TEI-204 Part II

GEOLOGY AND ORE DEPOSITS OFTHE MONUMENT VALLEY AREA, APACHE AND NAVAJO COUNTIES, ARIZONA

I. J. Witkind and R. E. Thaden

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by I. J. Witkind and R. E. Thaden

ABSTRACT

In 1951 and 1952, the U. S. Geological Survey conducted a program of uranium investigations and geologic mapping in the Monument Valley area, Apache and Navajo Counties, Ariz. About 700 square miles were mapped on the Navajo Indian Reservation. A resource appraisal of the area was an inherent part of the program, and is detailed in this report.

Production of vanadium and uranium is from two areas, the Monument No. 1 mine area in Navajo County, and the Monument No. 2 mine area in Apache County. In the period 1942-53 about 200,300 tons of ore was produced from these two areas. This ore yielded about 1,700,000 pounds of U_3O_8 and about 6,500,000 pounds of V_2O_5. The grade ranged from 0.15 percent U_3O_8 to 0.60 percent U_3O_8, and from 0.38 percent V_2O_5 to 3.02 percent V_2O_5. The vanadium-uranium ratio is about 4:1.

The ore deposits are composed principally of the hydrous calcium-uranium vanadate tyuyamunite in basal channel sediments of the Shinarump member of the Chinle formation. Four types of ore bodies are present: (1) rods, (2) tabular ore bodies, (3) corvusite-type ore bodies, and (4) rolls.

The reserves of uranium- and vanadium-bearing material are classed as measured, indicated, inferred, and potential. The reserves are further divided into three grade classes for material 1 foot or more thick: (1) 0.10 percent U_3O_8 and 1.00 percent V_2O_5 and above; (2) 0.05 percent U_3O_8 and 0.50 percent V_2O_5 and less than 0.10 percent U_3O_8 and 1.00 percent V_2O_5; and (3) 0.01 percent U_3O_8 and 0.10 percent V_2O_5 and less than 0.05 percent U_3O_8 and 0.50 percent V_2O_5.

Measured reserves as of June 1953, in the Monument Valley area, Arizona, (all in the Monument No. 2 mine) total about 36,000 tons. Indicated reserves in the first grade class amount to about 62,000 tons. In this same grade class inferred reserves total about 3,000,000 tons. In the second grade class indicated and inferred reserves amount to about 2,000,000 tons. Inferred reserves in the third grade class total about 345,000 tons of mineralized material. Potential reserves in all grade classes for the Monument Valley area amount to about 13,000,000 tons.

It is recommended that an extensive exploration program be carried out in the Monument Valley area, Arizona. This program would consist of two phases. The first phase would involve a geophysical survey of selected channels and would have as its principal objective the delineation of the trend, length, width, and depth of scour of the channels. The second phase would consist of a diamond-drilling program that would make use of the data secured by the geophysical survey. This drilling program would have as one of its principal objectives the determination of which channels are most likely to contain ore bodies. Once the favorable channels are discovered, the drilling program could be carried on most suitably by private operators.

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INTRODUCTION

Purpose

In 1951 and 1952, the U. S. Geological Survey undertook a program of uranium investigations and geologic mapping in the Monument Valley area, Arizona, on behalf of the U. S. Atomic Energy Commission. An appraisal of uranium resources of the area was an inherent part of this program. This report provides a summary of production trends and estimated reserves, and indicates the potential of the area as a source of uranium.

Location of area

The Monument Valley area, as defined for the purposes of this report, consists of three 15-minute quadrangles in parts of Apache and Navajo Counties, northeastern Arizona. This area, about 700 square miles, extends westward from the 109°45' meridian to the 110°30' meridian. It is bounded by the 36°45' and 37°00' parallels. It is all within the Navajo Indian Reservation. The area is served by graded and graveled roads from the south (via Flagstaff, Ariz.); north (via Monticello, Utah); and east (via Shiprock, N. Mex.). All roads are impassable during and following heavy rainstorms.

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Method and scope of work

The area was mapped during two field seasons in 1951 and 1952. Each season was of 5 months duration. A geologic map of the entire area was prepared and studies were completed of all mines and mineralized prospects. Geologic contacts and all other pertinent data were sketched onto aerial photographs of a scale of 1:31,680 and 1:20,000 by geologists in the field. This information was transferred by inspection onto topographic base maps of a scale 1:48,000. During the course of the work all mineralized exposures, channels, fractures, and other related data were plotted on these maps. Preliminary and interim reports (Witkind and others, 1951; Witkind, Thaden, and Lough, 1953a, 1953b; Witkind, 1954) have presented the basic material of our work.

During the same period the U. S. Atomic Energy Commission maintained geologic and exploration parties in the area. The results of their work are given in unpublished reports (Chester, 1951a, 1951b; Chester and Donnerstag, 1953).

HISTORY AND PRODUCTION

In comparison with existing uranium and vanadium producing areas in other parts of the Colorado Plateau, such as the Uravan district, the San Rafael Swell, and the Carrizo Mountains, Monument Valley is a relatively new area. Although discrete specimens of "carnotite" in association with wood have been reported from Monument Valley (Gregory, 1917, p. 50 and 148), sizeable uranium and vanadium deposits have been known in the area only since 1942. In 1948, under the stimulus of the demand for uranium, production from Monument Valley increased rapidly. Its rate of production has increased phenomenally in the period 1948-53 (fig. 44 and table 7.). In 1948, about 8,500 tons of ore were produced. This increased to about 24,500 tons in 1949; to about 59,500 tons in 1952; and in the first 6 months of 1953, production from Monument Valley amounted to about 47,200 tons. In the period 1942-53, the total production from Monument Valley has been about 200,300 tons of ore. This ore yielded about 1,700,000 pounds of uranium oxide and 6,500,000 pounds of vanadium oxide. The vanadium-uranium ratio has been about 4:1. The fame of the area as a producer of uranium and vanadium ore rests almost completely on the productivity of the Monument No. 2 channel. Of the 200,300 tons of ore produced from Monument Valley, 197,500 tons of ore has come from the Monument No. 2 channel. The balance of the ore produced has come from the Monument No. 1 mine area. Production data for both these areas are summarized in table 7.

