ARIZONA GEOLOGICAL SURVEY

Geology and Uranium Deposits of the Carrizo Mountains Area, Apache County, Arizona and San Juan County, New Mexico

by

Robert E. Hershey

with a section on the Martan and Rattlesnake Incline Mines

by

Víctor A. Manns and Donald K. Labrecque

1958
GEOLOGY AND URANIUM DEPOSITS OF
THE CARRIZO MOUNTAINS AREA
APACHE COUNTY, ARIZONA AND
SAN JUAN COUNTY, NEW MEXICO

By
Robert E. Hershey

with a section on the

MARTIN AND RATTLE SNAKE INCLINE MINES

By
Victor A. Means and Ronald K. Labrecque

Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed in this report, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

August 1953
Grand Junction, Colorado

UNEDITED MANUSCRIPT
# CONTENTS

<table>
<thead>
<tr>
<th>Abstract</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Purpose, Scope and Methods</td>
<td>1</td>
</tr>
<tr>
<td>Geography</td>
<td>2</td>
</tr>
<tr>
<td>Location and Accessibility</td>
<td>2</td>
</tr>
<tr>
<td>Topography</td>
<td>2</td>
</tr>
<tr>
<td>Climate and Vegetation</td>
<td>2</td>
</tr>
<tr>
<td>Water Resources</td>
<td>3</td>
</tr>
<tr>
<td>Nature of Rock Exposures</td>
<td>3</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>3</td>
</tr>
<tr>
<td>History of Mining and Exploration</td>
<td>3</td>
</tr>
<tr>
<td>General Geology</td>
<td>4</td>
</tr>
<tr>
<td>Stratigraphy and Sedimentary Rocks</td>
<td>4</td>
</tr>
<tr>
<td>Permian</td>
<td>4</td>
</tr>
<tr>
<td>Triassic</td>
<td>4</td>
</tr>
<tr>
<td>Jurassic</td>
<td>5</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>10</td>
</tr>
<tr>
<td>Igneous Rocks</td>
<td>10</td>
</tr>
<tr>
<td>Geologic Structure</td>
<td>11</td>
</tr>
<tr>
<td>Geologic History</td>
<td>12</td>
</tr>
<tr>
<td>Uranium Deposits</td>
<td>13</td>
</tr>
<tr>
<td>Nelson Point No. 1 Mine</td>
<td>14</td>
</tr>
<tr>
<td>Martin and Rattlesnake Incline Mines (by Victor A. Means and Ronald K. Labrecque)</td>
<td>17</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>20</td>
</tr>
<tr>
<td>Paragenic</td>
<td>21</td>
</tr>
<tr>
<td>Vanadium Distribution</td>
<td>21</td>
</tr>
<tr>
<td>Geochemical Studies</td>
<td>21</td>
</tr>
<tr>
<td>Ore Guides</td>
<td>22</td>
</tr>
<tr>
<td>Favorability Features</td>
<td>24</td>
</tr>
<tr>
<td>Origin of the Uranium Deposits</td>
<td>22</td>
</tr>
<tr>
<td>Summary and Conclusions</td>
<td>24</td>
</tr>
<tr>
<td>References</td>
<td>27</td>
</tr>
</tbody>
</table>
NOTE: All figures included at back of report on microfiche

LIST OF ILLUSTRATIONS

Figures

1. Location map of the Carrizo Mountain area.
2. Geologic map of the Carrizo Mountain area.
3. Generalized section, Carrizo Mountain area.
4. Isopach map of the Salt Wash, also showing sedimentary trends and typical sections.
5. Approximate drilling depths to Salt Wash.
6. Map showing structure, igneous rocks, and uranium-vanadium analyses in the Carrizo Mountains and vicinity.
7. Structure contour map of Toh Atin anticline, showing distribution of ore bodies.
8. Alignment of ore bodies, and histograms showing elongation of ore bodies, Carrizo Mountains area.
9. Plan of Nelson Point No. 1 mine showing fractures.
10. Plan of Nelson Point No. 1 mine showing sedimentary features.
11. Nelson Point No. 1 mine, longwall sections.
12. Section showing reverse fault displacing ore zone, Nelson Point No. 1 mine.
13. Sedimentary trend favorability map, using straight line project from known clusters of ore bodies along sedimentary trends.
14. Structural favorability map Salt Wash et. al. Assumed 2 miles either side of axis is favorable.
15a. Possible deep seated fault underlying a monocline.
15b. Possible tension fracture zone underlying a monocline.
17. List of symbols used on mine maps.
18. Longwall sections, Martin Mine
19. Plan map of Rattlesnake Incline Mine
20. Geology on horizontal planes, Rattlesnake Incline Mine
21. Longwall sections, Rattlesnake Incline Mine
GEOLOGY AND URANIUM DEPOSITS OF THE CARRIZO MOUNTAINS AREA
APACHE COUNTY, ARIZONA AND SAN JUAN COUNTY, NEW MEXICO

ABSTRACT

Although uranium was first discovered in the Carrizo Mountains area in 1913, the ores were not developed until 1942. They have, however, been mined continuously since 1948.

Formations in the area range from the Permian Cutler formation through the Cretaceous Mancos shale, and all are intruded by a dioritic laccolith and its related dikes. The older structures, which include the Defiance Uplift, the San Juan Basin, and the Four Corners Platform are somewhat disrupted by the effects of the intrusion. A number of mines are described, and mineralogical and geochemical studies made are outlined. The primary uranium mineral is unknown, but the chief uranium ore-mineral is the secondary mineral, tyuyamunite.

It is concluded that there is at least minor structural control of the ore bodies along sedimentary trends and joints, and that all ore bodies of 500 tons or more are on the Defiance monocline or its extensions.

The uranium may have been syngenetic in the sediments, and redistributed by solutions or, more likely, that it rose vertically in hydrothermal solutions from the local intrusive bodies.

Purpose, Scope, and Methods

The objective of this study was an evaluation of resources of the Carrizo Mountains area. Four factors: distribution of ore bodies, relation of uranium to the host rock, relation of ore to structure, and circumstances that might precipitate uranium were studied in search of data bearing on manner of distribution of ore, the time and causes of deposition, and the probable source of the uranium-bearing solutions.

Data for this report was obtained in geologic mapping of selected mines in the Salt Wash member of the Morrison formation, during reconnaissance of the mining district, and by a review of the literature. Mapping in mines and study of fractures was in progress from 1955 through the first half of 1956. Reconnaissance and drilling projects were in progress from 1952-1955.

The area covered by this report is approximately 2,050 square miles. Figure 1 is an index of mining districts and to mines discussed.

The Martin mine was mapped as one typical of those in the Northwest Carrizo area. The Rattlesnake Incline was selected for mapping because it contained intensely crossbedded clastics and the Nelson Point No. 1, (East Carrizo area) because uranium-vanadium ore is as common in planar beds as it is in crossbedded sediments.

Plan maps were made of the three mines; on these were recorded sedimentary trends and structure. Longwall sections (figs. 11, 18 & 21) were made showing lithology and attitude of beds and the spatial relationship of uranium to these fractures.

Fractures were mapped in selected areas around the Carrizo Mountains (fig. 2), in order to relate fractures in the mines to the regional pattern.
Geography

Location and Accessibility

The Carrizo Mountains area lies in the northeast corner of Arizona and the northwest corner of New Mexico; it is bounded on the north by Utah and Colorado lines. The nearest through highways, US 666 and US 550, are at Shiprock, New Mexico, about 20 miles east of the area.

Roads within the area are shown on fig. 1. Flash floods from late summer thunder showers make stretches of the roads impassable for a few hours. Winter snows though usually not deep cause considerable trouble.

Farmington, New Mexico, 30 miles east of Shiprock, and Cortez, Colorado, 40 miles north of Shiprock, are the nearest towns which have mining and drilling equipment and repair facilities. Both towns are served by regularly scheduled airline flights and Farmington is served by narrow gauge railroad from Durango, Colorado. Uranium processing mills are located at Shiprock, New Mexico, and at Durango, Colorado; most of the uranium-vanadium ore from the Carrizo area is processed at Durango, Colorado. The Shiprock mill generally treats ore of lower vanadium content from the Lukachukai Mountains.

Topography

The lowest elevation in the area is 4600 feet above sea level at the northeast corner near the San Juan River; the highest elevations are Pastora Peak, 9412 feet, and Zilbetod Peak, 9284 feet. Sedimentary beds steeply dipping from the Carrizo Mountain mass have been dissected by intermittent streams into mesas and valleys of very rugged topography. Steep cliffs of the mesas may be as much as 1200 feet high, as at Segi Ho Cho mesa. The dip decreases rapidly away from the sparcely timbered mountains and the country takes on the aspect of a semi-desert broken terrain in which outcrops are partly covered by either outwash from the central mountains or by dune sand.

The precipitous nature of the terrain flanking the mountains on the west and in the Carrizo Mountains results in higher cost of road building. Road construction in the remainder of the area would be about standard for semi-desert, broken terrain.

Beclabito dome is an outstanding topographic as well as structural feature on the east flank of the Carrizo Mountains; the uplift is encircled by thick red Wingate sandstone, in turn surrounded by white and tan beds of the Chinle formation.

Volcanic plugs and dikes are very common in the east and southeast portions of the area; individual dikes may be as much as two miles long and the plugs may be several hundred feet high, as at Walker Peak (Black Rock).

The Carrizo Mountain area is covered by four fifteen minute quadrangles, scale 1:62,500, published by the U. S. Geological Survey. Toh Atin Mesa quadrangle includes the northwest quarter; Pastora Peak quadrangle the northeast quarter; Los Gigantes Buttes quadrangle the southwest quarter and Red Rock Valley quadrangle the southwestern quarter.

Climate and Vegetation

The climate is semi-arid. Average precipitation on the central Carrizo mountain mass is between 10-15 inches per year and on the lower surrounding area rainfall averages about 5 inches per year. The rainfall occurs as late summer thundershowers or
as snow in the winter. Summer temperatures are usually high in the daytime except at the higher elevations and are relatively low at night. Winter temperatures may range as low as zero degrees.

Vegetation is zoned according to elevation and rainfall. The lower elevations contain "cold desert" zerophytic type of vegetation, such as sagebrush and small cactus; at intermediate altitudes cactus, sagebrush, pinon and juniper intermingle; higher elevations contain pinon, scrub oak, ponderosa pine and quaking aspen. Vegetation is sparse throughout the area though slightly more abundant in the higher elevations.

Pinon pine and ponderosa pine adequate for mine timbering are available. Most mine portals are timbered but generally the mines require little timbering because they are small and the roof will stand unsupported for long periods.

