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GEOLOGICAL SURVEY

POSSIBLE URANIUM MINERALIZATION, MINERAL MOUNTAINS, UTAH

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Abstract

The Mineral Mountains block in west-central Utah is a horst whose core stands structurally high relative to all nearby basin-and-range fault blocks. Rocks of the Mineral Mountains range from Precambrian to Quarternary in age, but mostly consist of Tertiary granitic rocks. The range lies with the Wah Wah-Tusher mineral belt. Lead, silver, gold, and tungsten have been mined commercially.

During a geochemical survey conducted in the summer of 1978, 30 water samples and 29 stream-sediment samples were collected from the Mineral Mountains area. The interpretation of simple plots of uranium concentrations and the results of a Q-mode factor analysis indicate that potential exists for uranium mineral deposits within the Mineral Mountains. The most favorable areas are in the granitic pluton near its contacts with sedimentary and metamorphic rocks. The most likely source of the uranium anomalies is uraninite-bearing epigenic veins along faults and fractures within the pluton. Three hypothetical models are proposed to account for the uranium mineralization.

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Introduction

The Mineral Mountains (fig. 1) in west-central Utah are bounded on the west by the Escalante Desert and on the east by the Beaver Valley. Utah State Highway 21 bounds the area on the south. The northern part of the Mineral Mountains was not studied during this investigation. The dominant rock type is granite, which forms the core of the range and is the largest exposed pluton in Utah. The area lies within the Wah Wah-Tusher mineral belt and has been extensively explored for mineral deposits. The area has produced lead, silver, gold, and tungsten in commercial quantities. The Roosevelt Hot Springs area, a known geothermal resource area (KGRA), is along the western margin of the range.

During a geochemical survey conducted in the summer of 1978, evidence was collected that indicates a potential for uranium resources within the Mineral Mountains area.

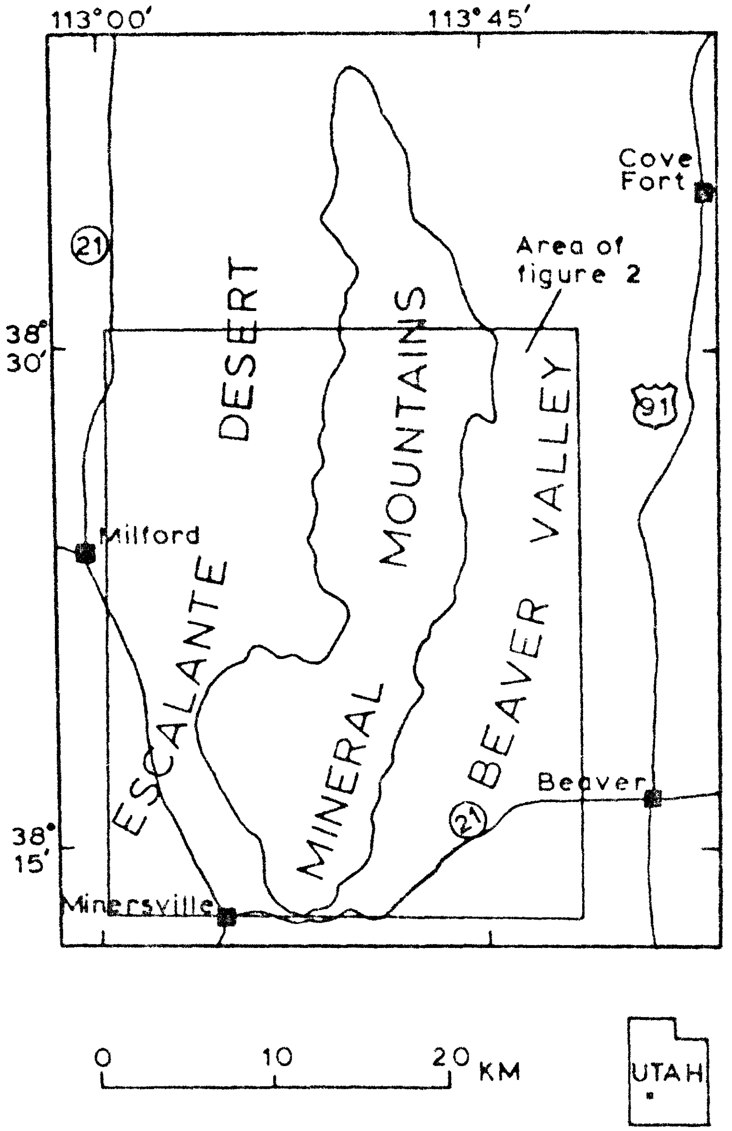

Figure 1.--Index map showing location of the Mineral Mountains, Utah.

General Geology

The general geology of the Mineral Mountains area has been described by Liese (1957), Earll (1957), Condie (1960), and Evans (1977). The geology of the Roosevelt Hot Springs area has been described by Peterson (1975) and Nielson and others (1978). A geologic map of the study area, generalized from Nielson and others (1978) and Hintze (1963), is shown in figure 2. The Mineral Mountains block is a structurally high, basin-and-range type horst which stands approximately 1 km above the surrounding basins. Faults generally trend either north or east and dip steeply (Nielson and others, 1978). A felsic pluton approximately 250 km^2 in area forms the core of the Mineral Mountains. Nielson and others (1978) have recognized five major phases of the pluton in the Roosevelt Hot Springs area: quartz monzonite, porphyritic granitic, syenite, coarse-grained granite, and fine-grained granite. Average modal analyses of these phases, taken from Nielson and others (1978), are shown in table 1. Discordant potassium-argon radiometric ages on various felsic phases, determined by Park (1968), Armstrong (1970), and Bowers (1978), seem to indicate emplacement between 9 and 15 million years ago. These radiometric ages, however, are probably anomalously young and may represent heating by younger intrusives (Peterson, 1975).

Table 1.--*Average modal analysis on the basis of 1,000 points counts*
[from Nielson and others (1978). Leaders (--) indicate not determined]

Mineral	Quartz monzonite (n=4)	Porphyritic granite (n=4)	Syenite (n=4)	Coarse-grained granite (n=4)	Fine-grained granite (n=4)
Microcline (alkali. feld.)	41.2	49.7	61.2	53.8	57.1
Plagioclase-------------	30.5	12.9	24.8	16.2	8.7
Quartz------------------	19.9	27.4	4.6	23.4	29.0
Biotite-----------------	4.3	7.3	3.6	3.7	2.9
Hornblende--------------	--	--	.4	--	--
Sphene------------------	1.7	.3	1.5	1.1	Trace
Opaques-----------------	1.2	.6	.8	.8	1.0
Chlorite----------------	.2	.3	1.1	.2	.6
Apatite-----------------	.4	.5	.35	.3	--
Zircon------------------	Trace	Trace	.15	Trace	--
Sericite----------------	.5	1.0	1.0	.5	.7
Epidote-----------------	.1	--	--	--	--