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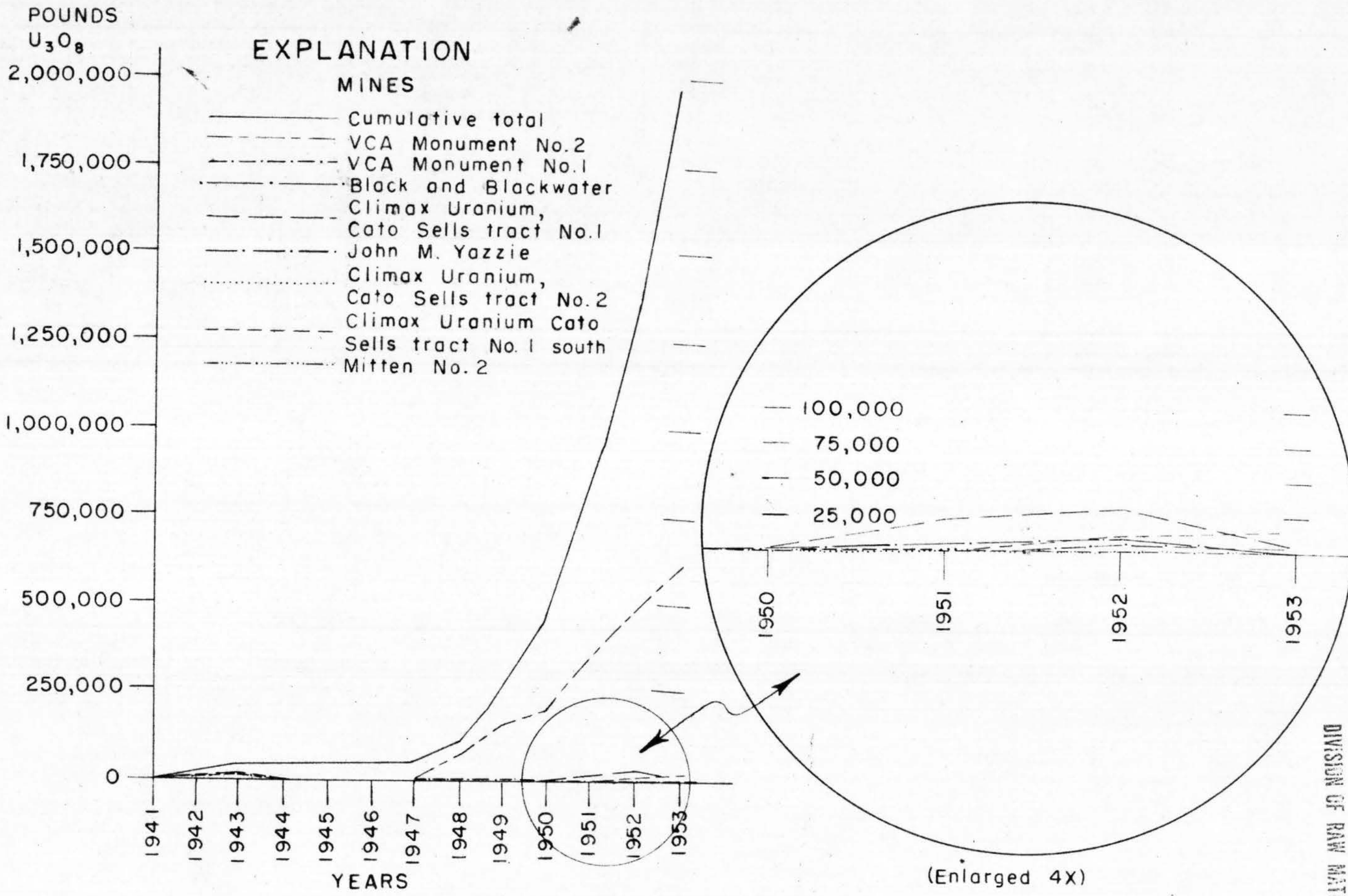

Figure 44.--GRAPH SHOWING URANIUM PRODUCTION IN THE MONUMENT VALLEY AREA, ARIZONA. PRACTICALLY ALL OF THE URANIUM PRODUCED HAS COME FROM THE MONUMENT NO 2 MINE. PRODUCTION OF THREE OF THE MINES IS SO SLIGHT IT DOES NOT SHOW EVEN ON THE 4X ENLARGEMENT.

Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1942				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	700	0.56	7,840.00	2.80	39,200.00
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1					
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1					
	Climax Uranium Co. Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co., Cato Sells Tract No. 1 South	6.3:1					
	Black and Blackwater	4.3:1					
	John M. Yazzie	1.9:1					
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1	700	0.56	7,840.00	2.80	39,200.00
	Foutz Mining Co. Mitten No. 2	2.5:1					
	Totals		1,400	0.56	15,680.00	2.80	78,400.00

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Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1943				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	1,501	0.47	14,137.00	2.33	70,018.76
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1					
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1					
	Climax Uranium Co. Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co., Cato Sells Tract No. 1 South	6.3:1					
	Black and Blackwater	4.3:1					
	John M. Yazzie	1.9:1					
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1	1,407	0.48	13,471.00	2.39	67,356.00
	Foutz Mining Co. Mitten No. 2	2.5:1					
	Totals		2,908	0.47	27,608.00	2.36	137,374.76

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Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1948				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	8,272	0.40	65,557.00	1.57	260,062.00
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1					
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1					
	Climax Uranium Co. Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co., Cato Sells Tract No. 1 South	6.3:1					
	Black and Blackwater	4.3:1					
	John M. Yazzie	1.9:1					
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1	237	0.23	1,093.00	1.67	7,916.00
	Foutz Mining Co. Mitten No. 2	2.5:1					--
	Totals		8,510	0.39	66,650.00	1.57	267,978.00

