Geology and Uranium Deposits of Monument Valley San Juan County, Utah

By RICHARD Q. LEWIS, SR., *and* DONALD E. TRIMBLE

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

GEOLOGICAL SURVEY BULLETIN 1087-D

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ABSTRACT

Exposed consolidated sedimentary rocks in the Monument Valley area, Utah, range from Permian to Jurassic in age and attain an aggregate thickness of more than 3,000 feet. As all the uranium-vanadium deposits in the area are restricted to the Shinarump member of the Chinle formation of Late Triassic age, this study was principally concerned with that unit.

The contact between the Shinarump member of the Chinle formation and the underlying Moenkopi formation is marked by a number of deep scour channels cut into the Moenkopi and filled with sandstone and conglomerate of the Shinarump. All the uranium-vanadium ore deposits are restricted to the lower channel sediments of the Shinarump. All channels are considered worthwhile areas for prospecting.

The ore deposits are small tabular to lenticular bodies that range from a few inches to 10 feet in thickness and are commonly less than 20 feet in width. The ore minerals replace the cementing material in the sandstone and coat fractures, joints, and bedding planes. The common uranium ore mineral is tyuyamunite. Uranophane, autunite, and uraninite are also present in important quantities. The common vanadium mineral is corvusite; navajoite and hewettite are found in lesser amounts. The deposits are zoned both laterally and vertically, with the higher grade vanadium ore generally below and downdip from the uranium. In general the deposits are oxidized or partly oxidized. Most of the ore is the yellow hydrous uranium vanadate; however, quantities of black unoxidized ore, containing uraninite and vanadium minerals with an intermediate valence are found in the deeper parts of some deposits.

Good guides to ore within channel sediments are high radioactivity, uranium, vanadium, and copper minerals, and fluorescent silica, commonly hyalite.

INTRODUCTION

The Monument Valley, Utah, area is in San Juan County, in the southeastern part of the State. (See fig. 10.) The area is bordered on the south by the Utah-Arizona State line and on the north by the San Juan River and lat 37°15′ N., and extends from long 110° W. to about 110°37′ W. It is 115 miles southwest of

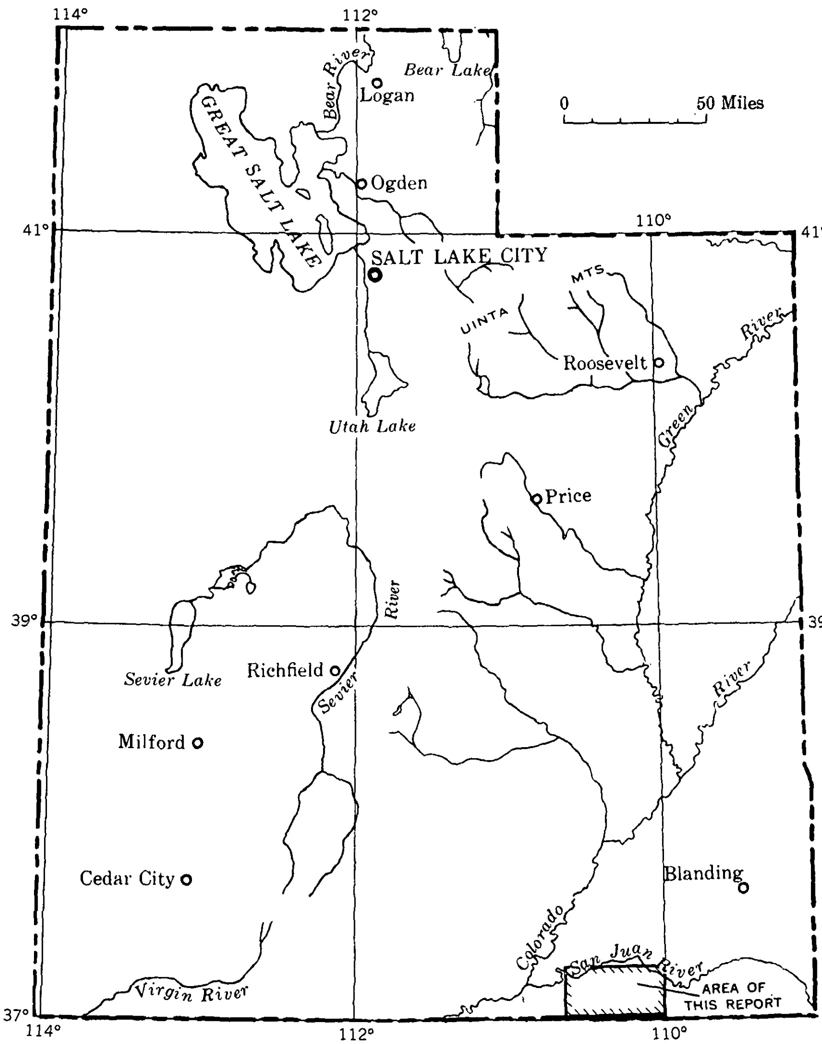

FIGURE 10.—Index map of Utah showing the Monument Valley area.

Monticello, Utah, via Utah State Highway 47, and about 25 miles north of Kayenta, Ariz. All roads in the area are unimproved and may be temporarily impassable because of local rainstorms or shifting sand.

The area is bordered on the south and west by high mesas. Within the area are many buttes, mesas, and spires, which are erosional remnants of the Permian, Triassic, and Jurassic rocks.

Because uranium minerals are known to occur in the Shinarump member of the Chinle formation close to its contact with the Moenkopi formation elsewhere on the Colorado Plateaus, a detailed study was made of this contact in Monument Valley, Utah, during the summer of 1952. Of the 200 miles of contact in the area, about half was accessible and was examined in detail visually and with Geiger counters.

The geologic map (pl. 10) shows in detail the stratigraphic units of Triassic age in part of the Monument Valley area, Utah. This area was mapped earlier by Baker (1936) as part of the oil and gas investigations of the U.S. Geological Survey. The increased interest in uranium and the discovery of significant deposits in the Shinarump member in Monument Valley, Ariz., made it desirable to reexamine part of the area. During the present investigation the Shinarump, the overlying Chinle, and the underlying Moenkopi were mapped.

During the fieldwork 37 channels were found on rim exposures of the Shinarump member. The location, size, and shape were noted and the probable trends of all channels were plotted on the field map. Samples were taken from 16 areas where uranium minerals were found or high radioactivity was noted. This investigation resulted in the discovery of one significant ore deposit which was subsequently drilled by the U.S. Atomic Energy Commission (Isachsen and Evensen, 1956, p. 264–269).

Topographic maps were not available at the time the fieldwork was done. The geologic data were plotted on aerial photographs in the field and then compiled on a planimetric base. The work was done by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

GENERAL GEOLOGY

Consolidated sedimentary rocks exposed in the Monument Valley area, Utah, range from Permian to Jurassic in age (fig. 11) and have a minimum aggregate thickness of more than 3,000 feet. Most of the rocks are red shale, siltstone, and fine-grained sandstone which were deeply eroded during Tertiary and Quaternary time. The best exposures are on the sides of the numerous buttes and mesas that rise above the general level of the valley.