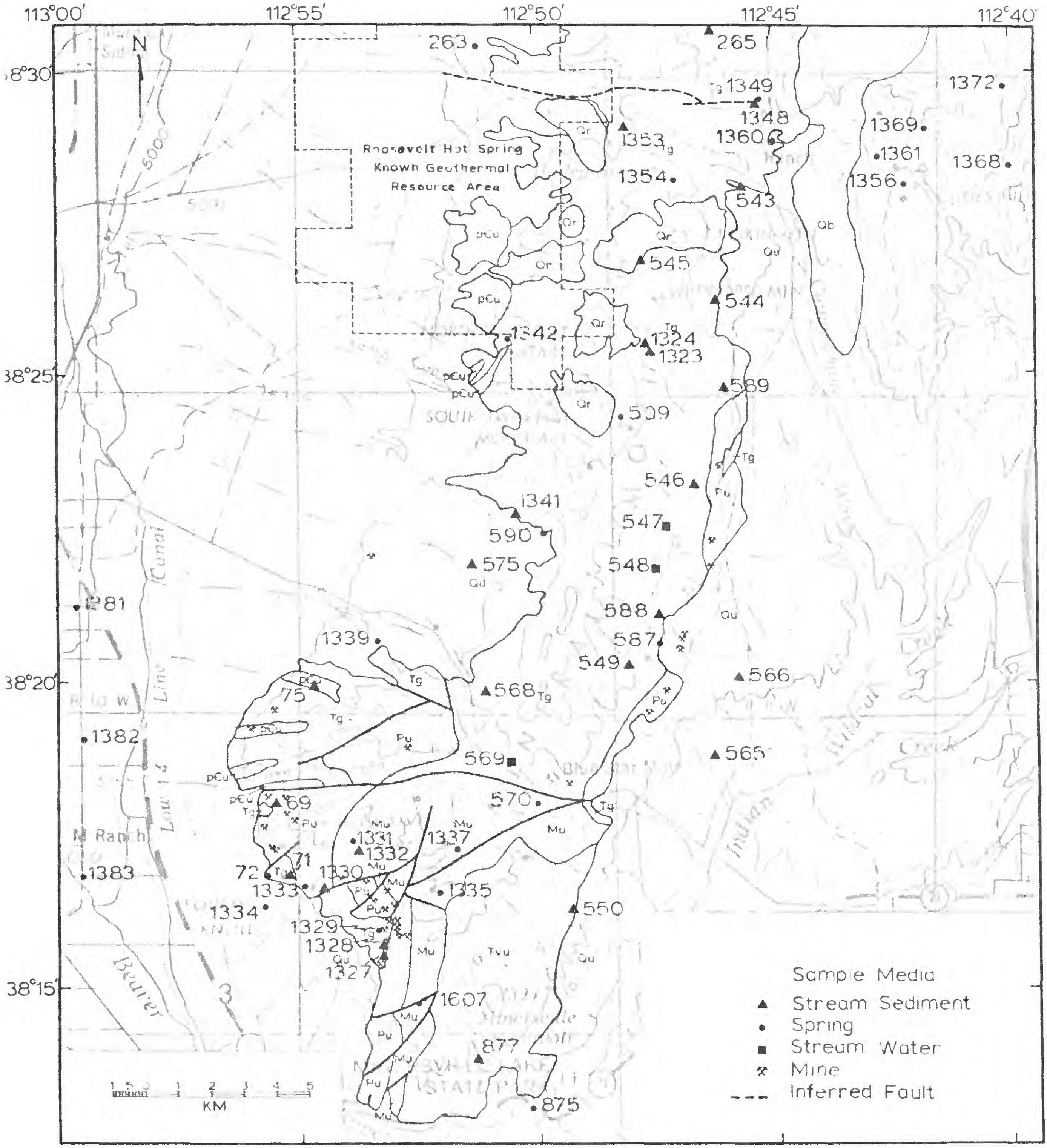

Figure 2.--Generalized geologic map and location sites of 30 water and 29 stream-sediment samples, Mineral Mountains, Utah. Modified from Nielson and others (1978) and Hintze (1963).

Figure 2.--Map explanation.

Symbol	Age	Description
Qu	Quaternary	Unconsolidated sediments, undivided
Qb	Quaternary	Basalt flows
Qr	Quaternary	Rhyolite, flows and interbedded pyroclastics
Tvu	Tertiary	Volcanic rocks, undivided
Tg	Tertiary	Granitoid rocks
Mu	Jurassic-Triassic	Mesozoic rocks, undivided (Carmel Formation, Navajo Sandstone, and Moenkopi Formation)
Mu	Permian-Mississippian	Paleozoic rocks, undivided (Kaibab Limestone, Talisman Quartzite, and Callville, Pakoon, and Redwall Limestones)
Pfu	Precambrian	Metasedimentary and plutonic rocks

Rocks of Precambrian age crop out in an irregular belt along the western margin of the range. Banded gneiss is the oldest rock unit and is intruded by hornblende gneiss (Nielson and others, 1978). Both rock units are highly variable in composition. Other units are also highly variable in composition and include minor amounts of metaquartzite, sillimanite schist, and biotite gneiss. For simplicity, all Precambrian rocks are included as one unit on the generalized geologic map (fig. 2).

The southern part of the Mineral Mountains consists of Paleozoic and Mesozoic sedimentary rocks and Tertiary volcanic rocks. The volcanic rocks range from andesitic to latitic in composition and are grouped together as one unit on the generalized geologic map (fig. 2). The stratigraphy of the sedimentary rocks is shown in table 2. The Paleozoic as well as the Mesozoic rocks are each grouped together as a single unit on the geologic map (fig. 2).

Quaternary rhyolitic volcanic rocks form flows, pyroclastic rocks, and domes which rest on dissected granite along the crest of the Mineral Mountains. Potassium-argon radiometric ages of the rhyolites, reported by Lipman and others (1978), indicate eruption from 0.8 to 0.5 million years ago. Smith and Shaw (1975) suggested that young rhyolites such as these indicate the presence of an upper level magma chamber which could serve as a heat source for a geothermal system, and a genetic association with the nearby Roosevelt Hot Springs KGRA area has been suggested (Nielson and others, 1978).

Table 2.--*Stratigraphy of Paleozoic and Mesozoic sedimentary rocks of the southern Mineral Mountains, Utah.*
[from Peterson (1975)]

Age	Unit	Description
Jurassic	Carmel Formation	Limestone and shale.
	Navajo Sandstone	Sandstone.
Triassic	Moenkopi Formation	Conglomerate, sandstone, and shale.
Permian	Kaibab Limestone	Limestone with abundant chert.
	Talisman Quartzite	Quartzite.
Permian-Pennsylvanian	Callville and Pakoon Limestones, undivided	Limestone.
Mississippian	Redwall Limestone	Dolomite and dolomitic limestone.

Quaternary basalt flows occur in the northeastern part of the Mineral Mountains area. The basalts are approximately contemporaneous with and younger than the rhyolites. This association constitutes a bimodal volcanic assemblage common in late Cenozoic volcanic sequences in the Western United States (Lipman and others, 1978).

Mineralization

The Mineral Mountains lie within the Wah Wah-Tusher mineral belt, which contains many of the known mineral resources in southwestern Utah. The four mining districts present within the Mineral Mountains are the Granite, North Granite, Bradshaw, and Lincoln. Mineral deposits occur either in fissure-vein and replacement deposits in limestone and dolomitic limestone, as in the Bradshaw and Lincoln districts, or as contact-metasomatic deposits, as in the Granite district. The vein and replacement deposits produced mainly lead, silver, and gold, with minor copper and zinc, largely from oxidized ores. Gold was originally associated with pyrite and silver with galena. Lead, copper, and zinc were originally present as galena, chalcopyrite, and sphalerite (Earll, 1957).

Contact-metasomatic deposits containing scheelite with a high content of molybdenum are present in a belt of tactite along the eastern margin of the Mineral Mountains, where Paleozoic limestones were intruded by the granitic pluton. The major metal mined was tungsten although fluorite, muscovite, tourmaline, and molybdenite have been identified (Hobbs, 1944). No occurrences of uranium minerals have been reported.

Geochemical Survey

Water samples were collected from 28 springs and 2 small streams using acid-rinsed polyethylene bottles. At each site, a 60-ml sample was collected and filtered through a 0.45-μm membrane filter and then acidified with reagent-grade concentrated nitric acid to pH <2. An untreated 500-ml sample was also collected. Temperature was measured at the sample site. pH was determined either at the site or at the motel in the evening of the same day, using the untreated water sample that was collected. Calcium, magnesium, sodium, potassium, alkalinity, specific conductance, sulfate, chloride, fluoride, and silia were determined using the untreated sample. Zinc, copper, molybdenum, arsenic, uranium, and lithium were determined using the filtered and acidified sample. The analytical techniques used for the analysis of each constituent are shown in table 3. The results of the analyses are all within 10 percent of the ionic-charge balance and 60 percent are within 5 percent.

Thirty-three stream-sediment samples were collected from small, unbranched stream drainages throughout the Mineral Mountains. Each sample was composited by collecting at several locations along the active drainage channel. The concentration of uranium and thorium was determined by H. T. Millard, R. B. Vaughn, M. F. Gaughlin, and M. W. Salt on the stream-sediment fraction finer than 0.180 mm by delayed neutron activation. In addition, eU (equivalent uranium) was determined radiometrically by J. C. Negri using a multichannel scintillometer on the same fraction of the stream sediment.