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Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1949				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	23,999	0.31	149,533.14	1.29	617,337.61
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1	353	0.10	750.83	0.70	4,972.78
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1					
	Climax Uranium Co. Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co., Cato Sells Tract No. 1 South	6.3:1					
	Black and Blackwater	4.3:1					
	John M. Yazzie	1.9:1					
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1	120	0.15	364.07	0.90	2,171.41
	Foutz Mining Co. Mitten No. 2	2.5:1					
	Totals		24,472	0.31	150,648.04	1.28	624,481.80

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Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1950				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	22,878	0.43	196,120.31	1.96	896,539.33
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1	323	0.10	670.24	0.70	4,569.93
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1					
	Climax Uranium Co., Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co., Cato Sells Tract No. 1 South	6.3:1					
	Black and Blackwater	4.3:1	370	0.18	1,364.53	0.80	5,943.09
	John M. Yazzie	1.9:1					
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1	258	0.20	1,026.00	0.91	4,704.00
	Foutz Mining Co. Mitten No. 2	2.5:1					
	Totals		23,829	0.42	199,181.08	1.91	911,756.35

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Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1951				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	28,511	0.62	353,784.00	1.93	1,104,911.00
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1					
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1	7,862	0.33	5,168.53	1.20	18,844.27
	Climax Uranium Co., Cato Sells Tract No. 2	4.3:1	65	0.26	339.98	1.12	1,464.51
	Climax Uranium Co. Cato Sells	3.0:1	1,746	0.45	15,866.11	1.36	47,359.49
	Climax Uranium Co. Cato Sells Tract No. 1 South	6.3:1					
	Black and Blackwater	4.3:1	1,272	0.19	4,784.02	1.00	25,394.66
	John M. Yazzie	1.9:1	65	0.47	611.60	1.06	1,369.59
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1					
	Foutz Mining Co. Mitten No. 2	2.5:1					
	Totals		32,446	0.58	380,554.24	1.85	1,199,343.52

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Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Calendar Year 1952				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America - Monument No. 2	3.7:1	52,721	0.46	485,026.39	1.60	1,686,825.00
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1					
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1	4,062	0.36	29,142.07	1.94	157,725.01
	Climax Uranium Co., Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co. Cato Sells Tract No. 1 South	6.3:1	599	1.07	12,861.98	4.22	50,558.11
	Black and Blackwater	4.3:1	1,508	0.28	8,422.67	1.05	31,650.67
	John M. Yazzie	1.9:1	516	0.53	5,455.56	1.11	11,453.77
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1					
	Foutz Mining Co. Mitten No. 2	2.5:1	81	0.15	240.20	0.38	610.58
	Totals		59,486	0.45	541,148.87	1.63	1,938,823.14

Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	January 1 to July 1, 1953				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	44,063	0.34	295,565.68	1.35	1,190,806.00
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1					
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1	438	0.30	2,624.73	1.51	13,200.52
	Climax Uranium Co., Cato Sells Tract No. 2	4.3:1					
	Climax Uranium Co. Cato Sells	3.0:1					
	Climax Uranium Co. Cato Sells Tract No. 1 South	6.3:1	2,451	0.34	16,430.52	2.73	133,887.55
	Black and Blackwater	4.3:1	15	0.08	24.12	0.78	235.19
	John M. Yazzie	1.9:1	259	0.78	4,059.12	1.25	6,495.00
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1					
	Foutz Mining Co. Mitten No. 2	2.5:1					
	Totals		47,227	0.34	318,704.05	1.42	1,344,624.26

Table 7.--Production data from 1942 to July 1, 1953, Monument Valley area, Apache and Navajo Counties, Ariz.--Continued.

Channel	Mine	Vanadium-uranium ratio	Totals				
			Dry ore tons	Grade pct. U_3O_8	Pounds U_3O_8	Grade pct. V_2O_5	Pounds V_2O_5
Monument No. 2	Vanadium Corporation of America Monument No. 2	3.7:1	182,645	0.43	1,567,563.52	1.61	5,865,699.70
	Vanadium Corporation of America - Mexican Hat stock pile	6.5:1	676	0.11	1,421.07	0.71	9,542.71
	Climax Uranium Co., Cato Sells Tract No. 1	5.1:1	5,287	0.35	36,935.33	1.79	189,769.80
	Climax Uranium Co., Cato Sells Tract No. 2	4.3:1	65	0.26	339.98	1.12	1,464.51
	Climax Uranium Co. Cato Sells	3.0:1	1,746	0.45	15,866.11	1.36	47,359.49
	Climax Uranium Co. Cato Sells Tract No. 1 South	6.3:1	3,050	0.48	29,292.50	3.02	184,445.66
	Black and Blackwater	4.3:1	3,166	0.23	14,595.34	1.00	63,223.61
	John M. Yazzie	1.9:1	839	0.60	10,126.16	1.15	19,318.36
Monument No. 1	Vanadium Corporation of America Monument No. 1	5.1:1	2,722	0.44	23,794.07	2.23	121,347.41
	Foutz Mining Co. Mitten No. 2	2.5:1	81	0.15	240.20	0.38	610.58
	Totals		200,278	0.42	1,700,174.28	1.62	6,502,781.83

Six mines are in the Monument No. 2 channel, and all six are, or were, producing ore from the same channel fill; i. e., the same deposit. These six mines are:

(1) The Vanadium Corporation of America's Monument No. 2 mine.

(2) The Climax Uranium Company's Cato Sells Tract No. 1 (also called Cato Sells Monument mine).

(3) The Climax Uranium Company's Cato Sells Tract No. 2.

(4) The Climax Uranium Company's Cato Sells Tract No. 1 south.

(5) The Black and Blackwater mine (leased in 1953 to W. E. Pollock and B. M. Byler).

(6) The John M. Yazzie mine (operated jointly by John M. Yazzie and Thomas Clani).

Of the six mines listed above, mines nos. 2-6 were either closed or in the process of curtailing operations, as of June 1953. The only one still producing ore (1953) in sizeable amounts is the Monument No. 2 mine.