STRATIGRAPHY

CUTLER FORMATION

The Cutler formation of Permian age crops out over most of the Monument Valley area, Utah, particularly in the area east of Copper Canyon. The total thickness of the Cutler within the area is not known because the base is not exposed. The Cutler has been divided into five easily identifiable units (Baker, 1936):

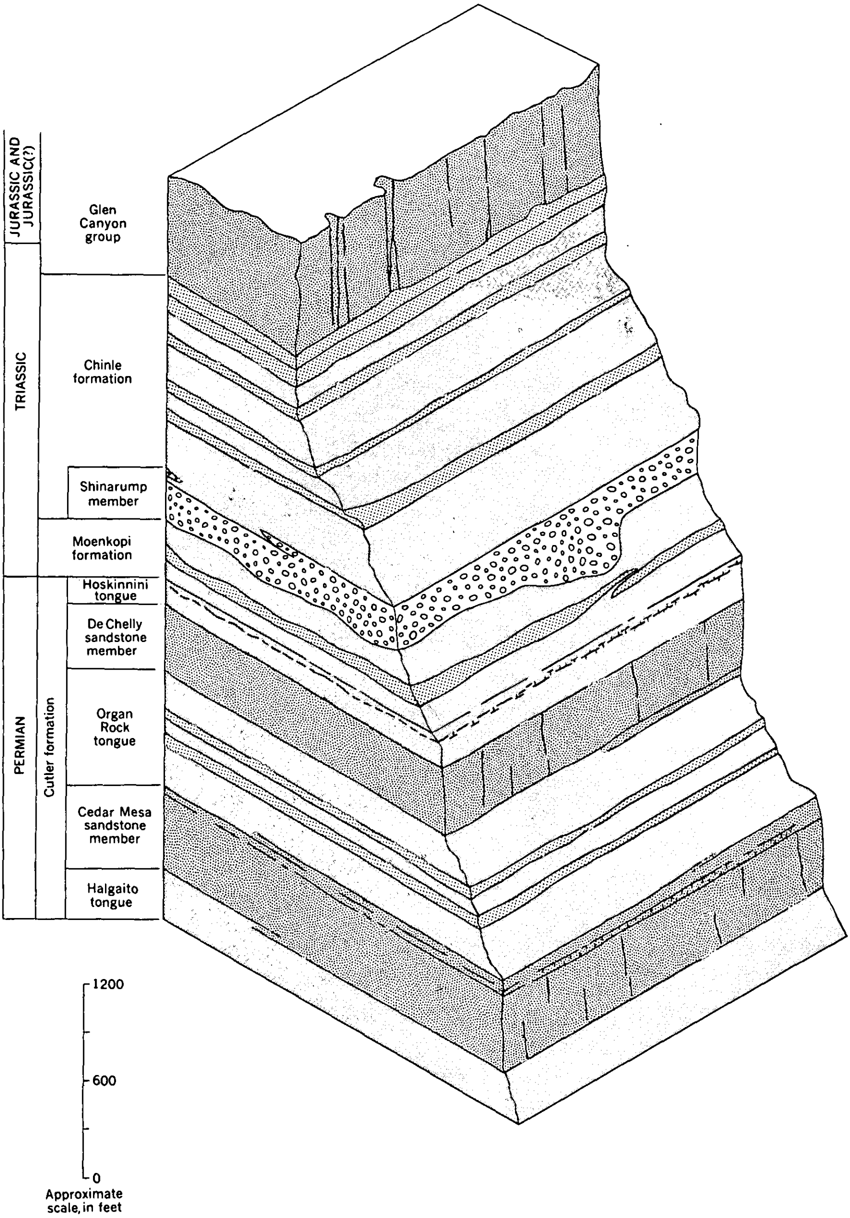

FIGURE 11.—Block diagram showing generalized geologic columnar section of the formations in the Monument Valley area, San Juan County, Utah.

the Halgaito tongue, Cedar Mesa sandstone member, Organ Rock tongue, DeChelly sandstone member, and Hoskinnini tongue.

The Halgaito tongue is red to brown silty sandstone and shale between 380 and 465 feet thick. The Cedar Mesa sandstone member is gray to brown festoon-crossbedded sandstone about 500 feet thick. The Organ Rock tongue attains a thickness of 696 feet (Baker, 1936, p. 34). It is a series of red sandy siltstone and shale.

The DeChelly sandstone member ranges from 0 to 450 feet in thickness. It thins northward and pinches out on Monitor Butte. It is a massive sandstone unit lithologically similar to the Cedar Mesa but generally red in color. The Hoskinnini tongue is composed mostly of red silty sandstone and ranges in thickness from 100 feet to a knife edge and pinches out east of Monument Pass (Baker, 1936, p. 39).

In the Monument Valley area, Utah, the Cutler formation is conformably overlain by the Moenkopi formation. However, a disconformity was observed in the White Canyon area, Utah, by Benson and others (1952, p. 8), and near Kayenta, Ariz., about 30 miles to the south, Baker (1936, p. 40) observed a similar relation.

MOENKOPI FORMATION

The Moenkopi formation of Early and Middle(?) Triassic age, the oldest Mesozoic rock in the region, forms a steep slope between the resistant Shinarump member of the Chinle formation, which caps most of the mesas, and the cliff-forming Hoskinnini tongue and DeChelly sandstone members of the Cutler formation, below. The Moenkopi underlies about 100 square miles in the western part of the area, but it is exposed only in the sides of the steep buttes and mesas (pl. 10). The Moenkopi ranges in thickness from about 80 feet in the eastern part of the area to about 300 feet in the lower part of Copper Canyon and Nakai Creek. The Moenkopi formation is composed chiefly of thin reddish-brown to chocolate-brown sandy shale beds. Thicker sections of Moenkopi in the western part of the region can be subdivided into three units: a lower shale unit of thin-bedded alternating sandy shale and fine sandstone, a middle unit of two or more massive sandstone beds, and an upper unit of alternating gray and brown shale and mudstone. Lateral gradation of the individual units makes boundaries between them indefinite; therefore, these units were not mapped separately (pl. 10).

A marked erosional unconformity separates the Moenkopi for-

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mation from the Shinarump member of the Chinle formation. The upper surface of the Moenkopi was deeply scoured and the depressions subsequently were filled with sediments of the Shinarump member.

The uppermost Moenkopi strata have been bleached in most places. The red beds have been altered to drab greenish gray. The zone of alteration is thicker in siltstone and mudstone, and thinner or absent in sandstone. In most places the bleached zone ranges from 3 to 5 feet in thickness and reaches a maximum thickness of nearly 7 feet. The zone is nearly parallel to the contact of the Shinarump member and Moenkopi formation, and either follows or crosscuts bedding. It bears no relation to sedimentary structures or lithologic changes in the Shinarump member and has no apparent relation to the presence or absence of uranium minerals in the Shinarump.

CHINLE FORMATION

Because of the importance of the known ore deposits in the Shinarump member of the Chinle formation in Monument Valley, the Shinarump member is described in considerable detail in this report. The remainder of the Chinle formation is described in less detail under the heading "Chinle Formation, Undifferentiated."

SHINARUMP MEMBER OF THE CHINLE FORMATION

Exposures of the Shinarump member of the Chinle formation form a rough semicircular outcrop pattern in Monument Valley, Utah. (See pl. 10.) The Shinarump caps most of the isolated buttes and mesas and is exposed over approximately 70 square miles on the tops of the larger mesas. The member is resistant to weathering and forms vertical cliffs above the steep Moenkopi slopes. The thickness of the member is not uniform. Baker (1936, p. 45) reports a maximum thickness of 210 feet on the south side of Monitor Butte. On the east side of Monitor Butte and west of Copper Canyon the characteristic sandstone and conglomerate beds are locally missing, and for short distances mudstone of the overlying Chinle units is in contact with bleached Moenkopi. A short distance north of the San Juan River the Shinarump occurs only as small isolated lenses (T. E. Mullens and H. A. Hubbard, written communication, 1952).

For the convenience of mapping, the contact between the Shinarump member and the undifferentiated Chinle on the accompanying geologic map (pl. 10) has been arbitrarily drawn at the base of the first prominent and continuous mudstone unit of the Chinle formation. This mudstone is the lowest unit in the Chinle above the Shinarump that can be consistently recognized. Thus the area shown as Shinarump on the map contains beds placed in the "Chinle D" by some workers (Gregory, 1917) and in the Monitor Butte member by others (I. J. Witkind, R. E. Thaden, and C. F. Lough, written communication, 1953).

The age of the Shinarump member is considered to be Late Triassic because of its gradational relation with the remainder of the Chinle formation, which contains Late Triassic fossils, and its unconformable relation with the Moenkopi formation. Two bone fragments collected from the Shinarump in Monument Valley, Utah, were identified by G. Edward Lewis of the U.S. Geological Survey and D. H. Dunkle of the U.S. National Museum. One bone was identified as a vertebral centrum belonging to the phytosaurs; another, as a cephalic plate of a labyrinthodont belonging to the family Metaposauridae; both indicate a Late Triassic age.