Water Resources

Water of the area is adequate only for small scale mining and drilling. All streams are intermittent, but several springs occur at the base of the Lukachukai member of the Wingate sandstone and are scattered throughout the area. Between Red Mesa Trading Post and the Carrizo Mountains, in the northwest Carrizo area, moderate quantities of water are encountered at depths of less than 100 feet.

Nature of Rock Exposures

Sparse vegetation leaves most of the formations bare. Talus on the mountain slopes and dune sand on the lower elevations cover portions of outcrops but in general, good rock exposures are abundant.

Acknowledgments

Various members of the United States Geological Survey have given information and exchanged ideas. J. D. Strobell, Jr., of the USGS allowed access to maps, provided descriptions of formations and data of their thickness. The Navajo Tribe allowed access to the area.

Special thanks are due to Capitol Mining Company, Vanadium Corporation of America, and Paul Shorty for many courtesies extended during the period of field exploration. Thanks are due other operators who cooperated generously.

History of Mining and Exploration

Uranium was discovered in the Carrizo area in 1913 by John Wade, while prospecting for radium and vanadium. First development of the uranium-vanadium ores was in 1942. Production declined after the war until 1948 when uranium became an important ore. Since then, mining has continued in the Carrizo area to the present.

Several thousand tons of ores of uranium and vanadium have been mined from the Salt Wash member of the Morrison formation in the Carrizo area. Most of the production has come from Cove Mesa but the northwest and east Carrizo areas have supplied relatively constant production since 1948. Other small mines are located in and around the Carrizo Mountains. Almost all of the mines are under less than 100 feet of overburden.

Most of the mines are operated by 2-5 men underground, but a few are of a size requiring 14 or more men underground. Early mining was by random drifting from a mineralized outcrop with little or no exploratory drilling. Later mines were developed by close-spaced drilling followed by a modified room and pillar system of mining.
Gregory (1917) made the first detailed reconnaissance of the area. Union Mines Development Corporation studied the uranium and vanadium resources of the Carrizo area for the Manhattan Engineer District (Harshbarger, 1946). An Oil and Gas Investigations Map includes the Carrizo area (Strobell, 1956). In more recent years the Atomic Energy Commission and the USGS have drilled in various portions of the region.

The entire Carrizo area is within the Navajo Indian Reservation, and all exploration permits and mining leases must be obtained from the Tribal Council at Window Rock, Arizona.

GENERAL GEOLOGY

Stratigraphy and Sedimentary Rocks

Approximately 5,000 feet of sedimentary rocks ranging in age from the Permian Cutler formation to the Upper Cretaceous Mancos shale are exposed in this area. Ranges in thickness, idealized topographic expression, and age are shown on fig. 3, and areal distribution on fig. 2.

The Salt Wash member of the Morrison formation is the only uranium ore-bearing unit known in the Carrizo area and is discussed in detail in subsequent paragraphs. Discussion of other formations is limited to mention of outstanding characteristics and their comparative favorability as host-rock for uranium deposits.

At depths from 700 to 2500 are the older sedimentary formations ranging in age from the Cambrian (?) Ignacio Quartzite through the Pennsylvanian Rico formation. Boundaries commonly accepted for the Rico may, in some places, include Permian strata (Strobell, 1956).

PERMIAN Cutler Formation

The lower member of the Cutler formation of Permian age consists of alternating beds of mudstone and fine-grained sandstone, both hematite-stained. In general appearance it is very similar to the Petrified Forest member of the Chinle formation. Because of the fine grade of clastics in this unit and the consequent low permeability, it is considered to be unfavorable for the accumulation of uranium.

The De Chelly sandstone is the uppermost member of the Cutler formation in the Carrizo area. A large outcrop of De Chelly on the southeast flank of the Carrizo mountains has the appearance of a "bleached" mass of Wingate. The "bleaching" has proved to be surficial and not a result of reduction by uranium because of its high permeability and lack of recognized precipitants.

TRIASSIC Moenkopi Formation

The Moenkopi formation of Triassic age is absent in the area and the Shinarump rests directly on the De Chelly sandstone member of the Cutler formation.

Chinle Formation

Shinarump Member

The Shinarump member of the Triassic Chinle formation is exposed only on the southeast flank of the Carrizo Mountains where it rests unconformably on the De Chelly sandstone. At this locality, the Shinarump comprises about 30 feet of cross-stratified sandstone. The lower, more conglomeratic portion contains pebbles up to several inches
in diameter. The usual cement is silica and completely silicified jet-black logs have been found. The less silicious, upper part, of the Shinarump is difficult to distinguish from the overlying sandstones of the Chinle formation. Pre-Shinarump erosion cut into the underlying De Chelly sandstone channels of widths up to 30 feet and maximum depth of 5 feet. It is these variations in the level of the lower contact which account for some changes in thickness of the Shinarump member.

The low permeability of the Shinarump, a result of abundance of cement, and the scarcity of carbonaceous debris may account for absence of uranium in it.

Upper Members

The "D" member of the Chinle formation (Gregory, 1917) of Triassic age is exposed on the southeast and southwest flanks of the Carrizo Mountains where the unit is alternating beds of red to purple siltstone, mudstone and sandstone. The individual beds are usually thin and have a relatively large areal extent.

"C" and "B" members are alternating beds of siltstone, mudstone and sandstone very similar in appearance to Chinle "D". Colors range from red to purple and are usually lighter in color than Chinle "D".

Just south of the Carrizo area, near Cove School (fig. 1) uranium minerals have been found in one of the lower sandstone beds of "D" member. Within the Carrizo area, uranium is not found in any bed of the Chinle formation.

Wingate Sandstone

Rock Point (?) member of the Wingate sandstone of Triassic age is siltstone enclosing a few beds of fine grained sandstone. The Lukachukai member is a massive, very fine-grained sandstone with large scale cross-bedding. This unit forms sheer cliffs up to 400 feet high in the southwest part of the area.

Because of its fine grade the lower member is relatively impermeable. The upper massive member does not have the usually recognized favorability features such as bleaching, intricate small scale cross-bedding or a notable abundance of mud pebble conglomerates, pyrite or carbon. No uranium has been found in the Wingate.

JURASSIC Kayenta Formation

The Kayenta formation of Jurassic age has a maximum thickness of 50 feet and thins rapidly southward and eastward to zero. The formation is not present east of the Carrizo Mountains or south of the area. The Kayenta is a heterogeneous unit of irregular beds of sandstone, quartz-pebble conglomerate, siltstone, mudstone and mud-pebble conglomerate. The sandstone beds are coarser than those in either the Wingate or Navajo formations. The siltstone and mudstone beds are purple in places, a feature which is diagnostic for the formation. Plant fragments and thin beds of limestones are present locally (Strobell, 1956).

The heterogeneous character of the Kayenta formation and the abrupt changes in lithology are phenomena favorable for the accumulation of uranium. No uranium has been found to date in the Kayenta in this area.

Navajo Sandstone

The Navajo sandstone of Jurassic age is practically co-extensive with the Kayenta formation but does not extend quite as far to the southeast. The Navajo sandstone has a
maximum thickness of 200 feet in the northwest corner of the area where it is massively
cross-bedded. The formation does not appear to be as well cemented as the Lukachukai
member (?) of the Wingate. Uranium does occur in the Navajo sandstone as stain adjacent
to a dike at Garnet Ridge about 40 miles west of the Carrizo Mountains, but uranium has
not been found in the Navajo in the Carrizo area.

Carmel Formation

The Carmel formation of Jurassic age is a series of relatively thin mudstone units
enclosing some sandstone beds. The Carmel pinches out in the east Carrizo area but in
the remainder of the region it is present throughout and overlaps the Kayenta and Navajo
formations to rest directly on the Wingate sandstone. No uranium has been found in the
Carmel possibly because of the high percentage of relatively impermeable material and
the discontinuous nature of the sandstone beds.

Entrada Sandstone

The Entrada sandstone of Jurassic age in this area is composed of an upper sandstone
member and a lower siltstone member. Both are reddish-orange to reddish-brown and the
lower member is usually the darker. The upper sandstone is a cliff-former but does not
develop into the typical "slick rim" cliff as it does in exposures in Colorado and
Utah. The fact that uranium has not been found may be due to lack of bleaching of the
Entrada and the homogeneity of the sediments.

Todilto Limestone

The Jurassic Todilto limestone is present only in the east Carrizo area. Near Horse
Mesa the unit is three feet thick. The upper foot is a dense oolitic limestone with
scattered grains of coarse recrystallized calcite. The remainder is a slabby arenaceous
limestone. No small scale folding, as is common in the Grants, New Mexico area, was
observed and joints are inconspicuous. Several miles south of the area, near Sanostee,
where the unit is thicker, tyuyamunite has been found as fracture-filling.

Very little prospecting has been done on the Todilto and to date no uranium has been
found. The thinness of the unit in the area would limit the size of any ore body found.

Summerville Formation

The character and appearance of the Summerville formation of Jurassic age vary from
place to place. In the northwest Carrizo area, the formation contains thin, alternating
beds of brownish siltstone and sandstone with few thin mudstone beds. The unit is
deformed to folds of two to five feet in amplitude, but the folds do not extend into the
overlying Bluff sandstone.

At Horse Mesa, the upper quarter of the Summerville is more sandy, forming a single
lithologic unit with the overlying Bluff sandstone. Elsewhere the Summerville is light
brown, thin-bedded siltstone, and lacks the folding found in the northwest Carrizo
area. At Segi Ho Cho Mesa, lateral facies changes are noticeable within short
distances. At one point on the south side of the mesa, the Summerville is all sandstone
forming a continuous vertical cliff with the Bluff and Salt Wash sandstone; laterally,
within tens of feet, it grades to a more typical banded Summerville.

The upper, sandy, portion of the Summerville formation has characteristics which
suggest it as a suitable host to uranium minerals but none have been found in the
Summerville in this area. The bedding characteristics of the formation differ from
those in most uranium host rocks.
Bluff Sandstone

The Jurassic Bluff sandstone is thick and friable, medium- to coarse-grained, consisting of grains of rounded frosted quartz and abundant white chert. The Bluff intertongues with the overlying Salt Wash sandstone and it is very difficult to place the contact, especially in drill holes. The Bluff and Salt Wash sandstones are distinguished on the outcrop by their different topographic expressions: the Bluff sandstone forms a single cliff and the Salt Wash usually forms ledgy cliffs characterized by overlapping lenses of sandstone with thin mudstone or siltstone partings. The method used to separate the Bluff and Salt Wash in drill holes is to place the contact at a change in sand grain size; the Salt Wash is usually fine-grained and the Bluff, medium- to coarse-grained.

