



The uranium deposits of northeastern Arizona

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1973, pp. 139-149. <https://doi.org/10.56577/FFC-24.139>

in:

Monument Valley (Arizona, Utah and New Mexico), James, H. L.; [ed.], New Mexico Geological Society 24th Annual Fall Field Conference Guidebook, 232 p. <https://doi.org/10.56577/FFC-24>

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THE URANIUM DEPOSITS OF NORTHEASTERN ARIZONA*

by

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INTRODUCTION

In northeastern Arizona and adjacent areas in Utah and New Mexico significant amounts of uranium have been produced from deposits in the Chinle and Morrison formations. Minor deposits occur in the Bidahochi, Kayenta, Moenkopi and Toreva formations. A total of 14,017,000 pounds of U_3O_8 has been produced to date. Although this is only a fraction of the total U.S. production, the Chinle here represents approximately 13 percent. Production from the Morrison Formation in northeastern Arizona, and the adjacent area in New Mexico, is restricted to the Salt Wash Member and represents approximately 5 percent.

All of the mines, with the exception of those in the Winslow-Holbrook-St. Johns area and those near Black Point in the Cameron area, are on the Navajo Indian Reservation. On the reservation, mining permits and leases are granted by the Navajo Tribal Council at Window Rock, Arizona. Uranium mining has provided the tribe with significant income from royalties and rentals, as well as employment for the members of the tribe. At the present time, the area is inactive and there are no leases in effect on the reservation in northeastern Arizona and adjacent areas.

DEPOSITS IN THE CHINLE FORMATION

Exposures of the Chinle Formation in northeastern Arizona occur in Monument Valley on the Monument uplift, along the west and south flanks of the Black Mesa basin, and on the Defiance uplift on the east side of the basin. In Monument Valley, the formation is composed of five members which, in ascending order, are: the Shinarump, Monitor Butte, Petrified Forest, Owl Rock and Church Rock. Uranium deposits in northeastern Arizona occur in the Shinarump and Petrified Forest members and in an equivalent of the Monitor Butte Member.

Shinarump Member—The Shinarump consists of fluvial sediments which were deposited in stream channels and flood plains. These sediments are composed of lenticular beds of sandstone, conglomerate, siltstone and mudstone; they contain abundant fragments of carbonized wood and minor amounts of silicified wood. This resistant unit generally forms a broad bench and in Monument Valley it caps mesas and buttes. The sandstone is commonly light tan to light gray in color, cross-stratified, medium- to coarse-grained and usually conglomeratic at the base. The conglomerate is composed of well-rounded to sub-angular pebbles and cobbles of quartzite, quartz, chert with some limestone, sandstone, siltstone and

mudstone. Calcite is the most common cementing material in the sandstone and conglomerate. Mudstone in the member consists of lenses varying in color from pale red to greenish gray. The thickness of the member varies greatly as it fills valleys and scours eroded into the underlying rocks. In Monument Valley, the thickness of the Shinarump ranges from approximately 10 feet to nearly 250 feet.

The recognition of Shinarump channels and channel patterns is important, because all of the significant uranium deposits in Monument Valley are located in these features.

Monitor Butte Member—The Monitor Butte intertongues with the Shinarump and consists of red to greenish-gray mudstone and siltstone with some light brown to gray, very fine- to coarse-grained sandstone. The member ranges in thickness from 50 to 200 feet. Lateral equivalents of the Monitor Butte in northeastern Arizona include the sandstone and mudstone member, the lower red member, and the Mesa Redondo Member (Stewart and others, 1972). Minor uranium deposits in the Cameron area occur in the sandstone and mudstone member.

Petrified Forest Member—Overlying and gradational with the Monitor Butte and its correlatives is the Petrified Forest Member. The lower part of the member is comprised of blue, gray and white mudstone and tuffaceous siltstone. Lenticular sandstones are present in the lower part of the member in the Cameron area. The upper part of the member consists of grayish red, pale reddish-brown, and pale reddish-purple mudstone, siltstone and sandy siltstone. In the eastern part of the Black Mesa basin the Sonsela Sandstone Bed separates the two parts of the member. The Petrified Forest Member ranges in thickness from 500 to 1,200 feet in northeastern Arizona.

Monument Valley Area

The Monument Valley area is in the southern portion of the Monument upwarp where erosion has dissected a high tableland. The name of the mining area is derived from Monument Valley where erosion of massive eolian sandstones has produced spectacular monolithic landforms. Here, the Shinarump Member of the Chinle Formation crops out around the perimeter of the uplift and also caps mesas within Monument Valley (fig. 1).

A brightly-colored outcrop of uranium-vanadium minerals, which was to become the Monument No. 2 mine, was brought to the attention of the Vanadium Corporation of America, who leased the area in August, 1942. This discovery resulted in additional prospecting which found other exposures in the central part of the area. Although some vanadium ore was produced during 1942-1944, significant production did not begin until 1948 when uranium became important. In the late 1940s and early 1950s, many deposits, small to medium in size were discovered in paleochannel exposures at rim outcrops. In

*Publication authorized by the Atomic Energy Commission.

The authors wish to acknowledge the assistance of Benny Bowyer and Luther Smith for critically reviewing the paper and the help of Betty Learned for compiling the production statistics.

