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Preliminary study of radioactive limonite localities in Colorado, Utah, and Wyoming

By T. G. Lovering and E. P. Beroni, 1919

Trace Elements Investigations Report 427

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GEOLOGICAL SURVEY

PRELIMINARY STUDY OF RADIOACTIVE LIMONITE LOCALITIES IN COLORADO, UTAH, AND WYOMING*

By

T. G. Lovering and E. P. Beroni

January 1956

Trace Elements Investigations Report 427

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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PRELIMINARY STUDY OF RADIOACTIVE LIMONITE LOCALITIES IN COLORADO, UTAH, AND WYOMING

By T. G. Lovering and E. P. Beroni

ABSTRACT

Nine radioactive limonite localities of different types were sampled during the spring and fall of 1953 in an effort to establish criteria for differentiating limonite outcrops associated with uranium or thorium deposits from limonite outcrops not associated with such deposits. The samples were analyzed for uranium and thorium by standard chemical methods, for equivalent uranium by the radiometric method, and for a number of common metals by semiquantitative geochemical methods. Correlation coefficients were then calculated for each of the metals with respect to equivalent uranium, and to uranium where present, for all of the samples from each locality. The correlation coefficients may indicate a significant association between uranium or thorium and certain metals. Occurrences of specific metals that are interpreted as significant vary considerably for different uranium localities but are more consistent for the thorium localities.

Samples taken from radioactive outcrops in the vicinity of uranium or thorium deposits can be quickly analyzed by geochemical methods for various elements. Correlation coefficients can then be determined for the various elements with respect to uranium or thorium; if any significant correlations are obtained, the elements showing such correlation may be indicators of uranium or thorium. Soil samples of covered areas in the vicinity of the radioactive outcrop may then be analyzed for the indicator elements and any resulting anomalies used as a guide for prospecting where the depth of overburden is too great to allow the use of radiation-detecting instruments.

Correlation coefficients of the associated indicator elements, used in conjunction with petrographic evidence, may also be useful in interpreting the origin and paragenesis of radioactive deposits.

Changes in color of limonite stains on the outcrop may also be a useful guide to ore in some areas.

INTRODUCTION

The radioactive limonite localities discussed in this report were examined in order to determine whether field criertia could be found that would differentiate between indigenous radioactive limonite and transported radioactive limonite. Nine localities with differing geologic environments and types of radioactive material were selected. At each locality samples were taken of both the radioactive and non-radioactive material; wherever possible, a continuous channel, consisting of individual samples representing one-foot intervals, was taken across the radioactive limonite zone, extending into the non-radioactive material on both sides. Changes in color and texture were noted. The samples were analyzed for equivalent uranium, uranium, and a number of metals, for which geochemical field tests are available. The purpose of analyses was to determine whether any of these metals shows significant correlations, or dispersion halos, with respect to uranium or thorium in the outcrop.

Semiquantitative spectrographic analyses for about sixty elements were obtained on the samples from some of the localities. The sensitivity of both spectrographic and geochemical analysis varies greatly from one element to another. The spectrograph will reveal the presence of as little as 0.00005 percent silver in a sample but cannot detect mercury in concentrations less than 0.1 percent. The concentrations of the elements are reported in spectrographic analyses in powers of 10 with + and - appended to indicate whether the concentration is near the top or bottom of the range, thus: $.x^{+}$ = 0.5-1.0 percent, $.x$ = 0.2-0.5 percent, $.x^{-}$ = 0.1-0.2 percent. The geochemical analyses are reported in parts per million rather than in percent and are accurate approximately to the first significant figure.

Most of the field examinations were made by the authors during the latter part of October 1953. The Lucky Break iron mine was visited by T. G. Lovering and W. R. Griffitts in June 1953, and the mines in the Golden Gate Canyon area were visited and sampled by E. P. Beroni early in November 1953. The localities discussed in this report are shown on the index map (fig. 1).

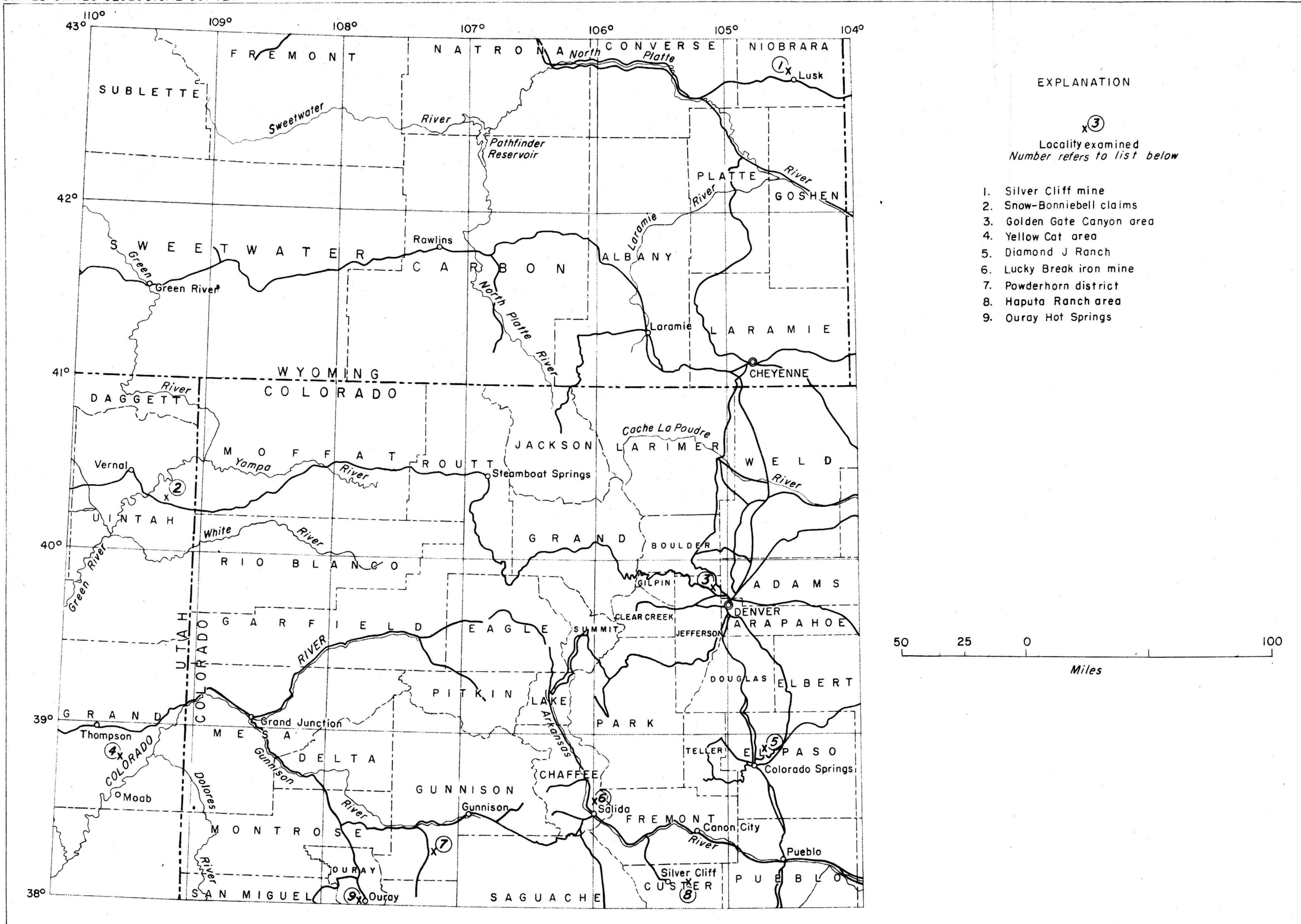

FIGURE 1.- INDEX MAP SHOWING LOCALITIES EXAMINED FOR RADIOACTIVE LIMONITE

Correlation coefficients have been calculated for each group of samples in an attempt to express mathematically the relative degree of association between the radioactive elements and some of the other metals in the sample. The authors feel that where high correlations were obtained the possibility of a significant association warrants further investigation, even though the small number of samples obtained from the various localities does not constitute a valid approximation to a representative statistical sample.

The correlation coefficients were determined by a modification of the method used by Miesch and Shoemaker (1953). In calculating the correlation coefficients, all assays were first expressed in parts per million in order to make relative concentrations of the various elements more readily apparent. The logarithms of the assays were then tabulated and average values for the log concentrations of each element were determined. The use of logarithms was considered preferable to the use of straight assay data because of the extreme range in concentrations represented by the assays. (The logarithmic transformation greatly decreases the effect of a few extremely high values, thus making correlations more nearly representative of the whole group of assays involved.) Next, for each element, the deviation from the average log assay was determined for each log assay; these deviations were then squared and the sum of the squares was found so that the standard deviation could be calculated according to the formula:

$$\sigma = \sqrt{\frac{\Sigma D^2}{n - 1}}$$

where σ = standard deviation, D = deviation from the mean log assay, n = number of assays.

The individual log assays for equivalent uranium and for uranium, where present, were next multiplied by the corresponding log assays of each of the other elements in turn, and the mean value of the products determined thus:

$M = \frac{\Sigma ab}{n}$, where M = mean product, Σ = summation, a = uranium log assay value, b = log assay value of some other element, n = number of assays. The correlation coefficients were then calculated according to the formula:

$$r_{ab} = \frac{\frac{\Sigma ab}{n} - (\Sigma a/n \cdot \Sigma b/n)}{\sigma a \cdot \sigma b}$$

where r = correlation coefficient, a = log assay eU or U, b = log assay of one of the other elements, σ a = standard deviation for U, σ b = standard deviation for the other element. A perfect positive correlation is +1, a perfect inverse relationship is indicated by a correlation of -1, and a completely random distribution of 2 elements with respect to each other is represented by a correlation of 0. For normally distributed populations, the threshold of significance of a correlation coefficient is inversely proportional to the number of samples analyzed. Most of the individual sample groups collected for this study contained only from 5 to 15 samples, so only those correlation coefficients exceeding $\pm$ 0.4 were considered significant (Dixon and Massey, 1951, p. 164).

Only those elements were correlated that showed a significant variation in concentration from one sample to the next in each group. No elements were correlated whose concentration fell below the threshold of analytical sensitivity in more than 25 percent of the samples within a given group. If the concentration of an element fell below the threshold of sensitivity in only a few samples within a group, the concentration of that element was arbitrarily assigned to the middle of the next lower order of magnitude. For example, the arsenic concentration of 2 samples from the Little Johnny mine area was reported as $<$ 10 parts per million; these samples were assigned a value of 5 parts per million; if a few analyses were reported as $<$1 part per million, the same procedure was followed, but all assays were multiplied by 10 to avoid the use of negative logarithms.

The writers wish to express their appreciation to the analysts of the U. S. Geological Survey who furnished the analytical data on which this report is based. H. E. Crowe and J. H. McCarthy made the geochemical determinations, and S. P. Furman and R. F. Dufour made the uranium, equivalent uranium, and thorium analyses. Thanks are also due to many members of U. S. Geological Survey field parties for valuable aid in finding outcrops for study and for assistance in understanding their geologic setting. The cooperation of the various owners in allowing access to their properties was much appreciated. The work was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

DESCRIPTION OF LOCALITIES

Yellow Cat area, Grand County Utah

The Yellow Cat area, Thompson district, is principally within T. 22 S., Rs. 22 and 23 E., in east-central Grand County, Utah. The rocks exposed are the Summerville and Morrison formations of Jurassic age and consist of alternating conglomerates, sandstones, and mudstones of continental origin. The area has produced more than a hundred thousand tons of uranium and vanadium ore; nearly all of it has come from sandstone beds in the Salt Wash member of the Morrison formation, which overlies the Summerville formation with slight disconformity, and is overlain conformably by the Brushy Basin member of the Morrison formation which consists predominantly of red mudstones. All the rocks in the area dip gently to the north, a few gentle folds are present locally, and there is little evidence of faulting.

The uranium-vanadium deposits of the Yellow Cat area have been examined and described by many geologists during the past fifty years. The most recent, and probably the most comprehensive, published report on the area has been written by Stokes (1952).

Sample data

Thirteen samples were collected from the Yellow Cat area (table 1). All the samples were analyzed by geochemical prospecting methods for a number of common elements, and a separate split of each sample was analyzed fluorimetrically for uranium and radiometrically for equivalent uranium.

The variation of uranium, equivalent uranium, and various metals in the 7-foot vertical channel sample, taken on the Cactus Rat claim, is shown in figure 2. In order to avoid confusion, only those metals are graphed that appeared to show significant changes in concentration and for which assays were available on all samples.

Correlation coefficients for eight metals with respect to both uranium and equivalent uranium are shown in table 2.

Table 2.--Correlation coefficients, Yellow Cat area, Grand County, Utah.

(13 samples)

	Mo	As	Sb	Zn	Cu	V	Mn	Fe
eU	+0.38[x]	+0.70[xx]	+0.55[xx]	+0.09	-0.07	+0.58[xx]	-0.47[x]	-0.01
U	+ .29	+ .65[xx]	+ .46[x]	+ .17	- .06	+ .70[xx]	- .45[x]	- .08

xx = probably significant

x = possibly significant

Conclusions

Information derived from samples taken in the Yellow Cat area suggests that geochemical prospecting for elements associated with uranium may be a useful tool in exploration, but there is no visible characteristic of the limonite that is diagnostic of proximity to uranium deposits.

Table 1. Description and Analyses[1] of Samples from the Yellow Cat area, Grand County, Utah.

Sample Number	Location and type of sample	Description of Sample	eU	U	Zn	Pb	Cu	Ni	Co	Sb	As	Mo	V	Mn	Fe[3]
			Analyses[2]												
	Top														
F54-TL-53	Seven-foot vertical channel sample broken into 1-foot intervals, through upper (No. 1) sand of Salt Wash sandstone, in bench on Cactus Rat claim	Light-gray barren arkosic conglomerate	30	<20	200	<10	20	<10	<10	1	10	8	300	750	50
F55-TL-53		Light-gray, medium-grained, cross-bedded sandstone	20	<20	20	<10	20	<10	<10	2	10	8	600	500	20
F56-TL-53		Same as F55	120	210	100	<10	50	50	50	1	20	12	1,500	750	32
[5]F57-TL-53		Pale yellowish-gray, fine-grained sandstone with limonite coating fractures	120	110	50	<10	50	15	<10	3	100	200	[4]---	250	30
[5]F58-TL-53		Same as F57, with less limonite stain	1,100	700	<10	<10	20	<10	<10	10	600	500	[4]---	250	38
F59-TL-53		Light-brown, medium-grained sandstone impregnated with limonite	80	50	40	<10	20	<10	<10	4	150	200	<300	500	32
F60-TL-53		Light-brown and medium-gray arkosic conglomerate	240	300	100	<10	20	<10	<10	4	150	32	<300	1,000	39
	Bottom														
[5]F61-TL-53	Two feet W. of F56	Carbonaceous material in a "trash pocket" with limonite-stained sandstone	1,200	2,000	70	<10	<10	<10	<10	3	150	32	10,000	250	33
F80-TL-53	Grab sample, Allor #2 claim	Light-brown, fine-grained sandstone with gray-brown clay partings	400	430	500	<10	70	<10	50	1	130	12	600	<200	10
F81-TL-53	Float from above F54	Reddish-brown Brushy Basin mudstone with black manganese stain on surface	10	<20	50	<10	20	<10	<10	<1	<10	8	<300	500	17
F82-TL-53	Grab sample, Flat Top claim	Light-buff, fine-grained sandstone with light-brown to moderate-brown limonite coatings	40	<20	70	<10	<10	<10	<10	2	150	500	600	<200	11
F83-TL-53	Grab sample, Flat Top claim	Light-brown, medium-grained arkosic sandstone with patches of carnotite and dark-brown limonite	2,400	2,500	50	<10	<10	<10	<10	4	100	150	1,500	<200	14
F84-TL-53	Grab sample, Allor #2 claim	Pale-brown, medium-grained sandstone with carnotite (?) and moderate-brown limonite coating fractures	1,200	1,600	600	<10	70	<10	50	2	200	80	1,500	<200	13

[1]All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly and James Wahlberg of the U. S. Geological Survey Denver Laboratory.

