Uranium Deposits at Base of the Shinarump Conglomerate Monument Valley Arizona

GEOLOGICAL SURVEY BULLETIN 1030-C

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By I. J. WITKIND

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

URANIUM DEPOSITS AT BASE OF THE SHINARUMP CONGLOMERATE, MONUMENT VALLEY, ARIZONA

By I. J. Witkind

ABSTRACT

Exposed sedimentary rocks on the Navajo Indian Reservation in Apache and Navajo Counties, northeastern Arizona, range from the Halgaito tongue of the Cutler formation (Permian) to the Salt Wash member of the Morrison formation (Jurassic). The dominant structural element of the area is the Monument upwarp, a large asymmetrical anticline whose northern end is near the junction of the Green and Colorado Rivers in Utah and whose southern end disappears near Kayenta, Ariz. Asymmetrical anticlines with steeply dipping east flanks and gently dipping west flanks are superimposed on the upwarp. These subsidiary structures trend northward.

The uranium-ore bodies are localized in conglomeratic sandstone of the Upper Triassic Shinarump conglomerate that fills stream channels scoured in the underlying Lower and Middle Triassic Moenkopi formation. These channels range from narrow and shallow, 15 feet wide and 10 feet deep, to broad and deep, 2,300 feet wide and 70 feet deep. Two types of channels can be distinguished—a short type, less than 2 miles long, and a long type, traceable for distances greater than 2 miles. Plant matter in the form of trees, branches, and twigs was deposited with Shinarump sediments in the channels. It is probable that when the Shinarump conglomerate was invaded by mineralizing solutions the uranium ore was deposited primarily in localities formerly occupied by the plant material. Also, it is thought that the short channels are more likely to have ore accumulations than long channels.

INTRODUCTION AND ACKNOWLEDGMENTS

During the summers of 1951 and 1952 the U. S. Geological Survey, on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission, mapped the geology and uranium deposits in three 15-minute quadrangles on the Navajo Indian Reservation in Apache and Navajo Counties, northeastern Arizona (fig. 12). The area mapped includes the southern half of Monument Valley. The work was undertaken to establish guides to uranium deposits and to appraise the relative favorableness of different formations for the occurrence of uranium deposits. Special emphasis was placed on the study of the Shinarump conglomerate (Late Triassic) because all

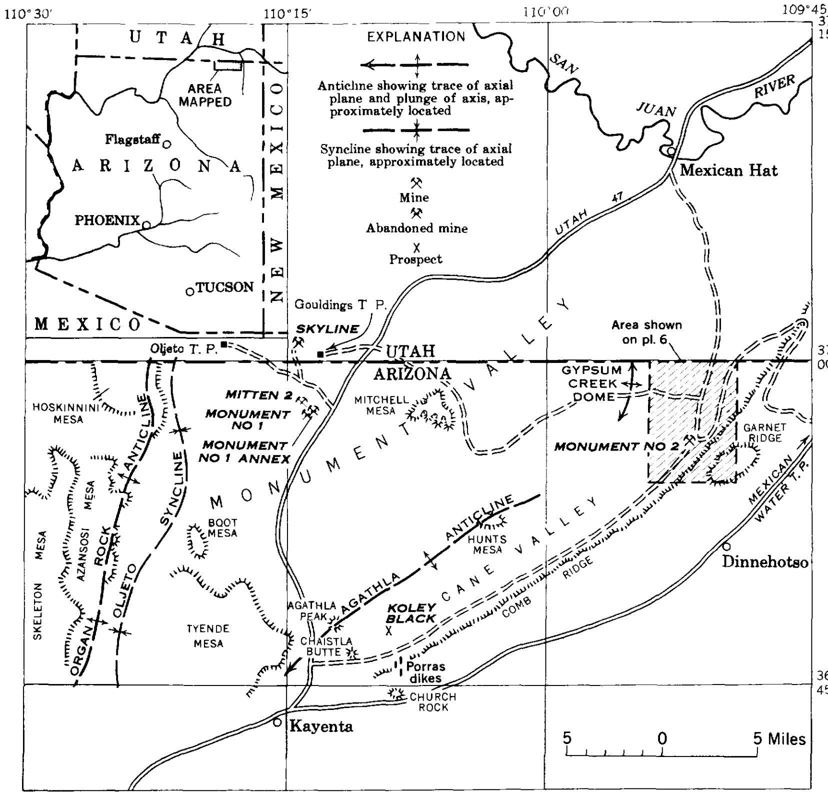

FIGURE 12.—Index map of part of the Monument Valley area in the Navajo Indian Reservation, Apache and Navajo Counties, Ariz.

uranium-ore deposits so far known in the Monument Valley area are in Shinarump sedimentary rocks which fill ancient channels at its base. In the Shinarump conglomerate a close relationship exists between uranium-ore deposits and channel sediments.

D. W. Viles, vice president in charge of mining, Vanadium Corporation of America, kindly permitted access to the Monument No. 2 mine by members of the Geological Survey. Our work in the mine was greatly assisted by Robert Anderson, mine superintendent, and Carl Bell, mine foreman.

GENERAL GEOLOGY

In Monument Valley, Ariz., exposed consolidated sedimentary rocks are of Permian, Triassic, and Jurassic age. (See geologic section below.) Most of the strata are continental in origin, eolian and water-laid rocks alternate in a nearly regular sequence. Volcanic necks and lamprophyric dikes, thought to be Tertiary in age, cut the sedimentary rocks. The dikes generally follow a joint set that trends

Sedimentary rocks exposed in the Monument Valley Area, Arizona

Age	Stratigraphic unit: Group	Formation	Member	Thickness (feet)	Lithologic and topographic characteristics
Jurassic		Morrison formation	Salt Wash member	?	Gray to chocolate-brown mudstone alternating with white to gray fine-grained sandstone lenses.
	San Rafael group	Bluff sandstone		45	Chocolate-brown fissile siltstone alternating with reddish-brown fine-grained sandstone. Few discontinuous white siltstone lenses.
		Summerville formation		35	Brown to reddish-brown even-bedded siltstone; cliff former; white fine-grained sandstone 1 foot thick at base.
				— Unconformity —	
		Entrada sandstone		110	Lower part reddish-orange massive fine-grained sandstone that weathers as smooth, rounded slopes. Upper part chocolate-brown to reddish-brown even-bedded shaly siltstone and sandstone weathering to rounded structures resembling hoodoos. Base of upper part locally marked by white fine-grained sandstone 1 foot thick.
		Carmel formation		118	Predominantly red fissile siltstone with local lenses of red platy sandstone; few beds of discontinuous thin ledge-forming white crossbedded medium-grained sandstone.
				— Unconformity —	
	Glen Canyon group	Navajo sandstone		665	Pink and buff massive eolian crossbedded sandstone with interbedded thin lenses of siliceous limestone.
Jurassic (?)		Kayenta formation		150–200	Light-violet to reddish-brown irregularly bedded quartz sandstone with local lenses of conglomerate.
Triassic		Wingate sandstone		350	Reddish-brown massive eolian crossbedded sandstone weathering to steep rounded slopes or vertical cliffs.
		Chinle formation		1,000	Lower part, variegated mudstone and siltstone with dark sandstone lenses near base and thin beds of gray cherty limestone near top; upper part, reddish-brown even-bedded siltstone and sandstone weathering to rubble-covered slopes.
		Shinarump conglomerate		50–100	Light-gray fluviatile crossbedded conglomeratic quartz sandstone with rounded pebbles as much as 2 inches in diameter; much silicified wood present.
				— Unconformity —	
		Moenkepi formation		30–250	Reddish-brown even-bedded ripple-marked shaly siltstone weathering to gentle slopes.
Permian		Cutler formation	Hoskinnini tongue	10–60	Reddish-brown parallel-bedded siltstone with some interbedded lenses of sandstone.
				— Unconformity —	
			De Chelly sandstone member	350–450	Buff massive eolian crossbedded quartz sandstone weathering to steep rounded slopes or vertical cliffs.
			Organ Rock tongue	650–750	Reddish-brown siltstone locally interbedded with red to gray sandstone; weathers to massive ledges about 5 feet thick.
			Cedar Mesa sandstone member	500	Reddish-orange crossbedded sandstone with thin beds of gray limestone.
			Halgaito tongue	380	Red siltstone and silty shale with thin beds of nodular-weathering gray limestone.

from due north to about N. 45° W. Xenoliths in the volcanic necks are only moderately metamorphosed and include pre-Cambrian(?), Pennsylvanian, Permian, Triassic, and Cretaceous rocks. In many places all strata are masked by a thin veneer of alluvium or dune sand, but exposures on the mesa faces are excellent.

The major structural feature in the region is the Monument upwarp, a broad asymmetrical anticline. It extends from near the junction of the Green and Colorado Rivers in Utah southward into the Monument Valley area of Arizona (Baker, 1935, p. 1482) where it plunges southward and disappears. The upwarp is about 125 miles long and has a maximum width of about 75 miles. In the Monument Valley area, Arizona, (fig. 12) the eastern flank of the Monument upwarp dips steeply and is well defined by Comb Ridge; the western flank, however, dips gently, and its limits are poorly defined.