Table 3.--*Analytical methods used for water analyses, Mineral Mountains, Utah*

Constituent	Method	Reference
Alkalinity	Gran's plot potentiometric titration with sulfuric acid	Orion Research, Inc. (1975).
Sulfate	Ion chromatography	Dionex Corp. (1978)
Chloride	---do	Do.
Fluoride	---do	Do.
Sodium	Flame atomic absorption spectrophotometry	Perkin-Elmer Corp. (1976).
Magnesium	---do	Do.
Potassium	---do	Do.
Calcium	---do	Do.
Lithium	---do	Do.
Copper	Flameless atomic absorption spectrophotometry	Miller and Ficklin (1976).
Zinc	---do	Do.
Molybdenum	---do	Do.
Arsenic	---do	Aruscavage (1977).
Uranium	Fluorometric	Ward and Bondar (1977).
Silica	Molybdate blue	Brown, Skougstad, and Fishman (1970), p. 138-140.
Specific conductance	Conductivity bridge	Do. p. 28-29.

Geochemistry of the Waters and Stream Sediments

The geochemistry of natural waters can be 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), Miller (1978), and Cameron (1978). Water samples were collected from 28 springs and 2 small streams (fig. 2). A summary of the chemical analyses is shown in table 4. The Mineral Mountains contain mostly calcium bicarbonate waters, although two samples of calcium sulfate, two of calcium chloride, and one of sodium chloride waters are also present. Water from the central portion of the Mineral Mountains are more dilute than the waters from the margins and surrounding basins, probably because of a shorter contact time between bedrock and water in the central and higher parts of the range.

Correlation coefficients of the logarithm (of the base 10) of concentrations of ions are shown in table 5. Several pairs with significant correlation are present. Uranium, molybdenum, and fluoride all display significant correlation with each other (table 5), and all three seem to reflect a similar chemical control. A plot of uranium concentration is shown in figure 3.

Table 4.--*Summary of chemical analyses of 30 water samples, Mineral Mountains, Utah*

Variable	Minimum	Maximum	Geometric mean	Geometric deviation
As, µg/ℓ	0.2	740	1.66	4.56
Li, µg/ℓ	4.0	21,000	18.2	6.62
Ca, mg/ℓ	13	285	60.0	2.08
Cu, µg/ℓ	.7	13	1.58	1.83
U, µg/ℓ	.2	740	3.32	6.05
K, mg/ℓ	1.0	257	2.54	3.03
Mg, mg/ℓ	3.0	100	14.3	2.71
Mo, µg/ℓ	1.0	93	3.32	2.75
Na, mg/ℓ	2.3	1,623	21.71	3.06
Zn, µg/ℓ	1.4	43	4.35	2.41
SiO_2, mg/ℓ	10	46	22.39	1.44
F, mg/ℓ	.06	2.5	.35	2.51
Cℓ, mg/ℓ	7.3	3,636	46.98	3.49
SO_4, mg/ℓ	3.6	952	28.45	4.31
Alkalinity, mg/ℓ	41	391	171.5	1.90
Sp. Cond., µmhos/ℓ	120	10,000	542.3	2.51
pH	6.05	8.25	7.53	1.07

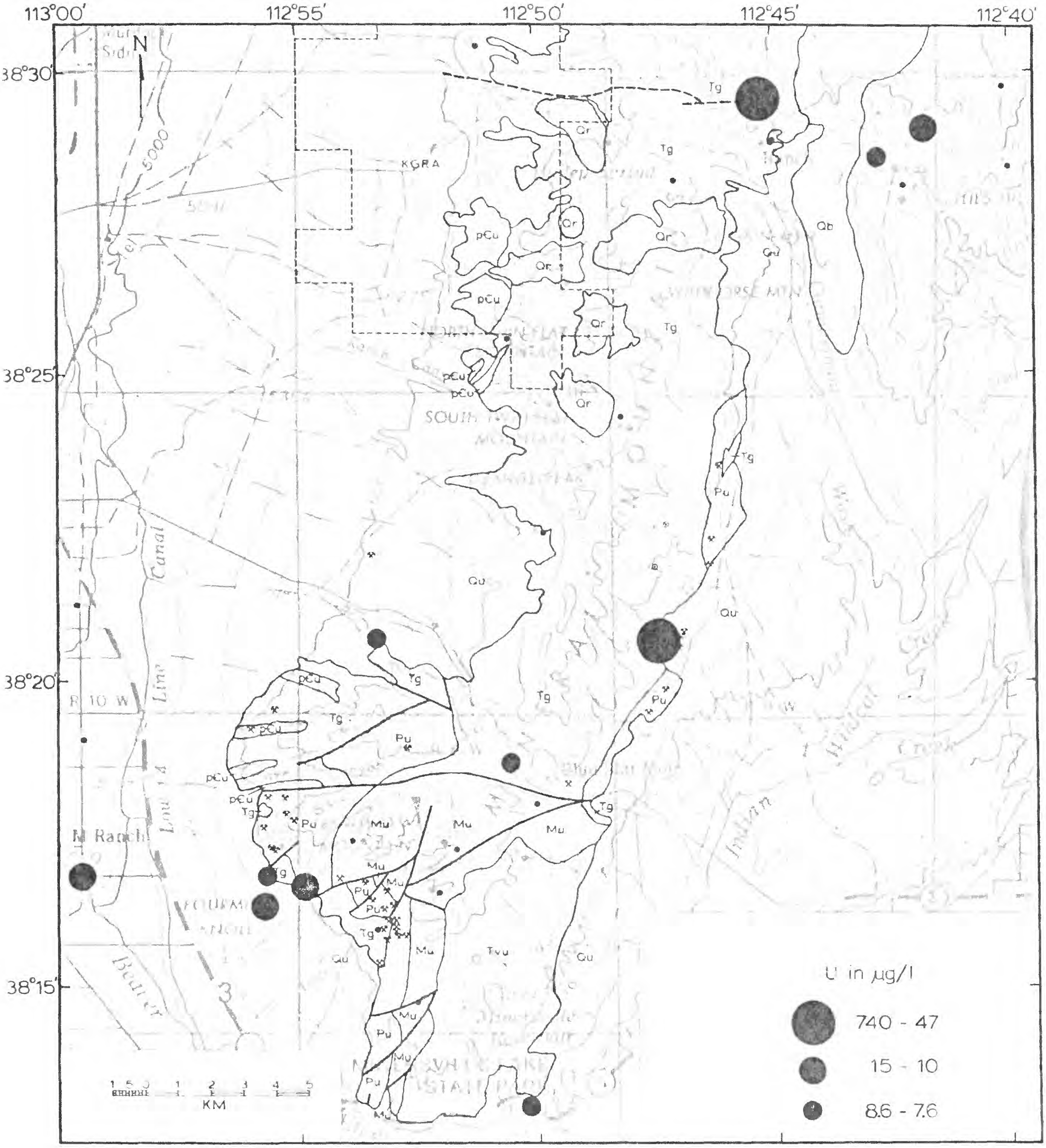

Figure 3.--Uranium concentrations of 30 water samples, Mineral Mountains, Utah.

Table 5.--*Matrix of correlation coefficients of the log-transformed original data (number of valid pairs are shown below diagonal)*

	As	Li	Ca	Cu	U	K	Mg	Mo	Na	Zn	SiO_2	F	Cℓ	SO_4	Alkalinity	Sp. Cond.	pH
As--------	1.00	0.83	0.50	0.64	0.13	0.81	0.45	0.05	0.67	0.49	0.48	0.26	0.83	0.23	0.43	0.76	-0.34
Li--------	30	1.00	.41	.76	.51	.82	.33	.05	.85	.37	.47	.44	.81	.08	.39	.78	- .54
Ca--------	30	30	1.00	.44	.20	.30	.93	.19	.49	.28	.03	- .01	.73	.81	.82	.87	.07
Cu--------	28	28	28	1.00	.16	.64	.34	- .15	.63	.47	.37	.27	.66	.21	.24	.65	- .39
U---------	28	28	28	26	1.00	.19	.17	.68	.30	.15	.33	.67	.33	.22	.38	.30	.20
K---------	30	30	30	28	28	1.00	.24	- .17	.72	.42	.65	.40	.69	.02	.31	.64	- .39
Mg--------	30	30	30	28	28	30	1.00	.22	.40	.24	- .04	- .01	.64	.90	.77	.82	.18
Mo--------	23	23	23	21	21	23	23	1.00	.03	.04	- .04	.49	.19	.26	.30	.20	- .11
Na--------	30	30	30	28	28	30	30	23	1.00	.07	.44	.36	.77	.15	.53	.77	- .46
Zn--------	30	30	30	28	28	30	30	23	30	1.00	.26	.07	.40	.22	.18	.37	- .21
SiO_2------	30	30	30	28	28	30	30	23	30	30	1.00	.49	.47	- .09	.07	.28	- .13
F---------	30	30	30	28	28	30	30	23	30	30	30	1.00	.30	- .07	.12	.26	- .19
Cℓ--------	30	30	30	28	28	30	30	23	30	30	30	30	1.00	.44	.56	.91	- .20
SO_4-------	30	30	30	28	28	30	30	23	30	30	30	30	30	1.00	.57	.60	.32
Alkalinity	30	30	30	28	28	30	30	23	30	30	30	30	30	30	1.00	.77	.03
Sp. Cond.-	30	30	30	28	28	30	30	23	30	30	30	30	30	30	30	1.00	- .19
pH--------	30	30	30	28	28	30	30	23	30	30	30	30	30	30	30	30	1.00

