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Comparison of abundances of chemical elements in mineralized and unmineralized sandstone of the Brushy Basin Member of the Morrison Formation, Smith Lake District, Grants uranium region, New Mexico

By

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ABSTRACT

Statistical treatment of analytical data from the Mariano Lake and Ruby uranium deposits in the Smith Lake district, New Mexico, indicates that organic carbon, arsenic, barium, calcium, cobalt, copper, gallium, iron, lead, manganese, molybdenum, nickel, selenium, strontium, sulfur, vanadium, yttrium, and zirconium are concentrated along with uranium in primary ore. Comparison of the Smith Lake data with information from other primary deposits in the Grants uranium region and elsewhere in the Morrison Formation of the Colorado Plateau suggests that these elements, with the possible exceptions of zirconium and gallium and with the probable addition of aluminum and magnesium, are typically associated with primary, tabular uranium deposits. Chemical differences between the Ruby and Mariano Lake deposits are consistent with the interpretation that the Ruby deposit has been more affected by post-mineralization oxidizing solutions than has the Mariano Lake deposit.

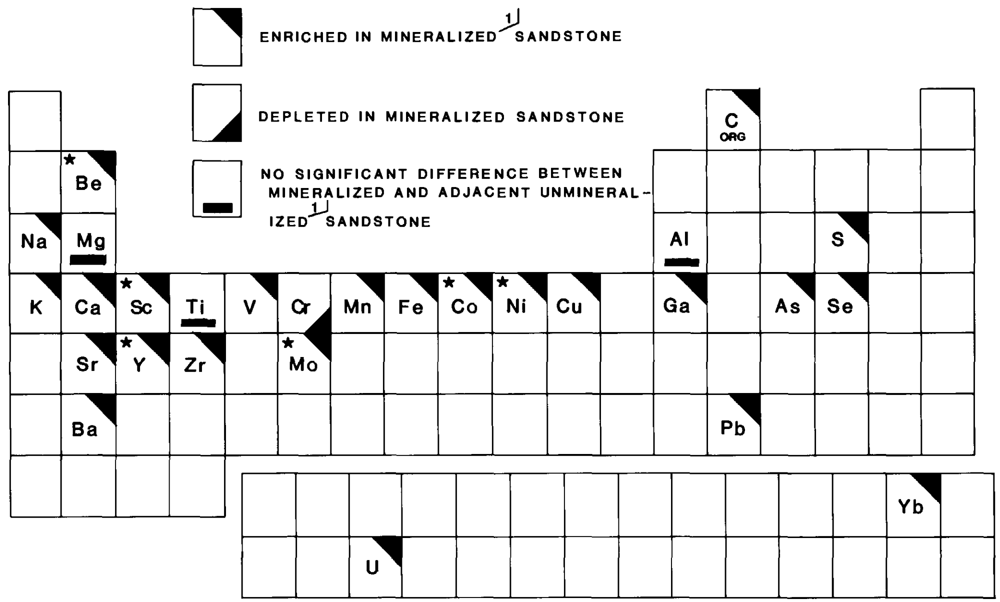
INTRODUCTION

This paper summarizes the chemical characteristics of 299 samples of mineralized and unmineralized sandstone collected from the Mariano Lake and Ruby uranium deposits in the Morrison Formation, Smith Lake district, New Mexico. The samples were collected by J. F. Robertson, N. S. Fishman, and R. L. Reynolds. These data place constraints on the chemistry of the genesis and alteration of primary tabular uranium deposits.

The Smith Lake district lies in the western part of the Grants uranium region (Chenoweth and Holen, 1980). The organic-rich character of the Mariano Lake and Ruby deposits indicates they are of primary origin (Granger, 1968); both are found in sandstone in the lower part of the Brushy Basin Member of the Morrison Formation of Late Jurassic age. Additional information on the uranium deposits in the Brushy Basin Member in the Smith Lake district may be obtained from papers by Hoskins (1963), Ristorcelli (1980), Jenkins and Cunningham (1980), Sachdev (1980), Place and others (1980), and Fishman and Reynolds (1982a and b).

