An occurrence of rhenium, associated with uraninite, in Coconino County, Arizona

By R. G. Petersen, J. C. Hamilton, and A. T. Myers

Trace Elements Investigations Report 651

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
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WASHINGTON 25, D. C.

February 6, 1958

AEC - 288/8

Mr. Robert D. Nininger
Assistant Director for Exploration
Division of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-651, "An occurrence of rhenium, associated with uraninite, in Coconino County, Arizona," by R. G. Petersen, J. C. Hamilton, and A. T. Myers, August 1957.

We plan to submit this report for publication in Economic Geology.

Sincerely yours,

John H. Eric

for W. H. Bradley
Chief Geologist

Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

AN OCCURRENCE OF RHENIUM, ASSOCIATED WITH URANINITE, IN COCONINO COUNTY, ARIZONA*

By

Richard G. Petersen, John C. Hamilton, and Alfred T. Myers

August 1957

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

USGS - TEI-651

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AN OCCURRENCE OF RHENIUM, ASSOCIATED WITH URANINITE, IN COCONINO COUNTY, ARIZONA

By

Richard G. Petersen, John C. Hamilton, and Alfred T. Myers

ABSTRACT

Twenty-nine samples of sedimentary rocks of Triassic age from the Sun Valley uranium mine in northern Arizona were analyzed spectrographically, and 11 of these samples contained 0.005 to 0.1 percent of the rare metallic element, rhenium.

The rhenium is associated with uranium and molybdenum (and probably with lead and zinc), and is probably in the form of the water-soluble oxide (Re_2O_7) or perrhenic acid ($HReO_4$). The rhenium may have been contained originally in the mineral jordisite. This is suggested by the association of the water-soluble molybdenum mineral, ilsemannite, with the rhenium oxide.

The Sun Valley mine is the only uranium deposit on the Colorado Plateau known to contain any rhenium.

INTRODUCTION

In the process of a routine semiquantitative spectrographic analysis for trace elements in a sample of uranium ore, an unusual amount (about 0.02 to 0.05 percent) of the rare metallic element, rhenium, was detected. Later, from 28 additional samples, 10 more were found to contain 0.005 to 0.1 percent rhenium.

The 29 samples used in this study came from the Sun Valley uranium mine in Coconino County, Ariz. The samples were collected in the summer of 1956, during geologic mapping and investigation

of the east Vermilion Cliffs area (fig. 1) by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

ACKNOWLEDGMENTS

The writers would like to thank the Uranium-Petroleum Company of Salt Lake City, Utah, for their permission to collect samples from the Sun Valley mine and to publish the results of this investigation.

GEOLOGY

General

The east Vermilion Cliffs area is located in north-central Coconino County, Ariz., and is part of the Colorado Plateau province (fig. 1). Erosion in House Rock Valley and in the Colorado River Valley has exposed a section of sedimentary rocks more than a mile thick. This section includes rocks from the Supai formation of Pennsylvanian and Permian age to the Entrada sandstone of Jurassic age (fig. 2). The faulted East Kaibab monocline in the western part of the area is separated from the Echo Cliffs monocline in the east by a gently folded structural terrace.

Most of the uranium deposits in the area occur in paleostream channels at or near the base of the Shinarump member of the Chinle formation. The Shinarump member ranges widely in thickness, areal extent, and composition. In channels the member is as much as 130 feet thick. In other places, perhaps only a few hundred feet from these channels, the Shinarump is absent. Where occurring as a persistent bed, it

