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GEOCHEMICAL STUDIES OF MINERAL DEPOSITS IN THE LISBON VALLEY AREA, SAN JUAN COUNTY, UTAH

by

Vance Clifford Kennedy, 1923–

1961

Open-file report

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1. Geochemical studies of mineral deposits in the Lisbon Valley area, San Juan County, Utah, by Vance C. Kennedy. 157 p., 15 figs., 34 tables.

2. TEI-757, Geologic reconnaissance of the Topopah Spring and Timber Mountain quadrangles, Nye County, Nevada, by P. P. Orkild and J. S. Pomeroy. 20 p., 2 figs., 1 table. On file in the Geological Survey libraries, Building 25, Federal Center, Denver, Colo., and 345 Middlefield Road, Menlo Park, Calif.; 232 Appraisers Building, San Francisco, Calif.; 1031 Bartlett Building, Los Angeles, Calif.; 504 Federal Building, Salt Lake City, Utah; 279 Geology Building, University of New Mexico, Albuquerque, N. Mex.; and Library, Mackay School of Mines, University of Nevada, Reno, Nev.

3. Geologic map of Tippipah Spring quadrangle, Nye County, Nevada, by P. P. Orkild. 1 map, with explanation and cross-sections. On file in Geological Survey libraries, Building 25, Federal Center, Denver, Colo., and 345 Middlefield Road, Menlo Park, Calif.; Geological Survey offices in Mercury, Nev.; 232 Appraisers Building, San Francisco, Calif.; 1031 Bartlett Building, Los Angeles, Calif.; 504 Federal Building, Salt Lake City, Utah; 279 Geology Building, University of New Mexico, Albuquerque, N. Mex.; and Library, Mackay School of Mines, University of Nevada, Reno, Nev.

4. Geologic map of Oak Spring quadrangle, Nye County, Nevada, by Harley Barnes, F. N. Houser, and F. G. Poole. 1 map with explanation. On file in Geological Survey libraries, Building 25, Federal Center, Denver, Colo., and 345 Middlefield Road, Menlo Park, Calif.; Geological Survey offices in Mercury, Nev.; 232 Appraisers Building, San Francisco, Calif.; 1031 Bartlett Building, Los Angeles, Calif.; 504 Federal Building, Salt Lake City, Utah; 279 Geology Building, University of New Mexico, Albuquerque, N. Mex.; and Library, Mackay School of Mines, University of Nevada, Reno, Nev.

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Kennedy, Vance Clifford (Ph.D., Geology)

Geochemical Studies of Mineral Deposits in the Lisbon Valley Area, San Juan County, Utah

A geochemical study was made of uranium-vanadium, copper, and manganese deposits in the Lisbon Valley area of southeastern Utah during the period 1954 to 1957. The composition of the various types of ore was determined and the information was combined with mineralogic and geologic data to evaluate various hypotheses of ore genesis.

Uranium-vanadium deposits occur as generally tabular bodies in or near sandstones of the Permian Cutler formation, the Triassic Chinle formation, and the Salt Wash member of the Jurassic Morrison formation. The Cutler ores contain uranium, vanadium, copper, barium and lesser--but still anomalous--concentrations of cerium, dysprosium, erbium, germanium, holmium, lanthanum, lead, niobium, neodymium, silver, and yttrium. Copper concentrations are highest in Cutler ore near the Lisbon Valley fault.

Large deposits in basal of the Chinle Formation sandstones lie along the southwest flank of the Lisbon Valley anticline. These deposits consist mainly of uranium and vanadium but contain anomalous concentrations of arsenic, barium, beryllium, cadmium, cobalt, copper, iron, lead, molybdenum, nickel, some rare earths, selenium, strontium, thallium, zinc, and zirconium. The vanadium:uranium ratio is highest in the southeastern Chinle ores and decreases northwestward. This ratio also decreases down dip, possibly because of selective leaching of uranium. Arsenic, molybdenum, and yttrium are most concentrated in the southeastern deposits; cadmium and copper in the middle area, and strontium and beryllium in the northwestern deposits.

The ore-associated elements in Chinle deposits show only a poor correlation with uranium, except for lead. The uranium:lead ratio is relatively consistent and averages approximately 33:1. Assuming that very little common or old radiogenic lead is present, the uranium:lead ratio indicates an apparent age of the ores of about 225 million years. Corrections for alteration of the ore might give an age in the range indicated by some isotopic data, that is 180-190 million years.

Comparison of barren and mineralized of the Salt Wash Member sandstones indicates that arsenic, barium, beryllium, calcium, cobalt, copper, lead, manganese, molybdenum, strontium, uranium, vanadium, yttrium, and zinc are enriched in one or more mineralized samples. The Rattlesnake deposit, which is cut by the Lisbon Valley fault, contains more selenium than other Salt Wash ores analyzed. In the southeastern part of the Lisbon Valley area copper minerals are more common in Salt Wash deposits within about a mile of the Lisbon Valley fault than they are elsewhere. Otherwise no evidence of chemical zoning was noted.

Copper minerals occur mainly in veins and bedded deposits near the Lisbon Valley fault zone, but are present in minor amounts in some uranium-vanadium deposits several miles from the fault. Copper-bearing veins also cut altered diorite porphyry in the La Sal Mountains. The copper deposits vary somewhat in composition, but most contain arsenic, barium, molybdenum, selenium, and silver.

Manganese oxides are present as vein fillings and disseminated deposits along the Lisbon Valley fault. Compared to barren sandstones the manganese ores are enriched in arsenic, barium, cobalt, copper, molybdenum, selenium, silver, strontium, vanadium, and zinc.

The genesis of the uranium-vanadium ores is believed to be different from that of the copper and manganese ores. The latter are thought to have been deposited mainly from solutions circulating along and spreading outward from fault zones. Most copper ores are not older than the Cretaceous, and the Chinle uranium-vanadium deposits seem to be of Triassic or Early Jurassic age. Because connate waters squeezed from red beds during compaction must have passed through the sites of present uranium-vanadium deposits and because it seems possible that these fluids could have carried the ore elements in solution, connate waters are believed to have constituted the ore fluid.

INTRODUCTION

Uranium-vanadium deposits in the sedimentary rocks of the Colorado Plateau have been studied by numerous geologists over a period of many years in an effort to understand their nature and genesis. Much of the earlier work consisted of geologic mapping, but in recent years increasing interest has been shown in the mineralogy and geochemistry of these ores. This report is concerned primarily with the results of an investigation of the geochemistry of ore deposits in the Lisbon Valley area of southeastern Utah, where some of the richest large uranium-vanadium ore bodies in the United States are found.

The solution and later concentration of elements to form an ore deposit are basically chemical processes, and a knowledge of the chemical character of the ores is important in determining the probable nature of the ore-bearing solutions. In the Lisbon Valley area this geochemical study was part of a general investigation which also included extensive geologic mapping and much mineralogic work. The results of the latter studies have already been published in part and have been used in this report.

The major purpose of the geochemical study was to obtain information which would be useful in determining the origin of the uranium-vanadium ores. Analyses were made for about 30 elements on samples taken from uranium-vanadium, copper, and manganese deposits as well as on samples collected from apparently unmineralized parts of the host rocks. The various types of ore were compared with barren rocks and with each other to demonstrate the chemical character of the mineralized rocks. In the final section of the report chemical data have been combined with available geologic and mineralogic information in a discussion of possible origins of the ore deposits.

Geography

The location of the Lisbon Valley area is shown in figure 1. The northern boundary of the area is about 20 miles southeast of Moab, Utah, and is reached by paved highway over U.S. Route 160. Numerous mine roads and jeep trails make the area relatively accessible. The climate is arid and the approximate annual temperature range is between 0° and 100°F. The topography is generally characterized by mesas and gently rolling lowlands, except near faulted areas and on the flanks of the La Sal Mountains. Pinon pines, one-seed junipers, and Utah junipers are sparsely distributed on the rocky slopes and on the mesa tops. Sage brush grows on the lowlands and also is found on the mesas. The rocks of the area are, in general, well exposed.

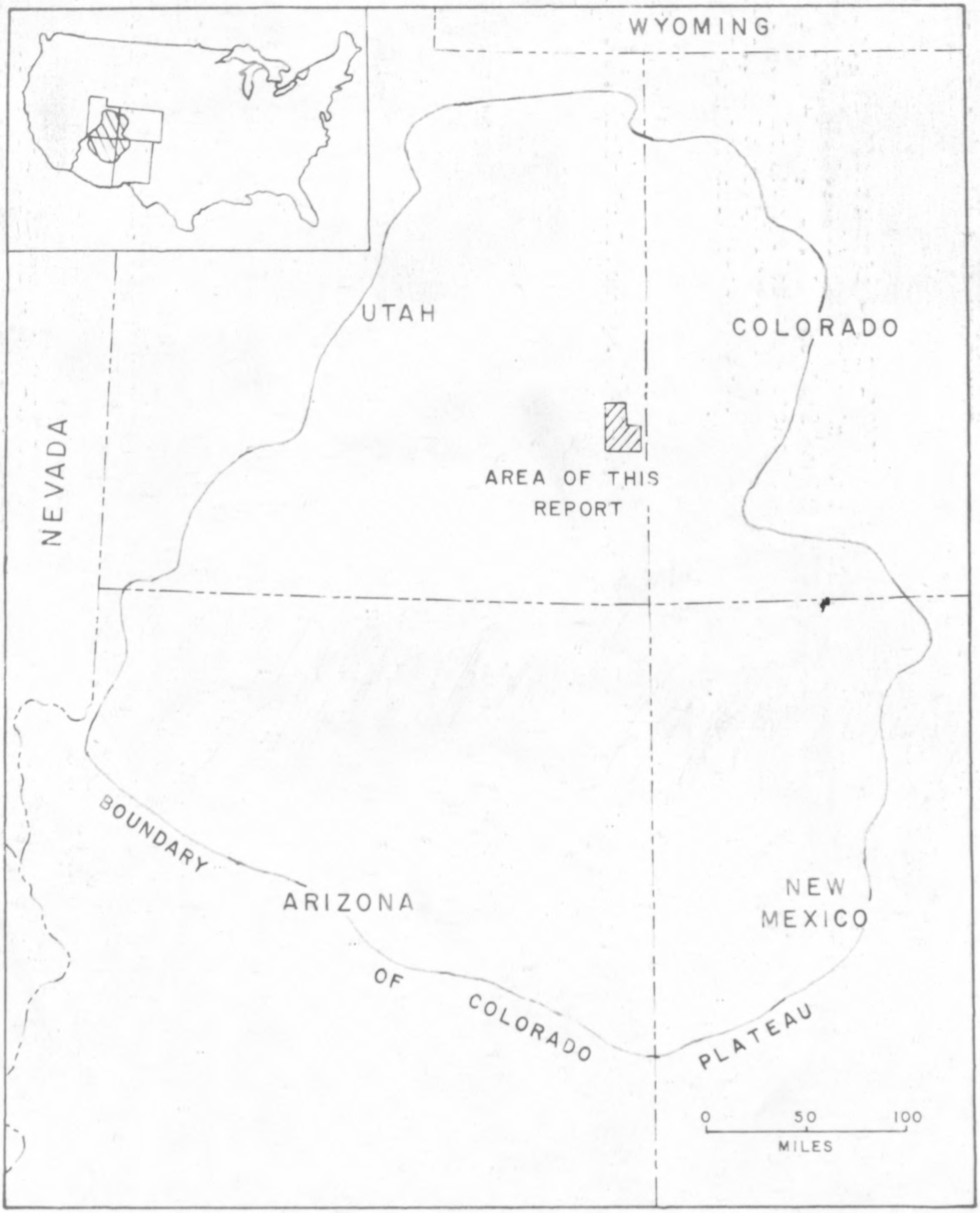

FIGURE I.— INDEX MAP SHOWING THE COLORADO PLATEAU AND THE LOCATION OF THE AREA OF THIS REPORT.

Previous work

Some geochemical work was done in the Lisbon Valley area prior to the present study. Mill-pulp samples from several uranium-vanadium deposits were analyzed as part of a study by A. T. Miesch (1958, written communication). Many of his data are incorporated in this report. Newman (1957, p. 478-490) included the Lisbon Valley area in his study of the distribution of elements in sedimentary rocks of the Colorado Plateau. Shoemaker (1955, p. 77, 83) and Shoemaker, and others (1959, p. 52-53) have listed the elements which appear to be enriched in uranium-vanadium ores of the Colorado Plateau. Several samples of mineralized rock from in the Chinle Formation deposits in the Lisbon Valley area were included in a study of the isotopic composition of some Colorado Plateau ores by Miller and Kulp (1958, p. 937-948). Holland, and others (1957, p. 546-569; 1958, p. 190-209) studied the distribution of leachable uranium in rocks and soils near ore. Jensen (1958, p. 602-603) determined the sulfur isotopes, and Coleman and Delevaux (1957, p. 516) determined the selenium content of several ore samples from the Mi Vida mine. Additional data concerning the chemical composition of the Chinle uranium-vanadium ores can be deduced from mineralogical studies of Gruner, and others (1954) and Gross (1956, p. 632-648).

Acknowledgements

The geochemical studies were made by the writer under the general supervision of G. W. Weir of the U. S. Geological Survey. The project was done on behalf of the Raw Materials Division of the U. S. Atomic Energy Commission.

The cooperation of several mining companies operating in the area was needed during the investigation. Without exception the companies helped by supplying samples and information and by giving permission for the collection of additional samples from drill cores and from the mines. Special mention should be made of the Continental Uranium Company, the Utex Exploration Company, the Homestake Mining Company, and the Hecla Mining Company. This help is gratefully acknowledged; without it the study would have been impossible.

During the course of the work the writer benefited from discussions with geologists of the U. S. Atomic Energy Commission. Nathan E. Salo, Mitchell A. Lekas, and Harry M. Dahl were particularly helpful.

I. G. Hendrickson assisted the writer in fieldwork during the summer of 1955.

Spectrographic analyses were made in the Trace Elements laboratory of the U. S. Geological Survey in Denver by R. G. Havens, N. M. Conklin, J. C. Hamilton, P. J. Dunton, and G. W. Boyes, Jr. Almost all of the chemical analyses were made either in the Trace Elements Laboratory under the supervision of L. F. Rader, Jr., or in the Geochemical Prospecting

Laboratory under the supervision of H. W. Lakin. Individual analysts were J. H. McCarthy, G. T. Burrow, H. E. Crowe, E. J. Fennelly, C. Huffman, Jr., J. P. Schuch, D. L. Ferguson, E. C. Mallory, W. R. Weston, H. H. Lipp, A. P. Marranzino, W. D. Goss, J. S. Wahlberg, W. Mountjoy, and E. F. Cooley. Radiometric determinations were made by C. G. Angelo, G. S. Erickson, S. Furman and D. L. Shafer. Mineralogical identifications were made by T. Botinelly, A. J. Gude, III, E. J. Young, and Betsy Levin. A. T. Miesch of the U. S. Geological Survey supplied analytical data for several samples which he obtained from the Lisbon Valley area.

GEOLOGIC SETTING

Rocks exposed in the Lisbon Valley area range in age from Pennsylvanian to Cretaceous. Unconsolidated and partially consolidated glacial, alluvial, colluvial, and eolian deposits of Quaternary age cover some areas. Generally, the beds dip gently or are nearly horizontal. However, on the flanks of the La Sal Mountains, near the Lisbon Valley fault, and in the northernmost part of the area the beds dip steeply. The stratigraphic section in the Lisbon Valley area is shown in table 1 (in pocket).

A generalized geologic map of part of the Lisbon Valley area showing the location of mines and geologic features referred to in the text is shown as figure 2 (in pocket). The faulted Lisbon Valley anticline is the most prominent geologic feature in the area, and major Chinle in the Formation uranium-vanadium deposits lie along the southwest flank of this structure. The uranium-vanadium deposits in the Salt Wash member of the Morrison formation occur both near and far from the Lisbon Valley anticline. The main copper and manganese deposits are found in and near the Lisbon Valley fault zone.

A diagrammatic cross section of the Lisbon Valley anticline near the Mi Vida mine (figure 3) demonstrates the

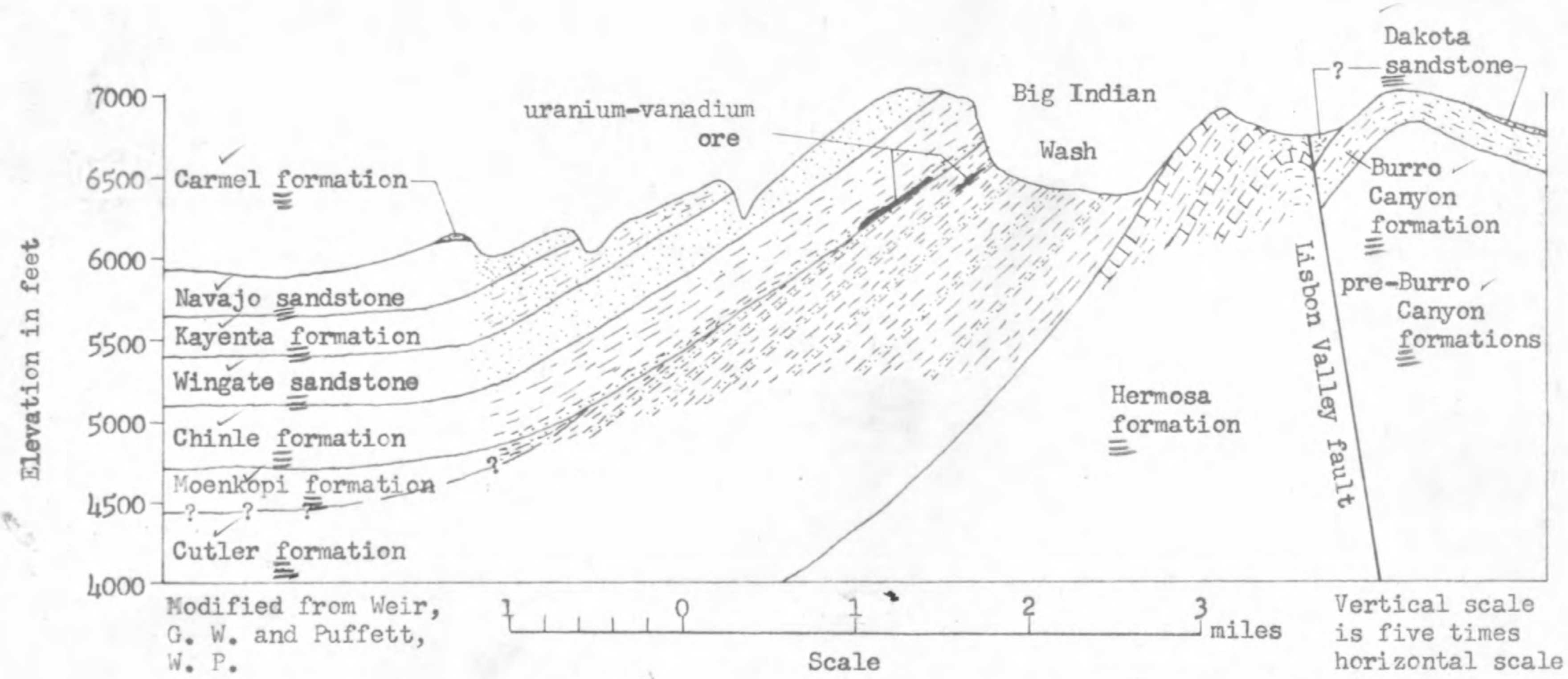

FIGURE 3. DIAGRAMMATIC CROSS-SECTION OF THE FAULTED LISBON VALLEY ANTICLINE NEAR THE MI VIDA MINE

relation of the Chinle ore bodies to the geologic structure. Much of the uranium-vanadium ore lies in sandstone lenses at or near the base of the Chinle formation where these sandstone lenses overlie truncated sandstones in the underlying Cutler formation. Smaller uranium-vanadium deposits occur in some sandstones in the upper part of the Cutler formation.

METHOD OF STUDY

The geochemical study of mineral deposits in the Lisbon Valley area was made to learn what elements were concentrated in the various types of ore and how ore-associated elements were distributed both within individual ore bodies and throughout the mining district.

In order to determine what elements were enriched in or near the mineral deposits it was first necessary to know the composition of unmineralized or "barren" rocks. In the case of the Chinle formation, three to five samples of each of the important rock types found in the basal 20 feet were selected as probably barren on the basis of appearance and scintillometer readings. These samples were submitted for chemical and spectrographic analyses. Samples found to contain less than 0.0010 percent uranium, or 0.002 percent or less equivalent uranium, were considered essentially barren if there was no visible evidence of mineralization by other elements. It seems quite possible that mineralizing solutions affected much of the apparently barren Chinle rocks, thus accounting for the relatively few samples containing only 0.0001 to 0.0005 percent (1 to 5 parts per million) uranium.

Similarly, rock fragments from the Salt Wash member of the Morrison formation were collected and analyzed. Samples taken more than 100 feet from known ore and having an equivalent uranium value less than 0.003 percent were considered barren.

After determining the chemical composition of barren rocks, mill pulps and hand samples of various types of uranium-vanadium ore were analyzed. (Mill pulps are representative portions of ore split from large ore shipments and are duplicates of samples analyzed to determine payment to the ore shipper). The composition of the ore was compared with that of barren rocks, and elements which appeared to be concentrated in the ore were noted.

The degree to which the various ore-associated elements were concentrated varied from one ore body to another. These changes in composition of ore appeared to be fairly systematic for some elements and of a random nature for others. An effort was made to relate these compositional changes to geologic structures. Also, scatter diagrams showing changes in concentration of an element with change in concentration of other elements were prepared in order to demonstrate the geochemical coherence between elements.