ANALYTICAL DATA

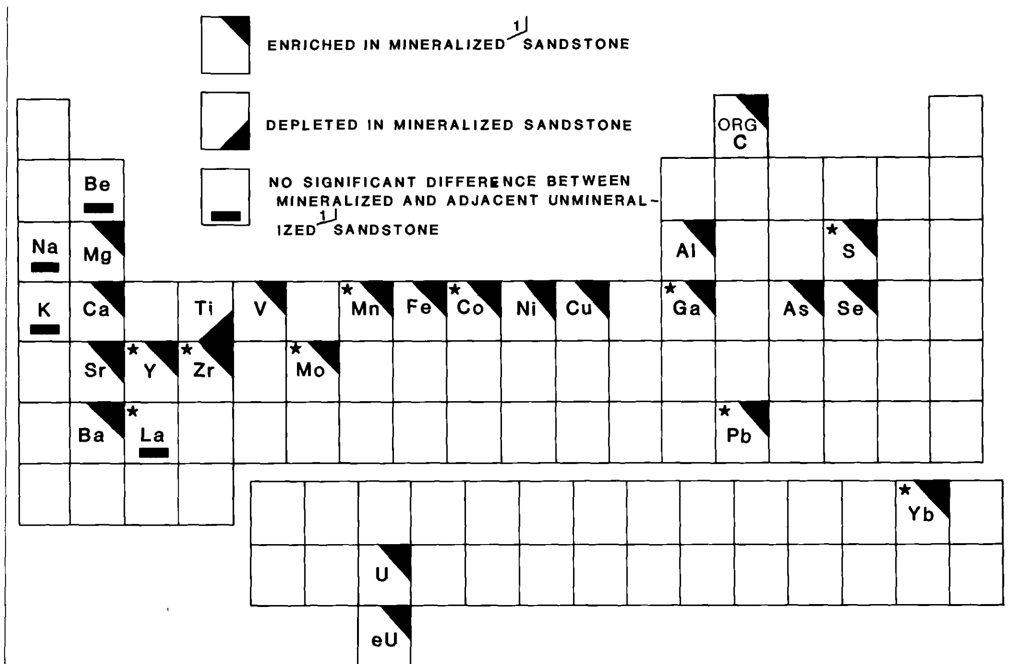
The chemical elements considered in the present study are shown on figures 1 and 2. Most of the analytical results were obtained by 6-step semi-quantitative emission spectrography, although about 63 percent of the spectrographic data for the Ruby deposit was obtained by a semi-quantitative, inductively-coupled, argon plasma (ICP) method. Elements determined by other than spectrographic methods are the following: uranium values, obtained by delayed neutron analysis; equivalent uranium, measured by geiger counter; carbonate carbon, organic carbon, and sulfur, obtained by the induction furnace technique; arsenic, determined by a wet chemical method; and selenium, obtained by X-ray fluorescence.



★ Denotes presence of 30% or more qualified values in data

1/ Samples with uranium content equal to or greater than 100 ppm are arbitrarily considered "mineralized", whereas samples with uranium content less than 100 ppm are considered "unmineralized."

Figure 1.--Chemical characteristics of the Mariano Lake Deposit.



★ Denotes presence of 30% or more qualified values in data

1/ Samples with uranium content equal to or greater than 100 ppm are arbitrarily considered "mineralized", whereas samples with uranium content less than 100 ppm are considered "unmineralized".

Figure 2.--Chemical characteristics of the Ruby Deposit.

DATA TREATMENT

In order to compare the chemical characteristics of the Mariano Lake and Ruby deposits, the samples used in this study were divided into four arbitrary, partly overlapping groups for each deposit (tables 1 and 2). The groups, which range from mineralized to essentially non-mineralized, are defined with respect to uranium content as follows: 1) equal to or greater than 1,000 ppm (G1000); 2) equal to or greater than 100 ppm (G100); 3) less than 100 ppm (L100); and 4) equal to or less than 20 ppm (L20). For the Mariano Lake deposit, 98 samples (including those of the G1000 group) contain more than 100 ppm uranium, and 73 samples (including those of the L20 group) contain less than 100 ppm uranium. The numbers of samples containing more than 1,000, or less than 20 ppm, are 54 and 7, respectively. For the Ruby deposit, 81 samples (including those of the G1000 group) contain more than 100 ppm uranium, and 47 (including those of the L20 group) contain less than 100 ppm. Of these, 46 contain more than 1,000, and 16 contain less than 20 ppm uranium. Most of the conclusions concerning apparent enrichment or depletion of the "mineralized" groups (G1000 and G100) as compared to the "unmineralized" groups (L100 and L20) were obtained by comparing the two non-overlapping groups (G100 and L100). In some cases it was helpful to have the G1000 and L20 groups, where trends of enrichment or depletion generally tend to exhibit higher contrast than between the G100 and L100 groups.

With the aid of a computer, the geometric means and deviations for each of the elements in the four groups were computed for each deposit (tables 1 and 2). The computations are straightforward for all elements for which no qualified values are present. Where qualified values are present, special methods described below were used.

Qualified values are of the three following types: 1) element not detected (N); 2) element detected, but present in an amount less than the lower limit of determination (L) for that element; or 3) present in an amount greater than the upper limit of determination (G) for that element. For cases where data are either singly censored on the left (data contain only N or L values, or on the right (data contain only G values) of the normality curve, a method devised by Cohen (1959, 1961) and programmed by VanTrump, Jr. (1978) was used to calculate geometric means and deviations. In this procedure, log normality for the data is assumed, and the geometric means and deviations, which should be considered as estimates, are calculated from functions of the following quantities for each element: 1) the geometric mean and deviation of the unqualified values; 2) the numerical value of the limit of determination; and 3) the number of qualified values in the set of data for that element. In Cohen's method, N's are not distinguished from L's, and moreover, as the percentage of qualified values increases, the accuracy of the geometric mean and deviation decreases.