Two significant anomalies are present. The more important is at Mud Spring (Sample No. 587) along the eastern margin of the range, designated the Mud Spring anomaly, which contains 740 μg/l uranium. Molybdenum and floride concentrations are also anomalously high at 93 μg/l and 1.8 mg/l respectively. Uranium concentrations reported in the literature for natural waters range from less than 1 μg/l to several mg/l. Waters that contain uranium above 100 μg/l are certainly interesting and in many cases reflect uraniferous aquifers. The Mud Spring water thus can be classified as excepionally anomalous. Mud Spring is located within the granite bedrock, but above and near the contact with a tactite zone within the Paleozoic limestones.

A second spring containing anomalous uranium (Sample No. 1439) is in the northeastern part of the range, where it appears to lie along the east-trending Negro Mag fault (designated the Negro Mag anomaly). The water from this spring contains 45 μg/l uranium, 1.7 μg/l molybdenum, and 0.79 mg/l fluorite.

Several other springs in the Mineral Mountains contain uranium concentrations in the range from 10 to 15 μg/l; most of these occur in the southwestern part of the study area. Because of the high mobility of uranium and the ability of oxidizing waters to pick up uranium, no particular significance was assigned to values in this range.

The two waters in which the dominant anion is sulfate probably reflect reaction of oxygenated water with sulfate minerals. Sample No. 1329 is from a spring within the Lincoln mining district, where sulfides are known to exist, but Sample No. 1607 is from a spring several kilometers south of the Lincoln mining district. The latter sample may indicate the presence of hitherto unknown sulfide deposits.

The concentrations of uranium and thorium in 29 samples of stream sediments are shown on table 6. Uranium and thorium contents range from 1.6 to 50 ppm and 4.6 to 331 ppm respectively. A plot of uranium content of stream sediments is shown on figure 4. The most anomalous area is along the eastern margin of the range and generally supports the Mud Springs anomaly obtained by uranium concentrations in waters. In addition, the uranium content of Sample Nos. 265 and 1348 are anomalous and generally support the Negro Mag wash anomaly obtained by uranium concentrations in water.

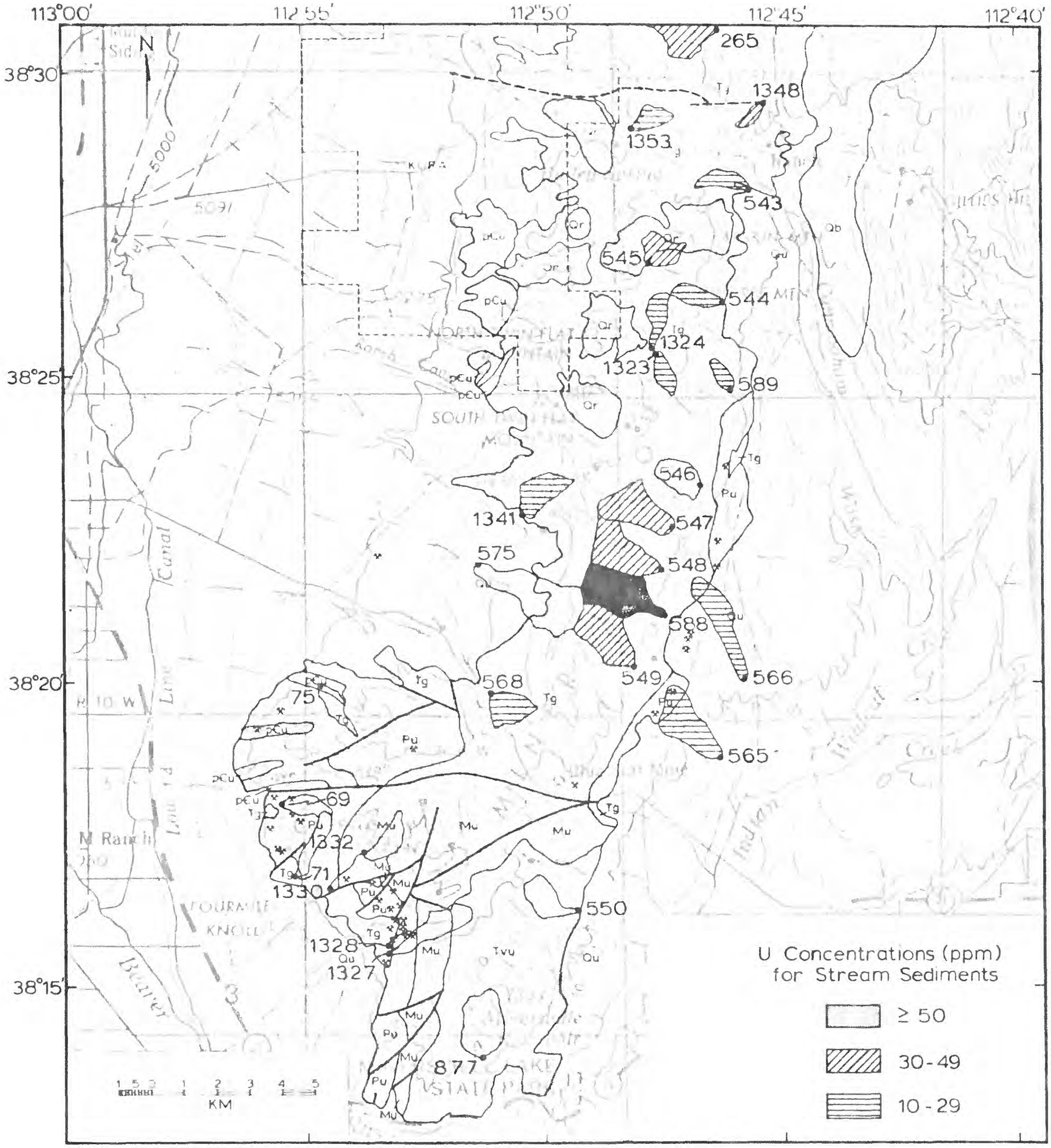

Figure 4.--Uranium concentrations of 29 stream-sediment samples, Mineral Mountains, Utah.

The average ratio of Th/U for the samples of stream sediments is 4.6. This is within the range of many accessory heavy minerals, which would be common in stream sediments derived from granites, and does not suggest the presence of uranium deposits. However, uranium is more soluble than thorium, and the stream sediments thus may contain minerals in which uranium has been preferentially leached relative to the more insoluble thorium. The ration Th/U then would represent a maximum figure only and the ratio may originally have been less. A comparison of eU with the sum of uranium and thorium concentrations determined by delayed neutron activitation (table 6) indicates significant disequilibrium; eU values are much less than the sum of uranium and thorium, particularly for Sample Nos. 547, 548, 549, 566, and 588, near the Mud Springs anomaly, and Sample No. 265 near Negro Mag wash anomaly. This difference between eU and the sum of uranium and thorium may indicate that uranium was carried in solution by water in the drainages and later adsorbed or precipitated as "young" uranium within the stream sediments, thus causing the disequilibrium.