The Bluff is a very porous, clean sand and has not been found to be a good host rock for uranium deposits.

Morrison Formation

Salt Wash Member

According to Craig et. al. (1955) the Salt Wash member of the Jurassic Morrison formation was deposited as a large alluvial fan by a system of braided, aggrading streams. The Salt Wash member in the Carrizo perimeter is presumed to be a separate lobe of that fan. The unit thins to the south, northeast and the east of the area (fig. 4).

This member is the only uranium ore-bearing unit of the Morrison in the Carrizo Mountains area. The sandstone intertongues with the underlying Bluff to a minor extent and into the overlying Recapture member over a larger area (Nestler & Chenoweth, 1958).

As is characteristic in fluvialite deposits, the Salt Wash sandstone contains an abundance of primary current lineation, rib and furrow markings, ripple marks and festoon cross-bedding (Stokes, 1953). These sedimentary trends useful in determining current directions in paleostream deposits. Figure 4 shows the averages of sedimentary trends as mapped in the Salt Wash member by Stokes (1953). In the northern two-thirds of the Carrizo area, the pattern of trends suggests the Salt Wash paleostreams came from the northwest. The trend directions change in the southern third of the area to an apparent source from the west and southwest but, the actual source lay to the south. The change in trend directions is an effect of the Recapture fan, the source area of which also was in the south. The interfingering of the two fans resulted in a change of stream directions for both members and a very minor exchange in actual sediments from member to member.

In outcrop the Salt Wash sandstone appears as either steep vertical cliffs of massive thick-bedded sandstone with minor mudstone or siltstone splits in the west and southwest Carrizo areas, or in ledgy slopes with sandstone ledges up to 40 feet high, with intervening thin mudstone partings in the northwest Carrizo area. The east Carrizo area is characterized by essentially co-equal sandstone lenses in the upper two-thirds of the Salt Wash and alternating beds of sandstone and mudstone in the lower one-third. The mudstone beds are as much as ten feet thick.

In general, the sandstone lenses are composed of fine- to very fine, rounded to sub-rounded quartz grains with 5-10 percent feldspar and sparse heavy minerals. Pyrite and limonite are quite common. The cement is either calcium carbonate or interstitial clay. The former is the more abundant throughout the section near the Carrizo mountains, and the sandstone is friable when calcium carbonate is not present.
Authigenic quartz as overgrowths is a cement to a minor degree. The sandstone varies from white to gray, green, buff and yellow to red. Yellow limonite staining is very common throughout the area.

Mudstones are an integral part of the Salt Wash sandstone member, comprising 5-15 percent of the total section. They usually occur as thin partings between sandstone lenses but may appear in beds up to 10 feet in thickness (fig. 4). The frequent change in regimen of Salt Wash streams is responsible for partial erosion of some mudstones and the frequent development of mud galls and mudstone-pebble conglomerates. Where mudstones or mudstone-pebble conglomerates are in proximity to uranium-bearing rock they are invariably grey; elsewhere they vary from grey to green or from brown to red.

In some parts of the Carrizo area the lower 10-20 feet of the Salt Wash sandstone member is variable from calcareous sandstone to arenaceous limestone. Carbonaceous material is a common constituent of the Salt Wash of the Carrizo area either in logs and "trash piles"-concentrations of carbonaceous fragments- or as small flecks disseminated throughout the sandstone lenses and in planar, thin bedded sandstones as stringers along bedding planes.

The northwest and east Carrizo area are in the main body of the Salt Wash while Cove, Kinusta, Toh Acon, Segi Ho Cho, Sunnyside, Friday and Altar Mesas are capped by outliers of the Salt Wash. At Cove Mesa, the Salt Wash sandstone member of the Morrison formation outcrops in step-like benches with short sloping treads. The sandstones are thin- to thick-bedded with flat to steep cross-stratification, (Blagbrough, et. al., 1959). The mudstones are usually thin partings but may be up to 3 feet thick. Green to maroon clay galls are present up to .1 foot in diameter; and carbonaceous material is common.

On Cove Mesa the base of the member is either calcareous sandstone or sandy limestone. Salt Wash paleostream trends vary from southeast to east to northeast (fig. 4) and are similar in direction to those of the Lukachukai area, (Nestler and Chenoweth, 1958). The uranium ore is generally between 40 and 90 feet above the base of the Salt Wash but may be as low as 10 feet above the base.

Salt Wash sandstone on Kinusta Mesa is identical to the unit elsewhere except that the paleostream directional trends are eastward. Very little ore has been mined on Kinusta Mesa.

On Toh Acon Mesa the Salt-Wash member appears as gently cross-stratified sandstone ledges with thin mudstone partings, the latter more frequent than on Cove or Kinusta Mesas. The base of the Salt Wash here may be either mudstone or limestone. Uranium ore occurs between 30 and 80 feet above the base and most frequently in the interval 40-60 feet above the base. The uranium is mostly associated with carbonaceous logs.

At Segi Ho Cho Mesa, the Salt Wash sandstone appears in massive cliffs with gentle to steep cross-stratification and with very few mudstone partings. On the western end of the mesa the upper portion is extensively stained by limonite and is separated from the unstained lower portion, by a thin discontinuous mudstone bed. Limonite staining in the eastern part of the mesa is restricted to the middle part of the member with unstained sandstone above and below. Uranium occurrences are usually 55-90 feet above the base of the Salt Wash, in association with mudstone and carbonaceous material, (Harshbarger, 1946).

On Altar, Sunnyside and Friday Mesas the Salt Wash member outcrops in ledgy lenticular sandstones with a few mudstone partings. A small amount of uranium has been found 25-60 feet above the base of the Salt Wash. These mesas have not been explored extensively.
Near Emanuel Mission and Sweetwater, Salt Wash sandstone outcrops are similar to those of the northwest Carrizo area: sandstone ledges with intervening mudstone partings; thin limestones are locally prominent. No occurrence of uranium-bearing minerals has been found in the Emmanuel Mission locality but small deposits are known in the Sweetwater locality.

Ledges and slopes are characteristic of the Salt Wash outcrop in the northwest Carrizo area. The sandstones are fine-grained and the rounded to subrounded grains are well sorted. Cross-stratification is common and most of ore deposits are in cross-stratified beds. Mudstone units are thin and compose about 5-15 percent of the total Salt Wash section. Limestone beds occur at the base of the member, (Strobell, 1956). Carbonaceous matter is common in logs and small fragments. Uranium minerals are found from 1-50 feet above the base of the Salt Wash member but most of the ore bodies are 10-30 feet above that horizon.

The Salt Wash member in the East Carrizo area is 220 feet thick and is predominately sandstone fine- to very-fine-grained and well sorted. Most of the sandstone is cross-stratified but planar bedding is present and more frequent than in the other areas. In the lower portion of the member, mudstone beds are persistent and attain a maximum of 10 feet, a thickness not frequent elsewhere. Carbonaceous material is common in the Salt Wash sandstone throughout the east Carrizo area and is abundant near Beclabito Dome.

The uranium ore bodies are all in the lower one third of the unit. Approximate drilling depths to the Salt Wash are shown on Figure 5.

Recapture member - The Recapture member of the Morrison formation, like the Salt Wash member, is a part of an alluvial fan having a source to the south. The Carrizo area is at the margin of intertonguing of the two. Where the Salt Wash sandstone is thin the Recapture sediments are thicker (Strobell, 1956). The Recapture member is not as resistant to erosion as either the underlying Salt Wash or overlying Westwater members and forms a steep slope between the two. The Recapture member is a series of lenticular sandstones and mudstones. The mudstones, usually brown with bands of green, are more abundant and darker in color in the Recapture than in the Salt Wash member and sandstones of the Recapture are coarser grained, generally thicker and darker colored than those of the Salt Wash.

Uranium has not been found in the Recapture in the Carrizo area but neither has its outcrop been prospected intensively. Near Sanostee, New Mexico, several miles to the south, ore has been found in the Recapture.

Westwater Canyon member - The Westwater Canyon member of the Morrison formation is a series of light colored sandstones and mudstones which contrast with those of the underlying darker Recapture member. Sandstones comprise most of the Westwater section; mudstones forming only a small percentage. Pyrite is absent but limonite is abundant and colors the sandstone yellow. The sandstones consist of medium-grained, well-rounded quartz grains with an abundant fresh feldspar. Fragments of granite are common in conglomeratic lenses, (Strobell, 1956). Carbonaceous trash and "asphaltite" are notable by their absence, (Cadigan, personal communication). Interstitial kaolin is very sparse in contrast to the kaolin content of the Recapture member at the Ambrosia Lake area. The differences observed between the sandstones of the Carrizo area and the productive Ambrosia area is that the sandstones in the Carrizo area lack carbonaceous material, "asphaltite", an abundance of interstitial kaolin, and pyrite.

Calcium carbonate is present as a cement but is not as abundant as in clastics of the Salt Wash member. Authigenic quartz as overgrowths is common in the upper part of
the Westwater member and is more abundant than in the Salt Wash sandstones.

The upper part of the Westwater Canyon is gradational into the overlying Brushy Basin member.

Uranium has not been found in the Westwater Canyon member in the Carrizo area due either to lack of prospecting or the differences noted above between the productive Westwater member of Ambrosia Lake the Carrizo Westwater in the Carrizo area.

Brushy Basin member - This member of the Morrison formation is composed mostly of mudstones and siltstones but thin beds of sandstone, limestone and conglomerate are present. Bentonitic clays are common and, according to Waters and Granger, (1953) may have supplied the silica which is abundant as cement. No uranium has been found in the Brushy Basin member in the Carrizo area.

CRETACEOUS

Dakota Sandstone - The Dakota sandstone is a series of interbedded sandstones and conglomerate. Very few beds of mudstone or carbonaceous shale are present, however, carbonaceous shale and coal is part of the Dakota sandstone near Beclabito Trading Post.

The widespread regional unconformity between the Dakota sandstone and the underlying Morrison formation is not evident in the Carrizo area.

The sandstones and conglomerates are highly silicified and resistant to erosion. Sandstones of the Dakota cap mesas such as Dinee Mesa (Toh Atin), forms resistant cliffs, or appears as ridges along monoclines. Impermeability of the coarse clastics may account for the absence of uranium which has not been found in the sandstone or conglomerates nor have radioactive anomalies been found in the carbonaceous or coal beds of the Dakota.

Mancos shale and Gallup tongue of the Mesaverde Group - The Mancos formation is a thick series of marine shales containing abundant invertebrate fossils. The Gallup sandstone, which is up to 150 feet thick in the area, intertongues with the Mancos. It is present outside the eastern edge of the Carrizo area as a ridge on the "Tocito" or Gallup monocline and within the area as a cliff high in the Carrizo mountains on Chezindeza Mesa. Associated with this cliff of Gallup sandstone are small areas of thick Mancos shale where the shale has been protected from erosion by sills of diorite. No uranium has been found in either the Mancos shale or in the Gallup sandstone.