[2]Expressed in parts per million.

[3]In thousands of parts per million.

[4]---indicates concentration indeterminate because of interference.

[5]For petrographic description see Table 21.

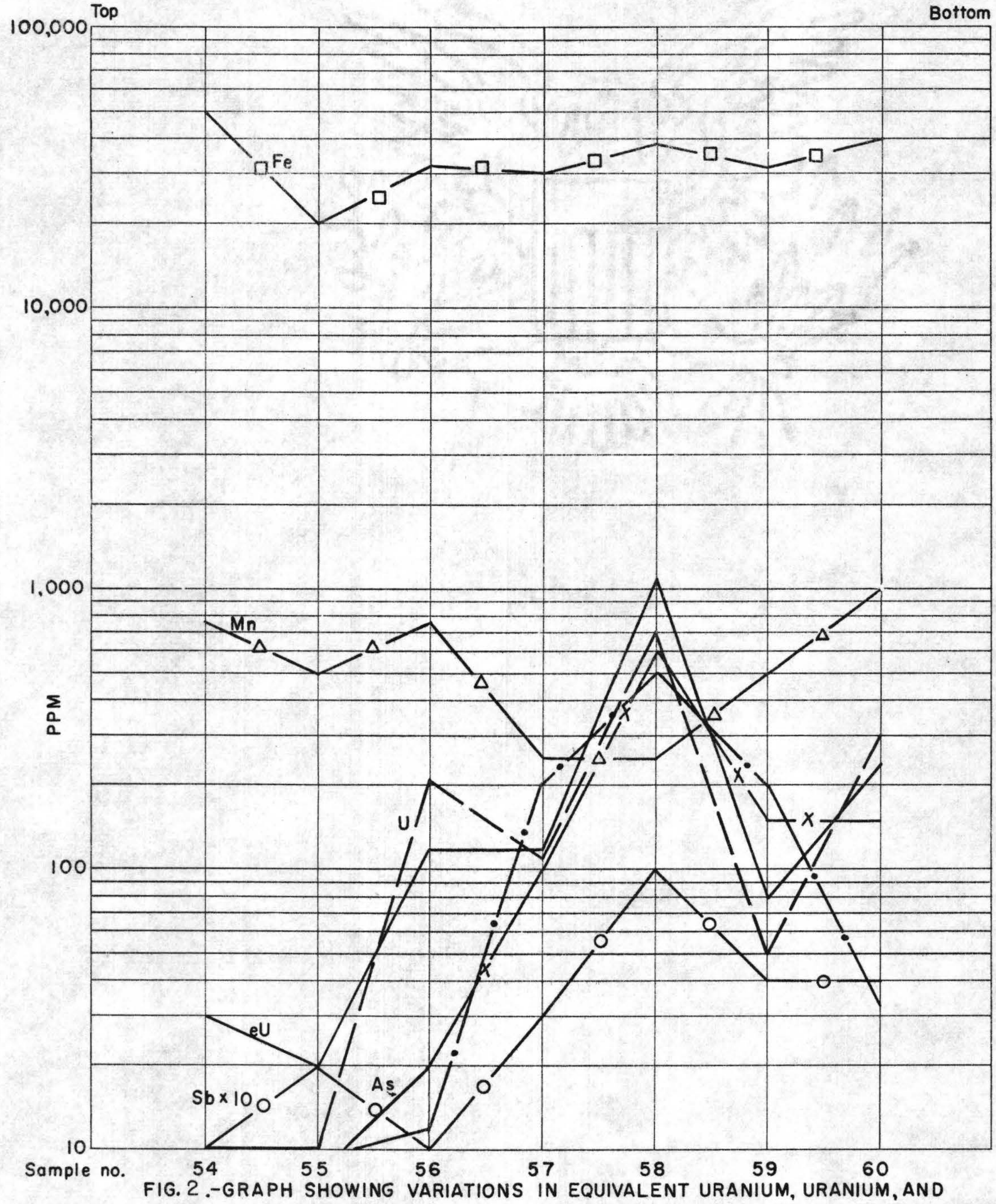

FIG. 2.-GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM, URANIUM, AND SELECTED METALS, IN SAMPLES FROM CACTUS RAT CLAIM, GRAND COUNTY, UTAH

A comparison of thin and polished sections of sample F57 with those of sample F58 does not reveal any significant difference in the nature of the iron oxides that can be correlated with the difference in the uranium content. Red hematite breccia, in a veinlet cutting goethite-impregnated sandstone, in sample F61, is surprising because of the proximity of this ferric oxide to carbonaceous material that might have been expected to reduce the iron to the ferrous state. The work of Tunnell and Posnjak (1931) has shown that under atmospheric conditions in the Fe_2O_3-H_2O-SO_3 system, goethite is stable below 130° C and hematite above that temperature. The presence of gypsum indicates that sulfate ion was probably available. The late hematite thus suggests that moderately hot solutions may have come in along small fractures at some time after the lithification of the sandstone and the development of early goethite.

The variation in metal content of the channel sample shown in figure 2 suggests leaching of iron from a zone about two feet below the surface and reconcentration of this iron in the surface layer. Iron content appears to be completely unrelated to uranium content, manganese shows an inverse relationship with uranium, but arsenic, antimony, and molybdenum correlate positively with uranium.

A study of the correlation coefficients shown in table 2 also brings out the random distribution of uranium with respect to iron, its negative correlation with manganese, and good positive correlation with arsenic and antimony. In addition the table illustrates that vanadium gives a good correlation with uranium but that, for the total 13 samples, molybdenum does not correlate as well with uranium as it appeared to in the 7 samples that constitute the channel sample. Zinc and copper, like iron, appear to have a more or less random distribution with respect to uranium.

If more detailed sampling in this area should confirm the relationship between uranium and arsenic, antimony, and vanadium suggested by this preliminary work, geochemical prospecting for these indicator elements might be of value in the search for additional uranium deposits in the Yellow Cat area, wherever depth of overburden precludes the use of Geiger counter or scintillation counter.

The close association of antimony and arsenic, as well as vanadium, with the uranium indicates that these two minor elements may also be present in small amounts in carnotite--the major ore mineral of the district. It also suggests the possibility that they were present in the primary mineral from which the carnotite was derived.

Snow-Bonniebell claims, Uintah County, Utah

The Snow-Bonniebell claim group is in secs. 17, 18, and 24, T. 6 S., R. 24 E., in the eastern part of Uintah County, Utah. The claims are at an elevation of about 5,500 feet on the crest and south slope of a hogback ridge of sandstone of the Mesaverde formation of Cretaceous age. This sandstone ridge is on the southern flank of the large Split Mountain anticline; the ridge rises about 200 feet above a nearly level plain cut on the underlying Mancos shale to the north.

Small areas of anomalous radioactivity occur at intervals along a high-angle normal fault, which cuts the sandstone near the ridge crest. The fault trends nearly parallel to the sandstone outcrop and dips steeply southward. Spotty radioactive anomalies are also present as much as several hundred yards south of the fault.

The Snow-Bonniebell group of claims was examined and sampled in 1950 by E. P. Beroni and F. A. McKeown (1953).

Sample data

Eleven samples were collected from the Snow-Bonniebell claim group (table 3). Three of these constitute a channel sample across a limonite seam on the east wall of a cut on the Bonniebell No. 3 claim about a quarter of a mile south of the ridge crest. Six other samples were taken in consecutive one-foot intervals across a radioactive fault zone approximately half a mile east-northeast of the open cut. In addition, two grab samples of radioactive limonitic material were collected, one from the vicinity of the cut and one from the fault zone.

All eleven samples contained less than 0.03 percent vanadium and less than 10 parts per million of cobalt and nickel. The concentrations of other elements in these samples are shown in table 3.

Table 3. Description and analyses[1] of samples from the Snow-Bonniebell claim group, Uintah County, Utah.

Sample number	Location and type of sample	Description of sample	Analyses[2] eU	U	Zn	Pb	Cu	Sb	As	Mo	Mn	Fe[3]
F62-TL-53	Grab sample Bonniebell No. 3 claim	Light-gray, medium-grained sandstone with bands of dark yellowish-orange limonite	190	220	20	<10	<10	1	20	<1	<200	10
F63-TL-53	One-foot channel sample 2 feet N. of F65	Pale yellowish-brown laminated siltstone	20	<20	20	<10	<10	2	40	<1	<200	22
F64-TL-53	One-foot channel sample 1 foot S. of F65	Pale-brown laminated siltstone	20	<20	50	20	50	<1	30	100	<200	7
F65-TL-53	10-inch channel sample limonite seam, E. wall of open cut	Medium-brown and black laminated siltstone	130	170	100	<10	130	3	250	1,000	<200	49
	South end											
F66-TL-53	6-foot channel sample broken into one-foot units, across fault zone, from one foot S. of fault plane to 4 feet N. of it	Very light-gray, medium-grained sandstone	40	<20	20	<10	20	<1	<10	6	<200	6
F67-TL-53		Light-brown, fine-grained sandstone with dusky-brown limonite coating	310	480	20	<10	50	<1	10	3	750	19
F69-TL-53		Pale yellowish-brown, fine-grained sandstone stained with dark yellowish-orange limonite	250	380	150	<10	50	<1	10	2	500	13
F70-TL-53		Pale yellowish-brown, fine-grained sandstone stained with dark yellowish-orange limonite	120	170	40	<10	50	<1	10	3	750	20
F71-TL-53		Dark yellowish-brown, fine-grained sandstone with thin dusky yellowish-brown claystone partings	180	340	50	<10	50	<1	<10	1	750	14
F72-TL-53		Very light-gray to yellowish-gray, medium-grained sandstone	30	<20	40	<10	50	<1	<10	3	250	13
	North end											
F-68-TL-53	Grab sample from fault zone	Yellowish-brown, fine- to medium-grained sandstone with dusky-brown limonite and yellow-green uranium mineral	790	1,200	20	<10	50	1	10	8	750	28

[1] All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory

[2] Expressed in parts per million

[3] In thousands of parts per million

The graphs in figure 3 indicate the variations in concentrations of selected elements in the six samples collected across the fault zone.

The correlation coefficients for uranium and equivalent uranium with respect to these elements are shown in table 4.

Table 4.--Correlation coefficients, Snow-Bonniebell claims, Uintah County, Utah.

(11 samples)

	Zn	Mo	Mn	Fe	As
eU	+0.04	-0.07	+0.61[xx]	+0.38[x]	+0.12
U	- .40[x]	- .08	+ .65[xx]	+ .39[x]	- .13

xx = probably significant
x = possibly significant

Conclusions

Sample F65 from the iron-stained clay seam on the wall of the open cut contains high concentrations of zinc, copper, arsenic, molybdenum, and uranium, compared to the wall-rock samples (F63-F64) on either side. Yet none of these elements show significant correlation with uranium in the samples across the fault zone, half a mile away (fig. 3). Manganese, on the other hand, shows no increase in concentration in the limonitic clay seam relative to the wallrock samples in the open cut, but it is the only element of the group that correlates well with uranium in the fault zone. This may indicate that the elements concentrated in the clay seam were deposited with the clay, but the uranium and manganese along the fault were deposited by ground water circulating along this permeable zone. It is, of course, also possible that the number of samples collected was too small to be representative and that the apparent correlations are merely coincidental.

In any event, the available data do not appear to indicate the presence of any large concentrations of uranium minerals in this area.

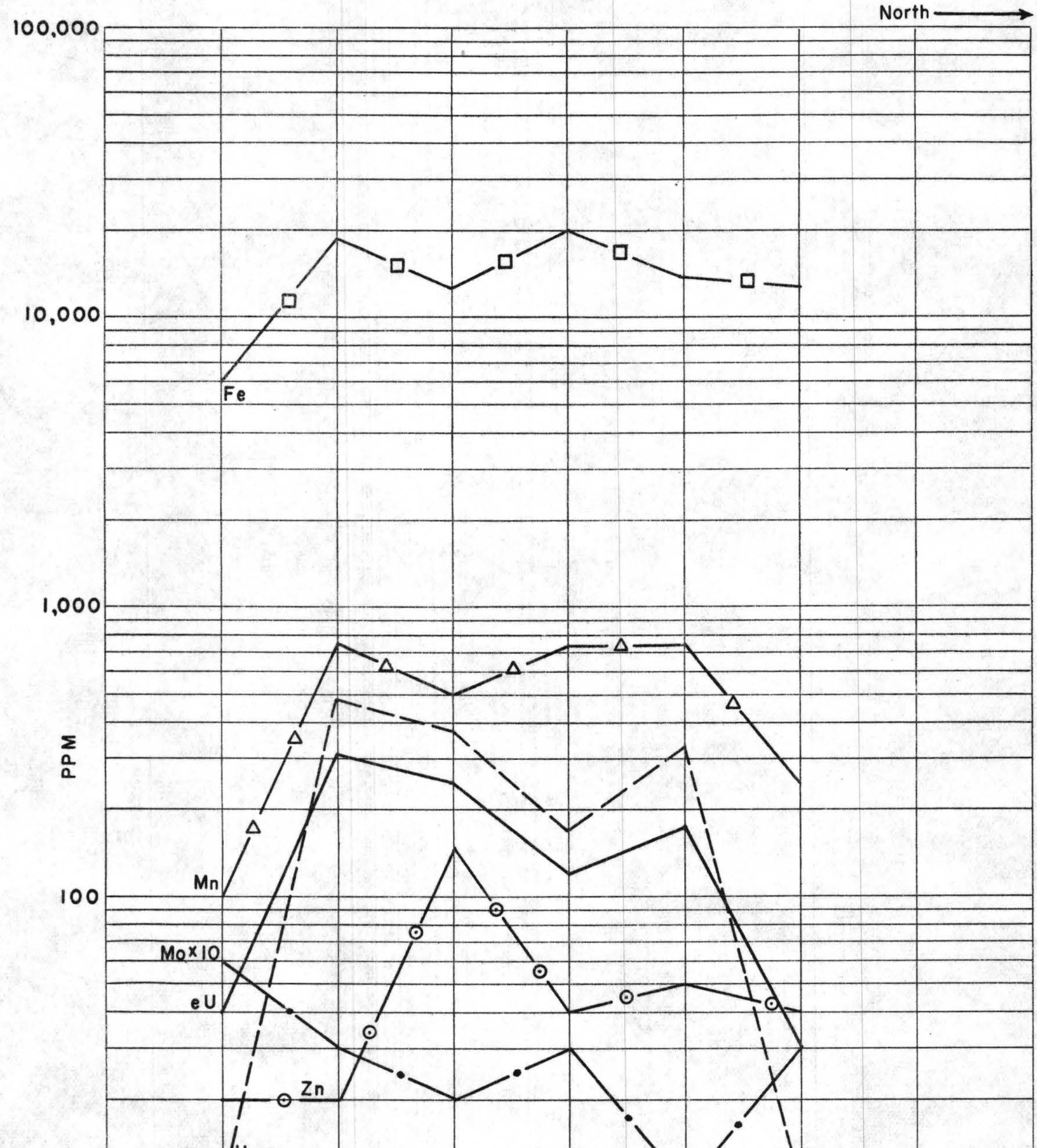

FIGURE 3.–GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM, URANIUM, AND SELECTED METALS, IN SAMPLES FROM SNOW-BONNIEBELL CLAIMS, UINTAH COUNTY, UTAH.

Silver Cliff mine, Niobrara County, Wyoming

The Silver Cliff mine is in sec. 7, T. 32 N., R. 63 W., half a mile west of Lusk, Niobrara County, Wyo. The mine is at an elevation of about 5,200 feet near the crest of a prominent hill, which is capped by dense brown Cambrian quartzite. The quartzite lies unconformably on a Precambrian metamorphic complex consisting of schist, gneiss, and quartzite, intruded by pegmatite dikes. A high-angle, northerly-trending, reverse fault that dips about 60° east is exposed near the crest of the hill, where Precambrian rocks in the hanging wall have been moved into contact with the Cambrian quartzite of the footwall.

