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Favorable Environments for the Occurrence of Sandstone-Type Uranium Deposits, Milford basin, Utah

by

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Favorable environments for the occurrence of sandstone-type uranium deposits, Milford basin, Utah

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Abstract

A geochemical survey was made of ground water in the Milford basin of west-central Utah. Wells accessible for sampling were largely limited to the part of the basin south of Milford, and the results discussed in this report apply largely to this area. Solution-mineral equilibria studies show that the chemical environment of parts of the Milford basin is favorable for the occurrence of sandstone-type uranium deposits. Several areas have been identified as possible targets for exploration. The methods described in this study can be utilized to evaluate waters from wells and exploration drill holes as indicators of possible sandstone-type uranium deposits in other alluvial basins in the western United States.

Introduction

A hydrogeochemical survey conducted in the Beaver basin in west-central Utah (Miller and others, 1980) suggested that the chemical environment of the Beaver basin is favorable for the occurrence of sandstone-type uranium deposits. Inasmuch as water drains from the Beaver basin into the adjacent Milford basin, a similar hydrogeochemical survey of ground water was conducted in the Milford basin during the summer of 1980, in order to evaluate the possibility for sandstone-type uranium deposits in that area.

The Milford basin is a fault-block depression near the eastern margin of the Basin and Range Province in west-central Utah (fig. 1). The basin is bounded by basalt and rhyolite flows on the north, the Black Mountains on the south, the Mineral Mountains on the east, and the Star Range, Rocky Range, and southern Wah Wah Mountains on the west. No topographic feature marks the southwest boundary of the basin where it merges with the Escalante Desert. The Beaver River enters the basin from the Beaver basin through a gap between the Mineral and Black Mountains, and flows northward through a gap into the Black Rock Desert. The Beaver River channel within the Milford basin is usually dry because the water is diverted for irrigation.

The structural basin is filled largely by Quaternary and Tertiary fluviatile and lacustrine deposits of clay, silt, sand, and gravels, mostly derived from the surrounding mountains. The basin during Pleistocene time was occupied, in part, by ancient Lake Bonneville.

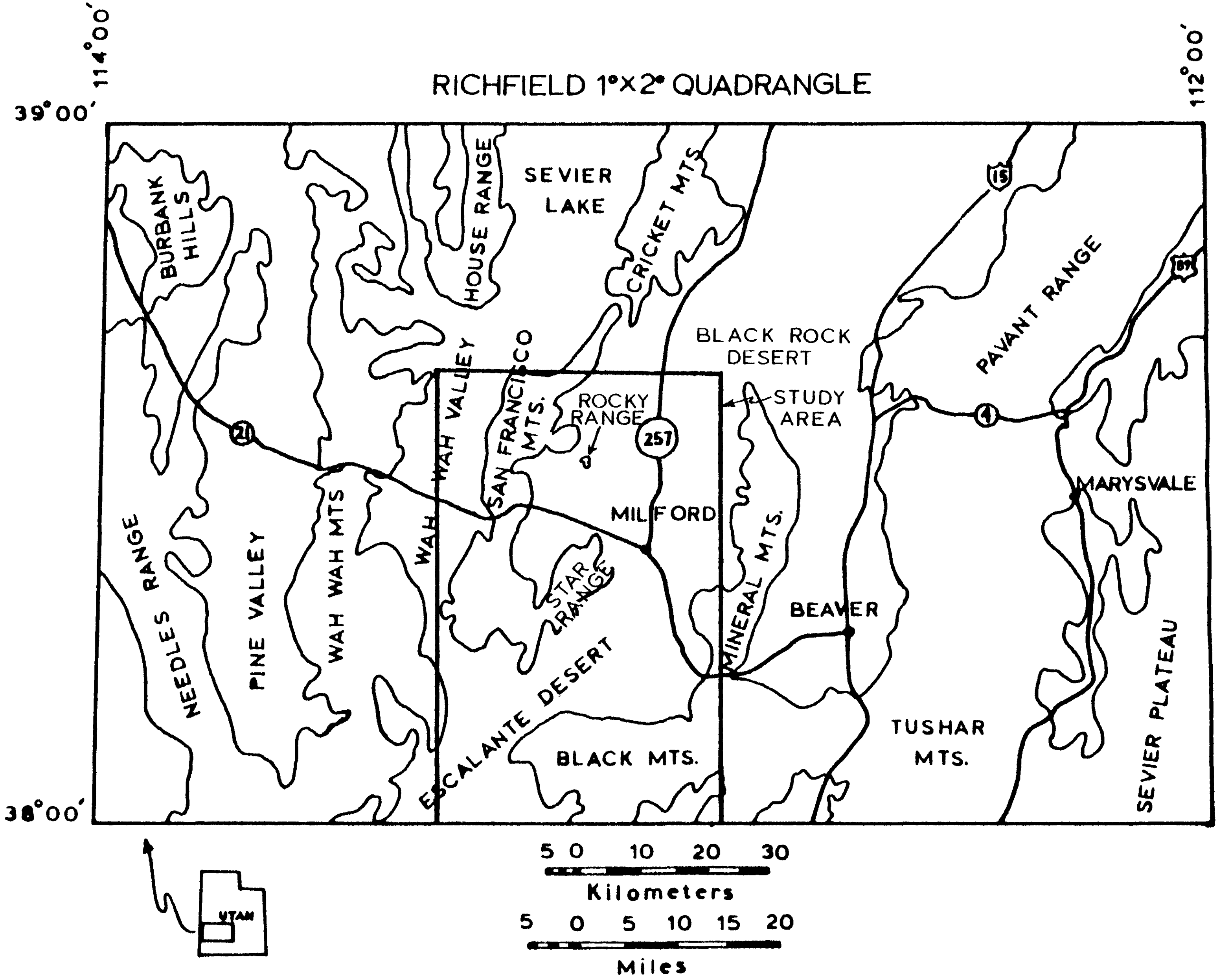

Figure 1.--Location map of the study area, Milford basin, Utah

Uranium-rich springs have been reported in Miller and others (1979), and the adjacent Beaver basin, which drains into the Milford basin, contains uranium-rich ground water (Miller and others, 1980) and potential sandstone-uranium deposits (Cunningham and Steven, 1979; Miller and others, 1980). In addition, the watershed area draining into the Beaver basin contains numerous potential sources of uranium (Steven and others, 1980). Therefore, sources exist for possible uranium deposits in the Milford basin.

Collection and analytical procedures

Water samples were collected from 50 sites within the Milford basin. Most of the sites were south of Milford, where irrigation wells are most abundant. Samples were collected using acid-rinsed polyethylene bottles. At each site, a 60-mL and a 30 mL sample were collected and filtered through a 0.45-µm and a 0.10-µm membrane filter, respectively, and acidified with reagent-grade concentrated nitric acid to pH <2. An untreated 500-mL sample was also collected. Temperature and pH were measured at each sample site. Alkalinity, specific conductance, sulfate, chloride, fluoride, uranium, and nitrate were determined using the untreated sample. Calcium, magnesium, sodium, potassium, silica, zinc, copper, molybdenum, arsenic, vanadium, selenium, and lithium were determined using the 0.45-µm filtered and acidified sample, and iron, manganese, and aluminum were determined using the 0.10-µm filtered and acidified sample. The analytical techniques used for the analysis of each species are shown in table 1. The results of the charge balance for 35 of the samples are within 5 percent, and the remaining 15 are within 10 percent.

Table 1.--Analytical methods used for water analyses, Milford basin, Utah

Constituent	Method	Reference
Alkalinity	Gran's plot potentiometric titration	Orion Research, Inc. (1978).
Sulfate	Ion chromatography	Smee and Hall (1978).
Chloride	do	Do.
Fluoride	do	Do.
Nitrate	do	Do.
Calcium	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976).
Magnesium	do	Do.
Sodium	do	Do.
Potassium	do	Do.
Lithium	do	Do.
Silica	do	Do.
Zinc	do	Do.
Copper	Flameless atomic absorption spectrophotometry	Perkin-Elmer Corp. (1977).
Molybdenum	do	Do.
Arsenic	do	Aruscavage (1977).
Iron	do	Perkin-Elmer Corp. (1977).
Manganese	do	Do.
Aluminum	do	Do.
Selenium	do	Do.
Vanadium	do	Do.
Uranium	Laser-excited fluorescence	Scintrex Corp. (1978).
Specific conductance	Conductivity bridge	Brown, Skougstad, and Fishman (1970), p. 28-29

Geochemistry of the waters

The geochemistry of natural waters is useful both for geochemical exploration and for an understanding of the geological and geochemical processes active in an area. Background information and limitations on the use of hydrogeochemical prospecting can be found in Boyle and others (1971), Cameron (1978), and Miller (1979).

Water samples were collected from 3 springs, 20 shallow windmill-pumped wells, and 27 generally deeper irrigation wells (table 2). A summary of the chemical analyses is shown in table 3. The sample sites are concentrated in the area south of Milford; thus the geochemical survey is not representative of the entire Milford basin.

The waters from the Milford basin may be classified according to the dominant cation and anion, which are Ca-HCO_3 (20 samples), Ca-SO_4 (11 samples), Na-HCO_3 (10 samples), and Na-SO_4 (9 samples). The distribution of dominant anions and cations are shown in figures 2 and 3. Most bicarbonate-type waters cluster in an area within 15 km south of Milford, whereas most sulfate-type waters occur further southwest in the southern Milford basin (fig. 2). Calcium-type waters cluster in the area within 15 km south of Milford and along the eastern flank of Blue Mountain, 30-48 km southwest of Milford, whereas the sodium-type waters are mainly restricted to that part of the basin west and north of the Black Mountains (fig. 3).

The waters from the Milford basin contain abundant dissolved salts. The waters with the highest concentrations of dissolved salts as measured by specific conductance at 25°C are at sites 2, 46, 30, and 47 (fig. 4); the values are 5,900, 3,400, 3,300, and 3,200 µmhos/cm, respectively. There is no one central area in the basin having high concentrations of dissolved salts in water, but high concentrations of dissolved salts occur at sites scattered throughout the basin.