No rocks younger than the Upper Cretaceous Mancos shale have been found in the area. Chuska sandstone of the Tertiary crops out several miles to the south in the Lukachukai Mountains.

Igneous Rocks

The Carrizo Mountain mass is a partly dissected, multiple laccolith associated with numerous sills, all covering an area of about 80 square miles. The intrusive rocks of the composite laccolith range from diorite to diorite porphyry. Diorite or diorite porphyry sills intrude rocks as young as Upper Cretaceous Mancos shale. Dikes, mostly biotite-rich minette and to less extent feldspar-free monchiquite, intrudes sections of the mountains and surrounding area (Williams, 1936). Both kinds of dikes are up to several feet thick and attain lengths of 2 miles. The position and extent of igneous bodies are shown on figure 6.
Several volcanic plugs, either minette or agglomerate, are distributed over the eastern half of the area. The contacts between dikes and intruded sedimentary beds, and between most plugs and intruded sedimentary rocks, are very smooth with very little displacement or alteration of the interbedded sediments. Metamorphism is limited to a few inches. Some silicification of sediments has been found at the contacts.

The best developed diatreme in the area is the "Eastside Diatreme" (Williams, 1936). Here minette is mixed with tuffs and agglomerate extruded from the diatreme. A collapse structure is well developed around this diatreme where all beds dip inward, toward the vent. Blocks of Mancos shale are present in the collapse at the stratigraphic level of the Summerville. No uranium or copper was found in the vicinity of this diatreme as has been found near diatremes in the vicinity of Red Mesa Trading Post in the northwestern part of the Carrizo area, and at Garnet Ridge several miles to the west. Two mines in the Salt Wash sandstone member on King Tutt Mesa are adjacent to minette dikes, but no uranium has been found in the dike.

Mine studies in the east Carrizo area have indicated that the uranium minerals were in place in the Salt Wash before intrusion of the dikes and plugs. It is suggested that uranium minerals found adjacent to the nearby dikes or plugs came from uranium minerals in an underlying host-rock cut by the dike or plug.

Plugs and dikes similar to those in the Carrizo area intrude the Tertiary Chuska sandstone in the Chuska Mountains, several miles to the south. Based on the similarity both of material and distribution, the intrusives of the Chuska Mountains and the dikes and plugs of the Carrizo area would be the same age. The diorite of the Carrizo Mountains is presumed to be older than the dikes and plugs. Supporting evidence is discussed under Structure.

The sequence of igneous rocks in the Carrizo Mountains, that is, earlier rocks more acidic and later rocks progressively more basic is also present near Grants, New Mexico.

Geologic Structure

The Carrizo Mountain multiple laccolith is the dominant topographic feature of the area and partly obscures earlier structures adjacent to the Carrizo Mountains.

The major regional structural features influencing the Carrizo area are the Defiance Uplift, San Juan Basin and the Four Corners Platform (fig. 6). The Defiance Uplift is expressed topographically by the Chuska and Lukachukai Mountains and by the Defiance Monocline. North of Fort Defiance near Sanostee, the Defiance mononcline begins to lose its identity and splits into a series of minor monoclins, anticlines and synclines.

The Lukachukai anticline with the adjacent Chuska syncline are northward extensions of the Defiance monoclinc. The Lukachukai anticline plunges northward beyond the Lukachukai Mountains and evidence of its extension northward beyond Cove Mesa is obscured by the later structure developed by intrusion in the Carrizo Mountains, however, the writer believes it to be present.

Another northward extension of the Defiance monoclinc passes just west of Beautiful Mountain and continues northward as Red Rock monoclinc. The writer proposes tracing an extension of the Red Rock monoclinc north and westward around the Carrizo Mountains and through Toh Atin anticline (fig. 7). The westward divergence of the monoclinc at the Carrizo Mountains would be caused by the Four Corners Platform. The Four Corners Platform was stable during the formation of the Defiance uplift and the downwarping of the San Juan Basin and stresses directed against it would be diverted to the west or east.
Another northward extension of the Defiance monocline is the "Tocito" or Gallup monocline which at its most northward recognizable limit begins to swing westward. Its merging with the Boundary Butte anticline appears probable.

The Hogback monocline which encircles the northwest area of the San Juan Basin is also a split from the Defiance monocline, diverted eastward by the Four Corners Platform.

Baker (1946) suggests that the monoclines are a result of flexure of sediments over deep seated faults. They may have been the result of differential uplift from horizontal stresses.

Studies of fractures in a belt partly circumscribing the Carrizo Mountains show several sets, (fig. 2). Several of these are common to both the Defiance monocline extensions and to the Carrizo uplift. It is suggested that the earlier fractures of the Defiance extensions would be merely accentuated by the later Carrizo uplift. The greatest increase in fracture intensity is radial to the Carrizo Mountains.

Joints tangential to the Carrizo uplift are more pronounced on Cove Mesa and in the east Carrizo area. They decrease in frequency westward around the Carrizos to Toh Atin anticline where the only joints are those radial to the Carrizos and by sets of shear joints (fig. 2).

The openness of joints in the east Carrizo area as seen in the Nelson Point No. 1 mine together with the suggestion of ring dikes near Walker Peak and Whirling Mountain (fig. 6) indicate a direct relationship to the Carrizo uplift.

Fractures of the Nelson Point mine do not have any relations to distribution of ore. The grade of mineralization does not increase in areas more intensely fractured nor are ore bodies elongated along fracture directions. By a comparison of paragenetic sequence and type of fracturing, it appears that the fractures in the mine were opened after the emplacement of the ore.

While direct evidence that distribution of ore is related to fractures caused by the Carrizo uplift is lacking, there are indications that some elongations of ore bodies, other than along the sedimentary trends, are parallel with joint sets (fig. 3) common to the Defiance monocline extensions. This evidence combined with the fact that all ore bodies of 500 tons or more of ore are on the Defiance monocline or extensions of this monocline.

Faults are rare and of small magnitude in the Carrizo area. Small faults (fig. 7), up to 1 foot of displacement, were found in the Nelson Point mine. These faults are post ore (fig. 9), and are related either to the nearby Eastside Diatreme or the nearby dike on King Tutt Mesa.

Radial fractures that have been filled by dikes are illustrated by dikes near Teec Nos Pas. Fractures tangential to the periphery of the Carrizo Mountains are well developed in the east Carrizo area and some are filled by dikes. Dikes at Walker Peak appear to be ring dikes. The abundance of dikes indicate the presence of throughgoing fractures capable of tapping a magma source (Bowen 1953). The dikes in the Carrizo area were too late to have supplied the uranium to the area, however, they do indicate a direction and mechanism from which earlier uranium-bearing solutions could have come.

Geologic History

The earliest record of sediments in the Carrizo area are questionable Cambrian and Ordovician terrestrial sediments. Silurian Rocks are absent.
Marine transgressions, started during the Devonian and continued through the Mississippian, left a series of marine limestones. Both marine and continental sediments were deposited in Pennsylvanian time. The emergence of the Pennsylvanian continued into the Permian period during which time terrestrial, mudstones and siltstones were deposited. The upper Permian is represented by the De Chelly sandstone. Absence of the Triassic Moenkopi formation suggests that the Carrizo Mountains area was probably emergent in early Triassic time. A succession of terrestrial clastics were deposited, followed by uplift recorded by the wedging out of the Kayenta and Navajo formations.

A period of downwarping began with the Carmel formation and extended through the shallow-marine or marginal marine environment in which the Entrada and Todilto formations were deposited. The western half of the area was higher during the deposition of the Todilto limestone and possibly was representative of the beginning of reemergence of the area for the deposition of the terrestrial Summerville and Bluff sediments. These were followed by the terrestrial Morrison formation which is gradational into the underlying Bluff. Intertonguing of the various members of the Morrison indicate differential amounts of uplift in the source areas of the different members.

No record of pre-Dakota erosion has been found in the area but regionally it is prominent. Deposition of the terrestrial and near-shore Dakota sandstone was followed by a general subsidence, entrance of the Cretaceous seas and deposition of the Mancos shale.

A break in the record occurs after the deposition of the Mancos shale as no younger sedimentary rocks are present in the area. It is possible that the Defiance fold was formed during Eocene or post-Eocene deformation recorded in the San Juan Basin. The Chuska sandstone, just south of the Carrizo area may be as old as Eocene or as late as Pliocene (Strobell, 1956). Dikes intrude the Chuska, south of the Carrizo area. As the dikes were later than the Carrizo laccolith, the Carrizos are probably pre-Chuska.

Post-Chuska uplift renewed erosion continuous to the present.

**URANIUM DEPOSITS**

All of uranium ore deposits of economic-size and grade in the Carrizo area are in the Salt Wash member of the Morrison formation. Other rocks that contain uranium ore deposits in other areas outcrop in the Carrizo area but to-date no uranium deposits have been found in them.

The extent of the Salt Wash member and approximate depths to the ore zones in the Salt Wash are shown on Figure 5. Ore bodies in the northwest Carrizo mining area, east Carrizo mining area and Cove Mesa mining area are larger in size and more frequent in occurrence than in other areas of the Carrizos (Figure 2). Most of the drilling projects carried out under Government auspices were concerned with relating uranium deposits to sedimentary features and to criteria of favorability. One project was intended to develop any possible relationship of uranium deposits to structure. The "structural" drilling program was not conclusive; the structure tested was a syncline with very gentle dips (Bollin et. al., 1959).

Drilling on a grid provided ample data concerning gross lithology of the area tested. Maps showing ratio of mud to sand in section drilled outlined "channels" indicative paleostreams. Maps of orebodies superimposed on the mud-sand ratio maps indicated the close relationship of ore to "channels" and the extension of clusters of ore bodies parallel to the paleostreams channel directions.
Stokes (1953) mapped stream directional trends over most of the Carrizo area, using such features as current lineation, rib and furrow marks, ripple marks and dips of cross-bed sets. Sedimentary trends obtained from these data on the outcrop can be used to project trends of paleostream flow into areas under cover. If uranium minerals are found on the outcrop or in a drill hole, a projection along the sedimentary trends observed in the area would be the direction in which to look for deposits, since alignment of ore with current direction of paleostreams appeared as a favorable criterion. Fences of holes perpendicular to the sedimentary trend would be most apt to find any hidden ore bodies.