The gently dipping west flank of the upwarp is interrupted by northward-trending subsidiary folds. Like the major upwarp, these subsidiary folds are also asymmetrical, with steep eastern flanks and gently dipping western flanks. Extensive dissection along these structural features has produced the cuestas, mesas, and buttes that characterize the spectacular landscape of Monument Valley.

SHINARUMP CONGLOMERATE

In Monument Valley, Ariz., the only known uranium-ore bodies are in channel sediments at the base of the Shinarump conglomerate.

On weathered exposures the Shinarump is gray or light buff, and only locally does the color deepen to a more somber brown or gray. Fresh surfaces are much lighter, approaching a very light gray. Although called a conglomerate, the Shinarump in Monument Valley is more correctly a conglomeratic sandstone. Commonly a coarse conglomerate is at the base, grading upward into sandstone that ranges from medium to coarse grained. Both the conglomerate and the sandstone beds are crossbedded and lenticular, and they intertongue with one another. Most of the foreset beds dip northwestward, but they may dip in any direction. Within any one lens the textures show rapid gradation; for example, a lens of coarse-grained sandstone more than 5 feet thick can become a conglomeratic standstone within a lateral distance of 10 feet.

The Shinarump conglomerate consists principally of only the most durable materials. Quartz, quartzite, and chert predominate both in the pebbles and the matrix. Pebbles composing the conglomeratic facies are commonly well rounded, with smooth, unbroken surfaces and ellipsoidal shapes. They are white, red, black, green, and yellow, or have many color combinations. Small quantities of limestone, clay, and sandstone pebbles are found in a few localities. Silicified wood is scattered throughout the Shinarump as fragments 1 or 2 inches in length and as logs as much as 50 feet long and 4 to 5 feet in diameter. Although much of the wood within the Shinarump has been silicified, some has not, and localized areas of small pockets of black carbonaceous material are found throughout the formation.

Lenses of claystone as much as 100 feet across and a few inches to 8 feet thick are common in the uppermost parts of the conglomerate. In some places the clay is concentrated within the formation in the form of angular blocks that range from 4 feet long and 2 feet high to small clay pebbles 1 or 2 inches in diameter. In these localities more interstitial clay is present than in areas where clay pebbles are rare.

The formation is cemented by a number of materials either individually or in combination: authigenic quartz, iron oxide, calcite, and clay are predominant.

Despite the relative thinness of the Shinarump conglomerate in the Monument Valley area, it is remarkably uniform in thickness over its widespread area of outcrop. The formation is generally about 75 feet thick, although locally, as the result of channeling, it thickens to 150 feet or more; elsewhere, it thins laterally and disappears.

The contact of the Shinarump with the overlying Chinle formation is gradational, and, locally, the two formations intertongue. The contact between the Shinarump and the underlying Moenkopi formation, however, is a widespread disconformity marked by deep channels. Except for the channels the relief along the disconformity ranges from 2 to 4 feet and is marked by a notable textural and compositional change.

In Monument Valley the Shinarump forms a resistant sandstone ledge that caps most of the mesas. On outcrop it tends to form steep cliffs as much as 60 feet high, that are almost unscalable for considerable distances along the exposure. The formation is jointed throughout, and large talus blocks mantle the slopes and commonly conceal the lower contact of the formation. Some talus slides extend from the base of the Shinarump cap to the bottom of the mesa, which is as much as 800 feet below. Where the Shinarump conglomerate forms a widespread surface, it is extremely irregular, pitted with basinlike depressions as much as 20 feet in diameter and 4 feet deep, and ridged with hummocks that rise as much as 30 feet above the general surface. In some localities the Shinarump forms a bench around the flanks of mesas capped by younger rocks.

CHANNELS

APPEARANCE

In Monument Valley the symmetric and asymmetric troughs that are cut into the Moenkopi and filled with Shinarump conglomerate are referred to as channels. These channels accentuate the disconformity between the two formations. Deposits of uranium and copper minerals are localized within these channel sediments, and as a result the channels are of special interest to geologists and prospectors in this part of the Colorado Plateau.

The channels are exposed in three different ways in the Monument Valley area. Principally, they are exposed along mesa rims and in valley walls as U-shaped depressions. In this mode of outcrop the channels are buried beneath overlying beds of Shinarump conglomerate (fig. 13*A*). Where erosion has been more extensive and the overlying beds of Shinarump have been removed, the channel sediments appear as narrow elongate exposures of gray conglomeratic sandstone bounded by the red shaly siltstone of the Moenkopi formation (fig. 13*B*). Where erosion has proceeded still farther, the softer shaly siltstone of the Moenkopi has been removed, leaving the more resistant channel fills as ridges (fig. 13*C* and fig. 14).

The details of the origin of the channels are still in doubt, but it seems likely that the channels are the result of stream erosion. Typical cross sections of channels at the base of the Shinarump conglomerate are shown in figures 15, 16, and 17.

CLASSIFICATION

The channels are difficult to trace commonly, because they are not well exposed or because they differ greatly in length. A channel may be so short that it is exposed only on one side of a mesa. This is well shown by R. A. Black and W. H. Jackson of the U. S. Geological Survey in their interpretations of the resistivity of the channels in the Koley Black area where channel 45 ends within 350 feet of the outcrop and cannot be traced farther to the northwest (fig. 18). The Koley Black group of channels (nos. 37–45 of fig. 18) has confirmed the short linear character of some channels. Other channels may persist across the mesa and be exposed on both sides. One channel was traced for 4 miles; others disappear within a mile. I have called the shorter channels "short channels," and the longer ones "long channels," and have arbitrarily established the distance of 2 miles as a dividing line between the basinlike short channels and the more continuous long ones.

How the short channels terminate is uncertain, although the results of drilling by the U. S. Atomic Energy Commission suggest that some of the short channels have ends that are gently concave (pl. 5*C*). Because of insufficient drilling it is not known how the long channels terminate.

These short channels may represent deep scours along the course of a former stream, but as yet I have not found these channels alined in such a manner as to confirm this. If these short channels do repre-

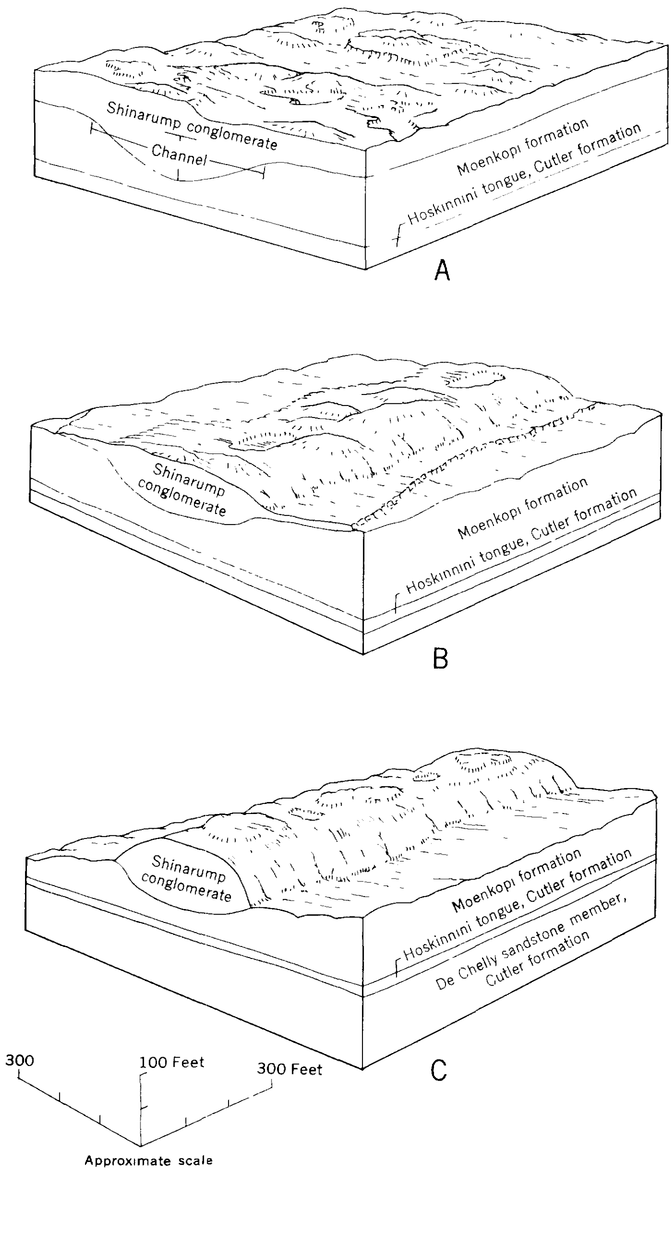

FIGURE 13.—Schematic block diagrams showing modes of outcrop of channels in the Monument Valley area, Arizona.

