig. well	8.00	240	---do---	.90	----------do---------	.087	-3.881	-2.026
36	irrig. well	7.44	650	---do---	6.2	----------do---------	.172	-5.852	-4.011
37	domestic well	7.60	900	Na, HCO$_3$	9.6	----------do---------	.100	-3.719	-1.819
38	spring	7.41	710	Ca, Na, HCO$_3$	15	----------do---------	.198	-6.522	-4.693
39	irrig. well	8.15	280	Na, HCO$_3$	3.4	----------do---------	.042	-2.499	-0.618
40	irrig. well	8.16	270	---do---	2.4	----------do---------	.021	-2.110	-0.322
41	irrig. well	8.13	280	---do---	3.1	----------do---------	.052	-2.836	-1.010
42	irrig. well	8.35	240	---do---	.50	----------do---------	-.014	-1.769	0.020
43	artesian well	8.22	250	---do---	.90	----------do---------	.005	-2.311	-0.516
44	artesian well	8.09	320	Ca, Na, HCO$_3$	1.4	----------do---------	-.017	-1.387	0.413
45	spring	7.64	470	---do---	3.7	----------do---------	.144	-4.816	-2.883
46	irrig. well	9.00	580	Na, HCO$_3$	8.1	$U(OH)_5^{1-}$–$UO_2(CO_3)_3^{4-}$	-.137	0.789	2.245
47	spring	7.03	490	Ca, HCO$_3$	740	$UO_2(CO_3)_2^{2-}$–UO_2CO_3	.188	-3.195	-1.736
48	irrig. well	8.02	420	---do---	5.2	$UO_2(CO_3)_2^{2-}$–$UO_2(CO_3)_3^{4-}$	.028	-1.632	-0.023
49	spring	7.44	190	---do---	1.6	$UO_2(CO_3)_2^{2-}$–UO_2CO_3	.089	-2.142	-0.749
50	spring	7.00	540	---do---	17	----------do---------	.203	-5.151	-3.280
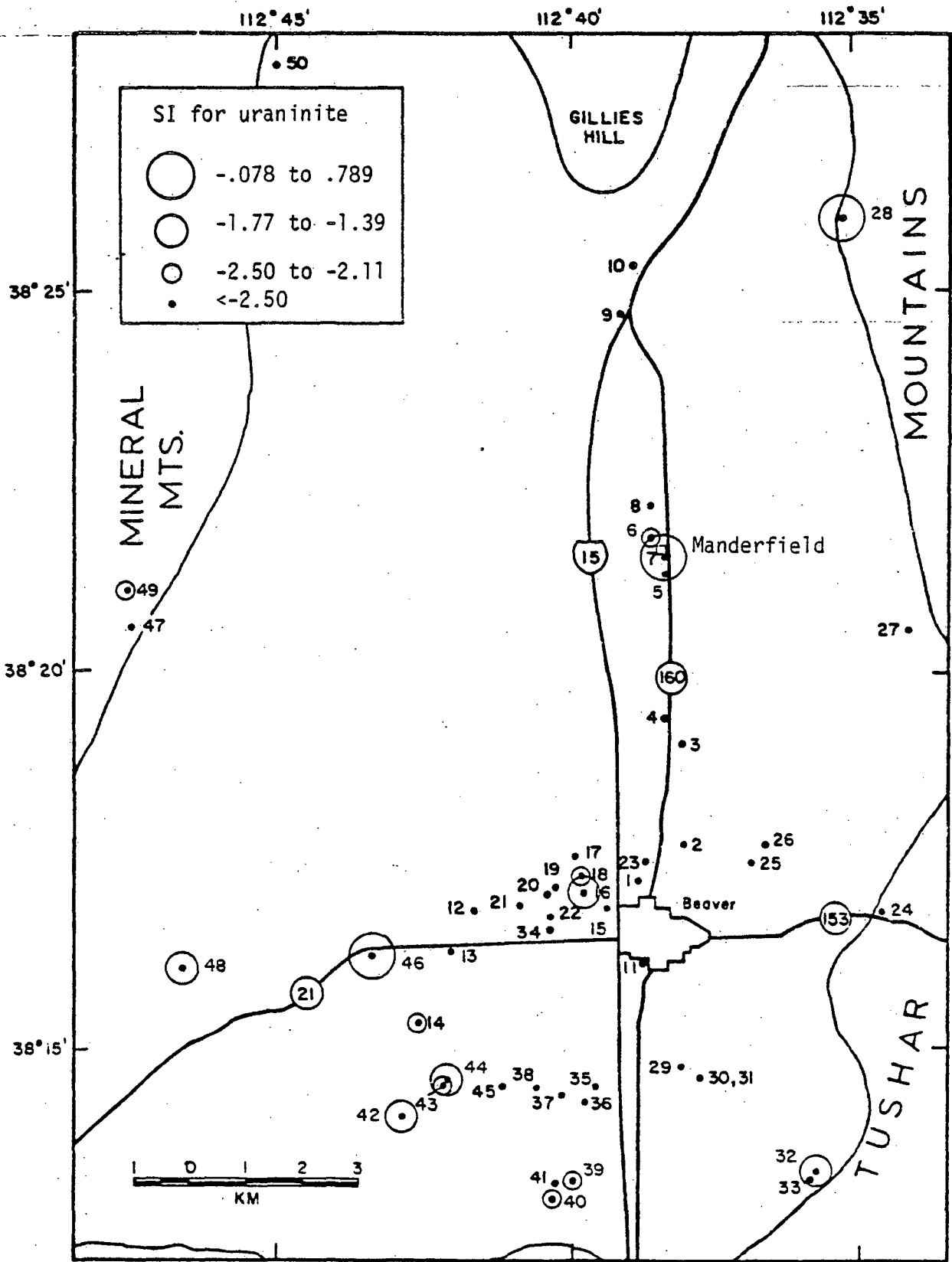
Figure 4.--Distribution of satuation indexes for uraninite for water from the Beaver basin, Utah (numbers show sites).
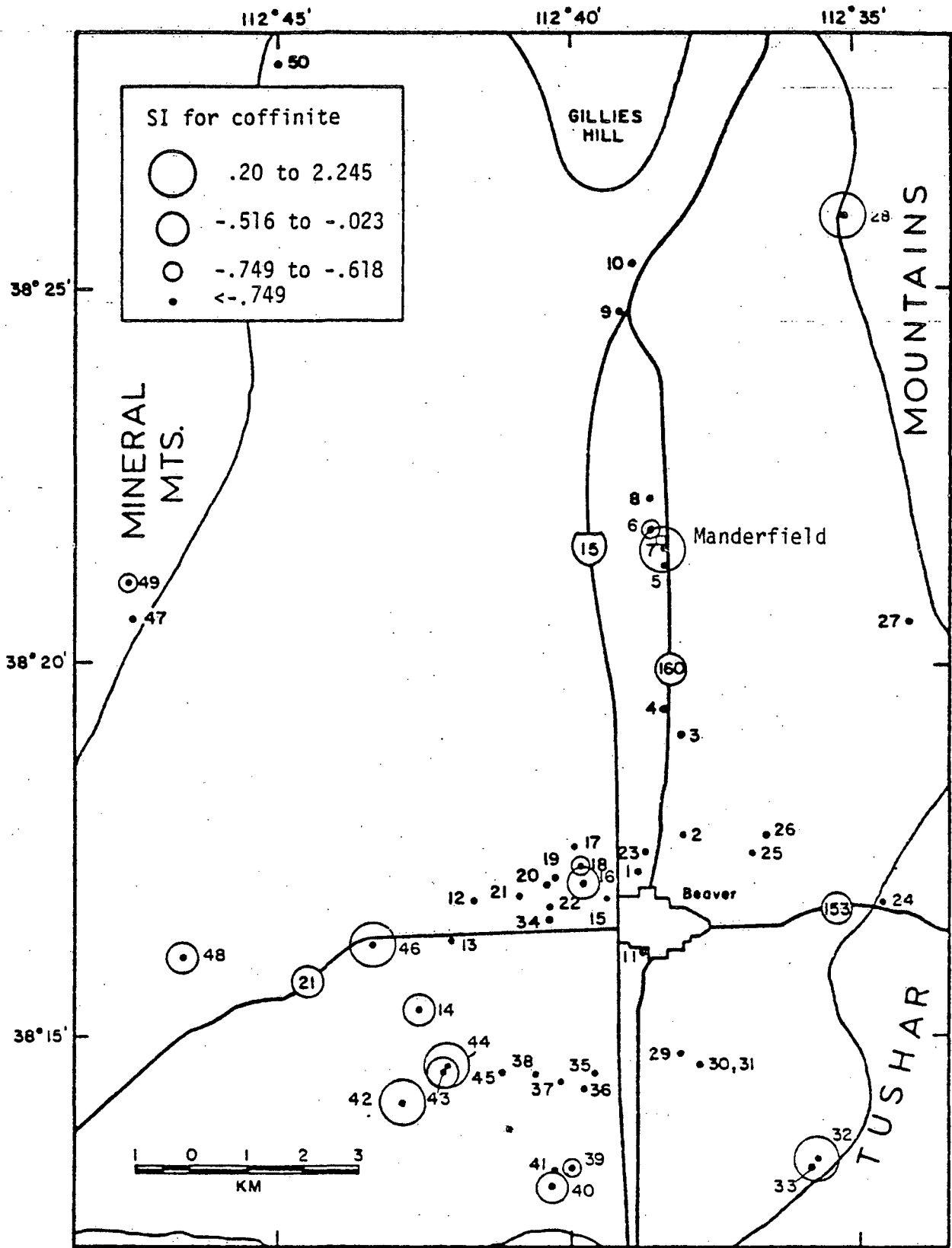
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Figure 5.--Distribution of satuation indexes for coffinite for waters from the Beaver basin, Utah (numbers show site).