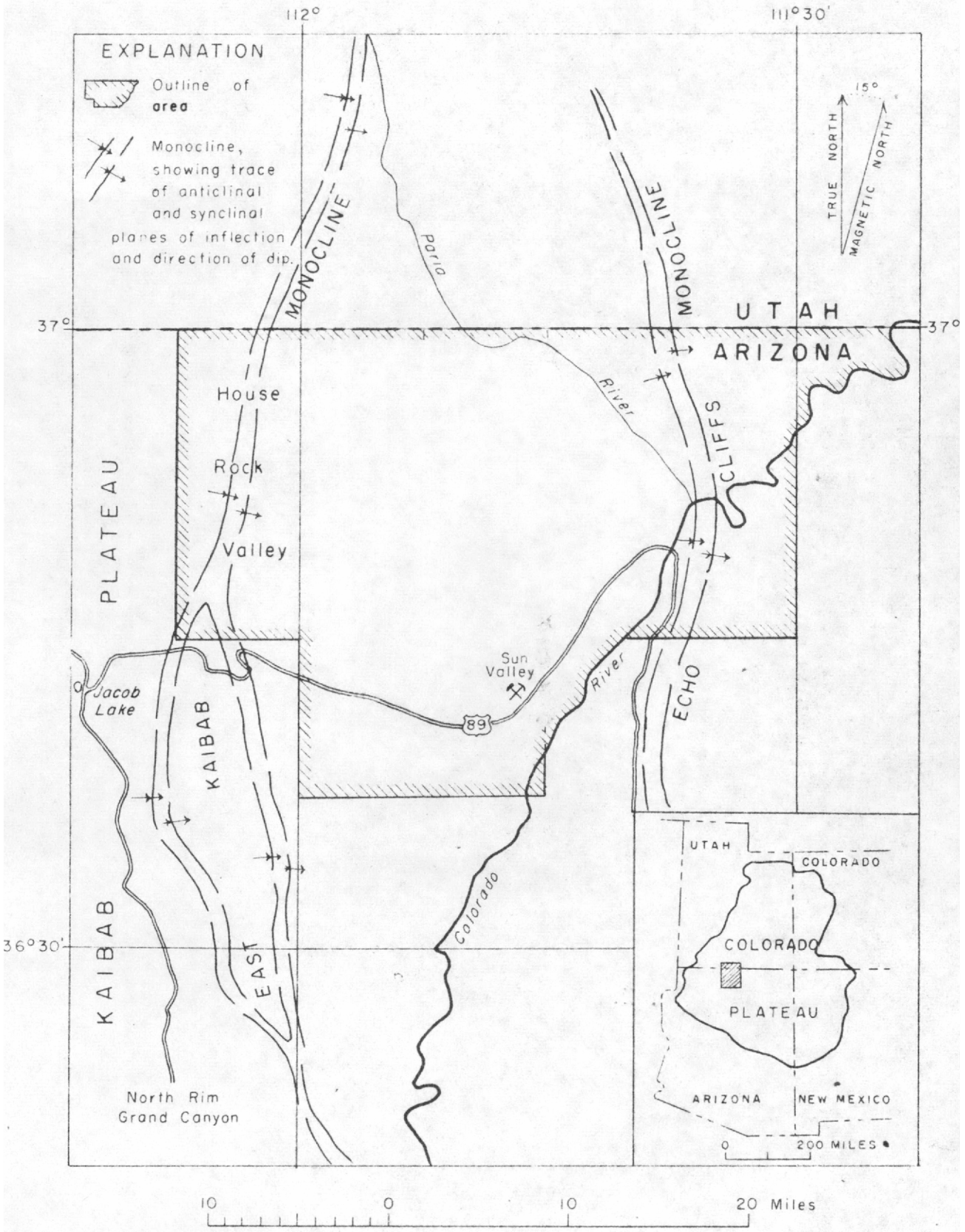

FIGURE 1.--INDEX MAP SHOWING LOCATION OF EAST VERMILION CLIFFS AREA, COCONINO COUNTY, ARIZ.