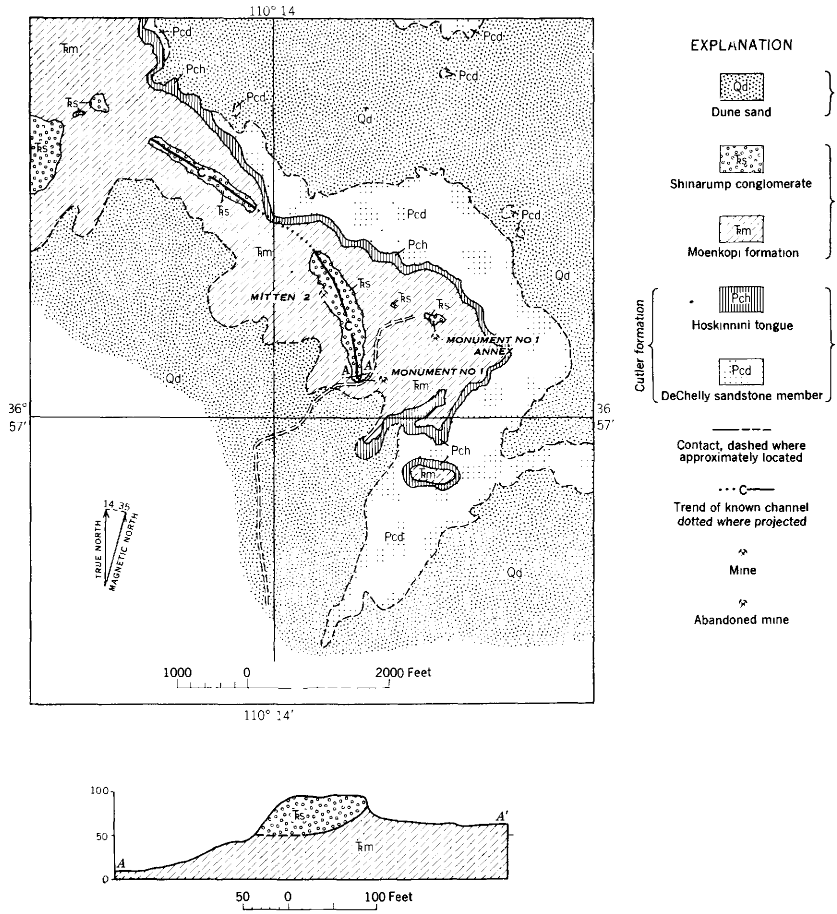

FIGURE 14.—*Geologic map and cross section of Monument No. 1 channel, Navajo County, Ariz.*

sent sporadic scouring, it may be possible to project the trends and locate other short channels now concealed beneath overlying beds of Shinarump.

TRENDS

In this area the dominant orientation of the channels is northwestward (fig. 19). In an area as small as Monument Valley, Ariz., this northwest orientation is merely suggested by a diagram of the channel trends (fig. 20*A*). This orientation is more apparent in the diagram of channel trends in the adjacent part of Monument Valley in Utah (fig. 20*B*). Thus, a diagram (fig. 20C) of all the channel trends noted in a much larger area (the Utah and Arizona parts of Monument Valley) clearly indicates the dominant northwest orientation.

FIGURE 15.—View of Mitchell Mesa channel 1, Navajo County, Ariz., showing the Shinarump conglomerate (Ꞧs), Moenkopi formation (Ꞧm), Hoskinnini tongue of the Cutler formation (Pch), and De Chelly sandstone member of the Cutler formation (Pcd).

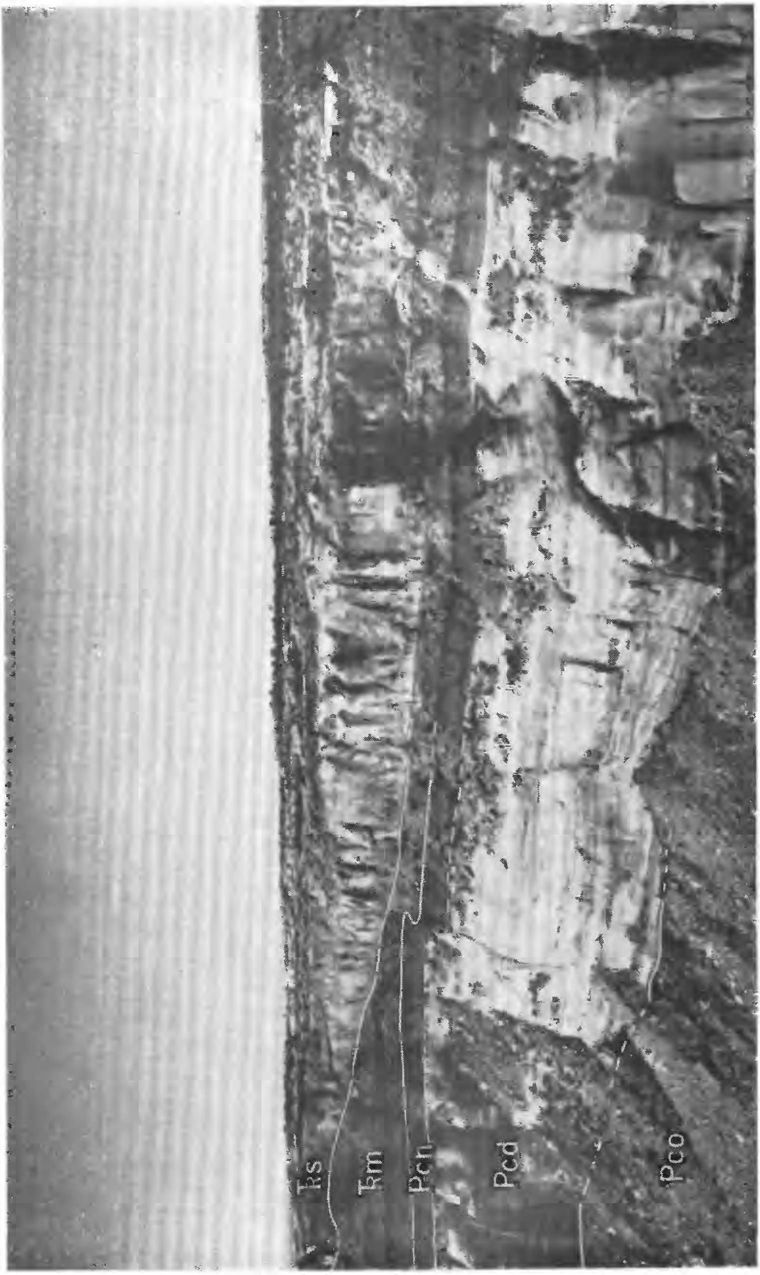

FIGURE 16.—Northeasterly view across the West Fork of Copper Canyon showing the broad deep Alfred Miles channel 1, Navajo County, Ariz., and the Shinarump conglomerate (R̄s), Moenkopi formation (R̄m), Hoskinnini tongue of the Cutler formation (Pch), De Chelly sandstone member of the Cutler formation (Pcd), and Organ rock member of the Cutler formation (Pco).

FIGURE 17.—Southeasterly view of South Ridge showing shape of Monument No. 2 channel, Apache County, Ariz., and the Shinarump conglomerate (Ꞧs), Moenkopi formation (Ꞧm), Hoskininni tongue of the Cutler formation (Pch), and De Chelly sandstone member of the Cutler formation (Pcd).

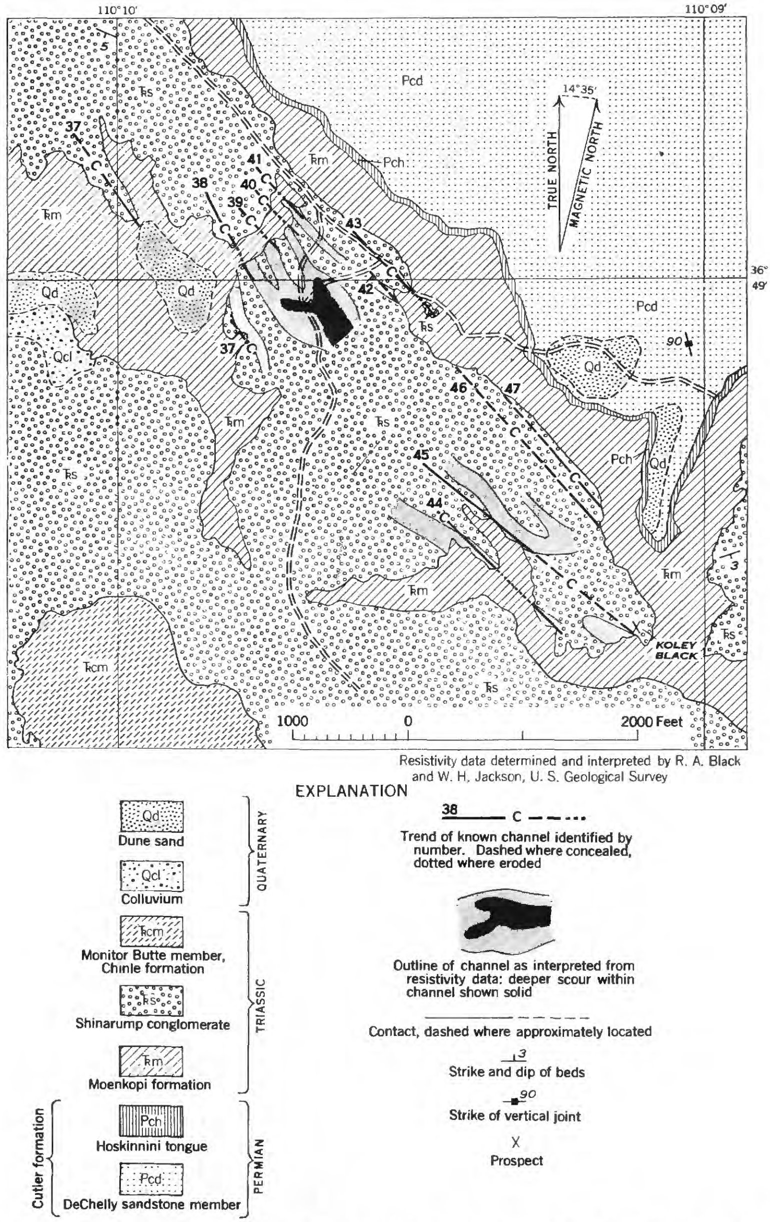

FIGURE 18.—Geologic and resistivity interpretations of channels in the Koley Black area, Navajo County, Ariz.

