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# GEOLOGY AND URANIUM-VANADIUM DEPOSITS IN THE SALT WASH MEMBER, MORRISON FORMATION, KING TUTT MESA AREA, SAN JUAN COUNTY, NEW MEXICO

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**Abstract**—Uranium and vanadium minerals were first discovered in 1918 in the King Tutt Mesa area in the east Carrizo Mountains. These minerals in the east Carrizo Mountains are restricted to the Salt Wash Member, the basal member of the Jurassic Morrison Formation, which was deposited in an eastward prograding fluvial system. The ore bodies at King Tutt Mesa tend to parallel fluvial, paleostream channels in the lower third of the Salt Wash Member and are restricted to discontinuous paleostream channel sandstones that are separated by thin lenses of siltstones, shales and mudstones. The ore bodies tend to form small, irregular, subhorizontal clusters that are elongate and blanket-like; only a few ore bodies have yielded more than 1000 lbs of $U_3O_8$. The deposits at King Tutt Mesa are high in vanadium, unlike most uranium deposits in the Grants district in New Mexico; the U:V ratio averages 1:10 and ranges from 1:1 to 1:16. Most models for formation of sandstone-hosted uranium deposits suggest deposition at a ground-water interface between two fluids of different chemical compositions and/or contrasting Eh conditions. During diagenesis, dilute ground water flowed down dip and encountered deeper saline, basin brines. At this interface, uranium-vanadium minerals precipitated forming the tabular ore bodies. Subsequent oxidation locally occurred, forming a halo of uranium-vanadium minerals surrounding the primary deposits. The King Tutt Mesa area has excellent potential for additional, small uranium deposits down-dip of the known deposits and also on nearby Horse Mesa.

## INTRODUCTION

The King Tutt Mesa area is in the southern part of the east Carrizo Mountains district, along the New Mexico and Arizona border, and includes the area south of Oak Spring and north of Horse Mesa (Figs. 1, 2). It derives its name from the homestead and grazing rights held by King and Despah G. Tutt (Chenoweth, 1993). Total production from the Carrizo Mountains subdistrict for the period 1948 to 1967 was 525,555 lbs $U_3O_8$ (Chenoweth, 1985); approximately 29% of this production came from the King Tutt Mesa area (Tables 1, 2). Production data in Tables 1 and 2 are revised from previous reports using unpublished data from the U.S. Atomic Energy Commission files.

Numerous studies have described the uranium-vanadium deposits in the Carrizo Mountains (Masters et al., 1955; Huffman et al., 1980) and many theories of their origin have been proposed (Hilpert, 1969; Turner-Peterson, 1985; Fishman and Turner-Peterson, 1986; Granger and Santos, 1986; Sanford, 1982, 1992). This paper summarizes the geologic and stratigraphic relationships to the mineral deposits at King Tutt Mesa and vicinity and presents the various theories proposed for the formation of tabular uranium-vanadium deposits found in the King Tutt Mesa area. This study involved field examination of the deposits, measuring stratigraphic sections, and integrating field data with published and unpublished data. It also includes new information not available when earlier reports were released (Chenoweth and Learned, 1980, 1984; Chenoweth, 1985, 1993).

## MINING HISTORY AND PRODUCTION

Uranium and vanadium minerals in the Carrizo Mountains were first discovered by John Wade of Sweetwater, Arizona, about 1918 (Chenoweth, 1993). At that time, the Navajo Reservation was closed to prospecting and mining, but on June 30, 1919, a Congressional Act opened the reservation to prospecting and locating mining claims in the same manner as prescribed by the Federal mining law. The locator of the claim could then lease the claim under contract with the Commission of Indian Affairs. By 1920, Wade, operating as the Carriso Uranium Co., had located 40 claims in the eastern Carrizo Mountains, near Milepost 16. The area remained inactive from 1927 to 1942, at which time the Vanadium Corporation of America (VCA) was the highest bidder on a 104 mi² exploration lease for vanadium in the east Carrizo Mountains. The lease known as the East Reservation lease (I-149-IND-5705) was subsequently reduced to 12 plots or claims. When production began, ore from the East Reservation Lease was shipped to Monticello, Utah, where VCA operated the mill for the Metals Reserve Co. Uranium in the vanadium ore was secretly recovered via a uranium circuit at the Monticello mill for the Manhattan Project in 1943-1945. The total amount of recovered uranium is estimated as 44,000 lbs $U_3O_8$, mostly from King Tutt Mesa (Chenoweth, 1985).

The U.S. Atomic Energy Commission was created in 1947 and soon after, the VCA began exploring their East Reservation Lease for uranium. This led to the first uranium ore shipments in April 1948. Mining ceased in the east Carrizo Mountains in 1967. Production from King Tutt Mesa by year is presented in Table 1 and by mine in Table 2. Some vanadium production was reported from the King Tutt Mesa area in 1942-1947, but actual vanadium production figures from these mines are unknown.

