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Comparison of the chemical composition of mineralized and unmineralized (barren) samples of the Morrison Formation in the Ambrosia Lake uranium area, New Mexico

By

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Abstract

Existing multielement spectrographic and chemical analyses of samples from the Morrison Formation were used to determine the chemical characteristics of primary and secondary uranium ore, barren sandstones, and mineralized and unmineralized mudstones. The analyses were for 696 sandstone samples and 32 mudstone samples from mines in the Ambrosia Lake area of New Mexico, 100 other sandstone samples from the Ambrosia Lake area, and 321 sandstone samples from elsewhere in the San Juan basin. Statistical treatment of the data indicates that organic carbon, beryllium, vanadium, uranium, molybdenum, selenium, lead, manganese, yttrium, copper, iron, barium, strontium, aluminum, magnesium, potassium and possibly sodium, sulfur, arsenic, and mercury are concentrated in the primary ore; aluminum, uranium, vanadium, selenium, manganese, calcium, strontium, sodium(?), copper, iron, carbonate carbon, and barium are enriched in the secondary ore; and organic carbon, uranium, vanadium, beryllium, manganese, molybdenum, selenium, and lead were added to the mineralized mudstones.

Introduction

The major goal of this study is to summarize the chemical characteristics of the uranium deposits in the Ambrosia Lake area of New Mexico. It is hoped that this information may be useful for placing some restrictions on the source(s) of the elements in these deposits, on the nature of the solutions that transported these elements, and on the geochemistry of the precipitation mechanism(s). These data might also be helpful in identifying dispersion haloes of various elements around the deposits and in characterizing the chemistry of the alteration associated with these deposits. Similar studies are being conducted in other uranium districts. Both the similarities and differences of the chemical characteristics of the districts are likely to add to our understanding of the genesis of sedimentary uranium deposits.

The Ambrosia Lake area is a major uranium producing district in the southern part of the San Juan basin (figure 1). In the district, the Upper Jurassic Morrison Formation is known to contain two types of uranium deposits (Granger, 1968). One is primary ore, which is also referred to as trend or prefault ore. The other type of deposit is termed redistributed, secondary, postfault, or stack ore. Unstructured organic matter (usually referred to as humate or humic material) is intimately associated and coextensive with the primary ore and is widely believed to be critical to the genesis of these deposits. The secondary ore is thought to have been derived from the primary ore and probably is genetically similar to roll-type deposits in many ways.

Nature of the data

Rather than collecting new data, we used data that already existed for the study. Most of the data for the approximately 700 samples used in this study were taken from Granger (1966). The other major source of data was the computerized chemical data bank of the U.S. Geological Survey, referred to as RASS (Rock Analysis Storage System). All of the analyses were made by personnel of the analytical laboratories of the Geological Survey. Interested readers may obtain a copy of the original data for the cost of retrieval from the computer files.

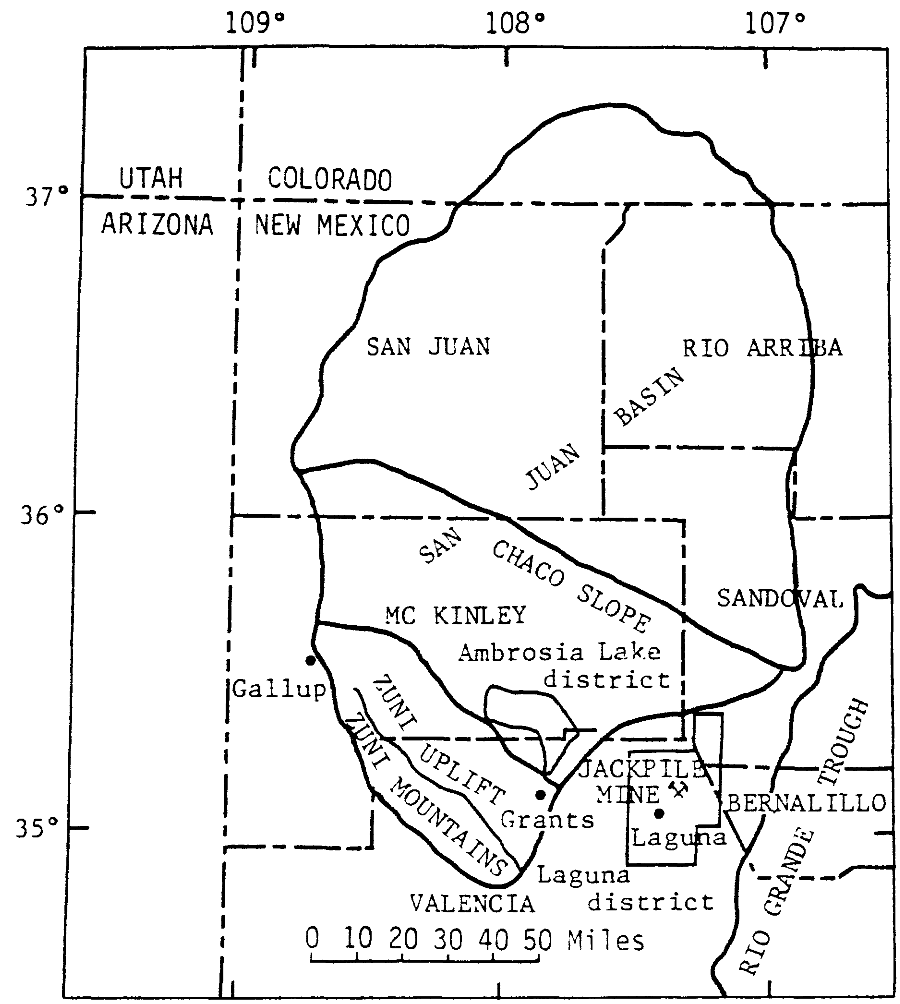
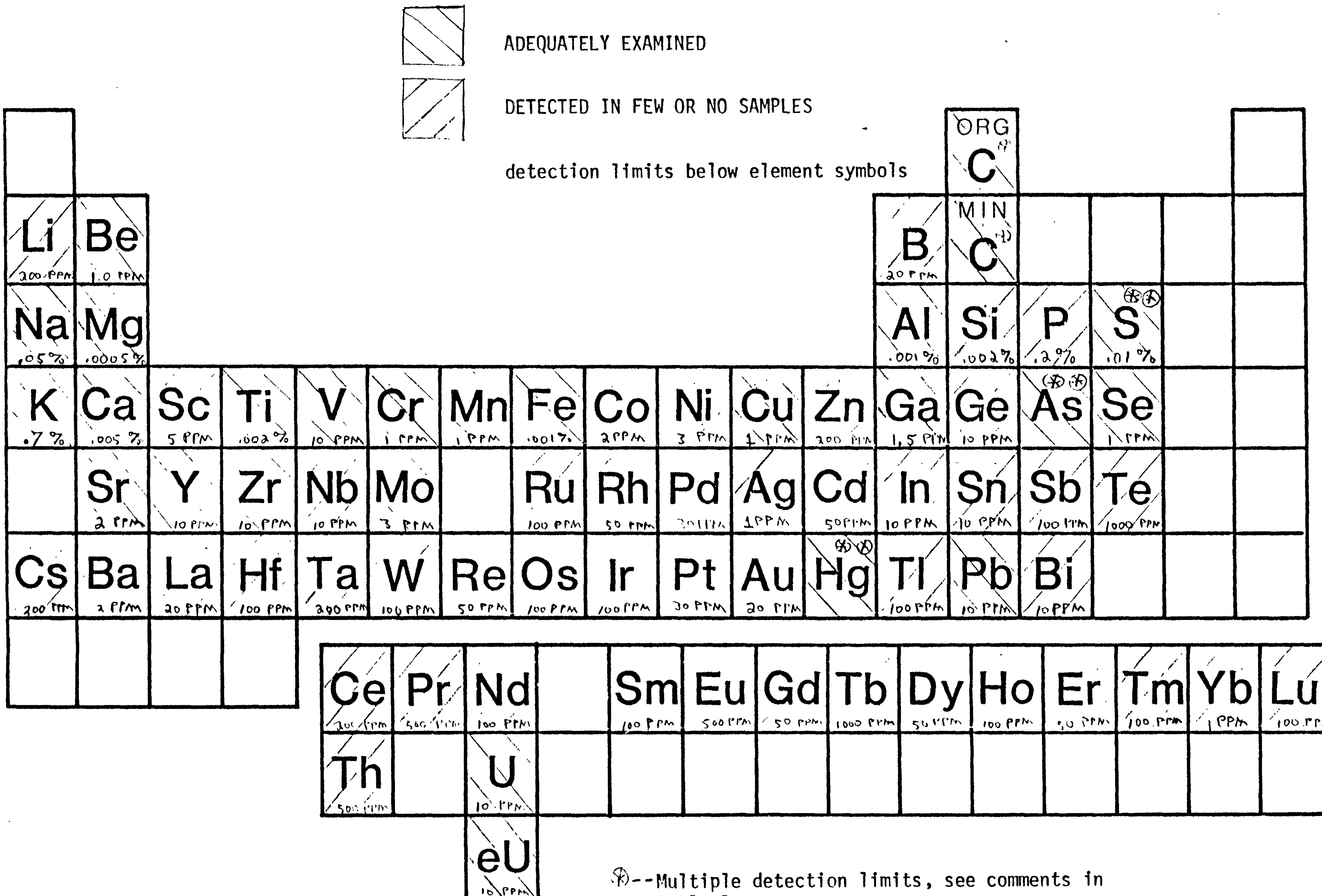