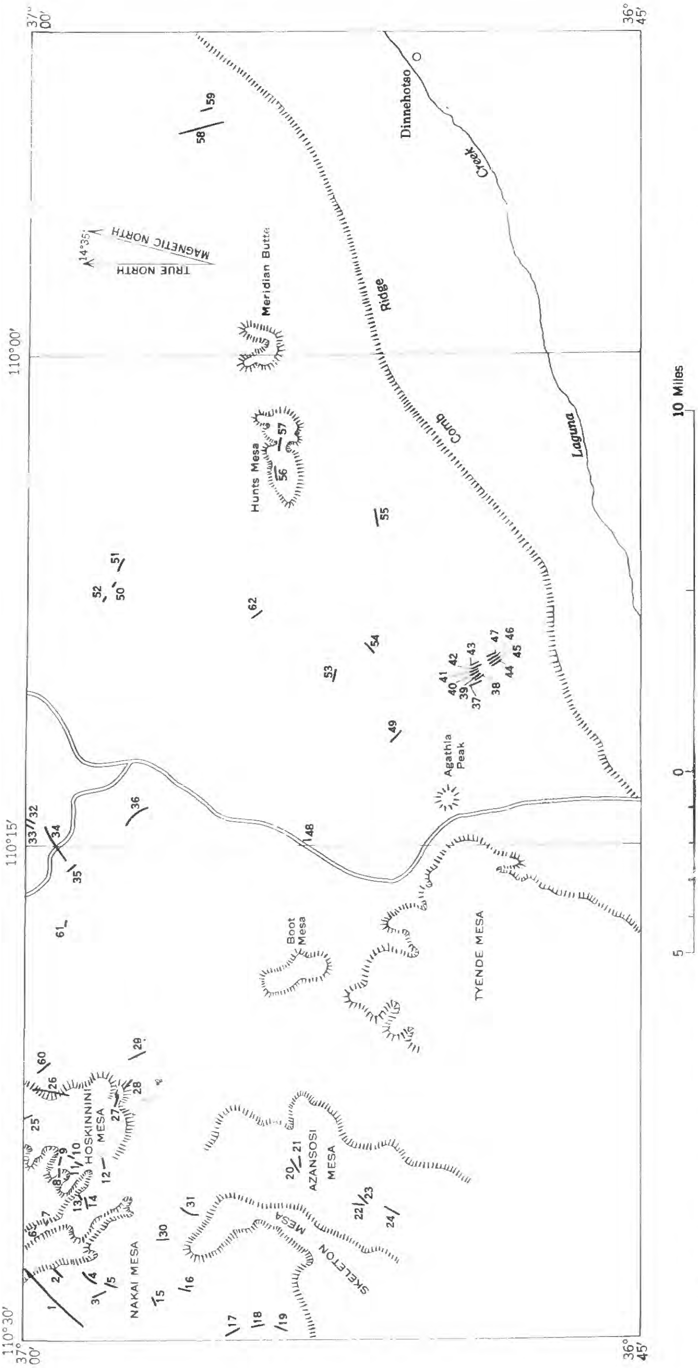

FIGURE 19.—Map showing distribution of channels in the Monument Valley area, Arizona. Channels are identified on page 114.

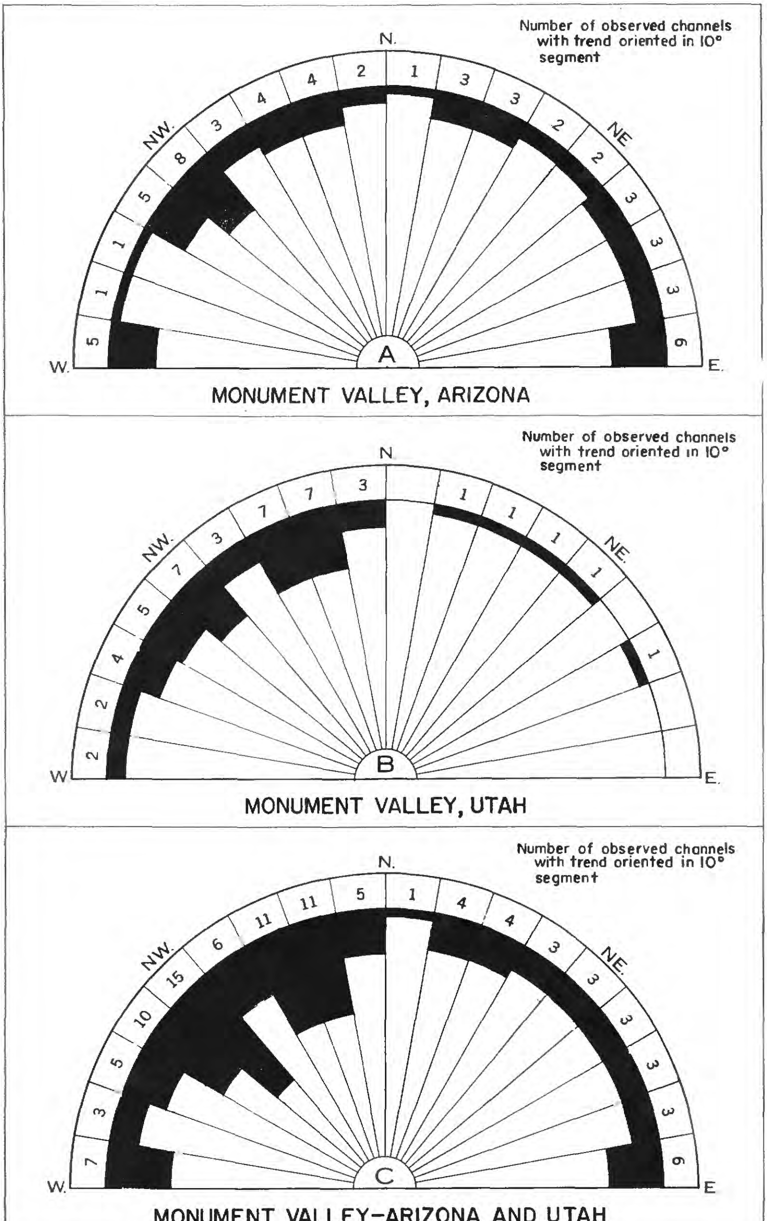

FIGURE 20.—Diagrams showing channel trends in the Monument Valley area, Arizona and Utah.

Although several channels curve (fig. 19), most are nearly straight. This observation is substantiated by recent geophysical work in this area.

Single channels are most common, but several do bifurcate, and of these at least one, in the Koley Black area, appears to give way to a series of parallel smaller channels (fig. 18).

WIDTHS

For purposes of discussion the channels are classified roughly into three categories based upon width. The first category (narrow) includes channels as much as 50 feet wide, the second category (intermediate) comprises channels ranging from 50 to 350 feet in width, the third category (broad) includes channels ranging from 350 to 2,300 feet in width (fig. 19). Of the 62 channels noted during the course of field work, 17 were narrow, 32 were intermediate, and 13 were broad. (See table on following page.)

Channel sediments, sorting, and bedding appear identical in all three categories of channels.

FLOORS

Little is known about the configuration of channel floors. Judging from workings in the Monument No. 2 and Skyline mines (fig. 12), the floor is known to be undulatory and locally extremely irregular. Geophysical work in the Koley Black area (fig. 18) and along the Alfred Miles channel 1 (fig. 19) has also indicated that broad shallow scours are in channel floors. It has been suggested by geologists of the U. S. Atomic Energy Commission (J. W. Chester, 1952, personal communication) that these scours may be important centers of uranium-ore accumulation.