Hand samples of copper and manganese ores from the Lisbon Valley area were analyzed by spectrographic and chemical methods. The manganese and copper deposits are apparently related to the Lisbon Valley fault, so the trace element content of these ores was compared with that of the uranium-vanadium ores to determine whether or not there were similarities. A significant chemical similarity between the uranium-vanadium ores and the manganese and copper ores would support the idea that all ores are related to the fault.

A final section of the report has been devoted to a discussion of probable limitations on the nature of the ore-bearing solution, some possible sources for the ore solution, and a feasible mechanism for ore deposition. This discussion is based upon data obtained both from the geochemical study and from the results of other work done in the Lisbon Valley area.

Sampling methods

Materials analyzed in this study included drill core, grab samples of mineralized or barren rock, and mill pulps representing 10 to 500 tons of ore. Grab samples weighing in the range 200 to 2,000 grams were selected to represent various kinds of ore and different rock types. Most of the barren rock samples from the lower part of the Chinle formation were taken from drill cores. A scintillometer was used to check radioactivity of the core, and the core was then broken according to lithology and sampled. If an individual bed was less than about 6 inches thick, all of the core representing that bed was taken. Thicker beds were sampled by collecting several small pieces representing the unit.

Drill core which was contaminated with drilling mud was scrubbed in tap water using a fiber brush. Almost all barren Salt Wash samples were prepared by compositing a series of small chips collected from the outcrop of a particular type of rock.

Mill pulps were obtained either from the U. S. Atomic Energy Commission's Monticello plant (operated by the American Smelting and Refining Company) or from individual mine owners. The sampling process at the Monticello plant has been described by the Colorado School of Mines Research Foundation (1954, p. 46-49). When a shipment of ore is made to a mill, the mill prepares a representative sample of the ore by alternately crushing the ore and splitting, the crushed rock until a 1,000 to 2,000 gram split is obtained. Part of this sample pulp is kept by the mill, part is sent to the shipper, and part goes to the assayer. Grinding is usually done using cast-iron disks with the result that some contamination from grinding plates is inevitable. The average amount of iron introduced has been estimated by Shoemaker and others (1959, p. 27) as 0.1 percent by weight. They point out that if the composition of the tramp iron is similar to that analyzed by Myers and Barnett (1953, table 2) the amount of spectrographically detectable minor elements introduced with the iron are probably below or near the spectrographic limit of sensitivity.

All of the barren rocks and many of the grab samples of ore were ground using ceramic plates. It is believed that contamination due to grinding of these samples was insignificant. (Barnett and others, 1955, p. 121-124).

Analytical methods

Spectrographic, chemical, radiochemical, and radiometric methods of analysis were used in this study. In general, chemical methods were used only when the anticipated concentration of particular element was less than the normal sensitivity of the spectrographic method.

Spectrographic.--Most of the data presented in this report were obtained by semiquantitative spectrographic analyses. Sixty elements are detectable with one exposure by the method used. However, only about 30 elements were commonly detected in the samples obtained in this study. The method of reporting the spectrographic analyses is explained in table 2 and the normal sensitivity of the method for various elements is shown in table 3.

According to A. T. Myers (written communication, 1957) "Experimental work has shown that approximately 60 percent of the reported results fall within the proper portion of an order of magnitude."

Chemical.--Analyses were made for antimony, arsenic, calcium, copper, molybdenum, selenium, uranium, and zinc using standard quantitative methods in most cases. Rapid semiquantitative tests were used, however, on a few samples.

Radiochemical and radiometric.--The measurements of equivalent uranium and the analyses for the daughter products

Table 2.--Method of reporting semiquantitative spectrographic analyses

Concentrations reported by laboratory	Theoretical range (percent)		Theoretical midpoint (percent)
	From -	To -	
XX.	10.0	100.0	
X.+	4.6	10.0	6.8
X.	2.2	4.6	3.2
X.-	1.0	2.2	1.5
.X+	.46	1.0	.68
.X	.22	.46	.32
.X-	.10	.22	.15
.0X+	.046	.10	.068
.0X	.022	.046	.032
.0X-	.01	.022	.015
.00X+	.0046	.01	.0068
.00X	.0022	.0046	.0032
.00X-	.001	.0022	.0015
.000X+	.00046	.001	.00068
.000X	.00022	.00046	.00032
.000X-	.0001	.00022	.00015

Symbols used in reporting analytical data:

Tr., trace, near threshold of spectrographic method (below limit of detectability)

0, looked for, but not detected by spectrographic methods

-0-, looked for but not detected; spectrographic sensitivity much less than normal because of sample dilution prior to analysis

-----, not looked for

Table 3.--Approximate detection limits for the elements by the semi-quantitative spectrographic procedure used for this study

(After a table prepared by the U.S. Geological Survey, August 1956)

Element	Percent	Element	Percent	Element	Percent
Si	0.002	Dy	0.005	Rb	10.0
Al	.001	Er	.005	Re	.005
Fe	.0008	Eu	.05	Rh	.005
Mg	.0005	Ga	.0002	Ru	.01
Ca	.005	Gd	.005	Sb	.01
Na	.05	Ge	.001	Sc	.0005
K	.7	Hf	.01	Sn	.001
Ti	.0002	Hg	1.0	Sr	.0002
P	.2	Ho	.01	Sn	.01
Mn	.0002	In	.001	Ta	.02
Ag	.0001	Ir	.01	Tb	.1
As	.1	La	.002	Te	.1
Au	.002	Li	.02	Th	.02
B	.002	Lu	.01	Tl	.01
Ba	.0002	Mo	.0005	Tm	.01
Be	.0001	Nb	.001	U	.05
Bi	.001	Nd	.01	V	.001
Cd	.005	Ni	.0003	W	.01
Ce	.02	Os	.01	Y	.001
Co	.0005	Pb	.001	Yb	.0005
Cr	.0001	Pd	.0003	Zn	.02
Cs	2.	Pr	.05	Zr	.001
Cu	.0001	Pt	.003		

of uranium were made under the supervision of John N. Rosholt in the Denver Trace Elements Laboratory of the U. S. Geological Survey. C. G. Angelo, G. S. Erickson, Sylvia Furman, and D. L. Shafer made the radiometric analyses. The precision and accuracy of the methods used are given in tables 4 and 5.

Table 4.--Precision of Measurements of Percent Equivalent Uranium[1]

Range of eU (Percent)	Precision (Percent)
0.001 - 0.010	±0.001
.011 - .030	.002
.031 - .050	.003
.051 - .070	.004
.071 - .090	.005
.091 - .020	.01
.21 - .50	.02
.51 - .90	.03
.91 - 1.0	.04
1.0 - 1.2	.05
1.2	.1

[1] Data supplied by J. N. Rosholt, U. S. Geological Survey.

Table 5.--Accuracy of Radiochemical Analyses[1]

Radiochemical Analyses Exclusive of Rn^{222}		Analyses of Rn^{222}	
Range of concentration (Percent)	Accuracy (Percent of Amount Present)	Range of concentration (Percent)	Accuracy (Percent)
0.005 - 0.1	±8	0.01 - 0.10	±0.01
.1 - 1.	6	.11 - 0.51	.03
1 -20	4	.51 - 1.0	.06
20 -75	2	1.1	.10

[1] Data supplied by J. N. Rosholt, U. S. Geological Survey

CHEMISTRY OF THE URANIUM-VANADIUM-BEARING FORMATIONS

Cutler formation

About a dozen small uranium-vanadium deposits are known in the Cutler formation of the Lisbon Valley area. These deposits are tabular in general form, but in detail have very irregular boundaries. They occur in lenses of arkosic sandstone within the upper few hundred feet below the Cutler-Chinle contact. G. W. Weir and W. P. Puffett (1960, p. 141-142) state that, "These deposits are little-developed and have yielded only about 1,000 tons of low-grade ore, but several have estimated reserves of thousands of tons of ore averaging more than 0.1 percent U_3O_8 and 0.2 percent V_2O_5."

The uranium-vanadium deposits are oxidized and contain as the chief ore minerals, carnotite, becquerelite, and vanadium hydromica (Weir and Puffett, op. cit.). Dix (1954) described the mineralogy of the ores of the Cutler formation in Big Indian Wash. He found the ore to be of two types; one type consists of carnotite and becquerelite disseminated in arkosic sandstone, and the other type consists of concretions up to four inches in diameter containing barite, celestite, calcite, and uranium, vanadium, and copper minerals.

Little visible carbonaceous material is present in the ore. The host rock is mottled in shades of purplish red and reddish brown, and in the immediate vicinity of ore minerals the rock is commonly very light in color, suggesting removal of ferric iron.

No barren Cutler rocks were analyzed in this study, but five barren samples of the Cutler formation from various places on the Colorado Plateau were analyzed for Newman, Shoemaker, and Miesch (1960, written communication). The median composition and the range in composition of their samples are given in table 6 (in pocket) along with that of mineralized Cutler rocks and that of barite from a vein cutting Cutler rocks near Wood's Ranch.

Elements whose concentration in one or more mineralized samples is more than twice that in any of the barren samples include Ag, Ba, Cu, Dy, Ge, La, Nb, Nd, Pb, Sr, U, V, and Y. The elements Ce, Er, and Ho are probably anomalous also, but the sensitivity of the analytical method did not permit detection of these elements in the barren rocks. Barium and strontium were abnormally concentrated only in the barite specimen.

The various mineral deposits in the Cutler formation of the Lisbon Valley area range from almost pure barite with little copper, through a deposit high in copper with moderate barium and slight uranium, to uranium-vanadium deposits containing some copper and barium.

Chinle formation

Unmineralized rocks

A study of unmineralized Chinle rocks was made so that a comparison could be made between barren and mineralized material. All barren Chinle samples were taken from the lower 20 feet of the formation because this is the part of the formation which contains most of the uranium-vanadium ore. Study of representative specimens under the binocular microscope indicated that lower of the Chinle rocks could be considered a mixture of two distinct rock types.

One type is composed of those rocks in which most of the grains are silicate minerals. The fine-grained members of this type contain clay, micas, and silt-sized quartz with some feldspar. The coarse-grained members are composed mainly of quartz and feldspar, with lesser amounts of rounded limy rock fragments. Commonly the fine-grained quartzose rocks are low in lime, whereas, the coarse-grained members have considerable calcite cement.

The second rock type (which, for the purposes of this report, will be referred to as calcarenite) consists mainly of rounded fragments of fine-grained rock which contain from 50 percent to more than 90 percent calcium carbonate. In the high-lime examples the residue insoluble in hydrochloric acid is mainly quartz ranging in size from fine sand to silt. The rock fragments themselves range from about 0.25 mm to 3 cm in diameter. The finer-grained calcarenites are, in some instances, well sorted, but the coarse-grained calcarenites are almost invariably poorly sorted.

Few rocks in the lower part of the Chinle of the Big Indian Wash area are "pure" calcarenites or "pure" quartzose sandstones. Mixtures of the two types are common. However, no calcarenites finer than fine sand were seen, and the very coarse-grained sandstones and conglomerates tended to be fairly pure quartzose sandstones or fairly pure calcarenites. Medium- to coarse-grained sandstones could be found with almost any proportion of calcarenite to quartzose material.

Because much of the ore in the Chinle is associated with quartzose sandstones, emphasis in this report is placed on the chemical composition of the quartzose rocks.

Quartzose rocks.--Quartzose rocks collected from the basal part of the Chinle formation were checked with a scintillometer and, if radioactivity did not appear abnormal, they were subjected to spectrographic and fluorimetric analysis. A total of 51 "barren" samples were analyzed, but not all were found to contain background concentrations of uranium. The samples are grouped below according to their uranium content.

Uranium Content (ppm)	Number of Quartzose Samples	Number of Calcarenite Samples[1]
0 - 4	17	1
5 - 9	11	4
10 -19	6	3
20 -29	2	2
30 -39	2	0
40 -49	0	0
>50	3	0

1. If the rock contained more than 50 percent $CaCO_3$ by chemical analysis, it was considered a calcarenite.

Quartzose rocks containing less than 10 ppm (parts per million) uranium were considered barren unless there were other reasons for considering them to be mineralized. Six of the "barren" samples were collected from an apparently unmineralized part of the ore sandstone in the Continental Uranium No. 1 mine. Although four of these samples contained less than 4 ppm uranium and all had less than 10 ppm uranium, the vanadium, lead, and copper concentrations were slightly higher than that of rocks far from ore. Therefore, these six samples were not considered completely barren. One "quartzose" sample contained almost 50 percent $CaCO_3$ and was not considered a typical quartzose specimen. Thus only 21 samples could be considered as typical barren quartzose rocks.

Rocks containing more than 10 ppm uranium were not restricted to any particular lithologic type, and the barren rocks chosen are not believed to be biased as a result of

25 follows

discarding from consideration those having more than 10 ppm uranium. The composition of the 21 barren samples is given in table 7.

Holland and others (1957, p. 564) found that 91 percent of the in the lower part of the Chinle siltstones (88 samples) in the vicinity of the Homestake La Sal mine contained less than 5 ppm leachable uranium, 85 percent of the fine sandstones (88 samples) contained less than 5 ppm, and 75 percent of the conglomerates (36 samples) contained less than 5 ppm. The coarse sandstones contained more uranium, for only 37 percent of the 27 samples analyzed contained less than 5 ppm leachable uranium. The leaching technique used by Holland, and others (1957) removed only about 50 percent of the uranium present in samples containing less than 10 ppm uranium; hence the percentage of samples containing less than 5 ppm leachable uranium corresponds to about the percentage of samples containing less than 10 ppm total uranium. These data indicate that barren lower of the Chinle rocks in the Big Indian Wash contain less than 10 ppm total uranium. The coarse sandstones are probably more permeable than the other rocks studied by Holland's group and presumably served as channels for uranium ore solutions. Such rocks would be expected to contain unusual amounts of uranium. In the barren quartzose rocks studied by the author, no obvious correlation between uranium and grain size or uranium and other elements was noted.

The average concentration of uranium in sandstones was reported as 2 ppm by Holland and Kulp (1954, p. 203). The uranium content of 21 barren quartzose samples from the Lisbon Valley area averages 4.5 ppm uranium and the median value was 4 ppm. This indicates that, if sampling of lower rocks of the Chinle ~~rocks~~ was representative in the present study, the uranium content is about twice the average of normal sandstones. This may be due either to low-grade mineralization or to above-normal concentrations of uranium in the original sediments. The widespread occurrence of visible uranium minerals in the basal of the Chinle rocks of the Lisbon Valley area suggests that ore solutions may have raised the general background concentration of uranium slightly.

When the concentrations of various elements were plotted against median grain size of rock samples (as estimated, using a binocular microscope and reference samples of graded sand and silt), many elements showed an inverse correlation, a few elements correlated directly, and a few elements showed no relation to grain size. Elements showing an inverse correlation with grain size included aluminum, boron, chromium, cobalt, copper, gallium, iron, magnesium, nickel, potassium, scandium, sodium, titanium, vanadium, ytterbium, yttrium, zirconium and, to some extent, arsenic, niobium, and lanthanum. Calcium and manganese tended to increase in concentration with increasing grain size, and barium, lead, and strontium showed no obvious correlation.

The relation between grain size and concentration of aluminum and titanium is shown in figures 4 and 5. Elements which correlate inversely with median grain size show a positive correlation with each other. Examples of this are presented in figures 6 and 7. Calcium correlates positively with manganese as seen in figure 8. Lead, barium, and strontium, however, showed no obvious correlation with each other when plotted on scatter diagrams.

The tendency for many elements to increase with decreasing grain size is attributed to the fact that the sandstones are composed mainly of quartz and feldspar, whereas siltstones and mudstones have a much greater percentage of clay and various accessory minerals, which contain a wider variety of elements than do the major minerals of the sandstones. Calcium carbonate is commonly present as a cement or as detrital fragments in the sandstones. The mudstones have relatively little carbonate cement and the siltstones only moderate amounts. Thus, the concentration of calcium is highest in the sandstones. Manganese can substitute for calcium in the carbonate lattice and apparently does so in the Chinle rocks, as indicated by the calcium-manganese correlation.

Calcarenites.--Many of the rock samples collected for this study contained carbonate detritus, but only five were composed of more than 50 percent calcium carbonate and had 9 ppm or less uranium. Comparison of the composition of calcarenites with that of quartzose rocks containing similar

percentages of aluminum and titanium, indicated that the calcarenites could be considered as normal quartzose rocks which had been greatly diluted with calcite containing small amounts of manganese and possibly a little molybdenum.

Description of ore deposits

The uranium-vanadium deposits in the Chinle formation are broad, irregular lenses whose thickness is commonly less than 20 feet but may range as high as 35 feet (G. W. Weir and W. P. Puffett, 1960, p. 143). They are as much as a few hundred feet wide and several thousand feet long. Most of the ore is just above the angular unconformity between the Cutler and Chinle formations but, in places, it extends for a few inches to a few feet into the Cutler. In general, sandstone is the host rock for the ore. However, some mudstones and limestone-pebble conglomerates are mineralized where they are near sandstone.

The deposits are mostly unoxidized and the chief ore minerals are uraninite, coffinite and montroseite (Weir and Puffett, op. cit.; Gross, 1956, p. 639). Analyses of uraninite and coffinite from the Mi Vida mine suggest that these minerals are not completely reduced, for a uraninite specimen contained 29.15 percent UO_3 and coffinite 41.67 percent UO_3 (Gross, op. cit.). Other minerals are pyrite, molybdenite, galena, barite, chalcopyrite, native copper, "V+4 oxide," corvusite, vanadium clay, and calcite. Small quantities of greenockite, metatyuyamunite, celestite, azurite, and malachite are also present.

The host rocks contain carbonaceous matter, some of which is highly mineralized. Mudstones associated with the ore-bearing strata are characteristically a gray-green color and, in places, contain euhedral pyrite crystals. These features, plus the presence of ore elements in a reduced state, emphasize the reducing environment of the host rocks.

Comparison of unmineralized and mineralized rocks

One of the main purposes of this study was to determine what elements were added during uranium-vanadium mineralization. This has been done for Chinle rocks by comparing the composition of 21 barren samples with the composition of mill pulps from 13 in the Chinle ore deposits and of 12 hand samples of ore containing one percent or more uranium or vanadium. The composition of mill pulps and hand samples is given in tables 8 and 9.

One method of comparison consists of preparing histograms of the concentrations of various elements in barren rocks and superimposing upon them histograms for mill pulps and hand samples, thus demonstrating any differences. Such a comparison has been made in figure 9. In order for the comparison to be valid the lithology of the barren and mineralized material should be similar. Some indication of the lithology can be obtained by noting the aluminum, titanium, and magnesium content of barren and mineralized rocks in figure 9. The concentrations of these elements

Fig. 9
Pocket

reflect changes in lithology and they are thought to be unaffected by mineralization. It is believed that the two groups of samples are similar enough that a comparison will be meaningful.

Data in figure 9 indicate that arsenic, beryllium, cobalt, copper, lead, molybdenum, ytterbium, yttrium, and probably barium, lanthanum, nickel and zirconium were concentrated, at least locally, in the uranium-vanadium ores.

Several elements present in the ores were not shown in figure 9 either because they could be detected with the methods used in only a few or none of the barren samples or because not all samples were analyzed for a particular element. These elements were cadmium, cerium, dysprosium, erbium, gadolinium, neodymium, selenium, samarium, thallium, and zinc. Cadmium was detected spectrographically only in mill pulps, and greenockite (CdS) was seen in one specimen of high-grade uranium ore. Yttrium and several rare earths were found in some ore samples in concentrations which are relatively large compared to the concentrations reported by Minami (1935) for average shales (see table 10). The concentrations of most of the rare earths in barren Chinle rocks are below the sensitivity of the spectrographic method used, so direct comparison of the rare-earth content of barren and mineralized Chinle rocks is not possible. Data shown in table 10 suggest, however, that the cerium earths may be somewhat less concentrated in ore than the yttrium earths. Selenium and zinc concentrations in some ore are as much as fifteen times that found in barren rocks. Thallium was reported in only two ore samples, but its concentrations was approximately 100 times that reported by Shaw (1952, p. 143).

Table 10.--Comparison of the Yttrium and Rare Earth Content of Shales and High Grade Uranium Samples

Element	A. Percent in Shales (After Minami, 1935)	B. Maximum Percent in High Grade Uranium Samples	Approximate Ratio $\frac{B}{A}$	
La	.00216	.OX+	30	Cerium Earths
Ce	.00566	.X-	25	
Nd	.00278	.OX	10	
Sm	.00075	.OX-	20	
Gd	.00073	.OX	45	Yttrium Earths
Dy	.000513	.OX	60	
Er	.000283	.OX	110	
Yb	.000303	.OX	110	
Y	.00357	.X	90	

Another method of determining the elements in the uranium ores which are present in concentrations above or below normal for barren rocks is to prepare scatter diagrams showing the relation between two elements both in ore and in barren rocks. This can be best explained using figure 10 as an example. In the figure, aluminum is plotted against copper in both barren and mineralized rocks. A definite correlation exists between the two elements in barren rocks, but the mineralized samples generally contain more copper for a given aluminum content than do the barren rocks. The aluminum-copper correlation in barren rocks is believed due to the higher content of both elements in fine-grained rocks. To the writer's knowledge there is no

evidence indicating large scale addition or removal of aluminum during mineralization of Chinle rocks, and hence aluminum concentrations are thought to have remained essentially unchanged by the mineralizing solutions. Because the copper concentrations are higher in mineralized rocks than would be expected from its correlation with aluminum, the conclusion is reached that copper was introduced during mineralization.