The Silver Cliff mine was first opened in 1880; it has produced gold, silver, and copper in addition to uranium. The ore deposits are localized along the reverse fault and in fractured Cambrian quartzite in the footwall. The uranium deposits have been described by Lind and Davis (1919) and more recently by Wilmarth and Johnson (1954).

Sample data

Five samples were collected from one locality about 50 feet southwest of the entrance to the open cut leading to pit no. 1 (fig. 4 and table 5). Table 6 gives the correlation coefficients for equivalent uranium with elements that were present in determinable amounts in at least four of the samples.

Table 6.--Correlation coefficients, Silver Cliff mine near Lusk, Wyoming.

(5 samples)

	Zn	Cu	Co	As	Mo	V	Mn	Fe
eU	+0.72^xx	+0.73^xx	+0.40	+0.65^x	+0.60^x	+0.53	+0.63^x	+0.02

xx = probably significant
x = possibly significant

Table 5. Description and analyses[1] of samples from the Silver Cliff mine near Lusk, Wyoming

Sample number	Location and Type of sample	Description of sample	Analyses[2] eU	U	Zn	Pb	Cu	Ni	Co	As	Sb	Mo	V	Mn	Fe[3]
[4] F74-TL-53	1-foot channel sample through fracture zone 50 feet W. of portal	Light-brown to medium-brown, fine-grained quartzite	160	190	400	500	3,000	40	10	150	4	6	1,500	500	17
[4] F75-TL-53	1-foot channel sample 1 foot N. of F74	Pale-red, fine-grained quartzite with small dark reddish-brown spots	30	<20	70	20	180	<10	10	40	<1	6	1,000	250	17
F76-TL-53	1-foot channel sample 1 foot S. of F74	Grayish-orange pink, fine-grained quartzite with sparse dark-gray chert pebbles	30	<20	130	<10	700	<10	10	40	<1	1	300	250	14
F77-TL-53	Grab sample 10 feet above F74 in red zone	Dark reddish-brown, fine-grained quartzite	60	<20	70	<10	150	30	<10	40	1	<1	300	500	94
[4] F78-TL-53	Grab sample from dump	Dark-brown and brilliant-green, fine-grained sandstone	550	920	600	1,000	35,000	15	20	100	2	3	1,500	500	22

[1] All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory

[2] Expressed in parts per million

[3] In thousands of parts per million

[4] For petrographic description see Table 21

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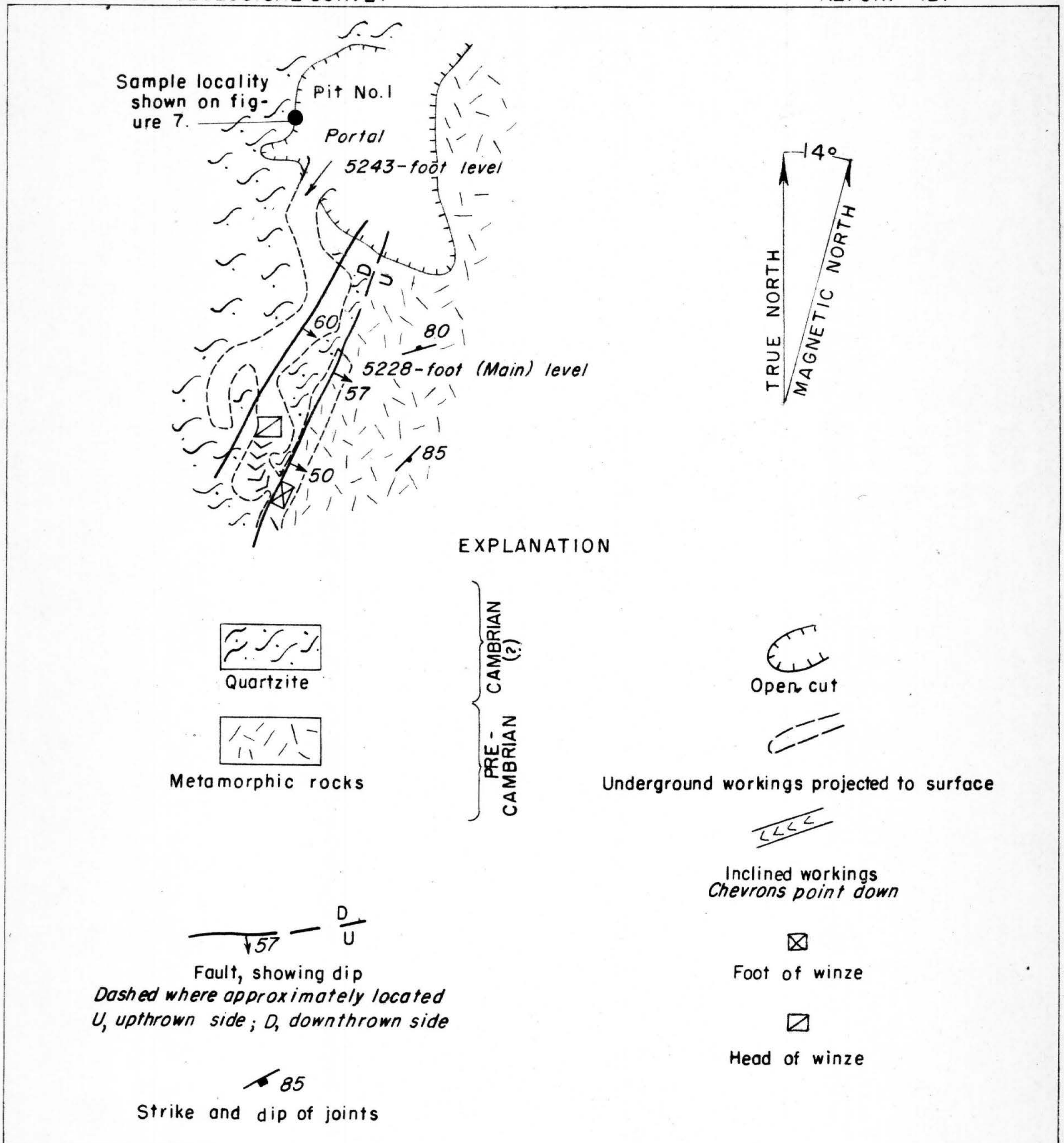


Geology by V. R. Wilmarth, August 1950.

FIGURE 4.— MAP OF PART OF THE SILVER CLIFF MINE, NIOBRARA COUNTY, WYOMING, SHOWING SAMPLE LOCALITY.

40 0 80 Feet

Datum is mean sea level

Conclusions

The relatively high correlations between equivalent uranium and all of the other elements tested, with the exception of iron, suggest that these elements were introduced along the same open fractures in the relatively dense impermeable quartzite and were then deposited in films or coatings on the fractures. The brown quartzite contains a certain amount of indigenous iron oxide as shown by rounded grains of hematite in a thin section of sample F75, and the barren red quartzite represented by sample F77 contains several times as much iron, in the form of primary red hematite, as do any of the other four samples. This indigenous iron oxide could easily account for the lack of correlation between uranium and iron. Sample F77 also contains an unusually large amount of nickel (30 parts per million) and of copper (150 parts per million). Two grab samples of the red quartzite, collected from separate localities a thousand feet or more away from the mine workings, also contained about 30 parts per million of nickel and about 120 parts per million of copper. These abnormal concentrations suggest that a certain amount of copper and nickel, as well as iron, was originally present in the sediments from which the quartzite bed was derived. The close association between eU and Zn, Cu, As, Mo, and Mn in samples from this deposit suggests that some or all of these five elements might be useful as uranium indicators for prospecting covered areas in this vicinity.

Golden Gate Canyon area, Jefferson County, Colorado

The Golden Gate Canyon area is in T. 35 S., R. 70 W., Jefferson County, Colo. Most of the uranium prospects are near the bottom of the canyon at an elevation of 6,500 to 7,000 feet.

Rocks exposed in the area consist of a thick series of steeply dipping schists and gneisses of the Precambrian Idaho Springs formation. These rocks have a regional trend of about N. 80° E.; they have been cut by numerous faults and breccia reefs striking northwesterly and dipping steeply.

Pitchblende and base-metal sulfides appear to have been localized by the intersection of northwesterly-trending faults or fractures with certain favorable stratigraphic zones in the Idaho Springs formation. The uranium deposits of the Golden Gate Canyon area have been studied and described by Adams, Gude, and Beroni (1953). Two of these deposits--the Union Pacific prospect and a road cut near the portal of the Buckman adit--were sampled for this study.

Sample data

A total of ten samples was collected from the two localities examined (table 7); four of these constitute a channel sample across the radioactive zone exposed in a road cut near the portal of the Buckman adit; the other six comprise a channel sample across the uranium-bearing vein and breccia zone exposed near the collar of the shaft on the Union Pacific property.

All samples were analyzed for equivalent uranium, uranium, copper, lead, zinc, arsenic, antimony, and molybdenum.

Correlation coefficients were determined for both uranium and equivalent uranium with respect to the other six elements (table 8).

Semiquantitative spectrographic analyses were made of all ten samples in order to determine whether any elements, in addition to the six tested geochemically, showed significant relations with uranium (table 9).

Table 8.--Correlation coefficients, Golden Gate Canyon area, Jefferson County, Colorado.

(10 samples)

	Cu	Pb	Zn	As	Sb	Mo
eU	-0.24	-0.36	+0.11	+0.13	+0.17	+0.45 x
U	+ .11	+ .15	+ .02	+ .02	+ .06	+ .34

xx = probably significant
x = possibly significant

Table 7. Description and analyses[1] of samples from the Golden Gate Canyon area, Jefferson County, Colorado

Sample number	Location and type of sample		Description of sample	Analyses[2] eU	U	Cu	Pb	Zn	As	Sb	Mo
F87-TL-53	2½ feet W. of vein	6-inch horizontal channel samples, Buckman adit, vein zone	Medium dark-gray, fresh hornblende gneiss	20	<20	100	20	100	10	2	3
F88-TL-53	1½ feet W. of vein		Moderate yellowish-brown, iron-stained hornblende gneiss	50	20	50	20	150	10	3	6
F89-TL-53	3-inch channel of vein		Pale yellowish-brown, bleached, silicified hornblende gneiss	8,200	10,700	250	70	200	20	10	16
F90-TL-53	1½ feet E. of vein		Medium dark-gray, fresh hornblende gneiss	20	<20	50	30	250	10	4	1
F91-TL-53	Horizontal channel sample broken into 1-foot intervals, from 2 feet E. of vein to 3 feet W. of vein, Union Pacific prospect		Light-brown to dark yellowish-orange altered gneiss	110	120	1,300	20	500	250	100	26
F92-TL-53			Moderate-brown to grayish-orange altered gneiss	50	30	300	20	400	70	50	12
F93-TL-53			Dark yellowish-orange altered gneiss heavily coated with limonite	320	200	4,000	300	900	1,000	500	20
F94-TL-53			Light-brown to dark yellowish-orange altered gneiss	100	50	3,000	600	500	800	500	32
F95-TL-53			Same as F94	150	60	2,000	500	500	400	250	20
F96-TL-53			Same as F94-F95	50	20	2,000	300	700	500	250	20

[1] All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory

[2] Expressed in parts per million

Table 9. Spectrographic analyses of samples from the Golden Gate Canyon area, Jefferson County, Colorado.[1/]

Sample	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	Ag	As	Ba	Be	Bi	Co	Cr	Cu	Mo	Nb	Ni	Pb	Sb	Sc	Sr	U	V	Y	Yb	Zn	Zr
87	xx.o	x.o	x.o+	o.x	o.x-	x.o-	x.o-	x.-	x.o-	0	0	o.oox+	0	0	o.ooox+	o.ooox+	o.ox-	0	0	o.ooox	o.ox-	0	o.oox-	o.ox-	0	o.oox	o.oox	o.ooox-	0	o.oox+
88	xx.	x.+	x.+	.x	.ox+	x.-	.x+	x.-	.x+	0	0	.ox+	0	0	.oox-	.oox-	.oox+	Tr.	0	.ooox+	Tr.	0	.oox	.ox-	0	.oox	.oox+	.ooox+	0	.ox-
89	x.+	x.	x.+	.x-	.x	x.+	x.	x.-	x.-	Tr.	0	.oox+	o.ooox	Tr.	.ooox-	.ooox+	.ox+	Tr.	0	.ooox+	.ox-	0	.oox	.ox-	o.x+	.oox+	.ox-	.oox	0	.ox-
90	xx.	x.+	xx.	.x+	.x-	x.	x.	x.-	x.-	0	0	.ox-	0	0	.oox	.ooox+	.oox-	Tr.	0	.ooox+	.oox-	Tr.	.oox	.ox	0	.ox-	.oox	.ooox	0	.ox-
91	xx.	x.+	x.+	.x+	.x-	.x+	.x+	x.-	x.-	Tr.	0	.ox+	.ooox	0	.oox	.ooox	.x-	o.oox	0	.ooox+	.oox	0	.oox	.ox	0	.ox-	.oox+	.ooox+	Tr.	.ox-
92	xx.	x.+	x.+	.x+	.ox+	.x+	.x+	x.-	x.-	o.ooox-	0	.ox	.ooox	0	.oox	.ooox+	.x-	.oox-	0+	.ooox	.ox	0	.oox	.ox-	0	.ox-	.oox	.ooox+	o.ox	.ox-
93	xx.	x.+	xx.	.x+	.ox	.x	.x-	.x+	x.+	.oox	Tr.	.ox	.ooox	o.ox-	.oox-	.ooox+	.x	.oox+	o.oox-	.oox-	.ox-	o.ox	.oox	.ox-	0	.ox-	.oox+	.ooox+	Tr.	.ox-
94	xx.	x.+	x.+	.x	.x-	.x-	.ox+	.x	x.+	.oox-	Tr.	.ox	0	.ox	.oox-	.oox-	.x	.oox+	.oox-	.ooox+	.ox+	.ox	.oox-	.oox+	0	.ox-	.oox+	.ooox+	Tr.	.ox-
95	xx.	x.+	xx.	.x+	.x-	.x+	.x	.x+	x.+	.ooox	0	.ox+	.ooox+	.oox+	.oox	.ooox+	.x-	.oox+	.oox	.ooox+	.ox+	.ox-	.oox	.ox-	0	.ox	.oox+	.ooox+	Tr.	.ox-
96	xx.	x.+	x.+	.x+	.x-	.x+	.x+	.x+	x.	.ooox-	0	.ox-	.ooox	0	.oox	.ooox-	.x-	.oox	.oox-	.ooox+	.oox+	0	.oox	.ox-	0	.ox-	.oox	.ooox	.ox	.ox-

Looked for but not found: P, B, Cd, Ce, Ge, La, Nd, Sn, Au, Dy, Er, Gd, Hf, Hg, In, Ir, Li, Os, Pd, Pt, Re, Rh, Ru, Sm, Ta, Th, Tl, Te, W.

1/ Analyses by R. G. Havens of the U. S. Geological Survey Denver Laboratory.

Conclusions

The correlation coefficients calculated for all ten samples appear to indicate a very poor correlation between uranium and the other metals, with the possible exception of molybdenum. However, when the assay values for the various metals are plotted separately against those of uranium and equivalent uranium for the two channel samples (figs. 5 and 6), it is apparent that this is not true. In the samples both from the Buckman adit and the Union Pacific prospect, copper, lead, arsenic, and antimony as well as molybdenum tend to vary directly with uranium. The poor correlation coefficients may be explained by the fact that uranium was high relative to the other metals at the Buckman adit; at the Union Pacific prospect the reverse situation was true. When the samples from the two localities were pooled for statistical study, the highest uranium assays did not correspond to the highest assays for the other metals; consequently, the correlation coefficients for the pooled sample were much lower than they would have been for either deposit, had the samples not been combined. This indicates a pitfall to be avoided in the application of correlation coefficients to assay data. If too many samples from different localities are combined in an effort to obtain a significantly large number of analyses for statistical treatment, the resulting correlation coefficients may obscure rather than emphasize the relationships sought.