SEDIMENTS

Sediments filling the channels range from medium- and coarse-grained sandstone to conglomerate. Some of the channels are filled completely with massive uniform-textured medium-grained sandstone that is totally devoid of pebbles or conglomerate. Other channels contain conglomerate with minor amounts of coarse sand filling the interstices. In general, however, the sediments filling the channels appear identical with sediments found elsewhere in the Shinarump conglomerate. The prominent difference between channel sediments and nonchannel sediments is the amount of fossil wood; channel sediments contain abundant fossil wood, whereas nonchannel sediments contain less wood. For example, in certain channels, especially the Monument No. 2 channel, the quantities of mineralized wood seem unusually high. Some of this wood is replaced by silica, some by

Characteristics of channels

Location number (fig. 19)	Name of channel	Width (feet)	Depth cut into Moenkopi formation (feet)	Length	Strike	Mineralization
1	Alfred Miles 1	2,150	70	Long	N. 50° E.	Cu, U.
2				Unknown	N. 35° E.	
3	Cutfinger Canyon	2,300		do	(?)	
4		1,500		do	(?)	
5		150	10–15	do	N. 40° E. (?)	
6	Double [1]	1,800	50	Long	East	Cu.
7	Alfred Miles 2 [1]	900	50	do	East	Do.
8	([1])	500	75	do	N. 80° W.	
9	([1])	250	30	do	N. 80° E.	
10	([1])	150	10	Unknown	(?)	
11		150	0	do	N. 12° E.	
12	Southwest Hoskinnini	600	30	do	N. 72° E.	
13		150	10	do	N. 55° E.	
14		20	6	do	East	
15		50	10–15	Short (?)	NE (?)	
16	Checker [1]	(?) 300	20–40	Short	N. 20° E.	
17	Road [1]	400	50	Long	N. 25° W.	Cu.
18	Fish [1]	400	40	do	N. 10° W.	
19	Reentrant [1]	600	40	do	N. 40° E.	
20		30	10	Unknown	N. 50° E.	
21	Cecil Todechenee	100	20	do	East	Cu, U.
22		45	8	do	N. 18° E.	
23		600	30	do	N. 35° E.	
24		140	20	do	N. 25° E.	
25		250	10	do	N. 30° W.	
26	East Hoskinnini	300	30	Long	N. 15° E. to N. 10° W.	
27		250	75	Long (?)	N. 65° W.	
28		150	50	do	N. 45° W.	Cu.
29	Ramp	50	20	Short	N. 10° W.	Do.
30		175	20	Unknown	North	
31		10		do	North	
32		25	15	Short	N. 65° E.	
33		15	8	do	N. 27° E.	
34		200	50	Long (?)	N. 80° E.	
35		250	30	Unknown	N. 35° W.	
36	Monument No. 1	250	50	Short	N. 10° W.	Cu, U.
37	Koley Black [2]	80–100	25	do	N. 35° W.	Cu.
38	do	80		do	N. 45° W.	
39	do	50	5–10	do	N. 44° W.	
40	do	50	5–10	do	N. 44° W.	
41	do	50	5–10	do	N. 44° W.	
42	do	35	20	do	N. 20° W.	
43	do	110	30	do	N. 45° W.	
44	do	35	25	do	N. 45° W.	Cu.
45	do [3]	270	30	do	N. 52° W.	Do.
46	do	35	20	do	N. 20° W.	
47	do	110	30	do	N. 45° W.	
48		150	30	Unknown	North	
49	Mystery Valley 1	150	16	Short	N. 50° W.	
50	Mitchell Mesa 2	(?) 350	50	do	N. 70° W.	
51	Mitchell Mesa 1	350	75	do	N. 55° W.	Cu, U.
52	Mitchell Mesa 3	300	70	Unknown	N. 82° E.	Cu, V.
53		70–80	15	Short	N. 85° W.	
54	Mystery Valley 2	50	20	Unknown	N. 75° E (?)	Cu.
55	Mike Brodie	150	20	do	N. 85° E.	Do.
56	Hunts Mesa 2	50	20	Short	N. 82° E.	Cu, U.
57	Hunts Mesa 1	300	50	do	East	Do.
58	Monument No. 2	400–700	50	do	N. 18° W.	Cu, U, V.
59	Cuesta	300	20	do	N. 25° W.	
60		150	25	Unknown	N. 55° W.	
61		300	40	Long	N. 67° E.	
62		300	20	Short	N. 50° W.	

[1] One channel (?).
[2] Koley Black refers to a group of unnamed channels in the Koley Black area.
[3] Main channel of the Koley Black group.

tyuyamunite and limonite, some by uraninite, and same has been altered to a carbonaceous material. Furthermore, many of the rich ore bodies at the Monument No. 2 mine may represent deposition of uranium minerals in localities once occupied by buried logs. In several other channels, notably the Alfred Miles channels 1 and 2, and the Double channel (fig. 19), fragments of wood partly replaced by copper minerals (azurite and malachite) are found in basal channel sediments. Lenticular pods of black coaly material (vitrain?) have been found associated with several ore deposits and are believed to represent buried logs.

It appears that two types of clay fragments are included in the Shinarump conglomerate. Most profusely distributed are those fragments derived from the Moenkopi formation. Other clay fragments, less common, may be the result of alteration of volcanic ash deposited during original accumulation of the Shinarump (Waters and Granger, 1953, p. 6).

In the Skyline mine (fig. 12) angular boulders of clay, derived from the Moenkopi formation, as much as 4 feet on a side, and clay fragments of smaller sizes are profusely distributed throughout the channel sediments. Similar clay fragments are found in other channels. Preliminary X-ray work by D. H. Johnson of the Geological Survey has indicated that most of these clay pebbles are composed of quartz, hydromica, and possibly a little montmorillonite. (See table below.)

Whether either type of clay fragment is instrumental in the localization of uranium ore is unknown. Conflicting evidence has been noted at several mineralized locations. Geologic mapping in the Monument No. 2 mine has suggested that clay has no significance in such localization, but at both the Monument No. 1 and the Skyline mines clay pebbles appear to have acted as focal points for the accumulation of uranium minerals.

Composition of some clay pebbles from the Monument Valley area, Arizona and Utah, as determined by means of the X-ray spectrometer

[Analyzed and compiled by D. H. Johnson, Denver Trace Elements Laboratory]

Sample no.	Location	Composition	Benzidine test
W-175A	Monument No. 1 mine, Navajo County, Ariz.	Quartz, hydromica, and a little kaolinite.	Very slightly positive (?).
W-175B	do	Quartz, hydromica, and carbonate apatite (?).	Do.
W-176A	Base of channel, Monument No. 1 mine, Navajo County, Ariz.	Quartz, hydromica, and a little carbonate apatite (?).	Very slightly positive.
W-176B	do	Quartz, hydromica, and a little carbonate apatite (?) and kaolinite or chlorite.	Negative.
W-180	Monument No. 1 mine, Navajo County, Ariz.	Quartz, hydromica, a little kaolinite, and possibly a little montmorillonite.	Very slightly positive.
W-182	Monument No. 1 Annex, Navajo County, Ariz.	Quartz, hydromica, and probably a little montmorillonite.	Do.
W-186	Skyline mine, San Juan County, Utah.	Quartz and hydromica	Do.
W-187	do	do	Do.
W-188	do	Quartz, hydromica, and perhaps a little montmorillonite.	Do.

SWALES ASSOCIATED WITH CHANNELS

The Monument No. 2 channel is in the center of, and collinear with, a broad very shallow, elongate swale in the top of the Moenkopi formation (pl. 6). However, this cannot be perceived from the ground because of the dissection of the area, as well as the great width and relative shallowness of the feature. An isopachous map, prepared from measured sections of the combined Hoskinnini and Moenkopi strata indicates its width and extent clearly (pl. 6). The swale is about 3 miles wide and can be traced southeastward for 3½ to 4 miles before it disappears below the alluvium of Cane Valley. At the edges of the swale the combined thicknesses of Hoskinnini and Moenkopi strata amount to about 80 feet. Along the flanks of the Monument No. 2 channel in the center of the swale, this thickness decreases to 30 feet. Erosion during the formation of the channel has removed these 30 feet of strata adjacent to the channel, and consequently channel sediments of the Shinarump conglomerate rest with pronounced disconformity on the De Chelly sandstone member of the Cutler formation.

Although this swale-channel relationship is best displayed in the Monument No. 2 area, analogous features have been noted on Hoskinnini Mesa. There, however, the swales are not as well formed nor as broad.

ORIGIN

One hypothesis regarding the origin of channels suggests that they were formed during a period following deposition of the Moenkopi formation but prior to deposition of the Shinarump conglomerate. This viewpoint is presented by Gregory and Moore (1931, p. 52) who wrote—

> After Moenkopi time there was widespread erosion which partly beveled the soft Moenkopi strata and in places carved distinct erosion channels in them. The subsequently deposited Shinarump conglomerate constitutes a very widespread thin veneer which covers this erosion surface and fills its depressions.

Stokes (1950, p. 94) interprets this as meaning that the unconformity and the channels were formed probably during Middle Triassic, with the Shinarump deposited much later in a second independent episode in Late Triassic time.

Another hypothesis suggests that the channels were formed by the streams that deposited the Shinarump, and thus are contemporaneous in age with basal Shinarump sedimentary rocks. This viewpoint is expressed by Stokes (1950, p. 97) who regards the unconformity as a Middle Triassic pediment surface formed during the deposition of the Shinarump conglomerate, which in turn represents a pediment deposit.