Figure 1.-Location of the Ambrosia Lake district, northwestern New Mexico. From Santos (1970).

The elements considered in this study are shown on figure 2. A variety of analytical techniques, including spectroscopy, fluorimetry, radiometry, gasometry, and wet chemical methods, were used to obtain the chemical data. Not all of the elements were determined for every sample. Quantitative chemical data for uranium were produced by wet chemical methods, fluorimetry, and neutron activation analysis. Other elements for which quantitative results were available are organic carbon, carbonate carbon, total carbon, selenium, arsenic, sulfur, equivalent uranium, and total iron as Fe_2O_3. Most of the remaining data are from 3-step or 6-step semiquantitative emission spectrographic analysis. These data are presented as midpoints (.15, .3, and .7 for 3-step and .15, .2, .3, .5, .7, and 1.0 for 6-step) of geometric brackets whose boundaries are 0.12, 0.26, 0.56, and 1.2 for 3-step and 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, and 1.2 for 6-step. Thus there are either three or six brackets for every order of magnitude; the boundaries and midpoints for higher or lower values are the same as these except for the position of the decimal. In 3-step data, about 60% of the results will be in the correct bracket. The precision of a reported value in 6-step data is approximately plus-or-minus one bracket at the 68-percent confidence level and plus-or-minus two brackets at the 95-percent confidence level.

Large sets of spectrographic analytical data, such as this one, inevitably include results from samples that contain too little of certain elements to permit accurate determinations of their abundances. Data for such samples in these results were presented in two categories. One category was for samples with such a low concentration of some element that no evidence for the presence of the element was found (N for "not detected" in the data); the

FIGURE 2. ELEMENTS STUDIED



⊛--Multiple detection limits, see comments in Table 1.

⊘⊕--Limited data

other category was for samples in which the element was present but at too low a concentration to permit an accurate determination (L for "less than the limit of determination" in the data).

In order to avoid adding zeros to the data set, a value of one-half of the determination limit was arbitrarily substituted for samples in the first category (N) and three-quarters of the detection limit was substituted for samples in the second category (L). The only exception to this method for estimating the concentration of an element was for organic carbon. For samples in which the concentration of organic carbon was below the limit of analytical sensitivity, its concentration was estimated on the basis of the color of the sample.

Data handling and results

On the basis of field relationships (described by Granger, 1966) and uranium contents, the 696 analyses of sandstone samples listed in Granger (1966) were divided into the following four groups: (1) 413 analyses of primary ore (P), including adjacent sandstones with more than 100 ppm uranium; (2) 101 analyses of secondary ore (S), including adjacent sandstones with more than 100 ppm uranium; (3) 63 analyses of barren oxidized rock samples collected near ore (BO); and (4) 119 analyses of barren reduced rock samples collected near ore (BR). Mudstones were separated into a mineralized group (MM with 15 samples) and an unmineralized group (MU with 17 samples). For classification purposes, samples with more than 100 ppm uranium were considered mineralized; those with less than 100 ppm uranium were considered barren. All of these samples came from mines. In order to determine the chemical changes associated with the ore-forming processes, it was necessary to compare these groups to a group of samples not in close proximity to mineralized rocks. An appropriate group of analyses for such a comparison was obtained by searching the USGS computer files (RASS) for analyses of Morrison sandstones from the Ambrosia Lake area with less than 100 ppm uranium. The search produced a group (SSJB) of 100 analyses, many of which were for samples from outcrops remote from ore. This group contained 8 or fewer analyses each for, organic, carbonate, and total carbon, selenium, iron as Fe_2O_3, and sulfur--too few for valid statistical comparisons. A more useful data set (SJB of 321 samples) for these elements was obtained by searching the computer files for analyses of unmineralized Morrison samples from the entire San Juan basin.