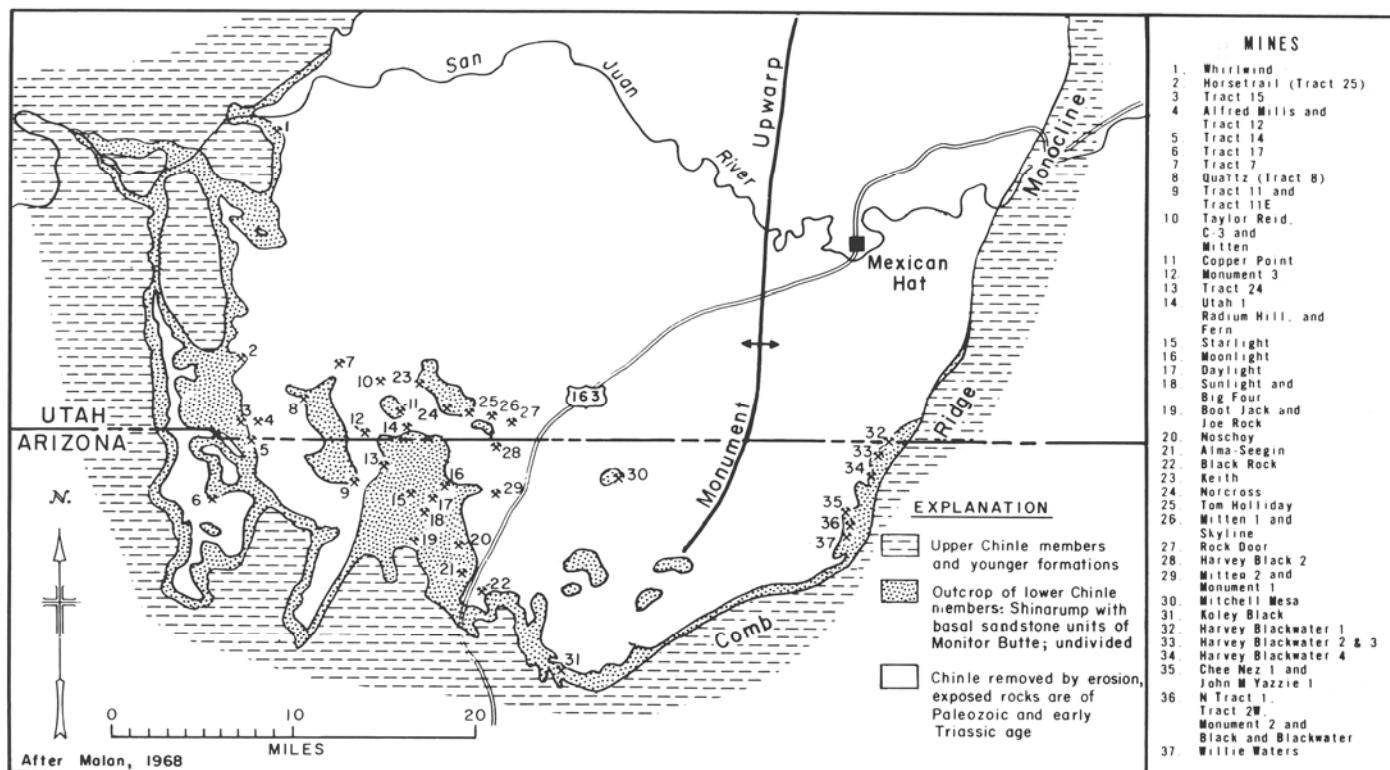


Figure 1. Mine locations: Monument Valley, Navajo and Apache counties, Arizona, and San Juan County, Utah.

1955 and 1956, a cluster of important deposits including the Moonlight mine was discovered in buried channels at moderate depths in the central portion of Monument Valley. Production in Monument Valley reached a peak in 1955, when 14 mines were operating, and gradually declined until the last shipment was recorded in late 1969. During this period, a total of 1,362,000 tons averaging 0.32 percent U_3O_8 and containing 8,730,000 pounds U_3O_8 were produced from 53 properties. Vanadium which was recovered from 97 percent of this production averaged 0.94 percent V_2O_5 and aggregated 24,780,000 pounds V_2O_5 . Most of the ore that was produced from the Monument No. 2 mine was beneficiated in an up-grader located at the mine site.

Shallow deposits at or near an outcrop were mined by adit or open pit, depending on the size of the deposit. Deeper deposits up to the economic limit of about 600 feet were developed and mined by shafts or inclines. At the Monument No. 2 mine, which produced more than half of the total production from the district, most ore was mined by open-pit methods.

The uranium deposits of Monument Valley have been studied by many geologists; more recent reports include those by Witkind and Thaden (1963), Young (1964) and Malan (1968).

As used in this paper, Shinarump channels are the courses of paleostreams which were incised into the underlying Moen kopi Formation and which were filled with fluvial sediments. Scours are the discontinuous, stream-incised, cut-and-fill components within the channels. These scours developed at stages during the lateral shifting of the main stream channel. Sediments in scours in the lower portions of channels are the hosts for the uranium deposits. Channels in Monument Valley are U-shaped in cross section, contain mainly sandstone and con-

glomerate, are quite narrow, and commonly contain only one ore-bearing scour. Not all scours in paleochannels contain uranium mineralization. Uranium deposits are primarily restricted to favorable carbonaceous sandstone and conglomerate beds in the lower part of the Shinarump Member of the Chinle Formation; however, in a few mines ore extends downward as much as 15 feet into underlying beds.

Ore bodies consist of closely-shaped, lenticular ore pods which are generally concordant with bedding. Single ore pods range from a few feet to a few hundred feet in length and from less than one foot to 12 feet in thickness. As viewed in plan, more ore deposits are linear. The ratio of length to width is commonly 5 to 1 and may reach 50 to 1. Deposits range in size from a few tons to approximately 800,000 tons of ore. About half of the deposits are smaller than 1,000 tons in size and all but two are smaller than 50,000 tons.

The deposits contain variable amounts of copper and vanadium. Ores from the Monument No. 2 mine contained an average of 1.40 percent V_2O_5 and little or no copper. In the other deposits for which some data are available, vanadium ranges from 0.22 percent to 0.81 percent and copper ranges from 0.29 percent to 2.50 percent; weighted averages are 0.60 percent V_2O_5 and 0.71 percent copper. These averages are not representative, because they are based solely on production from mines for which the vanadium and copper content was recorded. In general, the vanadium content of ores decreases from east to west, but copper increases from east to west.

In the unoxidized parts of the Monument No. 2 mine, uraninite and coffinite are associated with vanadium minerals such as montroseite, corvusite, doloresite and vanadium hydromica. Sulfides of iron, copper and lead are also present. Oxidized ore

minerals from this mine are tyuyamunite, carnotite, hewettite and navajosite. All of these minerals are associated with oxides of iron. In other mines in Monument Valley, the suite of unoxidized minerals is the same as that at the Monument No. 2 mine, but copper sulfide minerals are more abundant, and montroseite is less abundant. The uranium minerals, torbernite, uranophane, uranopilite, betazippite and johannite have been identified in samples from oxidized deposits. Malachite, azurite and hydrous copper and iron sulfates are common accessory minerals.

Calcium carbonate is present in ore mostly as cementing material in the sandstone host rock. In Monument Valley mines, calcium carbonate ranges from 1.4 percent to 10.3 percent and averages 4.6 percent. Calcium carbonate content generally is inversely proportional to vanadium content but it does not correlate with copper.

Cameron Area

The Cameron area is on the southwest flank of the Black Mesa basin. Here, the Chinle Formation crops out in a broad belt nearly parallel to the Little Colorado River. The main mining area forms a curved belt approximately 2 miles wide extending 6 miles north of Cameron along U.S. Highways 89 and 164, and 5 miles wide extending 18 miles southeast along the Little Colorado River (fig. 2). However, several additional deposits occur outside this area. The principal host rock in the area is the Petrified Forest Member. Underlying the Petrified Forest Member is the sandstone and mudstone member. The sandstone and mudstone unit has been included in the Shinarump by Akers and others (1962); however, recent mapping by the USGS in the Black Point area identifies this unit as a separate member (D. V. Haines, personal communication, 1970). Uranium deposits previously reported as occurring in the Shinarump are actually located in the sandstone and mudstone member.