high SI values are probably caused by weathering of hydrothermal uraninite upstream from these sites. The Mystery Sniffer, a uranium mine, is located upstream of site 28 along Indian Creek.

The Use of Pathfinder Elements Related to the Results of the Mineral-Solution Equilibria Approach

The mineral-solution equilibria approach delineated several areas favorable for sandstone-type uranium mineralization. A comparison of the use of pathfinder elements such as U, Mo, As, and Se can be made with the results of the mineral-solution equilibria approach. Wells at sites 12, 13, and 14 which are east of site 46 (whose ground water is supersaturated with respect to uraninite) contain higher concentrations of As than do ground waters at site 46. U, Mo and Se concentrations are variable (Table 2), but U concentrations of ground water from site 13, Mo concentration from site 12, and Se concentrations from sites 12 and 13 are higher than concentrations of groundwaters from site 46. The flow of ground water is generally southwestward toward Minersville canyon, indicating that the higher values of U, Se, and As are above site 46. Higher concentrations of As, Mo, Se, and U should usually occur in the oxidized portion of a redox front. In the Manderfield area, wells at sites 5, 6, and 8 which are near the well at site 7 (whose ground water is supersaturated with respect to uraninite) contain higher concentrations of U and Se and lower concentrations of As (Table 2) than does ground water from site 7; Mo concentrations are again variable. In addition, the Eh values indicate (Table 2) that oxidation-reduction fronts may be present in areas containing sites 7 and 46. The presence of multiple aquifers complicates the interpretation, and exact locations of oxidation-reduction fronts are not known, but one is probably east of site 46 and one near site 7.

In the Manderfield area, a survey of dissolved radon in ground water (McHugh and Miller, unpub. data) indicates relatively high values of Rn for three wells surrounding site 7. Wells at site 5, 6, and 8 contain Rn values of 2050, 2600, and 5800 pc/L, respectively. Rn content of ground water from site 7 was not determined because the water could not be sampled at the well head.

The use of pathfinder elements is not as diagnostic in selecting areas favorable for sandstone-type uranium mineralization as is the use of saturation indexes. The area west of Beaver that contained ground water supersaturated with respect to uraninite would not have been identified using pathfinder elements.

Table 2.--Selected chemical parameters of ground waters from wells of an area west of Beaver and an area near Manderfield, Beaver basin, Utah.