Unfortunately many of the samples in both groups from nonmineralized areas were from outcrops that were subject to weathering. Consequently, an apparent enrichment of some element in the ore samples relative to the unmineralized groups (SJB or SSJB) could be due to leaching of the outcrops instead of enrichment related to ore forming processes. In order to avoid misinterpretations caused by this leaching, we double-checked all conclusions based on comparisons of ore samples to barren samples removed from ore in this manner: the mean concentrations of each element in subsets of high grade ore (P with U greater than 1000 ppm and S with U greater than 1000 ppm) and in a subset of ore defined by field relationships as part of the dark-grey tabular ore body were compared to the mean concentrations in subsets of barren rock adjacent to ore with uranium contents of less than 50 ppm (BR with U less than 50 ppm, and BO with U less than 50 ppm). Results for specific elements are included in the comments on Table 1. For some elements, it was also informative to compare the means of our groups to the means for sandstones compiled by Turekian and Wedepohl (1961).

Summary statistics shown in Table 1 were calculated by computer using the USGS STATPAC programs. The minimum and maximum values and the geometric deviations provide information on the spread of the data, and the number of N and L values reveals how many values had to be estimated in order to arrive at the geometric means for each element in each group. According to Fisher (1950), the logarithms of geochemical data approach a normal distribution more closely than do the untransformed values in ppm or percent; consequently, geometric means (which are based on the logarithms of the data) are a better measure of the central tendency of the data than are arithmetic means. These geometric means were used to identify differences in the concentrations of the elements among groups.

Tests for statistical significance of differences between the above mentioned sample groups for a given element were made with a programmable hand-held calculator utilizing a "t" test described by Natrella (1963, p. 3-36). Summary statistics used in the test are the means and variances of the logarithmic values and the number of samples in each group. A standard table giving percentiles of the t distribution was used to determine whether the observed differences were significant at the 95 percent confidence level. It is this significance that is referred to in the comments in Table 1 and in the observations. The samples were not collected in anticipation of statistical treatment; consequently, they were not collected in a truely random manner and are not ideally suited for statistical tests.

The number of samples analyzed for mercury was too small for a valid statistical comparison. If, however, the mercury data are plotted across the deposits (figure 3), a concentration of mercury in the primary ores is suggested.

Observations

Organic carbon, beryllium, uranium, vanadium, molybdenum, selenium, lead, manganese, magnesium, iron, barium, yttrium, copper, and possibly, sulfur, arsenic, and mercury were enriched in the primary ore deposits and adjacent sandstones containing more than 100 ppm uranium (figure 4). Calcium, strontium, sodium, and inorganic carbon have significantly greater mean concentrations in the primary ore than in the barren rocks distant from ore but this difference may be the result of leaching of these elements from outcrop samples in the unmineralized groups. The high concentrations of strontium and to a lesser extent sodium in high-grade ore samples and in ore defined by field relationships suggest that the distribution of strontium and probably sodium is at least in part due to addition of these elements to the primary ore. Similar reasoning indicates that potassium and aluminum were also added to the primary ore. Calcium, strontium, and inorganic carbon have a greater abundance in the secondary ore (S) than in the primary ore (P) or in the barren reduced rock near ore (BR). This difference indicates that these elements were added to the secondary ore. Other elements that were added to the secondary ore deposits include aluminum, uranium, vanadium, selenium, manganese, iron, barium, copper, and possibly sodium (figure 5). The apparent lack of molybdenum in the secondary deposits might be a reflection of a zonal segregation of molybdenum down the hydrologic gradient from the secondary ore

Figure 3. Mercury concentrations compared to uranium concentrations across 4 ore deposits in the Ambrosia Lake district.