The increased production in the period 1948-53 is chiefly from new inclines and drifts opened by the Vanadium Corporation of America in its Monument No. 2 mine. Since June 1953, the Vanadium Corporation of America has mined its property primarily as an open pit.

The ore deposit in the Monument No. 2 channel is being depleted rapidly by the open-pit methods employed by the Vanadium Corporation of America. As of early 1954, no new ore deposits had been found in the Monument Valley area to offset this rapid rate of depletion. It seems likely that the rate of production will increase markedly as the open-pit methods gradually supplant the underground workings. However, this increasing production rate for the Monument Valley area, is bound to falter and production decrease (with the depletion of the Monument No. 2 channel deposit) unless successful exploration programs are undertaken.

GEOLOGY AND ORE DEPOSITS

In the exploration for uraniferous ore deposits in the Monument Valley area, Arizona, many factors influence exploration programs. Factors that assist such programs include: (1) uranium-vanadium ore deposits are in sediments filling scour channels; (2) the relative ease of recognizing the channels on outcrops; and (3) the possibility that many of the channels can be traced by geophysical methods where they are concealed beneath overburden or younger strata. Unfavorable factors include: (1) the irregular distribution of the ore bodies; (2) their relative smallness; and (3) the many problems involved in building access roads to favorable mineralized exposures.

All of the known uranium ore deposits are in channel sediments of the Shinarump member of the Chinle formation. The characteristics of these channels have been described elsewhere (Witkind and others, 1951; Witkind, Thaden, and Lough, 1953a, 1953b; Witkind, 1954). In general, two types of channels can be discerned, a long continuous type, traceable for distances greater than 2 miles and a short type less than 2 miles long. The channels range in width from 10 feet to about 2,300 feet and locally have been cut as much as 75 feet into the underlying strata. The short channels are basinlike and in gross aspect resemble the bowl of a spoon. Channel floors are irregular and gently undulatory (fig. 35). Sediments filling channels resemble sediments found elsewhere in the Shinarump member.

Four types of ore bodies are in the channels and underlying sediments. Most common are richly mineralized cylindroidal bodies known as rods. These are 10 to 15 feet long, 3 to 5 feet in diameter, and are scattered through channel sediments. No method exists as of 1954 for predicting their location. Large rods are collinear with the channel trend. Surrounding the rods are weakly mineralized sediments. A second type of ore body is a tabular blanketlike lens as much as 675 feet long, about 50 feet wide, and 1 to 18 feet thick. These are elongate parallel to the channel trend and generally are in basal channel sediments. A third type of ore body is (an irregular mass of vanadium impregnated minerals) known as a corvusite-type ore body. These consist of irregularly shaped masses of sediments impregnated with vanadium minerals. Vanadium minerals have impregnated both the Shinarump member and the underlying sediments; ore bodies of this type lack a regular outline and are scattered irregularly along the length of the channel. Rolls similar to those found in the Morrison formation are the fourth type of ore body.

The relationship between channels and mineralized ground is well known to the prospectors in the area. Consequently, almost every channel exposure is claimed despite the absence from many of the exposures of any sign of uranium or vanadium minerals, or any degree of abnormal radioactivity.

We have been unable to define any favorable belt of mineralized ground in Monument Valley, although Finch (1953, p. 32) has proposed that an arcuate belt of favorable ground extends across the northern part. He has also suggested that those channels near a pinchout of the Shinarump are most favorable (Finch, in preparation), and he postulates such a pinchout just north of the Monument Valley area, Arizona. Our work has suggested that the only parts of the Monument Valley area that can be considered favorable are those underlain by channel sediments. We are unable, however, to differentiate between mineralized and unmineralized channel fills. The basinlike shape of the Monument No. 2 channel implies that the short basinlike channels are more apt to contain ore bodies than long continuous channels.

Age determinations completed by Stieff, Stern, and Milkey (1953) indicate that the Monument Valley ore deposits were emplaced in late Cretaceous or early Tertiary time. The relations between ore deposits and channel sediments suggests that the ore deposits were formed by mineralizing solutions that moved into the channels along the base of the Shinarump member. Ore may have been precipitated in the channels in response to favorable conditions of permeability and porosity or in response to favorable chemical conditions possibly related to carbonaceous matter. Possibly both permeability and porosity as well as chemical factors were instrumental in localizing the ore.

RESOURCES

Introduction

As used in this report, the term "resources" includes both reserves and potential reserves. The difference between the various classes of reserves depends upon the degree of certainty with which the volume and grade of reserves can be calculated or estimated.

Reserve classes

Reserves in the Monument Valley area have been divided into four classes; they are measured, indicated, inferred, and potential. These classes are defined as follows:

Measured reserves are those for which tonnage is computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The sites for inspection, sampling, and measurements are so closely spaced and the geologic character so well defined that the size, shape, and mineral content are well established.

Indicated reserves are those for which tonnage and grade are computed from drill-hole samples, exposures in mine workings, natural outcrops, and production data. The tonnage is computed by projecting the mineralized ground for a reasonable distance on geologic evidence.

Inferred reserves are those for which quantitative estimates are based largely on the broad knowledge of the geologic character of the deposits and for which there are few, if any, samples or measurements.

Potential reserves are applied to ore bodies that have not been found as yet but whose existence is predicted upon geologic evidence alone.

Thickness cut off

Because ore bodies in Monument Valley vary so widely in shape, ranging from isolated well-outlined rods to broad ill-defined masses of sandstone impregnated principally with vanadium minerals, it is extremely difficult to select a thickness cut off that will apply to all ore bodies. Sediments within a foot or two of the rods may be so weakly mineralized as to contain only a trace of U_3O_8 despite the fact that the edge of the rod may contain more than 14 percent U_3O_8 (fig. 22). The unusual shape and extent of the rods necessitates that both weakly and richly mineralized ground (rods) be mined. The result is a very marked drop in grade. Other ore bodies are tabular. Common practice in mining these tabular bodies is to follow them until they pinch to a layer about 1 foot thick. However, if the ore is unusually rich, layers much less than 1 foot thick are mined. Faced with such variableness in the shape of the ore bodies, we have accepted as a thickness cut off a layer of mineralized ground 1 foot thick and of an average grade of 0.10 percent U_3O_8 and 1.00 percent V_2O_5.