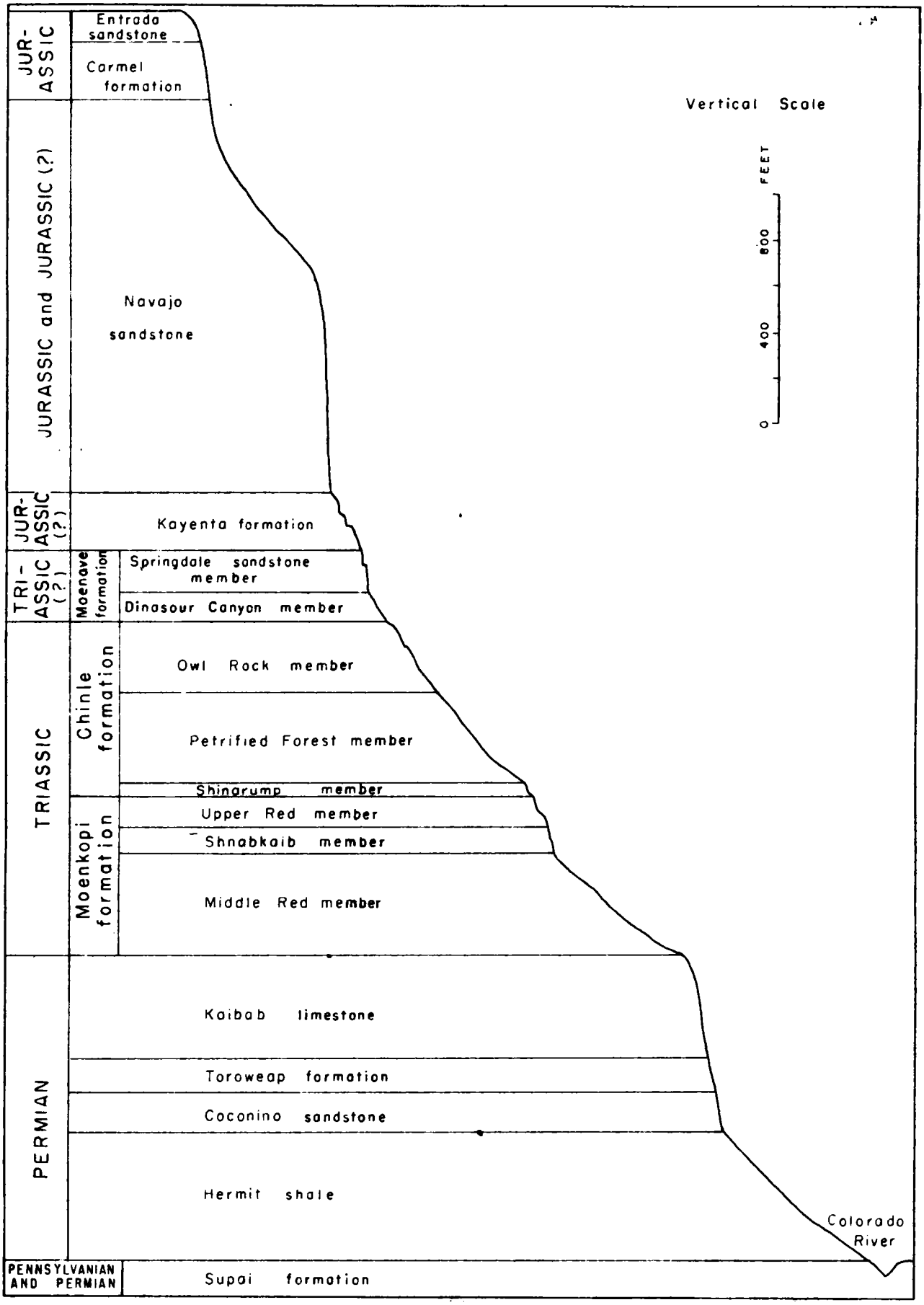

Figure 2.--COLUMNAR SECTION ALONG EAST VERMILION CLIFFS, COCONINO COUNTY, ARIZ.

generally is from 20 to 40 feet thick. The Shinarump ranges in composition from hard, well-cemented chert and quartzite conglomerate to poorly sorted sand and gravel. In places it is a clay-cemented crossbedded sandstone.

Sun Valley mine

Surface and drill hole data indicate that the Sun Valley mine is in a U-shaped bend of a paleostream channel filled with sediments of the Shinarump member. The channel is at least 1,000 feet long and 400 feet wide. In the deepest part of the channel, the Shinarump is about 130 feet thick and is composed of a basal bed of a chert- and quartzite-pebble conglomerate 40 feet thick overlain by 90 feet of crossbedded sandstone. The uranium deposits occur mostly in ellipsoidal-shaped ore "pods," about 3 feet long and 2 feet wide, in the bottom 2 to 5 feet of the basal conglomerate. Since early in 1956, several hundred tons of uranium ore have been mined.

The only unoxidized uranium ore mineral identified from the Sun Valley mine is uraninite, which occurs as interstitial material and as rounded grains (up to 1 mm, in diameter). Other minerals recognized are pyrite, sphalerite (light amber), hematite, and galena (rare). Although several samples analyzed as high as 10 percent molybdenum, no molybdenite has been identified, but there is possibly some jordisite. The jordisite was not identified in the samples, but is indicated by the abundance of the secondary molybdenum mineral, ilsemannite, which, according to Staples (1951, p. 609-614), forms more readily from jordisite rather than molybdenite. The possible difference between these latter two minerals is discussed by

Staples. The cementing material in the conglomerate is calcite with minor chalcedony. The probable paragenetic sequence is: (1) uraninite (interstitial type), (2) pyrite, and (3) sphalerite. The secondary uranium minerals found forming on the mine walls and on outcrops of the Shinarump are zippeite, a zippeite-like mineral, and an unnamed uranyl phosphate. In addition to these, ilsemannite is forming rapidly on the walls of the older mine workings. Carbonized wood and other carbonaceous material are found in the Shinarump member, but not necessarily associated with the uranium deposits.

RHENIUM

History

In 1871, when Mendeleev constructed his chart of the elements, number 75 was one of the blank spaces which he predicted would someday be filled. His prediction did not come true until the year 1925, when the German chemists, Ida and Walter Noddack, first isolated the new metallic element and named it rhenium. Little work was done with the metal from then until recently, when studies in Germany and in the United States (principally at the University of Tennessee) have shown that rhenium and its alloys have excellent heat- and corrosion-resistant properties. Rhenium can be utilized for electric contact points, corrosion-resistance alloys, and in high temperature thermometry. Carlson (1951, p. 1363) reports that a few hundred pounds of rhenium are produced annually. Meggers (1952, p. 9) refers to this element as a "new wonder metal," and states that "its remarkable properties insure increased concentration and extensive future application in science and industry."

Chemistry

The known valences of rhenium are 1, 2, 3, 4, 5, 6 and 7, but valences 4, 6 and 7 seem to be the more important states. This property of assuming several valences make the element quite sensitive to changes in redox conditions. The perrhenate ion ReO_4^- is more stable than the permanganate or perchlorate ions; it forms soluble compounds with many cations. The heptavalent rhenium compounds are practically limited to perrhenic acid, $HReO_4$, and its derivatives, including the anhydride, Re_2O_7, and certain sulfur and selenium compounds. The sulfides Re_2S_7, and ReS_2 are known.

Melaven (written communication, 1957) writes that there is considerable doubt as to the occurrence of rhenium as ReO_4, but the Re_2O_7 is common and is extremely soluble in water forming the acid $HReO_4$. The alkali and alkaline earth perrhenates are well defined white crystalline substances stable from room temperature to their melting points. $KReO_4$ is a rather insoluble salt (0.00494 g/ml at 2.0°C).

Rhenium has a naturally occurring radioactive isotope, Re^{187}, with a half-life of approximately 4×10^{12} years decaying to the osmium isotope, Os^{187}.