Table 2.--Source and well depth of 50 water samples, Milford basin, Utah (--, no information)

Sample number	Source of sample	Approximate depth of well[1] (feet)
1	Spring, Warm Spring	--
2	Spring	--
3	Windmill	--
4	--Do	--
5	Irrigation well	440
6	--Do	--
7	--Do	143
8	--Do	--
9	--Do	102
10	--Do	210
11	--Do	460
12	Windmill, Mollies Nipple well	227
13	Windmill, Martian well	68
14	Irrigation well	--
15	--Do	422
16	--Do	392
17	--Do	220
18	--Do	220
19	--Do	--
20	--Do	150
21	--Do	195
22	--Do	220
23	--Do	204
24	--Do	270
25	--Do	150
26	--Do	210
27	--Do	240
28	--Do	445
29	--Do	--
30	--Do	--
31	--Do	204
32	--Do	--
33	--Do	--
34	Windmill	--
35	--Do	50
36	--Do	74
37	--Do	75
38	--Do	90
39	Windmill, Moonshine well	--

Table 2.--Source and well depth of 50 water samples, Milford basin, Utah--Continued

Sample number	Source of sample	Approximate depth of well[1] (feet)
40	Windmill	--
41	--Do--	101
42	--Do--	--
43	--Do--	--
44	Windmill, Lamoreau well	323
45	Spring, Thermo hot spring	--
46	Windmill, Blue Knoll well	65
47	Windmill	--
48	Windmill, Lowe well	--
49	Windmill	149
50	--Do--	--

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[1] From Mower and Cordova (1974).

Table 3.--Summary of chemical analyses of 50 water samples, Milford basin, Utah (--, no information)

Variable	Minimum	Maximum	Mean	Geometric mean	Standard deviation	Geometric deviation
Ca (mg/L)-----	15	430	94.3	75.5	71.0	1.99
Mg (mg/L)-----	5.0	170.0	36.3	26.7	33.7	2.17
Na (mg/L)-----	21	910	98.2	64.7	139	2.24
K (mg/L)-----	1.9	53	7.35	5.82	7.67	1.84
Li (µg/L)-----	13	6500	211	48.8	928.	3.12
SiO_2 (mg/L)-----	19	110	40.6	38.4	14.9	1.47
Alkalinity (mg/L)	73	344	164	152	65.9	1.47
SO_4 (mg/L)-----	14	1060	186	117	210	2.61
Cl (mg/L)-----	11	1900	174	100	278	2.76
F (mg/L)-----	.13	5.4	.772	.561	.892	2.04
NO_3 (mg/L)-----	.10	70	10.4	3.82	12.9	6.26
Zn (µg/L)-----	2.0	186	27.4	12.6	46.0	3.12
Cu (µg/L)-----	.80	26	5.52	4.07	5.13	2.15
Mo (µg/L)-----	1.2	13	4.58	4.17	2.17	1.56
As (µg/L)-----	3.3	200	21.2	12.2	35.6	2.44
Fe (µg/L)-----	4.0	310	38.8	17.6	67.6	3.01
Mn (µg/L)-----	.50	85	4.89	1.57	13.3	3.16
Al (µg/L)-----	15.	150	31.4	28.0	21.1	1.53
U (µg/L)-----	.10	52	7.66	4.06	9.43	3.87
Se (µg/L)-----	.50	9.2	2.88	2.46	1.75	1.77
V (µg/L)-----	4.0	27	13.1	12.1	5.39	1.49
Specific Conductance--- (µmhos/cm^2)	300	5900	1260	1020	990	1.88
pH-------------	7.03	9.45	7.84	--	.358	--
Temperature (C°)	11	93	17.9	16.6	11.5	1.38

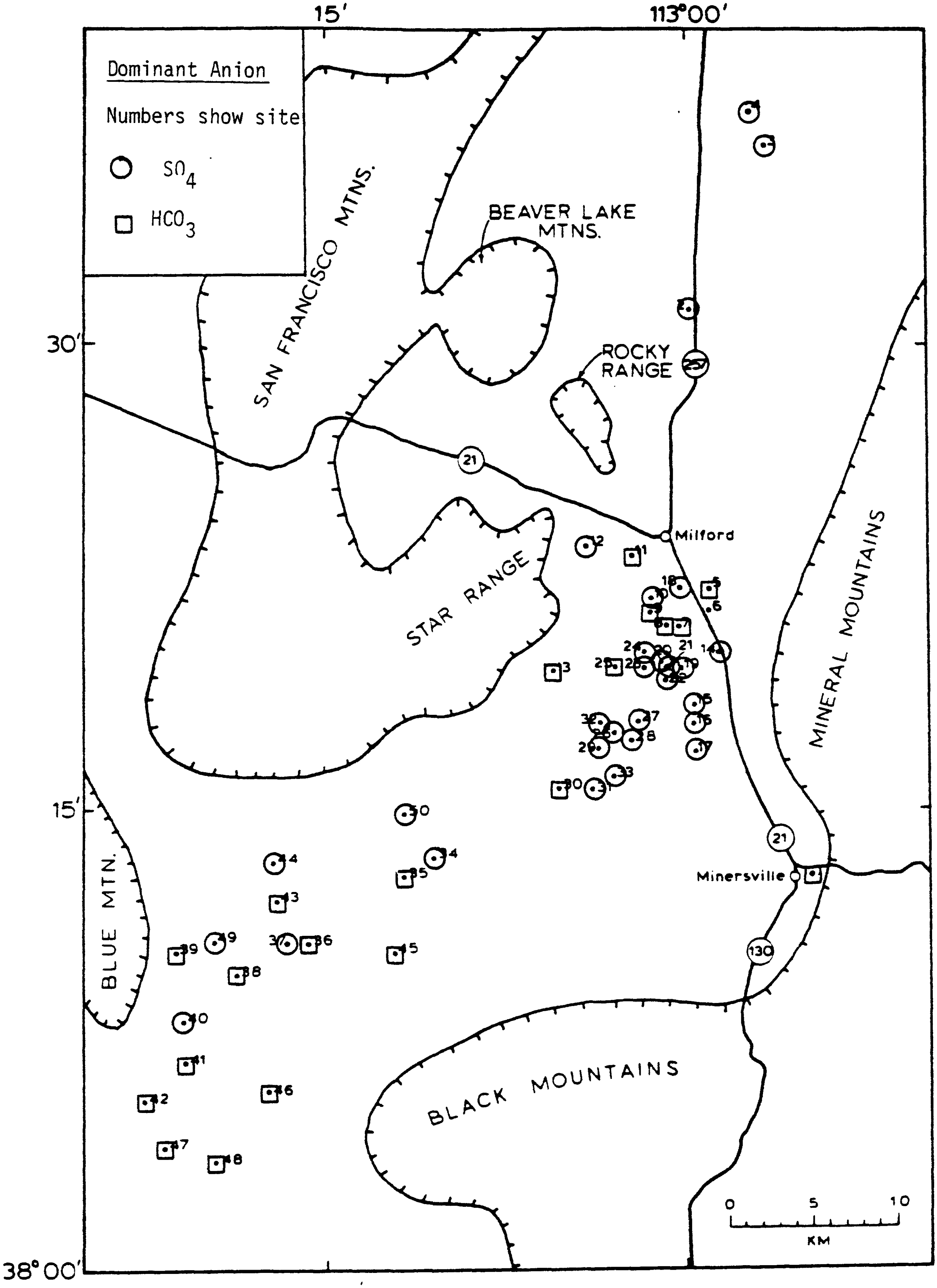

Figure 2.--Distribution of bicarbonate-dominant and sulfate-dominant waters, Milford basin, Utah.

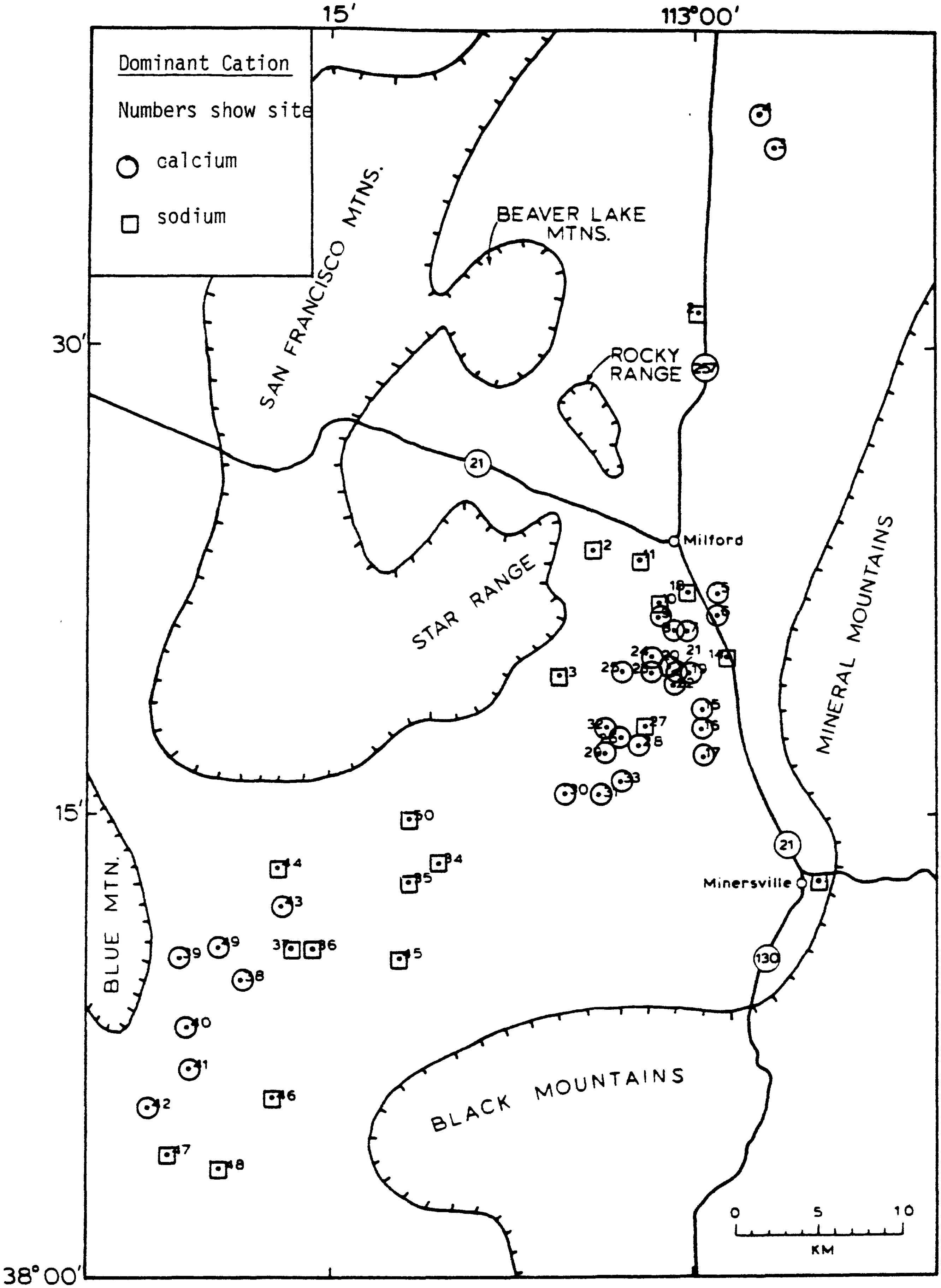

Figure 3.--Distribution of calcium-dominant and sodium-dominant waters, Milford basin, Utah.