SITES	PARAMETERS					
No.	U(μg/L)	Mo(μg/L)	As(μg/L)	Se(μg/L)	Eh(volt)	SI(UO_2)
			Area west of Beaver			
12	<.2	16	13	3.3	0.16	-3.34
13	17	8	17	3.6	.112	-3.24
14	<.2	10	17	1.0	-.002	-2.36
46	8.1	10	4.1	1.6	-.137	0.79
			Area near Manderfield			
5	52	1.7	3.6	2.9	.176	-4.67
6	12	1.1	3.4	2.6	.080	-2.30
7	5.6	1.3	6.6	1.0	-.051	.196
8	10	1.2	1.9	2.1	.187	-5.28

Conclusions

The results of the ground-water survey in the Beaver basin, Utah, indicate that the areas of sites 46 and 7 are the most favorable areas in the basin for sandstone-type uranium deposits. Reducing conditions are present at these sites, and the waters are supersaturated with respect to uraninite and coffinite. The well at site 46 is 440 feet deep and is west of the town of Beaver, so only shallow aquifers are being tested. Ground-water flow in the vicinity of site 46 is toward the hydrologic outlet through Minersville Canyon to the west. Higher concentrations of As, U, and Se in ground waters and variation of Eh values from wells east of site 46 suggest a redox front just east of site 46.

Site 7 is a 500-foot-deep well near the town of Manderfield of which the upper 300 feet are sealed. Water from wells surrounding site 7 are anomalous in dissolved radon. Wells nearby contain anomalous radon which indicate a nearby source. The anomalous radon in nearby wells and the presence of water supersatuated with respect to uraninite and coffinite indicate that the Manderfield area, in addition to the area west of Beaver, should be considered a favorable area for sandstone-type uranium deposits.

Other favorable areas correspond to anomalous values shown in figures 4 and 5 with the exceptions of two streams, sites 28 and 32 which probably represent weathering of hydrothermal uraninite upstream from these sites.

The presence of several aquifers complicates interpretation and may explain why chemical characteristics of waters from nearby wells can vary widely. It should also be noted that areas indicated to be most favorable for sandstone-type uranium deposits, using the mineral-solution interpretation, differ from anomalous sites identified by a map plot of pathfinder elements such as U, Mo, Se, and As concentrations in water.

The results of the geochemical survey show that, in parts of the Beaver basin, the environment is favorable for the precipitation of uraninite and coffinite, and several areas are potential targets for exploration for sandstone-type uranium deposits. Other targets may exist in the untested parts of the basin. The methods described in this study can be utilized for evaluation of waters from future exploration drill holes in the Beaver basin and for geochemical exploration for sandstone-type uranium mineralization in other basins of the Basin and Range Province.

References

Ball, J. W., Jenne, E. A. and Cantrell, M. W., 1981, WATEQ3- geochemical model
    with uranium added: U.S. Geological Survey Open-File Report 81-1183,
    81 p.

Cunningham, C. G., and Steven, T. A., 1979, Environments favorable for the
    occurrence of uranium within the Mount Belknap caldera, Beaver Valley and
    Sevier River Valley, west-central Utah: U.S. Geological Survey Open-File
    Report 79-434, 15 p.

Garrels, R. M., and Christ, C. L., 1965, Solution, minerals, and equilibria:
    New York, Harper and Row, 450 p.

Langmuir, D., and Chatham, J. R., 1980, Ground water prospecting for
    sandstone-type uranium deposits: a preliminary comparison of the merits
    of mineral-solution equilibria, and single-element tracer methods:
    Journal of Geochemical Exploration, v. 13, p. 201-219.

McHugh, J. B., Ficklin, W. H., and Miller, W. R., 1980, Analytical results for
    50 water samples from Beaver Valley, Utah: U.S. Geological Survey Open-
    File Report 80-517, 15 p.

Miller, W. R., McHugh, J. B., and Ficklin, W. H., 1979, Possible uranium
    mineralization, Mineral Mountains, Utah: U.S. Geological Survey Open-
    File Report 79-1354, 44 p.

_____ 1980, Possible uranium mineralization, Beaver Basin, Utah: U.S.
    Geological Survey Open-File Report 80-508, 35 p.

Mower, R. W., 1978, Hydrology of the Beaver valley area, Beaver County, Utah,
    with emphasis on ground water: Utah Department of Natural Resources
    Technical Publication 63, 90 p.

Runnells, D. D., Lindberg, R., Lueck, S. L., and Markos, G., 1981,
    Applications of computer modeling to the genesis, exploration, and in
    situ mining of uranium and vanadium deposits: New Mexico Bureau of Mines
    Memoirs on the Grants Mineral Belt, in press.