Associations

Rhenium and manganese belong to the same subgroup of the periodic system. However, rhenium is not closely associated with manganese in nature, but instead is found, in many places, associated with molybdenum. Noddack and Noddack (1931, p. 207-244), in their search for rhenium, have analyzed over 1,600 rocks and minerals. The only mineral they found to contain rhenium in appreciable amounts was molybdenite, 60 samples of which

contained from 0.05 to 20 ppm rhenium. Since then, analyses of molybdenite have been published by Aminoff (1943, p. 71-72), Geilmann, and others, (1948, p. 3-9) and Boyd and Larsen (1956, p. 707-715). All of these determinations are given in table 1.

Noddack and Noddack also report minor amounts (less than 1.1 ppm) in the following minerals: clausthalite (PbSe), berzelianite (Cu_2Se), columbite ((Fe, Mn) Nb_2O_6), thortveitite ($Y_2Si_2O_7$), gadolinite ($(Fe, Be)_2Y_2Si_2O_{10}$), and alvite ($(Zr, Hf)SiO_4$). Geilmann, and others, (1948, p. 3-9) analyzed 9 wulfenites ($Pb\ Mo\ O_4$) (including one from Mammoth mine, Arizona, one from Red Cloud mine, Yuma County, Arizona, and one from Bennett mine, New Mexico) and found from 0.3 to 3.3 ppm rhenium.

Rankama and Sahama (1950, p. 654-656) report that the copper deposits in the Kupferschiefer in Mansfeld, Germany, contain molybdenite with a rhenium content of 0.01 percent and also some uraninite.

According to Sargent (1956, p. 745-749), the only producer of rhenium in the United States is the University of Tennessee which extracts rhenium from flue dusts obtained from the roasting of molybdenite ores at the Miami Copper Company's mill at Miami, Arizona.

The similarity of the ionic radii (Rankama and Sahama, 1950, p. 654-656) of Mo^{4+} (0.68kX) and Re^{4+} (0.56 kX) probably permits the replacement of molybdenum by rhenium in the molybdenite.

Rhenium in the Sun Valley mine

Of the 29 samples from the Sun Valley mine analyzed for this study, all but 6 are from the Shinarump member of the Chinle formation from at or near (3 to 4 feet) the contact with the underlying upper red member of the Moenkopi formation. Three samples, nos. 19, 28, and 29 (table 2) are from the upper red member at the contact of

Table 1.--Rhenium content of molybdenite[1/]

No.	Source	Re, ppm	Reference
1.	"U.S.A."	140	Geilmann, and others, 1948
2.	Climax, Colorado	28	Geilmann, and others, 1948
3.	Climax, Colorado	20	Boyd and Larsen, 1956
4.	"Colorado"	1.8	Noddack and Noddack, 1931
5.	McGill, Nevada	1030	Boyd and Larson, 1956
6.	Miami, Arizona	152.	Boyd and Larson, 1956
7.	Miami, Arizona	150	Boyd and Larson, 1956
8.	Miami, Arizona	297	Boyd and Larson, 1956
9.	Miami, Arizona	688	Boyd and Larson, 1956
10.	"Canada"	20.4	Geilmann, and others, 1948
11.	Cananea, Mexico	120	Geilmann, and others, 1948
12.	"Peru"	36	Geilmann, and others, 1948
13.	"Bolivia"	0.05	Noddack and Noddack, 1931
14.	"Finland"	18.	Geilmann, and others, 1948
15.	Norway	8	Geilmann, and others, 1948
16.	Norway, Flekkefjord	12.1	Geilmann, and others, 1948
17.	Norway, Hvaleroyene	90	Geilmann, and others, 1948
18.	Norway	1400	Geilmann, and others, 1948
19.	Norway, Stavanger	3040	Geilmann, and others, 1948
20.	Norway, Telemark	21	Noddack and Noddack, 1931
21.	"Altenburg"	44	Geilmann, and others, 1948
22.	"Knabengruber"	13.3	Geilmann, and others, 1948
23.	"Mine di Gonnesfadiga"	19.8	Geilmann, and others, 1948
24.	"Bulgaria"	5.	Geilmann, and others, 1948
25.	Keskin, Turkey	50.	Geilmann, and others, 1948
26.	"Siberia"	0.6	Noddack and Noddack, 1931
27.	"Japan"	10	Noddack and Noddack, 1931
28.	Japan, Shirakawa	9.6	Geilmann, and others, 1948
29.	German East Africa[2/]	2710	Geilmann, and others, 1948
30.	Unknown	17.8	Geilmann, and others, 1948
31.	Unknown	3140.	Geilmann and others, 1948

1/ Prepared by Michael Fleischer, U. S. Geological Survey

2/ Stated in another place to be "Southwest Africa"

Shinarump and upper red members. Three samples, nos. 6, 16, and 17, are from a block of siltstone from the upper red member within the Shinarump member (fig. 3) about 2 feet up from the contact. Analyses for 15 elements are included in table 2. Of the other 54 elements looked for in the spectrographic analyses, some were omitted from the table because they were either not significant (e.g. Al, Si, etc.), absent in all samples (e.g. Hg, Li, Rh, etc.), or in nearly equal amounts in all samples (e.g. Yb, La, Tl, etc.).