Uranium was first reported in the Cameron area in 1950 in the Kayenta Formation of Early J urassic(?) age. As a result of the discovery, the AEC employed Navajos to prospect the entire area. The first discovery of commercial importance was made by Charlie Huskon, an AEC prospector, in the Petrified Forest Member of the Chinle Formation in early 1952. Surface prospecting supplemented by airborne radiometric surveying led to the discovery of additional ore bodies in 1953. As the area developed, many deposits having no surface expression were located by shallow exploration drilling. Initial production from the area was in late 1950 from the Hosteen Nez property in the Kayenta Formation. Production reached a peak in 1957 and gradually declined until the last shipment which was recorded in January 1963. During that period a total of 289,300 tons averaging 0.21 percent U_3O_8 and containing 1,211,800 pounds U_3O_8 were produced from 98 separate properties. Mining has been by open pits ranging in size from small shallow trenches containing a single mineralized fossil log to a large pit complex 2,400 feet long and 250 feet wide. Underground mining from the walls of the pits to recover additional ore was a common practice. Four vertical shafts were also used in the area.

The deposits have been described by Hinkley (1957), Bollin and Kerr (1958) and Chenoweth (in Akers et al., 1962). Chenoweth and Magleby (1971) prepared a map showing the location and relative sizes of the deposits, and Austin (1964) has described the mineralogy of the deposits. Sixty-seven

deposits, that occur in the lower part of the Petrified Forest Member, have yielded 1,177,500 pounds U_3O_8 or 97 percent of the area's total production. The ore occurs within elongated, lenticular deposits of poorly consolidated, cross-stratified, fine- to medium-grained sandstone, clay-pellet sandstone and clay-pellet conglomerate which contain varying amounts of carbonaceous matter, including carbonaceous fossil logs. The sandstone lenses were deposited in irregular depressions cut into bentonitic claystones and mudstones and are probable ancient fluvial channel fills. The maximum observed thickness of the lenses is approximately 35 feet; the average thickness is approximately 20 feet. The continuity of the sandstone lenses is poor, but individual lenses have been traced for more than a mile. Ore consists chiefly of secondary uranium minerals filling pore spaces in sandstone and in places uraniferous fossil logs. The ore tends to occur in abrupt depressions along channels or at changes in a channel's direction, and favors the more carbonaceous layers. Ore bodies are usually elongated parallel to the trend of the channels, but some ore bodies are oriented nearly normal to the sedimentary trends. Each ore body is encased in an alteration halo consisting of bleached sandstone and mudstone. Ore bodies and halos terminate abruptly downward against impervious mudstone. The most visible bleaching effect is a change from gray or occasionally red to yellowish or buff.

Ore bodies occur from the surface to a depth of 130 feet. As many as three ore zones may be present in 100 feet of section. Individual ore bodies range in size from a single mineralized fossil log to the Jack Daniels ore body, the largest known in the area, which was a nearly continuous body 450 by 300 feet containing 178,000 pounds U_3O_8 . By comparison, the second largest deposit is the Charles Huskon 4-Paul Huskie-3 from which was produced 135,600 pounds U_3O_8 from a cluster of ore pods occurring in an area 1,000 by 550 feet. The most productive area is east of Cameron where 10 properties, within one square mile, have been the source of 264,100 pounds or 22 percent of the total production.

Twenty-seven deposits in the sandstone and mudstone member occur with carbonaceous material in a thin-bedded, cross-stratified, medium- to fine-grained sandstone in the upper 30 feet of the member. Uranium-bearing fossil logs are common. The largest deposit in this member is Huskon-11 from which 6,600 pounds U_3O_8 were produced. The three small deposits in the Kayenta Formation occur in fine-grained sandstone lenses in the middle part of the formation. Total production from the Kayenta Formation in the Cameron area is 550 pounds U_3O_8 .

The Riverview mine occurs in a breccia pipe located within the Moenkopi Formation. Blocks of sandstone lithologically similar to sandstone in the Shinarump Member of the Chinle Formation fill the top of the pipe, and uranium minerals occur in these sandstone blocks, as well as in a siltstone and mudstone breccia, derived from the Moenkopi (Chenoweth and Blakemore, 1961).

A characteristic feature of the Cameron ores is their complex mineralogy. Uraninite is present in the unoxidized zone and also occurs in and near unoxidized logs in the oxidized zone in association with pyrite and marcasite. Oxidation has produced a complex suite of uranium oxides, sulfates, silicates, phosphates, carbonates, molybdates and rare vanadates (Austin, 1964). The yellowish-gray alteration associated with all deposits at or near the surface has been used as a