The Shinarump member is composed chiefly of crossbedded sandstone, with minor lenses of conglomerate, sandy siltstone, and mudstone. The sandstone is generally light gray, but locally is red to buff.

The sand grains are chiefly quartz and quartzite with lesser amounts of chert. Other minerals are rare and, in order of their abundance, consist of feldspar, zircon, tourmaline, and garnet. The presence of microcline feldspar and strain-shadowed quartz with sutured edges within individual grains suggests that much of the material probably was derived originally from metamorphic rocks.

Silica cement is the most common, but calcite is particularly abundant in the channel sediments. Most thin sections show that grains in the sandstone are tightly packed and that individual grains have sutured surfaces and overgrowths. Small fragments of sandstone indicate that some of the material is derived from older sediments.

The unconformable contact between the Shinarump member of the Chinle formation and the Moenkopi formation is a sharp lithologic break and can be easily seen in the field. It is marked by a number of deeply scoured channels. These scours were probably cut in the Moenkopi formation by the same streams that deposited the sediments of the Shinarump member.

The channels range in depth from 20 to 200 feet and in width from 40 to 2,000 feet. Figure 12 and table 1 show the general northwest trend, size, and mineralization of the channels. The

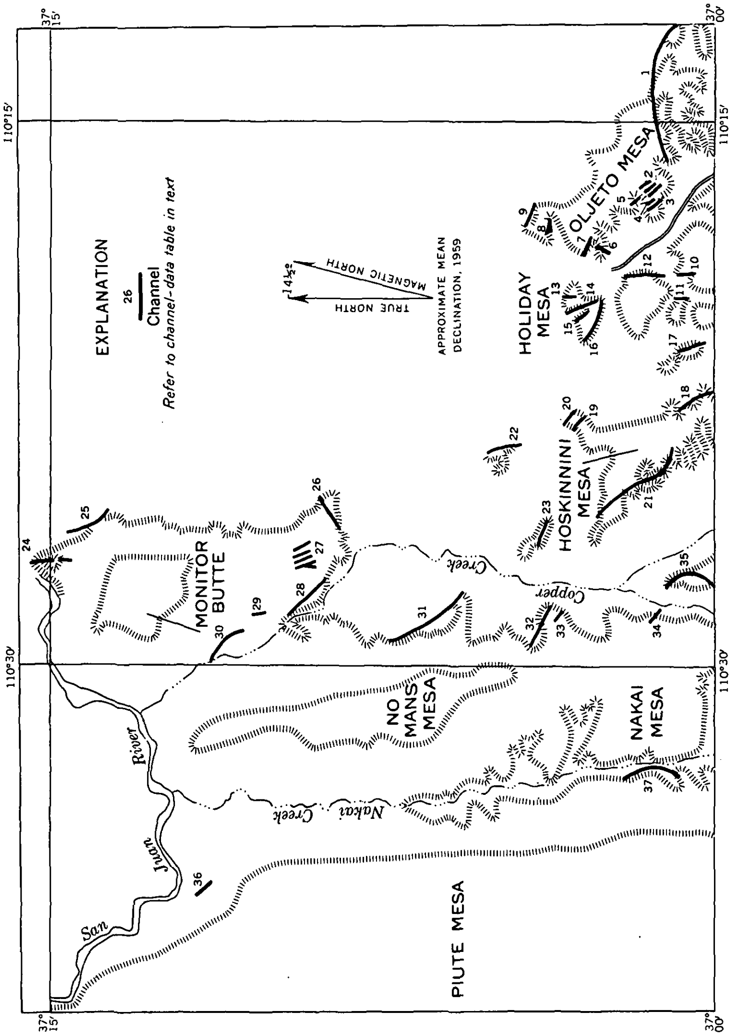


FIGURE 12.—Location of channels, Monument Valley, San Juan County, Utah.

general northwest trend is the same as that observed by I. J. Witkind, R. E. Thaden, and C. F. Lough (written communication, 1953) in Monument Valley, Ariz. Some of the channels are traceable for several miles (fig. 12), but most are represented only by 1 or 2 exposures on the mesa rims and their lineal extent and continuity have been inferred. In cross section the channels can be divided roughly into five types (fig. 13): symmetrical,

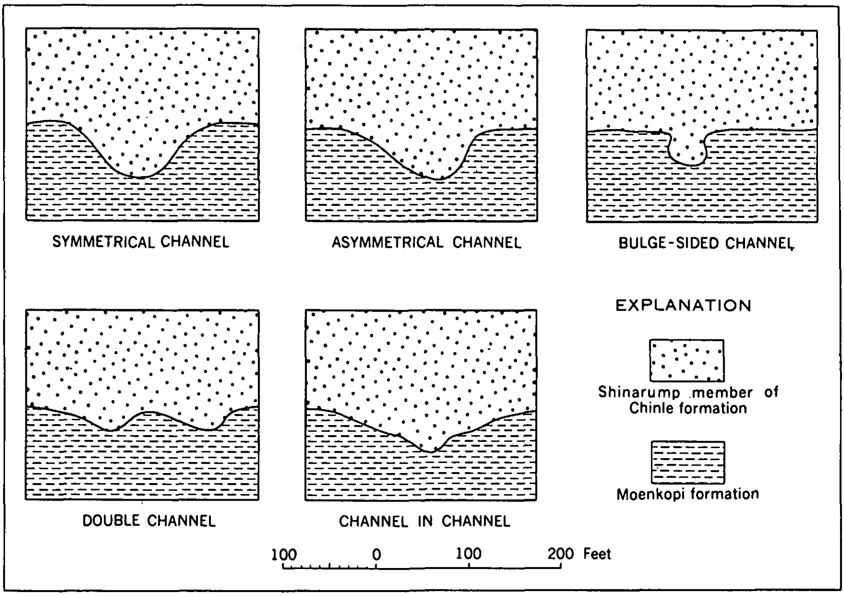


FIGURE 13.—Cross sections of five types of channels.

asymmetrical, channel within a channel, bulge sided, and double. In most places the channel terminations are not observable, but channel 31 (fig. 12) seems to broaden and become gradually shallower along its course and finally to grade into a group of shallow depressions on the contact.

Some of the channels in the area form geographic and, perhaps, genetic groups. These groups commonly consist of 1 or 2 large channels and a number of closely spaced smaller channels. Three such channel groups are known: one on Oljeto Mesa associated with the Skyline channel (pl. 11), one on Holiday Mesa (fig. 14), northwest of the Oljeto Trading Post, and one south of Monitor Butte. The trends of the channels and the associated sedimentary features indicate that they diverge to the northwest and possibly were distributaries of larger channels.