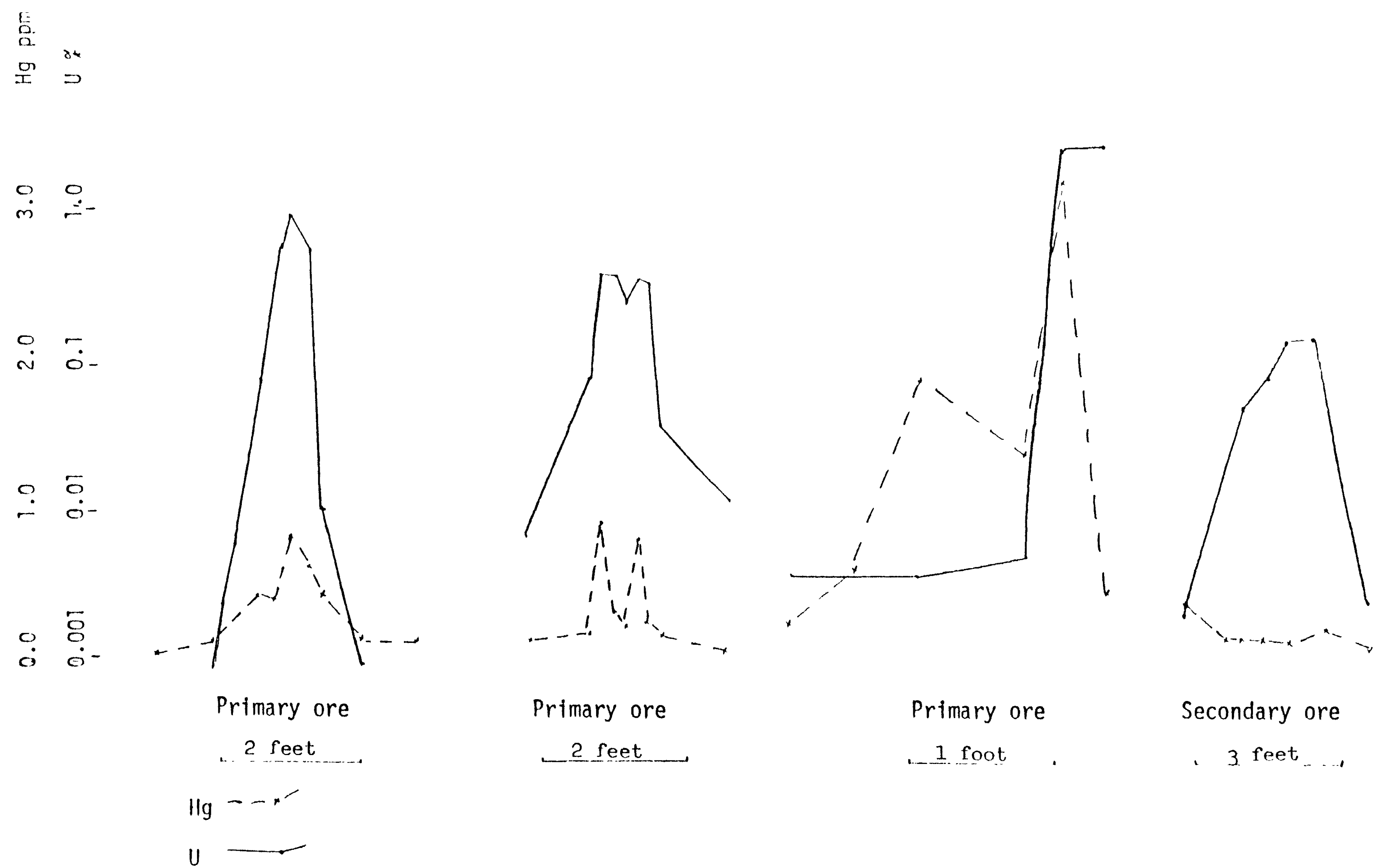
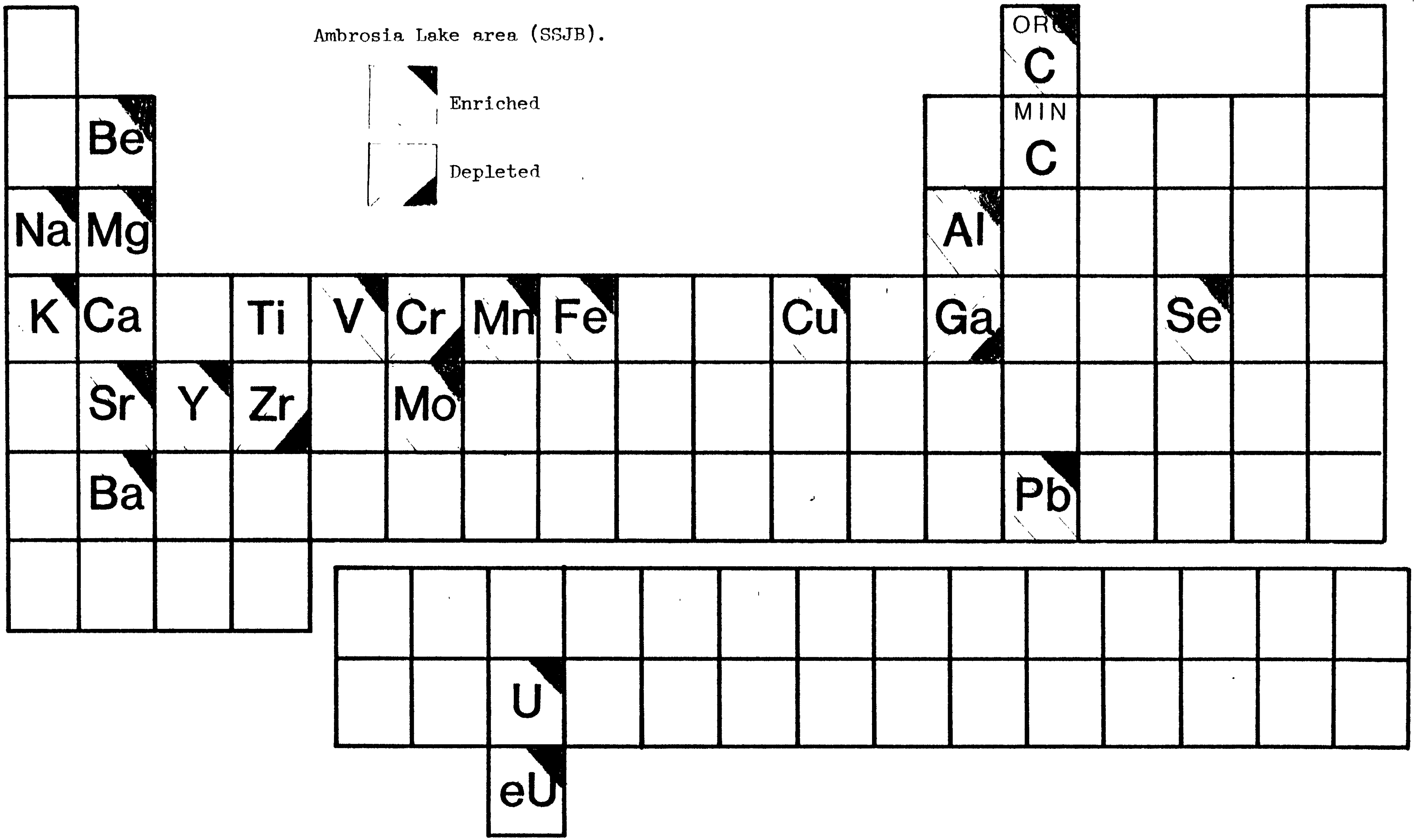
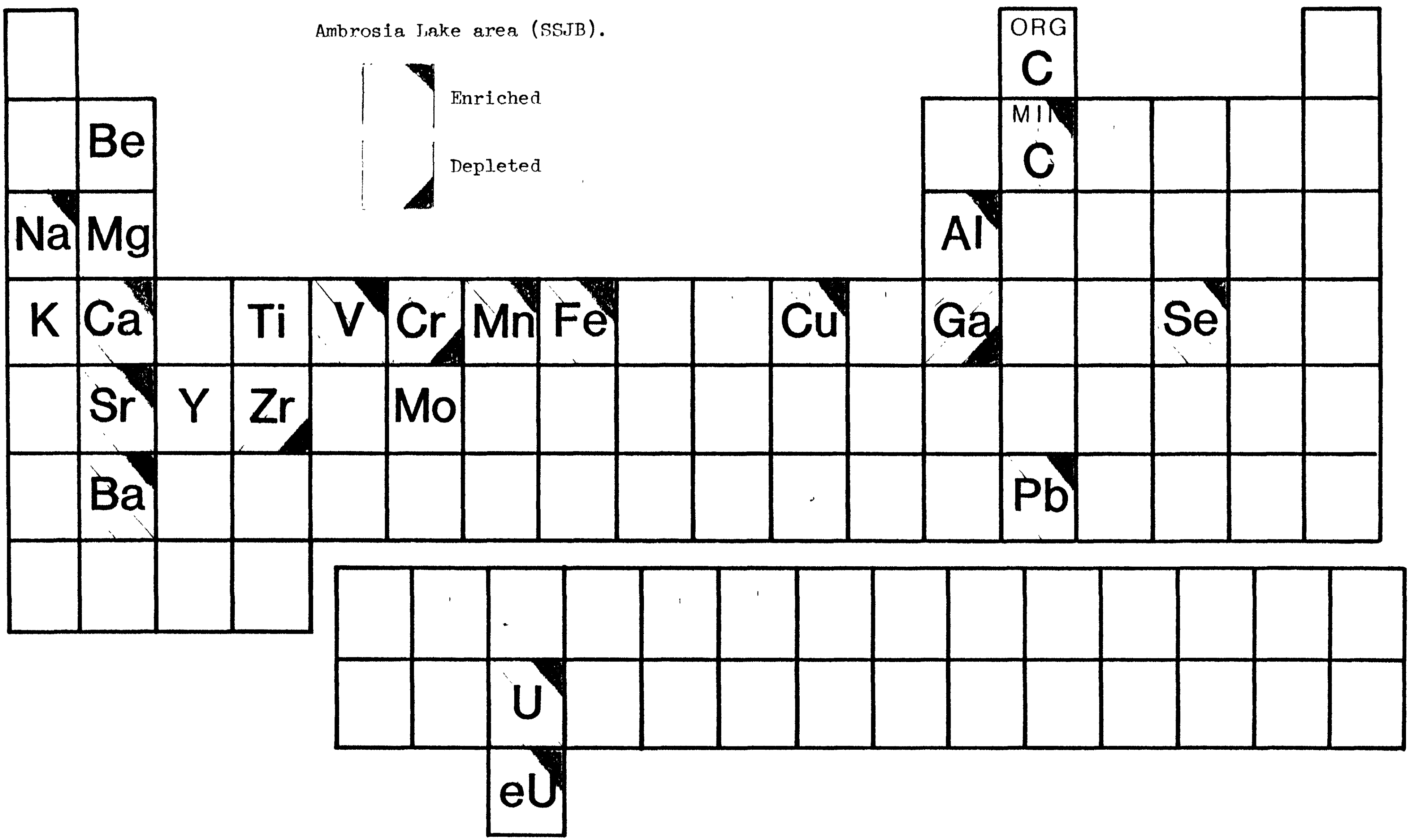