Table 6.--*Summary of chemical analyses of 29 stream sediment samples, Mineral Mountains, Utah*
[Leaders (--) indicate not determined]

Sample No.	U, ppm	Th, ppm	Th/U	eU	Σ(Th+U)	(Th+U)-eU
69	2.51	8.94	3.56	<20	11.5	--
71	2.24	5.2	2.33	<20	7.44	--
75	5.50	22.7	4.09	<20	28.2	--
208	2.86	10.8	3.78	<20	13.7	--
265	38.3	308	8.04	90	346	256
543	12.1	84.3	6.95	30	96.4	66.4
544	15.2	93.1	6.12	40	108	68.3
545	46.4	10.7	4.35	20	57.1	37.1
546	8.63	40.0	4.63	20	48.6	28.6
547	43.2	162	3.75	50	205	155
548	32.1	120	3.76	50	152	102
549	40.4	147	3.64	40	187	147
550	3.27	10.4	3.19	<20	13.7	--
565	14.8	73.2	4.96	40	88.0	48.0
566	14.8	66.6	4.50	50	81.4	31.4
568	14.7	76.9	5.23	30	91.6	61.6
575	7.20	32.2	4.47	20	39.4	19.4
588	50.0	331	6.63	150	381	231
589	11.4	68.2	5.98	40	79.6	39.6
877	4.71	13.3	2.82	<20	18.0	--
1323	23.4	110	4.71	50	133.4	83.4
1324	10.1	56.9	5.62	30	67.0	37.0
1327	4.21	12.1	2.87	<20	16.3	--
1328	6.08	14.4	2.37	<20	20.1	--
1330	4.18	18.5	4.43	<20	22.7	--
1332	1.59	4.6	2.88	<20	6.19	--
1341	11.3	51.3	4.56	20	62.6	42.6
1348	34.5	257	7.44	70	292	222
1353	10.5	59.8	5.69	30	70.2	40.2

Factor Analysis Applied to the Water Data

The results of the hydrogeochemical survey consist of a set of multispecie data. To better utilize this type of data, factor analysis, a multivariate technique, was applied to gain a better understanding of the interrelations within the data. Factor analysis is a mathematical technique that attempts to explain the variation in a set of data by redistributing this variation among a smaller number of relations or factors. This data-reduction capacity may enable the user to see possible underlying patterns that were originally obscured by the volume of the data. Background information on the use of factor analysis applied to geochemical studies includes Garrett and Nichols (1969), Miesch (1976), and Miller and Ficklin (1976).

In order to evaluate relations among samples, Q-mode factor analysis was applied to the water data. The technique determines a group of end-member compositions or factors that approximately describe the variation within the multisample data. Each end-member composition or factor represents a chemical control which affects water chemistry.

A loading of 1.0 would indicate an end-member composition for the sample for a particular factor. The sample would contain no other loadings or components for factors other than that particular factor. Most samples then contain different proportions of end-member compositions or factors. Individual samples can then be described in terms of components of these end-member compositions or factors. Factor analysis demonstrates these factors but does not explain them. The interpretation of these factors and the geological significance of the resulting patterns or plots are subjective and depend upon the user's knowledge of the local geological and geochemical environments.

Q-mode factor analysis was carried out using the U.S. Geological Survey's STATPAC library system. The basic algorithms for the program are from Klovan and Imbrie (1971) and Imbrie (1963). Logarithm transformations were applied to all data prior to factor analysis. A five-factor model was selected to represent the geochemical variation, because most of the variation among the samples was explained (communalities near 1.0) and no additional information was gained by higher factor models. The five-factor model accounts for 96 percent of the variation. The varimax-factor matrix and the factor-score matrix are shown in table 7 and 8.

Factors 1 and 2 are interpreted as reflecting major lithologies, factors 3 and 5 reflecting mineralization, and factor 4 as reflecting geothermal effects.

Table 7.--*Varimax rotated-factor matrix, Mineral Mountains, Utah*

Sample No.	Communality	Factors				
		1	2	3	4	5
547	0.98	0.22	0.88	-0.36	-0.13	0.05
548	.95	.25	.66	-.51	-.41	-.12
569	.99	.40	.66	-.60	-.13	.14
72	.97	.67	.48	-.38	-.27	.27
263	.93	.42	.18	-.20	-.82	.13
509	.93	.28	.74	-.31	-.31	.34
570	.98	.78	.30	-.44	-.25	.15
587	.96	.46	.30	-.72	-.26	.26
590	.95	.18	.94	-.12	-.09	.03
875	.96	.54	.51	-.52	-.37	-.01
132	.96	.69	.41	-.25	-.30	.40
1331	.98	.88	.28	-.14	-.31	.10
1333	.98	.66	.29	-.34	-.32	.48
1334	.98	.76	.40	-.45	-.17	.06
1335	.98	.90	.21	-.26	-.16	.18
1337	.94	.88	.28	-.14	-.24	-.01
1339	.96	.65	.38	-.58	-.24	.07
1342	1.00	.53	.45	-.53	-.48	.07
1349	.98	.54	.50	-.51	-.42	.09
1354	.96	.42	.62	-.28	-.55	.15
1356	.91	.48	.77	-.12	-.22	.13
1360	.96	.49	.51	-.39	-.55	.00
1361	.97	.64	.57	-.43	-.19	.08
1368	.98	.58	.70	-.10	-.35	.11
1369	.95	.81	.37	-.34	-.22	.01
1372	.96	.69	.48	-.25	-.42	.06
1381	.96	.70	.45	-.28	-.41	.11
1382	.97	.73	.48	-.25	-.36	.10
1383	.98	.62	.51	-.25	-.44	.27
1607	.94	.84	.20	-.28	-.34	.07

Table 8.--*Varimax rotated-factor score matrix, Mineral Mountains, Utah*

[Significant variables are underscored]

Variable	Factors				
	1	2	3	4	5
As	0.122	0.062	0.148	-0.241	0.031
Li	.017	-.066	-.032	-.245	-.031
Ca	.409	-.007	.039	-.084	.053
Cu	.062	.128	.114	-.313	-.169
U	.042	-.004	-.520	.059	.132
K	-.012	-.042	.027	-.369	-.009
Mg	.478	-.136	-.010	.004	.016
Mo	.073	-.105	-.408	.161	.315
Na	.088	.098	-.071	-.242	-.142
Zn	-.021	.214	.217	-.182	.862
SiO_2	-.138	.415	-.106	-.481	-.068
F	-.176	.194	-.636	-.159	.036
Cℓ	.158	-.036	.039	-.248	.055
SO_4	.364	-.058	-.013	.092	.206
Alkalinity	.458	-.095	-.229	-.144	-.143
Sp. Cond.	.249	-.106	-.032	-.196	-.020
pH	.302	.809	.040	.366	-.121

Factor 1

The first factor accounts for 38.7 percent of the total variation and is represented by significant scores (listed in order of importance) for magnesium, alkalinity, calcium, sulfate, pH, and specific conductance (table 8). Water is involved in the chemical weathering of rock, and it is common for the chemistry of this water to reflect the major lithologies of an area. Often the first several factors of a model reflect the major lithologies. The pattern obtained by plotting factor loadings for factor 1 for the five-factor model is shown on figure 5. The sample sites with the highest loadings for factor 1 all occur within Mesozoic rocks. Magnesium, alkalinity, and calcium, which are the dominant loadings for the factor-score matrix (table 8), are commonly released as dissolved species during chemical weathering; therefore, factor 1 is interpreted as reflecting chemical weathering of Mesozoic sedimentary rocks. The Mesozoic rocks include the Triassic redbeds and limestones of the Moenkopi Formation and the Jurassic limestones and calcareous shales of the Navajo Sandstone and Carmel Formation.