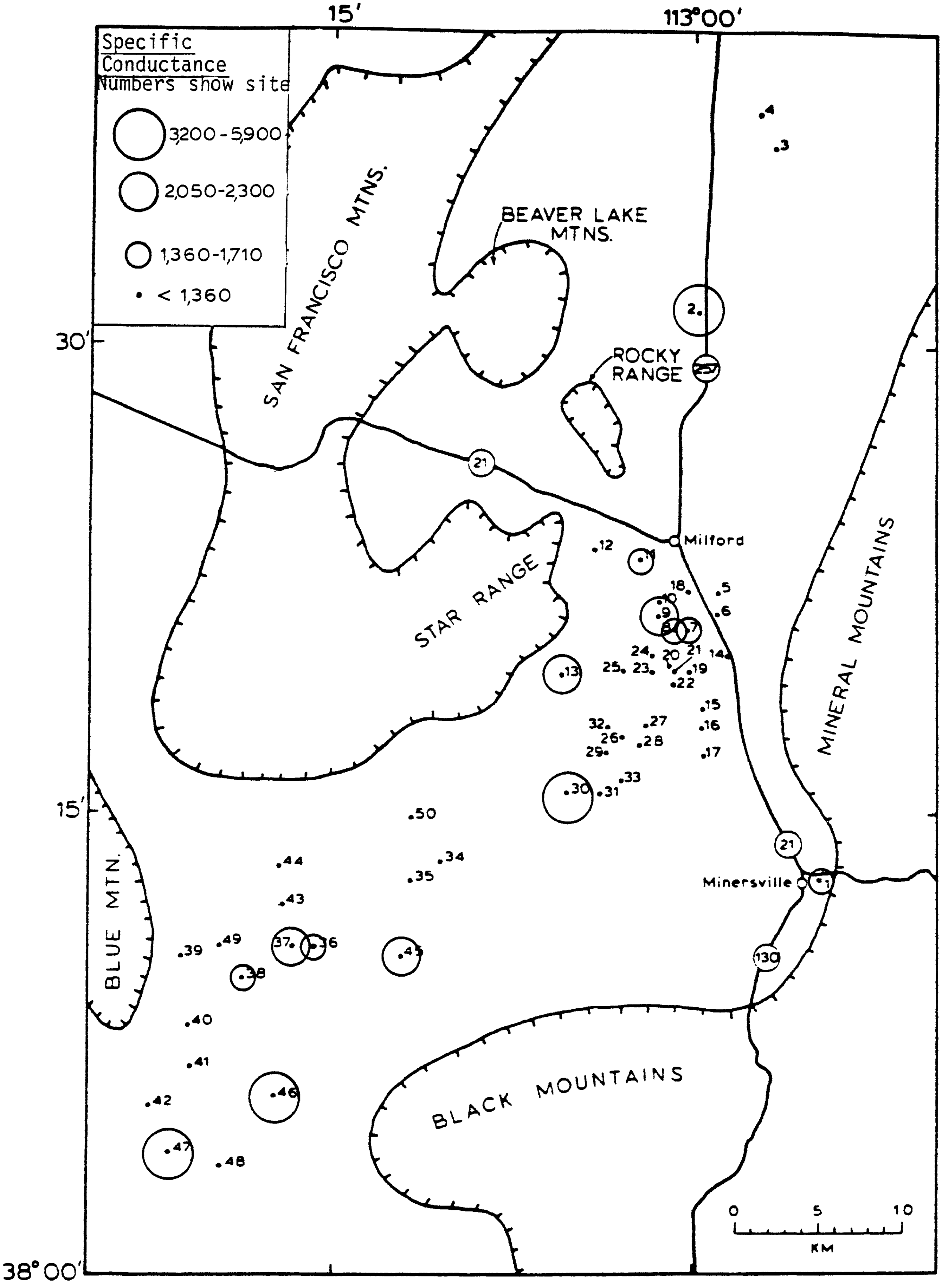

Figure 4.--Distribution of specific conductance in μmhos/cm^2 at 25°C for waters from the Milford basin, Utah.

The distribution of uranium in water is shown in figure 5. The highest concentration, 52 µg/L, occurs at site 22, south of Milford. Additional high values occur at sites 16, 17, 7, 8, and 31, with 30, 28, 22, 21, and 20 µg/L uranium, respectively. All the anomalous values for uranium occur in a restricted area within 15 km south of Milford (fig. 5). Uranium in water usually occurs as anionic complexes and can concentrate in oxidizing basin waters because of evaporation. By using the ratio U/Cl x 10^6 and normalizing the effect of evaporation (fig. 5), the distribution of U/Cl x 10^6 seem to be restricted largely to the same area south of Milford, with the exception of site 44. Therefore, the higher uranium contents cannot be attributed only to evaporative concentration effects.

According to Mower and Cordova (1974), 40 x 10^6 acre feet of water exist within the Milford basin. If the geometric mean of 4.06 µg/L (table 3) is used to estimate the average uranium in ground water of the basin, there are approximately .43 million pounds of dissolved uranium in the Milford basin. Uranium is mobile in an oxidizing environment, but if reducing conditions are present, uranium solubility decreases and can precipitate. Therefore, the presence of a reducing environment is essential for the formation of sandstone-type uranium deposits.

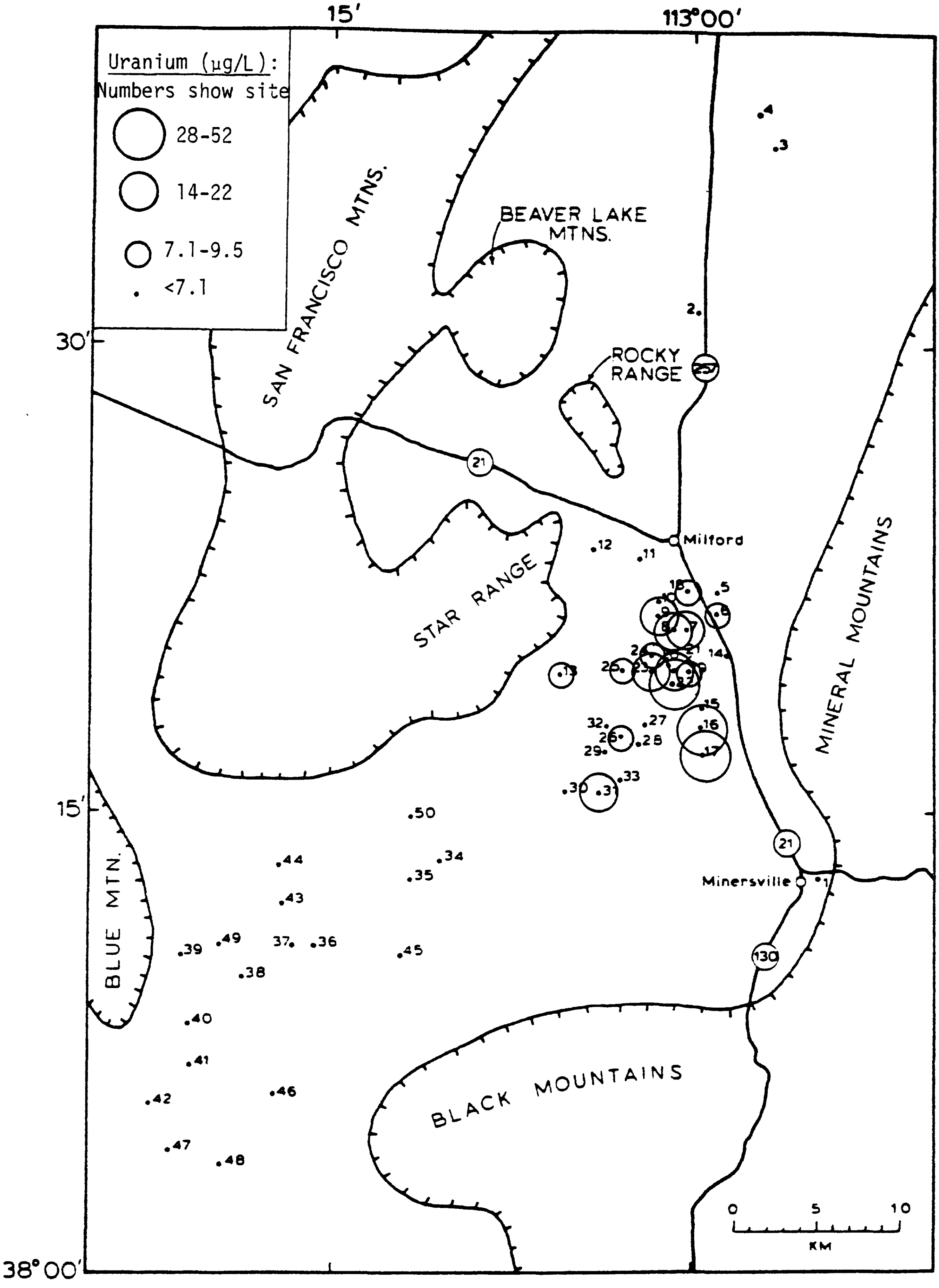

Figure 5.--Distribution of uranium in waters from the Milford basin, Utah.