Tables 1 and 2 present the numbers and types of qualified values as well as the geometric means and deviations, the number of analyses, the limits of detection, and the minimum and maximum values for each chemical element studied at the Mariano Lake and Ruby deposits. Where qualified values are present, the geometric mean may have a lower value than the minimum (unqualified) value given by the table. This apparent inconsistency arises because the technique of Cohen mathematically reconstructs that part of the frequency distribution curve that lies below the limit of analytical determination and calculates a mean based upon this part of the curve plus the part determined by the unqualified values.

Because the accuracy of a geometric mean estimated by Cohen's method decreases with an increase in the percentage of qualified values, an asterisk is appended whenever the percentage reaches 30 percent or more for a given element. No values for the mean or deviation are reported when the percent of qualified values is greater than 75 percent. The limits 30 percent and 75 percent are chosen arbitrarily because the usefulness of qualified data varies depending upon the precision and limits of detection of the analytical technique used, as well as upon the variability of element concentrations within the group of samples studied.

In order to identify statistically significant differences between geometric means of elements among the various mineralized and unmineralized groups, a "t" test, described by Natrella (1963, Chapter 3, p. 26-28), was used. This test, which employs the mean and variance of the logarithms of the chemical data as well as the numbers of samples in each of the two groups being tested against each other, was made at the 95 percent confidence level. Where more than 75 percent qualified values are present, the "t" test was not used, but rather judgment as to relative enrichment or depletion was made on the basis of the percentages of qualified values present in the groups being compared. For example, beryllium in the Mariano Lake deposit has percentages of unqualified values of 67 percent, 44 percent, 0 percent, and 0 percent, respectively, in the G1000, G100, L100, and L20 groups. In this case no statistical tests could be made between mineralized and unmineralized groups because no calculations of mean and variance could be made for the L100 or L20 groups. Beryllium, however, was judged to be enriched in the mineralized sandstone as compared to the unmineralized sandstone because the former group contains a much greater percentage of samples in which beryllium is found in amounts above the detection limit of the analytical method used.

OBSERVATIONS AND CONCLUSIONS

Interpretations concerning relative enrichment, depletion, or lack of difference in elemental composition between mineralized (G1000 and G100 groups) and unmineralized (L100 and L20 groups) sandstone in the Mariano Lake and Ruby deposits are shown graphically in figures 1 and 2. Results of statistical comparisons of geometric means are listed below. 1) The following elements are relatively enriched in the G1000 and G100 groups at both deposits compared to unmineralized or weakly mineralized rock (L20 and L100 groups): arsenic, calcium, organic carbon, cobalt, copper, gallium, iron, lead, manganese, molybdenum, nickel, selenium, strontium, sulfur, uranium, vanadium, yttrium, ytterbium and zirconium; 2) beryllium, potassium, and sodium are enriched in mineralized rock at Mariano Lake, but not at the Ruby deposit; 3) aluminum, and magnesium are enriched at the Ruby deposit, but not at Mariano Lake; 4) titanium is depleted at the Ruby deposit, but not at Mariano Lake; 5) chromium is depleted in the mineralized samples at Mariano Lake, but data are inadequate for comparisons of the Ruby deposit; 6) lanthanum shows essentially no change among the groups at the Ruby deposit, but data are inadequate to make a determination for the Mariano Lake deposit; and 7) scandium is probably enriched at Mariano Lake, but data are inadequate for a determination at the Ruby deposit.

Some of the differences in the chemical characteristics of the Mariano Lake and Ruby deposits suggest that the latter has been more extensively affected by oxidizing solutions than the former. Arsenic, iron, sulfur, and selenium are included in pyrite. Thus the lesser amounts of these elements at the Ruby deposit indicate a lesser pyrite content for the Ruby ore. Removal of pyrite by oxidation is a means of accounting for the lower pyrite content.

The higher barium content of the Ruby deposit may also be explained by the oxidation process postulated above. Such oxidation would produce sulphate. Because barium is extremely insoluble in the presence of sulphate (Plummer, 1971), any barium in the oxidizing solution would be precipitated as barite. Although barium is more concentrated around the Ruby deposit (L100) than within the deposit, the barium contents of the Mariano Lake and Ruby deposits and rocks immediately around these deposits are much higher than the barium contents of Morrison sandstones in the southern San Juan basin remote from mineralization (Spirakis, Pierson, and Granger, 1981) and higher than in average sandstones (Turekian and Wedepohl, 1961). Thus, barium is enriched in these deposits.

As noted by Fishman and Reynolds (1982b), authigenic calcite is more abundant at the Ruby than at the Mariano Lake deposit. The substitution of strontium for either barium in barite or calcium in calcite may be the reason that the Ruby deposit has a higher strontium content than the Mariano Lake deposit. The higher manganese content of the Ruby deposit probably also reflects the higher calcite content. The relative lack of molybdenum and vanadium in the Ruby deposit compared to the Mariano Lake deposit may be a reflection of the leaching of these elements by the oxidizing solution. All of these differences between the deposits are consistent with the interpretation that the Ruby deposit is more oxidized than the Mariano Lake deposit.