Essentially there appears to be general agreement that the Shinarump was deposited on a widespread surface of low relief. Stokes considers the surface to have formed synchronously with the deposition of the Shinarump; McKee (1951, p. 91), however, considers it to have been a flood plain upon which the Shinarump was deposited.

Apparently streams transported sands and gravels from a raised area to the south and gradually spread them northward as a thin blanket. When one considers the coarse-grained and resistant materials that compose the Shinarump conglomerate it seems unlikely that the formation could have been deposited without some scouring in the softer siltstones and shales of the underlying Moenkopi formation. It is suggested, therefore, that the major channel scour occurred during deposition of the Shinarump conglomerate and not in any period of erosion prior to this deposition.

Why one channel is continuous and another not, is unknown; the short channels may represent sporadic scour depressions. Bryan, (1920, p. 191) in discussing present streams, suggests that scour depressions are most likely to form near the outside bend of a stream where the erosive force of the stream is at a maximum. If this concept is applied to the Shinarump, it may be that a former meandering stream, carrying Shinarump sediments cut these deeper scours wherever it swung about. Thus, Monument No. 1 (fig. 14), a gently curving short channel, might have formed in this manner.

Another possibility is that local differences in the hardness of the Moenkopi formation that once formed the banks of the former streams may have caused the formation of "narrows". These narrows may have been instrumental in ponding the water and thus forming sizable lakes upstream. The attendant increase in gradient across the more resistant rocks would have augmented the velocity. Downward erosion would have increased at the expense of lateral planation, and the final result would have been the formation of short channels. Matthews (1917, p. 337–342), referring to elongate scour depressions as much as 2,000 to 7,200 feet long, 200 to 300 feet wide, and 40 to 60 feet deep in the floor of the Susquehanna River, suggests that these "deeps," as he calls them, are the result of such constrictions.

LOCALIZATION OF URANIUM ORE IN CHANNELS

This paper is concerned with the localization of uranium minerals, which are more correctly identified as uranium-vanadium minerals inasmuch as the chief ones are tyuyamunite [$Ca(UO_2)_2(VO_4)_2 \cdot nH_2O$] and carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$].

Although uranium ore is in channel sediments, the ore is not continuous along the channel's length nor does it appear to be restricted to any specific sector of the channel sediments. At the Vanadium Corporation of America's Monument No. 2 mine, where extensive workings permit examination of channel sediments, ore has been found in the basal, middle, and uppermost beds as well as along the channel flanks.

One fact, however, is clearly evident in the Monument Valley area: no ore has been found outside of channels. This is not to be construed to mean that uranium minerals are not found away from channels; they are, but to date they have been found in such small amounts as to make them of academic rather than economic interest. This relationship between uranium ore and channels is well known, and most prospectors seek and stake claims on such channels.

The relationship between uranium minerals and channels is repeated many times in the Monument Valley area of Utah and Arizona. Generally, these exposures are small and of slight extent, but more than one-third of the channel outcrops examined contain some uranium or copper minerals in their basal sediments.

The spatial relationship between uranium-ore deposits (economic concentrations of uranium minerals) and channels, is based on only two examples. Essentially, in the Monument Valley area, Arizona, uranium-ore deposits have been found in one of the intermediate-type channels, and in one of the broad channels. Despite this unimpressive accounting, it should be noted that many of the channels are as yet untested and may contain deposits of uranium ore. Most important, however, is the realization that of the thousands of miles of Shinarump outcrop examined, deposits of uranium minerals seem to be largely restricted to channel sediments. The apparent relationship between channels and uranium-ore deposits also seems to be suggested elsewhere on the Colorado Plateau.

As a result of the spatial association between channel sediments and uranium ore, a continuing search is underway for the factor or factors which were instrumental in localizing the ore in the channel sediments. The search has been unsuccessful in that conclusive evidence favoring any factor (or combination of factors) is yet to be produced. Strong "suggestions" have been noted by field geologists working in the Monument Valley area. For example, at the Skyline mine, ore is in channel sediments that contain much clay and pods of carbonized wood. A similar situation exists at Monument No. 1 mine. Despite this apparent relationship in these two localities between clay and carbonized wood and uranium ore, it is difficult to state conclusively what role these factors played in the localization of uranium ore. Clay as well as pods of carbonized wood are found away from channels, and ore is not present in these localities. In Monument No. 2 mine clay and carbonized wood are in considerable amounts within the channel sediments, but in no instance was a sizeable quantity of uranium ore associated with either. In fact, areas were found in the mine where concentrations of clay, boulders, and carbonized wood were distant from ore localities.

RODS

Throughout the Monument No. 2 mine many of the major bodies of uranium ore appear as flattened, cylindrical bodies. The miners refer to them as trees or logs. Because these two terms bear a genetic connotation, a new term, suggested by L. B. Riley of the U. S. Geological Survey, is proposed herewith. It is suggested that these crudely ovate, flattened, elongate, cylindrical bodies be known as rods.

All the rods are in channel sediments of the Shinarump conglomerate; none are in any of the underlying strata. Ore bodies similar to these have been noted in the Morrison formation and called cylindrical masses (Coffin, 1921, p. 163). The origin of these rods in the Shinarump is obscure. Some may result from chemical changes induced in the mineralizing solutions by carbonaceous matter; others may result from unusual conditions of permeability and porosity in the host rock.

The rods in the Shinarump can be classified roughly into two categories: simple and complex. The simple type of rod is illustrated in figure 21. Essentially it consists of an outer rim of sandstone impregnated with limonite, within which is a rim of tyuyamunite-impregnated sandstone, which in turn surrounds a core of extremely friable light-gray sandstone.

The complex type of rod is bounded similarly by an outer rim of limonite-impregnated sandstone within which is a rim of tyuyamunite-impregnated sandstone. These rims, however, are much more irregular than in the simple type. A further subdivision of the complex rod is possible. One type contains irregular masses of mixed limonite and tyuyamunite randomly distributed throughout the gray sandstone center (fig. 21*A* and fig. 22); a second type may have these irregular masses of limonite and tyuyamunite in the sandstone center, but in addition has a central core of silicified wood (figs. 21*B*, 23, and 24).

Near many of the rods the confining strata are interrupted at the rims; elsewhere, they arch over the rods. Grain size changes abruptly at the edges of some rods. Most rods are remarkably straight and, where mining operations have followed them, many have been found to taper and bifurcate. Many complex rods are associated with silicified wood; and, invariably, where longitudinal exposures are available, the silicified wood is seen to be collinear with the rods (block diagram in fig. 21; and fig. 24). In several rods, exposures are large enough to afford longitudinal examination of the gray sandstone core filling their centers. In these, the direction of crossbedding is totally different from the direction of crossbedding of those sediments outside the rods.

Small fractures cutting the sand grains are restricted to the limonite-impregnated sandstone zone and the tyuyamunite-impregnated sandstone zone, both of which form the rims of the rods. These fractures are not apparent in those grains that fill the cores of the rods, nor in the grains distant from the boundaries of the rods. Moreover, the fracturing halts along very definite boundaries which in some cases are so distinct they can be delineated in thin section. For example, in thin sections of edges of rods, the grains on part of the slide are intensely fractured, whereas the grains on the remainder of