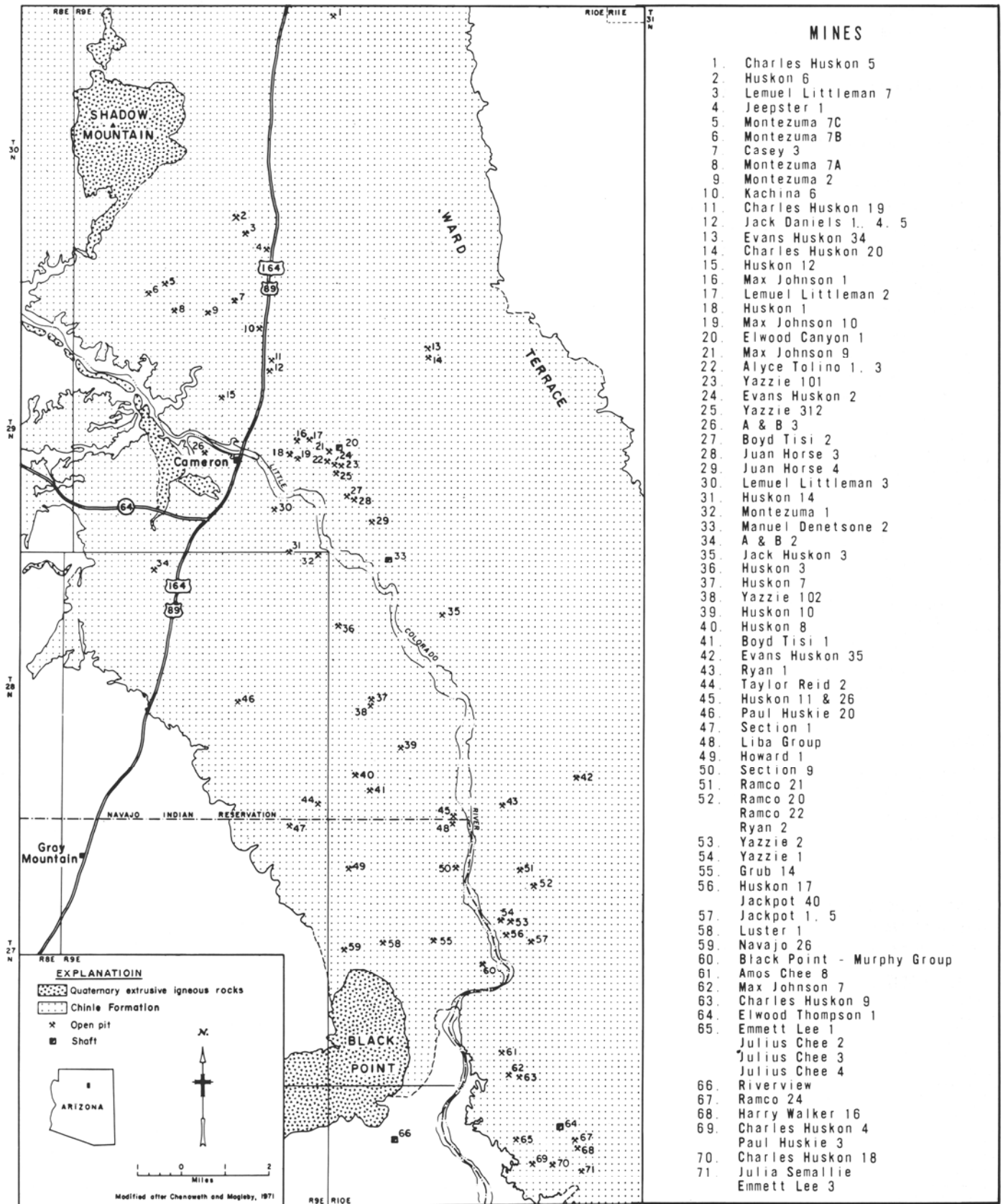


Figure 2.
 Mine locations: Cameron area, Coconino County, Arizona.

ing guide. According to Austin (1964) this so-called bleaching is chiefly due to oxidation products of sulfides but some actual bleaching of the clay has occurred.

Winslow-Holbrook-St. Johns Area

Deposits similar to those near Cameron occur in the upper Little Colorado River drainage from near St. Johns, Arizona, to the vicinity of Winslow, Arizona (table 1). The deposits, which are generally smaller than those at Cameron, occur in sandstone lenses in the lower part and in the Sonsela Sandstone Bed of the Petrified Forest Member.

Many of the deposits were located in the early 1950s by prospectors who were exploring exposures of the Chinle which was known to be productive elsewhere. Over two dozen uranium-bearing outcrops were located. During the period 1953 to 1960, 20 properties (table 1) produced 2,690 tons grading 0.15 percent U_3O_8 and containing 8,020 pounds U_3O_8 . Mining methods used have included shallow open pits and trenches, rim cuts and short underground adits. The most productive area is east of Holbrook in the SE1/4 T. 18 N., R. 23 E. and NE1/4, T. 17 N., R. 23 E., where seven properties produced 1,400 tons containing 0.21 percent U_3O_8 and 0.20 percent V_2O_5 . Of this total, 86 percent came from the Ruth claims.

The uranium deposits occur in sandstone lenses that are generally less than 200 feet wide and 10 feet thick. Some of these lenses have been traced for a distance of nearly one-half mile. Within the sandstone lenses, uranium is nearly always associated with carbonaceous plant material, often in the form of fossil logs. Uranium minerals identified from the Ruth claims include metatorbernite, metazeunerite, uraninite and coffinite (Gruner and others, 1954), and schroekingite, zippeite and autunite (Gregg and Moore, 1955).

Chinle Area

Uranium occurs in the Shinarump Member at the Zhealy Tso property, 6 miles northeast of Chinle, Arizona, adjacent to Canyon de Chelly National Monument. At four locations in the NW1/4, 5 N., R. 9 W., secondary yellow uranium minerals

have been observed in association with copper carbonates and carbonaceous plant debris in sandstone lenses in the upper part of the Shinarump. Exploration drilling during the middle 1950s, however, failed to locate any commercial ore.

DEPOSITS IN THE MORRISON FORMATION

Exposures of the Morrison Formation in northeastern Arizona occur on the north and east sides of Black Mesa, on the periphery and within the Carrizo Mountains and in the Lukachukai Mountains. The formation is composed of four members. In ascending order, they are the Salt Wash, Recapture, Westwater Canyon and Brushy Basin. Major uranium deposits are restricted to the Salt Wash Member.

Salt Wash Member—The Salt Wash consists of sandstone with lesser amounts of claystone and siltstone, which form resistant ledges, steep cliffs and cap broad benches and mesas. The sandstones are fine- to very fine-grained, well sorted, with rounded to subrounded grains of predominantly quartz with some chert and feldspar. Colors of the sandstone vary from pale gray to greenish gray to light pink. These lenses are generally gently cross-stratified and obscurely interfinger with flat, even-bedded flaggy layers, some of which are ripple-marked. A few steeply cross-stratified, laminated or platy, medium-grained beds occur locally. Lenses of sandstone are generally between 10 and 40 feet thick. The sandstone is generally friable with interstitial clay. Locally the sandstone is very competent because of secondary calcite cement. Calcareous layers are common in or near ore deposits but are not confined to them.

The siltstone and claystone separating the sandstone lenses constitute between 5 to 50 percent of the member and are distributed throughout the member. They occur as, (1) galls dispersed through the sandstone, (2) thin partings and contorted bands up to 3 inches thick, and (3) beds up to several feet thick. The claystone and siltstone vary in color from gray to greenish gray to reddish brown. There are no continuous siltstone and claystone layers as they pinch, swell, split and coalesce along bedding.

Thin beds of hard, blocky limestone occur within the Salt Wash Member and probably represent a lacustrine environment. Fossil logs and carbonaceous plant debris are common throughout the member. Fragmental particles and flakes of carbon form seams along the bedding and finer particles are disseminated throughout the sandstone.

The Salt Wash Member ranges in thickness from zero to approximately 220 feet. In the uranium areas it is usually at least 180 feet thick. North of the Carrizo Mountains the Salt Wash Member is absent. To the south, it cannot be recognized south of Sanostee, New Mexico, and on the east side of Black Mesa it is absent north of Rough Rock. According to Craig and others (1955), the Salt Wash was deposited by an aggrading, braided system on a massive alluvial fan system, the apex of which was near where the Colorado River now enters Arizona. Easterly and southeasterly sedimentary trends in the Carrizo and Lukachukai mountains substantiate this concept. However, since the Salt Wash is absent by non-deposition both to the north and south, it appears that the member of northeastern Arizona represents a separate lobe of the main fan which is farther to the north. This lobe of Salt Wash contains significant uranium deposits in the Carrizo and Lukachukai mountains.

Table 1.

Mine locations: Winslow-Holbrook-St. Johns area, Navajo and Apache counties, Arizona.