In order to determine which elements are characteristically enriched in primary tabular uranium deposits, the group of elements enriched in the Smith Lake district was compared to the group of elements enriched in the primary deposits of the Ambrosia Lake area (Spirakis and others, 1981) as well as to the group of elements enriched in primary tabular deposits in the Morrison Formation elsewhere on the Colorado Plateau (Shoemaker and others, 1959). These comparisons suggest that the elements typically enriched in primary tabular deposits of the Morrison Formation include aluminum, arsenic, barium, organic carbon, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, selenium, sulphur, strontium, uranium, vanadium, and yttrium.

The precipitation of molybdenum, selenium, uranium, and vanadium might be due to reduction or adsorption by organic carbon. Arsenic, cobalt, copper, iron, nickel, some selenium, and sulfur probably occur mostly as sulfides in the ores. The enrichment in yttrium may be the result of the substitution of yttrium for uranium in uranium minerals (P. Hansley, oral commun., 1982). The formation of chlorite and clay minerals in the ores may account for the enrichment of aluminum and magnesium. Some of the barium, manganese, and strontium enriched in the ores might occur in clay minerals, but in at least some of the deposits, the enrichment is related to the formation of post-ore sulphates and carbonates and is not necessarily produced by primary ore-forming processes. The enrichment of lead is probably due to the radioactive decay of uranium, thus it also is not related to the primary ore-forming process. Details of element concentration and residence for the Mariano Lake deposit are given by Fishman and Reynolds (1982a, p. 13-15).

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Table 1.--Statistical data for the Mariano Lake deposit

EXPLANATION

Types of analyses:

S -- emission spectrography

Chem -- wet chemical method

Ind -- induction furnace

XRF -- X-ray fluorescence

DNA -- delayed neutron analysis

Qualified values:

N -- element not detected

L -- element present in an amount less than the lower determination limit

G -- element present in an amount greater than the upper determination limit

Geometric mean and deviation:

1) Where no qualified values are present, the geometric mean and deviation are respectively the antilogs of the log mean and log standard deviation of the chemical data.

2) Where qualified data are present, the geometric mean and deviation are estimated by the technique of Cohen (1959, 1961). Inasmuch as the reliability of a geometric mean decreases as the amount of qualified values increases, an asterisk is appended when 30 percent or more qualified values are present. The geometric mean and deviation are not reported (two asterisks) when 75 percent or more qualified values are present. Three asterisks indicate that no data are available.

3) In some cases where qualified values are present, the geometric mean estimated by Cohen's technique may be less than the minimum value in the data. This will depend upon the number of qualified values, the geometric mean and deviation of the unqualified values, and the limit of determination of the analytical method used.

Note: The limit of determination given is that of the lower limit unless G values are present in the data. In these cases, both upper and lower limits are given.

Al%-S

Lower determination limit--.05%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	1.5	1.5	1.5	3.0
Maximum value	7.0	7.0	7.0	7.0
Geometric mean	5.26	5.54	5.31	5.63
Geometric deviation	1.44	1.38	1.40	1.38
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

As ppm-Chem

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	3	35	33	***
Minimum value	13	2.5	1	
Maximum value	340	340	42	
Geometric mean	48.7	23.1	3.67	
Geometric deviation	2.44	3.59	2.27	
No. of N's	0	0	0	
No. of L's	0	0	0	
No. of G's	0	0	0	

Ba-ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	500	500	500	500
Maximum value	10,000	10,000	5,000	2,000
Geometric mean	892.6	820.2	782.0	858.2
Geometric deviation	1.81	1.68	1.60	1.56
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Comments

The difference in the abundances of barium between the mineralized rock and the adjacent unmineralized (U <100 ppm) rock is not statistically significant at a 95 percent confidence level. The geometric means of barium in and around this deposit, however, are much higher than the background value (560 ppm) for the Morrison Formation in the southern San Juan Basin (Spirakis, Pierson, and Granger, 1981) and higher than the barium concentration of average sandstones (Turekian and Wedepohl, 1961). Consequently, barium is considered as enriched in this deposit.

Be ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	1.5	1.5	-	-
Maximum value	10	10	-	-
Geometric mean	1.67*	1.27*	**	**
Geometric deviation	1.78	1.87	**	**
No. of N's	2	22	65	7
No. of L's	16	33	8	0
No. of G's	0	0	0	0

Comments

The high number of N and L values in the data make the geometric means somewhat uncertain but the absence of detectable beryllium in the samples with less than 100 ppm U in contrast to the detection of beryllium in about half of the samples with more than 100 ppm U suggests that an enrichment of beryllium occurs in the mineralized rocks.

Org C%-Ind

Local determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	16	58	47	***
Minimum value	.28	.03	.01	
Maximum value	4.33	4.33	.10	
Geometric mean	1.21	.30	.02	
Geometric deviation	2.00	4.73	1.95	
No. of N's	0	0	0	
No. of L's	0	0	5	
No. of G's	0	0	0	

Carbonate C%-Ind

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	16	58	47	***
Minimum value	.10	.10	-	
Maximum value	1.70	1.70	-	
Geometric mean	.05*	**	**	
Geometric deviation	8.33*	**	**	
No. of N's	0	0	0	
No. of L's	8	50	47	
No. of G's	0	0	0	

Ca%-S

Lower determination limit--.05%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	.10	.07	.07	.07
Maximum value	5.0	5.0	.30	.20
Geometric mean	.26	.21	.15	.13
Geometric deviation	2.00	1.83	1.29	1.41
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Comments

The low concentration of calcium relative to the Ruby deposit as well as to the Ambrosia Lake deposits (Spirakis and others, 1981) is consistant with the field observation that the calcite content of the Mariano Lake deposit is low.