In figure 11, titanium is plotted against calcium. It is evident that calcium concentrations tend to decrease with increasing titanium content in barren rocks. Titanium concentrations are believed to be essentially unaffected by mineralization because the titanium-aluminum correlation, (see figure 12), is the same for both barren and mineralized rocks. Therefore, because the calcium:titanium ratio is less in mineralized samples than in barren rocks, it appears that calcium may have been removed from the mineralized samples or, possibly, the mineralizing solutions preferentially selected rocks unusally low in calcium.

Similar scatter diagrams were prepared for many of the elements determined in both barren and mineralized samples. The results agree well with those obtained using the histograms.

Figure 13 shows the correlation of magnesium and aluminum in barren and mineralized rocks. The fact that the correlations shows no significant change between barren and

mineralized samples strongly suggests that little or no dolomitization accompanied the mineralization.

Strontium is the only element which has been definitely introduced into one or more ore bodies and yet does not stand out as an anomalous element when interpreting the chemical data using either histograms or scatter diagrams. This is because the wide variation in strontium content of barren samples permits the percentage of strontium to be relatively great without appearing abnormal. However, celestite is found impregnating uranium-bearing sandstone and as vein-filling material in the Radon mine, and large tonnages of ore from the same mine contain well above average amounts of strontium.

Changes in composition of quartzose Chinle rocks during mineralization are summarized in table 11 (in pocket). It should be noted that for each element the maximum percent observed is compared with the estimated median percent in similar rocks. This was done because a median percent in mineralized rocks could not be estimated for many of the rarer elements and because the writer wished to emphasize the tendency of some of the ore-associated elements to form fairly high local concentrations even though the average concentration of that element in the whole ore body was not significantly above background. The ratios shown should not be used to indicate the degree of concentration of an element in an ore body as a whole.

In many instances the percent of an element in "similar barren rocks" (table 11) was estimated from a knowledge of the aluminum and titanium, content and the correlation between these elements and the element being studied.

Correlation among ore-associated elements

Despite the general increase in concentration of many elements in going from barren to mineralized rocks, the correlation between most ore-associated elements within the ore bodies is not high. The elements which have been introduced in greatest amount during mineralization are uranium, vanadium, molybdenum, barium, lead, and, in certain ores, strontium and copper. Of these, uranium can be identified with a Geiger counter, molybdenum compounds commonly oxidize to form bluish ilsemanite, and copper compounds oxidize to form malachite. If originally black ore is slightly oxidized, but shows little or no radioactivity and has no bluish coloration, it is probably composed mostly of vanadium minerals. These diagnostic features are of value in studying the distribution of elements underground.

In the southeastern mines where molybdenum minerals were common, both vanadium and molybdenum minerals were found in relatively low-lime areas, whereas high-grade uranium ore was commonly associated with calcite and carbonaceous matter. Certain parts of the mines showed unusual concentrations of uranium, vanadium, or molybdenum, but enrichment of one element did not necessarily indicate similar enrichment of the others. In the Big Buck mine where copper minerals were common, the chalcopyrite and related malachite did not appear to be associated with increased concentrations of other minerals. Barite was found in mineralized and barren logs near ore and occasionally as a cement in sandstone, but its general relation to other elements could not be detected visually. Galena was seen only in or near areas high in uranium. Strontium minerals were found along a fault in the Radon mine and as a cement in a few sandstone samples, but no consistent association with other minerals was detected.

Chemical analyses of hand samples of ore indicate that concentrations of lead, zirconium,and several of the, rare earths are relatively high in samples containing much uranium. However, very high grade uranium specimens do not always contain anomalous concentrations of the rare earths and zirconium. (See table 34 in pocket for analyses of 54 uranium-bearing samples tabulated in order of increasing uranium content).

Analyses were made of hand samples showing unusually great concentrations of one or more of the elements, copper, molybdenum, uranium, and vanadium to determine whether other elements were preferentially enriched in these samples. The analytical data are given in table 12 (in pocket). None of the ore-associated elements show good correlation with molybdenum, but silver appears to be enriched in high-copper samples. Arsenic, cobalt, several rare earths, zirconium and possibly selenium tend to be highest in concentration in high-uranium samples, but only lead appears to show a consistent positive correlation with uranium.

<u>Correlation of lead and uranium</u>.--The well-defined positive correlation of lead and uranium is shown in figure 14. The lead and uranium analyses were obtained by various methods and the accuracy of the analyses varies somewhat. In samples containing low concentrations of uranium and lead, the correlation between uranium and lead is poor, probably because radiogenic lead constitutes only a small fraction of the total lead. As the uranium concentration increases, so does the lead content, and the correlation becomes more pronounced. The average uranium:lead ratio is about 33:1, but there is variation in this ratio due both to the semi-quantitative nature of some of the analyses and to actual changes in the ratio. Extrapolation of the lead-uranium line to zero uranium indicated about 20 ppm lead not related to the uranium.

Lead concentrations in apparently barren Chinle rocks ranged from less than 0.000X+ percent to perhaps 0.00X+ percent with an average of about 0.002 percent (20 ppm). Thus, the uranium content of a sample would have to exceed about 0.15 percent before the total lead 0.002 percent background lead + $\frac{0.15}{33} = 0.0045$ percent radiogenic lead would exceed the range normally found in barren rocks.

Not only was there a consistent increase in lead in

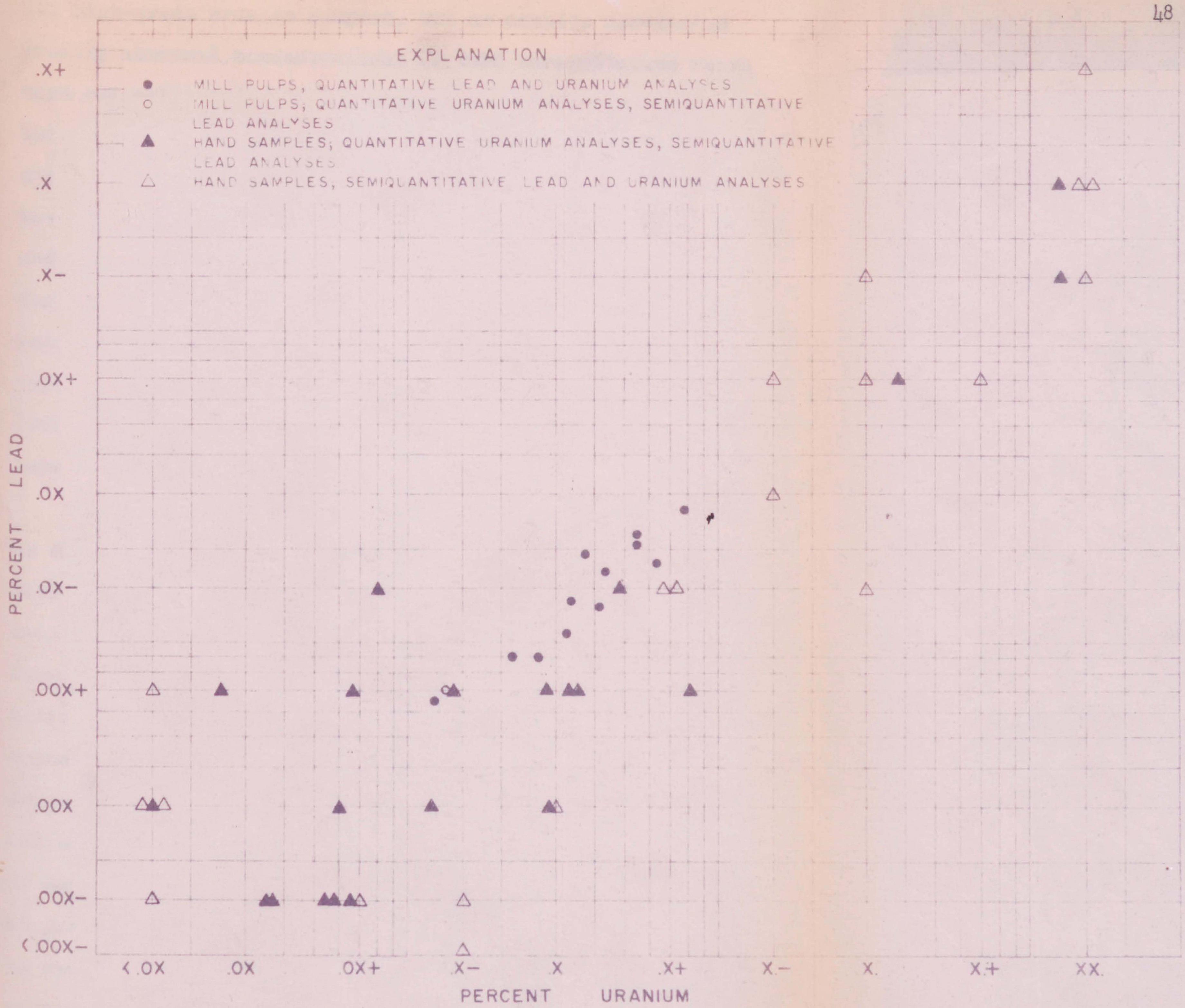

FIGURE 14. GRAPH SHOWING THE RELATION BETWEEN THE CONCENTRATIONS OF LEAD AND URANIUM IN MINERALIZED SAMPLES FROM THE CHINLE FORMATION OF THE LISBON VALLEY AREA

all high-grade uranium samples, but no samples containing greatly abnormal concentrations of lead were obtained which were not collected within a few inches of rich uranium ore. This close relation between lead and uranium must be considered in any hypothesis of ore genesis. It should be noted that approximately the same uranium:lead ratio is characteristic of samples ranging in size from small hand samples to a million or more pounds (as represented by mill pulps). The uranium-lead association is not without exception, however, for L. R. Stieff (oral communication, 1959) stated that a sample of galena was obtained from a barren drift in one of the in the Chinle mines.

Radiochemical analyses were made by John N. Rosholt on ore samples collected by the writer from the Mi Vida mine. From the data obtained Rosholt calculated the content of various radioactive isotopes. The available information is presented in table 13. The content of radioactive isotopes is expressed in terms of percent equivalent. Rosholt (1957, p. 1) defines "percent equivalent" as "the percent amount of primary parent, under the assumption of radioactive equilibrium, required to support the amount of daughter actually present in the sample. This amount of parent may or may not be present in the sample." Thus in sample number 256461 (table 13) there is 18.8 percent equivalent Pa^{231} and 17.5 percent equivalent of Th^{230} but only 12.4 percent of the parent uranium in the sample. Either the Pa^{231} and Th^{230} were carried into the sampling site and deposited or, more likely, a part of the uranium has been lost. Similarly, some radon, radium, and Pb^{210} have been lost.

Rosholt's analyses also indicate (1959, written communication) that samples 256463 to 256465 (table 13) may contain uranium which was leached from high-grade ore and redeposited. Evidence for this is the excess of uranium over daughter products in these samples.

Distribution of ore-associated elements in the mining district

Because of the more or less linear arrangement of ore bodies on the southwest flank of the Lisbon Valley anticline, it is convenient to consider chemical changes in ore from southeast to northwest in the Big Indian mining district (see figure 2). At the southeast end of the district the Continental No. 1 ore body approaches, but does not contact, a branch of the Lisbon Valley fault. After following an arcuate trend away from the fault, the line of ore bodies again approaches the fault at the northwest end of the district.

The weighted average composition of mill pulps analyzed in this study is summarized in table 8 and the vanadium: uranium ratios in ore produced from various mines prior to January 1, 1958 are shown in table 14.

Examination of tables 8 and 14 reveals that some ore-associated elements show pronounced trends in concentration

Table 14.--Vanadium:uranium ratios in of the Chinle Formation ores produced prior to January 1, 1958

Information from records of U. S. Atomic Energy Commission

Name of mine	Vanadium:uranium ratio
Continental No. 1	1.2
Divide Incline	1.1
Serviceberry	1.4
Little Beaver	.21
Big Buck	1.4
Mi Vida	.94
Ike	.24
San Juan	.09
La Sal	.05
Cord	.04
Radon	.04
Far West	.06
North Alice	.16

within the mining district whereas others do not. Because of the semiquantitative nature of much of the data, considerable caution must be used in interpretation. However, the figures presented in table 8 represent (except for the Serviceberry mine) averages of several semiquantitative analyses and, hence, are more reliable than single analyses.

Elements which are relatively high in concentration at the southeast end of the district and are lower toward the northwest include arsenic, molybdenum, vanadium, yttrium and possibly cerium, lanthanum, and zinc. Elements which are highest in concentration in ores near the middle of the district are cadmium and copper. Strontium and probably beryllium have been added in greatest amount to ores in the northwestern part of the mining district.

An estimate of the amount of barium added to or removed from mineralized rock must be based upon a knowledge of the average original barium content of the rocks. The average barium concentration of 27 barren lower of the Chinle rocks was 0.X percent. However, most barren samples contained 0.0X to 0.0X+ percent barium, whereas three of the samples contained 0.X+, X.-, and X. percent barium, respectively. These high-barium samples raise the arithmetic mean well above the median value. There has been solution and redeposition of barium in Chinle rocks, and the barren samples probably include rocks which were leached and others which were enriched in barium. The fact that the calculated average of 0.24 percent barium is well above the range (0.01-

0.06 percent) for common sandstones and shales (Krauskopf, 1955, p. 416) and that just three samples almost completely control the calculated average indicates that the number of samples was insufficient for determining the average barium content of the lower of the Chinle rocks. For the purposes of this study, then, the median value, 0.03 percent barium, was considered representative of the barren rocks. On this basis barium has been added to all Chinle ores, but the greatest concentrations are in ores from the Divide Incline and Cord mines.

Nickel and selenium are slightly enriched in ore, but no pattern of distribution was detected.

Distribution of elements near ore

The distribution of elements near ore was studied in three places: (1) in drill core above ore in sec. 2, T. 30 S., R. 24 E., about one-half mile northwest of the Mi Vida mine, (2) in slightly to moderately mineralized samples above high-grade ore in the Mi Vida mine, and (3) in "barren" sandstone within 25 feet of ore in the Continental No. 1 mine.

Rocks above uranium-vanadium ore in sec. 2 are of normal composition except for the content of molybdenum, uranium, and possibly zinc and calcium. The analyses of rock samples are summarized in table 15. Molybdenum was detected in all rocks in the zone extending from ore to a point about 9 feet above the ore. By comparison, only 3 out of 21 barren Chinle samples contained detectable molybdenum. Uranium concentrations exceeded 10 ppm from the ore upward to the point where molybdenum was no longer detectable. Above that point the concentration of uranium was less than 10 ppm in every sample. Thus, it appears that a "halo" of molybdenum and uranium is present for a distance of about 9 feet above ore.

The progressive decrease in zinc concentration from sample 243906 to sample 243902 (see table 15) suggests that zinc may be slightly enriched in the rocks close to ore. The increase in concentration over background is relatively small, however, and could conceivably be fortuitous.

The concentration of calcium in rock for a distance of about 2 feet above ore is lower than that in any of 21 barren samples and may indicate removal of calcium near ore. Fine to very fine grained sandstone from 0.7 to 1.6 feet above ore showed no effervescence in acid and was notable for its high percentage of euhedral quartz grains resulting from overgrowths on original detrital grains.

In mineralized rocks overlying high-grade ore in the Mi Vida mine, the uranium content did not show a consistent decrease with increasing distance from the high-grade ore (see table 16 in pocket). Vandium content was generally greater in the higher grade uranium samples, but the uranium:vanadium ratio ranged from 19:1 in the highest grade uranium sample to 0.2:1 in lower grade samples. Lead varied almost in proportion to the uranium content in the higher grade uranium samples. Calcium, manganese, and strontium concentrations are lower in the moderately mineralized rocks than in any of 21 barren samples, suggesting either that there may have been some leaching of these elements or that the ore solutions selectively mineralized low-lime areas. The highest grade uranium ore, however, contained abundant calcite.

Molybdenum has apparently been added to the mineralized rocks in small amounts, but shows no correlation with uranium or vanadium.

Although rare earths were found somewhat concentrated in many high-uranium samples, this was not true for the richer ore from the Mi Vida deposit. Instead, cerium, lanthanum, neodymium, and yttrium were slightly concentrated in samples 256467 and 256468 which contained only 0.14 and 0.48 percent uranium respectively.

Rock samples were collected in the Continental Uranium No. 1 mine from an apparently unmineralized part of the ore sandstone. Mineable ore was present within 25 feet horizontally on three sides of the sampling site. The ore sandstone, where sampled, was very friable and displayed no visible evidence of mineralization. Chemical and spectrographic analyses as shown in table 17 (in pocket) indicated that the uranium concentrations were normal but that the content of arsenic, cobalt, copper, iron, molybdenum, nickel, vanadium, and possibly lead was greater than that of lithologically similar barren rocks. The concentration of calcium, manganese, and strontium in some specimens was less than that of comparable barren rocks.

In all three groups of samples described above, molybdenum was found slightly enriched in rocks close to uranium ore and the calcium content was generally less than in comparable barren rocks. Some manganese and strontium may also have been removed. Apparently the rocks have been affected for at least 10 feet above ore in the section 2 drill core. In the Continental Uranium No. 1 mine trace amounts of several ore-associated elements, but no uranium, have been introduced into sandstones at least 15 to 25 feet form ore.

Composition of unmineralized and mineralized carbonaceous material

Uranium minerals are commonly found concentrated in or near carbonaceous trash. Examples of this are the high-grade ores found replacing some fossil logs. Because of the unusual affinity of uranium for some carbonaceous material, barren, slightly mineralized, and well mineralized samples were collected and analyzed to determine the chemical differences associated with varied degrees of mineralization. Some carbonaceous material in contact with high-grade uranium ore, but not appreciably mineralized, was also analyzed.

In table 18, analyses are presented of three barren carbonaceous samples collected far from known ore, one sample taken from in contact with slightly mineralized rock, and one sample from in contact with high-grade ore. Mineral and rock fragments were removed from the crushed samples by separation in an acetone-bromoform mixture of specific gravity 1.7.

Rankama and Sahama (1950, p. 331) reported that the following elements are concentrated in coal ashes relative to igneous rocks: Li, Be, Sr, Ba, B, Sc, Y, rare earth metals, Zr, Hf, V, Co, Ni, Mo, Rh, Pd, Pt, Cu, Zn, Ga, Ge, As, (Se?), Ag, Cd, In, Sn, Sb, I, Au, Tl, Pb, Bi, and sometimes Mn. The ashes of barren carbonaceous material analyzed in this study were enriched in U, Ba, V, Co, Ni, Mo, Cu, Zn, Ge, Pb, Mn, and possibly Sr, and Ag relative to barren Chinle rocks. Carbonaceous material near slightly mineralized rock contained about four times as much uranium as carbonaceous samples far from ore. Otherwise no significant differences were noted between the samples. The ash of a carbonized log in contact with high-grade ore contained lower concentrations of most of the major elements and higher concentrations of most minor elements than did the carbonaceous material collected far from ore. Part of this difference is due to the lower percentage of mineral matter in the sample collected near high-grade ore. However, if the samples are compared on an air-dried basis, the carbonaceous material near high-grade ore contains higher concentrations of boron, niobium, scandium, and uranium than that of carbonaceous material far from ore.

The carbonized log near high-grade ore referred to above was found in a well mineralized part of the Big Buck mine. A sample of the log was separated into seven fractions, using an acetone-bromoform mixture and a Frantz magnetic separator. The compositions of each fraction and that of the adjacent high-grade ore are given in table 19.

The elements which are concentrated in the organic fraction of the log can be distinguished from those held in the mineral fraction by their tendency to increase with decreasing ash content of the light fractions. Elements whose concentrations are higher in the ash of the organic fractions than in normal Chinle sediments are uranium, vanadium, arsenic, boron, barium, chromium, copper, molybdenum, niobium, scandium, yttrium, ytterbium, zinc, and zirconium. The analyses were made on air-dried fractions rather than on ash and the dilution of mineral matter by much organic material probably resulted in the failure to detect elements which might have been detected by direct analysis of ash.

The eU/U (percent equivalent uranium/uranium) ratio changes markedly in going from the light organic fractions to the heavy inorganic fractions. This is interpreted as indicating that uranium is held in the organic matter but that radioactive daughter products have migrated away from the uranium. The tendency for percent equivalent uranium to increase with increasing barium content suggests that radium as well as barium might have been precipitated as the sulfate. An isotopic analysis was made of sample 56-751 (0.021 percent U) by John N. Rosholt with the following results.

Isotope	Percent equivalent
Pa^{231}	0.027
Th^{230}	.014
Ra^{226}	.26
Rn^{222}	.20
Pb^{210}	.21

Apparently, radium is held in one or more of the heavy minerals, and has been there long enough for approximate radioactive equilibrium to be achieved. Alternatively, the shortage of parent isotopes might be interpreted as indicating leaching of uranium, Pa^{231} and Th^{230}, but this seems less probable.

A series of mineralized carbonaceous samples was collected in the Continental No. I mine to determine how the composition of samples changed with increasing uranium content. Analyses of the air-dried samples are given in table 20. It should be noted that samples 245969 and 245979 were diluted prior to analysis with the result that sensitivities for many of the trace elements were greatly reduced below that for the other samples in the set.

None of the elements determined showed obvious correlation with uranium in samples containing 0.066 percent or less uranium. In the three high-uranium samples only lead showed a relatively constant ratio to uranium. There is an obvious difference, however, between the average concentration of several elements in the slightly mineralized samples and in the well mineralized samples. Vanadium, arsenic, copper, manganese, lead, scandium, selenium, yttrium, zirconium, and possibly cobalt, molybdenum, nickel, thallium, ytterbium, and zinc are more concentrated in the high uranium samples.