Geologic mine mapping of the Rattlesnake Incline, Martin and Nelson Point No. 1 mines was done to determine the intimate association of orebodies to the host rock. Most of the uranium deposits in the Carrizo area are elongate about three times their width and are thin, as illustrated by those of the Nelson Point No. 1 mine (figs. 9, 11). Ore layers in the Nelson Point mine are about 1 foot thick; other mines contain ore layers averaging 3 feet thick and these may locally attain a thickness of 7 feet. Uranium ore bodies high in vanadium and up to 3,000 tons in size have been found. The uranium is almost invariably present in tyuyamunite. Distribution of ore bodies and mineral occurrences are shown on Figure 2.

Nelson Point No. 1 Mine

The Nelson Point No. 1 mine, on King Tutt Mesa in the east Carrizo area, is at the lower inflection of Red Rock monocline where sediments dip eastward about 3 degrees.

Two ore zones are present on King Tutt Mesa: the upper is 80 feet above the base of the Salt Wash sandstone member and the lower is about 40 feet above the same horizon. The Nelson Point No. 1 mine (fig. 11) is in the lower zone where thick red mudstones overlie and underlie the ore-bearing sandstone. Orebodies in the Nelson Point No. 1 are in planar-bedded flood plain deposits, as well as in cross bedded, channel-type deposits (figs. 10, 11). The grade of mineralization does not vary between the type of bedding. Longwall sections of the mine are shown on figure 11; other features are shown on plan maps (figs. 9, 10).

The mine contains both thick and thin-bedded sandstone beds and lenses (fig. 11). Thin beds of mudstone are present as well as mud-pebble conglomerates (fig. 11).

Structures resulting from paleostream flow, such as current lineation, ripple marks and cross bedding are frequent in the mine. These features indicate a source of the sediments to the northwest (fig. 10). Elongation of the ore bodies in the mine is parallel to the paleostream direction (fig. 10).

The following sections illustrate the relation of ore to lithology and sedimentary structures.

1. Section A-A' - The ore is in planar-bedded finer-grained sediments overlain and underlain by sandstone. The sandstone above the ore is well-cemented by calcium carbonate; the sandstone below the ore contains less carbonate cement but carried considerable limonite, especially along bedding planes. Thinner-bedded sandstones are less well-cemented with calcium carbonate than those more massively bedded. Both grey and red mudstones are present in the section.

2. Section B-B'-B" - The upper ore level is in very fine-grained sandstone and dies out at a lateral change into coarser-grained sediments. Very fine-grained sandstone overlies and underlies this ore layer and calcium carbonate is concentrated in and above the ore layer. The lower ore layer lacks the persistence of the upper. It is
in very fine-grained sandstone, very strongly cemented by calcium carbonate and rests directly on an eroded surface of a grey mudstone bed which grades laterally into siltstone. The mudstones in proximity to ore are gray and away from ore they are red. The upper ore layer averaged 1.37 percent U_3O_8 and the lower layer 1.38 percent U_3O_8. The vanadium percentage was much lower where the uranium content is high, 3.19 V_2O_5 compared to 8.23 V_2O_5 in the ore with the lower uranium content.

3. Section C-C'-C" - The main differences between this section which contains very little ore and others containing more, is that here there is less carbonate cement and more abrupt lateral changes in lithology: mudstone abuts directly the fine-grained sandstone of the section. Most of the mudstone in the section is grey but red mudstones are present. Section C'-C" is overlain by a relatively thick fine-grained sandstone as noted in the small raise.

4. Section D-D' - The upper ore layer is in the fine-grained sediments with fine-grained sandstone both above and below it, and the ore is presumably cut out by a bedding pinchout. The lower ore layer is a very fine-grained sandstone highly cemented with calcium and appears to at a lateral change from mudstone to siltstone.

5. Section E-E' - The upper ore layer is in siltstone with very fine-grained sandstone both above and below. One difference in this section from others is the heavy concentration of calcium carbonate in and below the ore layer. The lower ore-layer is in very fine sandstone, heavily cemented with calcium carbonate; it rests directly on a grey mudstone.

6. Section F-F'-F"-F"'- This section shows the change from planar bedded deposits to scour-and-fill bedding. The upper ore layer is cut out at a channel scour and the lower ore layer dies out at the channel scour. The scour-and-fill part of the section contains very little calcium carbonate and no ore but ore is found on both sides of the channel. Ore is found in other sections in the extension of this scour and where ore is found in the channel it is in more intricately cross-bedded parts.

7. East-West Section - This section shows a lateral facies change from siltstone to very fine-grained sandstone with the ore dying out with the change of siltstone to sandstone. The upper ore-bearing rock was apparently cut out at a bedding plane.

8. Section G-G' - The upper ore layer is in sandstone with an abundance of CaCO_3. Sandstone strongly cemented by calcium carbonate, and which lies immediately below this ore layer, is barren. The lower ore layer is in siltstone, which is a transition from mudstone to sandstone. Hematite-stained mudstone stringers are present below this lower ore zone, gray mudstone is absent. This section is parallel with a N 10 degrees E fracture plane partly filled with brown and black resinous material.

9. Section H-H' - The upper ore-layer is in siltstone and dies out at a gray mudstone-gall zone. The lower ore-zone, with sandstone above and below, transgresses stratigraphy in a southward direction to rest on gray mudstone, dies out then reappears at a zone of gray mudstone galls, i.e. at a sedimentary trap. No uranium minerals were found between the upper and lower ore layers along the mudstone-gall contacts.

10. Section I-I' - This section shows the ore is in siltstone, along bedding planes, except for scattered tyuyamunite in very fine-grained sandstone above the ore layer.

11. Incline Section, L-L' - Gray mudstones are limited to zones near ore. The thick mudstone layer above the ore contains limy nodules. The thick sandstone above the mudstone is clean and quartzose, with very little calcium carbonate cement.
12. Section K-K' - This section is near the edge of an ore body and the ore has a greater vertical distribution than is common. One ore layer dies out on one side of a channel fill then begins anew on the opposite side and continues partly through a gray mudstone and siltstone mass. A barren red mudstone lens directly abuts an ore layer at one place. Red sandstones are also adjacent to the ore zones here.

13. Section M-M' - The upper ore layer is in siltstone overlain by a gray mudstone and underlain by very fine-grained sandstone. Calcium carbonate did not appear to be concentrated in the ore zone but may be present and masked by the vanadium clays. From H' toward M a red mudstone changes to gray then intertongues with siltstone, then grades into a low-grade ore.

14. Section N-N' - This section is in an intensely cross-bedded area with the ore in siltstone layers and on sandstone bedding planes.

15. Entry Section O-O' - The ore is distributed over a vertical range of several feet with ore either in siltstone or sandstone. Small isolated sand lenses, above the main sandstone at mine level, contain tyuyamunite. The red mudstone surrounding these small lenses is altered to gray for a few inches away from the ore-bearing sandstones. These small lenses may be connected with the lower main sandstone back of the section but by a study of the incline section and data from gamma logs around the mine no such interfingering could be determined.

The sandstone beds in the mine are fine- to very fine-grained in texture. Quartz is the most abundant mineral, composing 75-85 percent of the rock. The quartz grains are subrounded to angular and poorly sorted. About 5 percent of the total silica present is chert and small amounts of silica is present as quartzite. Orthoclase and microcline with sparse plagioclase, similar in size and shape to the quartz grains compose 5-10 percent of the sandstones. Accessory detrital minerals are tourmaline, magnetite, hematite and rare zircon.

Most of the sandstone beds and lenses in the mine are gray but yellow, limonite-stained sandstones are common. Red sandstone is found at one place (fig. 11, Incline Section L-L').

Mudstones in the Nelson Point No. 1 mine are red except where they are in contact with uranium-bearing sandstone, here they are gray up to several inches away from the contact.

Carbonaceous material is present in ore-bearing rock as flakes and small debris concentrated along bedding planes. No carbonaceous logs were found in the Nelson Point No. 1 mine although they are quite common in the east Carrizo area. Carbon is abundant in barren areas as well as in the ore zones.

Gypsum is found associated with the carbon and independent of it as lining in small fractures in both mudstone and sandstone.

Limonite is more widespread in the mine than is carbon. The ferruginous material is more apparent in thin-bedded sandstones than in the more massive bedded clastics (fig. 11). Where limonite is abundant, calcium carbonate is sparse.

Calcium carbonate is abundant in clastics as a cement and in a few places sandstone grades into an arenaceous limestone (Corey, 1958). Such gradation indicates some carbonate was present as an original constituent. Study of thin-sections suggests that some was introduced later, and also that some of the carbonate was in place before the introduction of uranium and vanadium. This relationship is discussed under mineralogy.
The ore bodies in the Nelson Point No. 1 mine were parallel to the bedding planes and about three times as long as wide, the elongation being parallel to the sedimentary trend (fig. 10). All of the uranium present is in tyuyamunite; vanadium is in a wide variety of minerals.

Uranium-vanadium ore is found more frequently in very fine-grained sandstone and siltstone than in coarser clastics. When ore-bearing siltstone grades laterally into sandstone the ore dies out. In some places tyuyamunite does occur in the coarser sediments and in these places the uranium content is higher than in the finer-grained sediments. Where tyuyamunite is found in sandstone, it is always accompanied by heavy concentrations of calcite. Uranium without calcium carbonate has not been found in the Nelson Point, the Rattlesnake or Martin mines.

Tyuyamunite is a common uranium-bearing mineral of secondary origin in many deposits on the Colorado Plateau. It is assumed to be secondary in Carrizo mines, although no stages of its transition from a primary mineral were found. As a secondary mineral, it is certain to be younger than calcite of the diageneric stage of sedimentation. Calcium carbonate is far more widespread than either uranium and/or vanadium-bearing minerals. It is not considered to be a genetic associate but rather the carbonate is an index to permeability and suggests that permeability in zones where ore is now found was superior and that uranium-vanadium solutions had ready access.

Joints in the Nelson Point No. 1 mine are in two sets: N 8-12 degrees E and N 83 degrees W to due west; these directions are tangential and radial to the Carrizo Mountains and to ore the conjugate, tensional joints of the preexisting fold. Most of the joints are straight and smooth walled, suggestive of regular jointing of a homogenous body. The best examples of regular jointing were in the planar bedded part of the mine; only a few irregular or curved joints were found and these in rock not well-cemented by calcium carbonate. It is possible that bonding by calcite supplied the homogeneity which resulted in smooth jointing in heterogenous clastics. If so, calcite is pre-jointing in age.

Sandstone containing little or no calcite tended to fracture on curved lines (fig. 11, Section F-F'). No joints were found to be completely filled with calcite; however, some calcite crystals were found coating open joints. Vertical, or near vertical, joints may be open as much as one-half inch.