A study of the semiquantitative spectrographic analyses (table 9) suggests that silver, bismuth, yttrium, and ytterbium may also be closely associated with uranium in these deposits.

Diamond J Ranch, El Paso County, Colorado

The Diamond J Ranch is about 10 miles north-northeast of Colorado Springs in T. 12 S., R. 66 W. The deposit on the north face of a low hill at an elevation of about 6,500 feet was discovered in 1951 by H. E. Burgess. It is in the nearly flat-lying Dawson arkose of Tertiary age and consists of an irregular body of coarse sandstone and arkosic conglomerate heavily impregnated with iron and manganese oxide. It is very irregular in form, has a northwesterly trend, and appears to be nearly 150 feet long with a maximum width of about 25 feet and a maximum expoded thickness of about 10 feet (fig. 7).

The only report that has been written on this deposit, known to the authors, is an unpublished report by L. R. Page and G. B. Gott (1952).

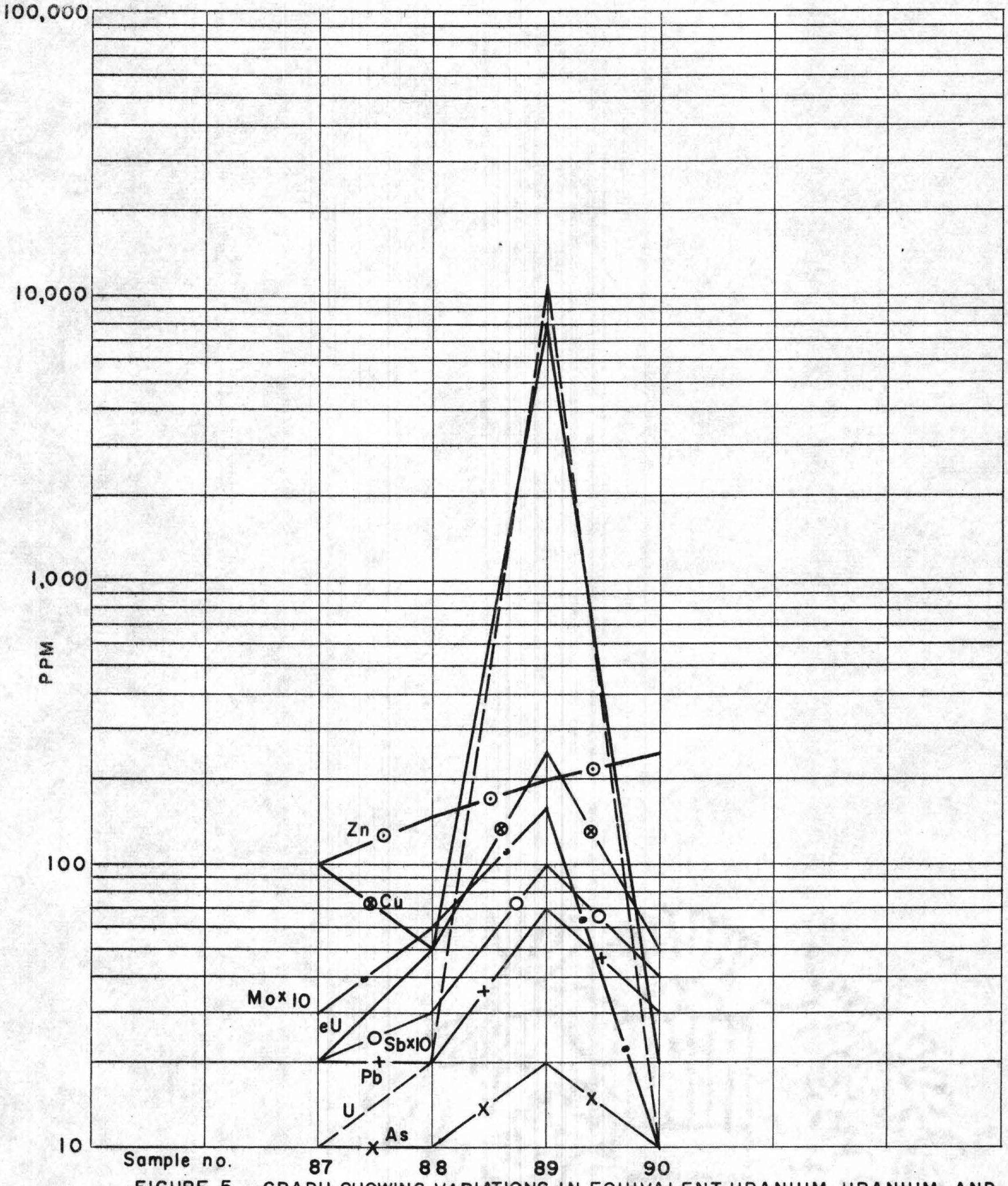


FIGURE 5 .–GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM, URANIUM, AND SELECTED METALS, BUCKMAN ADIT, GOLDEN GATE CANYON, JEFFERSON COUNTY, COLO.

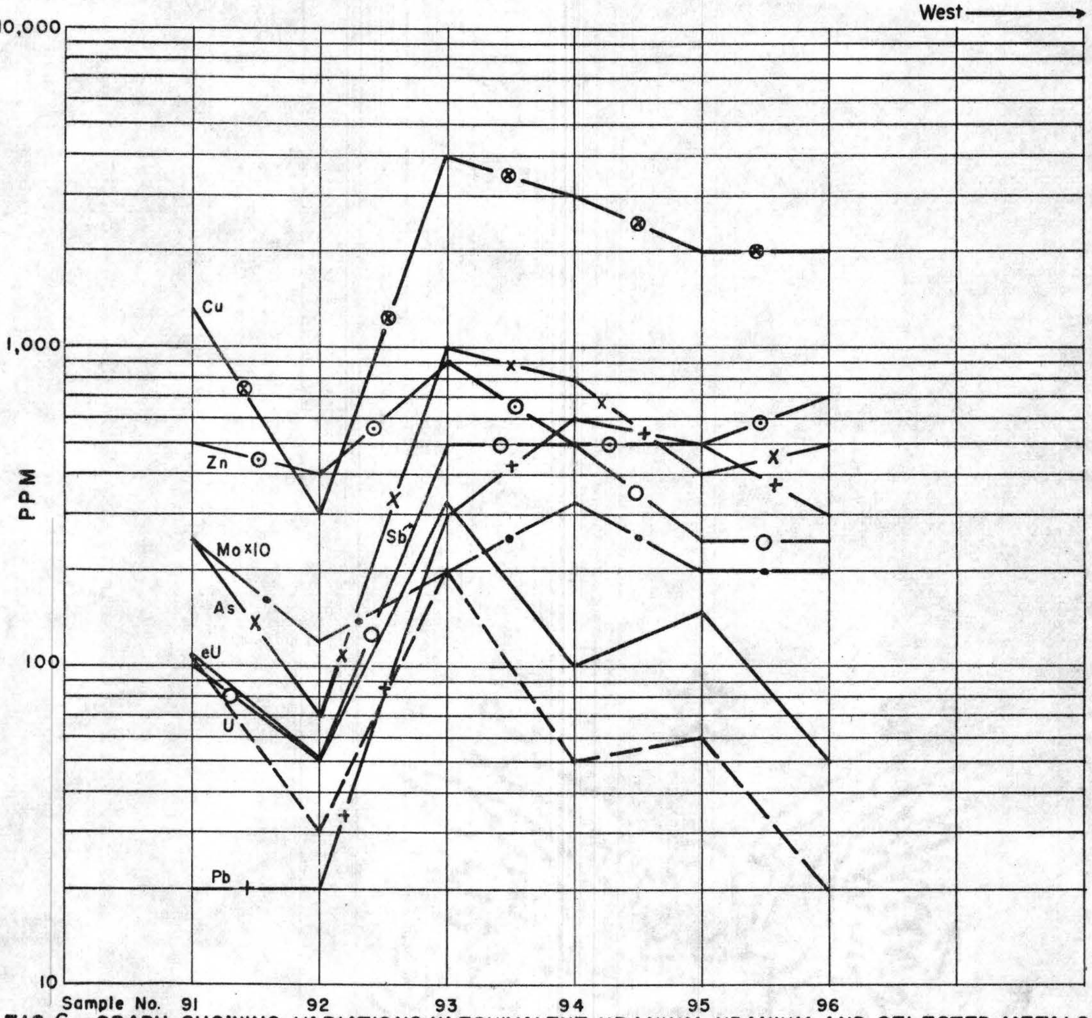
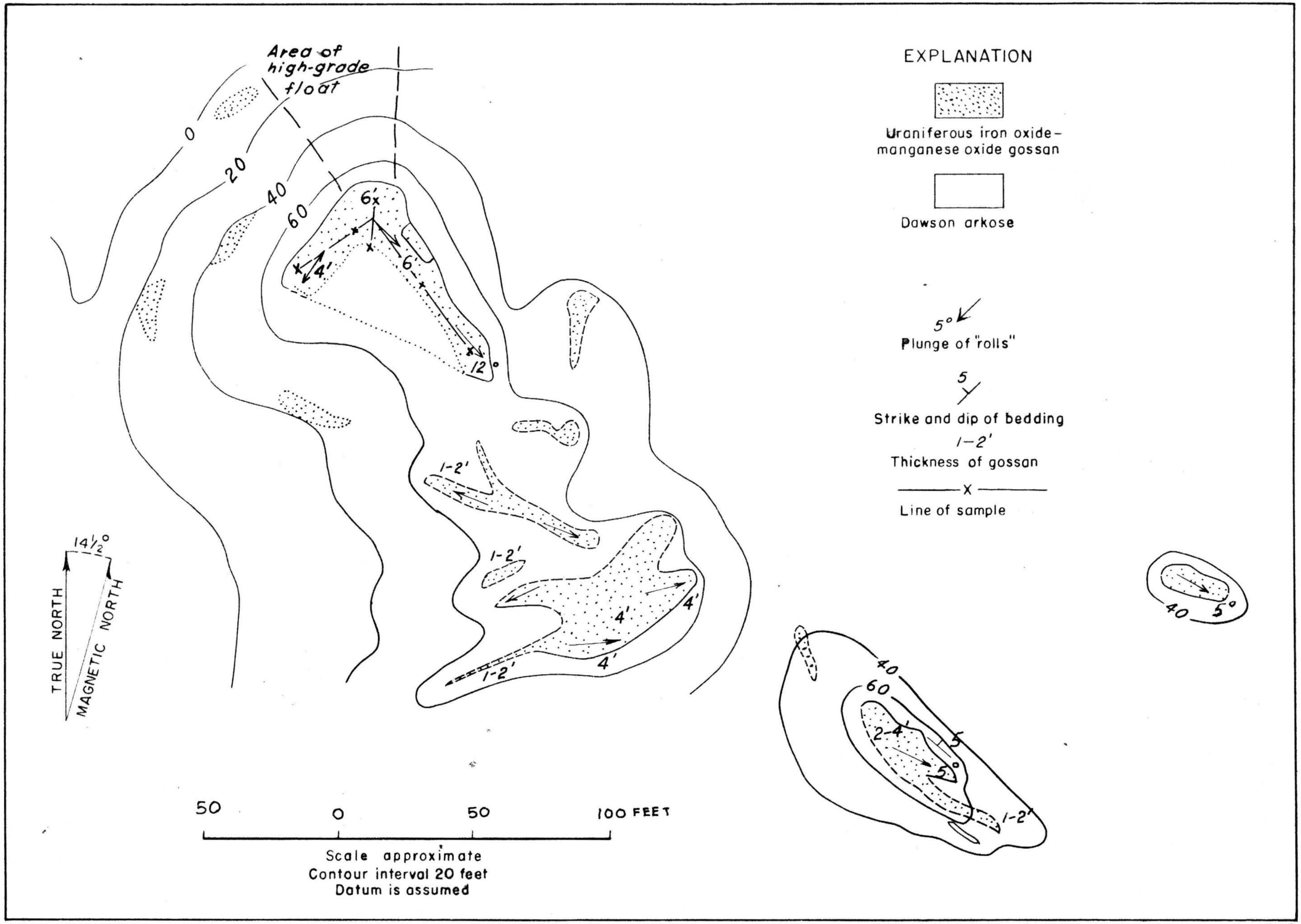


FIG. 6.—GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM, URANIUM, AND SELECTED METALS, UNION PACIFIC PROPERTY, GOLDEN GATE CANYON, JEFFERSON COUNTY, COLORADO



Geology by L.R. Page and G.B. Gott, 1952

FIG. 7.—SKETCH MAP OF RADIOACTIVE LIMONITE ZONE ON DIAMOND J RANCH, SHOWING SAMPLE LOCATIONS

Sample data

Thirteen samples were collected from the deposit. All samples were analyzed for equivalent uranium, uranium, zinc, lead, copper, nickel, cobalt, antimony, arsenic, molybdenum, manganese, and iron (table 10).

The variation in concentration of eU, U, Zn, Cu, As, Mo, Mn, and Fe for both the vertical and horizontal samples is shown in figure 8.

Correlation coefficients were calculated for copper, zinc, arsenic, molybdenum, manganese, and iron with respect to both equivalent uranium and uranium in all thirteen samples (table 11).

Conclusions

The negative or nearly random correlation of uranium and equivalent uranium with the other elements in this suite of samples is quite unusual. Field observations and petrographic studies indicate that iron and manganese oxides containing small amounts of copper, zinc, arsenic, and molybdenum were probably introduced early. The solutions from which they were deposited appear to have attacked the quartz but not the feldspar, which suggests that these solutions may have been alkaline rather than acid. At a later time, uranium and possibly silica were introduced along small fractures; the negative correlations between uranium and the other elements suggest that the other elements were locally leached out at the same time uranium was deposited, although there is no petrographic evidence of such leaching. The low U with respect to eU in these samples, particularly in sample F16, suggests leaching of uranium and residual enrichment in its daughter products. This probably represents recent groundwater action.