In general, the composition of the channel sediments of the

TABLE 1.—*Data on channels in Monument Valley, Utah*

Index No. (fig. 12)	Channel name or location	Depth (feet)	Width (feet)	Strike	Mineralization or radioactivity
1	Skyline	25–30	150	N. 55° W.–N. 70° E.	Uranium, copper, vanadium.
2	Oljeto complex	< 40	150	N. 25°–40° W.	Slight radioactivity.
3	Western part of Oljeto Mesa	30–40	200–300	N. 65° W.	No minerals.
4	do	20–25	100–200	N. 45° W.	Do.
5	do	30–40	200–300	N. 35° W.	Do.
6	Oljeto claim	105	500–600	N. 30° E.	Uranium, copper, vanadium.
7	Northwest Oljeto Mesa	25		N. 75° W.	Unknown [1].
8	Double	25	200–300	N. 75° W.	No minerals.
9	Claw	5–10	150	N. 70° W.	Do.
10	Mission Mesa	< 40	< 150	N.	Slight radioactivity.
11	T-Bone	20–30		N.	No minerals.
12	Copper Point	40	200–300	N. 10° W.	Uranium, copper.
13	Spur	< 40	< 150	N. 15° W.	No minerals.
14	Through Mesa	< 40	< 150	N. 20° W.	Do.
15	Short	< 40	< 150	N. 50° W.	Do.
16	Discovery	90	900	N. 70° W.	Uranium, copper.
17	Monument No. 3	50–60	400–500	N. 15° W.	Uranium, copper, vanadium.
18	East Hoskinnini	20		N.–NW.	No minerals.
19	North tip Hoskinnini	20–30		N. 25° W.	Unknown [1].
20	do	40–50	> 300	N. 40° W.	Uranium, copper, vanadium.
21	Hoskinnini large	[2] 250	2,000	Generally NW.	Uranium, copper.
22	Monument north	> 40	> 300	N. 25° W.	Unknown [1].
23	Monument northwest	> 40	> 300	N. 55° W.	Do.
24	Monitor north	10–12		N. 10° W.	No minerals.
25	Whirlwind	90	800	N. 20° W.	Uranium, copper, vanadium.
26	Monitor southeast	[2] 40		N. 55° E.	No minerals.
27	Complex of four	20–25	[3] 100–200	N. 25° W.	Do.
28	Monitor southwest	< 40	150–300	N. 45° W.	Do.
29	Spring	> 40	> 300	N. 40° W.	Do.
30	Copper Creek			N. 50° W.	Do.
31	West Wall	60–75		N. 20° W.	Do.
32	Horsetrail	[2] 200		N. 75° W.	Uranium, copper.
33	West Wall south	< 40	< 150	N. 50° W.	Unknown [1].
34	Alfred Miles extension	> 40	> 300	N. 70° W.	Do.
35	Alfred Miles	250	2,000	NE.–NW.	Copper.
36	River	75–100		N. 40° W.	No minerals.
37	Nakai	20–30		NE.–NW.	Unknown [1].

[1] Inaccessible. [2] Estimated. [3] Each channel.

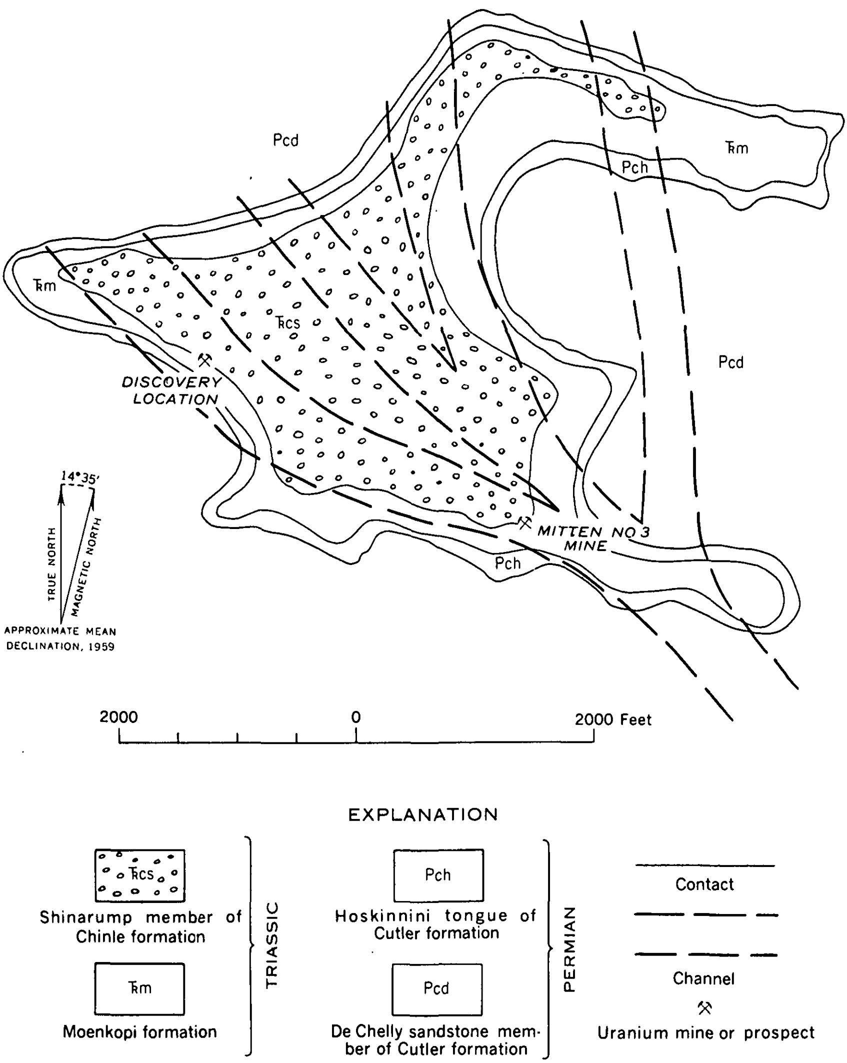


FIGURE 14.—Channel system in the Shinarump member of the Chinle formation on Holiday Mesa, Monument Valley area, San Juan County, Utah.

Shinarump member are similar to those outside the channels, though some minor differences were noted (table 2). Fragments of Moenkopi several feet long and up to 1 foot thick are common. These fragments of Moenkopi are found throughout the basal part of the Shinarump member but are more numerous and larger in the channel sediments, and they are particularly numerous in the sediments near the bottom of the channels. Sandstone in some channels appears to contain more calcite cement than sandstone of the Shinarump elsewhere. The large channel on the west side of Hoskinnini Mesa (fig. 12, no. 21), the southernmost channel on Holiday Mesa (fig. 14), and the Whirlwind channel (fig. 15) are particularly rich in calcite. Calcite, the

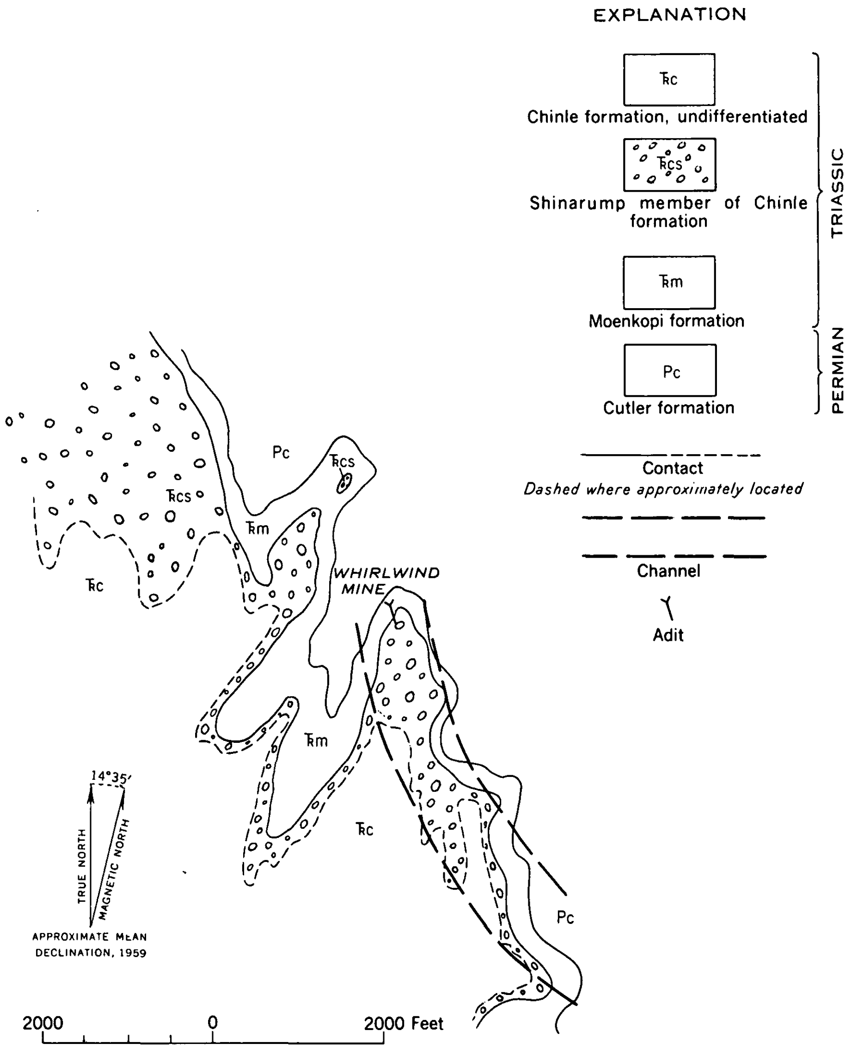


Figure 15.—Whirlwind channel in the Shinarump member of the Chinle formation on Monitor Butte, Monument Valley area, San Juan County, Utah.

dominant cement in these areas, has replaced the silica cement and also partly replaced the quartz grains in the sandstone (pl. 12). Carbonaceous and silicified wood is equally abundant both within and outside of the channel sediments.