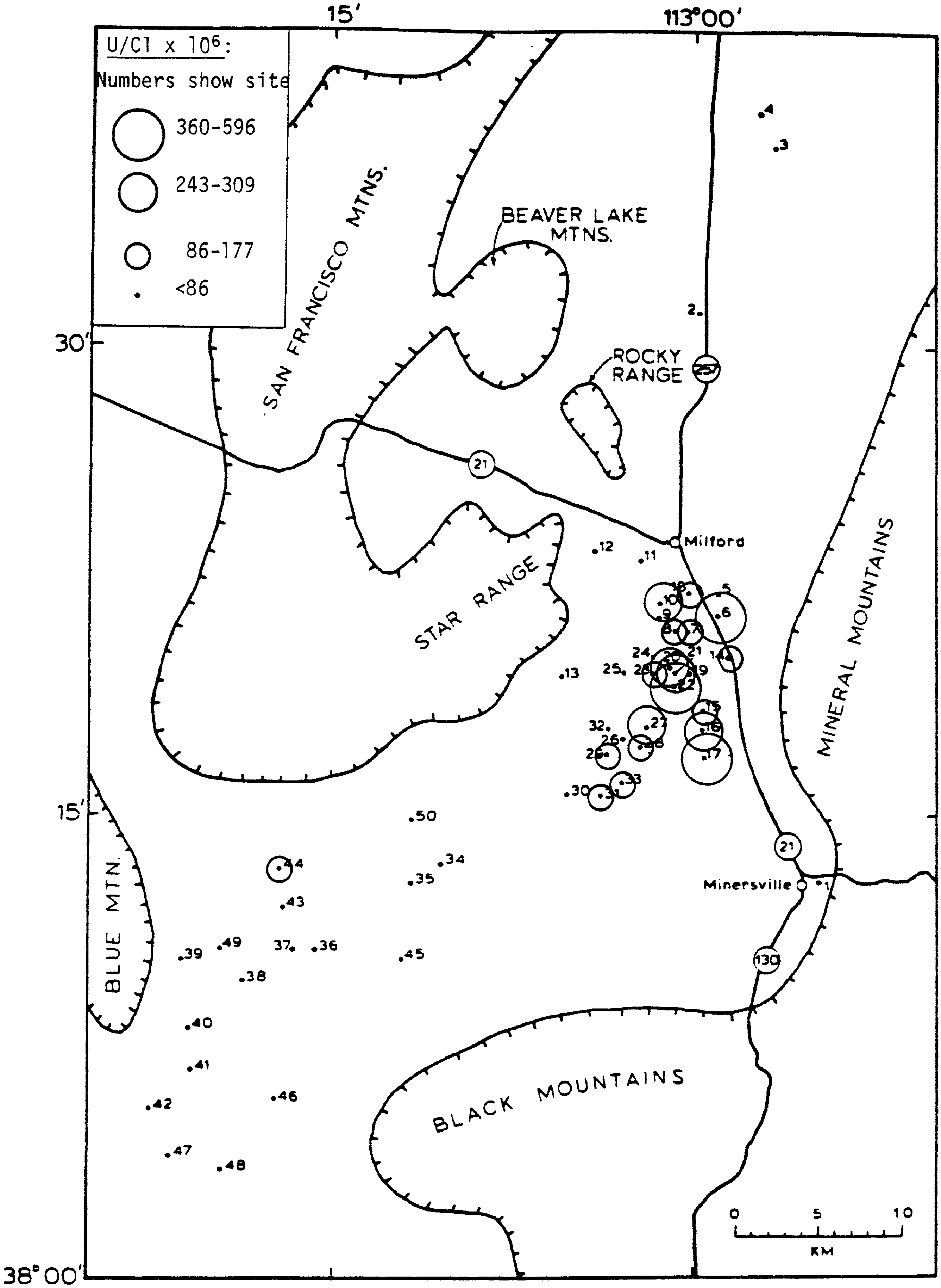

Figure 6.--Distribution of U/Cl x 10^6 ratios for waters from the Milford basin, Utah.

The distribution of molybdenum, fluoride, arsenic, selenium, and vanadium, which are sometimes used as pathfinders for sandstone-type uranium deposits, are shown in figures 7-11. The concentration of molybdenum in waters in the basin ranges from 1.2 to 13 µg/L (table 3), and has a geometric mean of 4.2 µg/L. Anomalously high concentrations of molybdenum are scattered throughout the basin (fig. 7), with the highest values determined on samples from sites 11, 13, and 41, with 13, 9.6, and 9.0 µg/L molybdenum, respectively. The concentrations of fluoride in waters in the basin ranges from 0.13 to 5.4 mg/L (table 3),and has a geometric mean of 0.56 mg/L. Anomalously high concentrations of fluoride are scattered throughout the basin (fig. 8), with the highest values determined on samples from sites 45, 3, and 1, with 5.4, 3.1, and 3.0 µg/L fluoride, respectively. The concentration of arsenic in waters in the basin ranges from 3.3 to 200 µg/L (table 3), with a geometric mean of 12.2 µg/L. Anomalously high concentrations of arsenic are scattered throughout the basin (fig. 9), with the highest values determined on samples from sites 3, 45, and 4, with 200, 140, and 110 µg/L arsenic, respectively. The concentration of selenium in waters in the basin ranges from 0.5 to 9.2 µg/L (table 3), and has a geometric mean of 2.5 µg/L. Anomalously high concentrations of selenium are mainly clustered south of Milford (fig. 10), with the highest values determined on samples from sites 3 and 8, with 9.2 and 7.7 µg/L, respectively. The concentration of vanadium in waters in the basin ranges from 4 to 27 µg/L, and has a geometric mean of 12.1 µg/L, respectively (table 3). Anomalously high concentrations of vanadium are scattered throughout the basin (fig. 11), with the highest values determined on samples from sites 30, 46, 35, and 9, with 27, 27, 26, and 24 µg/L vanadium, respectively.

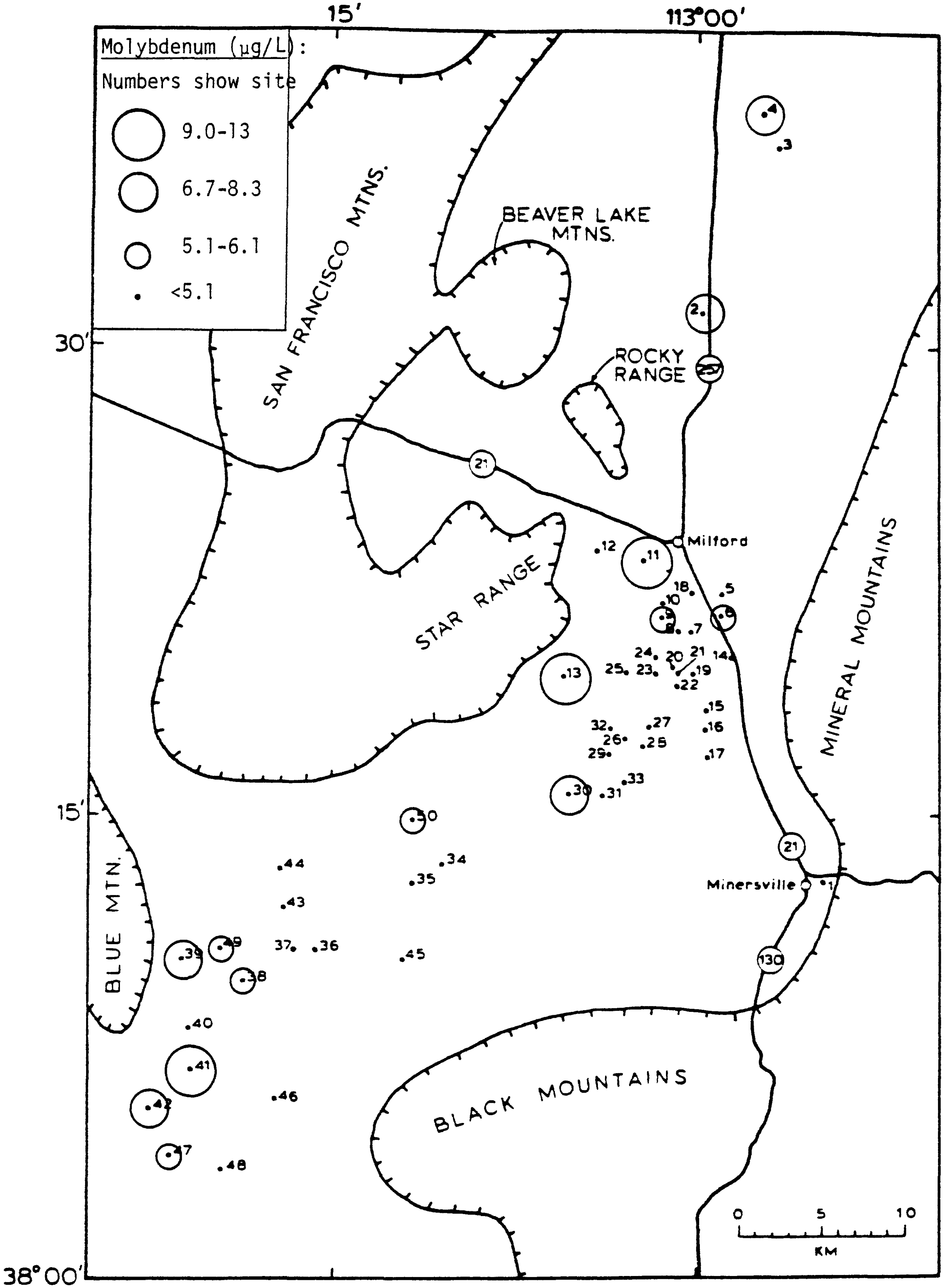

Figure 7.--Distribution of molybdenum in waters from the Milford basin, Utah.