Table 10. Description and analyses[1] of samples from the Diamond J Ranch, El Paso County, Colorado

Sample number	Location and type of sample	Description of sample	Analyses[2]											
			eU	U	Zn	Pb	Cu	Ni	Co	Sb	As	Mo	Mn	Fe[3]
F4-TL-53	1-foot channel, top of cliff near W. end of deposit	Moderate grayish-brown, coarse sandstone and arkose	60	50	150	50	50	<10	10	<1	60	3	25,000	165
F5-TL-53	1-foot channel 1 foot below F4	Pale-brown, very coarse sandstone	70	50	150	<10	20	<10	<10	1	40	1	1,500	165
F6-TL-53	1-foot channel 2 feet below F4	Moderate yellowish-brown to dusky-brown, very coarse sandstone	140	50	140	<10	20	<10	<10	1	<10	6	2,500	155
F7-TL-53	1-foot channel 3 feet below F4	Dark yellowish-orange to light-brown, medium coarse sandstone	230	130	120	<10	20	<10	<10	<1	<10	3	1,000	105
F8-TL-53	1-foot channel 4 feet below F4	Dark yellowish-orange, coarse sandstone and arkose	210	140	60	<10	20	<10	<10	<1	40	1	1,000	48
F9-TL-53	1-foot channel 5 feet below F4	Dark yellowish-brown to grayish-brown, coarse sandstone and arkose	100	70	130	<10	50	<10	<10	1	40	3	7,500	190
F10-TL-53	Grab sample, near F9	Moderate brown arkose with dusky brown coating	300	180	130	<10	20	<10	<10	1	80	1	1,500	230
F11-TL-53	1-foot channel, cliff at E. end of deposit	Moderate yellowish-brown to grayish-brown, coarse arkose	120	70	120	<10	20	<10	<10	1	100	1	5,000	150
F12-TL-53	1-foot channel 25 feet W. of F11 and 25 feet E. of F7	Same as F11	140	70	120	<10	20	<10	<10	1	80	3	15,000	165
F13-TL-53	Grab sample, fracture coating 1½ feet W. of F8	Moderate brown to dusky brown, coarse arkose	130	50	100	<10	20	<10	<10	<1	20	6	7,500	190
[4]F14-TL-53	1-foot channel, W. end of deposit, 25 feet W. of F7	Dusky brown, coarse sandstone and arkose	130	100	130	<10	<10	<10	<10	1	<10	<1	10,000	165
F15-TL-53	Grab sample	Grayish-brown to dusky-brown, coarse sandstone with dusky-brown fracture coating	300	140	120	<10	<10	<10	<10	<1	<10	<1	10,000	105
[4]F16-TL-53	Grab sample	Moderate brown to dusky-brown arkose with dusky-brown radioactive fracture coating	1,300	60	180	<10	<10	15	<10	1	30	3	2,000	190

[1] All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory

[2] In parts per million

[3] In thousands of parts per million

[4] For petrographic description see Table 21

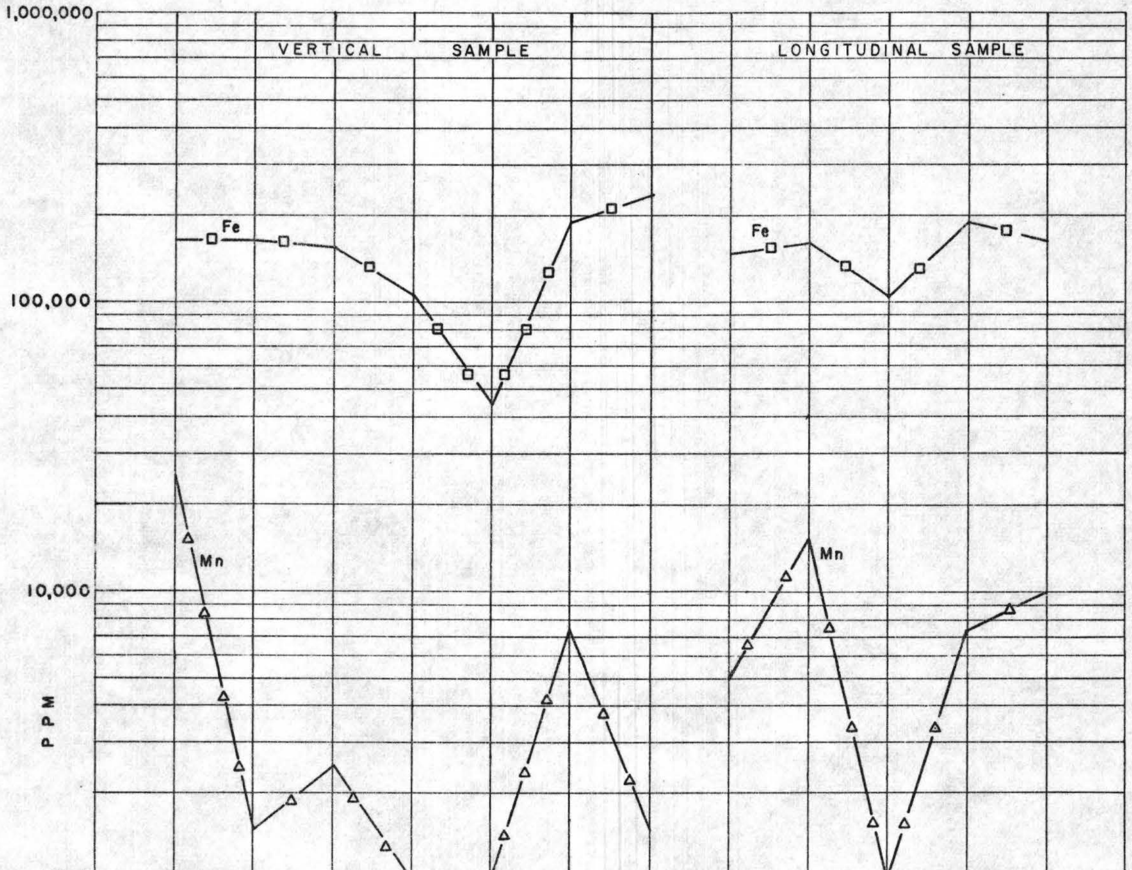


FIG. 8 .- GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM, URANIUM, AND SELECTED METALS IN SAMPLES TAKEN LONGITUDINALLY AND VERTICALLY ACROSS RADIOACTIVE ZONE, DIAMOND J RANCH, EL PASO COUNTY, COLORADO

Table 11.--Correlation coefficients, Diamond J Ranch, El Paso County, Colorado.

(13 samples)

	Cu	Zn	As	Mo	Mn	Fe
eU	-0.66xx	+0.13	-0.16	-0.12	-0.39x	-0.09
U	-.27	-.30	-.15	-.55xx	-.31	-.34

xx = probably significant
x = possibly significant

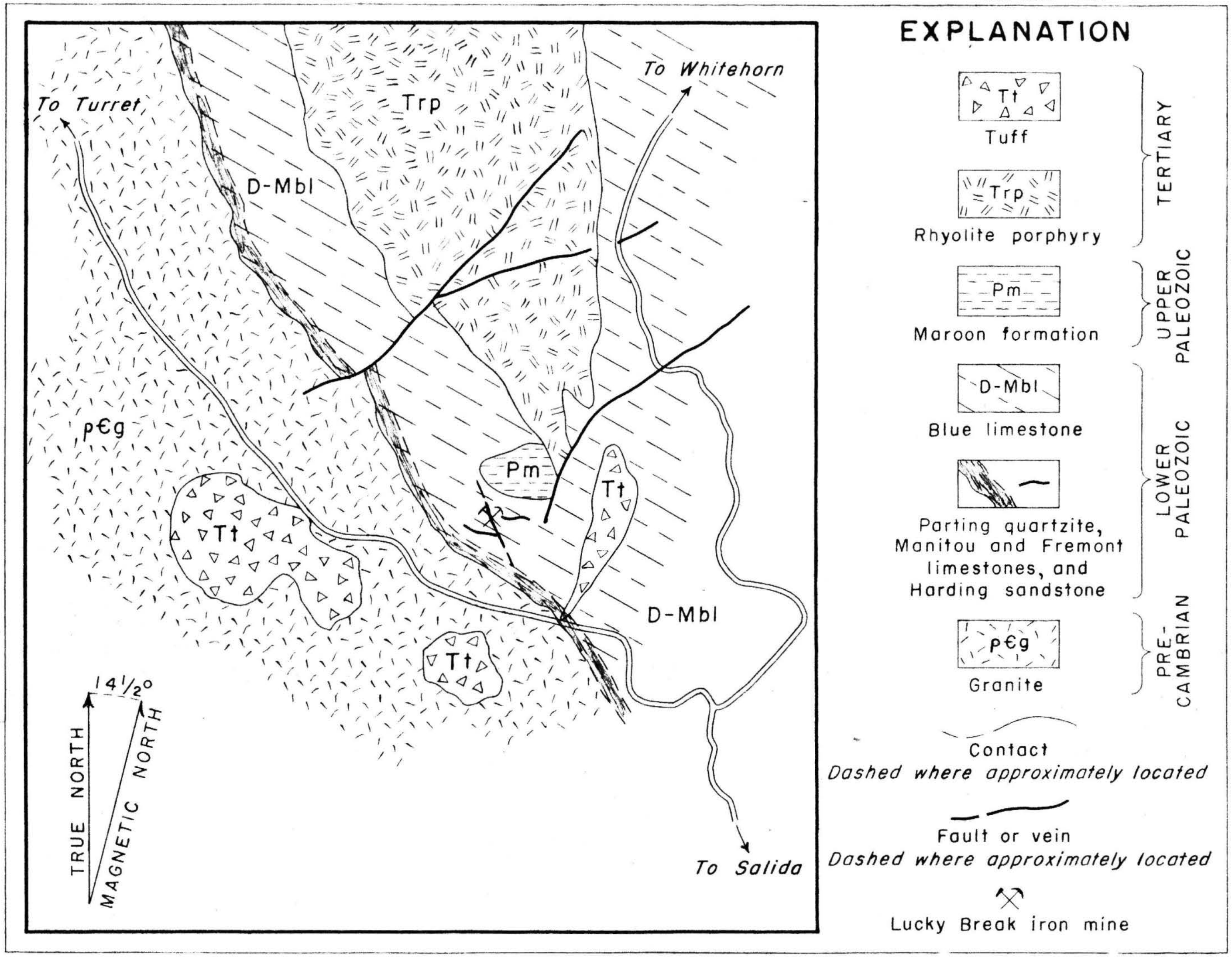
Lucky Break iron mine, Chaffee County, Colorado

The Lucky Break iron mine is about a mile northwest of the junction of the Turret and Whitehorn roads in Chaffee County, Colo. The deposit is at an elevation of approximately 9,000 feet, just south of the crest of a small ridge. In the vicinity of the mine, dark irregular bands of massive red and black iron oxides have replaced limestone of Devonian or Mississippian age. This limestone has been intruded by a large rhyolite porphyry sill a few hundred feet northeast of the mine (fig. 9).

According to K. G. Brill (1948) the deposit is cut and offset by a north-northwesterly trending normal fault dipping steeply to the east. Intense alteration in the vicinity of the mine appears to have obscured this fault.

Development on the property in June 1953 consisted of a large glory hole roughly 150 feet in diameter and 100 feet deep with a short adit providing access from a haulage road to the bottom of the pit on the south side.

The surrounding area has been studied by W. R. Griffitts, who accompanied the senior author to this locality in June 1953.



Generalized from geology on an aerial photograph, by W. R. Griffitts, 1950

FIGURE 9.-SKETCH MAP SHOWING GENERAL GEOLOGY AROUND LUCKY BREAK IRON MINE, CHAFFEE COUNTY, COLORADO

1500 0 3000 Feet

Approximate scale

Sample data

Four samples were collected from the south wall of the pit a few feet west of the adit (table 12). All four were analyzed radiometrically for equivalent uranium and spectrographically for 36 elements; X-ray (powder diffraction) studies were also made on all four samples in order to verify the major mineral constituents (table 13).

Conclusions

There is little to distinguish megascopically the radioactive from the non-radioactive material in this deposit. Examination of the mine walls with a Geiger counter suggests that the most highly radioactive material is localized along late fractures, and examination of sections cut from the most radioactive specimen shows that small fractures filled with late quartz are more common than in the sections cut from non-radioactive material. A study of the spectrographic data indicates a tendency toward enrichment in Cu, Zn, Co, Be, and Y, and depletion in Al, Ti, Ca, Mg, Na, K, Ba, Sr, Ga, and Zr in the more radioactive material.

It thus seems probable that uranium was introduced late, after the original replacement of limestone by iron oxide. The data suggest that the uranium was probably introduced along small fractures in the previously formed iron-oxide body by solutions high in silica and containing minor amounts of copper, zinc, and cobalt. If this hypothesis is correct, it could indicate the proximity of a uraniferous base-metal sulfide body, from which these solutions were derived.

Ouray hot springs, Ouray County, Colorado

The Ouray hot springs deposits are near the bottom of a steep walled canyon near the southwestern edge of Ouray, Colorado, just east of the Uncompahgre River, at an elevation of 7,700 feet.

Table 12. Description and radioactivity and X-ray analyses of samples from the Lucky Break iron mine, Chaffee County, Colorado

Sample number	Location and type of sample	Description of sample	Analyses 1/ eU (percent)	Analyses 1/ Mineral constituents
F1-TL-53	Grab samples 10 feet W. of adit on south wall of pit	Moderate reddish-brown to dusky-red, fine-grained hematitic iron ore	0.002	Hematite
2/ F1A-TL-53		Blackish-red ore with moderate reddish-orange and dark yellowish-orange bands	.002	Hematite, goethite
2/ F2-TL-53	Grab samples, fracture zone, 5 feet W. of adit on south wall of pit	Dusky-red fine-grained hematitic iron ore	.018	Hematite, goethite, quartz
2/ F3-TL-53		Same as F2	.069	Hematite, quartz

1/ Analyses by E. J. Fennelly and W. F. Outerbridge of the U. S. Geological Survey Denver Laboratory

2/ For petrographic description see table 21

Table 13. Spectrographic analyses of samples from the Lucky Break iron mine, Chaffee County, Colorado.[1/]

Sample number	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	Ag	As	B	Ba	Be	Bi	Ce	Co
F1	xx.o	x.o+	x.o-	o.x	o.ox	o.ox+	o.x	o.x-	x.o-	--	--	o.ox-	o.ox+	--	--	--	o.oox-
F1A	xx.	x.	xx.	.x	.oox-	.ox+	.x	.x-	x.-	--	--	.oox+	.ox	--	--	--	.ooox+
F2	xx.	x.-	xx.	.x-	.x-	.ox	.x-	.ox+	.x+	--	--	.oox	.ox-	o.ooox	--	--	.ox-
F3	xx.	x.-	xx.	.x-	.ox-	.ox	.x-	.ox+	.x+	--	--	.oox	.ox-	.ooox	--	--	.oox

Sample number	Cr	Cu	Ga	La	Mo	Nb	Nd	Ni	Pb	Sb	Sc	Sr	Th	U	V	Y	Yb	Zn	Zr
F1	o.oox+	o.oox-	o.ooox	--	--	--	--	o.oox+	Tr.	--	o.ooox+	o.ox-	--	--	o.ox-	o.ooox+	o.ooox-	--	o.ox
F1A	.oox	.ooox-	.ooox	--	o.oox	Tr.	--	.oox	Tr.	--	.oox-	.ox-	--	--	.oox	--	.ooox-	--	.ox
F2	.oox	.oox+	Tr.	--	.oox	Tr.	--	.ox	Tr.	--	.oox-	.oox	--	--	.oox	.oox	.ooox	o.x-	.ox-
F3	.oox	.oox	Tr.	--	.oox	Tr.	--	.oox+	Tr.	--	.oox-	.oox-	--	--	.oox-	.oox-	.ooox	.ox	.ox-

1/ Analyses by R. G. Havens of the U. S. Geological Survey Denver Laboratory.

The tufa deposits from the springs are interbedded with Quaternary stream gravel and overlie Mississippian Ouray limestone on the northwestern side of the northeasterly trending Ouray fault. This fault brings the Ouray limestone down against Precambrian slates and phyllites on the southwest.

The Ouray hot springs are in the area described in Burbank's report (Burbank, 1940), and their location is shown on his map. These deposits are briefly described in a later report by Burbank and Pierson (1953).

Sample data

Five samples of tufa were collected from two localities 100 yards apart. Three samples of tufa were collected near the fault about 250 feet southeast of the bridge where the Canyon Creek road crosses the Uncompahgre River; the other two were from the east bank of the river about 50 feet north of this bridge. All five samples were analyzed for eU, U, Zn, Pb, Cu, Ni, Co, Mo, As, Sb, V, Mn, and Fe. The uranium content of all samples was <20 ppm and the copper and nickel content was <10 ppm. Results of the other analyses are shown in table 14.

Correlation coefficients were determined for zinc, antimony, arsenic, molybdenum, manganese, and iron with respect to equivalent uranium in all 5 samples (table 15).

Table 15.--Correlation coefficients, Ouray hot springs, Ouray, Colorado.

(5 samples)

	Zn	Sb	As	Mo	Mn	Fe
eU	$+0.69^{xx}$	-0.06	$+0.47^{x}$	$+0.70^{xx}$	$+0.72^{xx}$	$+0.31$

xx = probably significant

x = possibly significant

Table 14. Description and analyses[1] of samples from the Ouray hot springs tufa deposit, Ouray, Colorado.

Sample number	Location and type of sample	Description of sample	Analyses[2]										
			eU	U	Zn	Pb	Co	Sb	As	Mo	V	Mn[3]	Fe[3]
[5]F49-TL-53	Grab samples	Black and light-brown porous tufa	1,300	<20	500	<10	10	4	1,000	100	--[4]	300	50
F50-TL-53	from tufa deposit	Moderate yellowish-brown, porous laminated	80	<20	150	50	10	3	150	1	<300	20	13
	about 250 feet	tufa											
[5]F51-TL-53	S.E. of the	Dark yellowish-brown porous tufa	20	<20	50	<10	<10	3	150	<1	<300	10	13
	bridge												
F52-TL-53	Grab samples	Dark yellowish-orange, less porous tufa	90	<20	500	<10	<10	100	2,000	20	--[4]	5	300
F53-TL-53	from tufa deposit	Black and moderate-brown, less porous	280	<20	150	20	<10	4	400	6	600	350	34
	50 feet N. of	tufa											
	the bridge												

[1] All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory.