Figure 4. Elements adequately examined in the primary ore (P) and those enriched or depleted in the primary ore relative to barren rocks distant from ore in the Ambrosia Lake area (SSJB).



Limited data suggest that mercury, sulfur, and arsenic are also enriched in the primary ore.

Figure 5. Elements adequately examined in the secondary ore (S) and those enriched or depleted in the secondary ore relative to barren rocks distant from ore in the Ambrosia Lake area (SSJB).



deposits. Although this secondary segregation has either not been observed or not recognized around these specific deposits, it is known to occur in other roll-type deposits (Harshman, 1974). The results of our statistical tests indicate that calcium, barium, strontium, vanadium, carbonate carbon, and aluminum are significantly more concentrated in the secondary ore deposits than in the primary ore deposits. The data also indicate a statistically significant depletion of chromium, zirconium, and gallium in sandstones in and around the ore deposits compared to unmineralized rock distant from the ore.

The concentrations of organic carbon, uranium, beryllium, vanadium, molybdenum, selenium, lead, and manganese are greater in the mineralized mudstones (MM) than in the nonmineralized mudstones (MU). A depletion of chromium and zirconium in the mineralized mudstones (MM) relative to the unmineralized mudstones (MU) is suggested by the data but is not statistically significant. An apparent enrichment of gallium in the mineralized mudstones relative to unmineralized mudstones also was not statistically valid.

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TABLE 1.--Statistical summary of the analytical data

P, primary ore; S, secondary ore; BR, barren reduced rock collected near ore; BO, barren oxidized rock collected near ore; SSJB, nonmineralized samples from Ambrosia Lake area (southern San Juan basin); SJB, nonmineralized samples from entire San Juan basin; MU, unmineralized mudstones; MM, mineralized mudstones. N and L refer, respectively, to samples in which a given element was not detected or was below the limit of determination. Uranium content is expressed in parts per million; units for other elements are as indicated on the individual pages.

Al %
Determination limit .001%

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	--	10	13
Minimum value	.30	1.5	.30	1.5	1.0	--	3.0	1.5
Maximum value	15	7.0	7.0	7.0	15	--	15	15
Geometric mean	3.55	4.20	3.24	2.98	3.60	--	6.38	5.11
Geometric deviation	1.86	1.54	2.07	1.63	1.93	--	1.59	2.12
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

These data indicate greater aluminum content in samples from the secondary ore than in the other groups of sandstones. The reason for this difference is not known. In the subset of primary ore defined by field relationships, the geometric mean of the aluminum concentration is 4.54%. This indicates that aluminum was also added to the primary ore.

As ppm
Determination Limit 1 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	18	--	10	--	--	--	--	--
Minimum value	8.	--	2.	--	--	--	--	--
Maximum value	330.	--	370.	--	--	--	--	--
Geometric mean	38.	--	25.	--	--	--	--	--
Geometric deviation	2.81	--	7.69	--	--	--	--	--
# of N's	0	--	0	--	--	--	--	--
# of L's	0	--	0	--	--	--	--	--

Comments

Only a few samples from the primary ore and a few samples from reduced rock near the ore were analyzed for arsenic. Our limited data suggest that compared to the average arsenic content of sandstones of 1 ppm (Turekian and Wedepohl, 1961) the primary ore and reduced rock near the ore are enriched in arsenic.

Ba ppm
Determination Limit 2 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	329	99	82	62	100	--	10	13
Minimum value	300	300	300	300	100	--	150	150
Maximum value	15,000	15,000	7,000	700	500	--	1,500	700
Geometric mean	669	826	649	578	560	--	386	394
Geometric deviation	1.51	1.83	1.50	1.43	2.01	--	2.11	1.66
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

The data indicate that barium is enriched in the secondary ore relative to the primary ore and also that the secondary ore, primary ore, and barren reduced rock adjacent to the ore are enriched in barium compared to unmineralized rock distant from ore and barren oxidized rock near ore. It is possible that oxidizing conditions removed barium from groups SSJB and BO; however, the concentration of barium in the subset of the barren reduced rock containing uranium in amounts less than 50 ppm is 556 ppm, which is similar to the means of SSJB and BO and is significantly less than the mean barium concentration of the primary ore. Rocks in the subset were not oxidized or leached; therefore the fact that barium concentration in the primary ore is higher than in the subset suggests that barium was added to the primary ore. The high concentration of barium in the high-grade ore (702 ppm in a subset of P with uranium greater than 1000 ppm) also indicates that barium was added to the primary ore. Barium is not enriched in the mineralized mudstones compared to the unmineralized mudstones. Compared to Turekian and Wedepohl's (1961) averages, the sandstones are high in barium and the mudstones are low.