All analyses (except selenium) were made by a general semiquantitative spectrographic method, used to determine about 66 elements at a time, and may therefore, be limited in the accuracy for certain elements. Because of this, no statistical methods have been used to reach conclusions. However, the authors believe that the following limited correlations and conclusions can be made by inspection of these analyses (29 samples):

(1) Eleven of the 29 samples contain from about 0.005 to 0.1 percent rhenium (limit of spectrographic sensitivity for rhenium is about 0.005 percent).

(2) A relationship between the rhenium and the molybdenum exists only in that when rhenium is present, the molybdenum content of the sample is relatively high (table 2). However, several samples which contain equally high or higher molybdenum, have no rhenium.

(3) A much better relationship seems to exist between the rhenium and the uranium content. An increase in uranium often accompanies an increase in rhenium. Although again there are several samples with a high uranium content but no rhenium.

(4) Some correlation can be seen in the rhenium-uranium-molybdenum-zinc relationship, but only to the extent that whenever rhenium is present, uranium, molybdenum, and zinc are present in amounts greater than 0.07 percent.

(5) The rare earths, dysprosium, erbium, neodymium, and samarium, are reported only in samples which contain rhenium, but not all of the rhenium-bearing samples contain these rare earths.

(6) Of the other trace elements, the only noticeable relationship is that, with the exception of samples 1 and 3, the yttrium content is higher in the rhenium-bearing samples than in those which contain no rhenium.

(7) Chemical analyses for selenium of 10 of the samples (6 of them containing rhenium), ranged from 0.5 to 4.0 ppm selenium; the selenium content showed no relationship to the rhenium content.

In an attempt to isolate the rhenium or rhenium-bearing mineral, several mechanical separations were made. Two samples, nos. 22 and 24, containing respectively 0.03 and 0.07 percent rhenium, were disaggregated in water in an ultrasonic transducer. The samples were screened, and the -325 mesh fraction was filtered through a Seitz filter. Spectrographic analysis of the several fractions showed that the high rhenium values were in the -325 mesh filtrate. The filtrates from sample nos. 22 and 24 were evaporated to dryness, and the residues contained about 0.3 and about 1.5 percent rhenium, respectively. Except for particles less than half a micron

in diameter which may have passed through the filter, these filtrates contained only that part of the sample which is soluble in hot water (about 90° C., from heat generated by the ultrasonic transducer). The filtrate of sample no. 24 contained about 72 percent by weight of the total rhenium reported in the raw sample. It is not known whether further treatment of the raw sample with hot water would have extracted the remaining 28 percent rhenium, or if this percent represents an insoluble rhenium compound.

Table 3 shows a comparison of spectrographic analyses between the raw sample and the filtrate from sample no. 24. With the exception of the uranium, only those elements which showed a two-step or greater increase or decrease are listed in the table (semiquantitative spectrographic analyses are reported to the nearest number in a series of steps: 3, 1.5, 0.7, 0.15, etc., in percent). The elements (Mg, Ca, Na, K, Mn) which commonly form soluble chlorides and sulfates, are understandably greatly increased in the filtrate. Titanium and zirconium, which are often found in detrital minerals, and lead, probably in the form of galena in the raw sample, all show a natural decrease in the filtrate. The complete disappearance in the filtrate of the rare earths, dysprosium, erbium, and neodymium, indicate that they were probably contained in a detrital mineral (monazite?) in the raw sample. The zinc, cobalt, and nickel show an unusual increase in the filtrate. The relatively high percentages of rhenium, molybdenum, and uranium in the filtrate indicate the possible presence of a soluble rhenium-containing molybdenum mineral (ilsemannite?) and a soluble

Table 3.--Semiquantitative spectrographic analyses (reported in percent) of raw sample and filtrate of sample no. 24 from Sun Valley mine, Coconino County, Ariz.

Analyst: J. C. Hamilton

Element	Limit of sensitivity	Raw sample	Filtrate	Step increase or decrease 1/
Mg	0.0005	0.15	3.0	+4
Ca	0.005	7.0	M	+2
Na	0.05	0.15	1.5	+3
K	0.7	0.7	3.0	+2
Ti	0.0002	0.15	0.0015	-6
Mn	0.0002	0.07	0.7	+3
Co	0.0005	0.03	0.3	+3
Mo	0.0005	0.07	3.0	+5
Nd	0.01	0.07	0	-2 2/
Ni	0.0003	0.015	0.3	+4
Pb	0.001	0.03	0	-4 2/
Re	0.005	0.07	1.5	+4
U	0.05	3.0	1.5	-1
V	0.001	0.003	0.015	+2
Zn	0.02	0.7	3.0	+2
Zr	0.001	0.015	0	-3 2/
Dy	0.005	0.03	0	-2 2/
Er	0.005	0.015	0	-2 2/

M - major constituent; greater than 10 percent.

0 - looked for but not detected (below limit of sensitivity).

1/ Semiquantitative spectrographic analyses are reported to the nearest number in a series of steps (7, 3, 1.5, 0.7, 0.3, 0.15, etc. in percent). Sixty percent of the reported results may be expected to agree with the results of quantitative methods. With the exception of uranium, only those elements which show a two-step or greater increase or decrease are listed in this table.