[2] Expressed in parts per million

[3] In thousands of parts per million

[4] --indicates concentration indeterminate because of interference

[5] For petrographic description see Table 21

One sample of radioactive tufa collected from this deposit by Burbank and Pierson was analyzed for uranium and equivalent uranium and also submitted to semiquantitative spectrographic analyses. This sample contained 0.11 percent eU and 0.001 percent U. Other elements detected were present in the following concentrations:

PPM	Element
XX.	Mn
X.	Si, Fe, Ca, Ba, Sr, W
.X	Al, Mg, Na, As
.OX	Ti, Be, Cu, Mo, Sb, Ti, V, Zn
.OOX	Co, Pb, Zr
.OOOX	Cr

Conclusions

The colloidal texture of manganese oxide, evident in polished sections, together with the high positive correlation between equivalent uranium and manganese, suggests that the radioactive element was adsorbed by colloidal manganese oxide hydrate and precipitated with it. The high ratio of equivalent uranium to uranium suggests that the radioactive element now present in these deposits is probably radium. The unusually large amounts of W, Mo, As, Sb, and Zn in these samples also suggest the possibility of a uraniferous base-metal sulfide ore body in the vicinity, from which radium has been leached by the hot spring waters. Several silver-lead-zinc deposits occur in the Paleozoic rocks near the Ouray fault, within a mile of the Ouray hot springs (Burbank, 1940).

Haputa Ranch area, Custer County, Colorado

The Haputa Ranch area is in the western foothills of the Wet Mountains 4 miles east-northeast of Querida in Custer County, Colo. The deposit, examined and sampled in detail, was a small open cut at an elevation of about 9,250 feet. The deposit is in a northwesterly-trending shear zone cutting Precambrian amphibolite which has been intruded by a biotite granite gneiss about 25 feet south of the shear zone. An andesite dike, striking parallel to the shear zone, cuts the amphibolite near its contact with the gneiss (fig. 10). Drill hole data indicate that this dike crosses the shear zone at a depth of approximately 100 feet.

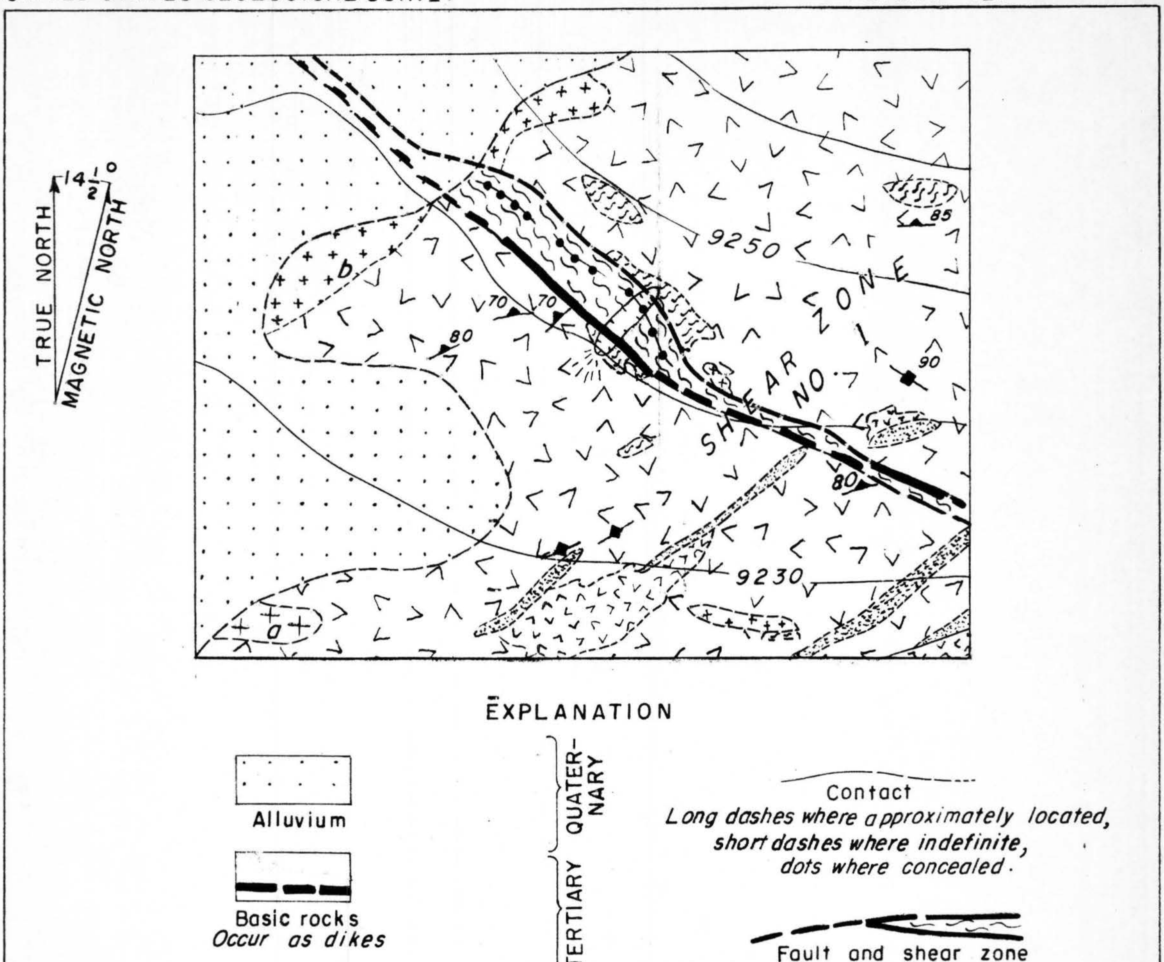
This locality has previously been examined by Christman, Heyman, Dellwig and Gott (1953) and it is described in their report.

Sample data

Eleven samples were collected from the Haputa Ranch area. All eleven samples were analyzed radiometrically for equivalent uranium and geochemically for zinc, lead, copper, nickel, cobalt, arsenic, antimony, molybdenum, vanadium, manganese, and iron. In addition, three of the more radioactive samples were analyzed chemically for thorium. The results of these analyses are shown in table 16.

A special sample of the thorium-bearing mineral was analyzed spectrographically by Katherine E. Valentine of the U. S. Geological Survey, and the results of this analysis were made available by R. A. Christman. The analysis shows the following components:

Percent	Element
XX.	Th, Si
X.	Fe
.X	Cu, Ce, La, Y, Ca, Ba, Nd, Pb
.OX	Al, Pr, Ni, Co, Dy, Gd, Er, B, Yb, Lu, Eu
.OOX	Mn, Mo, Sr, Zr, V, Sc, Be, Mg
.OOOX	Cr, Ti, Ag



Geology by R.A. Christman and A.M. Heyman, June 1952.

FIGURE 10.– GEOLOGIC MAP OF PART OF THE HAPUTA RANCH, CUSTER COUNTY, COLORADO

100 50 0 200 Feet

Contour interval 10 feet
Datum is assumed

Table 16. Description and analyses[1] of samples from the Haputa Ranch area, Custer County, Colorado

Sample number	Location and type of sample	Description of sample	eU	Zn	Pb	Cu	Ni	Co	As	Sb	Mo	V	Mn	Fe[3]
			Analyses[2]											
[5]F17-TL-53	Grab sample, vein on Rare Earth Special No. 1 claim	Light-brown and dark reddish-brown, silicified vein material	630	2,500	50	70	15	30	10	2	32	300	7,500	230
F18-TL-53	1-foot channel, 1 foot S. of shear zone, cut above DDH 8, Haputa Ranch	Dark yellowish-brown, altered amphibolite, with dark yellowish-orange limonite coating fractures	50	200	<10	70	50	<10	30	1	<1	1,500	1,500	82
F19-TL-53	1-foot channel, S. wall of shear zone, 1 foot N. of F18	Similar to F18 but locally impregnated with moderate red hematite (?) or thorite	60	180	20	70	40	<10	20	1	<1	3,000	1,000	88
[5]F20-TL-53	1-foot channel 2 feet N. of F18	Altered amphibolite, stained with dusky-brown and yellowish-orange limonite cut by pale reddish-brown siliceous veinlets	40	150	<10	130	30	<10	10	<1	<1	1,500	1,000	88
F21-TL-53	1-foot channel 3 feet N. of F18	Dark yellowish-brown and light-brown, brecciated, altered amphibolite	260	500	100	70	60	10	30	<1	3	600	2,000	72
F22-TL-53	1-foot channel 4 feet N. of F18	Dusky-brown to moderate yellowish-brown and dark reddish-brown altered amphibolite with slickenside surfaces	930	800	500	70	50	<10	40	1	1	1,500	1,500	60
F23-TL-53	1-foot channel 5 feet N. of F18	Moderate yellowish-brown, silicified altered amphibolite	540	400	2,000	50	30	<10	30	2	6	600	1,500	96
F24-TL-53	1-foot channel 6 feet N. of F18	Dark yellowish-orange, altered amphibolite	(6,300)[4] 1,400	200	500	100	30	20	60	3	1	600	1,500	52
[5]F25-TL-53	1-foot channel, N. wall of shear zone 7 feet N. of F18	Dusky-brown vein filling and amphibolite breccia, with local spots of moderate red to dusky-red thorite (?)	(18,000)[4] 3,800	400	2,500	100	30	10	40	2	1	600	1,500	105
F26-TL-53	1-foot channel, wall rock 8 feet N. of F18	Moderate yellowish-brown, altered amphibolite	40	100	50	70	15	10	<10	<1	<1	3,000	1,000	96
F86-TL-53	Grab sample, prospect pit E. of DDH 8	Light-gray, moderate-brown, and dark reddish-brown vein breccia with bladed texture in some fragments	(127,000)[4] 36,000	150	50	150	<10	<10	80	5	<1	600	500	90

[1] All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory

[2] In parts per million

[3] In thousands of parts per million

[4] Figures in parentheses are chemically determined thorium

[5] For petrographic description see Table 21

An exploratory diamond drill hole cut the shear zone at a depth of 140 to 160 feet beneath the exposure from which samples F18-F26 were taken. The core from this hole was analyzed spectrographically by G. W. Boyes of the U. S. Geological Survey. Table 17 indicates the concentrations of the same elements in the drill core for which goechemical assays were made on samples from the outcrop. The corrected sample lengths and equivalent uranium concentration of drill core samples were taken from Circular 290, table 5, p. 14 (Christman and others, 1953).

The variations in concentration of equivalent uranium and selected elements in the 9-foot horizontal channel sample taken at the outcrop, are shown in figure 11. Only those elements are graphed that showed significant changes in concentration.

Correlation coefficients were determined for zinc, lead, copper, nickel, arsenic, antimony, vanadium, and manganese with respect to equivalent uranium in all eleven samples for which geochemical assay data are available (table 18).

Table 18.--Correlation coefficients, Haputa Ranch area, Custer County, Colorado.

(11 samples)

	Zn	Pb	Cu	Ni	As	Sb	V	Mn
eU	+0.21	+0.76^{xx}	+0.53^{xx}	-0.48^{x}	+0.67^{xx}	+0.77^{xx}	-0.59^{xx}	-0.11

xx = probably significant

x = possibly significant

Conclusions

Much of the quartz has a rosy color due apparently to submicroscopic particles of red hematite or thorite. The theory that these submicroscopic particles are radioactive is substantiated by the comparison of a polished section of high-thorium material from locality F25 with an autoradiograph made from the polished section (fig. 12).

Table 17.--Spectrographic analyses of selected elements in drill core from mineralized shear zone, Haputa Ranch, Custer County, Colorado 1/

Sample length (feet)	eU	Zn	Pb	Cu	Ni	Co	As	Sb	Mo	V	Mn	Fe
4.0	60	< 0.0x	Trace	0.00x	0.00x-	0.000x+	< 0.x-	< 0.0x	Trace	0.00x+	0.0x+	x.0
.7	1,300	< .0x	0.0x-	.00x	.00x	.00x-	< .x-	< .0x	0	.00x+	.0x+	x.
.2	30	< .0x	Trace	.00x-	.00x	.000x+	< .x-	< .0x	0.00x-	.00x+	.0x	x.
.7	360	< .0x	.00x	.00x	.00x	.00x-	< .x-	< .0x	0	.00x+	.0x+	x.
1.1	50	< .0x	Trace	.00x	.00x	.00x-	< .x-	< .0x	.00x-	.00x+	.0x	x.
2.2	970	< .0x	.00x+	.00x+	.00x+	.00x-	< .x-	< .0x	0	.00x+	.0x	x.
1.4	400	< .0x	Trace	.00x-	.00x	.000x+	< .x	< .0x	0	.00x+	.0x-	x.
.4	2,900	< .0x	.00x	.00x	.00x+	.000x+	< .x-	< .0x	0	.0x-	.0x-	x.+
.8	320	< .0x	.00x+	.00x+	.00x	.00x-	< .x-	< .0x	0	.0x-	.0x+	x.
3.9	50	< .0x	.00x	.00x	.00x	.00x-	< .x-	< .0x	Trace	.0x-	.0x+	x.
8.0	30	< .0x	Trace	.00x+	.00x	.00x	< .x-	< .0x	.00x-	.0x-	.0x+	x.+

1/ Analyses by R. G. Havens of the U. S. Geological Survey

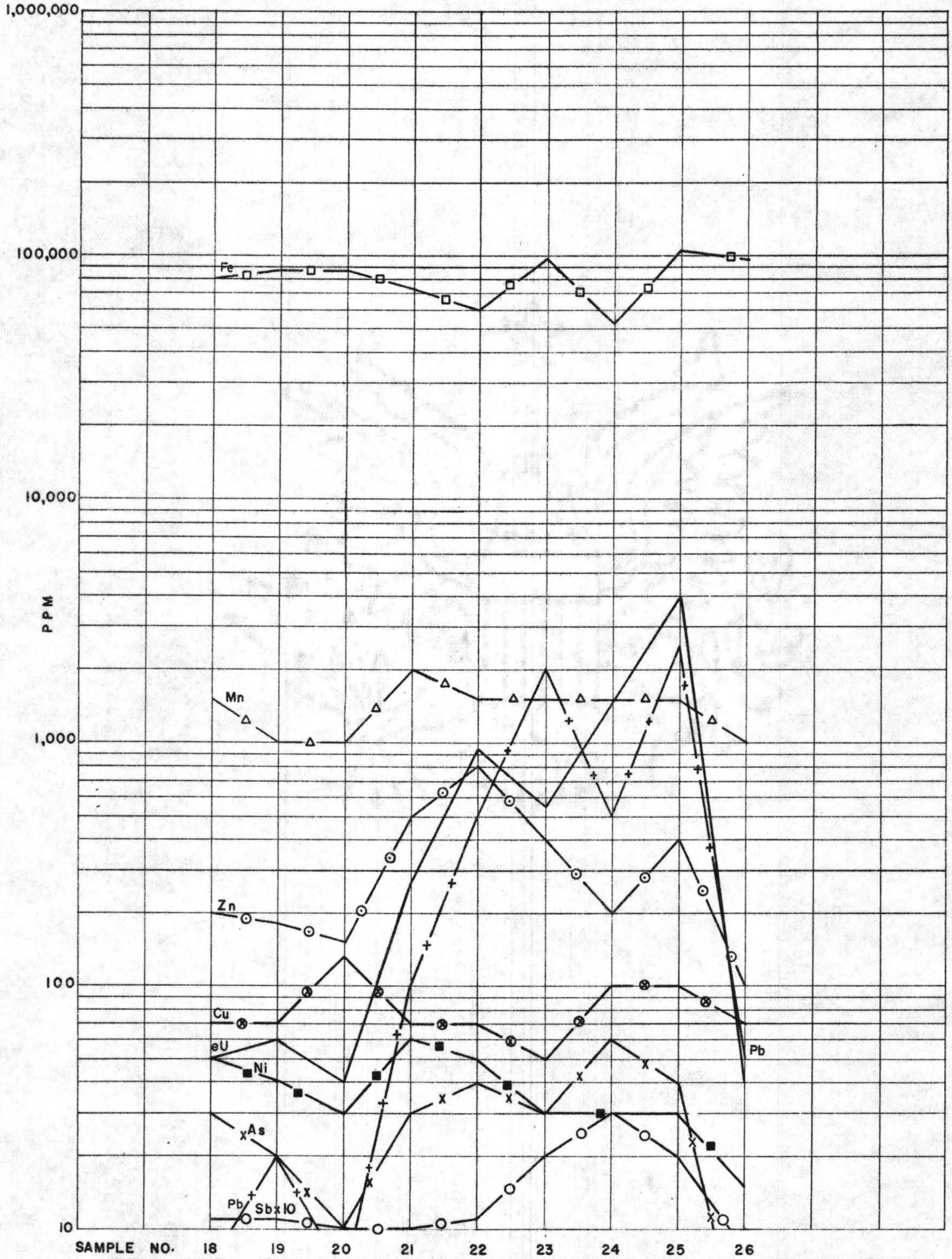


FIG. 11.-GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM AND SELECTED METALS IN SAMPLE TAKEN ACROSS RADIOACTIVE SHEAR ZONE, HAPUTA RANCH, CUSTER COUNTY, COLORADO