TABLE 2.—*Semiquantative spectrographic analyses*[1] *of samples from Monument Valley, Utah*

[Trace, near threshold amount of element: O, not present in threshold amounts or higher. All analyses by the U.S. Geological Survey]

Mineral	Specimen		
	1	2	3
Si	XX.O	XX.	XX.
Al	XX.O	.X+	.OX
Fe	X.O−	.X+	.OX+
Ti	.X	.OX	.OOOX+
Mn	.OX−	.OX+	Trace
Ca	.X+	X.+	.X
Mg	X.O	.OX+	.X−
Na	.X+	.X−	O
K	X.O	.X+	O
B	.OOX+	O	O
Ba	.OX−	.OX−	.OOX
Be	Trace	O	O
Co	.OOX−	.OX−	.OOX−
Cr	.OX	.OOOX+	.OOOX−
Cu	.OOX	.OOX	.OOX−
Ga	.OOX	Trace	O
La	Trace	O	O
Mo	O	.OOX	.OOX−
Ni	.OOX	.OOX	O
Sc	.OOX	O	O
Sr	.OX−	.OOX+	Trace
Pb	.OOOX	.OOX	O
V	.OOX+	.OX−	.OOX
U	O	.OX+	.X−
Y	.OOX	O	O
Yb	.OOX	Trace	O
Zr	.OX−	.OOX−	O
Zn	O	O	.OX+

[1] The concentrations of the elements as determined by semiquantitative spectrographic analysis are bracketed into groups each of approximately one-third of an order of magnitude, X+ indicating the higher portion (10 to 5 percent), X the middle portion (5 to 2 percent), and X— the the lower portion (2 to 1 percent). Comparisons of this type of semiquantitative results with those obtained by quantitative methods, either chemical or spectrographic, show that the assigned group includes the quantitative value in about 60 percent of the analyses.

NOTE.—Looked for but not detected: P, Ag, As, Au, Bi, Cd, Ce, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, Li, Nb, Os, Pd, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Th, Tl, Te, W.

1. D–86984 Mudstone from lower portion of the Chinle formation, northeast side of Monitor Butte. Sec. 11, T. 41 S., R. 13 E. Analyst: G. W. Boyes, Jr.
2. D–81175 Shinarump member from sec. 15, T. 42 S., R. 14 E., 2 miles northwest of Oljeto Trading Post. Analyst: R. G. Havens.
3. 226707 Hyalite opal in sandstone from near the base of the Shinarump member of the Chinle formation about 10 feet from ore in the East workings of the Skyline mine, SW¼NW¼ sec. 26, T. 43 S., R. 15 E. Analyst: N. M. Conklin.

CHINLE FORMATION, UNDIFFERENTIATED

The undifferentiated part of the Chinle formation crops out in the western part of the area, where it forms steep slopes and badland topography. The undifferentiated Chinle is 825 feet thick on the north side of Monitor Butte and 925 feet thick at the north end of Piute Mesa (Baker, 1936, p. 47–48). The formation apparently thins north and west of Monument Valley. Vertebrate and invertebrate fossils in the Chinle show it to be of Late Triassic age (Gregory, 1917, p. 46–47; Camp, 1930, p. 4). Baker (1933, p. 41) found fossils that indicated fresh-water deposition.

This part of the Chinle is composed chiefly of variegated shale and mudstone with minor amounts of sandstone and limestone. In general, red sandstone is common in the upper part of the formation, limestone is common in the middle of the unit, and gray sandstone lenses are scattered throughout the lower part of the formation. The limestone beds are thin and discontinuous, commonly cherty, and in many places associated with mud-pellet and limestone pebble conglomerate. Several investigators have reported the presence of montmorillonite clay and volcanic ash in the Chinle of Utah and New Mexico (Waters and Granger, 1953).

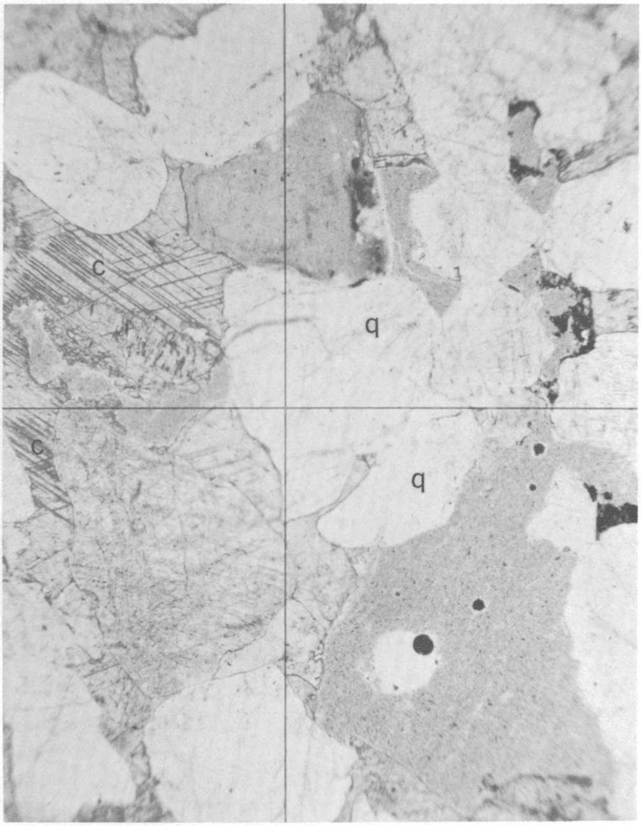
The Chinle represents a continuous unbroken sequence of deposition from the base of the Shinarump member to the contact with the overlying Wingate sandstone. The contact between the Chinle and the overlying Wingate in the Monument Valley area seems conformable; in other parts of the Colorado Plateau, Gregory (1917), Longwell and others (1925), and Gilluly (1929) report an unconformity between these units.

The lower mudstone units of the Chinle formation on Monitor Butte are more radioactive than other rocks in the region except for the Shinarump near known ore deposits. Readings as high as 0.2 milliroentgen per hour were recorded from outcrops along the Whirlwind mine road. A 4-foot channel sample taken from the mudstone assayed 0.002 percent U_3O_8.

GLEN CANYON GROUP

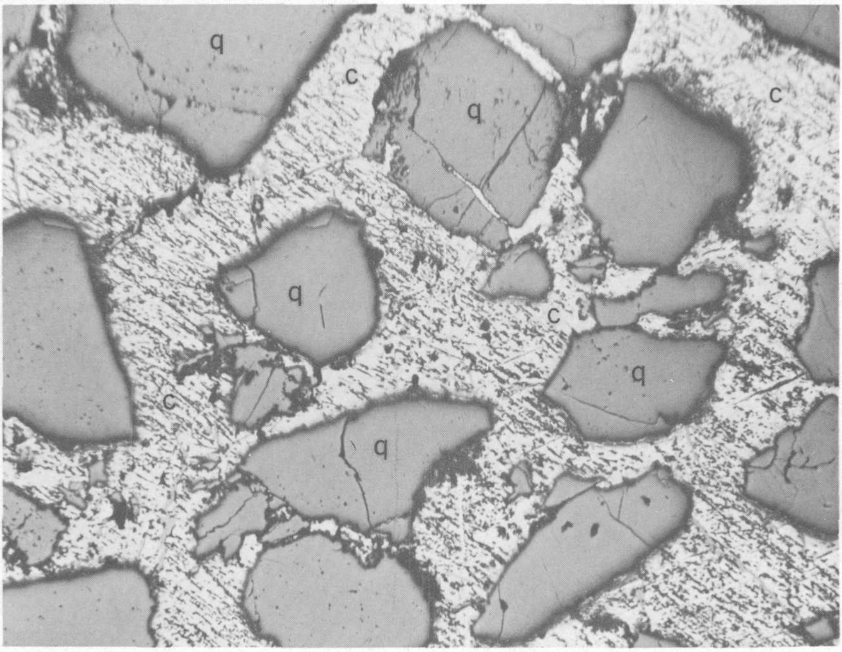
The Glen Canyon group, consisting of the Wingate sandstone (Upper Triassic), the Kayenta formation (Lower Jurassic?), and the Navajo sandstone (Jurassic and Jurassic?), was mapped as a unit. The Glen Canyon group caps Monitor Butte, No Mans Mesa, and Piute Mesa (pl. 10). Most of the Navajo sandstone has been removed by erosion, leaving the Kayenta covering most of the mesa tops above the vertical cliffs of the Wingate sandstone.