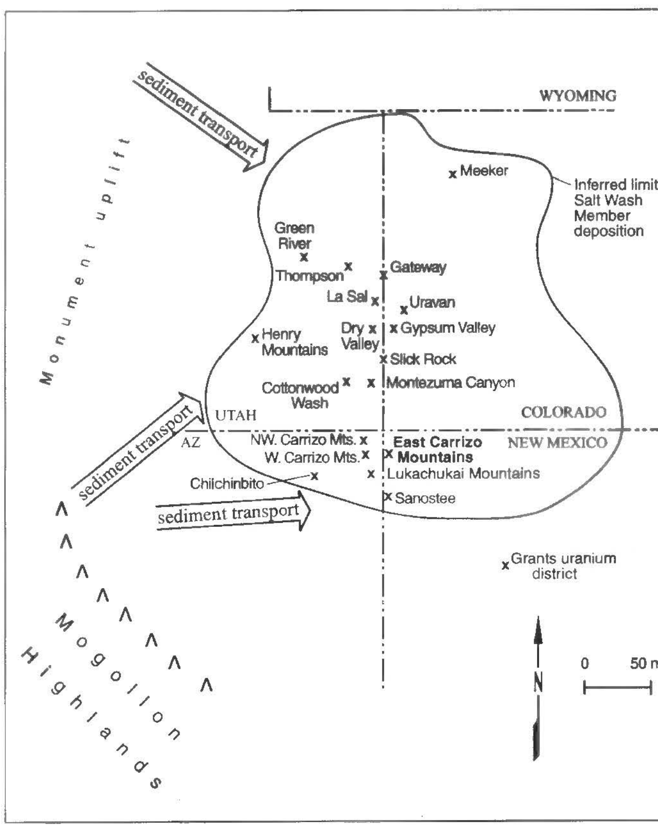


FIGURE 1. Location of the east Carrizo Mountains district, New Mexico and Arizona and other uranium districts in the Morrison Formation in the vicinity. The depositional extent of the Salt Wash Member is also shown (Stokes, 1954; Craig et al., 1955; Huffman et al., 1980; Sanford, 1982).