Be ppm
Determination Limit 1 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	81	62	100	--	10	13
Minimum value	.5	.5	.5	.5	.5	--	.5	1.5
Maximum value	15	3.0	30	3.0	3.0	--	3.0	7.0
Geometric Mean	1.08	.54	.63	.53	.65	--	1.64	3.78
Geometric deviation	2.30	1.35	1.86	1.35	1.66	--	2.33	1.91
# of N's	161	95	60	60	77	--	3	0
# of L's	1	0	1	0	0	--	0	0

Comments

In many of our samples, the concentration of beryllium was too low to be detected (N); therefore the means are only approximate. The data do, however, suggest that beryllium is enriched in the primary ore relative to the sandstones and in the mineralized mudstones compared to the unmineralized mudstones. The enrichment in primary ore could in part be due to the higher clay content of primary ore; however, the enrichment in the mineralized mudstones suggests that beryllium was added in the mineralizing process.

Total C %
Determination Limit - see comments

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	334	41	46	21	--	73	12	12
Minimum value	.03	.02	.03	.03	--	.005	.02	.03
Maximum value	7.5	2.7	3.0	1.6	--	3.9	.87	21.6
Geometric mean	.69	.36	.32	.20	--	.14	.090	.27
Geometric deviation	3.05	3.00	3.34	3.68	--	5.29	2.80	7.54
# of N's	0	0	0	0	--	0	0	0
# of L's	13	1	11	2	--	2	0	1

Comments

The groups of samples analyzed for total carbon, carbonate carbon, and organic carbon do not contain all of the same samples. Consequently the mean of the total carbon does not equal the mean of carbonate carbon plus the mean of organic carbon. An additional problem is that the determination limits for carbon species changed during the period in which the samples were analyzed. Some of the samples included in this study were analyzed with a determination limit for carbon species 0.3%; later the limit had decreased to .01%. Thus the means in the table are only approximations. Despite these shortcomings, the means are believed to represent a valid pattern for the distribution of carbon species among the groups of samples.

Organic C %
Detection Limit - see comments for Total carbon

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	303	37	34	15	--	87	5	7
Minimum value	.01	.01	.01	.01	--	.005	.01	.02
Maximum value	7.5	.40	.80	.50	--	1.99	.1	21.6
Geometric mean	.32	.048	.063	.068	--	.065	.048	.33
Geometric deviation	3.79	2.91	3.30	3.00	--	3.40	2.56	8.69
# of N's	9	0	0	5	--	0	0	0
# of L's	46	22	27	6	--	8	1	2

Comments

It is well known that organic carbon is enriched in the primary ore but not in the secondary ore; our data confirm this finding. The data also show that organic carbon is enriched in the mineralized mudstones.

Carbonate C %

Detection Limit - see comments in Total Carbon

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	352	64	76	40	--	88	13	13
Minimum value	.005	.02	.01	.005	--	.005	.03	.005
Maximum value	3.47	7.73	3.52	4.80	--	3.92	1.26	10.52
Geometric mean	.17	.40	.21	.11	--	.035	.086	.060
Geometric deviation	5.48	2.92	4.86	6.28	--	11.04	3.47	10.73
# of N's	4	0	0	1	--	0	0	1
# of L's	45	0	4	2	--	49	0	1

Comments

Carbonate carbon is concentrated in the secondary ore deposits relative to all of the other groups. The low mean concentration of carbonate carbon in SJB is probably due, at least in part, to leaching of calcite from outcrops. The strong positive correlation of carbonate carbon with calcium suggests that most of the mineral carbon in and around the deposits is in the form of calcite. The mineralizing process did not add carbonate to the mineralized mudstones.

Ca %

Determination Limit .005%

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	--	10	13
Minimum value	.07	.15	.15	.07	.007	--	.3	.3
Maximum value	15	15	15	15	15	--	3.0	15
Geometric mean	1.19	1.93	1.01	.92	.40	--	.79	.68
Geometric deviation	2.96	2.35	3.08	2.93	5.28	--	2.19	2.89
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

Calcium is enriched in the secondary ore relative to the primary ore and to the other sandstone groups. The low mean content of calcium in the SSJB group is probably related to leaching of calcite from outcrops. The calcium content of the primary ore is not significantly different from that of the barren reduced rock near ore, and the calcium content of the high-grade primary ore is similar to that of the entire primary ore group (P). Thus calcium probably was not added to the primary ore. The data also indicate that calcium was not added to the mineralized mudstones.

Cr ppm
Determination Limit 1 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	81	62	100	--	10	13
Minimum value	.5	1.5	1.5	1.5	1.0	--	7.0	3.0
Maximum value	300	150	70	30	100	--	150	30
Geometric mean	5.21	4.95	4.91	5.08	7.77	--	21.5	14.6
Geometric deviation	1.99	1.91	2.00	1.74	2.79	--	2.26	1.99
# of N's	1	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

Chromium is depleted in and around the ore deposits. The data suggest that chromium is also depleted in the mineralized mudstones relative to the unmineralized mudstones; however, this depletion is not statistically significant.

Cu ppm
Determination Limit 1 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	81	62	100	--	10	13
Minimum value	.5	.5	1.5	3.0	.75	--	15	7.0
Maximum value	300	150	300	300	30	--	30	70
Geometric mean	8.46	7.60	6.39	7.18	4.10	--	19.8	20.8
Geometric deviation	2.34	2.44	2.48	2.48	2.35	--	1.43	1.78
# of N's	1	1	0	0	0	--	0	0
# of L's	0	0	0	0	7	--	0	0

Comments

Statistical treatment of the data indicate a slight enrichment of copper in and around the deposits compared to rocks removed from ore (SSJB). If oxidation and leaching of outcrop samples included in SSJB caused the mean copper concentration of SSJB to be low relative to the other sandstone groups, then the barren oxidized rock near ore (BO) would also be expected to be low in copper, but it is not. Also, the mean concentration of copper in a subset of barren reduced rock near ore containing less than 50 ppm uranium is 4.69. This number is similar to the mean copper concentration of SSJB and significantly less than the means of the ore samples. Thus copper does appear to be enriched in and around the ores.

Fe %
Determination Limit .001%

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	319	10	13
Minimum value	.15	.15	.15	.15	.10	.038	1.5	.7
Maximum value	7.0	3.0	7.0	3.0	7.0	8.10	7.0	7.0
Geometric mean	.96	.82	.69	.66	.77	.66	2.65	1.87
Geometric deviation	2.08	1.95	2.17	1.99	2.50	2.66	1.60	1.75
# of N's	0	0	0	0	0	0	0	0
# of L's	0	0	0	0	0	4	0	0

Comments

Iron is enriched in the primary ore compared to the other sandstone groups, and iron is enriched in the secondary ore compared to the barren sandstones near the ore; however the difference between the iron content of the secondary ore and the barren rock removed from ore (SSJB) is not statistically significant. A comparison of the mean of S with the mean of SJB (which includes samples from a larger geographic area then SSJB) indicates that iron is significantly enriched in the secondary ore. The mean iron content of high-grade secondary ore (uranium greater than 1000 ppm) is .97, which is significantly larger than the mean of SSJB.