The Wingate sandstone is a massive festoon-crossbedded reddish-brown sandstone unit about 300 feet thick. The Kayenta formation is thick-bedded reddish-brown sandstone and shale about 250 feet thick. The Navajo sandstone is massive festoon-



PHOTOMICROGRAPH OF CALCITE REPLACEMENT IN THE SHINARUMP MEMBER OF THE CHINLE FORMATION

Calcite replacement typical of the lower channel sediments. The calcite (*c*) has completely replaced the original chalcedony cement and has partly replaced the quartz grains (*q*) of the sandstone. × 300 (approx).



PHOTOMICROGRAPH OF CHALCOCITE REPLACEMENT AT THE WHIRLWIND MINE

Chalcocite (*c*) has completely replaced the calcite cement and has partly replaced the quartz grains (*q*) of the sandstone. × 300 (approx).

crossbedded gray sandstone and was probably about 800 feet thick before erosion.

IGNEOUS ROCKS

One small igneous dike crops out on the south side of Oljeto Mesa about 2 miles southeast of the Oljeto Trading Post (pl. 10). It can be traced for about 800 feet from the valley floor to the top of Oljeto Mesa. It cuts the DeChelly sandstone member and Hoskinnini tongue of the Cutler formation of Permian age, the Moenkopi formation of Early and Middle(?) Triassic age, and the Shinarump member of the Chinle formation of Late Triassic age. Over the greater part of its outcrop the dike is about 15 feet wide. The contact with the country rock is sharp, and the adjacent sedimentary rocks are only slightly altered. Williams (1936, p. 133) described the dike as columnar minette, a potash-rich basaltic rock containing a mixture of potash feldspar and biotite associated with pyroxene and olivine.

The core of the dike is massive, black, and fresh, and near the margins the dike grades into somewhat altered gray and greenish-gray slabby rock. The dike reaches the present surface of Oljeto Mesa and spreads into a small mass of columns that are roughly fan shaped in cross section. The dike probably was intruded when the level of erosion was at the level of the present mesa surface, probably in the late Tertiary. Williams (1936, p. 148) regards the igneous rocks of the Monument Valley area as of probable Pliocene age.

STRUCTURE

The part of Monument Valley that was mapped is on the west flank of the northward-trending Monument upwarp, one of the major structural features of the Colorado Plateaus. The Monument upwarp is a broad regional anticline comparable to the Circle Cliffs (Waterpocket Fold) and the San Rafael Swell. It is asymmetrical, with the steeper dips on the east flank. The upwarp is modified by a number of superimposed northward-trending anticlines and synclines.

The normal faults shown on the map (pl. 10) trend generally eastward and displace the Triassic and Permian rock units 40 to 100 feet. They are probably tension faults associated with the southward plunging nose of the Monument upwarp.

All the rock units are strongly jointed. The joints in the thick sandstone units are best developed. Most of the joints plotted on the geologic map (pl. 10) were observed in outcrops of the Cedar Mesa and DeChelly sandstone members of the Cutler formation, the Shinarump member of the Chinle formation, and the Wingate sandstone. In general the joints form 2 well-developed seats, 1 of northwestward trend and 1 of northeastward trend. These 2 sets form a system oriented about 45° to the trend of the major fold axis of the region. All the joints noted were nearly vertical.

The pattern formed by the major folds and an observable northward-trending thrust fault, overthrust from the west, just north of the mapped area, suggests that the major folds were produced by strong compressional forces from the west. This supposition is strengthened by the strikes of the major joint system, which reflect shearing oblique to the direction of major stress. However, a second hypothesis, that the asymmetrical fold and associated joints are surface expressions of deep-seated faults in the crystalline basement rocks, is equally tenable.

URANIUM-VANADIUM DEPOSITS

Uranium ore has been found only within channel sediments of the Shinarump member. A careful check along many miles of the contact between the Shinarump member and the Moenkopi formation showed no abnormal radioactivity except at or near the bottom of channels. Uranium, vanadium, and copper minerals are usually restricted to the lower 3 feet of the channel sediments or to the Moenkopi formation at the bottom of the channels. The reason for this localization of ore deposition is not fully understood, but it is thought to be the result of the confinement of ground water to the channels at the time of ore deposition.

The uranium-vanadium deposits are tabular to lenticular bodies localized in basal channel sediments of the Shinarump member. In cross section the deposits are biconvex or planoconvex with a flat top and with the greatest thickness of ore near the deepest part of the channel. The margins of the ore bodies commonly pinch out abruptly against the flanks of the channel. Because the ore is restricted to the channel sediments of the Shinarump the trend of the deposits coincides with the trend of channels. The thickest and highest grade ore is commonly restricted to deep scours and irregularities in the channel bottoms.

All mineral deposits observed in the area are small. They range in thickness from a minimum of 1 to 2 inches to a maximum of 10 feet. Their linear extent has not been determined in most places, but drilling and mining operations have shown the deposits to be spotty and commonly less than 200 feet long. Barren ground separates adjacent deposits within the same channel.

Within the deposits uranium minerals are in small but high-grade pockets with lean, sparsely mineralized areas between.

The deposits consist of uranium, vanadium, and copper minerals disseminated throughout the rocks; distributed along bedding planes, fractures, and joints; or coating pebbles, clay galls, and carbonaceous material. In some of the deposits the ore minerals have replaced the cementing minerals (quartz and calcite) and have in part replaced the pebbles and sand grains of the sandstone. Ore is commonly restricted to conglomerate or to fractured or porous sandstone near the base of the unit.

MINERALOGY

The most common ore mineral is tyuyamunite, $Ca(UO_2)_2(VO_4)_2 \cdot 7\text{–}10\frac{1}{2}H_2O$, the yellow fine-grained hydrous calcium uranium vanadate. It occurs with lesser amounts of uranophane, $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$, autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$, and torbernite, $Cu(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$. Small amounts of uraninite, UO_2, UO_3, (identified by X-ray) have been found by the authors in the workings at the Mitten No. 1 mine and in drill core from Holiday Mesa. Uraninite is associated with corvusite, $V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$, and navajoite(?), $V_2O_5 \cdot 3H_2O$, in the Mitten No. 1 mine and with carbonaceous material on Holiday Mesa. Uraninite was also found in the Skyline mine (A. D. Weeks, oral communication), and calciovolborthite is common in the Whirlwind mine.

The uranium and vanadium minerals occur with copper minerals. Malachite, azurite, and chalcanthite are abundant in weathered exposures on the rim, and the copper sulfides, chalcocite, chalcopyrite, and bornite are common in the mines (pl. 13). In many places an apparent inverse quantitative relation exists between copper and uranium. For example, at the Quartz claim (pl. 10) on Hoskinnini Mesa, copper minerals impregnate basal sediments of a very large scour channel, but no uranium minerals have been found even though this type of environment is favorable elsewhere in Monument Valley for the deposition of uranium-vanadium ore. Conversely, copper is commonly less abundant in the higher grade uranium-vanadium deposits, as for example, in the Mitten No. 1 mine (pls. 10 and 11), the Skyline mine (pls. 10 and 11), and the Whirlwind mine (pl. 10 and fig. 15). This suggests that the copper and uranium and vanadium minerals may not be genetically related but prefer the same host rock. It is possible that the minerals were emplaced at different times and from different solutions.