Grade classes

Reserves in the Monument Valley area, Arizona, 1 foot or more thick are divided into three grade classes.

(1) The first grade class has as its minimum grade 0.10 percent U_3O_8 and 1.00 percent V_2O_5. This body of mineralized ground constitutes ore under the present (1953) U. S. Atomic Energy Commission cut-off price for uranium. This class largely represents the mineralized ground that will be mined in the near future.

(2) The second grade class includes mineralized rock containing, as a minimum, 0.05 percent U_3O_8 and 0.50 percent V_2O_5, and less than 0.10 percent U_3O_8 and 1.00 percent V_2O_5. It constitutes a large body of very weakly mineralized ground that may have considerable significance at a much later date when conditions might demand the use of this lower grade material.

(3) The third grade class includes mineralized rock containing, as a minimum, 0.01 percent U_3O_8 and 0.10 percent V_2O_5 and less than 0.05 percent U_3O_8 and 0.50 percent V_2O_5. This class constitutes a relatively small body of very weakly mineralized ground that is not likely to have any practical value in the foreseeable future.

The latter two grade classes cannot be construed as ore at the present time (1953), but they do give some idea as to tonnage of weakly mineralized rock.

Calculation of tonnage

In the Monument Valley area the reserves of measured and indicated ore are restricted principally to the Monument No. 2 channel, where exposures and mine workings are adequate to satisfy the definitions given above (p.).294 By definition, the tonnage of indicated reserves is "computed by projecting mineralized ground for a reasonable distance on geologic evidence." In most places indicated reserves are projected 5 feet from the face of mine workings and a similar distance from widely separated drill holes. Any projection that exceeds 5 feet is classed as inferred reserves. In general, inferred reserves have been projected 14 feet from the face of the mine workings, drill holes, or mineralized exposures.

The method used for calculating the tonnage of the potential reserves is based upon the premise that about 2 percent of the total volume of channel sediments are mineralized. In an attempt to determine the total volume of channel sediments, exposed and concealed, in Monument Valley a hypothetical "average" channel was established based on the measurements of 62 channels noted during the course of the work. This hypothetical "average" channel is about 7,920 feet long, about 320 feet wide, and has been scoured about 30 feet into the underlying strata. From these data the volume of an "average" channel was computed. Two percent of the volume of this "average" channel was assumed to be mineralized.

A constant of 14 cubic feet per ton was used to calculate tonnage.

Measured reserves

Measured reserves in the Monument Valley area are principally in the mine pillars in the Monument No. 2 channel. They amount to about 36,400 tons of an average grade of 0.53 percent U_3O_8 and 2.06 percent V_2O_5 (table 8).

Indicated and inferred reserves

The first grade class (0.10 percent U_3O_8 and 1.00 percent V_2O_5 and above) includes indicated reserves of about 62,000 tons and inferred reserves of about 3,000,000 tons. Of these amounts about 53,000 tons of indicated reserves and about 2,900,000 tons of inferred reserves are in the Monument No. 2 channel (table 9).

Indicated and inferred reserves in the second reserve class (0.05 percent U_3O_8 and 0.50 percent V_2O_5 and less than 0.10 percent U_3O_8 and 1.00 percent V_2O_5) amount to about 2,000,000 tons (table 9).

Inferred reserves in the third grade class (0.01 percent U_3O_8 and 0.10 percent V_2O_5 and less than 0.05 percent $U_3O_8$and 0.50 percent V_2O_5) amount to about 343,000 tons of mineralized material.

Table 8.--Class I reserves in the Monument No. 2 channel.