Analysis of carbonaceous samples from the basal part of the Chinle of the Lisbon Valley area shows that they are enriched in many of the elements commonly found concentrated in coal ash. Many of these same elements are also those which are anomalously high in uranium-vanadium ores. This tendency for coaly material to contain abnormal concentrations of many elements and the normal variation in composition of carbonaceous matter combine to obscure chemical changes due to proximity of mineralized rock.

The concentration of uranium shows the greatest percentage change in comparing barren carbonaceous matter far from ore and "barren" carbonaceous matter near ore. Thus in the search for a "halo" around uranium deposits, which might be of use in prospecting, uranium analysis of the organic matter from of the Chinle sandstones might be helpful as an indicator of the passage of ore-bearing solutions.

Organic carbon in of the Chinle Formation ores

Composite mill pulp samples from 12 Chinle ore bodies were analyzed for content of organic carbon. The data are shown in table 21.

Garrels and Pommer (1959, p. 154-164) determined the reducing capacity of fresh spruce and lignite and calculated the amount of reducing material needed for deposition of some reduced minerals from solution. Their data were used in estimating the amount of organic carbon necessary to cause deposition of pyrite and the various uranium and vanadium minerals found in the Mi Vida ores. The assumption was made that all uranium had been reduced from the U^{+6} to the U^{+4} state, the vanadium reduced from V^{+5} to V^{+3}, the iron from Fe^{+3} to Fe^{+2}, and the sulfur from S^{+6} to S^{-1}. The Mi Vida ores contained approximately 1.5 percent iron, all of which was assumed to be present in the ferrous state--one-half of it in combination with sulfur to form pyrite or marcasite. On this basis the organic carbon requirements would have been as follows:

Table 21.--Organic carbon content of of the Chinle Formation ore in the Lisbon Valley area

(Analyst: Wayne Mountjoy)

Field No.	Laboratory No.		Tons of ore sampled	Organic carbon in mill pulp composites (percent)
K-7/19/57-S1	5878S	Continental No. 1	567	0.34
K-7/19/57-S2	5879S	Divide Incline	287	0.26
K-7/19/57-S3	5880S	Big Buck	1,693	0.05
K-7/19/57-S4	5881S	Mi Vida	1,190	0.05
K-7/19/57-S5	5882S	Little Beaver	907	0.08
K-7/19/57-S6	5883S	Ike	1,622	0.14
K-7/19/57-S7	5884S	La Sal	859	0.05
K-7/19/57-S8	5885S	Cal Uranium	519	0.07
K-7/19/57-S9	5886S	Cord	1,283	0.07
K-7/19/57-S10	5887S	Radon	1,167	0.15
K-7/19/57-S11	5889S	Far West	1,360	0.13
K-7/19/57-S12	5888S	North Alice	592	0.10
		Total	12,046	Average - 0.12

Composition of ore analyzed (In percent)	Organic carbon required (In percent)
0.35 U	0.009
.42 V	.046
1.5 Fe	.075
.86 S (estimated)	.59
Total----------------------	.72

There is now only 0.05 percent organic carbon in the Mi Vida ore. If organic material is credited with being the ultimate source of reducing capacity in the basal of the Chinle rocks, at least 0.77 percent of organic carbon must have been deposited with the sediments originally. If the assumptions made above are valid, about three-fourths of the organic matter was utilized in reducing sulfur from sulfur to sulfide.

Some sulfur may have been present in a reduced state in organic material when it was deposited. If such sulfur were taken into account, less organic carbon would be required. However, even if the carbonaceous matter contained 5 percent sulfur at the time of deposition this sulfur would constitute only a small proportion of the sulfide now present.

Salt Wash member of the Morrison formation

Unmineralized rocks

The determination of the elements present in anomalous concentrations in the Salt Wash uranium deposits was made in much the same way as for the Chinle ore bodies. However, the background, or control, samples were collected differently from those chosen for the Chinle study. A series of samples was collected from the outcrop of the "ore sand" at varying distances from the Black Bottom mine (sec. 19, T. 31 S., R. 25 E.) and from the walls of an inclined shaft at the Profit mine (sec. 30, T. 31 S., R. 25 E.). In addition, two samples were taken from an outcrop of barren of the Salt Wash sandstone in southern Lisbon Valley. The sixteen samples for which the equivalent uranium value was 0.002 percent or less and which were collected more than 100 feet from any known mineralized rock were considered to be representative of barren Salt Wash sandstone in the Lisbon Valley area. Because some of the barren samples were collected from the surface of the ore sandstone, whereas all well-mineralized samples were collected beneath the surface, there may be differences which are due to weathering and not to mineralization. The effects of weathering on barren Salt Wash rocks were not determined, but the fact that many elements in the barren samples correlated well with aluminum concentrations, regardless of whether or not they were outcrop samples, suggests that weathering effects were not great.

Fourteen of the sixteen background samples were collected within less than 1,000 feet of known ore bodies.

There is a possibility, therefore, that the samples are not completely barren. Miesch and Connor (1956, p. 128-146) found that concentrations of vanadium, lead, and possibly uranium, copper, and zinc are slightly higher than normal for distances of several hundred feet away from ore in of the Salt Wash sandstones of the Henry Mountains mining district. Available analytical data, however, indicate that if such "halos" exist around ore in the Lisbon Valley area, they are of very low intensity.

The composition of barren Salt Wash rocks is shown in figure 15 along with the composition of mineralized rocks.

Scatter diagrams showing the relation of composition of Salt Wash rocks to grain size and aluminum content were prepared as for Chinle rocks. In general, the aluminum content shows an inverse correlation with grain size, and the elements B, Cr, Co, Ga, Fe, Pb, Mg, Ni, K, Na, Sr, Ti, V, and Y show a moderate to well-defined positive correlation with aluminum. Be, Cu, Sc, Zn, and Zr show a less well-defined positive correlation with aluminum. Calcium and manganese tend to correlate inversely with aluminum, but barium shows no detectable relation to aluminum content.

<u>Composition of mineral fractions</u>.--Two samples of stream sediment derived mainly from weathering of barren Salt Wash rocks were sieved and the various size fractions further separated on the basis of density and magnetic susceptibility differences. Grain counts were made on 12

of the 42 subsamples. Although a little contamination was present due to windblown sand and silt, the study gives some insight concerning the chemistry and mineralogy of the Salt Wash rocks.

The weight percent of the various mineral separates is given in tables 22a and 22b. The distribution of various elements in the separates is shown in table 23, and the mineral compositions of 12 of the mineral separates are given in table 24.

Many of the grains in the larger particle sizes are multimineralic with the result that a high proportion of the heavy minerals are attached to light particles and appear in the light fraction. Therefore, very small amounts of heavy minerals were removed from the coarse fractions. In the smaller particle sizes, more of the grains are monomineralic, and the heavy minerals are more easily separated from the light ones. The modal size of the light minerals in both samples is in the range 0.125-0.25 mm and the modal size of the heavy minerals is in the range 0.062-0.125 mm.

Although the weight of the light fractions is far more than that of the heavy fractions, the concentration of certain trace elements is so great in some heavy mineral fractions that more than half of the total quantity of an element in a particular size range may be in the heavy fraction. This is true for chromium in the 0.062-0.125 mm

Table 22a.--Weight percent of sample K2-5 in each mineral separate 1/

Particle size (mm)	Percent in light fractions	Percent in heavy fractions Magnetic	Slightly magnetic	Non-magnetic
0.5 - 1	8.63	0.0014	0.0029	0.026
0.25 - 0.5	27.3	.0018	.0047	.041
0.125 - 0.25	39.2	.010	.0088	.042
0.062 - 0.125	16.0	.029	.010	.035
0.043 - 0.062	5.10	.012	.0038	.020
0.043	3.58			

Table 22b.--Weight percent of sample K3-5 in each mineral separate 1/

Particle size (mm)	Percent in light fractions	Percent in heavy fractions Magnetic	Slightly magnetic	Non-magnetic
0.5 - 1	15.8	0.0004	0.0008	0.0044
0.25 - 0.5	23.7	.0021	.0028	.0067
0.125 - 0.25	35.1	.017	.011	.014
0.062 - 0.125	16.5	.074	.024	.033
0.043 - 0.062	4.45	.032	.0079	.039
0.43	4.19			

1/ Light grains were those which floated in bromoform of 2.85 specific gravity. Heavy grains sank in the bromoform.

Magnetic separations were made using a Frantz isodynamic separator. The magnetic fractions were those removed at a current of 0.5 ampere, a side rotation of 15 degrees, and a longitudinal slope of 20 degrees. The slightly magnetic fraction consisted of those grains which were not removed in the magnetic fraction but which could be withdrawn at a current of 1 ampere, a side rotation of 5 degrees, and a longitudinal slope of 20 degrees. The nonmagnetic fraction was the material remaining after the magnetic and slightly magnetic material was removed.

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~

sandstone of the Member

[Spectrographic analyst: R. G Havens]

Aluminum

Size range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	X. ,X. 1/	X.- ,X.-	X.- ,X.	X.- , .X+
0.25 -0.5	X. ,X.	X.- ,X.-	X.- ,X.	X.- , .X+
0.125-0.25	X. ,X.	X. ,X.-	X. ,X.+	X.- , X.-
0.062-0.125	X. ,X.	X. ,X.-	X.+ ,X.+	X.- ,X. -
0.043-0.062	X. ,X.	X.- ,X.-	X., ,X.	X.- ,X. -
0.043	X. ,X.			

Barium

Size range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.0X+ ,.0X	.X- ,.X	X. ,.X+	XX. ,XX.
0.25 -0.5	.0X+ ,.0X	.X- ,.X	X. ,.X-	XX. ,XX.
0.125-0.25	.0X+ ,.0X	.X- ,.0X+	X., ,.X	XX. ,XX.
0.062-0.125	.0X+ ,.0X+	.0X ,.0X-	.X+ ,.0X+	X.+ , X.
0.043-0.062	.0X+ ,.0X	.0X- ,.0X-	.X- ,.0X+	X. , .X+
0.043	.0X+ ,.0X			

Boron

Size range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	**Slightly magnetic**	Nonmagnetic
0.5 -1.0	.00X- ,.00X	-0- ,.0X-	-0- ,-0-	0 , 0
0.25 -0.5	.00X ,.00X	.0X- ,-0-	.0X ,.0X-	0 , 0
0.125-0.25	.00X ,.00X-	.0X+ ,.0X-	.X ,.X	0 , Tr
0.062-0.125	.00X ,.00X	.0X+ ,.0X	.X+ ,.X+	.00X- , Tr
0.043-0.062	.00X+ ,.00X+	-0- -0-	.0X+,.X-	-0- , -0-
0.043	.00X+ ,.00X+			

Beryllium

Size range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	**Slightly Magnetic**	Nonmagnetic
0.5 -1.0	0 ,0	.000X-,-0-	-0- , -0-	0 , 0
0.25 -0.5	0 ,0	.000X-,-0-	.000X-, Tr	0 , 0
0.125-0.25	0 ,0	-0- ,.000X-	Tr , -0-	0 , 0
0.062-0.125	0 ,0	-0- ,.000X-	.000X ,-0-	Tr , -0-
0.043-0.062	0 ,0	-0- ,.000X-	.000X-,-0-	-0- , -0-
0.043	0 , .000X-			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from sandstone of the Salt Wash ~~sandstone~~ Member--Continued

Calcium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	X. ,X.+	.X+ ,X.	X. ,X.	X.- ,X.
0.25-0.5	X. ,X.+	.X+ ,X.	X. ,X.	X.- ,X.
0.125-0.25	X. ,X.	.X+ ,X.-	X.- ,X.	X.- ,X.
0.062-0.125	X. ,X.	.X+ ; .X	X.- ,X.-	X.- ,X.-
0.043-0.062	X. ,X.+	.X- ,..X	X. ,X.	X.- ,X.
0.043	X.+ ,X.+			

Cerium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 , 0	-0- , -0-	-0- , -0-	0 , 0
0.25 -0.5	0 , 0	.0X- , -0-	.0X , -0-	0 , 0
0.125-0.25	0 , 0	-0- , -0-	.0X+, .0X+	0 , 0
0.062-0.125	0 , 0	-0- ; -0-	.0X+, .0X+	-0- , -0-
0.043-0.062	0 , 0	-0- , -0-	.X- , .X-	-0- , -0-
0.043	0 , 0			

Chromium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.00X , .00X	.00X+ , .0X	.00X , .00X+	.00X-, .00X-
0.25- 0.5	.00X- , .00X	.00X+ , .0X	.00X+ , .0X	.00X-, .00X-
0.125-0.25	.00X- , .00X	.X , .0X+	.0X+ , .0X+	.00X-, .00X
0.062-0.125	.00X- , .00X-	.X+ , .X	.0X+ , .X	.00X , .00X+
0.043-0.062	.00X , .00X	.X , .X+	.0X- , .X-	.00X , .00X
0.043	.00X+ , .00X+			

Cobalt

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.000X+ , .00X-	.00X+ , .00X+	.00X , .00X+	0 , 0
0.25 -0.5	Tr , .000X	.00X+ , .00X	.00X , .00X	0 , 0
0.125-0.25	Tr , .000X	.00X+ , .00X	.00X , .00X-	0 , 0
0.062-0.125	Tr , .000X	.00X+ , .00X+	.00X-, .00X	-0- , -0-
0.043-0.062	.000X , .000X	.00X+ , .00X+	.00X-, .00X-	-0- , -0-
0.043	.000X+ , .000X+			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~--Continued

sandstone of the Member

Copper

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.00X , .00X+	.0X , .00X+	.0X- , .0X-	.00X- , .00X
0.25 -0.5	.00X- , .00X	.00X+ , .00X+	.00X+, .0X-	.00X- , .00X
0.125-0.25	.00X- , .00X-	.0X- , .00X+	.0X- , .00X+	.00X- , .00X
0.062-0.125	.00X- , .00X	.0X- , .00X+	.0X- , .00X	.0X- , .0X-
0.043-0.062	.00X+ , .00X	.00X+ , .00X+	.0X- , .00X+	.0X , .0X
0.043	.0X- , .0X-			

Erbium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 , 0	-0- , -0-	-0- , -0-	0 ,0
0.25 -0.5	0 , 0	-0- , -0-	-0- ,	0 ,0
0.125-0.25	0 , 0	-0- , -0-	-0- ,	0 ,0
0.062-0.125	0 , 0	-0- , -0-	.00X, Tr	.00X+, .00X+
0.043-0.062	0 , 0	-0- , -0-	.00X+, .00X+	.00X+, .00X+
0.043	0 , 0			

Gadolinium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	-0- , -0-	-0- , -0-	0 ,0
0.25 -0.5	0 ,0	-0- , -0-	-0- , -0-	0 ,0
0.125-0.25	0 ,0	-0- , -0-	-0- , -0-	0 ,0
0.062-0.125	0 ,0	-0- ,	Tr , -0-	Tr , .00X+
0.043-0.062	0 ,0	-0- ,	.00X+, .00X+	Tr , Tr
0.043	0 ,0			

Gallium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.000X , .000X	-0- , -0-	-0- , -0-	0 ,0
0.25- 0.5	Tr , Tr	-0- , -0-	-0- , -0-	0 ,0
0.125-0.25	Tr , .000X-	-0- , -0-	-0- , -0-	0 ,0
0.062-0.125	Tr , .000X-	-0- , -0-	-0- , -0-	-0- , -0-
0.043-0.062	Tr , .000X-	-0- , -0-	-0- , -0-	Tr .000X-
0.043	.000X , .000X			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~--Continued

sandstone of the Member

Hafnium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	-0- , .0X+	-0- , -0-	0 ,0
0.25 -0.5	0 ,0	-0- , .0X-	-0- , .0X-	0 ,0
0.125-0.25	0 ,0	-0- , -0-	Tr , -0-	.0X-, .0X-
0.062-0.125	0 ,0	-0- , -0-	.0X- , .0X	.0X+, .0X+
0.043-0.062	0 ,0	-0- , -0-	.0X , .0X	.0X+, .0X+
0.043	0 ,0			

Iron

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	X.- , .X+	XX. ,XX.	X.+ ,X.+	.X , .X
0.25 -0.5	.X+ , .X+	XX. , X.+	X.+ ,X.+	.X , .X
0.125-0.25	.X+ , .X+	XX. ,XX.	X.+ ,X.+	.X , .X
0.062-0.125	.X+ , .X+	XX. ,XX.	X.+ ,XX.	.X- , .X-
0.043-0.062	.X+ ,X.	XX. ,XX.	X. ,X.+	.X , .X
0.043	X.- ,X.			

Lanthanum

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	.00X, -0-	.00X , -0-	0 ,0
0.25 -0.5	0 ,0	.00X+ ,.00X	.0X , .0X-	0 , .00X+
0.125-0.25	0 ,0	.00X ,.00X	.0X+ , .0X	.00X+, .0X-
0.062-0.125	0 ,0	.00X ,.00X	.0X+ , .0X+	.00X+, .00X+
0.043-0.062	0 ,0	.00X ,.00X	.X- , .X-	-0- , -0-
0.043	.00X , .00X			

Lead

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	Tr , Tr	.0X+ , .00X+	.0X , .00X+	0 ,0
0.25 -0.5	0 , 0	.0X+ , .0X-	.0X- , .0X-	.00X-, .0X+
0.125-0.25	0 , 0	.0X , .0X-	.0X- , .0X-	0 , .0X-
0.062-0.125	Tr , 0	.0X- , .0X-	.0X- , .0X-	.00X , .00X
0.043-0.062	.00X-, .00X-	.0X- , .0X-	.00X+, .0X-	.00X+, .00X
0.043	.00X-, .00X-			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~--Continued

sandstone of the Member

Magnesium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	X.- , .X+	.X+ , .X+	X.- , .X+	.X , .X-
0.25 -0.5	.X+ , .X+	.X+ , .X	.X+ , .X+	.X , .X
0.125-0.25	.X+ , .X-	.X+ , .X+	X.- .X.-	.X- , .X-
0.062-0.125	.X+ , .X+	.X+ , .X+	X. ,X.-	.X- , .X-
0.043-0.062	.X+ ,X.-	.X+ , .X+	X.- ,X.-	.X , .X+
0.043	X.- ,X.-			

Manganese

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.0X , .0X+	.X- ,X.+	.0X+ ,X.	.0X- , .0X
0.25 -0.5	.0X , .0X	.X- ,X	.0X+ ,X.-	.0X- , .0X-
0.125-0.25	.0X , .0X	.X , .X+	.0X+ , .X	.0X- , .0X-
0.062-0.125	.0X , .0X	.X , .X	.0X+ , .X-	.0X- , .0X-
0.043-0.062	.0X , .0X	.X , .X	.0X+ , .0X-	.0X- , .0X-
0.043	.0X+ , .0X+			

Molybdenum

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	.0X-, -0-	.00X , -0-	0 ,0
0.25 -0.5	0 ,0	.0x-, -0-	.00X , -0-	0 ,0
0.125-0.25	0 ,0	.00X, -0-	.00X-, -0-	0 ,0
0.062-0.125	0 ,0	-0-, -0-	-0- , -0-	-0- , -0-
0.043-0.062	0 ,0	-0-, -0-	-0- , -0-	-0- , -0-
0.043	0 ,0			

Neodymium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	-0- , -0-	-0- , -0-	0 ,0
0.25 -0.5	0 ,0	.00X+, -0-	.0X- , .00X+	0 , Tr
0.125-0.25	0 ,0	.00X+, Tr	.0X , .0X	0 , .0X-
0.062-0.125	0 ,0	.0X- , .0X-	.0X+ , .0X+	-0- , -0-
0.043-0.062	0 ,0	.0X- , -0-	.X- , .X-	-0- , -0-
0.043	0 ,0			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from sandstone of the Salt Wash ~~sandstone~~ Member--Continued

Nickel

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.00X- , .00X	.0X- , .00X-	.00X , .00X-	.000X+, .000X
0.25 -0.5	.000X+ , .000X+	.00X+ , .00X-	.00X , .00X-	.000X+, 0
0.125-0.25	.000X+ , .000X+	.00X+ , .00X	.00X , .00X	.000X , .000X
0.062-0.125	.000X+ , .000X+	.00X+ , .00X	.00X , .00X	-0- , -0-
0.043-0.062	.000X+ , .000X+	.00X+ , ..00X	.00X-, .00X	-0- , -0-
0.043	0 , .00X-			

Niobium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	.000X+ , .00X+	-0- , .00X	0 ,0
0.25 -0.5	0 ,0	.00X- , .00X-	.00X-, .00X	0 ,0
0.125-0.25	0 ,0	.00X , .00X	.00X+, .00X	Tr , .00X-
0.062-0.125	0 ,0	.00X+ , .00X+	.00X+, .0X-	-0- , -0-
0.043-0.062	0 ,0	.00X+ , .00X+	.0X- , .0X-	-0- , -0-
0.043	Tr ,0			

Potassium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	X. ,X.	X.- , -0-	X.- , -0-	X.- ,.X+
0.25 -0.5	X.- ,X.	X. ,X.	X. ,X.	X. ,.X+
0.125-0.25	X.- ,X.	X.- ,X.	X. ,X.	X.- ,X.-
0.062-0.125	X. ,X.	X.- ,X.-	X.- ,X.-	.X+ , .X+
0.043-0.062	X. ,X.	<X.- , .X+	X. ,X.	X.- ,X.-
0.043	X. ,X.			