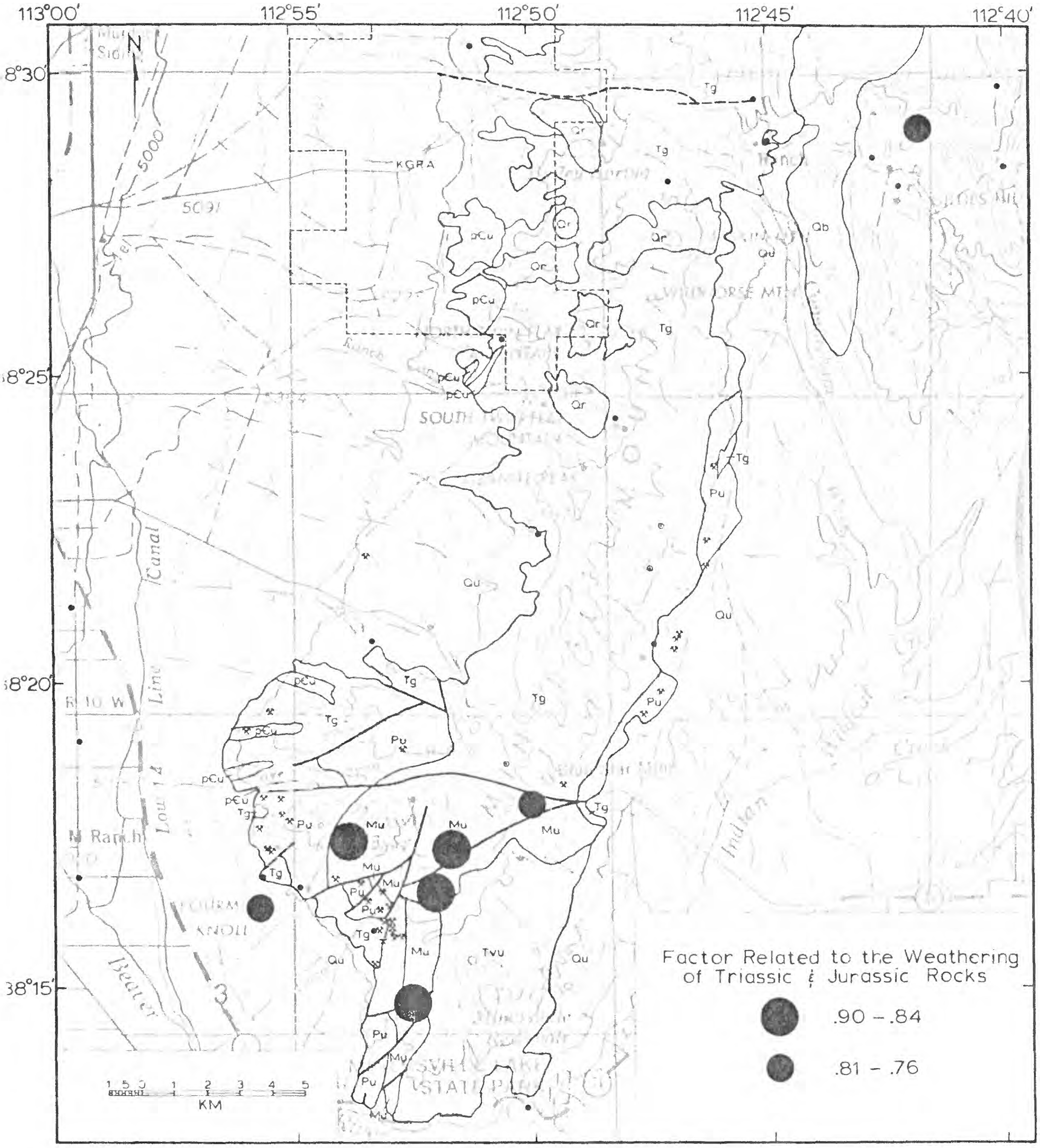

Figure 5.--Factor 1 loadings of 30 water samples, Mineral Mountains, Utah.

Factor 2

The second factor accounts for 27 percent of the variation and is dominated by a high score for pH, but also significant scores for silica, zinc, and fluoride (table 8). The pattern produced by plotting loadings for factor 2 is shown on figure 6. The sample sites with the highest loadings for factor 2 occur within the granite pluton. The remaining sites with significant loadings are in Quaternary sediments in the northeast portion of the study area. The waters of springs at these locations are probably in contact with the granite pluton at shallow depth. Therefore, the pluton is probably buried under shallow Quaternary sediments in this area. Factor 2 is interpreted as reflecting chemical weathering of granitic rocks. pH is the highest loading within factor 2. This indicates that the dominant control on the chemistry of water in contact with the pluton is the buffering of the pH by the weathering of the granitic rock.

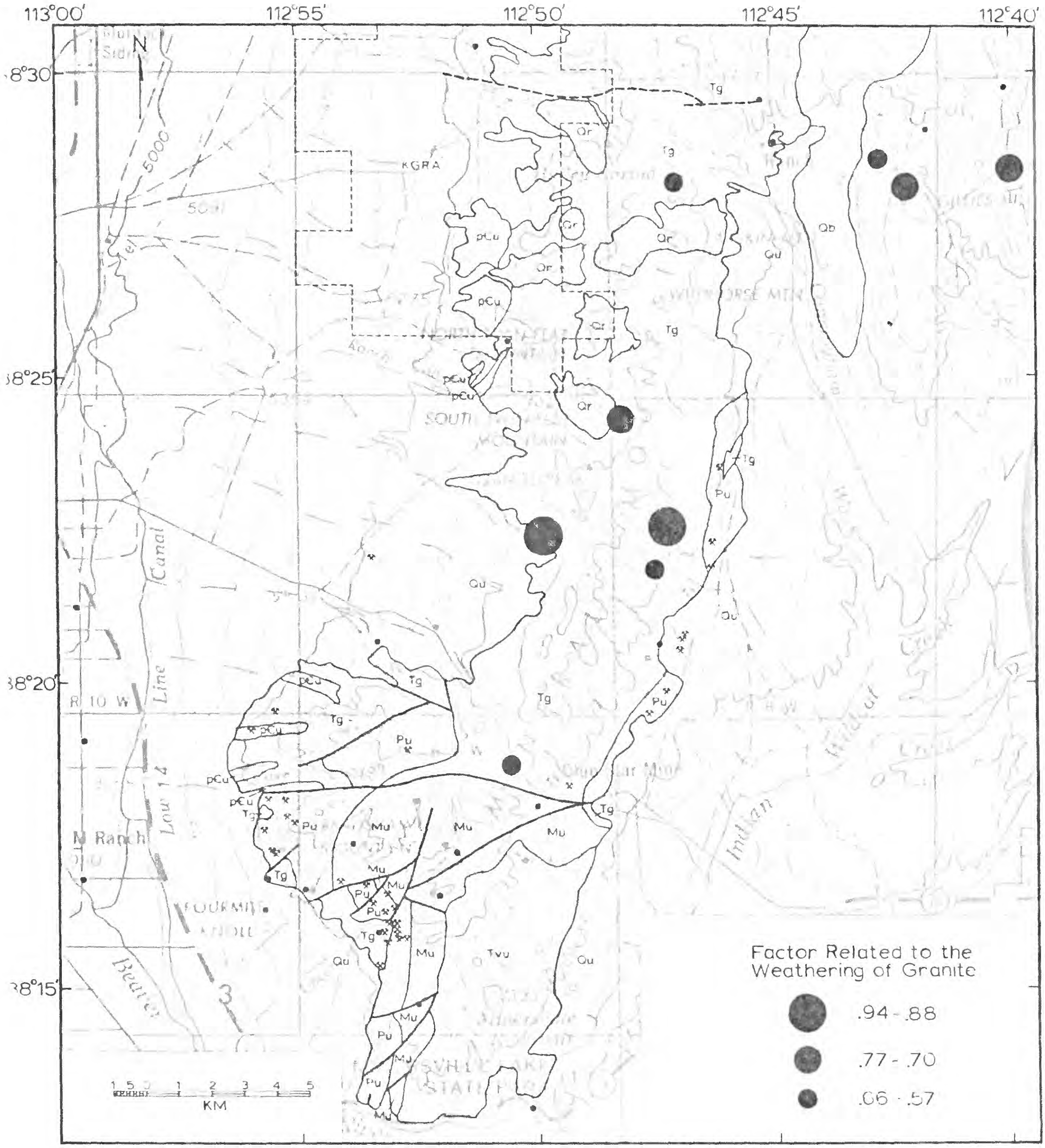

Figure 6.--Factor 2 loadings of 30 water samples, Mineral Mountains, Utah.

Factor 3

The third factor accounts for 14 percent of the total variation and is represented by significant negative scores for fluoride, uranium, and molybdenum (table 8). The presence of uranium and two species that are commonly associated with uranium suggests that factor 3 is reflecting uranium mineralization. The factor is probably a better indicator of uranium minerals than the simple plot of uranium concentrations in water because multiple species make up the factor. Therefore, the variations of one specie out of several species that compose the factor will not be critical as the variation of one specie that makes up a simple plot. The plot of loadings for factor 3 is shown on figure 7. The sample site with the highest loading is Mud Spring (Sample No. 587). This spring also contained the highest concentration of uranium (740 μg/l). Sample No. 1349 (Negro Mag Wash anomaly) contained the second highest concentration of uranium in the water (46.9 μg/l). This anomaly is not as important in terms of loadings for factor 3 and has been relegated to a less important anomaly. The sites of anomalous loadings for factor 3, in order of importance, include Samples Nos. 587, 569, 1339, 1342, 875, 548, and 1349. The locations of these samples are within but generally near the margin of the exposed pluton.