Mine	Zone	Measured Ore						Indicated Ore						Inferred Ore						Totals - All Indicated and Reserves of Ore					
		Volume (cubic feet)	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume (cubic feet)	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume (cubic feet)	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume (cubic feet)	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5
Vanadium Corporation of America's Monument No. 2	Upper barren							87,750	6,268	0.10	12,536	0.37	46,383	25,400,144	1,814,296	0.10	3,628,592	0.37	13,425,790	25,487,894	1,820,564	0.10	3,641,128	0.37	13,472,173
	Upper ore	310,800	22,200	0.56	248,640	2.07	919,080	419,580	29,970	0.56	335,664	2.07	1,240,758	8,190,462	585,033	0.56	6,552,370	2.07	24,220,366	8,920,842	637,203	0.56	7,136,674	2.07	26,380,204
	Middle barren													16,224,502	1,158,893	0.05	1,158,893	0.19	4,403,793	16,224,502	1,158,893	0.05	1,158,893	0.19	4,403,793
	Lower ore	154,000	11,000	0.56	123,200	2.07	455,400	207,900	14,850	0.56	166,320	2.07	614,790	7,502,740	535,910	0.56	6,002,192	2.07	22,186,674	7,864,640	561,760	0.56	6,291,712	2.07	23,256,864
	DeChelly ore	14,406	1,029	0.05	1,029	1.52	31,282	24,472	1,748	0.05	1,748	1.52	53,139	7,624,722	544,623	0.05	544,623	1.52	16,556,539	7,663,600	547,400	0.05	547,400	1.52	16,640,960
	Subtotal	479,206	34,229	0.54	372,869	2.05	1,405,762	739,702	52,836	0.49	516,268	1.85	1,955,070	64,942,570	4,638,755	0.19	17,886,670	0.87	80,793,162	66,161,478	4,725,820	0.20	18,775,807	0.89	84,153,994
Vanadium Corporation of America's South Extension	Middle barren													227,696	16,264	0.02	6,506	0.08	26,022	227,696	16,264	0.02	6,506	0.08	26,022
	Lower ore	16,240	1,160	0.10	2,320	1.00	46,400	11,200	800	0.05	800	0.50	8,000	127,666	9,119	0.05	9,119	0.50	91,190	155,106	11,079	0.06	12,239	0.66	145,590
	DeChelly ore													199,500	14,250	0.05	14,250	0.50	142,500	199,500	14,250	0.05	14,250	0.50	142,500
	Subtotal	16,240	1,160	0.10	2,320	1.00	46,400	11,200	800	0.05	800	0.50	8,000	554,862	39,633	0.04	29,875	0.33	259,712	582,302	41,593	0.04	32,995	0.38	314,112
Climax Uranium Cato Sells and Tract No. 1	Upper barren													2,454,494	175,321	0.05	175,321	0.19	666,220	2,454,494	175,321	0.05	175,321	0.19	666,220
	Upper ore							12,390	885	0.18	3,186	0.90	15,930	211,596	15,114	0.18	54,410	0.90	272,052	223,986	15,999	0.18	57,596	0.90	287,982
	Middle barren													1,047,004	74,786	0.02	29,914	0.08	119,658	1,047,004	74,786	0.02	29,914	0.08	119,658
	Subtotal							12,390	885	0.18	3,186	0.90	15,930	3,713,094	265,221	0.05	259,645	0.20	1,057,930	3,725,484	266,106	0.05	262,831	0.20	1,073,860
Climax Uranium Tract No. 2	Upper barren													310,002	22,143	0.02	8,857	0.08	35,429	310,002	22,143	0.02	8,857	0.08	35,429
	Middle barren													1,300,502	92,893	0.02	37,157	0.08	148,629	1,300,502	92,893	0.02	37,157	0.08	148,629
	Lower ore													12,096	864	0.13	2,246	0.56	9,677	12,096	864	0.13	2,246	0.56	9,677
	DeChelly ore													433,496	30,964	0.01	6,193	0.04	24,771	433,496	30,964	0.01	6,193	0.04	24,771
	Subtotal													2,056,096	146,864	0.02	54,453	0.07	218,506	2,056,096	146,864	0.02	54,453	0.07	218,506
Climax Uranium Tract No. 1 South	Middle barren													652,498	46,607	0.02	18,643	0.08	74,571	652,498	46,607	0.02	18,643	0.08	74,571
	Lower ore	10,500	750	0.48	7,200	3.02	45,300	14,910	1,065	0.24	5,112	1.51	32,163	226,744	16,196	0.24	77,741	1.51	489,119	252,154	18,011	0.25	90,053	1.57	566,582
	DeChelly ore													362,502	25,893	0.05	25,893	0.50	258,930	362,502	25,893	0.05	25,893	0.50	258,930
	Subtotal	10,500	750	0.48	7,200	3.02	45,300	14,910	1,065	0.24	5,112	1.51	32,163	1,241,744	88,696	0.07	122,277	0.46	822,620	1,267,154	90,511	0.07	134,589	0.50	900,083
Black and Blackwater	Upper barren													869,498	62,107	0.05	62,107	0.19	236,007	869,498	62,107	0.05	62,107	0.19	236,007
	Upper ore							840	60	0.12	144	0.50	600	71,274	5,091	0.12	12,218	0.50	50,910	72,114	5,151	0.12	12,362	0.50	51,510
	Middle barren													837,998	59,857	0.02	83,800	0.08	95,771	837,998	59,857	0.02	83,800	0.08	95,771
	Subtotal							840	60	0.12	144	0.50	600	1,778,770	127,055	0.06	158,125	0.15	382,688	1,779,610	127,115	0.06	158,269	0.15	383,288
John M. Yazzie	Middle barren													349,202	24,943	0.05	24,943	0.19	947,834	349,202	24,943	0.05	24,943	0.19	947,834
	Lower ore	4,340	310	0.10	620	0.37	2,294	2,520	180	0.05	180	0.18	648	83,930	5,995	0.05	5,995	0.18	21,582	90,790	6,485	0.05	6,795	0.19	24,524
	Subtotal	4,340	310	0.10	620	0.37	2,294	2,520	180	0.05	180	0.18	648	433,132	30,938	0.05	30,938	0.18	969,416	439,992	31,428	0.05	31,738	0.19	972,358
Totals	Exact	510,286	36,449	0.53	383,009	2.06	1,499,756	781,562	55,826	0.47	525,690	1.80	2,012,411	74,720,268	5,337,162	0.17	18,541,983	0.79	84,504,034	76,012,116	5,429,437	0.18	19,450,682	0.80	88,016,201
	Rounded	500,000	36,400	0.53	380,000	2.06	1,500,000	782,000	55,800	0.47	526,000	1.80	2,000,000	75,000,000	5,337,000	0.17	18,500,000	0.79	84,500,000	76,000,000	5,000,000	0.18	19,000,000	0.80	88,000,000

Table 9.--Cut off and cut-off classes of reserves in the Monument No. 2 channel.

	Measured Ore						Indicated Ore						Inferred Ore						Totals - All Classes of Ore					
	Volume Cubic feet	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume Cubic feet	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume Cubic feet	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume Cubic feet	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5
Class I: Mineralized rock 0.10 pct. U_3O_8 and 1.00 pct. V_2O_5 and above.	510,286	36,449	0.53	383,009	2.06	1,499,756	743,370	53,098	0.49	522,962	1.84	1,950,624	41,615,056	2,972,504	0.27	16,329,769	1.02	60,654,588	42,868,712 43,000,000 _/	3,062,051 3,000,000 _/	0.28 0.28	17,235,740 17,000,000 _/	1.05 1.05	64,104,968 64,105,000 _/
Class II: Mineralized rock 0.05 pct. U_3O_8 and 0.50 pct. V_2O_5 and less than 0.10 pct. U_3O_8 and 1.00 pct. V_2O_5.							38,192	2,728	0.05	2,728	1.13	61,787	28,296,016	2,021,144	0.05	2,021,144	0.58	23,324,595	28,334,208 28,000,000 _/	2,023,872 2,000,000 _/	0.05 0.05	2,023,872 2,000,000 _/	0.58 0.58	23,386,382 23,000,000 _/
Class III: Mineralized rock 0.10 pct. U_3O_8 and 0.10 pct. V_2O_5 and less than 0.05 pct. U_3O_8 and 0.50 pct. V_2O_5.													4,809,196	343,514	0.03	191,070	0.08	524,851	4,809,196 5,000,000 _/	343,514 343,000 _/	0.03 0.03	191,070 191,000 _/	0.08 0.08	524,851 525,000 _/

_/ Totals rounded.