PROPERTY NAME	LOCATION			
	SECTION		T. (N)	R. (E)
Winslow 7	S 1/2, NE, NW	32	20	17
Navajo	S 1/2, SW, NW	26	20	23
J. City 1	S 1/2, NW, SW	33	19	19
Sain	NE, NW, SW	24	19	20
Rock Garden 25	E 1/2, SE, SW	22	19	23
Hansen 1	E 1/2, SW	1	18	19
Kay Group	N 1/2, SE, NW	28	18	23
NMA Lease (Sec. 33)	SW, SE, SE	33	18	23
Juanita 3	S 1/2, NW, SE	14	18	25
Ruth 1	SW, NW, NW	2	17	23
Ruth 4	NW, NW, NW	2	17	23
Mac 3	NW, SW, SW	4	17	23
Sunrise	NE, SW, NW	4	17	23
Little John 2	SE, NW, NE	12	17	23
Rainbow Smith 1 & 2	NE, SE	36	16	22
Sharon Lynn	SW, SW	34	16	23
Chester 25	SW, SW, SW	26	15	25
NSM 2	SW, SW	34	15	26
Warhoop 1	SW, NE, SW	30	13	29
G & C 1	S 1/2, NW, NE	18	12	29

Lukachukai Mountains

The Lukachukai Mountains are the northwest spur of the Chuska Mountains and are on the northern tip of the Defiance uplift. Lukachukai Pass on the road between Red Rock and Lukachukai, Arizona, forms a separation from the main Chuska range. A flat-topped ridge with an elevation of approximately 8,800 feet forms the main mountain mass. Finger-like mesas and deep, steep-walled canyons form rugged topography on the perimeter of the mountains. Except where they join the Chuskas, the Lukachukais terminate as precipitous cliffs.

The finger-like mesas were named and numbered as such by AEC personnel in late 1950. The prominent mesas on the north side of the mountains are numbered I through VII toward their northwest terminus at Mexican Cry Mesa. The southside mesas bear such descriptive names as Two Prong, Camp, Cisco, Three Point, Knife Edge, Bare Rock, Flag, Step, Fall Down, Navajo Chair and Thirsty. In general, the mines are named for the mesas on which they occur and hence such minor divisions as Mesas 1^{1/2}, 1^{3/4}, 11^{1/2} and 1V^{1/2} do occur on the north side (fig. 3). Access to the mines is by a system of unimproved roads leading from Cove, Arizona.

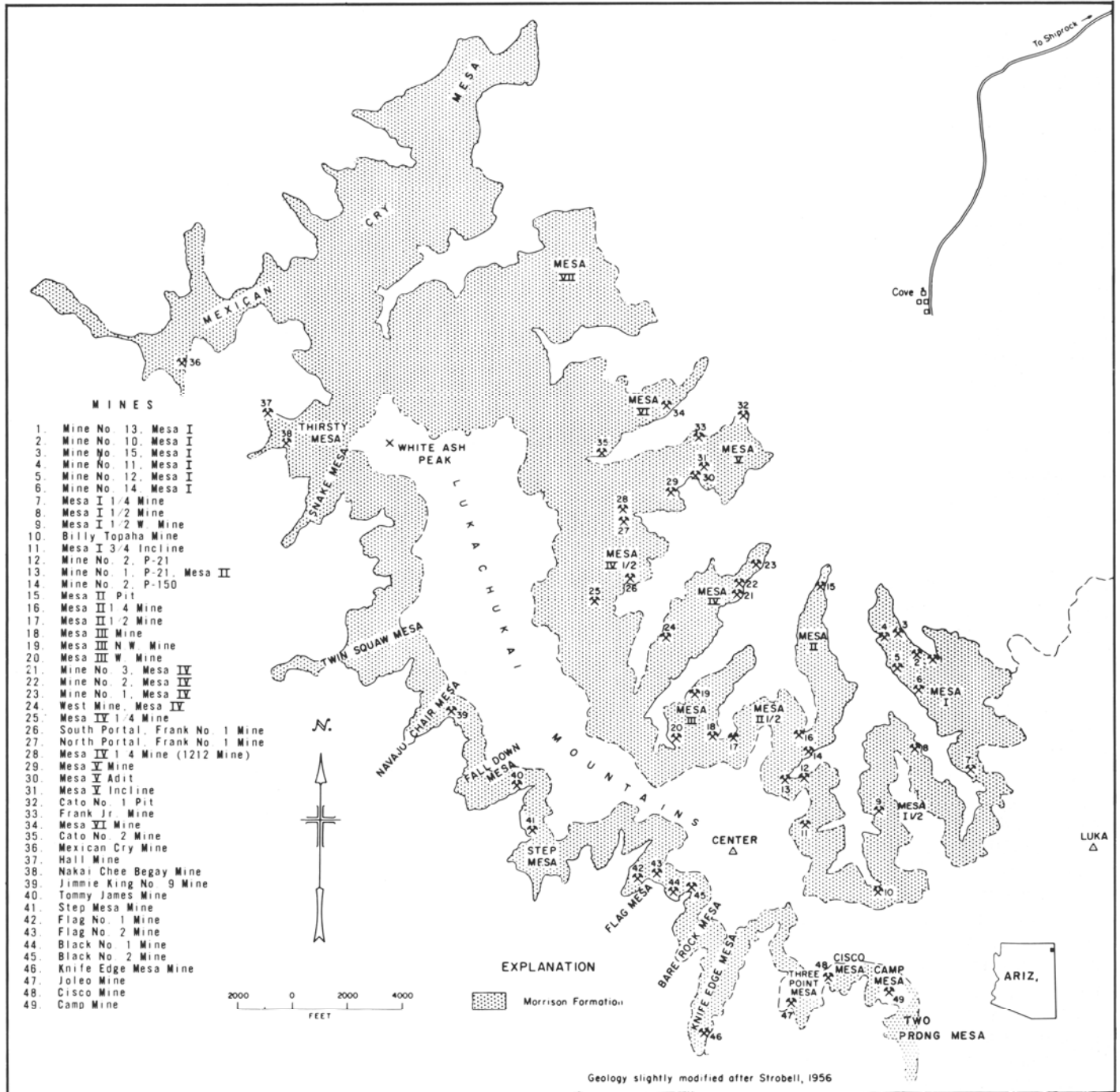


Figure 3.
Mine locations: Lukachukai Mountains, Apache County, Arizona.

Uranium-bearing outcrops in the vicinity of Mesa I were brought to the attention of prospectors from Colorado by local Navajos in 1949. An access road was built up Mesa I and production began in early 1950. In September, 1950, the AEC began the first drilling project which was followed by five others that continued intermittently to August, 1955. During this time, mine operators expanded exploration and development activities, and production increased steadily. Production reached its peak in 1960 and began to decline slowly until the last shipment was recorded in May, 1968. During these 19 years, some 50 separate mines produced 724,800 tons of ore grading 0.24 percent U_3O_8 and 1.02 percent V_2O_5 and containing 3,483,300 pounds U_3O_8 and 14,730,100 pounds V_2O_5 . Although some shallow or exposed ore bodies in the mountains have been successfully mined by stripping and open-pit methods, most ore bodies are mined underground by the room and pillar method, or modifications of it.

The ore bodies have been described by Nestler and Chenoweth (1958) and Chenoweth (1967). Paleodrainage patterns of the Salt Wash Member streams have been described by Stokes (1954). Dare (1959 and 1961) reported on two operations and gives an excellent review of the problems and costs.

The mountains are capped by the Chuska Sandstone of early Tertiary age which unconformably overlies a wedge of the Morrison Formation. The Salt Wash Member crops out continuously around the mountains. East of Mesa I and south of Two Prong Mesa, it has been removed by pre-Chuska erosion. In all, only 12.5 square miles of the mountains are underlain by this member of the Morrison.