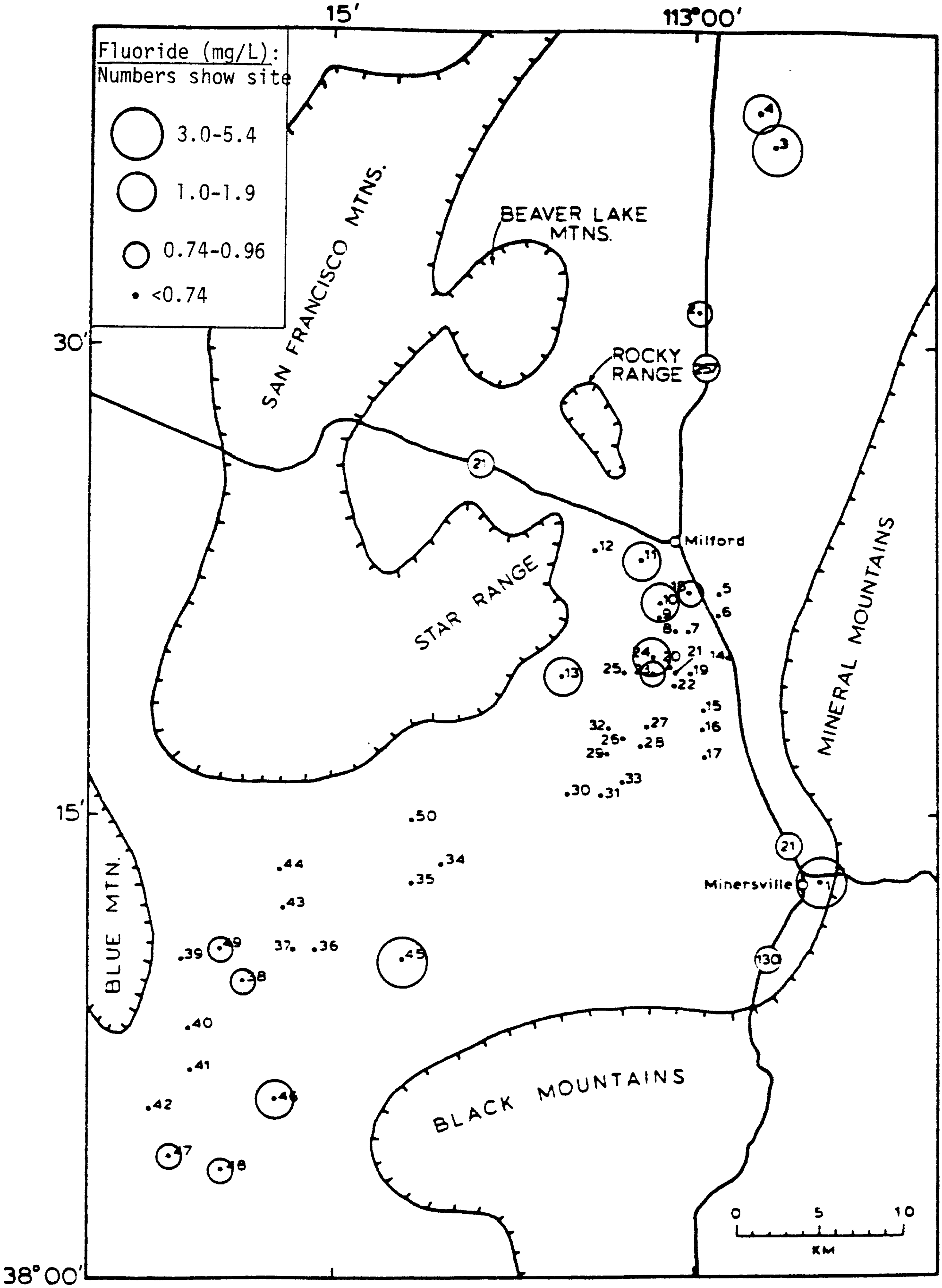

Figure 8.--Distribution of fluoride in waters from the Milford basin, Utah.

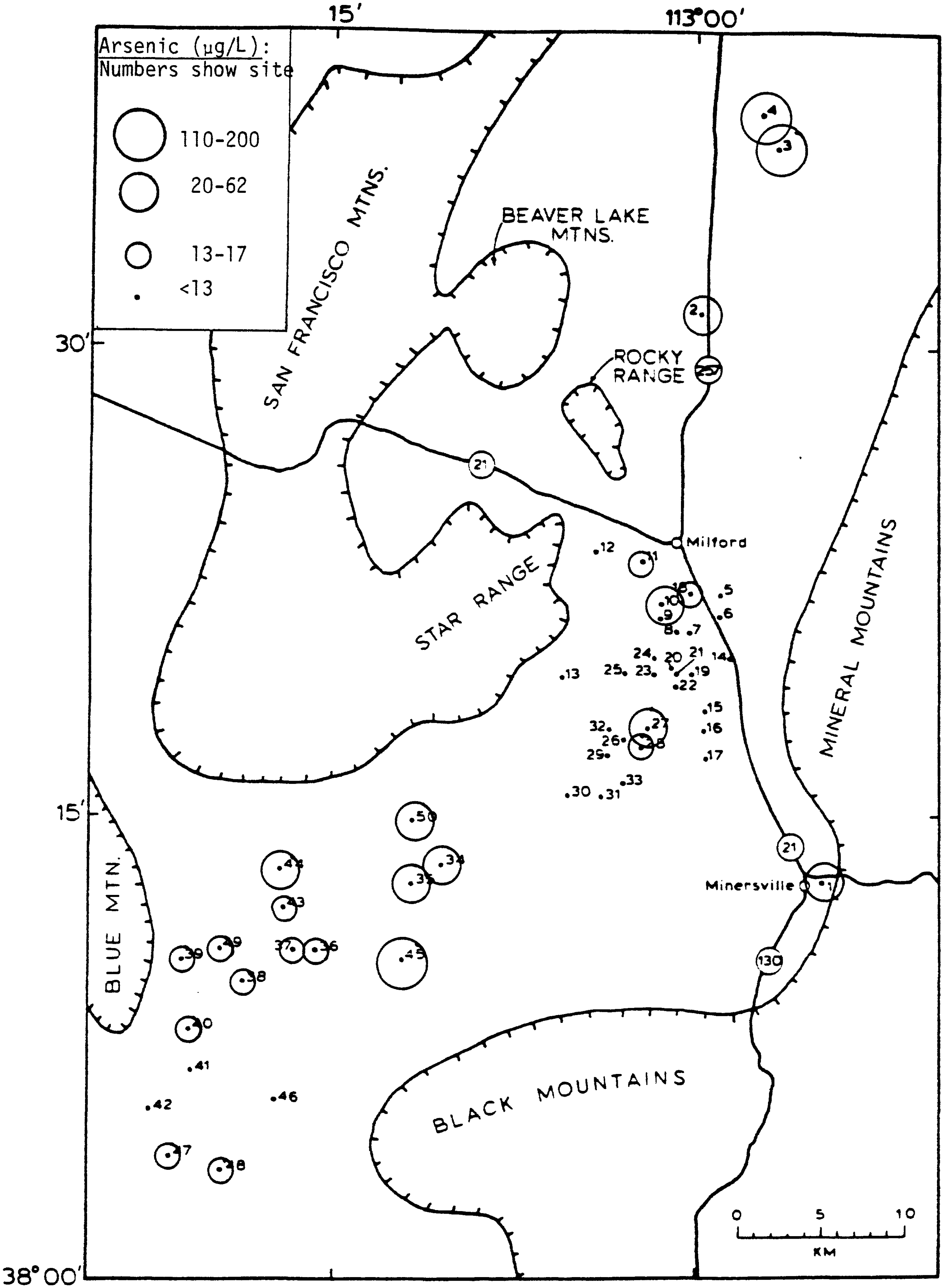

Figure 9.--Distribution of arsenic in waters from the Milford basin, Utah.

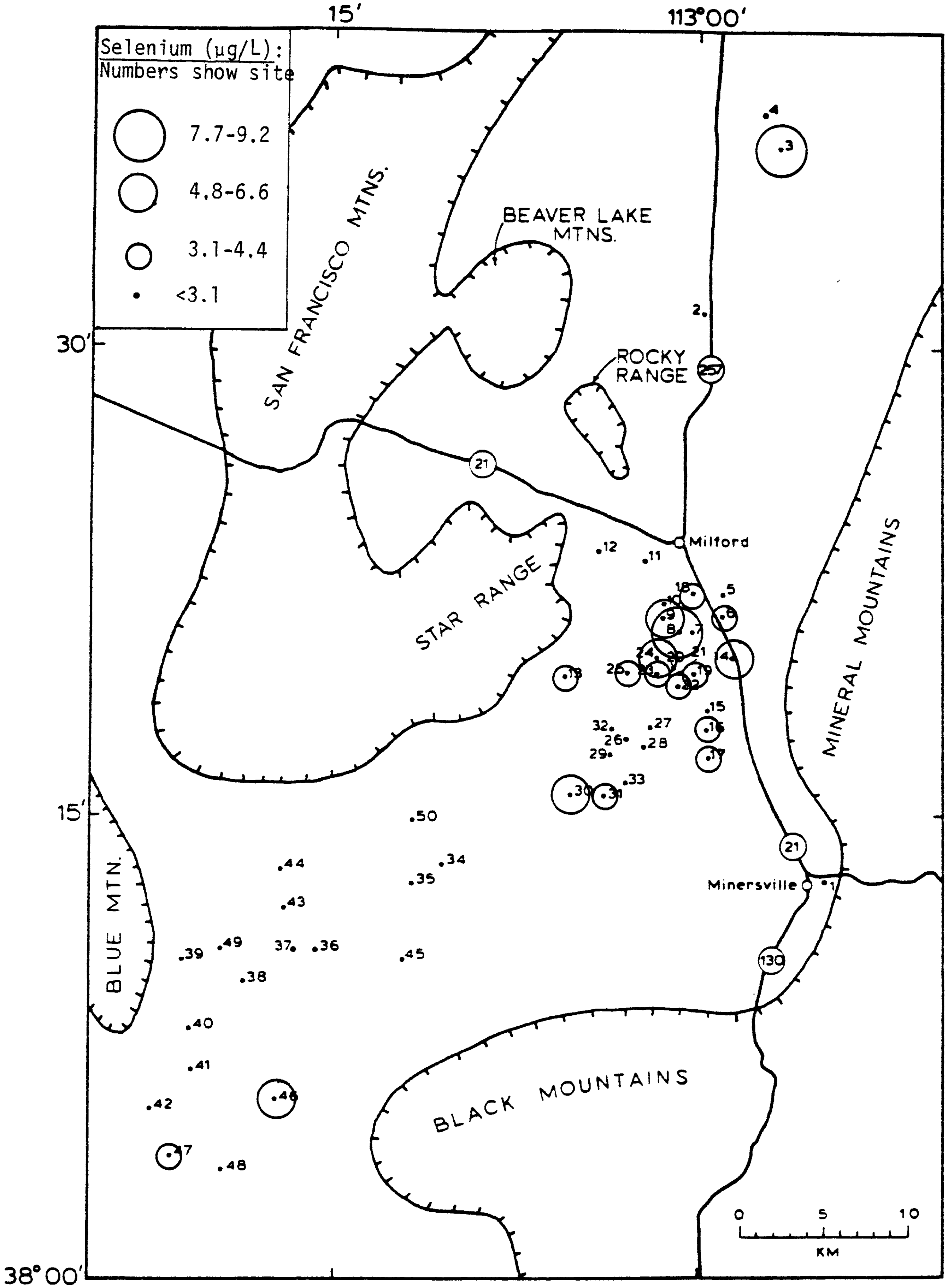

Figure 10.--Distribution of selenium in waters from the Milford basin, Utah.