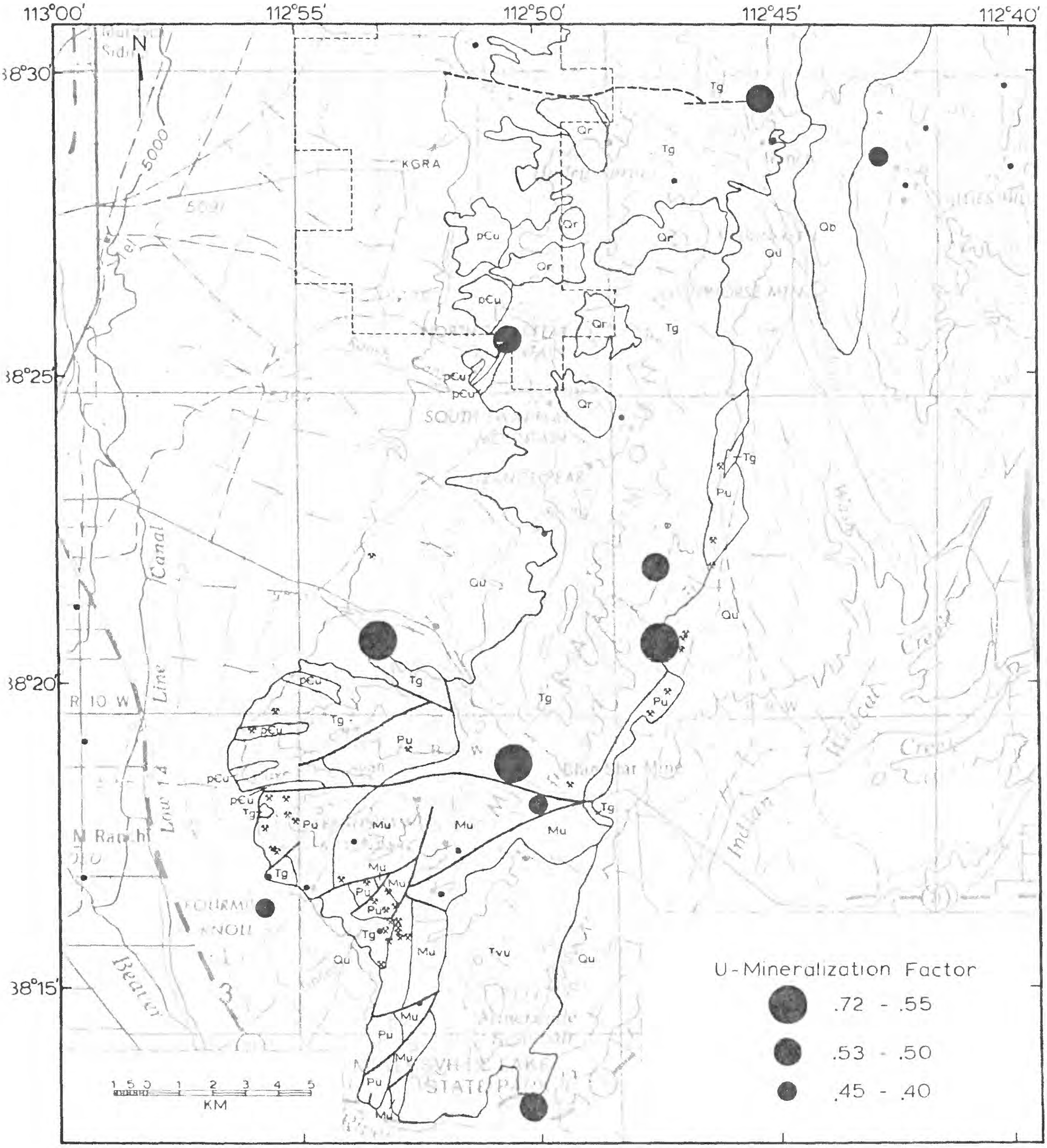

Figure 7.--Factor 3 loadings of 30 water samples, Mineral Mountains, Utah.

Factor 4

The fourth factor accounts for 13 percent of the total variation and is represented by significant negative scores for silica, potassium, pH, and copper (table 8). The plot of loadings for factor 4 is shown on figure 8. The site with the highest loadings is Salt Spring (Sample No. 263). Salt Spring is a warm spring within the Roosevelt Hot Spring KGRA. The water chemistry of this spring is the result of heated water intensely leaching the country rock. High concentrations of silica, magnesium, and potassium, which are the dominant factor scores for factor 4, are common for geothermal waters; therefore, factor 4 is interpreted as reflecting geothermal activity. In addition to Salt Spring, the water chemistry of several additional sites contains high loadings for factor 4. These sites are all located in the northern part of the area, particularly near the Negro Mag Wash fault (fig. 2). The distribution of these sites indicates springs that contain a component of water in which the chemistry is controlled by hot water leaching country rock.

Factor 5

The fifth factor accounts for 3 percent of the total variation and is represented by significant scores for zinc, molybdenum, and sulfate (table 8). The plot of loadings for factor 5 is shown on figure 9.

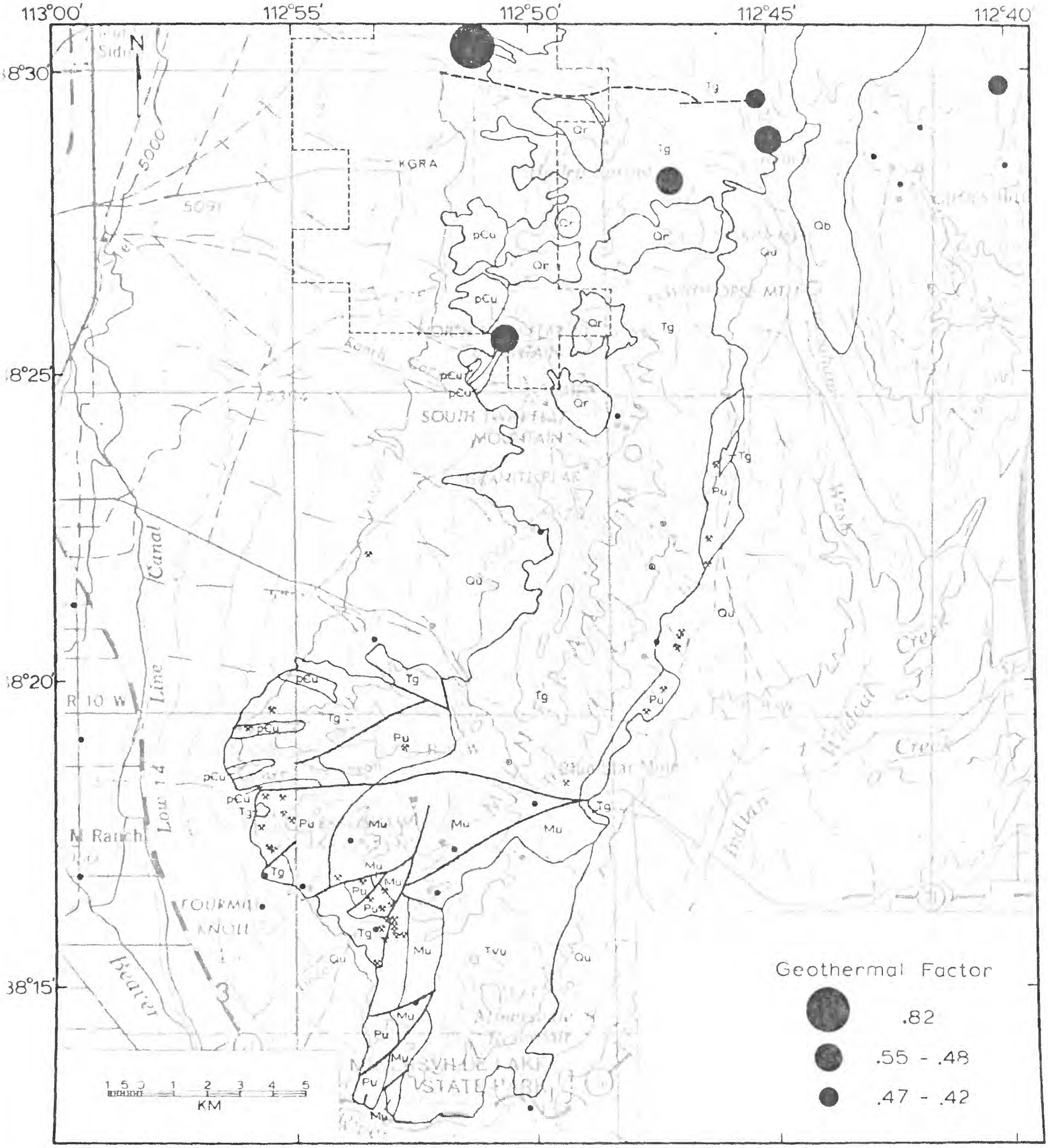

Figure 8.--Factor 4 loadings of 30 water samples, Mineral Mountains, Utah.