Ore bodies occur some 30 to 80 feet above the base of the Salt Wash which is roughly the middle half of the member. All of the significant deposits are located in a well-defined belt which trends nearly north-south across the southeast end of the mountains (Chenoweth, 1969). This belt accounts for 99.6 percent of the total production and includes an area of 6.5 square miles. The ore bodies are elongate and horizontally lenticular in shape and consist of one or more ore pods surrounded or separated by protore. The composite length of ore bodies consisting of two or more ore pods separated by protore ranges up to 1,100 feet; individual ore pods range up to 350 feet in length. The length is usually at least three times the width and is parallel to paleostream depositional trends measured in and near the ore bodies. Thicknesses of the ore bodies range from 1 to 22 feet. Claystone and/or siltstone beds nearly always underlie and frequently overlie the host sandstone units.

Ore occurs most commonly in trough-type, cross-stratified sandstone which fills scours and channels in the underlying claystone. Lithofacies maps and mine mapping by Nestler and Chenoweth (1958) show that ore bodies are restricted to areas of rapid lateral color change which in general are also areas of rapid change in the ratio of mudstone to sandstone. It is common for the elongation of ore pods to deviate from the paleostream depositional trend and parallel the prominent joint set. This feature suggests some redistribution of the ore.

One of the most striking ore trends in the mountains is the trend from the Mesa III mine through the Mesa I PA mine to the north ore bodies of the Mesa II (P-21) mine. Striking N. 25° W. and extending for 4,200 feet with a width of 200 to 400 feet, this trend was the source of approximately 180,000 tons averaging 0.24 percent U_3O_8 and 1.08 percent V_2O_5 . The ore bodies occurred in a 25 to 30-foot thick sandstone lense, the base of which is approximately 50 feet above the Salt

Wash-Bluff contact.

Tyuyamunite, the calcium uranium vanadate, is the most common ore mineral. It occurs irregularly disseminated, concentrated in lenses, or distributed in bands. It may fill the sand interstices, or only coat sand grains, or it may replace calcite and carbon. Other vanadium minerals include corvusite, pascoite, hewettite, metarossite, vanadium clays and possibly montroseite (S. R. Austin, personal communication, 1967). In addition, Gruner and others (1954) identified the vanadium minerals melanovanadite and hummerite. Laverty and Gross (1956) identified uraninite as replacing carbonaceous material and as a cement in some ore bodies that are not completely oxidized. Calcite is the usual cementing agent in the ore bodies. Pyrite and iron oxides are present.

Carrizo Mountains

The Carrizo Mountains are in extreme northeastern Arizona on the northeast margin of the Black Mesa basin. The mountains are an irregularly-shaped intrusive mass composed of a central stock and several sills of light-gray diorite porphyry that have been injected laterally into the surrounding sedimentary rocks. The mountains are about 13 miles in diameter and rise 2,000 to 3,000 feet above the surrounding plain. Pastora Peak, elevation 9,420 feet, is the highest point in the Carrizos. Access to the mining areas is by a network of unimproved dirt roads that crisscross the area surrounding the mountains.

The uranium-bearing vanadium deposits of the Carrizo Mountains were discovered about 1918 by John Wade. By 1920, Wade had 41 claims in the Carrizo Mountains (personal communication, 1955). Because of the lack of demand for domestic vanadium, little mining was done until 1942, when war conditions increased the demand for vanadium ores. In December 1941, the Vanadium Corporation of America leased 17 plots in the northwest Carrizo and Eurida Mesa areas, and in July, 1942, they also leased 12 plots in the east Carrizo area. Early in 1942, Wade, Curran, and Company leased 14 plots in the east, northwest, west and south Carrizos. Mining by these two companies was from surface exposures on the east, northwest and west sides of the mountains. According to Stokes (1951), during the period May, 1942, through February, 1944, the Carrizos yielded approximately 22,000 tons averaging 2.25 percent V_2O_5 .

Mining activity resumed in 1948 with the emphasis on uranium and continued until June, 1968, when the last shipment was recorded. During this period 120,600 tons grading 0.22 percent U_3O_8 and 1.93 percent V_2O_5 and containing 525,800 pounds U_3O_8 and 4,659,200 pounds V_2O_5 were produced from over 100 properties (fig. 4). Mining methods used include adits from mesa rims, inclined shafts and a few vertical shafts. Surface exposures were exploited using rim cuts, trenches and small open pits. In the larger underground mines, room and pillar methods or modifications of it were used.

The ore deposits of the Carrizo Mountains were first studied by geologists of the Union Mines Development Corporation who evaluated the uranium resources of the area for the Manhattan Engineer District. The results of their appraisal are summarized by Webber (1943), Coleman (1944), Eakland (1946) and Harshbarger (1946). Stokes (1954) studied the relation of sedimentary trends and structure to uranium deposits in three areas of the Carrizos. As the result of AEC