The extensive leaching, movement, and redeposition of both the copper and the uranium and vanadium minerals obscure the relationship. Where the sequence of deposition can be determined, the secondary uranium minerals appear to be later than the sulfide copper minerals.

Fluorescent silica is commonly associated with the uranium-vanadium deposits in Monument Valley. The silica is commonly hyalite and less commonly chalcedony. Though hyalite is widespread in the area, only that near ore is strongly fluorescent. In general, fluorescence decreases in intensity as the distance from ore increases. Fluorescent silica is localized near the bottom or on the sides of the channels and also downdip from ore deposits on rim exposures. It coats pebbles and clay galls and fills openings along joints and fractures. Preliminary laboratory studies indicate that the fluorescence is due to small amounts of uranium in the silica. The intensity of fluorescence increases directly with the increase in uranium content, as shown in table 3.

TABLE 3.—*Fluorescent-silica samples from Utah and Arizona tested by quantitative chemical methods*

[Analyses by J. Howard McCarthy]

Sample	Location	Mine	Type or source	Distance from ore (feet)	Fluorescence	U(ppm)	Remarks
1	Holiday Mesa, Utah.	Discovery location.	Chalcedonite	50	Pale yellow green.	60–80	
2	Skyline channel, Utah.	Skyline mine	Hyalite	10	Bright green	800	
3	Monument No. 1 channel, Arizona.	Monument No. 1 mine.	do	30	do	100	Some other mineral may be present.
4	White Canyon area, Utah.	Fry No. 4 mine	Hyalite	24	do	200	
5	Monument Valley, Arizona.	Chaistla plug	Hyalite		Very pale yellow.	<20	Coating on fracture of igneous intrusive.
6	Capitol Reef, Utah.	Boulder Mountain.	Hyalite			8	Amygdules in igneous flow rock.

GENESIS

Several hypotheses to account for uranium deposits in different parts of the Colorado Plateau have been proposed: syngenetic deposition (Fischer, 1942, p. 389), deposition from migrating ground-water solutions that had gained their uranium content by leaching preexisting ore deposits or slightly uraniferous rocks (Waters and Granger, 1953, p. 21–22), and deposition from ascending hydrothermal solutions (Waters and Granger, 1953, p.

23). Any hypothesis of genesis or the uranium deposits in the Monument Valley region must account for several features of the deposits. These features include apparent age as determined from lead-uranium ratios, physical environment, mineralogic type, and mineralogic association.

The apparent age of these deposits on the basis of lead-uranium ratios is 60–70 million years (Stieff, Stern, and Milkey, 1953). This figure is nearly 100 million years less than the age of the host rock and, therefore, is not compatible with a syngenetic or approximately syngenetic origin of the uranium deposits. The age of the deposits in the Shinarump member is also in general accord with age determinations made for deposits in the Entrada sandstone (Late Jurassic) and the Morrison formation (Late Jurassic) in other areas on the Colorado Plateaus. The general accordance of ages of deposits so widely distributed in the geologic section, if correct, can best be explained by a geographically widespread, approximately contemporaneous, mineralization of a number of geologically favorable formations on the Colorado Plateaus. Such widespread mineralization within restricted time limits could be explained most readily by widespread hydrothermal activity.

The fact that all known deposits in Monument Valley, Utah, are in the lower part of sediments of the Shinarump member that fill scour channels suggests that the ore was emplaced by migrating water. Ground water moving through a partly filled aquifer might be expected to migrate toward depressions or basins in the surface over which it moves and to deposit ore in these depressions.

ZONING

In the Monument Valley area, Utah and Arizona, many of the uranium-vanadium ore deposits are zoned both laterally—between individual ore bodies in the same channel—and vertically—within individual deposits. The higher grade vanadium ore is concentrated in the lower parts of the deposits, with higher grade uranium ore above. Where more than one deposit occurs in the same channel, those down the dip of the channel contain more vanadium. Hess (1933, p. 464) reports similar zoning within deposits in the Morrison formation, with ore in the lower parts of a deposit having a higher vanadium content than ore in the higher parts, although at that time there were no deep workings and little was known of the unoxidized ore bodies.

The lateral zoning is best observed in the Skyline channel on

Oljeto Mesa (pls. 10 and 11), where the mine workings are in two separate ore bodies in the channel. The deposit at the Skyline mine is updip, and half a mile east of the Mitten No. 1 mine. The vanadium-uranium ratio for ore from the Skyline mine is about 0.25:1 and the vanadium-uranium ratio for ore from the Mitten No. 1 mine is about 2:1. This difference is reflected in the ore minerals found in the two mines. The common ore mineral at the Skyline mine is tyuyamunite, which is associated with lesser amounts of uranophane and autunite. No vanadium-bearing minerals other than tyuyamunite were noted. In contrast, the deposit at the Mitten No. 1 mine contains corvusite and tyuyamunite in association with navajoite(?) and vanadium-rich clay. In the deeper parts of the scours the ore is very dark, usually black or blue black.

In Monument Valley, Ariz., lateral zoning was observed at the Monument No. 1–Mitten No. 2 workings, and R. E. Thaden (oral communication) noted a similar zoning at the Monument No. 2 mine.

Most of the ore deposits of the Monument Valley are zoned vertically. The vanadium-uranium ratio of the ore in the deeper parts of the scour channels is larger than the vanadium-uranium ratio of overlying ore.

We believe that both types of zoning represent primary depositional features of the ore deposits rather than the result of some process of supergene enrichment. If the zoning resulted from the oxidation of material in the upper parts of an originally homogenous ore body, high-valent vanadium (V^{+5}) would be expected in the upper (oxidized) zone, and low-valent (V^{+4}) minerals would be expected in the lower (less oxidized) parts of the deposits. Indeed, these relations are found in Monument Valley and elsewhere in the Colorado Plateau and have been discussed by Alice D. Weeks (written communication) and R. M. Garrels (written communication, 1953). However, supergene enrichment is inadequate to explain an increase in the vanadium-uranium ratio in the lower parts of the deposits. The result should be an increase in uranium downward and a decrease upward, as uranium is generally more readily soluble than vanadium in alkaline oxidizing solutions (Alice D. Weeks, oral communication). This is the reverse of the relative positions of high vanadium-uranium ratios observed in the mines; therefore, some other process or processes are necessary to explain the zoning.

It is assumed from the presence of vanadium minerals with values of $+3$ and $+4$, uraninite, and sulfide minerals associated with carbonaceous material, that the deposits were formed in a reducing environment. If this assumption is correct, then uranium, which is less soluble under acid reducing conditions, would be deposited before the vanadium from a solution containing both uranium and vanadium. If it is assumed that ore solutions were moving downdip in the channels it is reasonable to expect that the uranium would be deposited first, updip from the vanadium. This fits well with the distribution of the low-valent uranium and vanadium minerals in the mine. It is then assumed that the deposits were brought into the zone of oxidation by erosion. Under alkaline oxidizing conditions the uranium minerals are in general more readily soluble than the vanadium minerals. Under these conditions the uranium could become remobilized and move downdip along the bottoms of channels, transgressing the vanadium-rich pockets deposited downdip in the primary deposits. This process would account for the distribution of the uranium and vanadium as it is now observed in the deposits.

ORE GUIDES

Many guides to ore have been suggested by various writers. In general these guides can be divided into three categories: sedimentary, structural, and mineralogic. A list of many of the ore guides is given below. The presence of uranium and vanadium minerals and radioactivity are well established guides to uranium ore and need no further discussion here. Of the remaining guides listed, only those considered most important in the Monument Valley area, Utah, are discussed in detail. Those guides that the authors believe are outstanding for the area are in italic.