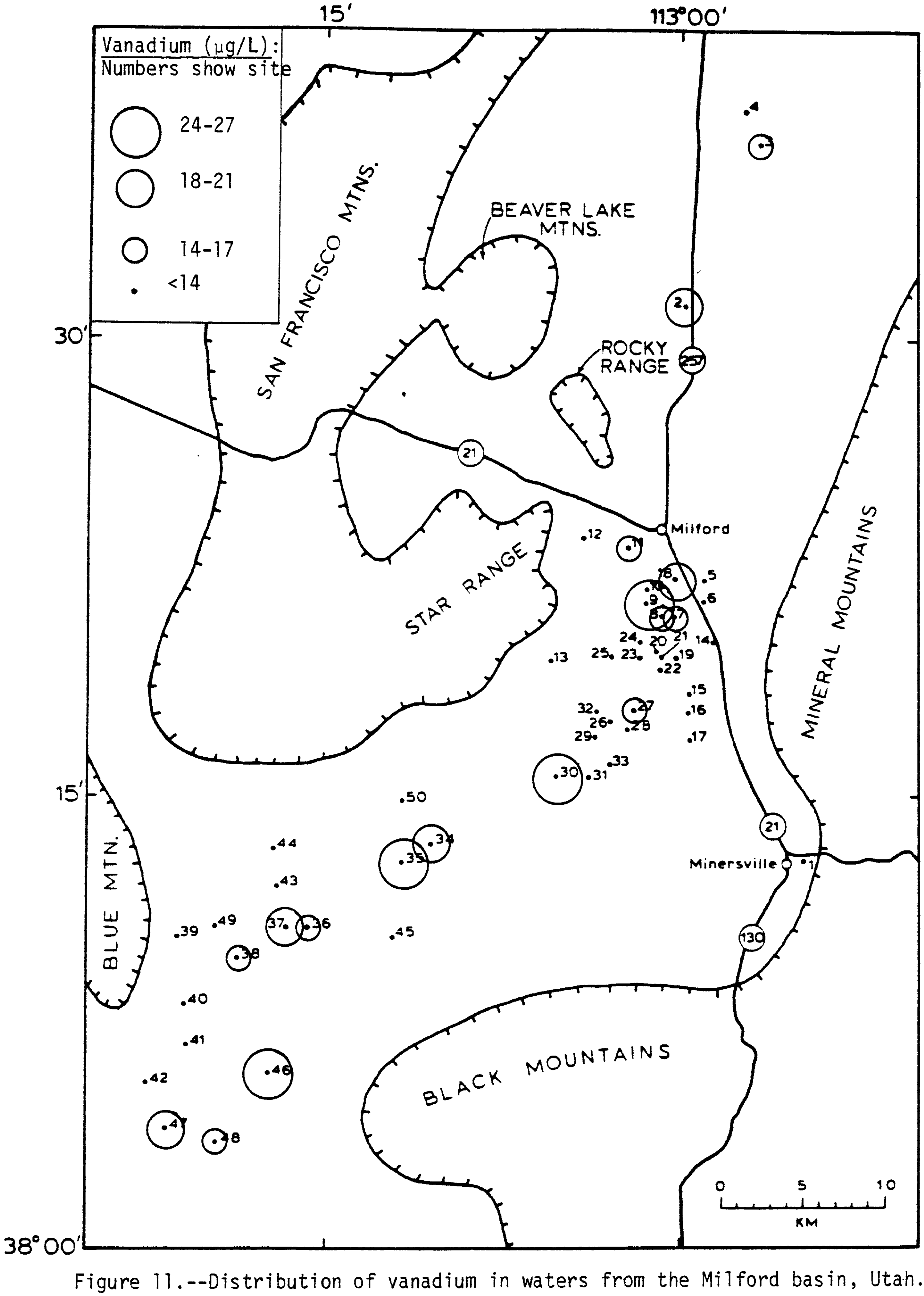

Figure 11.--Distribution of vanadium in waters from the Milford basin, Utah.

Of these possible pathfinder elements, only selenium has a distribution similar to that of uranium. The distribution of fluoride is similar to that of arsenic, but the distribution of molybdenum and vanadium shows no close similarities to those of any other elements. If the uranium concentration in water is used as a pathfinder for sandstone-type uranium deposits, then the area south of Milford (fig. 4) is clearly the most anomalous area.

Correlation coefficients of the logarithm (base 10) of the data are shown in table 4. Many pairs of significanc correlations are present. A Q-mode factor analysis was applied to the water data, similar to that done for water data from the adjacent Beaver basin (Miller and others, 1980), but the results from waters from the Milford basin are complex, and no interpretation was made based on the Q-mode factor analysis.

Mineral-solution equilibria

Thermodynamic data can be used to calculate the state of saturation of ground water with respect to mineral phases associated with mineralization. Recent studies by Langmuir and Chatham (1979) and Runnells and others (1981) have used thermodynamic data to investigate known sandstone-type uranium deposits in Texas, Wyoming, and New Mexico. Similar techniques were used to evaluate the possibility of uranium deposits in the adjacent Beaver basin (Miller and others, 1980).

By using thermodynamic data and assuming chemical equilibrium among the dissolved species, the computer program WATEQ3, which was modified by J. W. Ball from WATEQ2 (Ball and others, 1980) to include uranium species, was used to calculate the activities and chemical speciation in waters from the Milford basin.

Table 4.--Matrix of correlation coefficients of the log-transformed original data of chemical analyses of water samples from the Milford basin, Utah
[number of valid pairs are shown below diagonal]

Element	Ca	Mg	Na	K	Li	SiO_2	ALK	SO_4	Cl	F	NO_3	Zn	Cu	Mo	As	Fe	Mn	Al	U	Se	V	Sp. Cond.	pH	Temp
Ca	1.0	0.76	0.35	0.58	0.15	0.09	0.39	0.64	0.80	-0.16	0.27	0.03	0.42	0.34	-0.48	0.01	0.11	0.20	0.19	0.57	0.34	0.79	-0.51	-0.2
Mg	50	1.0	.59	.39	.39	-.06	.35	.61	.83	-.09	.24	.25	.49	.44	-.29	.30	.28	.22	-.01	.43	.54	.85	-.25	-.3
Na	50	50	1.0	.57	.85	.20	.55	.53	.67	.35	-.14	.26	.75	.19	.24	.34	.60	.42	-.46	.02	.37	.83	.12	.2
K	50	50	50	1.0	.62	.48	.45	.42	.61	.38	-.14	-.15	.43	.05	.20	-.02	.45	.36	-.45	.25	.08	.68	-.11	.4
Li	50	50	50	50	1.0	.32	.42	.21	.59	.48	-.17	.18	.62	.15	.51	.42	.65	.50	-.72	-.15	.16	.67	.27	.4
SiO_2	50	50	50	50	50	1.0	.09	.23	.19	.25	-.03	.09	.23	.23	.41	.13	.23	.03	-.28	-.11	.05	.18	-.25	.2
Alkalinity	50	50	50	50	50	50	1.0	.32	.39	.39	.10	.14	.57	.03	-.01	.12	.34	.24	.00	.16	.05	.55	-.17	.2
SO_4	50	50	50	50	50	50	50	1.0	.50	.09	.04	.25	.57	.09	-.27	.01	.20	-.02	.08	.33	.31	.66	-.59	-.0
Cl	50	50	50	50	50	50	50	50	1.0	-.03	.23	.14	.58	.34	-.12	.30	.36	.34	-.14	.33	.47	.93	-.12	-.1
F	50	50	50	50	50	50	50	50	50	1.0	-.35	.11	.20	.01	-.59	.16	.56	.33	-.56	-.09	-.37	.10	.00	.5
NO_3	50	50	50	50	50	50	50	50	50	50	1.0	-.01	-.05	.02	-.38	.06	-.04	-.18	.48	.15	.19	.12	-.24	-.4
Zn	50	50	50	50	50	50	50	50	50	50	50	1.0	.41	.31	.01	.45	.36	-.04	-.07	-.13	-.04	.18	-.18	-.2
Cu	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.07	-.02	.40	.42	.27	-.21	.04	.25	.74	-.03	-.2
Mo	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	-.23	.25	.22	.26	-.04	.10	.15	.29	-.06	-.2
As	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.26	.38	.24	-.72	-.38	-.22	-.12	.34	.4
Fe	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.47	.30	-.37	-.08	-.04	.28	.13	-.0
Mn	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.50	-.54	.04	-.06	.44	.08	.3
Al	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	-.46	.20	.00	.39	.23	.2
U	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	1.0	.21	.28	-.19	-.41	-.6
Se	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.15	.33	-.32	-.2
V	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.46	-.01	-.4
Specific Conductance	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	-.16	.0
pH	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0	.2
Temperature	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1.0

The Eh (redox potential)(fig. 12) was calculated by assuming equilibrium of the water 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 main uncertainty of using this method to estimate Eh is that the Gibbs free-energy for $Fe(OH)_{3(c)}$ can vary (Langmuir, 1969), causing errors in the calculated Eh.

The Eh in the Milford basin ranges from -0.276 to 0.254 volts (table 5). The lowest Eh occurs at a spring (site 2). Other low values occur at sites 44, 6, and 43, with values of -0.031, -0-011, and 0.000, respectively. Sites 43 and 44 are windmill-pumped shallow wells in the southwestern part of the basin, and site 6 is an irrigation well south of Milford. Reducing conditions (negative Eh values) decrease the solubility of uranium; therefore, these sites are favorable for the precipitation of reduced uranium minerals.

To evaluate if water in the basin is saturated with respect to reduced uranium minerals, the saturation indexes (SI) of uraninite and coffinite were calculated. Uraninite (UO_2) and coffinite ($USiO_4$) were chosen because they are the most common ore minerals of reduced uranium. The saturation index is the logarithm of the ratio of the ion activity product (Kap) to the equilibrium solubility product (Kt). A $SI > 0$ indicates that the water is supersaturated with respect to a mineral phase, indicating the mineral phase should precipitate. A $SI < 0$ indicates that the water is undersaturated (see Runnells and others (1981) for details).