Scandium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.000X+ , .000X	.000X+ , .00X-	.000X , -0-	0 ,0
0.25 -0.5	.000X , .000X+	.00X- , .000X+	.000X+, .00X-	0 ,0
0.125-0.25	.000X ,0	.00X , .00X	.00X- , .00X-	0 , .000X+
0.062-0.125	.000X ,0	.00X , .00X	.00X+ , .00X+	.00X, .00X+
0.043-0.062	.000X+ , .000X+	.00X , .00X	.00X , .00X+	.00X, .00X+
0.043	.000X+ , .000X+			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~--Continued
sandstone of the Member

Silicon

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	XX. ,XX.	X. , --	XX. , ---	XX. ,XX.
0.25 -0.5	XX. ,XX.	X.+ ,XX.	XX. ,XX.	XX. ,XX.
0.125-0.25	XX. ,XX.	X.+ ,XX.	XX. ,XX.	XX. ,XX.
0.062-0.125	XX. ,XX.	X. ,X.	XX. ,XX.	XX. ,XX.
0.043-0.062	XX. ,XX.	X. ,X.	XX. ,XX.	XX. ,XX.
<.043	XX. ,XX.			

Sodium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.X ,.X	.X- ,-0-	.X ,-0-	.X ,.X-
0.25 -0.5	.X ,.X	.X- ,.X	.X ,.X	.X ,.X-
0.125-0.25	.X ,.X-	.X ,.X-	.X ,.X	.X ,.X-
0.062-0.125	.X ,.X	.X- ,.0X+	.X+ ,.X	.X- ,.0X+
0.043-0.062	.X+ ,.X+	-0- ,-0-	.X+ ,.X	.X ,.X
< 0.043	.X+ ,.X+			

Strontium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.0X- ,.0X-	.0X- ,.X	.0X+ ,.0X	.X+ ,.X+
0.25 -0.5	.00X+ ,.0X-	.0X- ,.0X	.X- ,.0X+	.X+ ,.X+
0.125-0.25	.00X+ ,.00X+	.00X+ ,.00X+	.X- ,.0X+	.X- ,.X-
0.062-0.125	.0X- ,.00X+	.00X+ ,.00X+	.0X+ ,.0X	.X- ,.0X+
0.043-0.062	.0X- ,.0X-	.00X ,.00X	.0X ,.0X-	.0X+,.0X-
< 0.043	.0X ,.0X-			

Tin

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	0 ,0	.0X+ ,-0-	.0X ,-0-	0 ,0
0.25 -0.5	0 ,0	-0- ,-0-	-0- ,-0-	.00X, .0X+
0.125-0.25	0 ,0	-0- ,-0-	-0- ,-0-	0 , .0X
0.062-0.125	0 ,0	-0- ,-0-	-0- ,-0-	.00X, -0-
0.043-0.062	0 ,0	-0- ,-0-	-0- ,-0-	.00X+, -0-
< 0.043	0 ,0			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~--Continued

sandstone of the Member

Titanium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.X- , .X-	.X , .X	.X- , .X+	.0X+ , .0X+
0.25 -0.5	.X- , .X-	.X+ ,X.-	.X ,X.-	.X- , .0X+
0.125-0.25	.X- , .X-	X.- ,X.	X.- ,X.	.X+ ,X.-
0.062-0.125	.X- , .X-	X.+ ,X.+	X.+ ,XX.	X. ,X.
0.043-0.062	.X , .X-	X.+ ,XX.	X. ,X.+	X.- ,X.-
<0.043	.X , .X			

Vanadium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.00X+ ,.00X	.0X ,.0X+	.0X ,.0X+	.00X ,.00X
0.25-0.5	.00X ,.00X	.0X ,.0X	.0X ,.0X	.00X ,.00X
0.125-0.25	.00X ,.00X	.0X+ ,.0X+	.0X ,.0X	.00X ,.00X+
0.062-0.125	.00X ,.00X	.0X+ ,.X-	.0X ,.0X+	.00X+,.00X+
0.043-0.062	.00X+ ,.00X+	.0X+ ,.0X+	.0X- ,.0X	.00X+,.00X+
<0.043	.00X+ ,.00X+			

Ytterbium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.000X- ,.000X-	.00X- ,.00X	-0- ,.00X-	Tr ,.000X-
0.25 -0.5	.000X- ,.000X-	.00X- ,.00X-	-0- ,.00X-	.000X-,.000X-
0.125-0.25	.000X- ,.000X-	.00X ,.00X-	.00X-,.00X-	.000X+,.00X-
0.062-0.125	.000X- ,.000X-	.00X ,.00X-	.00X+,.00X+	.0X- ,.0X-
0.043-0.062	.000X- ,.000X	.00X ,.00X	.00X+,.00X+	.0X- ,.0X-
<0.043	.000X ,.000X+			

Yttrium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.00X- ,.00X-	.00X+ ,.0X-	.00X+,.0X-	.000X+,.00X-
0.25 -0.5	.00X- ,.00X-	.0X- ,.00X+	.00X+,.0X-	.00X- ,.00X
0.125-0.25	.00X- ,.00X-	.0X- ,.00X+	.0X- ,.0X-	.00X+ ,.0X-
0.062-0.125	.00X- ,.00X-	.0X- ,.0X-	.0X+ ,.0X+	.0X+ ,.0X+
0.043-0.062	.00X- ,.00X	.0X- ,.0X	.0X+ ,.0X+	.0X+ ,.0X+
<0.043	.00X ,.00X			

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Sandstone of the Salt Wash Member ~~sandstone~~--Continued

Zirconium

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	.0X- , .0X-	.0X+ ,X.-	.0X , .X+	.0X- , .0X
0.25 -0.5	.00X+ , .0X-	.0X+ , .X	.0X+ , .X+	.0X , .0X
0.125-0.25	.0X- , .0X-	.0X+ , .0X+	.X , .X	.X , .X
0.062-0.125	.00X+ , .0X-	.0X+ , .0X+	.X+, , .X	XX. ,XX.
0.043-0.062	.0X , .0X-	.0X+ , .X-	X.- ,X.-	XX. ,XX.
<0.043	.0X+ , .0X+			

1/ See table 2 for explanation of symbols used. Analytical data for elements not shown in the table are as follows:

Element	Laboratory No.	Percent
1. Arsenic	242230	X.-
	242231	.X-
	242234	.X+
	242235	.0X+
2. Dysprosium	242247	.00X+
	242268	.00X+

Table 23.--Distribution of elements in various mineral fractions of stream sediments derived mainly from Salt Wash ~~sandstone~~--Continued

Sandstones of the Member

Field Numbers of Mineral Fractions

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	K2-56B-4, K3-56B-4	K2-56B-1, K3-56B-1	K2-56B-2, K3-56B-2	K2-56B-3, K3-56B-3
0.25 -0.5	K2-56C-4, K3-56C-4	K2-56C-1, K3-56C-1	K2-56C-2, K3-56C-2	K2-56C-3, K3-56C-3
0.125-0.25	K2-56D-4, K3-56D-4	K2-56D-1, K3-56D-1	K2-56D-2, K3-56D-2	K2-56D-3, K3-56D-3
0.062-0.125	K2-56E-4, K3-56E-4	K2-56E-1, K3-56E-1	K2-56E-2, K3-56E-2	K2-56E-3, K3-56E-3
0.043-0.062	K2-56F-4, K3-56F-4	K2-56F-1, K3-56F-1	K2-56F-2, K3-56F-2	K2-56F-3, K3-56F-3
< 0.043	K2-56G-1, K3-56G-1			

Laboratory Numbers of Mineral Fractions

Size Range in mm.	Specific Gravity less than 2.85	Specific Gravity greater than 2.85		
		Magnetic	Slightly Magnetic	Nonmagnetic
0.5 -1.0	242233, 242254	242230, 242251	242231, 242252	242232, 242253
0.25 -0.5	242237, 242258	242234, 242255	242235, 242256	242236, 242257
0.125-0.25	242241, 242262	242238, 242259	242239, 242260	242240, 242261
0.062-0.125	242245, 242266	242242, 242263	242243, 242264	242244, 242265
0.043-0.062	242249, 242270	242246, 242267	242247, 242268	242248, 242269
<0.043	242250, 242271			

Table 24.--Percentage of minerals in fine-grained heavy fractions from samples K2-56 and K3-56

[Estimates of mineral percentages were made by Paul L. Williams of the U.S. Geological Survey based on counts of 200 to 400 grains]

Mineral	Magnetic				Slightly magnetic				Nonmagnetic			
	0.062 - 0.125 mm		0.043 - 0.062 mm		0.062 - 0.125 mm		1/ 0.043 - 0.062 mm		0.062 - 0.125 mm		0.043 - 0.062 mm	
	K2-56	K3-56	K2-56	K3-56	K2-56	K3-56	K2-56	K3-56	K2-56	K3-56	K2-56	K3-56
Apatite	Tr	-------	-------	Tr	0.5	Tr	-------	1	2	4.5	-------	Tr
Barite	-------	-------	-------	-------	.5	-------	-------	-------	33.5	8	4	Tr
Calcite	3.5	Tr	-------	-------	1.5	Tr	4	5.5	.5	.5	6.5	4.5
Feldspar	3	-------	-------	-------	11	9.5	65	49	14	12.5	34	35
Garnet	2	1	5	2	-------	1	-------	-------	-------	-------	-------	-------
Leucoxene	-------	-------	-------	-------	26.5	29	12	21.5	7.5	8.5	1.5	1.5
Opaques	81.5	96.5	94	97	12	30	-------	4	-------	5	-------	1.5
Pyrite	-------	-------	-------	-------	-------	-------	.5	1	-------	-------	-------	Tr
Quartz	7	1.5	-------	Tr	3	5	12.5	11	21	20	36	23
Rutile	-------	-------	-------	-------	.5	-------	.5	-------	-------	-------	.5	3
Tourmaline	.5	.5	1	1	40.5	22.5	3	4	-------	-------	-------	-------
Zircon	1.5	-------	-------	Tr	4	2	4	4	21	35	17	30

1/ A recount of 500 grains from the 0.043-0.062 mm, slightly magnetic fraction of K3-56, after cleaning in Hcl, gave percentages similar to those shown except for a content of one percent monazite.

range of sample K2-56 and for ytterbium in the 0.043-0.062 mm range for sample K3-56. In K2-56 the heavy fractions contain about one-third of the boron in the 0.062-0.125 mm range and one-third of the barium in the 0.5-1.0 mm range. In K3-56 one-third of the yttrium in the 0.043-0.062 mm fraction is in the heavy fraction.

Some of the minor elements are major constituents in rare minerals but many others are concentrated as nonessential constituents in certain relatively common minerals whose main constituents are major elements. These nonessential elements show a very good correlation with the major element concerned. The good correlations shown between iron and cobalt, nickel, and lead are probably examples of this relation.

The mineral composition of the 0.043-0.062 mm and 0.062-0.125 mm heavy fractions is helpful in explaining the chemical compositions of the various fractions. The coarse-grained magnetic fraction very probably contains magnetite, hematite, limonite, and a little ilmenite. In sample K3-56 there is also an anomalous content of manganese--possibly as a result of the concentration of small fragments impregnated with "desert varnish". Arsenic, cobalt, copper, lead, molybdenum, nickel, silver and zinc are also concentrated in this fraction.

The fine-grained magnetic fractions are enriched in iron, titanium, cobalt, chromium, nickel, and vanadium.

Here the titanium:iron ratio is higher than in the coarse-grained magnetic fractions, indicating that ilmenite and titaniferous magnetite are most concentrated in the fine-grained fraction of the Salt Wash. The cobalt, chromium, nickel, and vanadium are present in minor amounts and are commonly associated with titaniferous magnetite (Goldschmidt, 1954, p. 413-415).

No elements reach a maximum concentration in the coarse-grained, slightly magnetic fraction, but several are very highly concentrated in the fine-grained slightly magnetic fraction. The presence of much leucoxene, iron-stained feldspar, tourmaline, some zircon, and a little monazite accounts for most of the elements found concentrated.

Both barium and strontium are enriched in the coarse nonmagnetic fractions, but barium is present in an amount about 20 times that of the strontium.

The fine-grained nonmagnetic fraction contains much zircon, iron-stained quartz, and feldspar, some leucoxene, and lesser amounts of apatite, calcite, and barite. The hafnium present is probably held in zircon (Goldschmidt, 1954, p. 422) because its ionic radius is similar to that of zirconium. The ratio in the Salt Wash zircons is about 1 part hafnium to 200 parts of zirconium and is of the same order of magnitude as that reported by Goldschmidt (op. cit. p. 423).

In summary, the analysis of hand samples of sandstone and mudstone from the Salt Wash Member

~~sandstone and mudstone~~ shows that most elements determined tend to increase in concentration as the aluminum content increases and the grain size decreases. Calcium, manganese, and probably silicon decrease with increasing aluminum content, but barium shows no obvious correlation with aluminum. Analysis of mineral separates of stream sands derived from Salt Wash terrane demonstrates that aluminum, magnesium, calcium, sodium, and potassium, are present in at least moderate concentrations in several mineral fractions. Barium, boron, cerium, chromium, hafnium, strontium, yttrium, ytterbium, zirconium and neodymium are greatly concentrated in one or more of the heavy minerals. Titanium, iron, manganese, cobalt, copper, niobium, nickel, lead, scandium, and vanadium appear to be intermediate in the degree of concentration in any one mineral fraction.

Mineralized rocks

Description of ore deposits.--The uranium-vanadium deposits in of the Salt Wash Member sandstones generally consist of one or more tabular bodies and occur most commonly in the uppermost prominent sandstone bed. Some ore bodies, however, are narrow and elongate and curve sharply across bedding; these have been called "rolls". (Shawe and others, 1959, p. 396). Almost all of the uranium-vanadium deposits in the Salt Wash member of the Morrison formation in the Lisbon Valley area are highly oxidized. Weir, ~~G. W.~~, and Puffett, ~~W. P.~~ (written communication) state that the chief ore minerals are carnotite, tyuyamunite, and vanadium hydromica. Copper carbonates occur in only a few deposits which are mostly in the southeastern part of the area. Some corvusite, hewettite, and ilsemanite are present in the Dip mine in the northern part of the area.

The deposits range in size from those containing a few pounds of ore to one which has yielded about 100,000 tons. Only a few have yielded more than 10,000 tons of ore (Weir and Puffett, op. cit.).

The ore bodies generally occur in sandstone containing plentiful carbonaceous material. Mudstones interbedded with, or underlying, the mineralized sandstones are commonly greenish gray. At distances greater than a few tens or hundreds of feet from ore, the mudstones are commonly red-brown in color.

Comparison of unmineralized and mineralized rocks.--Analyses were made of mill pulps and selected hand samples of mineralized rock. The composition of these mineralized rocks is shown in figure 15 along with that of barren rocks. Apparently Ba, Co, Cu, Pb, Sr, Y, and possibly Be, Ca, Mn, Ni, and Zn are significantly higher in concentration in ore than in barren rocks. In addition to these elements selenium is enriched in ore.

Distribution of ore-associated elements relative to the Lisbon Valley fault.--The analyses of mill pulps in table 25 are arranged in order of increasing distance from the Lisbon Valley fault. An examination of the data reveals no consistent changes in composition of Salt Wash uranium-vanadium ores with distance from the fault. However, ore from the very large Rattlesnake deposit, which is cut by a branch of the Lisbon Valley fault, contains a higher concentration of selenium than that found in the other Salt Wash ores. Ore from the Liberty No. 1 deposit contains more copper than that from the other Salt Wash deposits and is nearer the Lisbon Valley fault.

The significance of these features is uncertain. There are more than 100 uranium-vanadium deposits known in the Lisbon Valley area (G. W. Weir and W. P. Puffett, written communication), and probably less than 5 percent of these are located within a few hundred feet of a fault. The chances that the Rattlesnake, the largest Salt Wash deposit in the area, would be found adjacent to the Lisbon Valley fault would appear to be small if there were no relation between the uranium-vanadium deposit and the fault.

Although the chemical data shown in table 25 indicate no significant relation between composition of ore and distance from the Lisbon Valley fault, G. W. Weir (written communication) has noted that Salt Wash ore bodies near the fault contain more copper minerals than those far from the fault in the area southeast of the Blackbird mine. Shawe, and others, (1959, p. 403) found the copper content of uranium-vanadium deposits to be relatively high near the Dolores fault zone which lies southeast of, and about in line with, the Lisbon Valley fault. Thus, a zoning of copper content with respect to faults seems probable in the southeasternmost part of the Lisbon Valley area.

Composition of rocks and colluvium near uranium-vanadium ores

The distribution of elements around ore was studied by comparing the composition of rock samples collected near ore with those far from known ore and by analyzing drill core collected at varying distances above ore. Many elements vary with the aluminum content of a rock sample; hence, only rock samples of similar aluminum content at varying distances from ore were compared to establish the presence or absence of a "halo" of ore-associated elements near ore bodies.

The Black Bottom deposit, located in the East Canyon of Dry Valley, was selected for a study of rock composition near ore. A few samples were also collected near the Profit No. 1 and Sunset mines located about 500 feet and 3,200 feet, respectively, south of the Black Bottom mine.

All three mines are in the uppermost prominent of the Salt Wash sandstone, which in places exceeds 80 feet in thickness. At the Black Bottom deposit the ore consists mostly of "rolls" of various types which have a general northeast trend (rolls are narrow, elongate ore bodies which curve sharply across bedding. See Shawe, and others, 1959, p. 409). The ore sandstone is underlain by greenish-gray mudstone and shale which is two or more feet thick were exposed in a road cut in front of the mine entrance. This basal mudstone and shale is covered by colluvium for a distance of about 200 feet away from the mine; where it is seen again, it is red-brown. The ore sandstone is very light brown in color but has thin, interlayered, predominantly greenish, mudstone lenses near the mine. At distances greater than 150-200 feet from the Black Bottom mine, the thicker mudstone lenses have increasing amounts of red-brown material.

The Black Bottom and Profit No. 1 mines, at the time of sampling, had produced less than 2000 tons of ore. The grade of ore in both mines was approximately 0.25 percent U_3O_8 and 2 percent V_2O_5 (G. W. Weir, written communication, 1960). The Sunset mine is considerably larger than the Black Bottom and Profit No. 1, but the writer has no accurate data concerning its ore production.

Fifty samples were collected representing ore, basal mudstone, massive sandstone, and interlayered mudstone, both near and far from known ore. The samples were grouped according to their aluminum content, and the median value for each determined element was found for each group. These median values were the standards against which the compositions of the various samples were compared.

The compositions of three samples of ore and one of slightly mineralized rock were compared with the median values for each element, and anomalous elements were thus identified. Barium, beryllium, cobalt, copper, nickel, lead, selenium, silver, strontium, uranium, vanadium, yttrium, zinc and possibly chromium were apparently concentrated in the ores. The slightly mineralized sample was enriched only in uranium, vanadium, and lead.

The compositions of six samples of basal mudstone collected within 30 feet of ore were compared with three similar samples collected more than 200 feet from ore and found to contain, on the average, slightly higher concentrations of copper, lead, selenium, and vanadium.

Four samples of interbedded mudstone collected within 30 feet of ore contained more barium and copper than five similar samples collected more than 200 feet from ore.

Six samples of massive sandstone collected near ore contained more chromium, copper, lead, and vanadium than five samples collected far from ore.

For both the mudstone and sandstone samples mentioned above, only samples of similar aluminum content were compared. Because copper, lead, and vanadium appear to be slightly concentrated within 30 feet of ore in both basal mudstone and massive sandstone, they are potentially more valuable in prospecting than other elements which were determined. Only small numbers of samples were used in the comparisons, however, and the semiquantitative nature of the analytical data must be considered in evaluating the results. No trace analyses for uranium were made in this

(p. 95 follows)

particular study, so the distribution of uranium around the Black Bottom mine is not known.

A study made by Miesch and Connor (1956, p. 128-145) indicated that vanadium in either the total rock or the acid-soluble fraction; copper, lead, and zinc in the acid-soluble fraction; or uranium in the total rock can serve to delineate broad areas favorable for detailed prospecting because of the increased concentration of these elements near ore. The distribution of cobalt, nickel, arsenic, selenium, and molybdenum did not form a useful pattern more than a few feet from ore. Thus, the results of the Lisbon Valley work generally agree with that conducted by Miesch and Connor.

As part of the study of distribution of elements near Salt Wash ore bodies, a series of core samples was collected from drill holes penetrating uranium-vanadium ore near the Blue Jay mine (sec. 28, T. 28 S., R. 23 E.). In addition, samples of colluvium overlying high-grade uranium-vanadium ore were collected at the Rattlesnake mine. The analytical data from the drill core are shown in table 26.

Ore samples from the drill core contained anomalous concentrations of cobalt, lead, cerium, silver, uranium, vanadium, and zinc as compared to barren samples collected in the Black Bottom area. Cobalt, cerium, uranium, and zinc show a very sharp decrease in concentration in going from ore to rock in contact with ore. Lead, silver, and vanadium are anomalous in rocks at least 0.4 foot above ore in hole number 21, but are not discernibly enriched more than 0.01 foot from ore in drill hole number 10. The abrupt change from ore to barren rock, which is noticeable as a change from medium or dark gray to very light brown rock, is apparently also marked by an equally abrupt change in concentration of many of the ore-associated elements.

The sample of drill core collected at 26.5 feet above ore in drill hole 10 was selected because of its purplish-gray color which, at first glance, resembles vanadium ore. Comparison of this sample with barren rock of similar aluminum content indicates that the sample probably contains anomalous amounts of iron, arsenic, and possibly manganese and vanadium. Similar appearing material (from a roll-type deposit) collected from a prospect in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 34, T. 27 S., R. 23 E. was examined by A. J. Gude 3d, and the minerals coating sand grains were found to be micaceous hematite and roscoelite with very fine chlorite and sericite(?). Spectrographic analysis of the sample examined by Gude showed X. percent iron, 0.X- percent vanadium, 0.004 percent equivalent uranium, 0.00X+ percent magnesium, and less than 0.X+ percent potassium, suggesting that most of the mineral coating was hematite. Other examples of these "hematite-roscoelite" deposits were found during geologic mapping. Apparently there is a high-iron, low-uranium-vanadium type deposit which imitates in appearance the better known uranium-vanadium deposits. D. R. Shawe (oral communication) has found similar deposits in the Slick Rock district, Colorado.