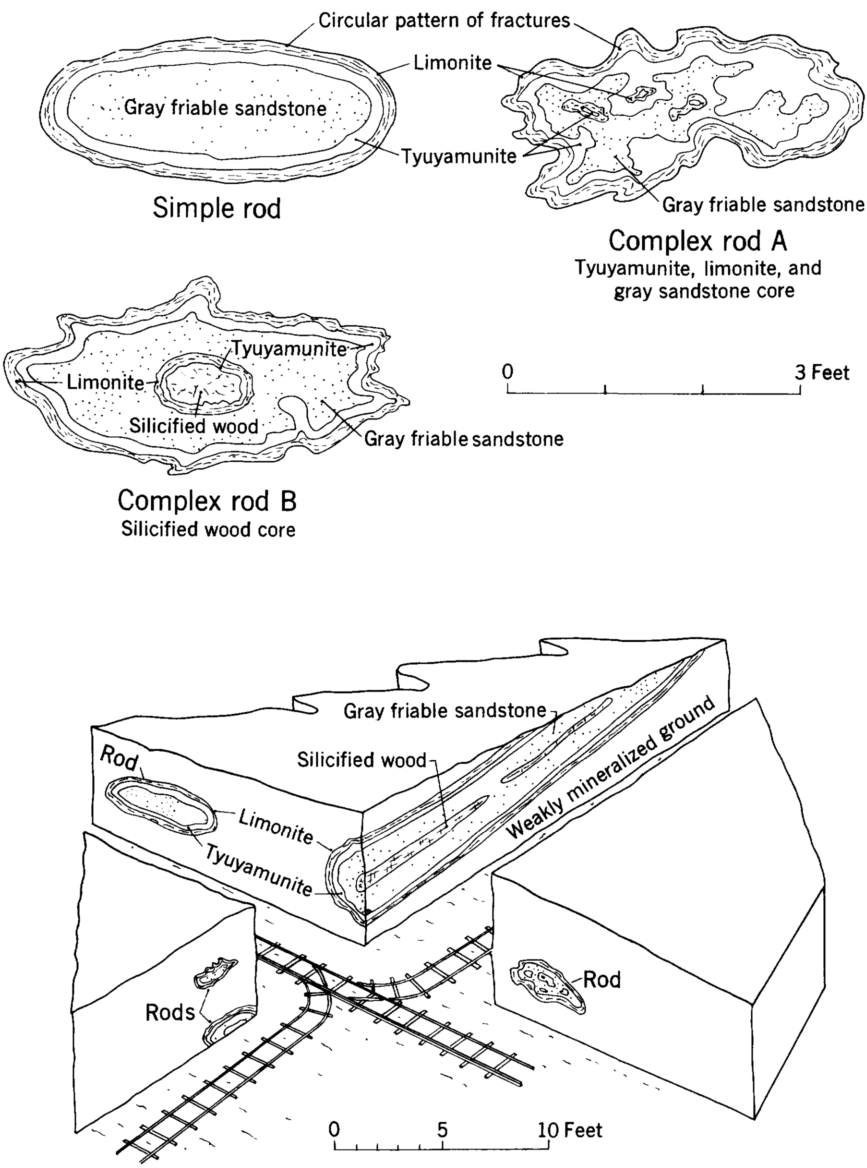

FIGURE 21.—Illustrations of simple and complex rods in Monument No. 2 mine, Apache County, Ariz.

FIGURE 22.—View of large complex rod in Monument No. 2 mine, Apache County, Ariz., showing mixed limonite and tyuyamunite (ss) in sandstone center, surrounded by rings of tyuyamunite (ty) and limonite (lt).

FIGURE 23.—Oblique view of complex rod in Monument No. 2 mine, Apache County, Ariz., showing core of silicified wood (sw) surrounded by gray friable sandstone with mixed limonite and tyuyamunite (ss), which in turn is surrounded by rings of tyuyamunite (ty) and limonite (lt).

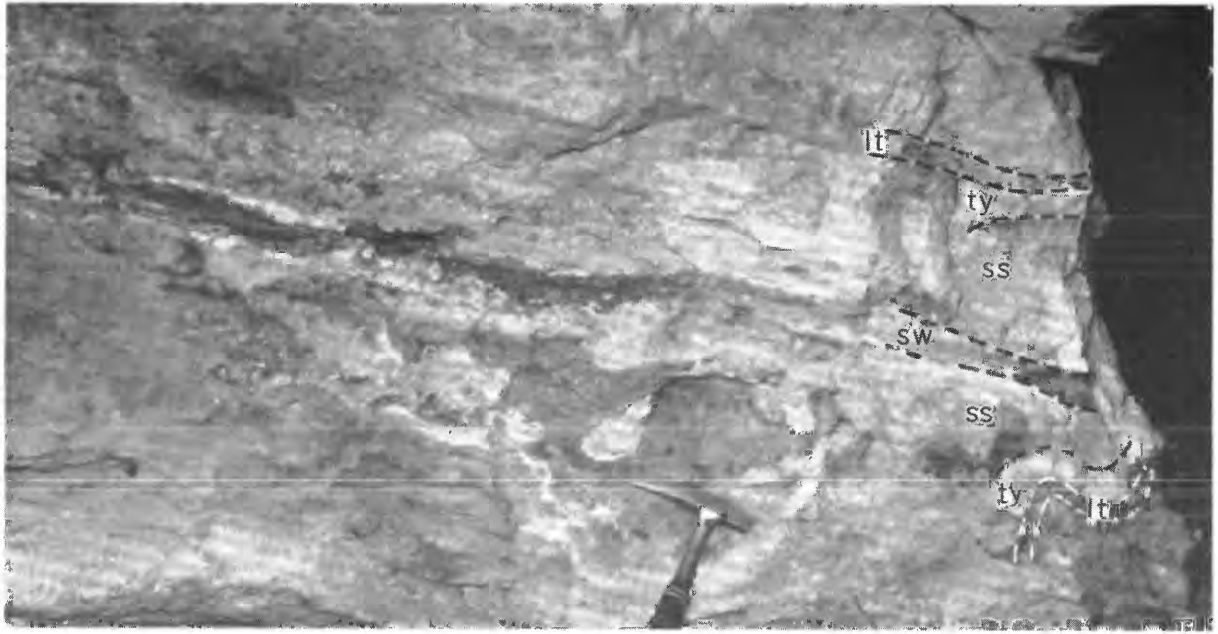

FIGURE 24.—Longitudinal view of complex rod in Monument No. 2 mine, Apache County, Ariz., showing thin core of silicified wood (sw), lying parallel to the trend of the rod and surrounded by rings of gray friable sandstone with mixed limonite and tyuyamunite (ss), tyuyamunite (ty), and limonite (lt).

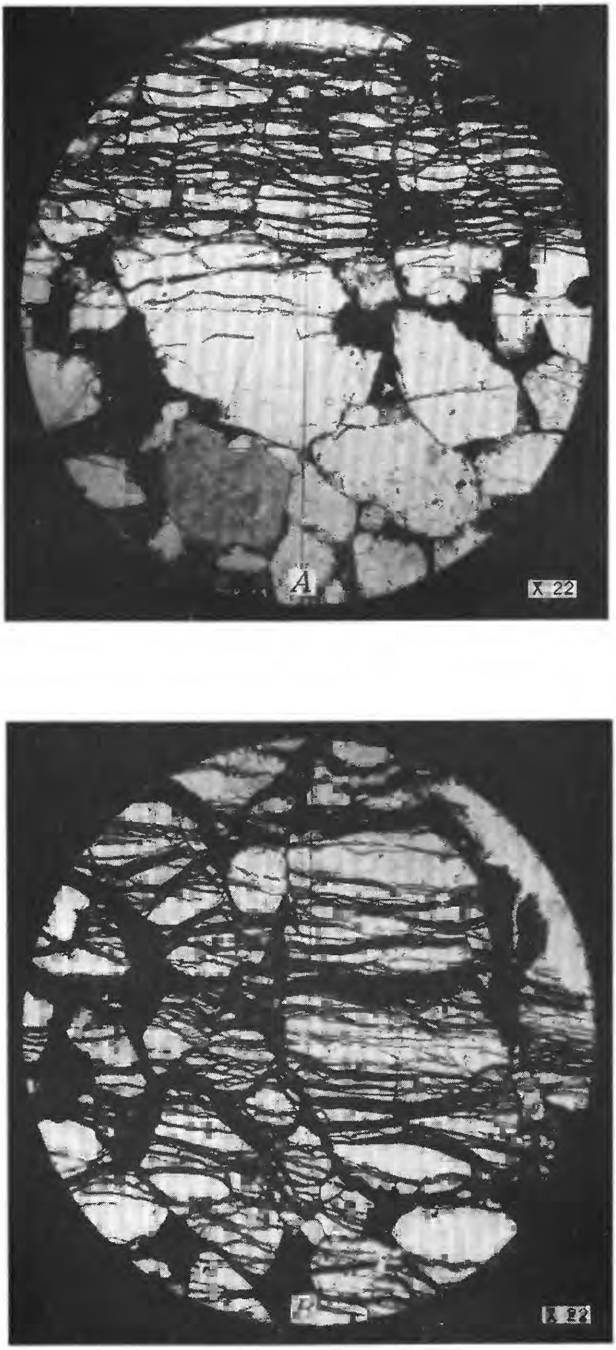

FIGURE 25.—Photomicrographs of thin sections of specimens collected in the Monument No. 2 mine; specimens contain secondary uranium and vanadium minerals in interstices and fractures. *A*, Rim of rod showing distinct boundary between fractured and unfractured grains. *B*, Rim of rod showing quartz grains broken by parallel set of fractures.

FIGURE 26.—Photomicrograph of thin section of specimen collected in the Monument No. 2 mine, showing irregular fractures of channel sediments about 1 foot away from rim of rod. Specimen contains secondary uranium and vanadium minerals in interstices and fractures.

the slide are whole (fig. 25). The separation between fractured and unfractured grains is a zone not more than 1 millimeter wide.

Two systems of fractures were noted: one consists of a set of parallel fractures (fig. 26) with a subsidiary set trending more or less at right angles; the other is a plexus of fractures that lacks orientation. Each fracture of the parallel set is as much as 1 millimeter away from adjacent fractures, and each fracture can be traced for as much as 10 to 15 millimeters in a relatively straight line as it continues uninterrupted through sand grains. In places this parallel set is cut by a subsidiary set that is at right angles to the main set. The subsidiary set offsets the main fractures slightly; but those fractures with no determinable pattern are less common. The fractures are jagged and end at the grain boundaries. The gross appearance of this fracture system is that of an interlacing network, devoid of orientation or system.

Filling the fractures, interstices, and other voids are secondary uranium and vanadium minerals, calcite, and authigenic quartz. The depositional sequence appears to be as follows: First, authigenic quartz; second, secondary uranium and vanadium minerals; and third, emplacement of calcite.