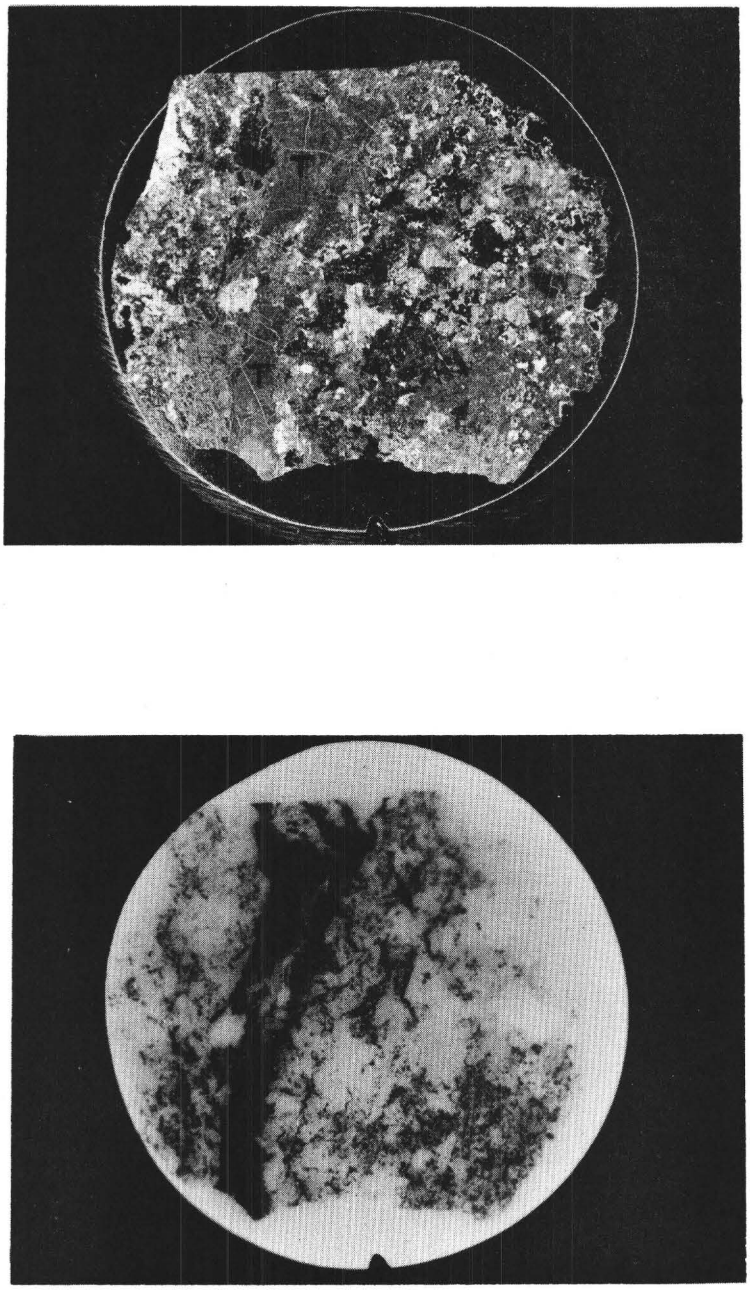


Figure 12. Photograph and autoradiograph of polished section of sample containing massive thorite (T), quartz with disseminated thorite, and limonite, from radioactive shear zone, Haputa Ranch, Custer County, Colorado. (X about 3.7)

The apparent dispersion through quartz of a thorium mineral in submicroscopic particles in some of the samples suggests that thorium may have been introduced in solution by hot silica-bearing waters and that some of it precipitated simultaneously with the quartz. The high positive correlation between equivalent uranium and lead, copper, arsenic, and antimony suggests that either these elements are present in the thorium minerals or that they form other minerals, probably sulfides, which are closely associated with the thorium minerals. The former hypothesis appears to be partly substantiated by the relatively high concentrations of lead and copper reported in the analysis of the pure thorium-bearing mineral, and by the high correlation coefficients coupled with low concentrations of antimony and arsenic. 1/ A comparison of the assay data from the drill core samples indicates a tendency toward enrichment in lead, vanadium, and manganese near the surface but little change in the concentration of equivalent uranium (which is directly proportional to thorium in this area), copper, nickel, cobalt, molybdenum, and iron from the surface to a depth of 150 feet.

Powderhorn district, Gunnison County, Colorado

The Powderhorn district is in T. 47 N., R. 2 W., Gunnison County, Colo., at an average elevation of about 9,000 feet. Thorium occurs in scattered pods and lenses in prominent northeasterly-trending silicified shear zones cutting Precambrian schist and gneiss. The surface exposures of these zones are heavily stained with hematite and limonite, and the country rock near them commonly has a bleached appearance.

The Precambrian rocks of this area are described by J. F. Hunter (1925), and the thorium deposits have been studied by Olson and Wallace (in preparation).

1/ These two elements cannot be detected by ordinary spectrographic methods in concentrations less than 500-1,000 parts per million, so it is not surprising that they were not reported in the spectrographic analyses.

Sample data

Twenty-two samples were collected from three localities in the Powderhorn district as shown in table 19. Some of the samples of radioactive vein material contained irregular finely porous areas. Examination with a hand lens shows that many of the individual pores consist of tiny, nearly square pits. This probably reflects the former presence of pyrite.

All 22 samples were analyzed geochemically for zinc, lead, copper, nickel, cobalt, antimony, arsenic, molybdenum, vanadium, manganese, and iron. They were also analyzed for equivalent uranium, and two of the most radioactive were analyzed chemically for thorium (table 19).

The variation in equivalent uranium and some of the metals in samples taken across the Little Johnny vein and in the more widely spaced grab samples at the Jeannie No. 2 claim, is shown graphically in figures 13 and 15. The sketch section (fig. 14) illustrates the location of samples from the Jeannie No. 2 claim relative to the vein.

Correlation coefficients were determined for zinc, lead, copper, antimony, arsenic, molybdenum, vanadium, manganese, and iron on all 22 samples (table 20).

Table 20.--Correlation coefficients, Powserhorn district, Gunnison County, Colorado.

(22 samples)

	Zn	Pb	Cu	Sb	As	Mo	V	Mn	Fe
eU	+0.69[xx]	+0.71[xx]	+0.15	+0.85[xx]	+0.61[xx]	+0.31	+0.39[x]	+0.46[x]	+0.54[x]

xx = probably significant

x = possibly significant

Table 19. Description and analyses[1] of samples from the Powderhorn district, Gunnison County, Colorado.

Sample Number	Location and type of sample	Description of sample	eU	Zn	Pb	Cu	Ni	Co	Sb	As	Mo	V	Mn	Fe[3]
			Analyses[2]											
F27-TL-53	1-foot channel across Little Johnny vein 2,000 feet W. of ridge crest	Dark yellowish-orange, altered quartz-biotite gneiss	(5,500 Th) 1,200	200	400	20	10	<10	3	80	32	1,500	500	70
F28-TL-53	1-foot channel 1 foot S. of F27	Moderate reddish-brown and black, silicified quartz-biotite gneiss	50	180	<10	20	<10	<10	1	20	1	300	500	62
F29-TL-53	1-foot channel 2 feet S. of F27	Light-brown and pale yellowish-brown altered quartz-biotite gneiss	40	130	<10	40	<10	<10	<1	30	<1	600	250	37
F30-TL-53	1-foot channel 1 foot N. of F27	Moderate yellowish-brown, quartz-biotite gneiss with dark yellowish-orange fracture coatings	40	100	<10	20	<10	<10	1	20	1	600	1,000	51
F31-TL-53	1-foot channel 2 feet N. of F27	Altered gneiss with dark yellowish-orange, dark yellowish-brown, and dark reddish-brown stains	180	150	100	20	<10	<10	1	80	<1	5,000	1,500	72
F32-TL-53	2-foot channel of Little Johnny vein 25 feet E. of F27	Fractured, silicified gneiss with dark reddish-brown and light-brown stains	40	200	20	20	<10	<10	1	<10	6	<300	500	46
F33-TL-53	1-foot channel 2 feet N. of Little Johnny vein 250 feet W. of ridge crest	Light-gray gneiss with dark yellowish-brown stains on fracture surfaces	50	70	<10	50	<10	<10	1	80	2	300	500	56
F34-TL-53	1-foot channel 1 foot S. of F33	Moderate-brown silicified gneiss	40	150	50	70	<10	<10	2	40	8	300	500	39
F35-TL-53	1-foot channel of vein 2 feet S. of F33	Moderate-red, light-brown, and dark yellowish-orange, slightly porous vein material	400	250	500	50	<10	<10	1	60	8	300	750	40
[4]F36-TL-53	1-foot channel of vein 3 feet S. of F33	Dusky-red vein material with dark yellowish-orange coatings, some are slightly porous	1,300	800	300	70	15	<10	3	150	12	600	1,000	50
F37-TL-53	1-foot channel of vein 4 feet S. of F33	Same as F36	(16,000 Th) 3,500	600	400	50	<10	<10	3	200	12	1,500	1,000	69
F38-TL-53	1-foot channel of vein 5 feet S. of F33	Same as F36, F37	1,800	500	300	50	<10	<10	3	150	1	600	1,000	51
F39-TL-53	1-foot channel of wall rock 6 feet S. of F33	Light-gray silicified gneiss with light-brown to moderate yellowish-brown coatings	20	150	<10	100	<10	<10	<1	10	<1	300	1,000	49
F40-TL-53	1-foot channel of wall rock 7 feet S. of F33	Medium-gray to dark-gray gneiss cut by dark reddish-brown veinlets and coated with light-brown stains	20	70	<10	50	<10	<10	<1	20	<1	300	500	40
F41-TL-53	Grab sample 20 feet N. of vein, open cut on Jeannie No. 2 claim	Yellowish-gray, altered biotite gneiss cut by light-brown veinlets, altering to moderate yellowish-brown	20	100	<10	20	<10	<10	<1	20	1	300	250	27
F42-TL-53	Grab sample 5 feet S. of F41	Similar to F41 but veinlets are moderate yellowish-brown	10	60	<10	20	<10	<10	<1	40	2	600	500	26
F43-TL-53	Grab sample 10 feet S. of F41	Light brown to moderate brown stained, silicified gneiss	20	50	50	20	<10	<10	<1	40	6	300	500	26
[4]F44-TL-53	Grab sample 15 feet S. of F41	Moderate brown stained gneiss	30	70	20	20	<10	<10	1	100	20	600	500	36
F45-TL-53	Grab sample 20 feet S. of F41	Moderate reddish-orange, black, dark yellowish-orange, and brown silicified gneiss and vein breccia, slightly porous locally	170	60	<10	50	<10	<10	1	200	12	<300	2,500	39
[4]F46-TL-53	Grab sample of vein on Jeannie No. 2 claim 25 feet S. of F41	Moderate reddish-orange to moderate red, siliceous vein breccia in a moderate-brown, slightly porous matrix	950	150	20	100	15	<10	3	20	2	600	1,500	80
F79-TL-53	Grab sample of country rock, Little Johnny claim	Medium bluish-gray, fresh quartz-biotite gneiss with light-brown to moderate-brown fracture coatings	10	200	50	150	<10	<10	<1	<10	1	300	750	45
F85-TL-53	Grab sample of vein in upper pit, Jeannie No. 2 claim	Moderate reddish-orange and dusky red, silicified vein breccia in porous, dark yellowish-orange to moderate-brown matrix	90	130	20	100	15	<10	1	40	1	<300	1,000	31

1/All analyses by H. E. Crowe, R. F. DuFour, S. P. Furman, J. N. Rosholt, J. L. Siverly, and James Wahlberg of the U. S. Geological Survey Denver Laboratory

2/In parts per million

3/In thousands of parts per million

4/For petrographic description see Table 21

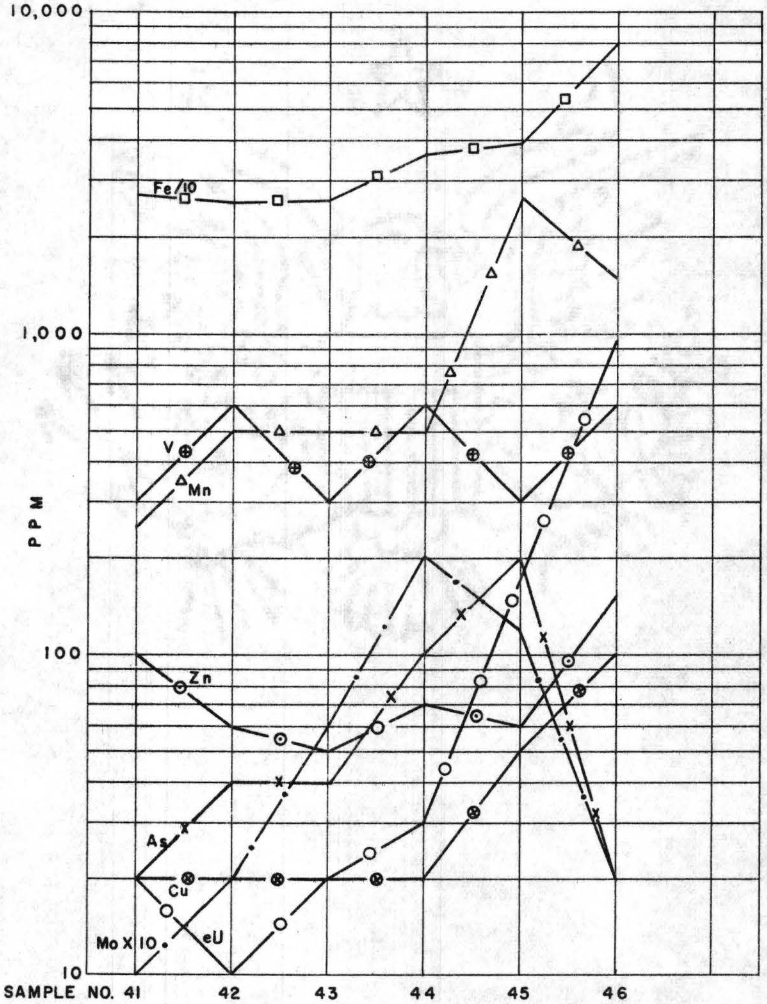


FIGURE 13.- GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM AND SELECTED METALS IN SAMPLES TAKEN AT FIVE-FOOT INTERVALS ON WALL OF CUT, JEANNIE NO. 2 CLAIM, GUNNISON COUNTY, COLORADO