Tyuyamunite was found on joint surfaces only in the immediate vicinity of the ore body. No alteration of red to gray was found on joints in mudstone either above or below ore bodies.

The elongation of ore bodies is not parallel to the joint set directions (fig. 9) and intensity of mineralization does not appear to have any direct relation to jointing.

Three small faults were found in the Nelson Point mine; all are post ore. One of these faults is shown on fig. 12.

Martin and Rattlesnake Incline Mines
by
Victor A. Means and Ronald K. Labrecque

The Martin mine (figs. 16 & 18) and the Rattlesnake Incline (figs. 19, 20, & 21) in the northwest Carrizo area, are on the southwest and northeast flanks, respectively, of the Toh-Atin anti-cline. At the Martin mine the host rock, the Salt Wash sandstone member of Morrison formation, has a strike of approximately N 50 degrees W and a dip of approximately 1 1/2 degrees SW. At the Rattlesnake mine attitude of the Salt Wash member
is N 75 degrees W; 6 1/2 degrees NE.

In the Martin mine the upper parts of the drifts are mostly in crossbedded sandstone, whereas the lower parts of the drifts are largely in nearly flat-lying sediments. (See especially sections D-D', F-F', and G-G', fig. 13). In the Rattlesnake Incline, the workings are almost entirely in crossbedded sandstone. In both the crossbedded and essentially horizontally-bedded portions there are considerable amounts of intercalated mudstones and siltstones. These units are usually thicker and more numerous in the nearly flat-lying beds, although a few thick irregular mudstones and mud-gall conglomerates are seen in the crossbedded zones (for example, section C-G', fig. 18). The crossbedded portions consist in large part of sandstone lenses "nested" into one another. A common feature of contacts between the lenses are zones approximately one to six inches thick of silty or silty and clayey sandstone, with numerous mud galls (for example, section R'-U'-V'-W', Rattlesnake Incline mine, fig. 21). Less often the contact between sandstone lenses is marked by fairly continuous thin beds, or "stringers", of mudstone or siltstone (for example, section A-B-C, Rattlesnake mine, fig. 21).

In the Martin mine most of the ore, montroseite and tyuyamunite, are in the upper, crossbedded zone, although a considerable amount of both occurs just below the crossbedded zone, and some well below it. (See sections C-C' and F-F', fig. 18).

In the Rattlesnake Incline mine, where the units are mainly imbricated sandstone lenses, the ore minerals are found most frequently in or adjacent to the zones of finer material marking the contacts of the sand lenses (for example, sections S'-T' and R'-U'-V'-W', fig. 21). The same statement applies to the Martin mine, but to a lesser degree, because there the mineralized and ore zones are larger and frequently extend through several sandstone lenses and the argillaceous contact zones between them (sections F-F' and G-G', fig. 18). Also, in the Martin mine many of the large irregular mud gall zones in the crossbedded portion of the host have been strongly mineralized (section C-G', fig. 18).

In both mines the zones of dark gray to black montroseite-bearing material coincide, for the most part, with the radioactive zones containing disseminated oxidized uranium minerals, chiefly tyuyamunite. There are exceptions to this general rule, however, and there are places where either montroseite or tyuyamunite occurs without the other (in Martin mine, fig. 18, sections E-E', F-F' and J-J'). In the Rattlesnake Incline particularly, there are a number of dark gray to black, montroseite-bearing zones, usually parallel to the lamination within sand lenses, which occur without uranium (for example, section P-Q). Also in the Rattlesnake Incline many of the mud gall zones separating sand lenses contain considerable tyuyamunite, with little or no montroseite (section R'-U'-V'-W').

Both mines contain large amounts of carbon trash, and it is likely that there is some genetic relationship between the mineralization and the carbonaceous material. However, many of the ore zones have little or no megascopic carbonaceous material, and many of the carbonaceous zones are not mineralized. (For uranium mineralization without visible carbonaceous material see sections S'-T', R'-U'-V'-W', and W-X-Y, Rattlesnake Incline mine, fig. 21, and sections C-C' and F-F', Martin mine, fig. 18; for concentrations of carbonaceous material with no apparent mineralization see sections C'-D' and I'-J', Rattlesnake Incline mine, (fig. 21), and sections H-U' and J-J', Martin mine, fig. 18).

In general, the most strongly mineralized zones contain the highest content of limonite, although there are exceptions (sections D-D' and F-F', Martin mine, fig. 18, and sections R-S, U-V, Rattlesnake Incline mine, fig. 21). The upper, crossbedded
portion of the Martin mine, for example, has on the average, a stronger brownish tinge than the lower, more horizontally-bedded portion. In a few places in the Martin mine, small (1/4 inches, approximately) oval masses of tyuyamunite with limonitic centers are observed.

Some of the mudstones, siltstones, and mud-gall beds have limonite stain; this is especially true of many of the mineralized mud-gall zones in the Rattlesnake Incline mine, where practically all of the mud-galls in some of the zones are completely or partially limonite-stained (section A'-B'-C'-D', Rattlesnake mine, fig. 21 and section G-G', Martin mine, fig. 19). In the northwestern portion of the Rattlesnake Incline mine, where mineralization is sparse, there is a considerable amount of red staining of mudstones and mudstone galls (sections J'-K'-L', Q'-R', U'-X', Y'-Z', A''-B'', C''-D'', E''-F'', and G''-H'', fig. 21). This is probably hematite staining, although possibly in part it may be staining by an oxidized vanadium mineral. The mudstone and siltstone are medium gray or greenish gray where not stained by oxidized iron or vanadium.

Interstitial carbonate is abundant in both mines, especially in the Martin mine. Most of the carbonate is unstained, although there are considerable amounts of limonite stained carbonate. In the Martin mine where ore is abundant, carbonate is also abundant, whereas in the barren connecting drifts carbonate is sparse and the sandstone is much more friable, due to the absence of cementing material (sections C-C' and H-H', fig. 18).

Gypsum is common in both mines; it is concentrated chiefly in logs and other carbonaceous fragments.

There appears to be very little control of mineralization by fractures in either mine. Some of the smooth joint surfaces in the sandstones of high carbonate content have coatings of tyuyamunite. Obviously there has been redistribution of uraniferous material since time of jointing.

By combining all data from mine-mapping, the following deductions can be drawn.

1. Most of the uranium ore bodies throughout the Carrizo area are elongate parallel to the sedimentary trends of the host rock and tend to occur in clusters aligned parallel to the same trends as shown on fig. 4.

2. Clusters of ore bodies on the west side of the Carrizo Mountains have the same alignment as clusters on the east side of the Carrizo Mountains (fig. 13).

3. Uranium ore deposits are more likely to occur in scour-and-fill type bedding than in planar bedding. It has not been proved that cross-bedding has mechanically induced precipitation of uranium from solutions by such processes as restriction of solution flow, change in speed, or "damming" of solutions. Mapping of crossbedded zones in mines did not give any indication of concentration of uranium at pinchouts between cross sets or consistancy in any one end of a cross set. This precludes the possibility of determining the direction of migration of the uranium solutions.

4. Thick homogeneous sandstones are barren of uranium ore bodies. The upper two-thirds of the Salt Wash member throughout the Carrizo area is nearly homogeneous sandstone and is lacking in uraniferous minerals (fig. 4).

5. Most uranium deposits were found in areas of alternating mudstone and sandstone beds, that is, at a lateral change in facies from predominantly sandstone to predominantly mudstone. The lower one-third of the Salt Wash contains such facies changes, both laterally and vertically. The lower third of the member contains all of the known ore bodies in the area.
6. Gray sandstone and gray or green mudstones are regarded as an index to nearby mineralization; red or brown colors are unfavorable features. Regardless of whether red sandstones or mudstones were bleached by uranium solutions or merely indicate permeable pathways for other solutions, uranium ore bodies tend to occur in gray or green sediments; however, red or brown sandstone or mudstone may be very near to uranium deposits either vertically or laterally as shown by sections in the Nelson Point No. 1 mine.

7. There is a conspicuous tendency of secondary uranium and vanadium-bearing minerals to concentrate in sandstone containing high percentages of silt, clay, and mud galls, as shown in the Rattlesnake Incline and Martin mines.

8. Uranium is common in siltstone particularly in the lateral facies change between mudstone and sandstone as shown in the Nelson Point mine.

9. Carbonaceous material is abundant and there may be a relationship between carbonaceous material and uranium but consistent positive evidence of the relationship is lacking.

10. A close relationship exists between interstitial calcium carbonate and uranium as found in all three of the mines mapped. This relationship is fortuitous because study of thin-sections suggests the uranium-bearing solution appeared before all carbonate was finally emplaced. The interstitial calcium carbonate is an indicator of a permeable zone.

11. Limonite is generally associated with uranium but sediments containing high concentrations of limonite are generally barren. Small limonite specks and stains surrounded by tyuyamunite indicate possible oxidation in place of pyrite and primary uraninite or coffinite.

Mineralogy

The petrographic studies of the Nelson Point No. 1 mine and the Martin mine were made by Alice S. Corey (1955, 1958). Other mines in the area contain the same mineral suite except for the abundance of vanadium minerals in the Nelson Point No. 1 mine. Megascopically at least, the mineral associations appear to be the same as in the two mines studied. The ore is very near equilibrium: Chemical assays are very slightly higher than radiometric.

No primary uranium minerals were found in either mine; tyuyamunite is the only uranium mineral found in the area. In the presence of calcite and vanadium, the uranium set free in complete oxidation of the unknown primary mineral, was quickly fixed in tyuyamunite. The uranium content of ore in the Nelson Point mine averages about .33 percent $U_3O_8$ and vanadium ranges up to 6.0 percent $V_2O_5$. The uranium content in the ore in the Martin mine averages about .25 percent $U_3O_8$ and the vanadium, 2.59 percent $V_2O_5$.

Most of the vanadium in the Nelson Point mine is present in clay, probably as trivalent substitution for aluminum, and lesser amounts as tyuyamunite, montroseite, sherwoodite, barnesite, duttonite, rossite, and an unknown vanadium mineral. Vanadium in the Martin mine is in tyuyamunite, vanadium-bearing clay, and montroseite.

Vanadium clay is found in lamellar flakes, sometimes bent around detrital grains. The vanadium clay appears to be earlier than the calcite cementing the detrital grains. Montroseite needles are found enclosed in the calcite cement in both mines. Other vanadium minerals appear to be later than the calcite cement. The calcium carbonate may
have been in the host rock before the introduction of ore solutions but the final distribution of calcite took place after the ore minerals were precipitated, after part of the vanadium was oxidized.