2/ Indicate the number of steps down to the lower limit of sensitivity.

uranium mineral (zippeite?). Ilsemannite and zippeite are found in the Sun Valley mine but were not identified in sample no. 24. Positive qualitative tests for chloride and sulfate were obtained on sample no. 24.

The rhenium may also be in the form of the soluble oxide (Re_2O_7) which forms perrhenic acid ($HReO_4$) in water. This was first indicated by the difficulty experienced in attempting to evaporate to dryness the water-soluble filtrate from sample no. 24. A. D. Melaven (written communication, 1957) writes that "the dehydration of a water solution of $HReO_4$ at room temperature would result in a solution of gradually increasing viscosity as the solution became more concentrated in $HReO_4$." To prove further the presence of Re_2O_7, the rhenium-bearing (about 1.5 percent Re) water-soluble fraction of sample no. 24 was treated with acetone (Re_2O_7 is soluble in acetone) and filtered. After the acetone-soluble filtrate was evaporated to dryness, the residue (probably containing $HReO_4$) was heated on a steam bath in the presence of an excess of KCl. According to Druce (1948, 92 p.) the reaction should now be $HReO_4 + KCl = KReO_4 + HCl$. The solution was then cooled to 0°C. to precipitate the relatively insoluble $KReO_4$ (Druce, 1948, 92 p.) and filtered. The precipitate weighing 2.0 mg., contained greater than 10 percent rhenium, further confirming the presence of Re_2O_7 (or $HReO_4$ in solution) in the original water extract from sample no. 24.

Figure 3 shows a typical ore "pod" as found in the Sun Valley mine, except that in this case the uranium mineralization has penetrated into a block of siltstone eroded from the Moenkopi formation and deposited with the Shinarump member of the Chinle formation (this block of siltstone probably broke away from the side of the stream channel during the deposition

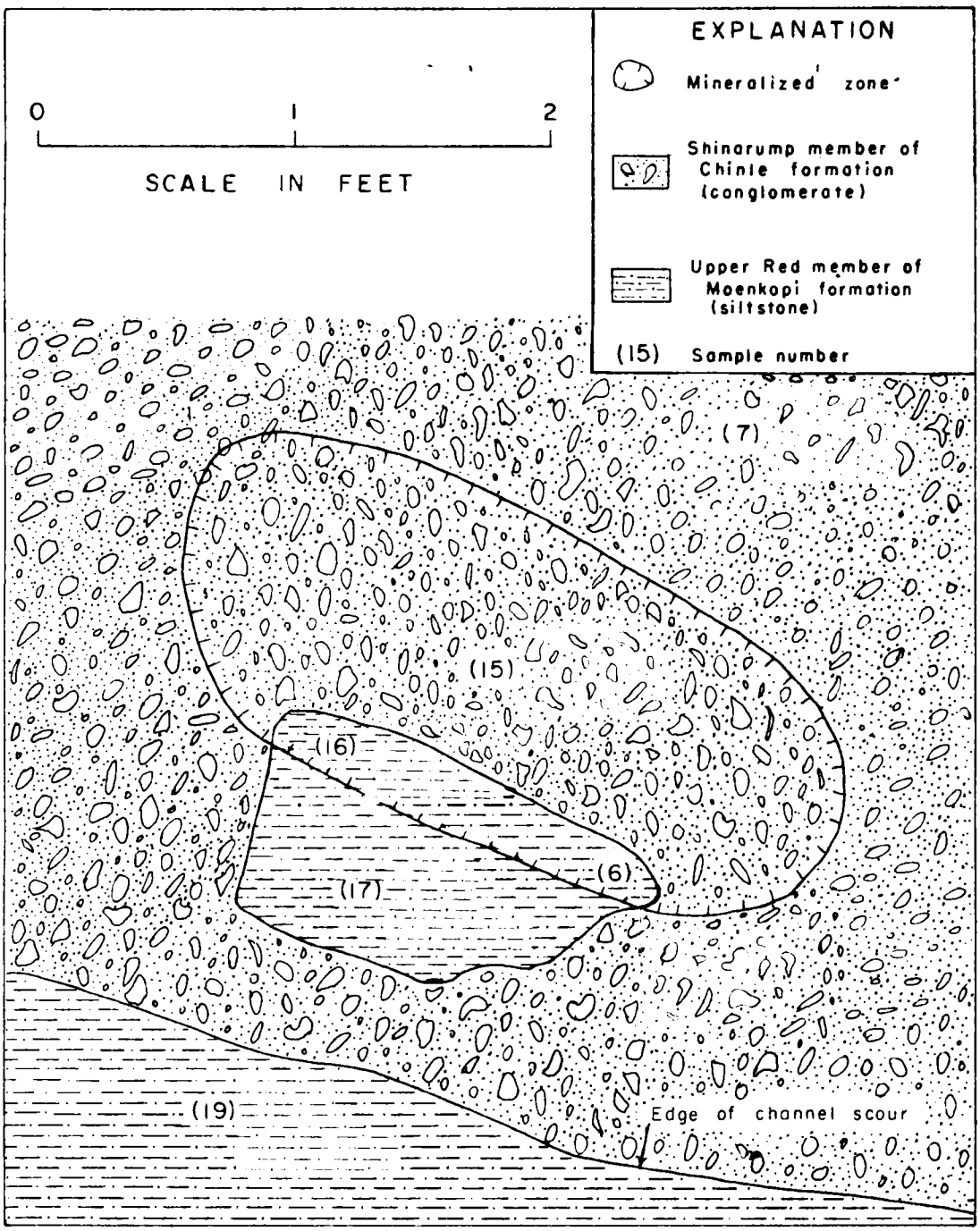

Figure 3.--SKETCH OF VERTICAL SECTION SHOWING URANIUM ORE "POD" AND LOCATION OF SAMPLES (ANALYSES GIVEN IN TABLE 3) IN SUN VALLEY MINE, COCONINO COUNTY, ARIZ.