Co ppm-S

Lower determination limit--5 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	5	5	5	-
Maximum value	70	70	20	-
Geometric mean	1.27*	1.50*	.49*	**
Geometric deviation	17.3	12.1	8.61	**
No. of N's	29	43	39	7
No. of L's	0	7	11	0
No. of G's	0	0	0	0

Comments

The high numbers of N and L values in these data and the large geometric deviations indicate that the geometric means for cobalt are only approximate. The detection of cobalt in a higher proportion of samples with uranium greater than 100 ppm than in samples with uranium of less than 100 ppm suggests a possible enrichment of cobalt in uranium ore.

Cr ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	1	1	1	3
Maximum value	30	200	70	70
Geometric mean	4.22	4.58	5.92	17.2
Geometric deviation	2.22	2.51	2.85	3.08
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Cu ppm-S

Lower determination limit--2 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	2	2	2	2
Maximum value	30	50	30	20
Geometric mean	6.23	6.21	5.08	3.71
Geometric deviation	1.87	1.91	1.92	2.13
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Fe%-S

Lower determination limit--.05%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	.70	.50	.30	.50
Maximum value	7	7	5	3
Geometric mean	2.29	1.67	.85	.97
Geometric deviation	1.69	1.85	1.85	1.97
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Ga ppm-S

Lower determination limit--5 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	53	97	73	7
Minimum value	5	5	5	7
Maximum value	20	20	20	15
Geometric mean	9.58	9.60	7.83	9.60
Geometric deviation	1.47	1.44	1.45	1.30
No. of N's	3	3	0	0
No. of L's	0	0	2	0
No. of G's	0	0	0	0

Comments

Enrichment of gallium in the G1000 and G100 groups is uncertain because of the relatively high geometric mean of the L20 group.

K%-S

Lower determination limit--0.1%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	1.5	1.5	1.5	1.5
Maximum value	5	5	3	3
Geometric mean	2.70	2.74	2.47	2.32
Geometric deviation	1.26	1.24	1.28	1.40
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Mg%-S

Lower determination limit--approximately .03%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	.07	.05	.03	.07
Maximum value	1.5	1.5	.5	.30
Geometric mean	.141	.136	.123	.144
Geometric deviation	1.58	1.61	1.64	1.66
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Comments

Statistical tests give no reason to believe that magnesium has been enriched in the Mariano Lake deposit.

Mn ppm-S

Lower determination limit--5 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	50	30	20	20
Maximum value	1,500	1,500	200	100
Geometric mean	107	81.64	43.39	36.72
Geometric deviation	1.98	2.01	1.71	1.78
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Mo ppm-S

Lower determination limit--3 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	3	3	3	70
Maximum value	3,000	3,000	700	70
Geometric mean	32.4	27.3	5.51*	**
Geometric deviation	10.7	13.3	18.7	**
No. of N's	8	20	27	6
No. of L's	0	0	2	0
No. of G's	0	0	0	0

Na%-S

Lower determination limit--.1%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	0.5	0.5	0.3	0.5
Maximum value	2	2	1.5	1
Geometric mean	.84	.81	.74	.78
Geometric deviation	1.42	1.36	1.34	1.30
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Ni ppm-S

Lower determination limit--2 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	5	5	2	2
Maximum value	30	30	10	2
Geometric mean	1.82*	1.48*	**	**
Geometric deviation	5.25	5.04	**	**
No. of N's	10	12	8	1
No. of L's	20	47	47	5
No. of G's	0	0	0	0

Comments

Formal statistical tests between the means of mineralized and unmineralized groups were not made because the latter has 75 percent or more qualified values; however, because the mineralized groups contain higher percentages of values above the limit of determination than do the unmineralized groups, it is concluded that Ni is relatively enriched in the mineralized groups.

Pb ppm-S

Lower determination limit--10 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	20	10	10	10
Maximum value	300	300	30	10
Geometric mean	56.7	37.6	12.9	10.0
Geometric deviation	1.68	1.94	1.49	0
No. of N's	0	0	6	0
No. of L's	0	0	2	0
No. of G's	0	0	0	0

Total S%-Ind

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	16	58	46	***
Minimum value	.23	.01	.02	
Maximum value	4.87	4.87	.42	
Geometric mean	1.15	.49	.07	
Geometric deviation	2.13	4.10	2.83	
No. of N's	0	0	0	
No. of L's	0	1	4	
No. of G's	0	0	0	

Sc ppm-S

Lower determination limit--5 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	5	5	5	-
Maximum value	20	20	7	-
Geometric mean	3.54*	**	**	**
Geometric deviation	1.58	**	**	**
No. of N's	23	44	43	4
No. of L's	16	32	26	3
No. of G's	0	0	0	0

Comments

Scandium is probably enriched in the ore because higher percentages of values above the detection limit are found in the G1000 and G100 than in the L100 and L20 groups.