Samples of colluvium taken above high-grade uranium-vanadium ore at the Rattlesnake mine also demonstrated the very slight tendency of ore-associated elements to migrate upward from ore. Analyses of samples collected just below the ore-colluvium contact, and at 0.5, 11.5, and 13.5 feet above ore are shown in table 27 (in pocket).

If the compositions of the ore and the overlying colluvium are compared with that of barren of the Salt Wash Member sandstone, the elements which are present in abnormal concentrations can be identified. The ore sample apparently contains anomalous amounts of barium, lead, antimony, selenium, uranium, vanadium, and zinc. Despite the fact that the ore contains about 7 percent uranium, the colluvium only 0.5 foot away contains less than 0.0004 percent uranium, thus demonstrating the failure of uranium to diffuse even a short distance upward. Barium, selenium, and vanadium are all more concentrated than normal in the colluvium 0.5 foot above ore and may have moved upward from the underlying ore.

Composition of carbonaceous material in the Dip mine

The Dip mine is located in sec. 4, T. 28 S., R. 23 E. The partially oxidized ore occurs in a gently dipping sandstone lens which is 10 to 12 feet thick and is exposed for a distance of about 150 feet along the strike. The production of the mine is estimated at about 200 tons of ore. Minerals identified in the ore by Theodore Botinelly (oral communication) include hematite, montroseite, carnotite, ilsemanite, and corvusite. Carbonized logs are very common in the walls and roof of the mine and have been replaced to a varying extent by ore minerals. Samples of three logs were collected representing highly mineralized, moderately mineralized, and slightly mineralized carbonaceous material. In addition, the rock near the highly mineralized log was sampled. Both rock and carbonaceous material were analyzed, and the data are shown in table 28 (in pocket). Differing amounts of inorganic matter are mixed with the carbonaceous samples, and this may account for the differences in concentration of aluminum, iron, manganese, and calcium found.

Comparison of the composition of the carbonized logs with that of barren of the Salt Wash sandstone indicates that the logs contain abnormally high concentrations of As, Ba, Mo, Pb, Se, U. V, Zn, and Zr. All of these elements show some evidence of positive correlation with uranium. In addition, Al, Fe, Ti, Mn, and Ca increase in concentration with increasing mineralization. Apparently the most highly mineralized log was the one containing the most intermixed sand and silt.

Comparison of uranium-vanadium ores from various formations

Uranium-vanadium ores have been produced from the Cutler, Chinle, and Morrison formations in the Lisbon Valley area. Analyses of samples of ore from each of these formations were made as a part of this study, and it was found that certain characteristics are common to ores in all formations and other characteristics tend to be restricted to ores from just one or two formations. In table 29, elements which are enriched in ores of all three formations are listed first; then elements known to be enriched in two formations are listed; and last are those elements which are known to be significantly enriched in the ores of only one formation. The failure to find anomalous amounts of some elements in the Cutler ores may be due to the small number of samples analyzed. More samples were analyzed from the Chinle than from other formations and more elements were found anomalous in at least some samples of the Chinle rocks.

The uranium-vanadium ores from the various formations not only have many similarities but also many differences. The ores in all three formations appear to favor quartzitic or arkosic sandstones and conglomerates as host rocks. Although small lenses of interbedded mudstone, individual mudstone fragments, or mudstone at the base or top of the ore sand may be mineralized, the writer knows of very few instances in any formation where appreciable quantities of high-grade ore are found more than a few feet from quartzose

Table 29.--Elements enriched in uranium-vanadium ores of the Lisbon Valley area

(Explanation for symbols used is as follows: X - element is present in anomalous concentrations; $\underline{X}$ - element is notably concentrated in ore; N.D. - not determined; ? - insufficient samples have been analyzed to determine whether the element is concentrated in ore).

	Formation		
Element	✓ Cutler	✓ Chinle	✓ Morrison ✓ (Salt Wash member)
Ba	X	X	X
Ce	X	X	X
Cu	$\underline{X}$	X	X
Pb	$\underline{X}$	$\underline{X}$	$\underline{X}$
U	$\underline{X}$	$\underline{X}$	$\underline{X}$
V	$\underline{X}$	$\underline{X}$	$\underline{X}$
Y	X	X	X
Ag	X	X	
As	N.D.	X	X
Be	?	X	X
Co	?	X	X
Dy	X	X	
Er	X	X	
Mo	?	$\underline{X}$	X
Nd	X	X	
Ni	?	X	X
Se	N.D.	X	$\underline{X}$
Sr	?	$\underline{X}$	X
Zn	N.D.	X	X
Zr	?	X	X
Cd	?	X	
Fe	?	X	
Gd	?	X	
Ho	X		
La	?	X	
Sb	N.D.	N.D.	X
Sm	?	X	
Tl	?	X	
Yb	?	X	

sandstone in the Lisbon Valley area. The ores from all formations contain anomalous amounts of barium, cerium, copper, lead, uranium, vanadium, and yttrium. If more analyses of Cutler ore had been made, this list might have included some other elements which are enriched in Chinle and Salt Wash ores.

The differences between ores from the three formations are mainly in the degree to which various elements are concentrated rather than in the elements which were concentrated. Thus, relatively high copper concentrations appear to mark the Cutler ores. Copper is also found in varying degree in the Chinle and Salt Wash ores, but generally is least common in of the Salt Wash Member sandstones. Silver is associated with copper enrichment and very little was detected in the Wash ores, possibly because the copper is so slightly concentrated there. Selenium, in contrast to copper, is most concentrated in Salt Wash ores and is only slightly enriched in the Chinle deposits. Cadmium is detectable in the ores from many of the Chinle mines but was not detected in ore from the Cutler or Salt Wash rocks. Visible carbonaceous material is characteristically associated with ore in of both the Chinle and Salt Wash sandstones but apparently is not associated with Cutler ore.

Another way in which the ores differ is in the state of oxidation. Both the Cutler and Salt Wash ores are relatively well oxidized compared to the Chinle ores. Thus, the Salt Wash deposits commonly contain bright yellow uranium-vanadium minerals; the Cutler deposits contain yellow uranium-vanadium minerals and green copper carbonates; and the Chinle ores are black due to the presence of low-valent vanadium and uranium oxides.

COPPER DEPOSITS

The copper deposits in the sedimentary rocks of the Lisbon Valley area are restricted almost entirely to sites along or near the Lisbon Valley fault zone. Copper minerals are found in the Dakota sandstone and in the Hermosa, Cutler, Chinle, Kayenta, Morrison, Burro Canyon formations. However, in the Lisbon Valley area, only the Dakota, and, possibly Burro Canyon, rocks are believed to have appreciable reserves of copper minerals.

The copper minerals found in the Hermosa were malachite, azurite, cuprite, and chalcocite in small lenses parallel to bedding, as coatings on carbonaceous fragments, and along fractures. The greatest concentrations were found in the vicinity of prospect pits near the south end of Lisbon Valley. However, no deposits of ore grade were seen in the Hermosa formation.

Uranium-vanadium deposits in Cutler rocks contain malachite and copper sulfate (Dix, 1954, p. 13), and a low-grade mineral deposit consisting mainly of disseminated copper carbonates with a little uranium is present in conglomeratic sandstone at the Woods mine at the south end of Lisbon Valley.

Although anomalous concentrations of copper are present in all the uranium-vanadium ores of the Chinle formation, copper minerals are generally sparse. The Mi Vida and Big Buck mines contain several zones in which copper minerals are found distances of a few inches to a few feet. In the Big Buck mine malachite, native copper, and chalcopyrite occur, but in the Mi Vida only malachite and chalcopyrite were seen.

Only one small copper deposit was found in the Kayenta formation. It is located near the south end of Lisbon Valley, a few hundred feet south of the Blackbird copper mine. The deposit consists primarily of malachite disseminated in carbonate-cemented sandstone.

Most of the copper found in the Lisbon Valley area is in medium- to coarse-grained sandstones and conglomerates of the Dakota sandstone. The two main deposits are the Big Indian Copper mine located near the junction of Big Indian Wash and Lisbon Valley and the Blackbird Copper mine located near the south end of Lisbon Valley. Much of the copper ore is present in the form of malachite and azurite, but minor amounts of chrysocolla, chalcocite, and covellite are reported by Isachsen (1954, p. 100).

In addition to the copper deposits in sedimentary rocks, there are small deposits containing azurite, malachite, chrysocolla, bornite and chalcopyrite associated with altered diorite porphry in Lackey Basin in the La Sal Mountains

(Weir, G. W., and Puffett, W. P., 1960, written communication).

Analyses were made of copper-bearing samples from several of the copper deposits in the Lisbon Valley area, and the results are given in table 30. Examination of the table shows that silver and commonly molybdenum are enriched in the copper samples regardless of source. Only the copper-bearing samples from uranium-vanadium deposits contain anomalous concentrations of cobalt and zirconium. Enrichment in these two elements is probably related to the presence of uranium rather than that of copper. The concentration of nickel seems above normal in just one sample--a sample of uranium ore. Most copper-bearing samples which are enriched in lead also contain uranium, and the correlation between the concentrations of lead and uranium is evident. Of the samples not from a uranium mine, only that from the Hermosa formation and one sample from the Blackbird mine contained more than 0.01 percent lead. It is apparent that the lead:copper ratio in the copper ores is very low.

Measurements of equivalent uranium in copper samples indicate that uranium or its daughter products are present in anomalous concentrations in the Cutler, Chinle, Kayenta, and Burro Canyon formations, but no correlation between copper minerals and eU is evident.

Other elements enriched in some of the copper samples are bismuth, arsenic, zinc, iron, strontium, the rare earths, and possibly vanadium.

The data from table 30 are summarized in table 31. The term "enriched" as applied in table 31 must, of necessity, be relative, for the normal concentration of the elements in copper ores is not known. In general, the concentration of an element was considered anomalous if it exceeded by a factor of 4 or more the median concentration found in Chinle or Salt Wash rocks of equivalent aluminum content. The purpose of the table is to emphasize the chemical relations between copper ores from various sources in the Lisbon Valley area.

MANGANESE DEPOSITS

Manganese and iron oxides fill near-vertical fractures and impregnate sandstones of the Navajo Sandstone ~~formation~~ near faults at many places near the north end of the Lisbon Valley fault zone in sec. 19, T. 28 S., R. 23 E., and in secs. 13, 14, 24, T. 28 S., R. 22 E. (See Baker, Duncan, and Hunt, 1952, p. 128). A small manganese deposit also is located in the Lisbon Valley fault zone in the W$\frac{1}{4}$ sec. 25, T. 29$\frac{1}{2}$ S., R. 24 E. Here, the mineralized sandstones are believed to be part of the Cutler formation. Lenses of high-grade manganese oxide ore exposed in sec. 19 are as much as 6 to 8 inches in width and 10 to 20 feet in length. The black manganese oxide has been identified as pyrolusite by Miss Betsy Levin, using X-ray methods.

Analyses were made of two manganese-bearing samples;

Table 31.--Elements enriched in copper-bearing samples from the Lisbon Valley area
(Explanation for symbols used is as follows: X - element is present in anomalous concentrations; X? - may be anomalous; N.D. - not determined)

Element	Rock unit						
	Hermosa formation	Cutler formation	Chinle formation	Kayenta formation	Burro Canyon fm. Formation	Dakota ~~formation~~ Sandstone	Diorite porphry La Sal Mtns.
Ag	X	X	X	X	X	X	X
As		N.D.	X	X	X	N.D.	X
Ba	X	X	X				X
Bi							X
Cd						X	
Ce			X			X	X
Co			X				
Dy			X				
Er			X				
Fe			X		X		X
Gd			X				
Ge		X					
Mo	X		X		X	X	X
Nd			X			X	X
Ni			X				
P						X	
Pb	X		X			X	
Se	X	N.D.	X	X		X	X
Sn					X		
Sr			X				X
Tl			X				
eU		X	X	X	X	X?	
U	N.D.	N.D.	X	N.D.	N.D.	N.D.	N.D.
V			X	X?	X?		X
Y			X			X?	
Yb			X			X?	
Zn			X		X?	X	
Zr			X				

one was a composite of ore from a prospect in sec. 19 and the other a composite of mineralized rock from sec. 25. The compositions of these two samples are shown in table 32.

The manganese samples, when compared with barren sandstones from the Lisbon Valley area, contain abnormal concentrations of silver, arsenic, barium, cobalt, copper, manganese, molybdenum, vanadium, zinc, and possibly nickel, selenium and strontium. The assemblage of anomalous elements is similar to those found in the copper-bearing samples from the Chinle uranium deposits except for the high concentration of manganese, and the absence of abnormal concentrations of zirconium, lead, uranium, and the rare earths.

The manganese ore containing the most copper also contains the most silver demonstrating again the geochemical coherence of copper and silver.

Hewett and Fleischer (1960, p. 14-53) have noted the tendency for manganese minerals to contain many trace elements. Thus the manganese ores in Lisbon Valley are not unusual in this respect.

SUMMARY OF THE CHEMISTRY OF THE ORE DEPOSITS

The study of the composition of mineral deposits and host rocks for ore in the Lisbon Valley area supplies information concerning (1) the elements which appear to have

Table 32.--Composition of manganese-bearing samples from the Lisbon Valley area

[Analysts: Spectrographic, R. G. Havens and J. C. Hamilton; Arsenic, J. P. Schuch and G. T. Burrow; Selenium, G. T. Burrow; equivalent Uranium, D. L. Schafer and C. G. Angelo; Zinc, W. D. Goss]

Element	Sample Number and Location		Element	Sample Number and Location	
	254208 - Sec. 19, T. 28 S., R. 23 E. 1/	251619 - Sec. 25, T. 29½ S., R. 24 E. 2/		254208 - Sec. 19 T. 28 S., R. 23 E. 1/	251619 - Sec. 25, T. 29½ S., R. 24 E. 2/
Si	XX. 3/	XX.	Cr	.000X 3/	.000X+
Al	.X	.X+	Cu	.X	.0X
Fe	X.+	.X	Mo	.00X+	.00X+
Mg	.0X	.X	Ni	.00X+	.00X+
Ca	.X	X.	Pb	.00X	.00X
Na	.X-	.X	Sc	.000X+	0
K	.X+	0	Se	0.0003	0.0001
Ti	.0X-	.0X-	Sr	.0X+	.X
Mn	XX.	XX.	V	.00X+	.0X+
Ag	.000X-	0	eU	< .001	.001
As	0.0050	0.0044	Y	.00X-	.00X
Ba	.X+	.X	Yb	.000X-	.000X+
Be	.000X+	.000X+	Zn	.0X	.0130
Co	.0X-	.0X-	Zr	.00X+	.0X-

1/ Field number is K-1/31/57-S1.

2/ Field number is [illegible]

been epigenetically added to or removed from mineralized rocks, (2) the relation between the composition of the ores and geologic structures, and (3) the distribution of elements within or near individual ore bodies.

in the Cutler Formation deposits

The mineral deposits in the Cutler formation are of relatively low grade, and the uranium-vanadium deposits contain, in general, a higher percentage of copper than those in other formations.

The Woods copper deposit near the Lisbon Valley fault has a high copper:uranium ratio. Deposits farther from the fault have a lower copper:uranium ratio. Elements whose, concentrations in one or more ore samples are more than twice as high as in barren Cutler samples are Ce, Cu, Dy, Er, Pb, Ho, Nd, Nb, Ag, U, V, Y, and possibly La. The ore controls are obscure, but all of the deposits are in lenses of arkosic sandstone or conglomerate.

Practically no carbonaceous material is visible (G. W. Wier, written communication), but the presence near mineralized rock of zones lighter in color than the surrounding host rock suggests that iron may have been removed near ore. One possible way of removing the iron would be by reduction to the ferrous state followed by migration as iron bicarbonate. Elsewhere in the Lisbon Valley area, copper carbonates appear to have been derived from the oxidation of original copper sulfides. This was probably the case for the Cutler ores also. If so, the sulfides must have formed under reducing conditions. If local areas of reducing environment existed in the Cutler rocks, as suggested by available evidence, then uranium-vanadium minerals could have been precipitated locally after reduction.

in the Chinle Formation deposits

The host rocks of the Chinle formation can be considered as being composed of quartzose and calcarenite rock types. The quartzose rocks range in grain size from mudstone to conglomerate and show a more or less systematic change in composition with grain size. The calcarenite commonly range in size from that of fine-grained sandstone to coarse conglomerate. Chemically, the calcarenites appear to be quartzose rocks containing very large percentages of calcium carbonate mixed with a little manganese, and possibly magnesium carbonate.

Mineralization of the lower of the Chinle rocks produced little, if any, changes in the concentration of aluminum and titanium in the host rocks. The content of boron, chromium, gallium, magnesium, niobium, potassium, and probably scandium was also affected very little. Because most elements show a positive correlation with aluminum or titanium in barren rocks, it is possible, given the concentration of these reference elements, to estimate the original composition of a mineralized rock.

Comparison of the composition of mineralized rocks and mill pulps with that of barren rocks, showed that arsenic, barium, beryllium, cadmium, cobalt, copper, lead, molybdenum, nickel, some rare earths, selenium, strontium, thallium, vanadium, uranium, yttrium, zinc, and zirconium were enriched in one or more mineralized samples. Two hand samples containing more than one percent uranium appeared to have anomalous concentrations of scandium; however, most mineralized samples contained the normal amount of scandium.

Although many elements are enriched in the Chinle ores, there is remarkably little correlation among most of the ore-associated elements. One part of a deposit will be relatively rich in copper minerals; another part may have visible quantities of cadmium sulfide; another, molybdenum sulfide; and still another may only have anomalous concentrations of uranium and vanadium. Great changes in the chemical composition of the ore can occur in a distance of a few inches or less, and a sharp boundary of ore commonly cuts across bedding for no obvious reason.

Magnesium correlates with aluminum in the uranium-vanadium ores and shows essentially no tendency to vary with the calcium concentration. Apparently the magnesium present is associated with the clay minerals or chlorite. There is no evidence of dolomitization accompanying the ore.

Some ore-associated elements do tend to correlate with each other. The best example of this is the lead-uranium correlation which suggests that the lead may have been derived by radioactive decay of uranium. The content of zirconium and rare earths is above normal in many high-grade uranium samples. This correlation is believed to result from the substitution of these elements in the coffinite or uraninite lattice. In some sample suites, the arsenic content increases with an increase in iron. The presence of 0.24 percent arsenic in a mineral separate containing much iron sulfide indicates that the arsenic-iron relation may be due to the presence of arsenic in pyrite or marcasite. Yttrium and ytterbium show good correlation and, in general, an increase in one rare earth signals an increase in others. This is to be expected from their similar ionic radii. Detectable silver concentrations are usually found only when the copper concentrations are above normal, indicating that silver is associated with the copper minerals.

The composition of the ores appears to be dependent, at least in part, upon distance from the southeast end of the district and upon location on the flank of the anticline. The V:U ratio is highest in ores from the southeastern mines where the ratio exceeds 2:1 and is lowest in ores from northwestern mines where the ratio is 0.05 or less. The ratio also increases going up-dip on the anticline as evidenced by the change from 0.3 in the Little Beaver to 2.1 in the Big Buck and the change from 0.07 in the La Sal mine to 0.2 in the Cal Uranium. Other elements which decrease in concentration toward the northwest are arsenic, molybdenum, yttrium, and possibly cerium, lanthanum, and zinc. Elements which are highest in concentration in ores near the middle of the district are cadmium and copper. Only strontium and possibly beryllium are highest in concentration in the northwestern ore deposits.

Inasmuch as the Chinle deposits which are most deeply buried have the lowest V:U ratios and the deposits nearest the surface have the highest ratios, it seems possible that selective leaching of uranium has taken place in some deposits prior to oxidation of vanadium. If such leaching took place the uranium-bearing waters may have percolated down dip where the uranium could have reprecipitated under more strongly reducing conditions, thereby accentuating the decrease in V:U ratio down dip. The radiochemical analysis of high-grade uranium ore from the Mi Vida deposit indicated that about one-third of the original uranium had been leached, yet the sample was taken from a mine wall showing only surficial oxidation due to exposure by mining. If leaching and redeposition of the apparently fresh ores was extensive, age determinations made using "black" ores from the Lisbon Valley area would show great variation.

yes now

Analyses of a few "barren" rock samples near ore suggested that molybdenum was slightly enriched and calcium leached in rocks close to uranium ore. Barren samples of ore sandstone from the Continental No. 1 mine contained above normal concentrations of arsenic, cobalt, copper, iron, molybdenum, nickel, vanadium, and possibly lead despite the fact that the uranium concentration was less than 10 ppm. Apparently ore-associated elements are slightly enriched in some rocks near ore even though there is no visual evidence of mineralization or abnormal concentration of uranium.

Samples were taken from a very slightly mineralized log in contact with high-grade uranium-vanadium ore, from mineralized carbonaceous trash, and from barren carbonaceous material collected both near and far from any known ore. Barren carbonaceous material collected far from ore was enriched in many elements known to be concentrated in coal ashes. Except for a slight increase in uranium near mineralized rock, no significant difference was noted between the composition of carbonaceous material near slightly mineralized (radioactive) rock and that of three similar samples collected far from ore.