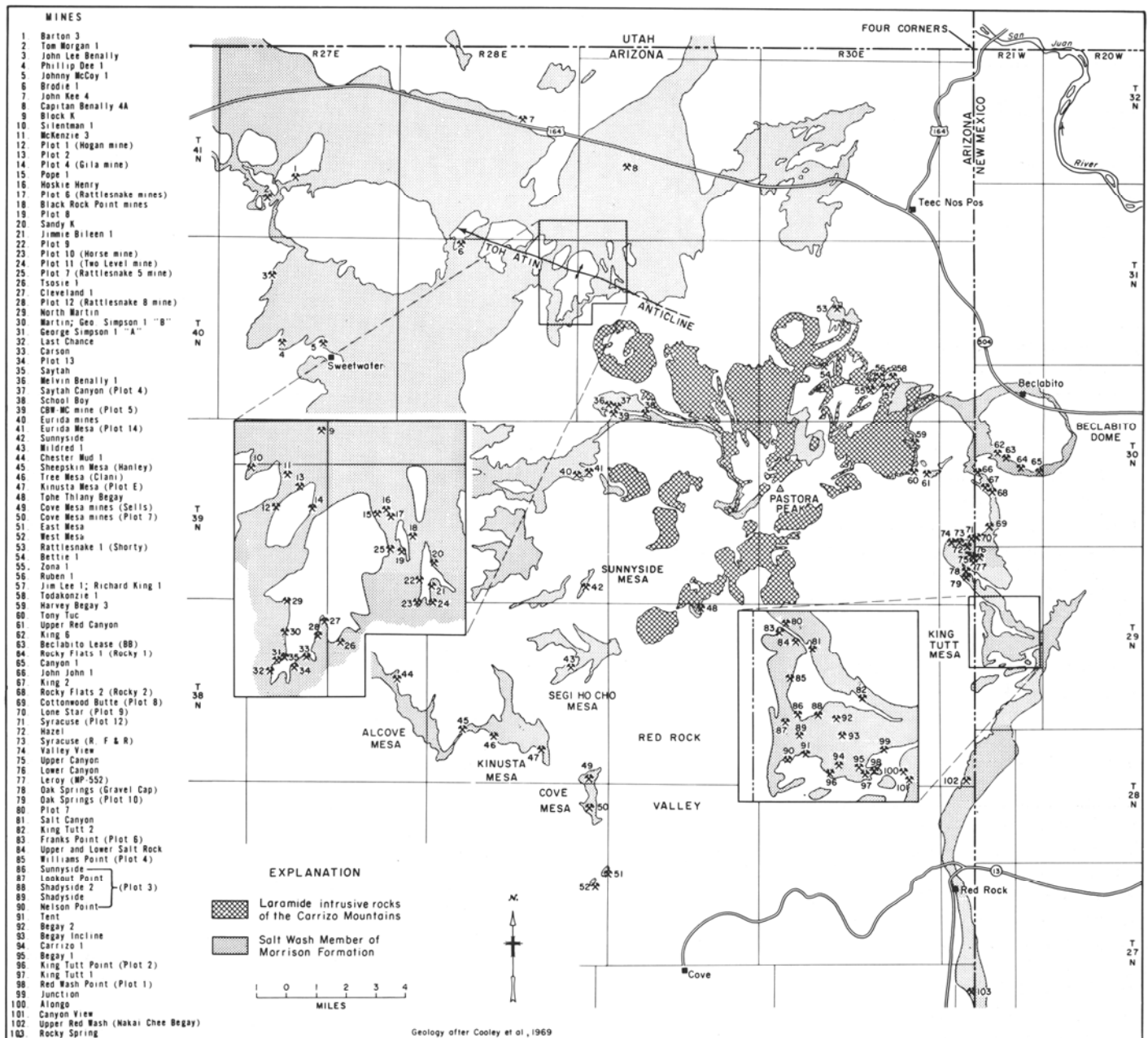


Figure 4. Mine locations: Carrizo Mountains, Apache County, Arizona, and San Juan County, New Mexico.

investigation, the deposits in more productive areas have been described by Chenoweth (1955), Masters and others (1955) and Blagbrough and others (1959).

The uranium deposits generally occur in clusters. Because of the clustering of deposits on the northwest, north and east flanks of the mountains, these areas have been designated localities. There are also the west and south localities which do not contain the clusters present in the other localities. Isolated deposits are known in all of the localities. Important features of the five localities are given in Table 2.

The Carrizo ore bodies are similar to those in the Lukachukai Mountains except that they are smaller and contain more vanadium. The vanadium to uranium ratio of the Lukachukai ores is 4:1 whereas the ratio for the Carrizo ores is 9:1. Ore bodies and clusters of ore bodies are elongated and

parallel to paleostream channels and redistribution of ore along fractures is not as noticeable in the Carrizos as in the Lukachukais. Also, ore roles are common in the Carrizo deposits.

Tyuyamunite and metatyuyamunite are the only uranium minerals identified in the Carrizo deposits, Gruner and others (1954), Corey (1956, 1958), and S. R. Austin (written communication, 1967). Vanadium clay and montroseite are present. These minerals have been oxidized to form a large number of secondary vanadium minerals which include sherwoodite, duttonite(?), hewettite, metahewettite, rossite, metarossite and hendersonite. All of these minerals were identified by Corey (1958) in her studies of the Nelson Point mine. The vanadium minerals pascoite, volborthite and montrosite

Table 2.
Significant features of deposits in the Carrizo Mountains.

LOCALITY	NO. OF PROPERTIES	MAP NOS. (FIG. 4)	TOTAL PRODUCTION			LOCATION OF ORE ZONES (FT. ABOVE Jb-Jms)	MOST PRODUCTIVE AREA				
			TONS	%U ₃ O ₈	%V ₂ O ₅		NAME	AREA	TONS	%U ₃ O ₈	%V ₂ O ₅
East	45	59-103	47,100	0.23	2.42	30-80	King Tutt Mesa	1.4 sq. miles	27,200	0.24	2.48 ^{1/}
North	7	53-58	3,700	0.17	2.30	30-40	--				
Northwest	36	1-36	27,400	0.21	1.54	1-40	Plot 6	52 acres	11,000	0.20	1.52 ^{2/}
West	11	37-47	2,200	0.13	2.03	40-95	--				
South	5	48-52	40,200	0.22	1.58	20-100	Cove Mesa	0.76 sq. miles	38,800	0.22	1.61

^{1/} Does not include production during 1940s from Plot 3
^{2/} Does not include 2,500 tons at 0.15% U₃O₈ and 1.86 % V₂O₅ produced in 1942-44 (Harshbarger, 1946)

also have been identified by Corey (1956) from the Martin mine. Calcite is a common cementing agent in ore. Pyrite, iron oxides and gypsum may also be present.

Field relationships of the Zona 1 and adjacent mines indicate the intrusion of the sills faulted and fractured the existing ore deposits in the Salt Wash Member. Paragenetic studies by E. B. Gross (written communication, 1954) indicate that silicification of the Salt Wash Member took place after deposition of the uranium and vanadium minerals. Both field and laboratory evidence indicate that the intrusion of the Carrizo laccolith took place after the deposition of the uranium-vanadium deposits.

Chilchinbito Area

Uranium occurs in the Salt Wash Member at the northeast foot of Black Mesa between Chilchinbito and Rough Rock, Arizona, where Navajo prospectors discovered uranium-bearing outcrops in late 1950. During the 1951 to 1958 period, several small shipments were made from two properties (fig. 5). Total production is 123 tons containing 0.74 percent U₃O₈ and 0.03 percent V₂O₅. The grade of individual shipments has ranged from 0.18 to 1.79 percent U₃O₈.

The Salt Wash in the Chilchinbito area consists of approximately 130 feet of interbedded fine- to very fine-grained grayish-brown sandstone and gray, green and reddish-brown siltstone and mudstone. Secondary uranium minerals are associated with carbonaceous fossil logs and other plant debris in sandstone lenses 10 to 40 feet above the base of the Salt Wash Member. Fossil logs, observed during mining operations, have been at least 14 inches in diameter and over 10 feet in length. Calcite crystals associated with the logs were responsible for ore shipments averaging 31 percent CaCO₃. Mining has been entirely by shallow rim cuts.

DEPOSITS IN THE TOREVA FORMATION

Rocks of the Mesaverde Group of Upper Cretaceous age occur in the central portion of the Black Mesa basin. Repenning and Page (1956) subdivided these rocks into three formations; in ascending order they are: Toreva Formation, Wepo Formation and Yale Point Sandstone. They represent a complex intertonguing of marine and non-marine beds.