Se ppm-XRF

Lower determination limit--approximately .3 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	33	65	49	***
Minimum value	5	2.3	.7	
Maximum value	260	910	580	
Geometric mean	22.9	20.4	9.49	
Geometric deviation	2.50	3.40	4.98	
No. of N's	0	0	0	
No. of L's	0	0	0	
No. of G's	0	0	0	

Sr ppm-S

Lower determination limit--2 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	50	30	30	30
Maximum value	200	200	150	150
Geometric mean	104.3	97.8	78.1	69.4
Geometric deviation	1.54	1.56	1.56	1.66
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Comments

The data indicate that strontium is enriched in the ore.

Ti%-S

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	.05	.05	.03	.07
Maximum value	.70	1.0	.70	.15
Geometric mean	.13	.13	.12	.10
Geometric deviation	1.70	1.67	1.66	1.37
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

U ppm-DNA

Lower determination limit--.1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	1,049	103	9.15	9.15
Maximum value	63,600	63,600	99	16.1
Geometric mean	4,402	1,280	42.2	12.6
Geometric deviation	2.22	4.85	1.75	1.24
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

V ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	500	30	20	20
Maximum value	7,000	7,000	1,000	150
Geometric mean	1,661	808.3	105.9	80.6
Geometric deviation	1.92	3.28	2.60	1.99
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Y ppm-S

Lower determination limit--10 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	10	10	10	10
Maximum value	500	500	30	10
Geometric mean	25.87	18.45	8.71*	**
Geometric deviation	2.56	2.94	1.61	**
No. of N's	0	9	12	0
No. of L's	2	12	29	6
No. of G's	0	0	0	0

Comments

Comparisons of the geometric means, the maximum values, and the proportion of samples with detectable amounts of yttrium between the groups of samples with more than 100 ppm uranium to the group of samples with less than 100 ppm uranium all indicate that yttrium is enriched in ore.

Yb ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	6	34	70	7
Minimum value	1.5	1	1	1
Maximum value	10	20	3	1
Geometric mean	3.60	1.88	1.14	1
Geometric deviation	2.90	2.79	1.51	1.01
No. of N's	1	2	5	0
No. of L's	0	3	14	2
No. of G's	0	0	0	0

Zr ppm-S

Lower determination limit--10 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	54	98	73	7
Minimum value	50	30	15	30
Maximum value	500	1,500	700	150
Geometric mean	120.6	120.0	99.4	63.0
Geometric deviation	1.89	2.00	2.00	1.70
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Al%-S

Lower determination limit--.05%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	2	2	3	3
Maximum value	7	7	7	5.9
Geometric mean	5.15	5.27	4.85	4.48
Geometric deviation	1.36	1.32	1.25	1.23
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

As ppm-Chem

Lower determination limit--approximately 1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	11	16	6	***
Minimum value	1.2	.9	.8	
Maximum value	61	61	16	
Geometric mean	5.59	5.36	1.40	
Geometric deviation	2.85	2.98	4.86	
No. of N's	0	0	0	
No. of L's	0	0	1	
No. of G's	0	0	0	

Table 2.--Statistical data for the Ruby deposit

EXPLANATION

Types of analyses:

S -- emission spectrography

Chem -- wet chemical method

Ind -- induction furnace

XRF -- X-ray fluorescence

DNA -- delayed neutron analysis

Rad -- radiometric counting

Qualified values:

N -- element not detected

L -- element present in an amount less than the lower determination limit

G -- element present in an amount greater than the upper determination limit

Geometric mean and deviation:

1) Where no qualified values are present, the geometric mean and deviation are respectively the antilogs of the log mean and log standard deviation of the chemical data.

2) Where qualified data are present, the geometric mean and deviation are estimated by the technique of Cohen (1959, 1961). Inasmuch as the reliability of a geometric mean decreases as the amount of qualified values increases, an asterisk is appended when 30 percent or more qualified values are present. The geometric mean and deviation are not reported (two asterisks) when 75 percent or more qualified values are present. Three asterisks indicate that no data are available.

3) In some cases where qualified values are present, the geometric mean estimated by Cohen's technique may be less than the minimum value in the data. This will depend upon the number of qualified values, the geometric mean and deviation of the unqualified values, and the limit of determination of the analytical method used.

Note: The limit of determination given is that of the lower limit unless G values are present in the data. In these cases, both upper and lower limits are given.

Ba ppm-S

Determination limit--1 ppm (lower); 5000 ppm (upper)

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	70	70	300	500
Maximum value	50,000	50,000	5,000	3,100
Geometric mean	800.8	907.3	1,052.1	1,082.7
Geometric deviation	2.75	2.34	1.77	1.68
No. of N's	0	0	0	0
No. of L's	1	1	0	0
No. of G's	0	1	0	0

Comments

The difference between the barium content of mineralized rock (U>100 ppm) and unmineralized rock (U<100 ppm) is not statistically significant. Barium, however, is depleted in highly mineralized rock (U>1000 ppm) compared to adjacent unmineralized rock (U<100 ppm or U L20 ppm). These data suggest that barium is more concentrated around the ore than in the ore. Compared to sandstones remote from mineralization (Turekian and Wedepohl, 1961; or Spirakis, Pierson, and Granger 1981) barium is enriched both in ore and in rocks near ore.