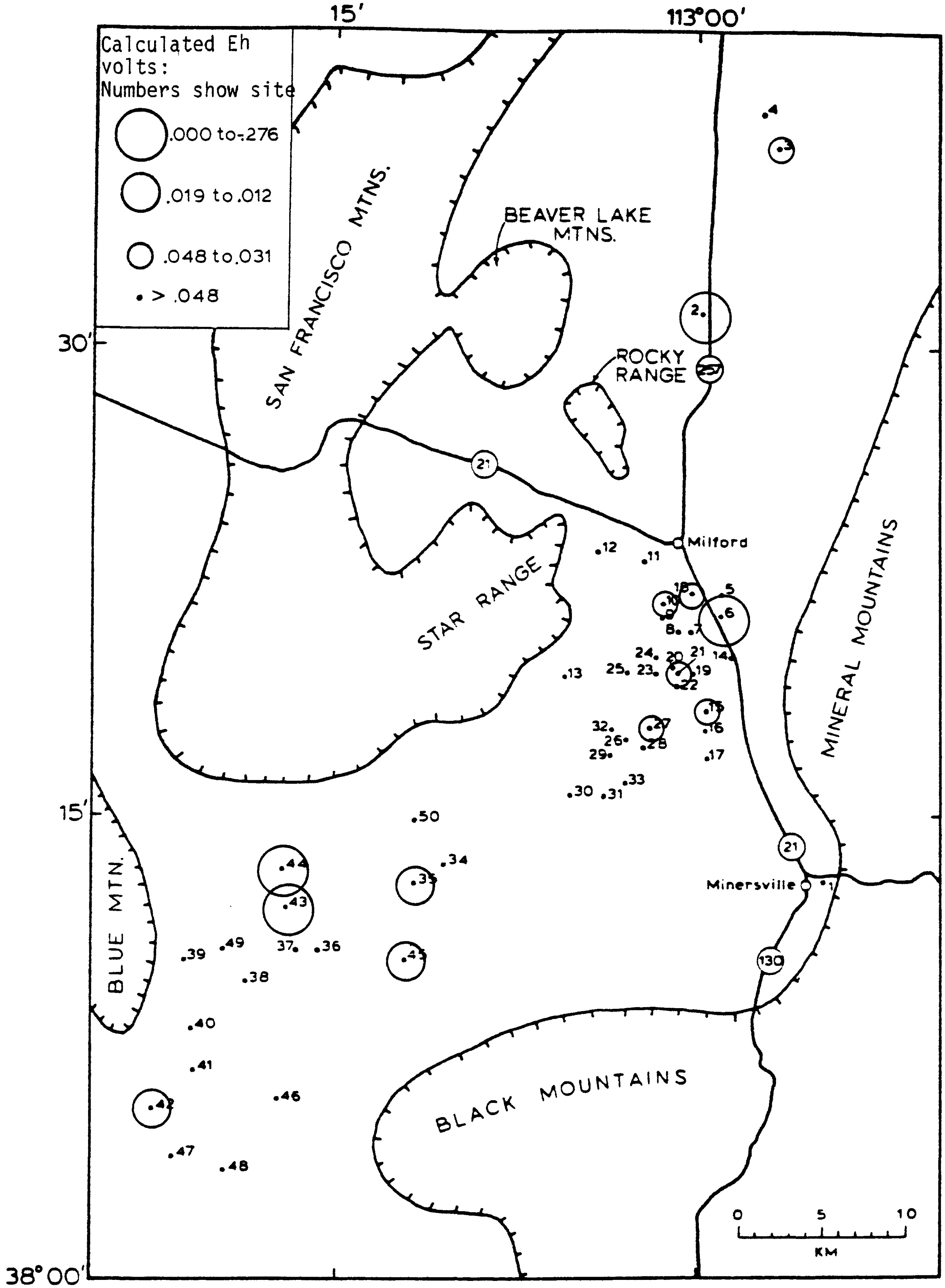

Figure 12.--Distribution of calculated redox potential (Eh) of waters from the Milford basin, Utah.

Table 5.--Calculated Eh values and the saturation indexes (SI) for uraninite and coffinite for waters from the Milford basin, Utah

Site number	pH	Specific conductivity	Water type	Uranium g/L	Dominant uranium species	Calculated Eh, volts	SI for uraninite	SI for coffinite
1	7.36	1.460	Na^+, $SO_4^=$	.52	$UO_2(CO_3)_2^{-2}$, $UO_2(CO_3)_3^{-4}$	.173	-7.40	-6.14
2	9.45	5,900	Na^+, HCO_3^-	<.10	$U(OH)_5^{-1}$	-.276	-1.28	-0.17
3	7.65	520	Ca^{++}, HCO_3^-	<.10	$UO_2(CO_3)_2^{-2}$, $UO_2(CO_3)_3^{-4}$	.031	-2.80	-0.97
4	7.77	950	Ca^{++}, HCO_3^-	3.2	----------do.----------	.095	-3.44	-1.51
5	8.03	1,040	Ca^{++}, $SO_4^=$	3.9	----------do.----------	.063	-3.21	-1.81
6	8.55	510	Ca^{++}, Na^+, HCO_3^-	9.0	----------do.----------	-.011	-1.77	-0.33
7	7.50	1,380	Ca^{++}, $SO_4^=$	22	----------do.----------	.134	-3.51	-1.83
8	7.55	1,360	Ca^{++}, $SO_4^=$	21	----------do.----------	.144	-4.00	-2.35
9	7.03	2,300	Ca^{++}, $SO_4^=$	14	----------do.----------	.254	-7.24	-5.49
10	8.15	300	Na^+, HCO_3^-	4.3	----------do.----------	.048	-2.09	-0.68
11	7.72	1,710	Na^+, $SO_4^=$	1.8	----------do.----------	.120	-5.06	-3.29
12	7.54	1,270	Na^+, HCO_3^-	6.0	----------do.----------	.118	-4.07	-2.37
13	7.44	2,050	Na^+, $SO_4^=$	9.5	----------do.----------	.112	-3.95	-2.48
14	7.98	840	Na^+, HCO_3^-	6.0	----------do.----------	.071	-3.40	-1.89
15	8.13	490	Ca^{++}, HCO_3^-	3.9	----------do.----------	.036	-1.86	-0.46
16	7.65	1,130	Ca^{++}, HCO_3^-	30	----------do.----------	.117	-3.73	-2.13
17	7.40	820	Ca^{++}, HCO_3^-	28	----------do.----------	.179	-5.42	-3.83
18	8.10	830	Na^+, SO_4^+, HCO_3^-	7.1	----------do.----------	.048	-2.64	-1.19
19	7.85	1,000	Ca^{++}, HCO_3^-	9.5	----------do.----------	.087	-3.07	-1.42
20	7.98	310	Ca^{++}, Na^+, HCO_3^-	3.4	----------do.----------	.072	-2.97	-1.46
21	7.75	600	Ca^{++}, HCO_3^-	14	----------do.----------	.033	-0.72	0.93
22	7.60	1,230	Ca^{++}, HCO_3^-	52	----------do.----------	.128	-3.79	-2.12
23	7.42	1,180	Ca^{++}, HCO_3^-	16	----------do.----------	.174	-5.29	-3.56
24	7.44	1,040	Ca^{++}, $HCO3^-$	9.0	----------do.----------	.160	-4.95	-3.20
25	7.92	1,120	Ca^{++}, $SO_4^=$	7.3	----------do.----------	.085	-3.12	-1.39

Table 5.--Calculated Eh values and the saturation indexes (SI) for uraninite and coffinite for waters from the Milford basin, Utah--Continued

Site number	pH	Specific conductivity	Water type	Uranium g/L	Dominant uranium species	Calculated Eh, volts	SI for uraninite	SI for coffinite
26	7.83	860	Ca^{++}, HCO_3^-	8.6	$UO_2(CO_3)^{-2}$ $UO_2(CO_3)_3^{-4}$	.100	-3.12	-1.46
27	8.13	350	Na^+, HCO_3^-	3.2	----------do.----------	.041	-2.32	-0.87
28	7.93	550	Ca^{++}, HCO_3^-	4.9	$UO_2(Co_3)_2^-$, $UO_2(CO_3)_3^{-4}$	.081	-2.92	-1.37
29	8.08	400	Ca^{++}, Na^+, HCO_3^-	3.7	----------do.----------	.055	-2.69	-1.01
30	7.66	3,300	Ca^{++}, $SO_4^=$	2.4	----------do.----------	.137	-4.58	-2.79
31	7.80	960	Ca^{++}, HCO_3^-	20	----------do.----------	.110	-3.74	-2.03
32	8.08	750	Ca^{++}, HCO_3^-	5.6	----------do.----------	.061	-2.05	-0.31
33	8.00	510	Ca^{++}, HCO_3^-	4.7	----------do.----------	.072	-2.53	-0.85
34	8.00	770	Na^+, $SO_4^=$, HCO_3^-	3.9	----------do.----------	.056	-2.50	-0.71
35	8.25	1,070	Na^+, $SO_4^=$	3.9	----------do.----------	.061	-2.02	-0.31
36	7.70	1,450	Ca^{++}, Na^+, $SO_4^=$	4.3	----------do.----------	.107	-3.38	-1.60
37	7.70	2,200	Ca^{++}, Na^+, HCO_3^-	3.4	----------do.----------	.094	-3.57	-1.73
38	7.70	1,650	Ca^{++}, $SO_4^=$	2.4	----------do.----------	.098	-3.50	-1.67
39	7.89	1,110	Ca^{++}, $SO_4^=$, HCO_3^-	2.0	----------do.----------	.057	-2.77	-1.41
40	7.80	880	Ca^{++}, HCO_3^-	2.8	----------do.----------	.076	-3.06	-1.42
41	7.85	940	Ca^{++}, $SO_4^=$	2.1	----------do.----------	.067	-2.83	-1.11
42	7.95	1,160	Ca^{++}, $SO_4^=$	2.2	----------do.----------	.019	-1.41	0.22
43	7.95	840	Ca^{++}, $SO_4^=$, HCO_3^-	2.4	----------do.----------	.000	-0.21	1.45
44	8.10	570	Na^+, HCO_3^-	4.3	----------do.----------	-.030	-0.03	1.81
45	8.00	2,250	Na^+, $SO_4^=$	<.10	$UO_2(CO_3)_2^{-2}$	.012	-6.87	-5.92
46	7.53	3,400	Na^+, $SO_4^=$	3.4	$UO_2(CO_3)_2^{-2}$, $UO_2(Co_3)_3^{-4}$	.123	-4.61	-2.76
47	7.54	3,200	Na^+, $SO_4^=$	3.0	----------do.----------	.114	-3.88	-2.12
48	7.80	1,190	Ca^{++}, Na^+, $SO_4^=$	3.9	----------do.----------	.084	-3.38	-1.55
49	7.75	790	Ca^{++}, HCO_3^-	1.5	----------do.----------	.103	-4.09	-2.57
50	7.90	500	Na^+, HCO_3^-	2.6	----------do.----------	.055	-2.62	-0.82

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

$$UO_2 + 2\ H_2O \rightleftharpoons U^{+4} + 4\ OH^-$$

and

$$USiO_4 \rightleftharpoons U^{+4} + H_4SiO_4 + 4\ OH^-.$$

Therefore, the log Kap for UO_2 = log a_{u+4} + 4 pH and log Kap for $USiO_4$ = log a_{u+4} + log $a_{H_4\ SiO_4}$ + 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 Milford basin are shown in table 5. The dominant uranium species present in waters from the Milford basin are $UO_2(CO_3)_2^{-2}$ and $UO_2(CO_3)_3^{-4}$.