Uranium deposits are known in the Toreva Formation in the northeastern corner of Black Mesa in the Lohali Point-Yale Point area. The Toreva Formation in the Yale Point area is

composed of the main ledge which is separated from an upper cliff-forming sandstone by a marine tongue of the Mancos Shale. South of Yale Point, the tongue of Mancos Shale pinches out and a non-marine tongue of the Wepo Formation, at a slightly higher stratigraphic horizon, separate the main ledge of the Toreva from the upper cliff-forming sandstone. All of the uranium deposits occur in the main ledge of the Toreva, a name used by O'Sullivan and others (1972) to distinguish this unit from the lower sandstone member of the Toreva found elsewhere. The main ledge consists of 140 to 170 feet of fine- to medium-grained sandstone with lenses of coarse- to very coarse-arkosic sandstone in the upper part. Small amounts of coal, carbonaceous shale and siltstone occur in the beds in the upper part of the main ledge.

Uranium-bearing outcrops in the vicinity of Burnt Corn Wash was brought to the attention of the AEC in January, 1954. Following this discovery, an AEC ground and airborne reconnaissance of the area was made and some 25 radioactive anomalies were located in Lohali Point-Yale Point area. Also three anomalies were indicated along Oraibi Wash, north of Pinon, Arizona (Clinton, 1956). Although several of the anomalies were caused by radioactive heavy mineral accumulations, many of the anomalies were developed into prospects and mines. During the 1954 to 1968 period, 16,800 tons grading 0.17 percent U₃O₈ and containing 55,700 pounds U₃O₈ were produced from 13 properties. Ore was mined by shallow open pits, rim cuts and in two places by underground methods. With the exception of two properties near Yale Point, all of the production came from properties located on both sides of the upper drainage of Burnt Corn Wash (fig. 5).

The uranium deposits occur in a quartzose zone in the upper part of the main ledge of the Toreva. Lenses of carbonaceous shale and siltstone are common in the ore-bearing zone. Some uranium occurs in the carbonaceous material but the majority of it occurs disseminated in the sandstone. In general, the ore occurs immediately below carbonaceous beds. The deposits consist of pods of ore grade material surrounded by protore. Clusters of these pods may occur to form an ore deposit within an area of 400 feet by 100 feet, having an average thickness of less than 2 feet.

Uranium minerals include tyuyamunite and metatyuyamunite, and vanadium minerals include vanadium clay, metahevetite and melanovanadite (E. B. Gross, written communication,

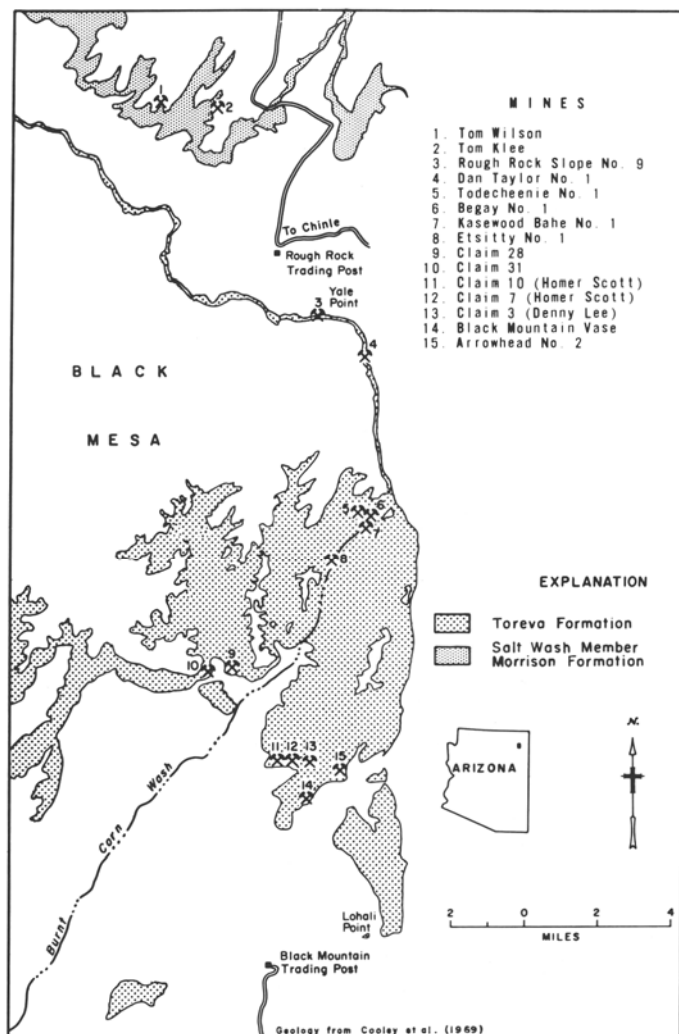


Figure 5.
Mine locations: Chilchinbito and Black Mesa areas, Apache County, Arizona.

1956). Production records on the initial 4,750 tons of ore shipped indicated an average vanadium content of 0.27 percent V₂O₅ and an average uranium content of 0.24 percent U₃O₈.

DEPOSITS IN THE BIDAHOCHI FORMATION

The Bidahochi Formation of Pliocene age is present in the southeastern part of Black Mesa basin and unconformably overlies older rocks. The Bidahochi consists of fluvial and lacustrine sedimentary rocks and basaltic volcanic rocks. Repenning and Irwin (1954) have subdivided the formation into three members: a predominantly lacustrine lower member, a medial volcanic member and an upper, chiefly fluvial, member. Associated with the volcanic member are approximately 150 diatremes of the Hopi Buttes volcanic field which have been described in detail by Hack (1942). Uranium in the Hopi Buttes is associated with these diatremes.

Uranium was first discovered in the Hopi Buttes in 1952 by E. M. Shoemaker of the USGS. Airborne radiometric reconnaissance by the AEC and private interests showed that the occurrence of radioactivity in the diatremes was widespread. Detailed geologic studies by the USGS have been summarized by Shoemaker and others (1962). Minor AEC investigations

have been reported on by Fair (1955) and Lowell (1956).

Uranium occurrences are restricted to diatremes containing bedded carbonate rocks. The uranium content of the carbonate rocks is low, generally 0.001 to 0.02 percent U₃O₈. Uranium of higher grade, occurs in non-volcanic elastic rocks, tuffs, and sedimentary rocks derived from the wall of the vents within the diatremes.

Although 35 diatremes contain significant uranium, from only one, Seth-la-kai, located five miles northeast of Indian Wells, Arizona, has ore grade material been produced. The Morale property at this diatreme produced 192 tons grading 0.15 percent U₃O₈ during 1954 to 1959. Unidentified uranium minerals occur in a 6- to 8-inch thick, coarse-grained, non-volcanic sandstone and in adjacent calcareous tuff beds within the diatreme. The high phosphate content of the Morale ore, 0.75 to 1.00 percent P₂O₅, made it unacceptable to processing in an alkaline leach circuit. The ore was mined from a rim cut and a short adit on the southeast rim of the diatreme.

Schroeckerite has been identified by Shoemaker and others (1962) at the Hoskie Tso claim at a diatreme 2 miles southeast of Indian Wells, and carnotite has been identified by Gruner and Smith (1955) at the Horseshoe diatreme, 9 miles north of Indian Wells.

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