A very slightly mineralized log in contact with high-grade ore was found to contain above normal concentrations of uranium, scandium, and niobium when compared on an air-dried basis with barren carbonaceous material collected far from ore. Analysis of organic and mineral fractions from this slightly mineralized log indicated that U, As, B, Ba, Cr, Cu, Mo, Nb, Sc, Y, Ys, Zn, and Zr were most concentrated in the ash of the organic fractions whereas, the uranium daughter products (ra^{226}, Rn^{222}, and Pb^{210}) were most concentrated in the mineral fractions along with silicon, iron, calcium, and the other major elements.

How good a separation of the fractions is possible?

The fact that a carbonized log contained only 0.008 percent uranium, despite its location in contact with rock containing about one percent uranium, shows that some organic matter is remarkably resistant to mineralization. Elsewhere in the same ore deposit, carbonaceous matter was preferentially mineralized. The reason for the great variation in susceptibility to mineralization of apparently similar carbonaceous material is unexplained.

The analysis of a series of mineralized carbonaceous samples from the Continental No. 1 mine indicated that vanadium, arsenic, cobalt, copper, manganese, lead, scandium, selenium, yttrium, ytterbium, zirconium, and possibly barium, molybdenum, nickel, thallium, and zinc tend to be more concentrated in samples containing much uranium than those with little uranium.

The similarity between the elements enriched in the uranium-vanadium ores and those enriched in coal ashes is striking. This suggests that the mechanisms of enrichment in the two types of material may be similar.

Mill pulp samples from the Chinle deposits contained 0.05 to 0.34 percent organic carbon. If organic material is assumed to be the ultimate source of reducing capacity for the uranium, vanadium, iron, and sulfide sulfur in the ores the percentage of organic carbon required to reduce these elements in the Mi Vida ores, for example, probably was in the range 0.5 to 1.0 percent. This is 10 to 20 times as

Note calcite-filled log in Mi Vida

much organic carbon as is now present in Mi Vida ore.

in the Salt Wash Member deposits

Analysis of barren rock samples from of the Salt Wash Member sandstone indicated that aluminum tended to correlate positively with boron, cobalt, chromium, gallium, iron, lead, magnesium, nickel, potassium, sodium, scandium, strontium, titanium, vanadium, and yttrium. The concentrations of copper, zinc, and zirconium show a less well-defined correlation with aluminum. Calcium and manganese tend to decrease with increasing aluminum concentration.

The composition of mineral separates from stream sands derived from Salt Wash terrane demonstrates that aluminum, magnesium, calcium, sodium, potassium, and beryllium show little tendency to be unusually high in concentration in any one particular mineral fraction. Barium, boron, cerium, chromium, hafnium, strontium, yttrium, ytterbium, zirconium and neodymium are major constituents of one or more of the heavy minerals and hence are most concentrated in the heavy fractions. Titanium, iron, manganese, cobalt, copper, niobium, nickel, lead, scandium, and vanadium appear to be intermediate in the degree of concentration.

Comparison of the composition of barren and mineralized Salt Wash samples indicates that arsenic, barium, beryllium, calcium, cobalt, copper, lead, manganese, molybdenum, strontium, uranium, vanadium, yttrium, and zinc are above normal in concentration in one or more mineralized samples.

There is relatively little evidence of change in composition of ore with distance from the Lisbon Valley fault except in the case of copper in the southeastern part of the Lisbon Valley area. The selenium concentration is higher in mill pulps from the Rattlesnake mine than in mill pulps from mines farther from the fault. The copper content of ore from the Rattlesnake mine, however, is about normal for Salt Wash ores of the Lisbon Valley area. None of the ore-associated elements shows a consistent decrease or increase away from the fault throughout the district.

A study of the composition of rocks near the Black Bottom mine indicated that samples of apparently unmineralized "ore sandstone" and of mudstone at the base of the "ore sandstone" contained higher concentrations of copper, lead, and vanadium within 30 feet of ore than did samples collected more than 100 feet from ore. This suggests that there may be a "halo" of copper, lead, and vanadium near the ore body. Samples collected from drill core penetrating ore near the Blue Jay mine, however, showed that in some cases no ore-associated elements are enriched in the rock for more than 0.01 foot above ore. It seems apparent that there is considerable variation in the extent to which a "halo" extends away from uranium-vanadium deposits in of the Salt Wash sandstones.

Analysis of carbonized logs from the Dip mine showed that such materials vary widely in degree of mineralization even though they are in the same sandstone lens and only a few feet apart. Elements enriched in the mineralized logs were arsenic, barium, molybdenum, selenium, uranium, vanadium, zinc, and zirconium. All of these elements tend to increase with increasing uranium concentration, but the relation is not a uniform one.

Comparison of uranium-vanadium ores

The uranium-vanadium ores from the various formations not only have many similarities but also many differences. The ores in the Cutler, Chinle, and Morrison formations all seem to favor quartzitic or arkosic sandstones and conglomerates as host rocks. All of the ores contain anomalous amounts of barium, cerium, copper, lead, uranium, vanadium, and yttrium. The differences between uranium-vanadium ores from the various formations are mainly in the degree to which various elements are concentrated rather than in the particular elements which were concentrated. Copper and silver are most concentrated in the Cutler ores, molybdenum and cadmium are most enriched in the Chinle ores, and the selenium and vanadium content is greatest in Salt Wash ores. Only the Cutler ores are not obviously associated with visible carbonaceous material.

Copper and manganese deposits

Both copper and manganese deposits are clearly associated with the Lisbon Valley fault. Many of the elements enriched in uranium-vanadium ores are present in manganese oxide samples in higher concentrations than in barren sandstones of the Chinle and Salt Wash ~~sandstones~~. However, manganese oxides are known to act as scavengers of minor elements from solution and this may explain the anomalous concentrations of many elements in the manganese deposits (see Goldschmidt, 1954, p. 627).

Copper deposits along the Lisbon Valley fault and in the La Sal Mountains contain some of the elements enriched in the uranium deposits, but the similarity is not so great that one can conclude that they were necessarily derived from the same solution. Uranium and vanadium minerals have been found in a few of the copper deposits. It is not clear from the composition of the copper ores whether the uranium and vanadium were carried in the same solution with the copper or whether two or more solutions were responsible for ore deposition. If local areas were characterized by a strongly reducing environment, uranium and vanadium may have been deposited there at one time and copper deposited in the reducing environment at the same time or later.

ORIGIN OF MINERAL DEPOSITS IN THE LISBON VALLEY AREA

Many different theories have been advanced to explain the origin of the copper deposits and of the sandstone-type uranium-vanadium deposits of the Colorado Plateau, but the problem is still not solved to the satisfaction of many geologists.

The Lisbon Valley area offers an unusually good opportunity to evaluate some of these theories because of the presence of several large ore deposits within a limited area and because much information is available from studies conducted there.

of the Chinle and Cutler Formations ores

Isotopic data and age of the ores

Stieff and Stern (1956, p. 549) noted that the calculated ages of uranium ores commonly show the following discordant age sequence: the Pb^{206}/U^{238} age is less than the Pb^{207}/U^{235} which is much less than the Pb^{207}/Pb^{206} age. Miller and Kulp (1958, p. 941) found a consistent tendency for the calculated ages of Lisbon Valley ores to show the same sequence. Stieff and Stern (op. cit. p. 553) have pointed out that, as originally indicated by Kovarik (1931, p. 73-123), old radiogenic lead deposited with the uranium may account, in some instances, for the failure of the lead-uranium and lead-lead ages to agree. Such an explanation seems unlikely in the case of the Lisbon Valley ores. Not only would the old radiogenic lead have to travel through thousands of feet of sedimentary rocks without picking up more than 10 to 15 percent common lead, but it would have to be deposited with uranium in a reasonably consistent ratio. Exchangeable ions on clay minerals might logically be expected to include some lead, in which case the ore solution could pick up a moderate proportion of common lead as it percolated through the rocks. On reaching the site of deposition of the uranium some lead might precipitate as the sulfide in the reducing environment, but there is no obvious reason why the lead:uranium ratio should remain relatively constant regardless of the size of the ore sample. Other elements, such as zirconium and the rare earths, resemble uranium in their geochemistry more than does lead, yet none shows the consistent relation with uranium that lead does. Thus it seems probable that much of the lead is radiogenic and has been derived by decay of uranium in place.

Miller and Kulp (1958, p. 941-942) made isotopic analyses of eight samples of lead from ore in the Lisbon Valley area. Without exception, all were very high in radiogenic lead. Their data, therefore, support the idea that very little common ore lead was introduced with the uranium.

Further evidence suggesting that almost all the anomalous lead in the uranium ores is radiogenic is the fact that extrapolation of the lead:uranium relation found in this study shows a content of approximately 20 ppm lead at zero uranium. This value is essentially identical to the normal, or background, content of lead in Chinle rocks.

As an alternative explanation for the discordant ages in Lisbon Valley ores it seems possible that loss of radium and radon may have occurred during or following ore deposition, and uranium and lead may have been lost recently.

Germanov, and others (1958, p. 164) stated that although uranium concentrations in solution are low within uranium ore when the environment is strongly reducing, the radium content is sharply anomalous. Ground waters flowing through such areas would carry away some radium. The low concentration or absence of SO_4 in such an environment would reduce the tendency for precipitation of radium sulfate. If the waters were moving slowly Ra^{223} could decay to Pb^{207} before leaving the ore zone, whereas, Ra^{226}, with a half-life about 53,000 times as long as Ra^{223}, could be carried beyond the ore zone before decaying to Rn^{222} and then Pb^{206}. Thus the Pb^{207}/Pb^{206} ratio would be increased in the ore and the Pb^{206}/U^{238} ratio reduced. That radium has migrated in the Lisbon Valley deposits is indicated by a high Ra^{226}/U ratio in the barite-bearing fraction of a slightly mineralized log in contact with apparently unoxidized ore.

Wickman (1942, p. 465-476) suggested that the observed sequence of ages in uranium ores could be explained by the relatively greater diffusion of Rn^{222} compared to the diffusion of Rn^{219}. His suggestion was based on the fact that the half life of Rn^{222} is 84,000 times as great as that of Rn^{219}. The selective loss of Rn^{222} would have the same effect on the apparent age as loss of Ra^{226}. Miller and Kulp (1958, p. 945) note that radon leakage for carnotite and other fine secondary minerals has been measured as high as 30 percent and leakage from deep sea sediments as much as 70 percent. Kulp (1955, p. 613) stated that radon leakage from uraninites and pitchblendes ranges from 0.1 to 10 percent. Even though the average radon leakage may have been only 5 to 10 percent, it seems possible that radon loss was still a significant factor in changing the Pb^{206} content of the ore.

Lead in galena from the Divide (Divide Incline) mine had almost exactly the same isotopic composition as lead in uraninite mixed with the galena (Miller and Kulp, op. cit.). This means, according to Miller and Kulp, that deposition of the uraninite "occurred within the last 5 m. y. or that an older deposit recrystallized and exsolved its lead during the last 5 m. y." The latter possibility seems more reasonable on the basis of the good uranium-lead correlation in Lisbon Valley ore. If radiogenic lead exsolved from uraninite and moved far enough to form megascopic galena crystals and veinlets, it seems possible that some moved beyond the boundary of the ore deposit. If so, the Pb^{206}/U^{238} and Pb^{207}/U^{235} ratios would decrease and cause a reduction in the apparent age of the ores.

Rosholt's data showing loss of uranium from high-grade black ore in the Mi Vida deposit indicate that the Lisbon Valley ores are not so unaltered as they appear. Part of the uranium leached from high grade Mi Vida ore may have been redeposited nearby, but it is quite possible that some uranium has moved out of the deposit. Recent loss of uranium would increase the apparent lead-uranium ages but would not affect the lead-lead ages.

If it is assumed that uranium and its daughter products have moved since deposition, then the determination of the exact age of the ores becomes very difficult, if not impossible. However, a rough approximation may still be made if it is assumed that alteration of the ore has not occurred on a very large scale.

Miller and Kulp (1958, p. 941) reported apparent Pb^{206}/U^{238} ages for six samples from Chinle ores of the Lisbon Valley area as 85, 112, 185, 190, 205, and 294 million years. Possibly the great spread in ages can be accounted for by loss or gain of uranium or its daughter products in varying degree. It should be noted, however, that three out of six of Miller and Kulp's values are quite close to 195 million years, and the average of all six ages is about 178 million years.

Estimations of the age of the ores can also be based on the lead-uranium relation in samples analyzed during the present study. E. M. Shoemaker (written communication, 1959) computed a regression coefficient of lead on uranium of 0.0321 from data for composite mill pulps from the Lisbon Valley area. He states "This regression coefficient takes account only of the variation in lead that is ascribable to its correlation with uranium." The regression coefficient may be taken as an indication of the ratio of radiogenic lead to uranium. If 95 percent of the radiogenic lead is Pb^{206} (calculated from lead isotope analyses given by Miller and Kulp (1958, p. 940, 943) and 99.29 percent of the uranium is U^{238}, then the estimated age of the ore is approximately 226 million years. Shoemaker (op. cit.), using an estimate of 95.5 percent Pb^{206} in the radiogenic lead, arrived at an age of 231 million years with a probable error from 226 million years to 238 million years. These figures are somewhat higher than those reported by Miller and Kulp (op. cit.), but still in the same general range.

The ages estimated above are near the age range (180-225 million years) attributed to Triassic rocks by Holmes (1960). The explanation for the discrepancy between the age calculated from lead-uranium ratios in ore (225 m. y.) and the age of Chinle rocks (perhaps 180 m. y.) is not known. However, a reasonable hypothesis may be that radon or radium was lost over a long period of time and that recently there has been some loss of uranium. Such a series of events could produce the type of discordant ages found and account for the range in apparent ages. The extent of uranium leaching is not known, but it seems unlikely that even 50 percent has been leached from the ore. If the uranium-vanadium ores were deposited during the Early Tertiary (perhaps 60 million years ago) and leached since the Pliocene, more than 70 percent of the original uranium must have been removed to get the lead-uranium ratios now found. This seems unlikely, and it is believed that the Chinle ores were deposited prior to the Tertiary period.

Age determinations made on ore samples from other uranium deposits on the Colorado Plateau indicate apparent ages which are much less than those of the Lisbon Valley ores. Stieff and Stern (1952, p. 707) have reported ages in the range 65-75 million years for ores from the Happy Jack mine and the Shinarump No. 1 claim, both of which are in lower rocks of the Chinle Formation ~~rocks~~. Stieff, Stern, and Milkey (1953, p. 11) in a study of 41 samples of uranium ore from the Colorado Plateau found a median age of about 75 million years with 50 percent of the age determinations falling in the range 60 to 90 million years. Thus the Chinle ores of the Lisbon Valley area are much older than many other Plateau deposits if the apparent ages are approximately correct.

Hypogene solutions from Lisbon Valley fault

One theory proposed (G. W. Weir and W. P. Puffett, 1960, p. 147) to explain the genesis of the Lisbon Valley ores is that hypogene solutions circulating along the Lisbon Valley fault system deposited the copper ores and that the same, or similar, solutions spreading outward from faults deposited uranium-vanadium ores in the sedimentary rocks. Weir and Puffett point out that if the Tertiary copper deposits of the La Sal Mountains are related to those along the Lisbon Valley fault and also to the uranium-vanadium deposits, then all are Tertiary. The copper ores of the La Sal Mountains are in general somewhat similar to those along the Lisbon Valley fault system in mineralogy, chemical composition, and habit. Thus, there may be a close genetic relation between the deposits. Copper minerals form bedded deposits in the Dakota sandstone and Cutler and Burro Canyon formations near faults and are more common in Salt Wash uranium-vanadium deposits near the Lisbon Valley fault than far from the fault in the southeastern part of the Lisbon Valley area. These features all strongly suggest that copper-bearing solutions moved along the Lisbon Valley fault system and spread out into adjacent sedimentary rocks as suggested by Weir and Puffett (op. cit.).

The question of whether the copper-bearing solutions also carried uranium and vanadium is not easily answered. The presence of small amounts of copper in uranium-vanadium deposits may or may not have great genetic significance. Garrels and others (1957, p. 1732) pointed out that copper, molybdenum, vanadium, and uranium can be carried together in a solution which is moderately alkaline, slightly reducing, and has a PCO_2 greater than 10^{-1} atmospheres. Normal ground waters on the Colorado Plateau may meet these requirements, and even waters which were of unusual composition initially might be expected to approach these conditions rapidly during passage through the rocks. This is because the tremendous exchange capacity of the sedimentary minerals would tend to maintain the character of interstitial waters relatively constant. Thus, the uranium-vanadium-bearing waters might take some copper into solution even if it carried none originally. On encountering a strongly reducing environment, copper, along with other elements, would be precipitated. The amount of copper taken into solution and later precipitated would depend mainly upon the nature of sedimentary beds serving as a conduit and upon the conditions at the site of deposition.

Some available evidence indicates that hypogene solutions moving outward from the Lisbon Valley fault may not have been the transporting medium for both copper and uranium-vanadium ores. The copper ores are not older than Late Cretaceous because they form veins and impregnations in the Dakota sandstone. In contrast, the available isotopic data for the Chinle uranium-vanadium ores strongly suggest that they are of Triassic or perhaps Early Jurassic age. Thus, the Chinle ores were probably in existence long before the main copper deposits were formed.

Another problem encountered in assuming that uranium solutions moved up the fault and then spread out through the Salt Wash and Chinle rocks is that tremendous volumes of solution containing high concentrations of uranium are required. This problem is discussed below.

Volume of ore solution required

Keys and Dodd (1958, p. 370) reported reserves of 3,635,000 short tons of ore averaging 0.43 percent U_3O_8 in the Chinle formation of the Big Indian District. This corresponds to a uranium content of about 26.6 million pounds. Presumably these figures do not include the considerable amount of ore mined between 1952 and 1958. It also does not include the uranium deposited by ore solutions in rocks which are below ore grade. Nevertheless, if the 26.6 million figure is accepted as a rough approximation of the uranium deposited, the minimum required concentration of uranium in various volumes of ore solution can be calculated.

Table 33.--Volumes of ore solution required to supply uranium for of the Chinle Formation uranium-vanadium deposits in the Lisbon Valley area.

Volume (Cu. mi.)	Concentration of uranium (ppm)
1,000	0.003
50	.06
1	3.
.05	60.

Some tentative conclusions concerning the probable source and nature of the uranium ore solutions may be drawn from the data in table 33, when combined with other available information.

If the Lisbon Valley fault is considered as a possible conduit for upward-moving uranium-bearing solutions, then the various paths through which the solutions could pass--besides the of the Chinle and Salt Wash sandstones--must be considered in calculating the volume of ore solution or the amount of uranium required. Presumably the ore solutions flowed in largest volume through the most permeable rocks. Therefore, if the solutions moved up the fault and spread out into of the Cutler, Chinle, and Salt Wash sandstones, then the solutions must also have flowed through the rocks of the San Rafael and Glen Canyon groups.

D. A. Jobin (written communication, 1959; 1956, p. 207-211) determined permeabilities and transmissivities of various rocks and formations on the Colorado Plateau. (The coefficient of transmissivity is defined as the product of the mean permeability and total thickness of the transmitting medium.) His data show that in the Lisbon Valley, area the ratio of transmissivity of the San Rafael and Glen Canyon rocks to the transmissivity of the basal of the Chinle sandstones is almost 2,000:1. Thus, if ore solutions moving upward along the Lisbon Valley fault spread outward into the sedimentary rocks in proportion to their ability to transmit fluids, almost 2,000 times as much ore fluid moved into the rocks of the San Rafael and Glen Canyon groups as flowed through the basal of the Chinle sandstones. This, in turn, would mean that much more uranium was supplied from the source than was deposited in the Chinle rocks.

But there is a limit to what is a reasonable estimate for the amount of ore solution available. If metamorphic or igneous rocks containing 10 percent water by volume are considered as possible sources for the ore fluids, then

1,000 cubic miles of such rock would supply only 100 cubic miles of solution. Perhaps 0.05 cubic mile of this solution passed into of the Chinle sandstones and the rest into other, more permeable, rocks. Assuming 100 percent efficiency in deposition, the Lisbon Valley Chinle deposits alone would require that the uranium concentration be at least 60 ppm. In order to achieve this, an average of 2.3 ppm uranium would have to be leached from 1,000 cubic miles of rock, dissolved in 100 cubic miles of solution, and moved up along the Lisbon Valley fault. If the ore mined between 1952 and 1958, and the uranium in rocks of less than ore grade are considered, the amount of uranium required would probably be 50 to 100 percent greater than that calculated.

The above calculations apply only if one is testing the hypothesis that there was only one stage of uranium mineralization in post-Salt Wash time. The volume of rock which must be leached and the amount of uranium required seem unreasonably large to the writer. Hence, it is presumed that one stage of mineralization in which the ore solutions moved up along the Lisbon Valley fault to deposit all the uranium ores is not probable. It should be noted that the problem of whether there were two stages of hydrothermal mineralization, perhaps in Late Triassic time and in Tertiary time, cannot be solved by the foregoing method of calculation.

Percolating ground waters of meteoric origin

Percolating ground waters contain some dissolved uranium and should be given consideration as a possible ore solution. Scott and Barker, (1959, p. 155) found a maximum of 0.12 ppm uranium in 486 samples of ground water collected from most major aquifers and many minor aquifers throughout the United States. The median concentration, however, was less than 0.002 ppm.

Some moderately high uranium concentrations have been found in ground waters by other investigators. In a study of waters collected in the Great Plains and in Tertiary basins of the Rocky Mountain region, Denson, and others (1956, p. 799) found 0.008 to 0.15 ppm uranium in waters from tuffaceous rocks. Denson (1956, p. 781) concluded from a study of an area near Denver, Colorado, that more than 0.05 ppm uranium in formation waters indicated the destruction of a uranium deposit.