Much of the vanadium is present in the trivalent and tetravalent states and minerals containing it are assumed to be primary. It is suggested that the invading uranium-vanadium solutions with vanadium in the +5 oxidation state were introduced. The vanadium was reduced by some constituent such as ferrous iron from pyrite or carbon. Where conditions were strongly reducing, +3 vanadium was formed and where less reducing, +4 vanadium was formed.

No primary uranium minerals were found in either mine and a direct relationship between originally deposited uranium and the host rock cannot be determined except by inference. The uranium may have been precipitated directly as a uranyl vanadate and not as uraninite or coffinite. Nevertheless, tyuyamunite was found surrounding spots of limonite indicating oxidation in place; the limonite oxidized from pyrite and the tyuyamunite from either uraninite or coffinite. Pyrite is very rare in the ore zones but is inferred to have been present because of the presence of specks and stains of limonite.

Vanadium replaced aluminum in the lattice of clay minerals forming vanadium clays and montroseite was found penetrating quartz and quartz grains along crystal faces. Most of the ore is interstitial filling.

Paragenesis (After Corey 1958)

1. Introduction of uranium-vanadium-bearing solution into Salt Wash sediments
2. Erosion and oxidation
3. Introduction and/or recrystallization of calcite.

Vanadium Distribution

Averages of vanadium percentages from many samples taken by Union Mines Development Corporation and others were plotted on an area map to develop evidence of zoning around the Carrizo Mountains. Percentages of vanadium were plotted instead of ratios of vanadium to uranium because of the large variation in ratio in a given locality opposed to the relatively constant vanadium percent value for a given locality. When the vanadium percentages were overlain on an area structure map (fig. 5), it is evident that the areas of highest vanadium content, 4–5 percent V₂O₅, are adjacent to the Carrizo Mountains indicating that solutions related to the Carrizo Mountain intrusives may have been the loci of vanadium-bearing solutions.

Geochemical Studies

Geochemical studies were made in the northwest Carrizo drilling area (Bollin et al., 1959) in search of relations between uranium and other heavy metals. The dithiazone method was used on samples from wagon-drilled holes to determine percentages of lead, zinc and copper. Contamination of the samples in the hole helped to distort evidence of any real relationship between percentages of uranium and heavy metals.
The following chart, compiled from data gathered during several different drilling and mine-mapping projects in the Salt Wash member, evaluates as either good, fair or poor, various favorability-criteria.

### Favorability Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Salt Wash Member</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NW Carrizo Area Drlg.</td>
</tr>
<tr>
<td></td>
<td>Mine Npg.</td>
</tr>
<tr>
<td></td>
<td>East Carrizo Area Drlg.</td>
</tr>
<tr>
<td></td>
<td>Mine Npg.</td>
</tr>
<tr>
<td></td>
<td>Cove Mesa Drlg. Only</td>
</tr>
<tr>
<td></td>
<td>Area Wide</td>
</tr>
<tr>
<td>Crossbedding</td>
<td>-</td>
</tr>
<tr>
<td>Interbedded mudstone &amp; sandstone</td>
<td>G</td>
</tr>
<tr>
<td>Sedimentary trend extension</td>
<td>G</td>
</tr>
<tr>
<td>Gray or green color</td>
<td>G</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>F</td>
</tr>
<tr>
<td>Organic debris</td>
<td>G</td>
</tr>
<tr>
<td>Limonite</td>
<td>G</td>
</tr>
<tr>
<td>Interstitial clay</td>
<td>-</td>
</tr>
<tr>
<td>Pyrite</td>
<td>-</td>
</tr>
</tbody>
</table>

(1) if not too extensive;

(2) most pyrite had been oxidized to limonite;

(3) good or poor, may be a permeability barrier or a precipitant of vanadium;

Combined with the above favorability criteria is the fact that all the uranium deposits in the Carrizo Mountains area are on structure. That is, statistically speaking, the most favorable areas for the accumulation or finding of uranium would be at the intersection of favorable host rock with structure. Actual positioning of clusters of ore bodies in this area fall within this pattern (fig. 14).

### Origin of the Uranium Deposits

The problem of determining the origin of uranium deposits contains many facets. Features influencing the precipitation of uranium, along with both horizontal and vertical pathways for uranium-bearing solutions must be considered before attempting to trace the uranium to its ultimate source. An attempt to place the deposition of the uranium in time is also a necessary factor.

Previous workers in the Carrizo Mountains area state that tectonic structure does not control ore bodies and make the inference that the ore districts in the area are not influenced by structure.
As stated before, most of the ore bodies in the Carrizo area are elongated parallel to the sedimentary trend and clusters of ore bodies are aligned parallel to the sedimentary trends, evidence that uranium-bearing solutions moved laterally through the host rock. Added to this are indications of ore body elongation parallel to fracture sets, suggesting some fracture control of ore bodies.

In addition to a northwest alignment of clusters of ore bodies in accord with the sedimentary trend, there is a north alignment of clusters of ore bodies on both the east and west side of the Carrizo Mountains. Extension southward of the north alignment comes through the ore bodies in the Lukachukai Mountains and the uranium deposits at Sanostee. This north alignment has no relation to sedimentary trends but does have a marked relationship with structure. All ore bodies of 500 tons or more that have been found in the Carrizo, Lukachukai and Sanostee areas are on monoclines, synclines, and anticlines (fig. 6). Small deposits of uranium and prospects are found at distances up to 10 miles away from any discernible structure, but no commercial ore bodies are found so far removed from structure.

The following are examples of ore on structures: (1) Ore bodies are concentrated on the flanks of Toh Atin anticline, the majority of the ore bodies are on the steeper 7 degrees flank of the anticline; isolated and smaller ore bodies are on the shallow 30 degree flank of the anticline (fig. 7); (2) Ore bodies of the east Carrizo area are concentrated at the lower inflection of Red Rock monocline (fig. 6); (3) Cove Mesa mines and ore bodies are at the "nose" of the Lukachukai anticline (fig. 6).

Just outside the Carrizo area, the ore bodies in the Lukachukai Mountains are on a flank of the Chuska syncline (Nestler and Chenoweth, 1958). They also state that ore bodies in the Lukachukai Mountains are present only in areas containing north-south shear fractures related to the syncline. At Sanostee the ore bodies are on the flank of the Defiance monocline.

If structure were a factor in uranium emplacement, it would be as a structural trap, petroleum type deposits, or as an area containing near-vertical channelways such as fractures. The irregular positioning of ore bodies on structure and without regard to type of structure would indicate that emplacement of uranium was not a result of a structural trap. The other alternative would be that fractures inherent in the structures would be channelways for either rising or descending uranium-bearing solutions.

According to Bowen (1958) if a fault exists in the basement rock (fig. 15a) sedimentary beds at the fault would be distorted in the zone ABC either by fracturing (competent beds) or flowage (incompetent beds). Easiest upward release, if a hydrothermal source is considered, would be from Points A and B, with some upward release at any point between A and B. Whether A or B would be chosen as a channelway would depend on the amount of hydrostatic pressure of the uranium-bearing solutions.

Competent beds directly overlie the basement rock in the Carrizo area, they are the Ignacio quartzite (?) and Mississippian limestones, which would fracture the way Bowen suggests. Farther south at Sanostee the basement is overlain by more incompetent beds, lower Cutler mudstones, and ore has not been found to be as abundant as in the Carrizo area. If a source of fluids from below were considered, this difference in types of rock in contact with the basement may be the reason for the difference in amount of uranium in the two areas.

The wide distribution of dikes in the Carrizo Mountains area and surrounding areas are taken as evidence of throughgoing fractures, thus voiding any inference that formations containing thick mudstones, such as the Cutler and Chinle, would be a barrier.
for vertical migrating solutions.

If a fault is not present under a monocline (fig. 15b) and the monocline is formed by either horizontal compression, shortening, or by differential uplift, a tension fracture zone will be present in the area ABC. Uranium-bearing solutions would have vertical access upward or downward through this zone.

Either a fault in the basement rock, a tension fracture zone or a combination of both would be an ideal place for the localization of rising or laterally migrating uranium-bearing solutions.

The existence of uranium in different stratigraphic levels; Salt Wash in the Carrizo area; Salt Wash, Recapture, and Todilto in the Sanostee area indicate vertical movement of migrating uranium solutions.

These solutions could have two sources either syngenetic, that is uranium already in the host rock moving laterally and vertically, or may have had a local origin from below, either on of which would be influenced by vertical pathways of release due to hydrostatic pressure of the fluids.

It is possible that the amount of uranium-bearing solutions entering a host rock would determine the pattern of an ore body. Greater amounts of solutions would tend to show a more marked relationship to structure such as fractures by thickening and for higher percentages whereas lesser amounts of solutions would be more the sedimentary trends, (Bowen, personal communication).

The apparent zoning of vanadium around the Carrizo Mountains indicates the loci of the source of the vanadium was local. The close relationship of uranium to vanadium and the existence of larger ore bodies only on structure indicate that the source was local and the writer believes that the uranium-bearing solutions came from below, moved upward through fracture zones to the host rock and then spread out through the host rock along sedimentary trends.

**SUMMARY AND CONCLUSIONS**

The formations in the Carrizo Mountain area range from the Cutler of Permian age through the Mancos shale of Cretaceous age, and they are intruded by a dioritic laccolith and the dikes associated with it. Before the diorite was emplaced, however, the region had been folded and faulted; older structures thus formed include the Defiance uplift, the San Juan Basin, and the Four Corners Platform.

All of the known deposits of uranium ore are in the Salt Wash member of the Morrison formation, and several of them have been drilled under federal auspices.

Maps of orebodies superimposed on mud-sand ratio maps indicate a close relationship of the ore to channels, and clusters of ore bodies are parallel to the paleostream channels.

Paleostream directional-trends were obtained by using such sedimentary features as current lineation, rib and furrow marks, ripple marks, and cross-bedding. These trends were used, in conjunction with outcrops of uranium minerals, to project the trends of the paleostream channels, and the possible position of additional uranium ore in them.

The Rattlesnake Incline, the Martin, and the Nelson Point No. 1 mines were mapped to determine the association between orebodies and the host rock. Orebodies range from about 1 to 7 feet in thickness, and bodies of as much as 2,000 tons of ore were found in channel-type sediments.
At the Nelson Point No. 1 mine structures resulting from paleostream flow are common, and orebodies are elongated parallel to them and are about three times as long as they are wide. Mudstones are red except where they are in contact with uranium-bearing sandstone where they have been bleached to gray for several inches away from the contact. Carbon is abundant in barren rock as well as in ore, and gypsum occurs with it as linings in small fissure both in mudstone and sandstone. Limonite is even more widespread than the carbon. Where limonite is abundant, calcite is sparse although it is locally so abundant as to form arenaceous limestone.