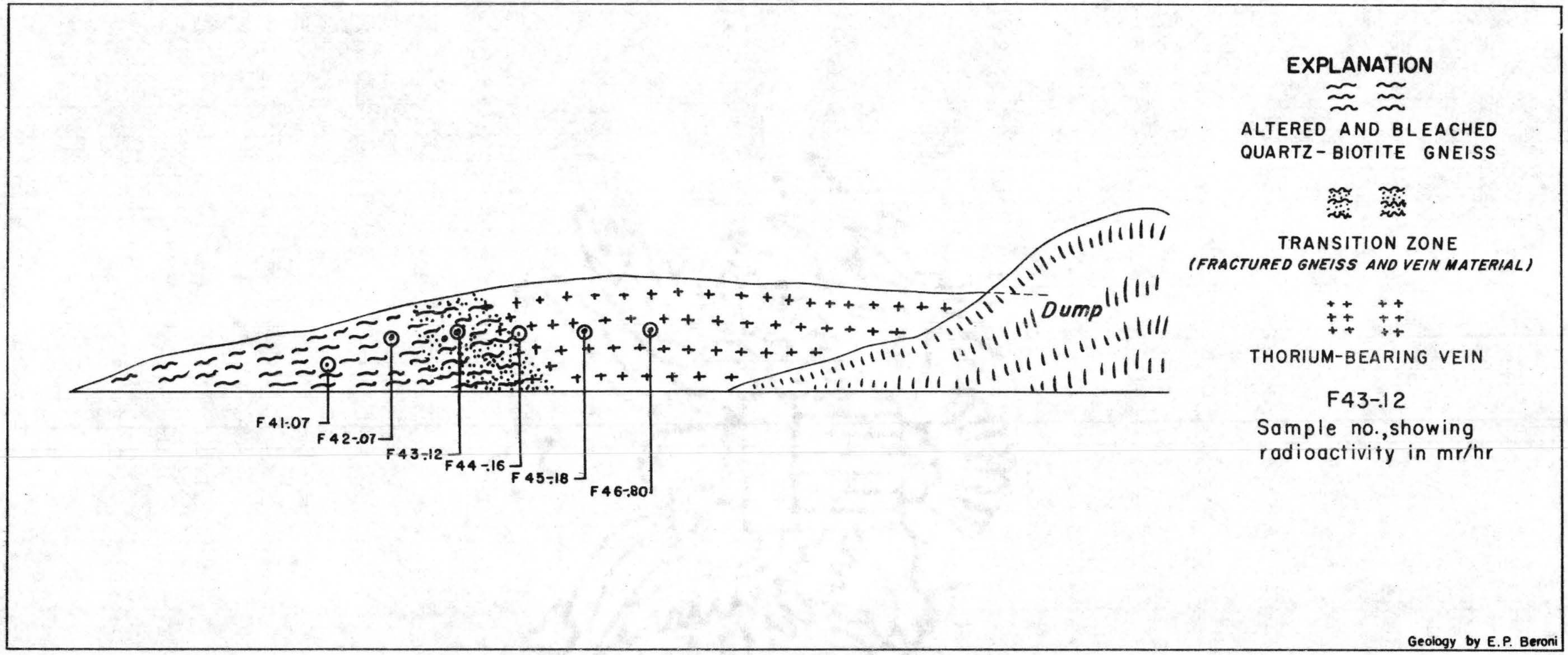


FIGURE 14—. SKETCH OF SOUTHEAST WALL OF BULLDOZER CUT, JEANNIE No. 2 CLAIM, POWDERHORN DISTRICT, GUNNISON COUNTY, COLORADO

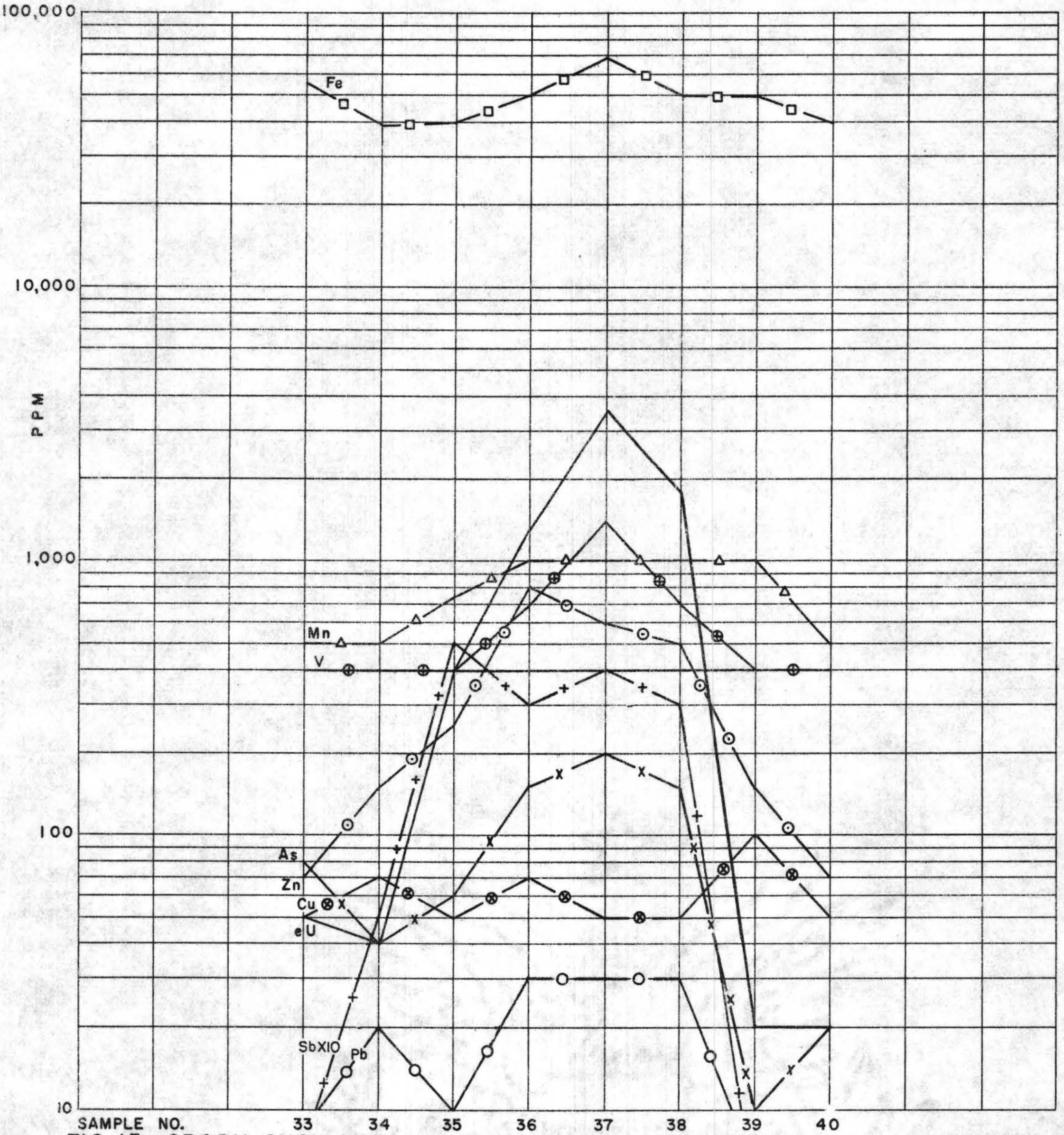


FIG. 15.- GRAPH SHOWING VARIATIONS IN EQUIVALENT URANIUM AND SELECTED METALS IN SAMPLE TAKEN ACROSS LITTLE JOHNNY VEIN, AT UPPER PIT, POWDERHORN DISTRICT, GUNNISON COUNTY, COLORADO

Conclusions

The abundance of red quartz in the high-thorium samples again indicates the possibility of submicroscopic thorium-mineral particles disseminated through the quartz and formed contemporaneously with it. There is a crude relationship between limonite colors and thorium concentration. In general, the limonite stains change from yellowish or grayish brown through light brown and moderate brown as the vein is approached, to a characteristic moderate to dusky red color in the high-thorium vein material. Petrographic studies reveal the presence of hematite pseudomorphs after pyrite in the high-thorium parts of the vein. This suggests a genetic relationship between the thorium ore and sulfide deposits at depth, which is also suggested by the relatively high correlation between eU and iron, zinc, lead, arsenic, and antimony. The arsenic and antimony appear to be present as minor constituents of the thorium mineral rather than forming separate minerals associated with it. If this were so, it would explain the high correlation of arsenic and antimony with eU, combined with their low concentrations.

SUMMARY

The results of this study indicate that preliminary sampling of radioactive limonite outcrops and geochemical analysis of the samples, followed by the determination of correlation coefficients from the assay data, may reveal important relationships between the radioactive element sought and other elements, which may be associated with it. These correlation coefficients may be used in two ways: (1) to eliminate randomly distributed elements and place emphasis on others that seem to show high correlations in further geochemical or geobotanical studies, and (2) to aid, by supplementing petrographic examination, in interpreting the origin and paragenesis of the ore deposits.

The results of petrographic studies of thin and polished sections cut from selected samples are summarized in table 21.

Table 21. Petrographic description of thin and polished sections cut from selected samples

Sample Number	Locality	Description
F1A-TL-53	Lucky Break iron mine	Grains of steel-gray hematite surrounded by red hematite rims in banded colloform goethite. Numerous small angular quartz fragments in goethite, also cavities filled with chalcedony
F2-TL-53	do.	Similar to F1A but contains less goethite, boundaries between red and gray hematite are gradational, undulating boundaries, suggestive of replacement, common in hematite
F3-TL-53	do.	Contains more steel-gray hematite than F2, gray hematite is early, followed by massive quartz which is embayed by microbreccia of red hematite with quartz fragments cut by late quartz veinlets
F14-TL-53	Diamond J Ranch	Angular fragments of quartz, orthoclase, and microcline in matrix of dark-brown goethite, red hematite, and black wad which fills voids in iron oxides and is cut by late quartz veinlets
F16-TL-53	do.	Fewer fragments than F14, wad predominates over hematite and goethite in matrix; some of goethite replaces red hematite, some stains fractures in quartz and may be older than hematite
F17-TL-53	Haputa Ranch area	Small euhedral apatite crystals in early quartz cut by veinlets of late quartz containing voids filled with colloform goethite, few rounded grains of gray hematite in quartz have goethite rims
F20-TL-53	do.	Biotite, hornblende, quartz, and plagioclase with accessory magnetite and apatite are cut by veinlets of rosy quartz and later goethite
F25-TL-53	do.	Altered feldspar fragments in rosy vein quartz containing few grains of thorite; quartz is cut by veinlets of red hematite and later goethite
F36-TL-53	Powderhorn district	Deep-red quartz with numerous small isometric pseudomorphs of hematite after pyrite; late veinlets of clear quartz cut red quartz
F44-TL-53	do.	Few large quartz grains with late quartz overgrowths in matrix of fine-grained quartz alternating with bands of biotite; goethite coats some quartz grains; few tiny specks of red hematite or thorite in groundmass
F46-TL-53	do.	Red quartz cut by clear quartz veinlets; small hematite pseudomorphs after pyrite in both red and clear quartz; microbreccia of clear quartz and goethite cements fragments of early red quartz
F49-TL-53	Ouray hot springs	Nodular masses of psilomelane with colloidal banding are cut and partly replaced by dense massive hematite
F51-TL-53	do.	Calcite and goethite with subordinate psilomelane; goethite is younger than psilomelane; small cavities filled with late quartz or barite
F57-TL-53	Yellow Cat area	Subrounded grains of quartz, chert, and limonite-stained, altered feldspar in a matrix of dark-brown goethite and cryptocrystalline quartz
F58-TL-53	do.	Quartz grains smaller and more angular, and chert less abundant than in F57; few grains of chalcedony; goethite cement more localized and lighter brown, some red hematite grains, gypsum fills fractures
F61-TL-53	do.	Small rounded grains of quartz and orthoclase cemented by cryptocrystalline quartz, cut by veinlet of brecciated red hematite altering to goethite cemented by late quartz
F74-TL-53	Silver Cliff mine	Fine- to medium-grained rounded quartz grains in matrix of yellowish-orange goethite replacing calcite; few grains of magnetite and irregular masses of sooty chalcocite
F75-TL-53	do.	Similar to F74 with calcite predominant over goethite; quartz grains are stained red, and a few grains of red hematite are scattered through the matrix
F78-TL-53	do.	Large angular quartz grains embedded in a matrix of yellowish-orange to light-brown goethite and green malachite which is younger than goethite; microbreccia of chalcocite and quartz embays quartz grains

No single element for which geochemical analyses were made showed consistently high correlations with uranium in all of the areas examined; however, in most of the uranium districts, at least one other element appeared to show a significant correlation with uranium. Both thorium districts, on the other hand, showed high positive correlations between thorium and lead, arsenic, and antimony. A larger number of thorium deposits should be studied in order to determine whether this association is widespread or merely an accidental result of the choice of areas for examination (table 22).

If an element such as copper, manganese, or cobalt, which has distinctively colored alteration products, shows high correlation with uranium or thorium in a given area, then those colors may be useful as field guides to the prospector. The limonite colors observed by the authors did not appear to be particularly useful field guides for uranium. In general, the limonite stains on uranium-bearing outcrops were some shade of brown from a light yellow brown through moderate brown to dusky brown--rarely were red iron oxides associated with uranium. This in itself does not, however, constitute a useful field guide in most areas because of the prevalence of brown limonite stains on barren outcrops. In the thorium deposits on the other hand, samples high in thorium commonly exhibited a characteristic red color. In some of the deposits, such as the Jeannie No. 2, the color of the limonite stains changes from yellowish or grayish brown through light brown to moderate or dusky brown as the thorium deposit is approached.

Small areas of porous limonite were noted in some of the high-thorium samples from the Powderhorn district and examination with a hand lens revealed numerous tiny square pits, which were thought to indicate the former presence of pyrite cubes in these areas. No sponge or boxwork textures were apparent in samples from any of the other localities examined.

Table 22.--Elements showing significant and possibly significant correlation with radioactive material in the localities examined.

Locality	Type of correlation	Elements*
Yellow Cat area,	Probably significant	As^{+}, Sb^{+}, V^{+}
Grand County, Utah	Possibly significant	Mo^{+}, Mn^{-}
Snow-Bonniebell claims,	Probably significant	Mn^{+}
Uintah County, Utah.	Possibly significant	Fe^{+}
Silver Cliff mine,	Probably significant	Zn^{+}, Cu^{+}
Niobrara County, Wyo.	Possibly significant	As^{+}, Mo^{+}, Mn^{+}
Golden Gate Canyon area,	Probably significant	- - -
Jefferson County, Colo.	Possibly significant	Mo^{+}
Diamond J Ranch,	Probably significant	Cu^{-}, Mo^{-}
El Paso County, Colo.	Possibly significant	Mn^{-}
Ouray hot springs,	Probably significant	Zn^{+}, Mo^{+}, Mn^{+}
Ouray County, Colo.	Possibly significant	As^{+}
Haputa Ranch area,	Probably significant	Pb^{+}, Cu^{+}, As^{+}, Sb^{+}, V^{-}
Custer County, Colo.	Possibly significant	Ni^{-}
Powderhorn district,	Probably significant	Zn^{+}, Pb^{+}, As^{+}, Sb^{+}, Mn^{+}, Fe^{+}
Gunnison County, Colo.	Possibly significant	V^{+}

* The sign following the element symbol indicates whether the correlation is positive or negative.

The value of indicator elements in prospecting for radioactive deposits could be tested in one or two of the more promising areas, such as the Powderhorn district (for thorium) and the Silver Cliff area (for uranium). This could be accomplished by 1) thorough outcrop sampling of both radioactive and barren material, (at least 50 samples should be collected and analyzed in order to provide a representative sample); 2) calculation of correlation coefficients on the assay data; 3) soil sampling of the overburden in the area surrounding the outcrops of radioactive material; 4) goechemical analysis of these samples for any elements that gave significant correlations with eU or U in step 2; 5) plotting anomalous concentrations of these "indicator" elements on a map; and 6) physical exploration consisting of removal of the overburden wherever such anomalies appear.

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