Fe_2O_3 (Fe) %

Determination limit--.1%

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	37	--	11	--	--	60	--	--
Minimum value	1.09	--	1.23	--	--	.09	--	--
Maximum value	4.60	--	10.70	--	--	8.02	--	--
Geometric mean	2.80	--	2.19	--	--	.62	--	--
# of N's	0	--	0	--	--	0	--	--
# of L's	0	--	0	--	--	0	--	--

Comments

Inspection of the data suggests that the samples in P and BR analyzed for Fe as Fe_2O_3 were selected on the basis of a high eU. They are therefore a biased subset and do not give as good a representation of the Fe content as do those samples for Fe%. They do, however, suggest an enrichment in iron in the primary ore and barren reduced rock near ore compared to SJB.

Ga ppm
Determination Limit 1.5 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	325	98	81	62	100	--	10	13
Minimum value	.75	.75	.75	.75	3.0	--	.75	.75
Maximum value	30	20	15	15	30	--	30	70
Geometric mean	4.42	3.76	3.83	3.84	9.9	--	9.46	18.49
Geometric deviation	2.20	2.55	2.34	2.13	1.68	--	3.92	4.66
# of N's	4	10	3	1	2	--	2	1
# of L's	79	41	33	17	5	--	0	0

Comments

According to these data, gallium is depleted in sandstones in and around the ore deposits compared to sandstones distant from the ore (SSJB). The data suggest an enrichment of gallium in mineralized mudstones relative to unmineralized mudstones but this apparent enrichment is not statistically significant.

K %

Determination Limit 0.7%

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	324	99	82	62	100	--	10	13
Minimum value	.35	.35	1.5	.70	.35	--	1.5	.35
Maximum value	7.0	5.0	3.0	7.0	5.0	--	3.0	7.0
Geometric mean	2.41	2.44	2.33	2.26	2.41	--	2.80	2.71
Geometric deviation	1.42	1.53	1.40	1.48	2.59	--	1.25	1.93
# of N's	1	1	0	0	5	--	0	1
# of L's	0	0	0	0	0	--	0	0

Comments

No statistically significant differences in the concentration of potassium among the above groups were identified. The concentration of potassium, however, was significantly higher in the subset of primary ore defined as part of the dark-grey ore layer by field relationships. This indicates an enrichment of potassium in the primary ore.

Mg %
Determination Limit .0005%

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	320	10	13
Minimum value	.07	.07	.07	.07	.03	.02	.7	.7
Maximum value	1.5	.70	1.5	.70	1.5	2.0	3.0	3.0
Geometric mean	.21	.16	.17	.15	.22	.17	1.4	1.05
Geometric deviation	1.89	1.56	1.84	1.75	2.52	2.62	1.52	1.63
# of N's	0	0	0	0	0	0	0	0
# of L's	0	0	0	0	0	10	0	0

Comments

From the presence of chlorite and clay minerals in the primary ore, one would anticipate an enrichment in magnesium in the primary ore. Such an enrichment in the primary ore relative to secondary ore, barren rock near ore, and to barren samples from the entire San Juan Basin (SJB) was borne out by statistical tests. The data, however, suggest that the magnesium concentration of barren samples distant from ore in the Ambrosia Lake area (SSJB) is even higher than that of the primary ore.

Mn ppm
Determination Limit 1 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this elements	326	99	82	62	100	--	10	13
Minimum value	30	50	30	70	.05	--	70	150
Maximum value	3,000	1,500	3,000	3,000	5,000	--	300	1,500
Geometric mean	264	226	170	163	174	--	109	356
Geometric deviation	2.41	2.00	2.41	2.00	4.92	--	1.85	2.15
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	2	--	0	0

Comments

The data indicate that manganese has been added to the primary ore, the secondary ore, and to the mineralized mudstones.

Mo ppm
Determination Limit 3 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	81	62	100	--	10	13
Minimum value	.3	2.5	2.5	2.5	3.0	--	2.5	2.5
Maximum value	15,000	700	7,000	3,000	15	--	30	7,000
Geometric mean	21.81	3.63	36.02	3.10	5.10	--	7.23	570
Geometric deviation	9.84	2.51	13.60	2.80	1.23	--	2.81	8.10
# of N's	123	83	23	58	86	--	4	1
# of L's	1	0	2	0	5	--	0	0

Comments

Although molybdenum was not detected in many of the samples, the determination limit is so low compared to the maximum concentrations in the samples that the 'less than' values are thought to have had little influence on the means reported in the table. Consequently the means are considered reliable, and they indicate that molybdenum is strongly concentrated in the primary ore, in the reduced rock near ore, and in the mineralized mudstones.

Na %
Determination Limit .05%

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	--	10	13
Minimum value	.15	.15	.70	.30	.05	--	.3	.025
Maximum value	7.0	3.0	3.0	1.5	1.5	--	1.5	1.5
Geometric mean	1.15	1.19	1.22	.99	.63	--	.64	.76
Geometric deviation	1.57	1.68	1.50	1.54	2.11	--	1.59	3.30
# of N's	0	0	0	0	0	--	0	1
# of L's	0	0	0	0	0	--	0	0

Comments

These data indicate that sodium is strongly concentrated in and around the ore deposits relative to unmineralized rock from ore (SSJB) but that sodium was not added to the mineralized mudstones. This enrichment in sodium might be related to the formation of albite overgrowths described by Adams and others (1978). It could also be a reflection of leaching of sodium from outcrops in SSJB and from the barren oxidized rock near ore.

Pb ppm
Determination Limit 10 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	323	99	82	62	100	--	10	13
Minimum value	5.0	5.0	5.0	5.0	5.0	--	5.0	15
Maximum value	1,500	70	150	70	70	--	70	700
Geometric mean	45.34	12.02	12.96	16.31	13.40	--	12.44	77.18
Geometric deviation	2.62	1.85	2.03	2.36	1.63	--	2.79	2.72
# of N's	8	14	18	14	5	--	4	0
# of L's	5	27	5	2	6	--	0	0

Comments

Lead is greatly enriched in the primary ore deposits and in the mineralized mudstones, but it is not enriched in the secondary ore deposits. Most of the enriched Pb is probably radiogenic lead derived from uranium in the primary ore and mineralized mudstone. (Although little confidence can be attached to the results, if 10 ppm Pb is allowed for common lead and the remainder treated as radiogenic Pb, the Pb/U ratio of the geometric means suggests an approximate age of 120 m.y. for primary ore and 10 m.y. for secondary ore.).