The circular pattern formed by the fractures as they outline the rods is distinctive and has been found only in the Monument No. 2 mine.

How these circular fracture patterns form and the reason why some grains are fractured whereas others only a few millimeters away are not fractured is unknown. One answer may involve factors of selective cementation. Perhaps those grains in the fractured zones were once tightly cemented. When stress was applied, possibly as a result of load, the cemented grains may have fractured, but the uncemented grains may have merely rolled and readjusted themselves to the forces applied.

Many of the rods were interpreted by me to represent replacement of coalified logs by silt, pyrite, and uraninite. Subsequent oxidation altered the pyrite to limonite, and the uraninite to becquerelite and carnotite. It was thought that the woody texture of these coalified logs is now reflected in the rims of the rods by these materials. To test this concept, six samples were sent to James M. Schopf of the Geological Survey. Five of the samples were collected from the rims of the rods, and the sixth was collected from silicified wood in the core of a rod. It was requested that he determine whether any of the samples represented replaced plant matter. In selecting the samples an effort was made to include a range from those that seemed to show woody texture to others that appeared to contain only rudimentary traces of former plant matter.

Of the six samples submitted, Schopf identified only one as replaced fossil wood, and that was the one collected from the core of the rod; the others contained no trace of organic matter. It appears, therefore, that although parts of some rods may represent replacement of some form of former plant matter, the mineralized rims of the rods do not show this phenomenon. The similar pattern between trends of rods and of silicified wood fragments (fig. 27), however, as well as the collinearity apparent between many of the rods and silicified remnants of logs, suggests that some relationship does exist between these former buried logs and the rods.

Possibly the shape, size, and distribution of the rods were determined by the buried logs. During or very shortly after burial the original organic matter of the buried logs may have been removed and other, more stable materials, such as sand, silt, and clay may have been deposited in the voids so formed. The removal of the organic matter and its subsequent replacement was probably a gradual process and affected only part of any log at any one time. It may have been during this episode that porosity and permeability conditions were changed; possibly this was sufficient to localize the ore solutions when they invaded the Shinarump conglomerate. Thus, those rods over which the bedding arches, as well as those that show abrupt changes in grain size between the confining strata and the rod boundaries, may merely represent the former presence of buried logs, which have since been replaced by sand, silt, and clay.

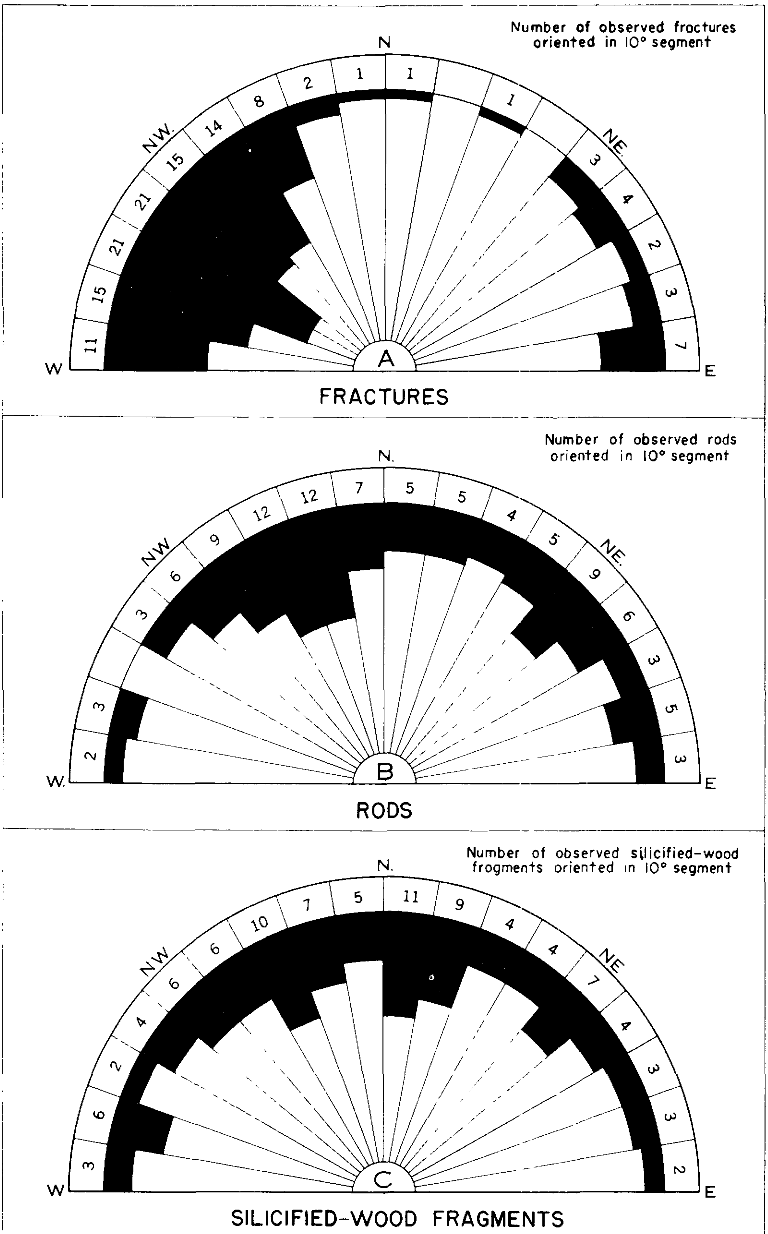

FIGURE 27.—Diagrams comparing orientation of fractures, rods, and silicified wood fragments in Monument No. 2 mine, Apache County.

Other rods may have formed from mineralizing solutions in response to halos of decomposition products, such as humic colloids and organic resins, spreading outward from buried coalified logs. Possible examples of this type are those rods that contain silicified wood at their centers.

Still another possibility is that the rods may be completely independent of plant matter and may merely reflect fracture patterns formed during processes of compaction and authigenic crystal growth.

Probably no single concept will explain how rods formed. Perhaps combinations of the processes mentioned above are involved. For instance, the shape, size, and distribution of the rods may have been determined by the presence of buried logs. During or shortly after the logs were buried, their rims may have been partly replaced by more stable materials. If at this time compaction and authigenic crystal growth began, fracturing may have occurred along the zones represented by the former edges of the logs. In the voids formed by this fracturing, the ore solutions may have deposited their minerals.

Although the rods constitute the richer concentrations of ore, considerable quantities of secondary yellow uranium minerals are found elsewhere and in different forms in channel sediments. Thus, in much of the conglomeratic sandstone exposed between rods, yellow uranium minerals fill interstices and coat pebbles and fractures. Although rods are not present in the De Chelly sandstone member, yellow uranium minerals coat cross-lamination planes, fill fractures, and also impregnate the sandstone. The concentration of uranium minerals in sediment between rods and in the De Chelly is low. These weakly mineralized localities are believed to represent secondary migration by percolating ground water. Most of the uranium minerals are thought to have been leached from the richer ore bodies represented by the rods, and then moved short distances both laterally and vertically before being deposited once again in the matrix of the sandstone.

Fischer (1947, p. 455), in discussing the vanadium deposits of the Colorado Plateau, implies that a close affinity may exist between vanadium deposits, channel sediments, and organic matter in the Morrison formation of Jurassic age. In a later report, still referring to the Morrison formation, Fischer and Hilpert (1952, p. 12) indicate that although fossil plants are erratically distributed most of the carnotite deposits are in parts of the sandstone that contain fairly abundant plant remains. From my observations in the Monument Valley area on the habits of uranium ore in the Shinarump conglomerate, I concur with Fischer and Hilpert and believe that a close spatial relationship exists between pockets of uranium ore, channel sediments. and former plant matter.

The channels, apparently, were places where plant matter was concentrated. Trees growing along the flanks of these channels may have fallen into them and then have been buried by the channel sediments. Other trees and organic material may have been rafted into the channels and buried. Subsequently, when mineralizing solutions moved through the Shinarump, favorable conditions of permeability and porosity resulting primarily from the former presence of buried logs may have been responsible for the formation of the rods.

Not all channels contain known uranium deposits even though they may contain organic matter. One possible explanation for the lack of ore in some channels is that ore may have been deposited but was later leached by ground water. The great length of long channels, for example, may have permitted accelerated movement of ground water solutions resulting in more effective leaching of ore. Conversely, leaching would have been less effective in the short channels. A final result would be ore accumulations in short channels and essentially barren strata in continuous channels.

SUMMARY

Six stages are proposed in the localization of uranium ore to achieve present conditions in Monument Valley, Ariz.: (1) Cutting of short and long channels prior to or during deposition of Shinarump sediments; (2) burial of plant matter (trees, branches, and twigs) in channels synchronously with deposition of Shinarump sediments; (3) some form of alteration of the plant matter resulting in unusual conditions favoring the precipitation of uranium minerals; (4) invasion of Shinarump sediments by mineralizing solutions; (5) precipitation and localization of uranium ore from these solutions primarily in localities formerly occupied by plant matter; and (6) leaching and movement of uranium minerals by ground water out of the continuous long channels, and retention of uranium minerals in the short channels.

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