of the Shinarump). The color of the ore "pod" is black and the surrounding Shinarump member is light gray. Both the undisturbed upper red siltstone and the siltstone block (where not mineralized) are a light greenish gray, which suggests a bleaching from the normal dark brownish-red color of the upper red member.

Table 4 lists the analyses for 23 elements in 6 samples from the ore "pod" and surrounding rock shown in Figure 3. The common soluble-salt-forming elements (magnesium, calcium, sodium, and potassium) are present in all of the six samples (from 0.7 to 3.0 percent) but with differences too insignificant to be meaningful, and were, therefore, omitted from the table. The following are observations made from the inspection of Table 3:

(1) Rhenium is again found associated with uranium.

(2) Gadolinium, germanium, neodymium, and thallium are present only in the ore "pod" samples, but in percentages probably too close to the lower limits of sensitivity to be significant.

(3) Titanium, nickel, manganese, barium, cobalt, vanadium, zirconium, and strontium are present in amounts which are nearly equal in all samples.

(4) Uranium, rhenium, molybdenum, cadmium, lead, and zinc show a major increase in the ore "pod" samples along with a minor increase in the copper and yttrium content.

Table 4.--Semiquantitative spectrographic analyses (reported in percent[1/]) for 23 elements in 6 samples from uranium ore "pod" and surrounding rock in the Sun Valley mine, Coconino County, Ariz. Analyst: J. C. Hamilton.

Element	Lower limit of sensitivity	Sample number[2/] and laboratory number					
		Ore "pod"			Surrounding rock		
		15	16	6	7	17	19
		253412	253413	248142	248143	253414	253040
U	0.05	1.5	0.7	0.15	0	0	0
Re	0.005	0.07	0.07	0.007	0	0	0
Mo	0.0005	0.15	1.5	0.7	0.03	0.03	0.007
Ti	0.0002	0.15	0.3	0.3	0.15	0.3	0.3
Mn	0.0002	0.03	0.015	0.015	0.07	0.003	0.07
Ba	0.0002	0.07	0.03	0.03	0.03	0.015	0.03
Cd	0.005	0.07	0.03	0	0	0	0
Co	0.0005	0.015	0.015	0.015	0.007	0.007	0.0015
Cu	0.0001	0.03	0.015	0.003	0.003	0.007	0.007
Gd	0.005	0.015	0.007	0	0	0	0
Ge	0.001	0.003	0.003	0.0015	0	0	0
Nd	0.01	0.015	0.015	0	0	0	0
Ni	0.0003	0.007	0.03	0.007	0.003	0.007	0.0007
Pb	0.001	0.07	0.07	0.015	0.015	0.015	0.0015
Tl	0.01	0.015	0.015	0.015	0	0	0
V	0.001	0.003	0.003	0.03	0.007	0.007	0.007
Y	0.001	0.07	0.03	0.003	0.0015	0.0015	0.0015
Zn	0.02	7.0	0.7	0	0	0	0
Zr	0.001	0.007	0.07	0.03	0.015	0.03	0.03
Sr	0.0002	0.03	0.007	0.007	0.015	0.015	0.007
Sm	0.01	0.015	0.015	0	0	0	0
Dy	0.005	0	0	0	0	0	0
Nd	0.01	0.015	0.015	0	0	0	0

0 - looked for but not detected (below limit of sensitivity).

1/ Semiquantitative spectrographic analyses are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc. in percent. Sixty percent of the reported results may be expected to agree with the results of quantitative methods.

2/ See Figure 3 for location of samples.

SUMMARY AND CONCLUSIONS

(1) Rhenium, in concentrations from about 0.005 to 0.1 percent, has been found in 11 of 29 samples from the Sun Valley mine and is associated with uranium and molybdenum (and probably with lead and zinc).

(2) The rhenium is concentrated (up to about 1.5 percent) in the hot-water-soluble (about 90°C.) fraction of the samples, and is associated with water-soluble uranium and molybdenum.

(3) Further chemical tests, concentrating the rhenium up to greater than 10 percent, substantiate the theory that the rhenium in the Sun Valley mine is in the form of the oxide (Re_2O_7), or, if in water, the perrhenic acid ($HReO_4$).

(4) The rhenium may have been contained originally in the mineral jordisite. This is suggested by the association of the water-soluble molybdenum mineral, ilsemannite, with the rhenium oxide.

(5) The localization of the uranium, molybdenum, cadmium, lead, zinc, and rhenium in the siltstone block of the Moenkopi within the Shinarump member and in the adjacent Shinarump member of the Chinle formation (Fig. 3), indicates that these elements were probably deposited at about the same time.