Be ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	1.5	1.5	1.5	1.6
Maximum value	5	5	3	2
Geometric mean	1.89	1.88	1.75	1.64
Geometric deviation	1.50	1.49	1.22	1.12
No. of N's	8	15	8	3
No. of L's	2	4	0	0
No. of G's	0	0	0	0

Org C%-Ind

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	34	59	42	16
Minimum value	.03	.01	.01	.01
Maximum value	2.41	2.4	2	.26
Geometric mean	.58	.43	.05	.05
Geometric deviation	3.00	3.55	2.92	2.45
No. of N's	0	0	0	0
No. of L's	0	0	2	0
No. of G's	0	0	0	0

Carbonate C%-Ind

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	34	58	42	16
Minimum value	.06	.01	.02	.06
Maximum value	3.15	3.15	.48	.14
Geometric mean	-	-	**	**
Geometric deviation	90.1	113.6	**	**
No. of N's	0	0	0	0
No. of L's	16	32	35	14
No. of G's	0	0	0	0

Comments

Although the percentages of qualified values are less than 75 percent for both the G1000 and G100 groups, the geometric means are not reported because of the extremely high geometric deviations.

Ca%-S

Determination limit--.05% (lower); 12% (upper)

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	.15	.15	.07	.15
Maximum value	12.0	12.0	10.0	1.6
Geometric mean	1.41	.96	.31	.26
Geometric deviation	4.69	4.66	2.61	2.07
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	2	0	0

Co ppm-S

Lower determination limit--approximately 1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	4.6	1.6	1.1	1.1
Maximum value	30	30	7	2.3
Geometric mean	3.92*	3.38*	1.29*	1.06*
Geometric deviation	5.66	4.60	1.95	1.55
No. of N's	15	21	10	3
No. of L's	1	5	10	6
No. of G's	0	0	0	0

Comments

The N and L values in the data make the geometric means somewhat uncertain but the differences in the means suggest an enrichment of cobalt in the ore.

Cu ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	2	2	1.5	1.5
Maximum value	50	50	20	4.4
Geometric mean	5.12	5.12	4.22	3.36
Geometric deviation	1.74	1.77	1.66	1.35
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Fe%-S

Lower determination limit--.05%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	.17	.17	.06	.06
Maximum value	7	9.2	3.6	1.4
Geometric mean	1.20	1.19	.55	.27
Geometric deviation	2.44	2.63	2.65	2.57
No. of N's	0	0	0	0
No. of L's	0	1	1	1
No. of G's	0	0	0	0

Ga ppm-S

Lower determination limit--5 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	5	5	5	7
Maximum value	30	30	16	15
Geometric mean	11.77	10.40	3.94*	**
Geometric deviation	1.65	1.83	2.51	**
No. of N's	1	1	0	0
No. of L's	4	14	29	12
No. of G's	0	0	0	0

Comments

There are too many L values for gallium in unmineralized or weakly mineralized sets for the means to be accurately determined. The high numbers of L's in the unmineralized sets do, however, suggest an enrichment of gallium in the mineralized rocks.

K%-S

Lower determination limit--0.1%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	1.5	1.5	1.5	2.7
Maximum value	5	5	5	4.6
Geometric mean	3.03	3.09	3.14	3.49
Geometric deviation	1.30	1.28	1.26	1.17
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

La ppm-S

Lower determination limit--20 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	26	20	21	23
Maximum value	70	150	52	34
Geometric mean	26.4*	21.6*	19.6*	22.1*
Geometric deviation	1.91	2.14	1.53	1.38
No. of N's	11	21	6	1
No. of L's	7	18	19	6
No. of G's	0	0	0	0

Mg%-S

Lower determination limit--approximately .03%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	0.10	0.10	.07	.13
Maximum value	.47	.55	.55	.23
Geometric mean	.184	.180	.133	.113*
Geometric deviation	1.55	1.64	1.51	1.56
No. of N's	0	0	0	0
No. of L's	1	4	7	5
No. of G's	0	0	0	0

Mn ppm-S[1]

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	22	36	11	3
Minimum value	70	30	30	30
Maximum value	3,000	7,000	5,000	70
Geometric mean	512	355	249	53
Geometric deviation	4.55	5.16	6.49	1.63
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Comments

[1] Data are from 6-step semi-quantitative spectrographic analyses. ICP semi-quantitative spectrographic analyses are not included because the determination limit for manganese was 200 ppm for the Ruby samples, which is much greater than the 1 ppm determination limit for the 6-step method. Moreover, there were 43 percent qualified values in the ICP data, but none in the 6-step results.