Potential reserves

The total area of Monument Valley, Ariz., is 716 square miles. Of this total 253 square miles of the Shinarump member of the Chinle formation has been removed by erosion; 28 square miles of the member is clearly exposed; 14 square miles is partly concealed by dune sand and debris; and 421 square miles of the member is deeply buried.

In the exposed and partly concealed Shinarump member 62 channels or segments of channels have been observed. Of these 13 are segments, extensions, or isolated remnants of others; thus the number of channels has been determined to be 47. On the assumption that 90 percent of the channels were discovered in the exposed Shinarump member and 60 percent in the partly concealed Shinarump member, it is estimated that 58 channels are present, in the 42 square miles of exposed and partly exposed Shinarump member, for examination. Based on a ratio of 58 channels in 42 square miles, 582 channels have been estimated to be concealed in the deeply buried Shinarump member.

Of the 47 exposed or partly exposed channels 7 show mineralized sediments on outcrop, and of the estimated 58 channels in 42 square miles 9 would possibly be mineralized; therefore, it is estimated that of the 582 channels in the deeply buried Shinarump member about 89 may be mineralized.

The average dimensions for the estimated 89 mineralized deeply buried channels (based on mean dimensions of observed channels) are estimated to be: length - 7,920 feet, width - 320 feet, and scour - 30 feet. The amount of mineralized ground in these 89 channels is estimated to be 2 percent of the total channel volume; on this basis we arrive at the following data: volume of mineralized channels - 4,335,012,000 feet, volume of mineralized rock - 86,700,240 feet, and tonnage of mineralized rock (volume/14) - 6,192,874 tons.

Potential reserves in the Monument Valley area can be divided into three categories. First, those in the Monument No. 2 channel; second, those in known mineralized channels, other than Monument No. 2; and third, those in channels that are buried beneath younger strata and have not yet been found. Potential reserves in the Monument No. 2 channel amount to about 5,000,000 tons (table 10). Other known mineralized channels are estimated to contain potential reserves of about 1,500,000 tons (table 11). The greatest potential reserve, however, is anticipated in about 89 channels that are concealed and have not yet been discovered. It is estimated that these 89 channels contain potential reserves of about 6,000,000 tons (table 10). The sum of all potential reserves, then, is about 13,000,000 tons of mineralized rock. It is estimated that of this amount about 7,000,000 tons will be in the first grade class; about 5,000,000 tons will be in the second grade class; and 1,000,000 tons will be in the third grade class.

Table 10.--Potential reserves in the Monument Valley area, Arizona.

Channels		Mineralized rock 0.10 pct. U_3O_8 and above (tons)	Mineralized rock 0.05 pct. U_3O_8 to 0.10 pct. U_3O_8 (tons)	Mineralized rock 0.01 pct. U_3O_8 to 0.05 pct. U_3O_8 (tons)	Totals (tons)
Monument No. 2		3,062,051	2,023,872	343,514	5,429,437
Except Monument No. 2		863,080	570,250	107,886	1,541,216
89 concealed		3,468,010	2,291,363	433,501	6,192,874
Totals (tons)	Exact	7,393,141	4,885,485	884,901	13,163,527
	Rounded	7,000,000	5,000,000	1,000,000	13,000,000

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Table 11.--Reserves and potential Class I ore computed for known mineralized channels in the Monument Valley area, Arizona.

Channel	Ore body					Indicated ore						Inferred ore						Potential ore						Remarks
	Maximum Width (ft.)	Maximum Length (ft.)	Maximum Thickness (ft.)	Volume1/ (cubic feet)	Tonnage (Volume/14)	Volume (cubic feet)	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume (cubic feet)	Tonnage (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	Volume (cubic feet)	Tonnage2/ (Volume/14)	Average grade pct. U_3O_8	Pounds U_3O_8	Average grade pct. V_2O_5	Pounds V_2O_5	
Mitchell Mesa channel No. 1	4	15	8.0	252	18							252	18	0.42	151	1.62	583	15,788,750	22,555	0.42	189,465	1.62	730,794	Uniform ore body 1 foot thick assumed.
Mitchell Mesa channel No. 2																		85,445,000	122,064	0.42	1,025,340	1.62	3,954,883	
Subtotal Mitchell Mesa channels				252	18							252	18	0.42	151	1.62	583	101,233,750	144,619	0.42	1,214,805	1.62	4,685,677	
Hunts Mesa channel No. 1	40	60	2.0	2,520	180							2,520	180	0.42	1,512	1.62	5,832	40,800,000	58,286	0.42	489,600	1.62	1,888,457	
Hunts Mesa channel No. 2 Upper ore body	8	12	1.5	76	5							76	5	0.42	42	1.62	162	756,250	1,080	0.42	9,075	1.62	35,002	
Hunts Mesa channel No. 2 Lower ore body	12	18	3.5	386	28							386	28	0.42	235	1.62	907							
Subtotal Hunts Mesa channels												2,982	213	0.42	1,789	1.62	6,901	41,556,250	59,366	0.42	498,675	1.62	1,923,459	
Alfred Miles channel No. 1	40	40	2.0	1,680	120							1,680	120	0.25	600	1.25	3,000	917,730,000	1,311,043	0.22	5,768,589	1.08	28,318,529	U-V ratio estimated at 1:5
Cecil Todechenee channel	30	90	5.0	7,088	506							7,088	506	0.24	2,429	1.49	15,079	843,750	1,205	0.24	5,784	1.49	35,909	U-V ratio estimated at 1:6.2
Vanadium Corporation of America's Monument No. 1	120	500	11.0	346,500	24,750	121,785 (1)	8,699	0.22	38,276	1.11	193,118	224,715	16,051	0.22	70,624	1.11	356,332	33,957,000	24,983 (2)	0.44	219,850	2.23	1,114,242	(1) Based on premise of about 1,060 feet of drifts. (2) Mineralized ground estimated 1.03 percent of total channel volume.
Totals Exact						121,785	8,699	0.22	38,276	1.11	193,118	236,717	16,908	0.22	75,593	1.13	381,895	1,095,320,750	1,541,216	0.25	7,707,703	1.17	36,077,816	
Totals Rounded						122,000	9,000	0.22	38,000	1.11	193,000	237,000	17,000	0.22	76,000	1.13	382,000	1,000,000,000	1,500,000	0.25	7,700,000	1.17	36,000,000	