Sedimentary guides:
- *Channels*
- *Potholes within channels*
- Channel bends (change in direction)
- Galls
- Carbonaceous material
- Conglomerate lenses
- Friable sandstone
- Fossil wood
- Crossbedded sandstone
- Lenticular sandstone
- Mudstone splits

Mineralogic guides:
- *Uranium and vanadium minerals*
- *Radioactivity*
- *Fluorescent silica*
- *Copper minerals*

Mineralogic guides—Continued
- Jarosite
- Pyrite
- Iron oxide
- Thick bleached zone in Moenkopi

Structural guides:
- Synclines
- Anticlines
- Faults and joints cutting channels
- Faults and joints on flanks of anticlines
- Broad swales in the Moenkopi (areas of thinner deposition)

CHANNELS

Scour channels cut into the top of the Moenkopi and filled with sediments of the Shinarump member are an important guide to ore. All known ore is in channels. Although some channels may be barren, any channel is a potential site for ore deposition and is worthy of some exploration. During the past few years most of the obvious channels have been prospected where they are exposed on the mesa rims; however, little drilling has been done outside of the Oljeto area and there are still many linear miles of unexplored channels.

FLUORESCENT SILICA

Fluorescent silica containing small quantities of uranium has been found adjacent to many of the uranium-vanadium ore bodies in the area. The silica usually fills fractures or coats pebbles. Under ultraviolet light the silica fluoresces with the green to yellowish-green color typical of uranium minerals. Under white light the silica is white to yellowish brown.

The presence of fluorescent silica on a channel outcrop or in a drill core may be evidence of the presence of uranium ore in the vicinity and may help to evaluate the favorability of the channels for the occurrence of uranium.

POTHOLES WITHIN CHANNELS

Potholes in the base of channels are common sites for the localization of ore. This has been well established by mining in the area. The higher grade ore at both the Skyline mine and the Mitten No. 1 has been found in deep potholes at the bottom of the channel. Any exploratory drifts or drilling should be directed toward the location of the deeper parts of the channels.

COPPER MINERALS

The presence of copper minerals is usually a good guide to ore in Monument Valley. In all the deposits examined the uranium and vanadium minerals are associated with copper minerals, but in some places copper minerals are found where there is no known uranium or vanadium. The value of this guide is the ease with which copper minerals can be seen on weathered outcrops or located by geochemical prospecting.

SUGGESTIONS TO PROSPECTORS

The locations of the mines and prospects in the Monument Valley area, Utah, suggest that the channels of intermediate size, 60–100 feet deep and about 300 feet wide, are more favorable for the occurrence of ore deposits than the extremely large channels or the smaller ones, and that the area around Oljeto and to the south along the Oljeto syncline is probably more favorable for prospecting than Hoskinnini Mesa and adjacent areas to the west.

All the ore deposits are in channels filled with sediments of the Shinarump member, and any channel may be regarded as a potential ore-bearing area. Careful examination of exposed channels should be made and the guides to ore, listed previously, evaluated. The presence of uranium minerals, high radioactivity, or fluorescent silica may well indicate ore behind the rim exposures.

Drill cores and cuttings should be carefully examined for radioactivity, uranium minerals, copper minerals, and fluorescent silica, and lithologic changes should be noted. Care should be taken to obtain reliable collar elevations of all holes, and the depth to the Moenkopi contact should be established. Any sudden decrease in the elevation of the contact may indicate a depression or deeper scour, many of which are known to contain ore deposits.

SELECTED BIBLIOGRAPHY

Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U.S. Geol. Survey Bull. 841, 95 p.

——— 1936, Geology of the Monument Valley–Navajo Mountain region, San Juan County, Utah: U.S. Geol. Survey Bull. 865, 106 p.

——— 1946, Geology of the Green River Desert–Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U.S. Geol. Survey Bull. 951, 122 p.

Baker, A. A., Dane, C. H., and Reeside, J. B , Jr., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geol. Survey Prof. Paper 183.

Baker, A. A., Dobbin, C. E., McKnight, E. T., and Reeside, J. B., Jr., 1927, Notes on the stratigraphy of the Moab region, Utah: Am. Assoc. Petroleum Geologists Bull., v. 11, p. 785–808.

Baker, A. A., and Reeside, J. B., Jr., 1929, Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 1413–1448.

Baker, A. A., and Williams, J. S., 1940, Permian in parts of Rocky Mountains and Colorado Plateau regions: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 617–635.

Benson, W. E., Trites, A. F., Jr., Beroni, E. P., and Feeger, J. A., 1952, Preliminary report on the White Canyon area, San Juan County, Utah: U.S. Geol. Survey Circ. 217.

Camp, C. L., 1930, A study of the phytosaurs with a description of new material from western North America: California Univ. Mem., v. 10, 174 p.

Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U.S. Geol. Survey Bull. 863, 184 p.

Fischer, R. P., 1942, Vanadium deposits of Colorado and Utah, a preliminary report: U.S. Geol. Survey Bull. 936–P, p. 363–394.

Garrels, R. M., 1953, Some thermodynamic relations among the vanadium oxides, and their relation to the oxidation state of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 38, p. 1251–1265.

Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U.S. Geol. Survey Bull. 806–C, p. 69–130.

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U.S. Geol. Survey Prof. Paper 150–D, p. 61–110.

Gregory, H. E., 1916, The Navajo country, a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Water-Supply Paper 380, 219 p.

——— 1917, Geology of the Navajo country, a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 93, 161 p.

——— 1938, The San Juan country, a geographic and geologic reconnaissance of southeastern Utah: U.S. Geol. Survey Prof. Paper 188, 123 p.

——— 1950, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, 200 p.

Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits region, a geographic reconnaissance of parts of Utah and Arizona: U.S. Geol. Survey Prof. Paper 164, 161 p.

Harshbarger, J. W., and Repenning, C. A., 1954, Water resources of the Chuska Mountain area, Navajo Indian Reservation, Arizona and New Mexico: U.S. Geol. Survey Circ. 308, 16 p.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geol. Survey Prof. Paper 291.

Harshbarger, J. W., Repenning, C. A., and Jackson, R. L., 1951, Jurassic stratigraphy of the Navajo country, *in* New Mexico Geological Society Guidebook of the south and west sides of the San Juan basin, New Mexico and Arizona: New Mexico Geol. Soc., p. 95–99.

Hess, F. L., 1933, Uranium, vanadium, radium, gold, silver, and molybdenum sedimentary deposits, in Ore deposits of the Western States (Lindgren volume): New York, Am. Inst. Mining Metall. Engineers, p. 450–481.

Isachsen, Y. W., and Evensen, C. G., 1956, Geology of uranium deposits of the Shinarump and Chinle formations on the Colorado Plateau, *in* Page, L. R., Stocking, H. E., and Smith, H. B., Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 263–280.

Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, 1925, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U.S. Geol. Survey Prof. Paper 132–A, p. 1–23.

McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U.S. Geol. Survey Bull. 908, 147 p.

Miser, H. D., 1924, The San Juan Canyon, southeastern Utah, a geographic and hydrographic reconnaissance: U.S. Geol. Survey Water-Supply Paper 538, 80 p.

——— 1925a, Geologic structure of San Juan Canyon and adjacent country, Utah: U.S. Geol. Survey Bull. 751–D, p. 115–155.

——— 1925b, Erosion in San Juan Canyon, Utah: Geol. Soc. America Bull., v. 36, p. 365–377.

Reeside, J. B., Jr., and Bassler, Harvey, 1921, Stratigraphic section in southwestern Utah and northwestern Arizona: U.S. Geol. Survey Prof. Paper 129–D, p. 53–77.

Stieff, L. R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some uranium ores of the Colorado Plateaus by the lead-uranium method: U.S. Geol. Survey Circ. 271, 19 p.

Waters, A. C., and Granger, H. C., 1953, Volcanic debris is uraniferous sandstones, and its possible bearing on the origin and precipitation of uranium: U.S. Geol. Survey Circ. 224, 26 p.

Williams, Howel, 1936, Pliocene volcanoes in the Navajo-Hopi country: Geol. Soc. America Bull., v. 47, p. 111–172.

Woodruff, E. G., 1912, Geology of the San Juan oil field, Utah: U.S. Geol. Survey Bull. 471, p. 76–104.

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