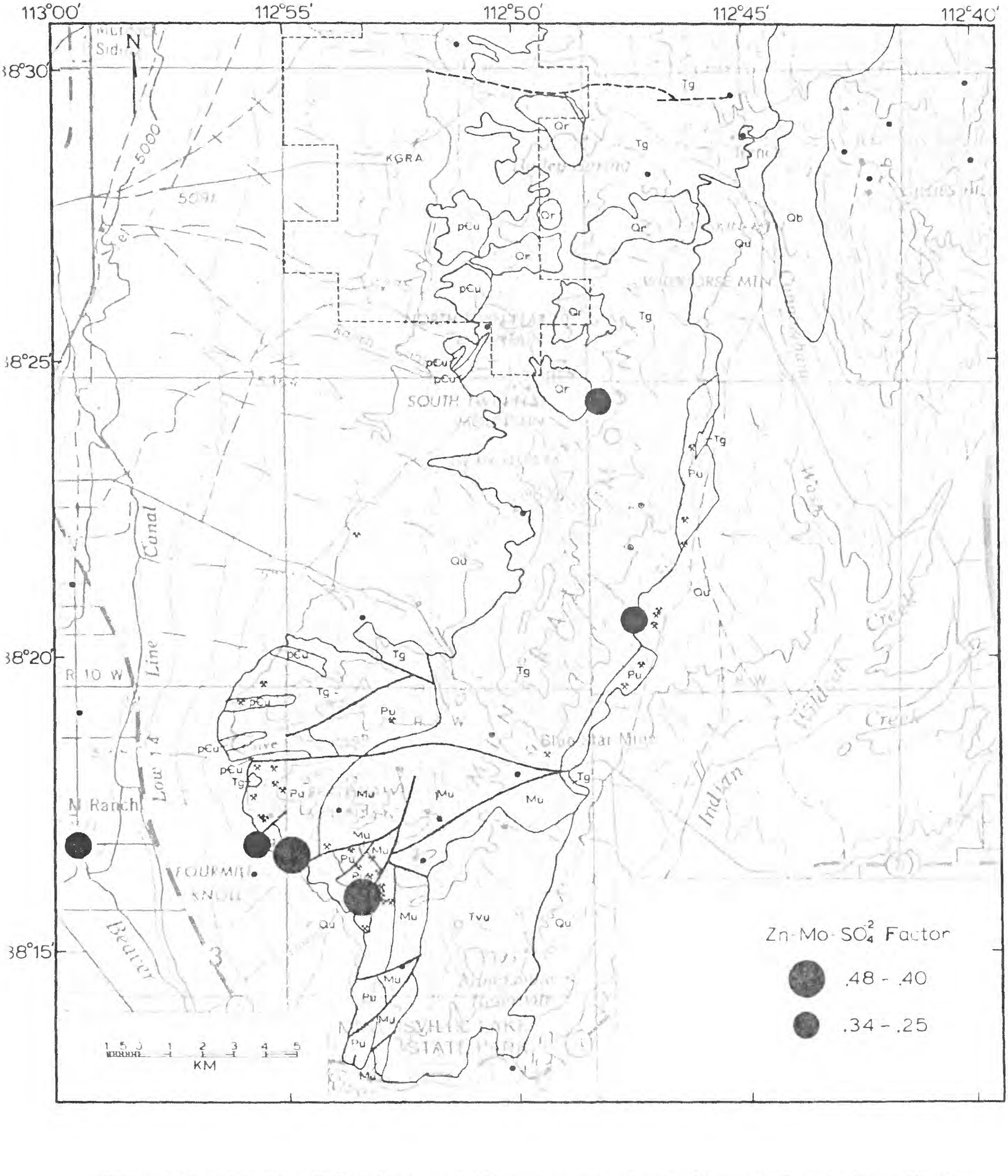

Figure 9.--Factor 5 loadings of 30 water samples, Mineral Mountains, Utah.

The sites with the highest loadings are in the southwestern portion of the study area, which contains the Lincoln mining district. Galena is the major sulfide that was mined. Lead is highly insoluble and therefore limited in mobility. This is not true for associated zinc, molybdenum, and sulfate, which are more soluble and mobile in the waters. Therefore, factor 5 is interpreted as reflecting replacement-type mineralization. Sample Nos. 587 and 509 (fig. 2) both contain a component of the water with high loadings for factor 5. Sample No. 587 (Mud Spring) is within the granite but near the tactite zone and also contains a high loading for factor 3.

Discussion

The results of a geochemical survey indicate that a good potential for uranium deposits exists in the Mineral Mountains, Utah. The results of the factor analysis, particularly factor 3, which is composed of several species thought to be associated with the uranium mineralization, is considered a more reliable indicator of uranium deposits than simple plots of the concentrations of uranium alone. The most important anomaly is west of Mud Spring, along the eastern margin of the Mineral Mountains pluton. The anomaly occurs within the granite, but near a marginal tactite zone. The high concentrations of uranium in water from Mud Springs suggest that water comes in contact with uranium minerals in a near-surface oxidizing zone. The high concentration of molybdenum in the water from Mud Spring indicates that molybdenum may be associated with the uranium minerals. Cunningham and Stevens (1978) reported the occurrence of uranium and molybdenum minerals from the central mining area near Marysvale, Utah, and discussed this association. Molybdenum is commonly associated with the uranium minerals and, like uranium, is mobile under oxidizing conditions as anoinic complexes in water. The most likely occurrence of uranium is in epigenic uraninite-bearing veins along faults and fractures within the pluton. Meteoric water circulating along mineralized faults probably feeds Mud Spring.

Other areas of interest include the sites of Sample Nos. 569 and 1339 (fig. 2). Although not as important as Mud Spring, factor-analysis technique applied to the water chemistry at these sites indicate a similarity to the water at Mud Spring. Most of these anomalies (fig. 7) occur within but near the margin of the granitic pluton, similar to the location of Mud Spring anomaly.

If uranium deposits are present within the Mineral Mountains, three possible hypothetical models are proposed to account for them. More detailed work is needed to chose which, if any, of the models is the most likely to account for the anomalies noted. For the first model, uranium mineralization took place late during the igneous cycle responsible for emplacing the host granitic pluton. Uranium was deposited along fractures and faults within the pluton, particularly near the margins and possibly in association with the contact-metasomatic mineralization. The uraniferous fluids were derived by fractionation of the magma which formed the pluton.

For the second model, a uraniferous solution was derived by fractionation of an underlying magma associated wih the Quaternary rhyolites. Uranium mineralization took place along faults, fractures, and zone of structural weakness such as the contact zone of the older granitic pluton with sedimentary rocks. Uranium mineralization was penecontemporaneous with the emplacement of the Quaternary rhyolites along the range crest.

For the third model, oxidizing meteoric water under the influence of gravity entered the bedrock via fractures and faults and circulated deep into bedrock, where it was heated, possibly by the hot magma chamber that fed the Quaternary rhyolite. The hot water leached the country rock and picked up significant uranium as well as other solutes and rose, along faults and fractures, where a change in chemistry, such as the degassing of CO_2 or an unknown reducing mechanism, caused the uranium to be precipitated as uraninite.

It is interesting to note that Salt Spring (Sample No. 263), which is the only warm spring sample within the Mineral Mountains, occurs within the Roosevelt KGRA area. This hot water contains large amounts of dissolved solids which have been leached from the country rock. Uranium concentration in this sample was not detected (<0.2 μg/l). The water must have originally carried higher concentrations of uranium which may have been precipitated as uraninite along faults and fractures.

Conclusions

The results of the geochemical survey suggests that potential exists for uranium mineralization within the Mineral Mountains. The important Mud Spring anomaly may reflect leaching of uranium by oxidizing meteoric water from an epigenetic vein-type deposit that also contains significant molybdenum. Until source for the uranium is determined, it will not be possible to determine which of several possible genetic models is the most applicable.

The uranium-bearing waters present within the Mineral Mountains are discharging toward adjacent basins where they possibly could form other types of uranium deposits across redox fronts within the sedimentary fills.

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