1/ Shape of ore body assumed to be ellipsoidal $4/3\pi(W/2)(L/2)(T/2)$. Shape of ore body assumed to be hemi-ellipsoid $\frac{4/3\pi(W/2)(L/2)(T/2)}{2}$ collinear with channel trend in following channels: Mitchell Mesa channel No. 1; Hunts Mesa channels Nos. 1 and 2.

2/ Computed on basis that 2 percent of the channel sediments may be mineralized.

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Prediction and recommendations

As of June 1953, only the ore deposit of the Monument No. 2 channel was producing sizeable amounts of uranium and vanadium ore. At that time operations by the Vanadium Corporation of America were gradually being shifted to the open-pit type of mining. If the rate of production continues at, or increases beyond, the level established in June 1953, it seems likely that the deposit in the Monument No. 2 channel will be depleted within the foreseeable future. As of June 1953, no new deposits had been found to replace the deposits being mined.

Although the work has permitted the determination of some useful guides for prospecting it has not been successful in presenting specific guides for the location of new uranium ore deposits. Until such guides are developed the possibility of finding new uranium and vanadium ore deposits rapidly and economically is remote. One of the major problems still to be solved is a determination of what constitutes feasible and acceptable guides to ore. The relationship between ore deposits and mineralized exposures to channel sediments has been noted many times in this report and elsewhere. The channels and their fill can be considered "favorable ground" and it is in this favorable ground that further work must be carried out. In our opinion this favorable ground can be investigated most readily by a two phase exploration program. The first phase would involve the determination of the trend, length, width, and depth of scour of the channels by geophysical methods. On the basis of these data the second phase, involving diamond drilling, would be undertaken. This second phase would determine which channels are most likely to contain ore deposits. There would be three objectives to this diamond drilling program; (1) the location of new deposits of uranium ore; (2) the reappraisal of the uranium resources of Monument Valley; and (3) the determination of guides that would assist in the discovery of new deposits of uranium and vanadium ore.

It seems likely that some of the channels investigated are bound to be barren; others, however, may contain deposits of uranium and vanadium ore of 100,000 tons or more. Whether any of the channels are as richly mineralized as the deposit in the Monument No. 2 channel is uncertain; likely at least one more channel either buried or exposed may be comparable to the deposit in the Monument No. 2 channel.

Once favorable ground is delineated by the diamond-drilling program the claim owners should be encouraged to do additional diamond drilling. We believe that such additional exploration in the favorable channel sediments will result in the discovery of new ore deposits.

Of the many favorable areas noted during the course of the work the six most promising are given below in order of decreasing priority. They should be the first ones tested in any future exploration program in the Monument Valley area, Arizona. The location of these favorable areas is shown on figure 14. They are:

(1) Hunts Mesa (channels nos. 56 and 57);

(2) Mitchell Mesa (channels nos. 50 and 51);

(3) Cecil Todechenee channel (channel no. 21);

(4) Channels at southeast edge of Hoskinnini Mesa (channels nos. 27 and 28);

(5) Koley Black area (channels nos. 37 to 47); and

(6) Alfred Miles channel No. 1 (channel no. 1).

LITERATURE CITED

Finch, W. I., 1953, Geologic aspects of the resource appraisal of uranium deposits in the Morrison formations of the Colorado Plateau: U. S. Geol. Survey Trace Elements Inv. Rept. 328A.

Gregory, H. E., 1917, Geology of the Navajo County: U. S. Geol. Survey Prof. Paper 93.

Stieff, L. R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some Colorado Plateau uranium ores by the lead-uranium method: U. S. Geol. Survey Circ. 271.

OFFICIAL USE ONLY

Unpublished reports

Chester, J. W., 1951a, Geology and mineralization of Hunts Mesa, Monument Valley, Arizona, with recommendations for exploratory drilling: U. S. Atomic Energy Comm., RMO 691.

Chester, J. W., 1951b, Geology and mineralization of Hunts Mesa, Monument Valley, Arizona: U. S. Atomic Energy Comm., RMO 801.

Chester, J. W., and Donnerstag, P. H., 1953, Drilling in the Monument Valley area of Arizona and Utah: U. S. Atomic Energy Comm., RMO 830 (Confidential).

Finch, W. I., in preparation, Geology of the uranium deposits in Triassic rocks of the Colorado Plateau: U. S. Geol. Survey Trace Elements Inv. Rept. 395.

Witkind, I. J., McKay, E. J., Johnson, D. H., Finnell, T. L., Claus, R. J., and Johnson, D. L., 1951, Preliminary report on geologic studies in the Monument Valley area, Arizona: U. S. Geol. Survey Trace Elements Memo. Rept. 318.

Witkind, I. J., Thaden, R. E., and Lough, C. F., 1953a, Preliminary report on geologic investigations in Monument Valley area, Arizona, 1952: U. S. Geol. Survey Trace Elements Memo. Rept. 536.

Witkind, I. J., Thaden, R. E., and Lough, C. F., 1953b, Interim report on geologic investigations in the Monument Valley area, Arizona: U. S. Geol. Survey Trace Elements Memo. Rept. 492.

Witkind, I. J., 1954, Localization of uranium minerals in channel sediments at the base of the Shinarump conglomerate, Monument Valley, Arizona: U. S. Geol. Survey Trace Elements Inv. Rept. 340.

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