Uranium-vanadium ore is more abundant in very fine-grained sandstone and siltstone than it is in the coarser clastics.

The common secondary uranium mineral is tyuyamunite, and uranium without calcium carbonate has not been found in these mines. It should be noted, however, that no primary uranium mineral has been found. Intensity of mineralization does not seem to be related to jointing, and the three small faults mapped are post-ore.

The Martin mine and the Rattlesnake Incline are on the southwest and northeast flanks, respectively, of the Toh-Atin anticline. Although most of the ore at the Martin mine (montroseite and tyuyamunite) is in the upper crossbedded zone, a considerable amount of ore lies just below the crossbedded zone, and some ore is well below it.

In the Rattlesnake Incline mine most of the strata are imbricated lenses of sandstone, and the ore minerals (tyuyamunite and montroseite) are in or adjacent to zones of finer sediments that mark the contacts of the sand lenses. This relationship also applies in part to the Martin mine, but there the ore zones are larger, and many of them extend through several sand lenses and the intervening contact zones. Here, also, many of the large irregular zones of mud galls have been mineralized.

In both mines the zones of dark gray to black montroseite-bearing rock coincide essentially with the radioactive zones that contain disseminated oxidized uranium minerals, chiefly tyuyamunite. Montroseite and tyuyamunite are not, however, always together.

Many of the carbonaceous zones are not mineralized, and some of the mineralized zones contain little or no megascopic carbonaceous material. With few exceptions, however, the most-strongly mineralized zones are highest in limonite.

Carbonate in the Martin mine is abundant in the ore but is sparse elsewhere.

Jointing seems to have had little effect in localizing ore.

It is concluded that most of the uranium ore bodies throughout the Carrizo area are elongated parallel to sedimentary trends on both the east and west sides of the Carrizo Mountains. The ore deposits are mostly in scour and fill sediments with interbedded gray or green mudstone, and not in thick homogeneous sandstones nor in red and brown sediments. The secondary uranium minerals are concentrated in sandstones that have a high percentage of silt, clay, and mud galls. Uranium is common in siltstone, particularly adjacent to sandstone, and a close relationship exists between the uranium and interstitial calcium carbonate, but evidence of a direct proportional relationship between uranium and carbonaceous material is lacking. Although the sediments high in limonite are barren, small specks and stains of limonite surrounded by tyuyamunite indicate possible oxidation of pyrite or primary uraninite or coffinite in place.

Petrographic studies show that tyuyamunite is the only uranium mineral found in the area. The ore from the Nelson Point No. 1 averages about 0.33 percent uranium oxide.
Most of the vanadium in the Nelson Point mine is in vanadium clay, and most of that in
the Martin mine is in tyuyamunite. Much of the vanadium is in the 3 and 4
valence-states, and the minerals that contain it are believed to be primary; inasmuch as
it is assumed that the vanadium was introduced in the 5 valence-state, it may have been
reduced by ferrous iron from pyrite, or by carbon.

The distribution of the vanadium indicates that vanadium-bearing solutions rose
around the perimeter of the Carrizo Mountains.

The best favorability features to guide the search for ore are (1) interbedded
mudstone and sandstone, (2) sedimentary trend extensions, (3) gray or green color, (4)
organic debris, and (5) limonite.

It is concluded that the uranium-bearing solutions moved upward through fracture
zones, and spread out along sedimentary trends in the host rocks.
REFERENCES


Harshbarger, J. W., 1946, Supplemental and summary report on the western Carrizo uplift and Chuska Mountains area of the northern Navajo Indian Reservation, northeastern Arizona: Union Mines Development Corp. RMO-441, open-file report.


Figure 1. Location map of the Carrizo Mountains area
Figure 2 is found at end of report
Figure 3
GENERALIZED SECTION
CARRIZO MOUNTAINS AREA
Figure 4 Isopach map of the Salt Wash, also showing sedimentary trends and typical sections
Figure 5. Approximate drilling depths to Salt Wash ore zone
FIGURE 6 is found at end of report
Figure 7 Structure contour map of Toh Atin anticline, showing distribution of ore bodies.
(a) Alignment of ore bodies along sedimentary trend
- ore body, King Tut Mesa

(b) Elongation of ore bodies, Cove Mesa area
- sedimentary trends

(c) Elongation of ore bodies, east Carrizo area

(d) Elongation of ore bodies, northwest Carrizo area

Fig. 8 Alignment of ore bodies, and histograms showing elongation of ore bodies, Carrizo mountains area.
Figure 9: Plan of Nelson Point
No. 1 mine showing fractures
Figure 10. Plan of Nelson Point No. 1 mine showing sedimentary features.
Figure 11 is found at end of report
Figure 12. Section showing reverse fault displacing ore zone
Figure 13. Sedimentary trend favorability map, using straight line projection from known clusters of ore bodies along sedimentary trends.
Figure 14 Structural favorability map. Salt Wash et al. Assumed 2 miles either side of axis as favorable.
Figure 15a. Possible deep-seated fault underlying a monocline.

Figure 15b. Possible tension fracture zone underlying a monocline.
Figure 16 is found at end of report.
EXPLANATION OF SYMBOLS

**SANDSTONE**, unstained, or only slightly stained, without concentration of carbonate. Color chiefly light yellow. Chiefly fine-to-med fine-grained. Chiefly laminated, non-massive, parallel lines indicate direction of lamination in plane of section.

**SANDSTONE**, same as above, with zone of dark gray to black ss., due to vanadium mineralization (chiefly montroseite).

**MUDSTONE & SILTSTONE** in beds, thin "stringers", irreg masses, and "galls", in ss. Mudstone except where labelled. Color chiefly light yellow. Chiefly fine- to med fine-grained. Chiefly laminated, non-massive, parallel lines indicate direction of lamination in plane of section.

Concentration of SECONDARY CaCO₃ in ss. Chiefly unstained or only slightly stained. Where strongly stained, labelled St.

▲▲▲ **CARBONACEOUS MATERIAL**

Low Grade

High Grade

OXIDIZED URANIUM ORE AND MINERALIZATION — chiefly tyuyamunite.

**ABBREVIATIONS**

- Lim — Strong limonite staining
- Hem — Strong hematite staining in ss
- m — Mottling in mudstone and siltstone: brown or red spots or zones in otherwise gray or green ms and sts. Cause of staining indicated in parenthesis, as m(lim) and m(hem).
- Sts — Siltstone
- Sty — Silty
- St — Strong ankeritic staining in secondary carbonate zones.
MARTIN MINE ~ SHEET 1 OF 9
LONG-WALL SECTIONS A-A' & B-B'

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'

VM, R.L.
March, '56
MARTIN MINE ~ SHEET 2 OF 9

LONG-WALL SECTION C - C' (First Sheet)

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'

vm, rl
March, '56
Figure 18

MARTIN MINE ~ SHEET 9 OF 9

LONG-WALL SECTION C - C' (Second Sheet)

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'

VM. RL
March, '56
Figure 18

MARTIN MINE ~ SHEET 4 OF 9
LONG-WALL SECTION D-D'
Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'
Figure 18

MARTIN MINE ~ SHEET 5 OF 9

LONG-WALL SECTION E - E'

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'
This ore-bearing mud-pellic conglomerate contains much CO₂ (both stained and unstained) and some scattered limonite.

Figure 18

MARTIN MINE ~ SHEET 7 OF 9

LONG-WALL SECTION G - G'

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'
Figure 18:

MARTIN MINE ~ SHEET 8 OF 9

LONG-WALL SECTION H-H'

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'
Figure 18

MARTIN MINE ~ SHEET 9 OF 9

LONG-WALL SECTION J - J'

Hor. Scale: 1" = 10'
Vert. Scale: 1" = 5'
Note: A map showing the location of the longwall sections (Fig. 21) cannot be located in February 1982.

Figure 19 Plan map of the Rattlesnake Incline Mine
**EXPLANATION**

- Contact between ss lenses
- Mud gaps and thin lenticular beds (most of the muddy zones are strongly limonitic)
- Secondary CaCO₃ cement
- Vanadium mineralization (chiefly montroseite)
- Uranium mineralization (chiefly tyuyamunite)

(For detailed lithologic descriptions, see legend on separate sheet)

Some mud gaps in this region of very weak mineralization are stained with hematite.

**Figure 20a**

Rattlesnake Incline mine
N. W. Corriza Area
Geology on horizontal plane at elevation 5521 (approx)

Regional strike N 75° W
Regional dip 6 1/2° NE

50 25 0 50 feet

SCALE
EXPLANATION

- Contact between ss lenses
- Mud galls in ss (mud galls zones are strongly limonitic)
- Secondary CaCO₃ cementation
- Carbonaceous material
- Vanadium mineralization (chiefly montrosaite)
- Uranium mineralization (chiefly tyuyamunite)

(For detailed lithologic descriptions, see legend on separate sheet)

Note: Plan of mine workings is a horizontal projection; geology shown only for elevation 5525 (approx)
Regional strike: N 75° W
Regional dip: 61/2° NE

Figure 20b
Rattlesnake Incline mine
N. W. Carrizo Area
Geology on horizontal plane at elevation 5525 (approx)
EXPLANATION

- Contact between ss. lenses.
- Mud galls in ss. (mud galls zones are strongly limonitic.)
- Secondary CaCO₃ cementation.
- Carbonaceous material
- Vanadium mineralization (chiefly montroseite)
- Uranium mineralization (chiefly tyuyamunite)

(For detailed lithologic descriptions, see legend on separate sheet).

Figure 20c
Rattlesnake Incline Mine
N. W. Carrizo Area
Geology on horizontal plane at elevation 5532 (approx.)

Note: Plan of mine workings is a horizontal projection; geology shown only for elevation 5532 (approx.).
Regional strike: N 75° W
Regional dip: 6 1/2° NE
RATTLESNAKE INCLINE MINE
(N.W. CARRIZO MTNS. AREA)
LONG-WALL SECTIONS

FIGURE 21

V.A. Means
Ronald Labrecque
June, 1956

Sheet 3 of 5
RATTLESNAKE INCLINE MINE
(N.W. CARRIZO MTNS. AREA)
LONG-WALL SECTIONS

LEGEND

A.D.P. — Assumed Datum Plane

5' 0' 5' 10'
Hor. & Vert. Scale

FIGURE 21
V. A. Means
Ronald Labrecque
June, 1956
Figure 2. Geologic map of the Carrizo Mountains area, Apache County, Arizona, San Juan County, New Mexico.
Figure 6. Map showing structure, igneous rocks, and uranium-vanadium analyses in the Carrizo Mountains and vicinity.
Figure 16. Plan map of Martin Mine showing location of longwall sections.