Mo ppm-S

Lower determination limit--2 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	2	2	3	-
Maximum value	1,200	1,200	12	-
Geometric mean	4.38*	1.67*	**	**
Geometric deviation	17.9	22.4	**	**
No. of N's	6	11	6	3
No. of L's	13	33	36	13
No. of G's	0	0	0	0

Comments

Because of the high percentages of qualified values in the L100 and L20 groups, no statistical tests can be made between them and the G1000 and G100 groups. However, molybdenum is judged to be enriched in the ore, albeit sporadically, on the basis of the very high maximum values in the ore as well as upon the lower percentages of qualified values present in the G1000 and G100 groups.

Na%-S

Lower determination limit--0.1%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	.61	.61	.70	.70
Maximum value	3	3	3	2
Geometric mean	1.21	1.22	1.32	1.36
Geometric deviation	1.46	1.44	1.34	1.34
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Ni ppm-S

Lower determination limit--2 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	2	2	2	2
Maximum value	20	20	10	5.2
Geometric mean	4.25	4.40	3.58	2.97
Geometric deviation	2.31	2.13	1.52	1.30
No. of N's	2	4	0	0
No. of L's	7	9	2	0
No. of G's	0	0	0	0

Pb ppm-S

Lower determination limit--10 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	14	10	10	10
Maximum value	150	150	100	15
Geometric mean	28.27	20.80*	5.90*	**
Geometric deviation	2.78	3.00	3.35	**
No. of N's	0	0	0	0
No. of L's	11	25	31	13
No. of G's	0	0	0	0

Comments

The geometric mean of lead in the L100 set is based on too many L values to be accurate. However, the relatively low value of the estimated geometric mean and the higher proportions of L values in the unmineralized sets indicate an enrichment of lead in the ore.

Total S%-Ind

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	34	59	42	16
Minimum value	.02	.02	.01	.01
Maximum value	2.79	5.4	1.4	.04
Geometric mean	.339	.273	.011*	.009*
Geometric deviation	3.71	3.80	.056	3.27
No. of N's	0	0	0	0
No. of L's	0	1	18	8
No. of G's	0	0	0	0

Se ppm-XRF

Lower determination limit--approximately 0.3 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	22	35	11	***
Minimum value	.4	.4	.3	
Maximum value	3,641	3,641	66	
Geometric mean	13.17	11.57	1.89	
Geometric deviation	10	10.62	5.85	
No. of N's	0	0	0	
No. of L's	0	0	1	
No. of G's	0	0	0	

Comments

A few very high values of selenium in the mineralized rock suggest a sporadic enrichment of selenium in the mineralized rock.

Sr ppm-S

Lower determination limit--2 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	70	70	70	70
Maximum value	700	700	300	170
Geometric mean	194.8	177.7	124.0	108.4
Geometric deviation	1.53	1.53	1.43	1.32
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Ti%-S

Lower determination limit--.01%

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	.04	.03	.05	.05
Maximum value	.70	.70	.40	.30
Geometric mean	.10	.10	.12	.09
Geometric deviation	1.78	1.72	1.74	1.53
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Comments

The data indicate a possible depletion of titanium in the mineralized rock (U>100 ppm) compared to adjacent nonmineralized rocks (U<100 ppm). This depletion is statistically significant at a 95 percent confidence level but not at a 99 percent confidence level.

U ppm-DNA

Lower determination limit--0.1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	1,010	104	8.1	8.1
Maximum value	20,100	20,100	97	16.5
Geometric mean	3,093	1,068	27.7	11.7
Geometric deviation	1.90	3.98	2.11	1.28
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

eU ppm-Rad

Lower determination limit--approximately 1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	10	14	6	3
Minimum value	970	170	40	40
Maximum value	4,400	4,400	300	50
Geometric mean	2,599	1,505	89.21	46.42
Geometric deviation	1.67	2.86	2.32	1.14
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

V ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	99	15	20	30
Maximum value	4,100	4,100	2,000	620
Geometric mean	957.9	642.4	185	135.5
Geometric deviation	2.11	2.96	3.33	2.40
No. of N's	0	0	0	0
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Y ppm-S

Lower determination limit--10 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	10	10	10	10
Maximum value	200	200	42	14
Geometric mean	18.8	17.6	10.8*	9.0*
Geometric deviation	1.97	1.93	1.73	1.32
No. of N's	1	3	2	1
No. of L's	1	7	17	9
No. of G's	0	0	0	0

Comments

Yttrium may substitute for uranium in uraninite (P. Hansley, oral commun., 1982) and this may explain the enrichment of yttrium in the ore.

Yb ppm-S

Lower determination limit--1 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	14	25	10	3
Minimum value	1.5	1	1	-
Maximum value	2	3	1.5	-
Geometric mean	.95*	1.20*	.89*	**
Geometric deviation	1.91	2.02	1.29	**
No. of N's	8	11	6	3
No. of L's	0	0	0	0
No. of G's	0	0	0	0

Zr ppm-S

Lower determination limit--10 ppm

Sample set	G1000	G100	L100	L20
No. of analyses for this element	46	81	47	16
Minimum value	70	23	20	70
Maximum value	450	610	550	410
Geometric mean	138.3	112.9	28.3*	2.50*
Geometric deviation	1.72	2.35	8.38	24.85
No. of N's	0	0	0	0
No. of L's	0	4	18	11
No. of G's	0	0	0	0