The distribution of saturation indexes for uraninite ranged from -0.03 to -7.24 (fig. 13). The most anomalous sites are 44, 43, and 21, with SI values of -0.03, -0.21, and -0.72. Waters from these sites are slightly undersaturated with respect to uraninite. Sites 43 and 44 are windmill-pumped wells and are in the southwestern part of the basin. The well at site 44 is at a depth of 323 feet (table 2). The depth of the well at site 43 is not known. Site 21 is an irrigation well south of Milford at a depth of 195 feet. These sites are the most favorable of the areas sampled in the Milford basin for the precipitation of uraninite.

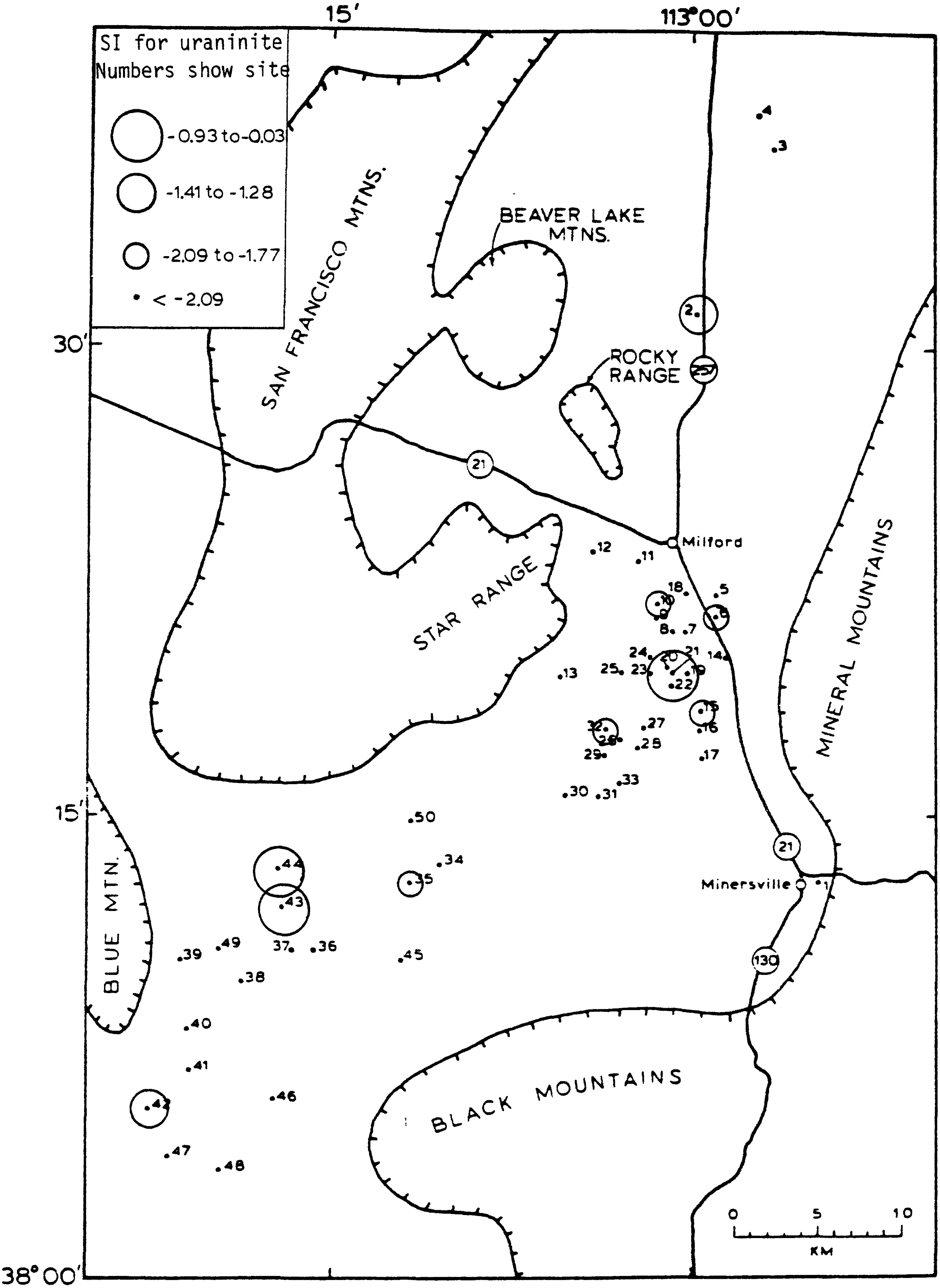

Figure 13.--Distribution of saturation indexes for uraninite of waters from the Milford basin, Utah.

The distribution of saturation indexes for coffinite ranged from 1.81 to -6.14 (fig. 14). The most anomalous sites are 44, 43, 21, and 42, with values of 1.81, 1.45, 0.93, and 0.22. Waters from these sites are supersaturated with respect to coffinite. Waters from sites 21, 43, and 44 were also slightly undersaturated with respect to uraninite. Site 43 is a windmill-pumped well in the southwestern part of the basin. Waters from sites 44, 43, and 21 are the most favorable of the areas sampled in the Milford basin for the precipitation of uraninite and coffinite. Other favorable areas in the Milford basin correspond to the remaining anomalous values shown in figures 13 and 14.

The mineral-solution equilibria studies do not demonstrate that uranium deposits are present at these sites, but that the environment is favorable for the precipitation of reduced uranium minerals. These areas, of the areas of the basin which were sampled, should be considered the most favorable sites for exploration for sandstone-type uranium deposits.

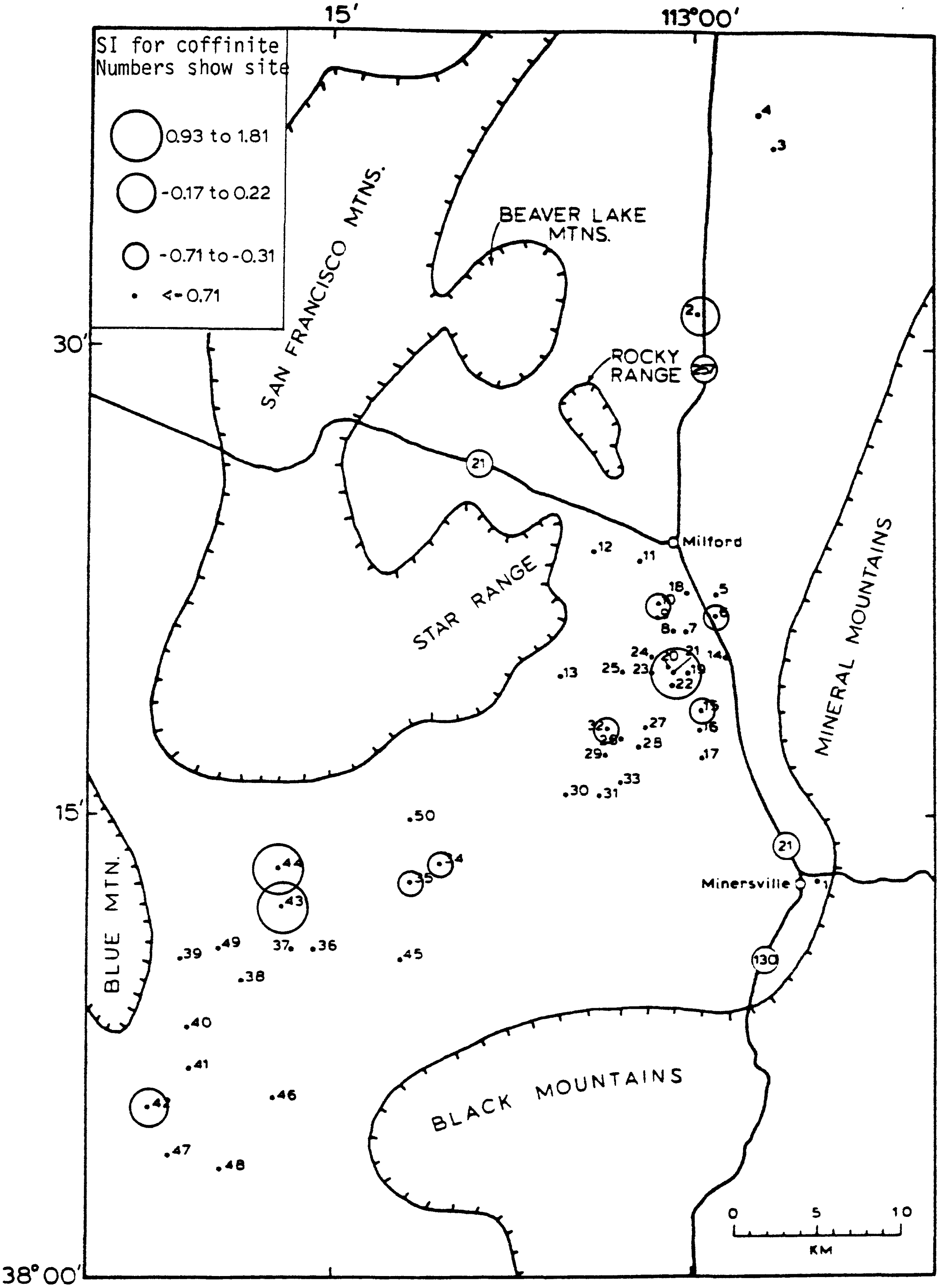

Figure 14.--Distribution of saturation indexes for coffinite of waters from the Milford basin, Utah.

Conclusions

The results of the ground-water survey in the Milford basin, Utah, indicate that the area containing sites 43 and 44 is the most favorable area in the basin for sandstone-type uranium deposits. Reducing conditions occur at both sites, and the waters from the two sites are supersaturated with respect to coffinite and nearly saturated with respect to uraninite. The well at site 44 is 323 feet in depth. Therefore, only aquifers within this interval of 323 feet are being considered at this site.

Site 21, south of Milford, is also favorable for sandstone-type uranium deposits. The water at this site is supersaturated with respect to coffinite and slightly undersaturated with respect to uraninite. Other favorable areas correspond to anomalous values shown in figures 13 and 14, with the possible exception of site 2. Site 2 is a spring with a high dissolved salt content whose water is strongly reducing but has a nondetectable uranium concentration (<0.10 µg/L).

The presence of several aquifers complicates the interpretation and may explain why water from one well has different chemical characteristics than water from a well nearby. An example is the difference between site 21 and site 22. It should also be noted that the areas indicated to be most favorable for sandstone-type uranium deposits, using the mineral-solution interpretation, differ from sites identified by plots of U or U/Cl ratios (figs. 5 and 6), which indicate that the most favorable area is south of Milford. The use of mineral-solution equilibria studies provides an added dimension to the use of ground water data.

The results of the geochemical survey show that, in parts of the Milbord 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 Milford basin and for geochemical exploration for sandstone-type uranium mineralization in other basins of the Basin and Range Province.

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