(6) The Sun Valley mine is the only uranium deposit on the Colorado Plateau known to contain any rhenium.

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Table 2.--Semiquantitative spectrographic and chemical analyses (reported in percent[1/])

for 15 elements in 29 samples from the Sun Valley mine, Coconino County, Ariz.

Analysts: J. C. Hamilton - spectrographic; G. T. Burrow - chemical.

Sample number	Laboratory number	Elements and lower limit of sensitivity														
		Re	U	Mo	Ge	Dy	Er	Nd	Sm	Zn	Se (chemical)	Pb	Cu	Co	Ni	Y
		0.005	0.05	0.0005	0.001	0.005	0.005	0.01	0.01	0.02		0.001	0.0001	0.0005	0.0003	0.001
1	248137	0	7.0	0.07	0.007	0	0	0	0	0.7	0.0001	0.07	0.03	0.03	0.03	0.07
2	248138	0	0.07	1.5	0	0	0	0	0	0.15	0.00005	0.15	0.03	0.03	0.015	Tr
3	248139	0	1.5	0.15	<0.005	0	0	0	0	0.15	--	0.07	0.007	0.015	0.015	0.03
4	248140	0	0.15	1.5	0	0	0	0	0	0.3	--	0.15	0.07	0.03	0.015	0.003
5	248141	0.03	7.0	0.3	0.007	0	0	0.03	0	1.5	0.0001	0.15	0.03	0.015	0.015	0.03
6 [2/]	248142	0.007	0.15	0.7	0.003	0	0	0	0	0.07	--	0.015	0.003	0.015	0.007	0.003
7	248143	0	0	0.03	0	0	0	0	0	0.03	--	0.015	0.003	0.007	0.003	0.0015
8	248144	0	0	0.015	0	0	0	0	0	0	--	0.03	0.007	0.015	0.007	0.0015
9	253035	0.007	0.07	0.7	0	0	0	0	0	0.3	--	0.07	0.015	0.015	0.007	0.003
10	253036	0.015	0.07	0.7	0	0	0	0	0	0.07	--	0.03	0.015	0.015	0.007	0.003
11	248564	0	0.07	1.5	0	0	0	0	0	0.07	--	0.03	0.015	0.015	0.007	0.003
12	253037	0	0	0.007	0	0	0	0	0	0	--	0	0.003	0	0	0.003
13	253038	0	0	0.003	0	0	0	0	0	0	--	0.003	0.003	0.0015	0.0007	0.0015
14	253039	0	0.03	1.5	0	0	0	0	0	1.5	--	0.7	0.03	0.015	0.007	0.0015
15	253412	0.07	1.5	0.15	0.003	0	0.007	0.015	0.015	7.0	0.0002	0.07	0.03	0.015	0.007	0.07
16 [2/]	253413	0.07	0.7	1.5	<0.005	0	0	0.015	0.015	0.7	0.00005	0.07	0.015	0.015	0.03	0.03
17 [2/]	253414	0	0	0.03	0	0	0	0	0	0	0.00005	0.015	0.007	0.007	0.007	0.0015
18	253415	0	0.07	0.15	0	0	0	0	0	0.15	0.00005	0.015	0.03	0.015	0.007	0.003
19 [3/]	253040	0	0	0.007	0	0	0	0	0	0	--	0.0015	0.007	0.0015	0.0007	0.0015
20	254391	0.03	0.3	0.7	0	0	0	0	0	0.7	0.0001	0.07	0.03	0.015	0.015	0.015
21	254392	0	0.15	0.3	0	0	0	0	0	0.3	--	0.07	0.03	0.015	0.007	0.003
22	254393	0.03	3.0	0.3	0.007	0.03	0.015	0.07	<0.05	1.5	--	0.03	0.03	0.03	0.015	0.15
23	254394	0	0.07	0.15	0	0	0	0	0	0.3	--	0.015	0.03	0.03	0.015	0.0015
24	254395	0.07	3.0	0.07	0.007	0.02	0.02	0.07	0	0.7	0.0001	0.03	0.015	0.03	0.015	0.07
25	254396	0.015	M	0.07	0.007	0.02	0.01	0.07	0	0.7	--	0.15	0.03	0.07	0.15	0.15
26	254397	0.015	M	0.15	0.015	0	0	0.15	0	1.5	0.0004	0.07	0.03	0.07	0.07	0.15
27	254398	0	0.15	0.3	0	0	0	0	0	0.15	--	0.07	0.03	0.015	0.015	0.003
28 [3/]	254399	0	0.03	0.007	0	0	0	0	0	0	--	0.015	0.015	0.015	0.015	0.003
29 [3/]	254400	0	0	0.15	0	0	0	0	0	0	--	0.003	0.003	0.007	0.003	0.003

0 - looked for but not detected (below limit of sensitivity).

M - major constituent; greater than 10 percent.

1/ Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc. in percent.
Sixty percent of the reported results may be expected to agree with the results of quantitative methods.

2/ From siltstone block of the upper red member of the Moenkopi formation within the Shinarump member of the Chinle formation (illustrated in Fig. 3).

3/ Siltstone from upper red member of the Moenkopi formation.

Samples not footnoted are from conglomerate from the Shinarump member of the Chinle formation.