If 0.10 ppm is taken as a probable upper limit for the average concentration of uranium in ground waters flowing through the lower of the Chinle sandstones, then more than 30 cubic miles of water would be required to form the Chinle ore deposits if 100 percent of the dissolved uranium was deposited.

The length of time required to pass this amount of fluid through lower of the Chinle sandstones can be estimated using the equation: (1) $Q = 62.4\ K\ \frac{AP}{LV}$ (modified from Pettijohn, 1957, p. 87) where Q = quantity of water in pounds per year

K = permeability in millidarcies

A = cross-sectional area in square feet

P = pressure head in feet of water

L = length of the aquifer in feet

V = viscosity of water in centipoises

The equation can also be written as:

(a) $$Q = 0.624\ K\ \frac{AP'}{V}$$

where the units are as in equation (1) except that

$$P' = \frac{P \times 100}{L}$$ = hydraulic gradient in percent.

In estimating the maximum amount of water which passed through the lower of the ✓ Chinle sandstones per year, many assumed values must be used in the above equations. Such assumptions are based upon available information. Tolman (1937, p. 200) stated that normal ground-water gradients seldom exceed 1 percent (53 feet per mile). On the Colorado Plateau, except during the erosion of the present canyons, hydraulic gradients were probably relatively low and the average gradient over long periods of time may not have exceeded 0.1 percent. Coleman's work (1957, p. 1-4) indicates that the temperature during ore-deposition porbably did not exceed 138°C. Most ground-water circulation (exclusive of that due to squeezing out of connate water) probably occurred either shortly after deposition of the host rocks before overlying sediments were very thick or after uplift in the Tertiary period. Lead isotope data indicate that the period immediately after deposition was the more probable time if circulating ground water was the ore solution. Ground-water temperatures then were presumably on the order of $20^{\circ}C$ and the viscosity of water at that temperature can be used in equation (2).

Data concerning permeability and cross-sectional area of the host rocks are also needed if an estimate of the volume of ground water passing through the rocks is to be made. According to D. A. Jobin (written communication, 1959), the permeability of samples from of the Cutler ore sand and of the Chinle ore sand on the Big Buck claims averaged about 20 millidarcies. Manger (1956, p. 160-163) found that mineralized sandstone at the Continental No. 1 mine had an average permeability of 99 millidarcies. Barren sandstone 50 feet away had an average permeability of 3,115 millidarcies. The host rocks for ore at the Continental No. 1 mine are, in general, coarser grained and probably more permeable than those found in the northern deposits. This is evident from visual examination and from the higher concentration of aluminum (and hence, clay) in the northern ores. Because the average permeability of the Chinle host rocks at the time of ore deposition may have been different from that measured now, it will be assumed for purposes of calculation that the average permeability then did not greatly exceed 300 millidarcies.

The total length of the ores along the flank of the Lisbon Valley anticline containing more than 0.1 foot-percent of uranium in the lower part of the Chinle is about 6 miles

(Keys and Dodd, 1958, p. 370, 375). The average thickness of ore throughout this length is estimated at 10 feet. This gives a cross-sectional area for the ore zone of about 320,000 square feet, if the ore fluid is assumed to have moved either up or down the flank of the anticline.

The quantity of water passing through the Chinle host rocks annually can be calculated using the estimates given above.

$$Q = \frac{0.624 \times 300 \times 320{,}000 \times 0.1}{1.00} = 6 \times 10^6 \text{ pounds of}$$

water per year. Thirty cubic miles of water weigh about 275×10^{12} pounds. Therefore, the time required to pass 30 cubic miles of water through the ore host rocks may have been approximately 46 million years. Although several factors used in estimating the period of flow are subject to question (particularly the figures for permeability and hydraulic gradient), an effort has been made to use what seem to be reasonable values.

If percolating ground waters did move through basal of the Chinle sandstones in the tremendous volumes necessary to deposit ore they must have been moving toward an area of lower hydraulic pressure. There seems to be no obvious reason for a hydraulic gradient which would cause ground water in large volumes to move into the basal of the Chinle sandstones during the period after burial under upper Chinle sediments and before uplift and erosion took place in the Tertiary. Instead, there is ample reason to believe that waters moving through of the Chinle sandstones were escaping from mudstones which were being compacted.

It would seem from the above discussion that if ground water was the ore solution it must have had an anomalously high concentration of uranium, and deposition probably took something like 40 million years either after uplift during the Tertiary period or, more probably, immediately after deposition of the host rocks.

Connate water in red beds

In the Lisbon Valley area the uranium ores in the Chinle formation show a pronounced tendency toward concentration in the 10-foot interval just above the Cutler-Chinle contact. Where very little uranium has been deposited it is commonly at or just a few inches above the contact. Furthermore, the large Chinle ore bodies overlie, in part, areas where of the Cutler sandstones--truncated prior to Chinle deposition--are in contact with basal of the Chinle sandstones. These relations suggest that solutions moving from the Cutler formation into the basal of the Chinle sandstones may have encountered changed conditions and thus deposited uranium, vanadium, and the other ore-associated elements.

Inasmuch as the Cutler formation is composed largely of red beds intercalated with relatively rare greenish-gray mudstones, it is apparent that the Eh of the Cutler formation waters did not drop below that required to reduce ferric iron, except locally. By contrast, much of the basal part of the Chinle formation contains carbonaceous material, iron sulfides, and relatively little ferric oxide as grain coatings, thus demonstrating the presence of fairly strong reducing conditions.

Consideration of the spacial and structural relations of the Cutler and Chinle formations in the Lisbon Valley area (see figure 3) suggests that connate waters from the Cutler formation may have moved upward into the basal of the Chinle sandstones during compaction of the Cutler rocks. Interbedded mudstones and sandstones of the upper part of the Cutler formation probably were buried under only a few hundred feet of sediments prior to deposition of the Chinle formation. Thus the porosity of of the Cutler mudstones was still perhaps in the range of 35 to 45 percent when basal of the Chinle sediments were deposited (Athy, 1930). As Chinle and Wingate sediments were laid down, increasing lithostatic pressure was applied to the buried sediments, and connate water from of the Cutler mudstones must have escaped toward areas of lower pressure. A logical path of escape for some of this connate water would have been horizontally through of the Cutler sandstones to the flank of the Lisbon Valley anticline where these sandstones are truncated and overlain by of the Chinle sandstones. The low permeability of the upper Chinle of the mudstones and shales would have restricted vertical movement of the connate waters and caused them to flow through the basal of the Chinle sandstones toward the Lisbon Valley fault

? spatial

where escape may have been easier. If these connate waters contained elements in solution such as uranium and vanadium which could be precipitated in a reducing environment, then deposits of these elements would form at, or just above, the transition from red beds of the Cutler to the carbonaceous beds of the Chinle.

The presence of uranium-vanadium ores in what were probably locally reduced areas in upper of the Cutler sandstones proves that ore solutions did move through the of the Cutler sandstones.

The question of whether red mudstones are a possible source of uranium and vanadium deserves consideration. Garrels~~,~~ and others (1957, p. 1732) have pointed out that not only uranium and vanadium but also copper and molybdenum can be carried in aqueous solution if the solution is moderately reducing, moderately to strongly alkaline, and contains somewhat higher than normal amounts of carbon dioxide in solution. Carbonate cement in Cutler rocks indicates that interstitial waters have probably been alkaline in the past. The presence of apparently syngenetic ferric oxides in the red beds demonstrates that, assuming a pH of 8.5 and total activity of dissolved sulphur of 10^{-1}, the Eh never dropped below about -0.25 (Garrels, 1960, p. 151). The Eh of ground waters which are deoxygenated in the zone of rock-pore saturation ordinarily ranges from zero to slightly minus values (Garrels, 1953, p. 1264). Thus it seems possible that the of the Cutler red beds may have met the Eh and pH requirements needed to hold uranium and vanadium in solution. Garrels and Richter (1955, p. 457) point out the common occurrence of CO_2-rich gas wells on the Colorado Plateau. Thus there may have been much CO_2 in solution in connate waters of the Cutler formation.

If uranium ore in the Chinle formation of the Lisbon Valley area is assumed to have been deposited from connate water squeezed from red beds of the Cutler formation, some estimates can be made of the concentration of uranium in solution, the volume of connate water required, and the volume of rock needed to supply the connate water.

For purposes of calculation assume that the porosity of of the Cutler mudstone was reduced from 40 to 15 percent during the Late Triassic and Early Jurassic ~~periods~~ Epochs because of deposition of overlying rocks. If the mineral matter of the rock contained 3 ppm uranium and 20 percent of this uranium dissolved in the connate water, the uranium concentration in the water would be about 2.4 ppm. Approximately 1.3 cubic miles of such water could supply the uranium present as reserves in 1958 in the Chinle deposits of the Lisbon Valley area. This volume of connate water would be squeezed from rock having a final volume of about 3.5 cubic miles if the porosity were reduced from 40 to 15 percent. This volume is equal to that of a rock unit 15 miles square and about 80 feet thick.

The Moenkopi formation overlies the Cutler formation west of the Lisbon Valley anticline. Because of its fine-grained character the vertical permeability of the Moenkopi formation was probably low, thus encouraging horizontal movement of connate water in of the Cutler sandstones toward an area of high vertical permeability such as the Lisbon Valley anticline. Connate waters from Moenkopi rocks would have tended to move vertically into basal of the Chinle sandstones, then horizontally beneath the thick upper of the Chinle mudstones and siltstones toward areas of relatively high vertical permeability. When connate waters from of the Moenkopi red beds migrated into the basal of the Chinle sandstones, reducing conditions there could cause precipitation of any uranium or vanadium in solution. Significant ore deposits would have formed, however, only in areas where large volumes of connate water flowed through a relatively small cross-sectional area of of the Chinle sandstones, which had great reducing capacity. The time of most ore deposition would have been during the period when connate water was escaping in greatest volume. In the case of the Cutler and Moenkopi rocks this probably occurred during Late Triassic and Early Jurassic time. Compaction continued more slowly during the rest of the Jurassic period and also through the Cretaceous period as sediments continued to accumulate. However, the deposition of the thick Late Cretaceous Mancos and Mesa Verde formations would have caused an increased rate of escape of connate water. The age of Chinle ores deposited from connate waters would thus be mainly Late Triassic and Early Jurassic but some may have been deposited as late as Early Tertiary.

Stewart, and others (1959, p. 527) show that the uranium deposits from the Moab area to the Monument Valley area are near the base of the Chinle formation, regardless of the member that is in that position. It is pointed out that "localization of the deposits near the base of the Chinle may have been caused by the damming of vertically rising ore-bearing solutions by the bentonitic rocks of the Chinle." Noble (1960a, p. 2038; 1960b, p. 26-39) and Kennedy (1960, p. 1904) have suggested that connate water, squeezed out during compaction of fine-grained sediments, may have been the ore solution responsible for many of the uranium-vanadium deposits on the Colorado Plateau.

OF THE SALT WASH MEMBER ORES

The genesis of the uranium-vanadium ores in of the Salt Wash Member sandstones is thought to be similar, in a general way, to that of the Cutler and Chinle ores. of the Brushy Basin Member mudstones and siltstones were deposited during the Late Jurassic, but no more than a few hundred feet of sediments covered the Brushy Basin sediments until the Late Cretaceous. Thick Mancos and Mesa Verde deposits caused compaction of the Brushy Basin sediments and the resultant escape of interstitial waters. These connate waters must have flowed in greatest volume along paths of least resistance in escaping toward the surface. Water from the lower part of the Brushy Basin member probably found it easier to move downward into uppermost of the Salt Wash sandstones and then horizontally toward vertical escape routes rather than moving vertically through several hundred feet of of the Brushy Basin mudstones. Measurements of horizontal permeability of of the Salt Wash sandstones by Phoenix (1956, p. 215-217) and estimates of vertical permeability of of the Brushy Basin mudstones (D. A. Jobin, written communication, 1959) indicate that the ratio of horizontal permeability of sandstone to vertical permeability of mudstone is in the range 10,000:1 to 100,000:1. In other words, water could flow as easily through about 10 miles of of the Salt Wash sandstone horizontally as through 1 foot of of the Brushy Basin mudstone vertically.

Although the ratio $\frac{\text{horizontal permeability of sandstone}}{\text{vertical permeability of mudstone}}$ may have been only 5,000:1 or even less during compaction of the Brushy Basin, it seems probable that much connate water from the lower part of the Brushy Basin member would have moved toward the Lisbon Valley fault zone through the upper of the Salt Wash sandstones. Some of these sandstones were fairly thick, relatively continuous, lenses and were probably conduits for tremendous volumes of water.

The Eh of Brushy Basin connate waters was generally above that required to reduce ferric iron as evidenced by the red, brown, and purple color of the fresh rock. However, some gray-green mudstones are found suggesting that iron may have been reduced locally. Phoenix (1959, p. 61) found the pH of waters flowing from Brushy Basin rocks to range from 6 to 9, according to field measurements. He also found as much as 0.06 ppm uranium and 0.3 ppm vanadium in Brushy Basin waters. Garrels (1957) has pointed out that tuffaceous sediments (such as those of the Brushy Basin) may contain waters which are moderately to strongly alkaline, high in carbonate, and mildly reducing in character when saturated by water. Thus the connate waters probably were able to dissolve uranium, copper, vanadium, and molybdenum from the tuffs.

In order for much uranium and vanadium to be precipitated in of the Salt Wash sandstones from Brushy Basin connate waters certain favorable conditions must have been met. The number of through-going of the Salt Wash sandstones must have been relatively few so that the flow of water would have been concentrated along a few "favorable" paths. These "continuous" sandstones must have had an outlet to the surface which offered appreciably less resistance to flow than the vertical path through unfractured of the Brushy Basin mudstones. Finally, local areas of strong reducing environment must have been present in the of the Salt Wash sandstones to precipitate the ore.

The greenish-gray alteration around carbonaceous trash pockets in the of the Salt Wash sandstones suggests that strongly reducing conditions were present within these pockets and that diffusion outward from such pockets caused reduction of iron-bearing minerals to form the characteristic "halos" near ore. Weeks and Garrels (1959, p. 8) state that sandstone favorable for ore is light brown at the surface, but white or light gray with disseminated pyrite at depth. This contrasts with the common red-brown color of of the Salt Wash sandstone. It seems possible that in certain areas carbonaceous trash was deposited in a less permeable part of a larger permeable sandstone. After burial, bacteria, working on the carbonaceous material, would produce a strongly reducing environment in this area of relatively stagnant waters. In the immediate vicinity of the carbonaceous trash the Eh may have been near that required to produce hydrogen gas from water. Farther away the Eh was less negative but still low enough to cause alteration of mudstone from red to green. Beyond this zone ferric iron coatings on sand grains may have been reduced and pyrite precipitated. Beyond the pyrite zone the Eh presumably was above that necessary to reduce ferric iron.

Jensen (1958, p. 612) has suggested that hydrogen sulfide may have been formed near organic matter in of the Salt Wash sandstones and remained there until connate water from the Brushy Basin member migrated through the area. The hydrogen sulfide then presumably reduced the uraniferous solutions. If the connate waters contained 2.4 ppm uranium (as assumed above for Cutler connate waters), then more than 400,000,000 gallons of water would have had to move through an ore body with dimensions of 10 x 50 x 100 feet containing 0.1 percent uranium in order to supply the necessary uranium. It seems probable that so much water would have soon flushed out any H_2S in solution and stopped further ore deposition. In contrast, a solid sulfide would have been unaffected by the flow of fluids and yet could react to precipitate uranium and vanadium. Therefore, Jensen's idea, with modification, seems reasonable.

CONCLUSIONS

Consideration of various hypotheses for the origin of mineral deposits in the Lisbon Valley area lead to the following conclusions.

1. The close association of copper-bearing veins and bedded deposits with the Lisbon Valley fault zone is strong evidence that hypogene fluids circulating along the fault zone carried the copper to its present location.

2. The fact that copper veins cut Dakota sediments near the Blackbird mine and that veins of somewhat similar composition cut Tertiary igneous rocks in the La Sal Mountains suggests that both types of veins may be of the same age and of similar origin.

3. The uranium-vanadium deposits show no obvious zoning with respect to the Lisbon Valley fault, except for copper which is more concentrated in uranium-vanadium deposits near the fault in the southeastern part of the Lisbon Valley area. However, the presence along the Lisbon Valley anticlinal structure of large Chinle ore bodies and of a very large Salt Wash ore body certainly suggests that there is some relation between the deposits and the structure or fault system.

4. Lead isotope data and the lead-uranium correlation

in ore samples can be interpreted to mean that the Chinle ores are Late Triassic or Jur~~r~~assic in age. If this interpretation is correct, these ores are much older than the post-Mancos copper ore along the Lisbon Valley fault.

5. Tremendous amounts of uranium were required if it is assumed that Cutler, Chinle, and Salt Wash ores were deposited during one period of mineralization by hypogene solutions spreading out from the Lisbon Valley fault. This is because much ore solution would have moved away from the fault through the rocks of the Glen Canyon and San Rafael groups. The amount of uranium required seems too great to make this a probable method of ore genesis. An hypothesis suggesting two or more stages of mineralization by solutions spreading outward from the Lisbon Valley fault cannot be tested properly by the above type of reasoning, however.

6. If percolating ground waters of the type found in present day wells (but containing above normal concentrations of uranium) were the source of the Chinle ores, the most probable time of deposition was in the period of approximately 40 million years following the lower part of Chinle sedimentation. Because there is no obvious reason why such waters should be circulating in the basal of the Chinle sediments long after their deposition, this hypothesis seems less probable than one suggesting connate water as the ore fluid.

7. Connate waters squeezed from the sediments during compaction almost certainly flowed through interbedded sandstones toward escape routes to the surface. The connate waters from red beds could have had an Eh, pH, and carbonate content such that they were capable of carrying dissolved uranium, vandium, molybdenum, and copper in solution. When such waters migrated into a strongly reducing environment the ore elements could have formed insoluble low-valent compounds.

8. Salt flowage into the Lisbon Valley anticline apparently began before of the Chinle beds were laid down and may have continued intermittently through the Mesozoic era. Thus the Lisbon Valley area may have been one of long-continued fracturing where connate waters could move toward the surface. If so, it would have been a focal point toward which connate waters flowed, and any areas of strongly reducing environment nearby would have had unusually large volumes of fluid pass through them.

9. On the basis of available isotopic, geologic, and chemical data, the hypothesis that seems most reasonable for the origin of the uranium-vanadium ores is that Cutler and Chinle ores of the Lisbon Valley area formed from connate water squeezed from red beds in the Cutler formation and that Salt Wash ore formed from connate water squeezed mainly from the Brushy Basin member of the Morrison formation. Presumably the greatest amount of ore formed during

periods of greatest compaction. In the case of the Cutler and Chinle ores this was during the Late Triassic and Early Jurassic ~~periods~~ Epochs. For the Salt Wash ores this was during the Late Cretaceous and Early Tertiary ~~[illegible]~~ ~~periods~~.

10. It seems possible that variations in the character of both the source rocks and host rocks could affect the nature of the ores deposited. However, detailed explanations for the many local and district-wide changes in chemical composition of ore were not found.

11. It is possible that the explanation proposed for the genesis of uranium-vanadium deposits in the Lisbon Valley area can be applied to similar deposits elsewhere on the Colorado Plateau. The consistent presence of ore in reducing environments within permeable zones at the base of the Chinle formation may be due to deposition of the ores from connate waters squeezed from of the Moenkopi red beds. It seems quite probable that such waters would have moved through these permeable zones in the basal of the Chinle sediments toward areas of relatively high vertical permeability. The areas of greater vertical permeability may have been faults, anticlines, or simply sandy parts of the upper part of the Chinle formation. The great load of overlying sediments must have produced tremendous pressures so that the connate waters were forced out through rocks that under ordinary conditions would be considered practically impermeable.

If red beds were the source of the uranium ore solutions, the consistent association of "sandstone type" deposits with continental sediments would be understandable. Marine sediments commonly contain enough organic matter so that strong reducing conditions develop shortly after burial. This environment would cause uranium, vanadium, molybdenum, copper, and many other ore-associated elements to be held in an insoluble form. When such marine sediments were compacted, none of these elements would be dissolved in the connate waters and uranium deposits could not form along the escape path of these solutions.

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APPENDIX

The analyses of 54 mineralized samples from the basal 20 feet of the Chinle formation are shown in table 34 (in pocket). The data are arranged in order of increasing uranium content so that one can see which elements tend to correlate with uranium simply by glancing down along the columns.

packet contains 23 stems

Tab

/Analysts: Spec
and E. J. Fennel

	Na	K	Ti	Mn	As	B
-	X.-	X.+	.X+	.0X	0.0005	.0X-
+	X.-	X.	.X	.0X	.0001	.00X+
	X.-	X.	.X+	.0X	.0013	.0X-
	.X+	X.	.X	.0X+	.0014	.00X+
	X.-	X.	.X	.X-	.0007	.00X
+	.X+	X.	.X	.0X+	.0001	.00X+
	X.-	X.	.X	.0X+	<.0005	.00X+
+	X.-	X.-	.X	.0X+	<.0005	
	X.-	X.-	.X	.0X+	<.0005	
+	X.-	[illegible]	.X	.0X+	<.0005	
+	X.-	X.-	.X	.X-	<.0005	
	X.-	X.	.X	.X-		
	X.-	X.-	.X	.X-		
	X.-	X.	.X-	.X-		
	.X+	X.-	.0X+	.0X+		
	.X	X.-	.0X			
+	X.-	X.	.X			
	.X+	X.				
	.X+	X.				