S %
Determination Limit .01%

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	14	--	3	--	--	37	--	--
Minimum value	.11	--	.4	--	--	.0075	--	--
Maximum value	3.05	--	.63	--	--	.89	--	--
Geometric mean	.55	--	.49	--	--	.0088	--	--
Geometric deviation	3.17	--	1.26	--	--	2.22	--	--
# of N's	0	--	0	--	--	0	--	--
# of L's	0	--	0	--	--	35	--	--

Comments

The number of samples are too few to be conclusive, but the data suggest enrichment in sulfur in the primary ore and in the adjacent reduced rocks. The results include both sulfide and sulfate sulfur, but the sulfate S was minor in the few samples tested.

Se ppm
Determination Limit 1 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	374	94	105	62	--	29	15	15
Minimum value	.38	.50	.38	.38	--	.50	1.0	3.0
Maximum value	11,000	2,100	1,900	1,500	--	395	38	3,500
Geometric mean	59.65	15.42	41.36	22.20	--	7.65	6.70	79.88
Geometric deviation	4.86	7.32	7.83	7.11	--	7.07	2.77	10.06
# of N's	0	0	0	0	--	0	0	0
# of L's	4	0	4	2	--	1	0	0

Comments

The data indicate increased concentrations of selenium in and around the ore deposits compared to unmineralized rock distant from ore and in the mineralized mudstones compared to unmineralized mudstones. The lack of selenium in the secondary ore relative to the primary ore probably results because selenium is segregated into a narrow band in the secondary ore instead of being distributed throughout the ore.

Sr ppm
Determination Limit 2 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	--	10	13
Minimum value	70	100	70	30	5.0	--	150	70
Maximum value	700	3,000	700	700	500	--	700	300
Geometric mean	177	196	164	146	94	--	361	229
Geometric deviation	1.68	1.55	1.61	1.65	2.33	--	1.66	1.59
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

Like calcium, strontium is concentrated in and around the ore deposits compared to unmineralized rock distant from ore (SSJB) and is most concentrated in the secondary ore. The similarity of the calcium distribution to the strontium distribution and the high correlation of strontium with both calcium and carbonate carbon are evidence that the distribution of strontium is influenced by the substitution of strontium for calcium in calcite. Calcite probably was leached from outcrop samples in SSJB. Therefore the high concentration of strontium in P compared to SSJB does not necessarily indicate that strontium was added to the primary ore. The high concentration of strontium in high-grade primary ore samples, however suggests that stronium was added to the primary ore. There is also a significant difference between the strontium concentrations of S and BR, which indicates that strontium was added to the secondary ore.

Ti %

Determination Limit .0002%

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for this element	326	99	82	62	100	--	10	13
Minimum value	.02	.02	.03	.03	.02	--	.15	.07
Maximum value	1.5	.7	.3	.7	1.0	--	.30	.7
Geometric mean	.098	.089	.092	.108	.099	--	.23	.24
Geometric deviation	1.95	3.70	2.03	1.85	2.15	--	1.43	1.75
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

These data indicate that there is no statistically significant variation in the concentration of titanium among the various groups of sandstone samples, but mudstones appear to be much richer in Ti than sandstones.

U ppm
Determination Limit 10 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for time element	407	101	118	63	27	--	17	15
Minimum value	100	100	1.0	6.0	1.1	--	4.0	*60
Maximum value	152,000	48,600	100	90	90	--	100	10,670
Geometric mean	1,817	1,253	34.92	23.70	17.98	--	17.09	606.6
Geometric deviation	4.87	3.33	2.33	2.04	3.17	--	2.61	4.47
# of N's	0	0	2	2	0	--	0	0
# of L's	1	0	1	0	3	--	2	0

Comments

*One sample that contained only 60 ppm uranium was included among the mineralized mudstones on the basis of a very high vanadium content.

eU ppm

Determination Limit 10 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for time element	406	101	118	63	88	--	17	15
Minimum value	90	70	10	7.5	7.5	--	10	60
Maximum value	70,000	37,100	1,900	1,100	340	--	130	48,700
Geometric mean	1,828	1,103	111	71.55	19.48	--	47.33	1,414
Geometric deviation	3.55	2.82	2.90	2.59	2.17	--	2.21	5.78
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	2	5	--	0	0

Comments

Mudstone tends to be much more radioactive than its U content would suggest.

V ppm
Determination Limit 10 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for time element	326	99	82	62	100	--	10	13
Minimum value	30	70	30	30	7.0	--	30	70
Maximum value	15,000	30,000	3,000	3,000	1,500	--	300	7,000
Geometric mean	634	1,517	243	249	51.86	--	98.68	1,166
Geometric deviation	2.89	3.56	2.71	2.46	2.47	--	2.44	3.92
# of N's	0	0	0	0	0	--	0	0
# of L's	0	0	0	0	0	--	0	0

Comments

Vanadium is enriched in and around the ore deposits and is particularly concentrated in the secondary ore deposits.

Y ppm
Determination Limit 10 ppm

	Sandstone						Mudstones	
Group	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for time element	326	99	82	62	100	--	10	13
Minimum value	5.0	5.0	5.0	5.0	5.0	--	15	5.0
Maximum value	300	300	30	70	300	--	70	70
Geometric mean	16.26	11.47	6.99	9.00	13.00	--	33.16	14.45
Geometric deviation	2.65	1.98	1.62	1.90	1.97	--	1.57	2.58
# of N's	76	21	48	26	10	--	0	5
# of L's	14	18	8	10	12	--	0	0

Comments

Yttrium appears to be depleted in the rocks adjacent to the ore deposits. The mean concentration of yttrium in the high-grade primary ore (uranium greater than 1000 ppm) is 20.48 ppm. This suggests that yttrium was added to the primary ore.

Zr ppm
Determination Limit 10 ppm

Group	Sandstone						Mudstones	
	P U >100	S U >100	BR U <100	BO U <100	SSJB U <100	SJB U <100	MU U <100	MM U >100
# of analyses for time element	326	99	82	62	100	--	10	13
Minimum value	15	5.0	15	30	15	--	150	5.0
Maximum value	1,500	700	700	700	700	--	300	300
Geometric mean	93.22	83.14	83.66	114	112.3	--	160.8	107
Geometric deviation	2.31	2.31	2.30	2.45	2.41	--	1.25	2.97
# of N's	0	2	0	0	0	--	0	1
# of L's	0	0	0	0	1	--	0	0

Comments

Zirconium is depleted in the ore deposits and in reduced rock adjacent to the ore relative to unmineralized rock distant from ore. Such a depletion might be related to the breakdown of heavy minerals. The data also suggest a depletion of zirconium in the mineralized mudstones relative to the unmineralized mudstones; however this apparent depletion was not statistically valid. With small data sets, such as that for the mudstones, a large difference in geometric means is required for a statistically significant difference.