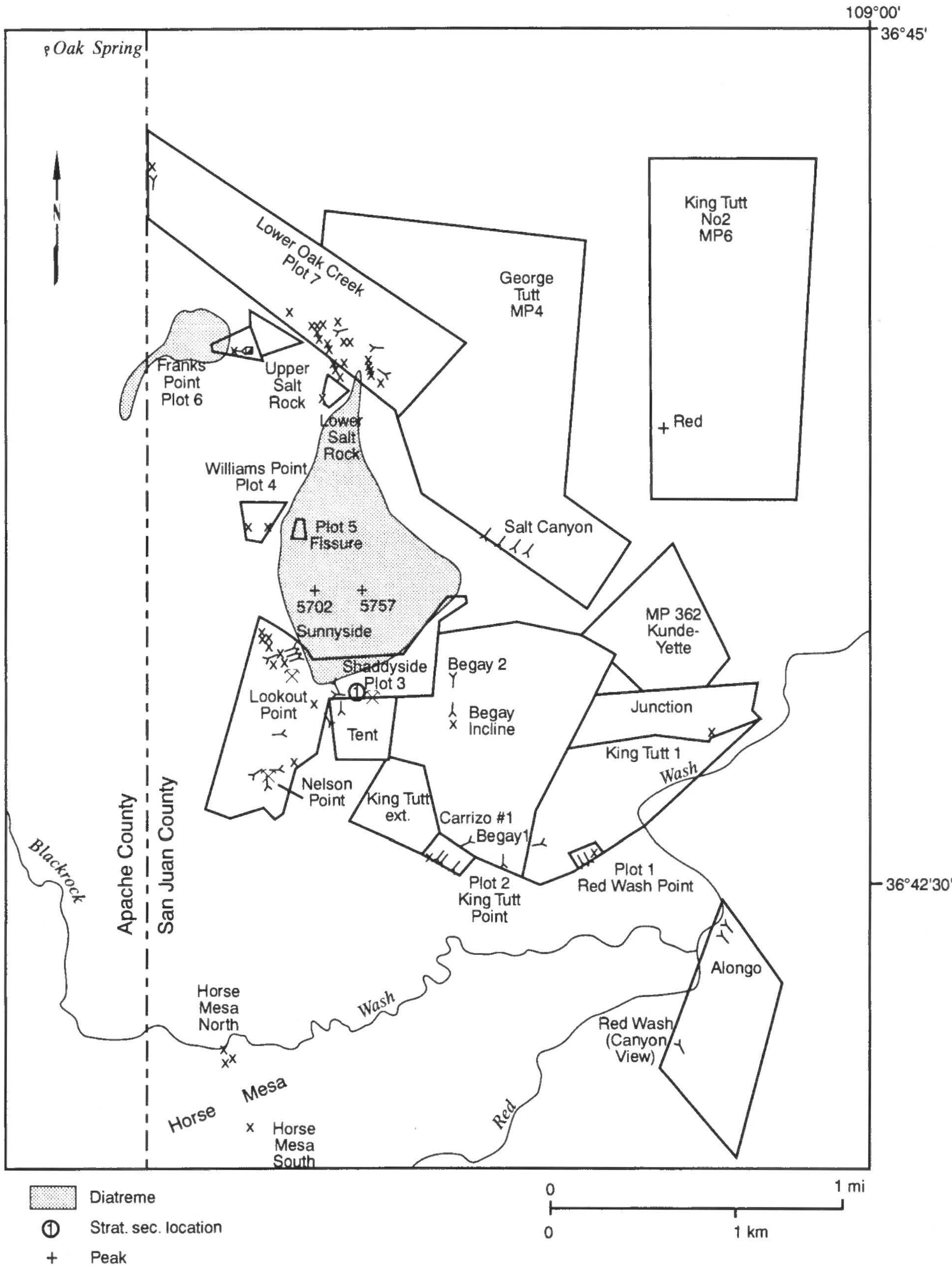


FIGURE 2. Location of mines, prospects, and measured stratigraphic sections in the King Tutt Mesa area.

TABLE 1. Production from the East Carrizo Mountains area, San Juan County, New Mexico, and Apache County, Arizona (from unpublished ore production records, U.S. Atomic Energy Commission).

| YEAR | TONS OF ORE | POUNDS $U_3O_8$ | $U_3O_8$% | POUNDS $V_2O_5$ | $V_2O_5$% | NUMBER OF OPERATORS | NUMBER OF MINES |
|---|---|---|---|---|---|---|---|
| 1948 | 1,303 | 7,614 | 0.29 | 67,386 | 2.59 | 1 | 5 |
| 1949 | 4,332 | 15,091 | 0.17 | 174,222 | 2.01 | 1 | 6 |
| 1950 | 2,836 | 19,121 | 0.34 | 174,907 | 3.08 | 14 | 13 |
| 1951 | 1,612 | 9,619 | 0.30 | 101,722 | 3.16 | 12 | 13 |
| 1952 | 1,121 | 7,402 | 0.33 | 69,919 | 3.12 | 7 | 9 |
| 1953 | 3,143 | 15,458 | 0.25 | 175,557 | 2.79 | 5 | 8 |
| 1954 | 3,965 | 18,030 | 0.23 | 191,604 | 2.42 | 5 | 9 |
| 1955 | 2,293 | 12,340 | 0.27 | 134,502 | 2.93 | 4 | 9 |
| 1956 | 1,492 | 7,036 | 0.24 | 70,251 | 2.35 | 8 | 11 |
| 1957 | 1,328 | 5,323 | 0.20 | 54,032 | 2.03 | 5 | 5 |
| 1958 | 1,022 | 5,852 | 0.29 | 37,214 | 1.82 | 4 | 4 |
| 1959 | 247 | 1,401 | 0.28 | 11,505 | 2.33 | 2 | 2 |
| 1960 | 884 | 4,195 | 0.24 | 35,191 | 1.99 | 2 | 2 |
| 1961 | 286 | 1,409 | 0.25 | 14,344 | 2.51 | 4 | 6 |
| 1962 | 1,643 | 7,332 | 0.22 | 71,041 | 2.16 | 2 | 3 |
| 1963 | 1,304 | 6,089 | 0.23 | 56,833 | 2.18 | 4 | 3 |
| 1964 | 726 | 1,783 | 0.12 | 20,598 | 1.42 | 2 | 4 |
| 1965 | 278 | 1,096 | 0.20 | 10,173 | 1.83 | 2 | 3 |
| 1966 | 950 | 4,170 | 0.22 | 46,871 | 2.47 | 2 | 4 |
| 1967 | 740 | 2,089 | 0.14 | 17,772 | 1.20 | 1 | 3 |
| TOTAL | 31,505 | 152,450 | 0.24 | 1,535,644 | 2.44 | — | — |

TABLE 2. Production from mines in the King Tutt Mesa area, Carrizo Mountains, New Mexico (from unpublished ore production records, U.S. Atomic Energy Commission). Mines are located in Figure 2. *Includes 1948–1950 production from Plots 1, 2, 3, 4, 6 and 7. The lease also yielded 10,231 tons of 6.47% $V_2O_5$ ore in 1942–1945, 1947 not included in this table. **Included with another entry.

| MINE | DEVELOPMENT | SIZE OF PLOT (acres) | TONS ORE | POUNDS $U_3O_8$ | % $U_3O_8$ | POUNDS $V_2O_5$ | % $V_2O_5$ | U:V RATIO | PERIODS OF PRODUCTION |
|---|---|---|---|---|---|---|---|---|---|
| Lower Oak Creek (Plot 7) | 200 ft adit, pits | 205.39 | 3,975 | 21,407 | 0.27 | 176,650 | 2.22 | 1:8 | 1950-1952, 1954-1964 |
| Salt Canyon | adits, pits | | 39 | 165 | 0.21 | 2,360 | 3.01 | 1:13 | 1953, 1955 |
| Franks Point (Plot 6) | 100 ft trench | 6.23 | 0 | 0 | — | 0 | — | — | — |
| Upper and Lower Salt Rock | cuts, 25 ft adit, 25 ft shaft | | 107 | 358 | 0.17 | 4,122 | 1.93 | 1:11 | 1950-1951, 1961-1962 |
| Williams Point (Plot 4) | pits, adits | 8.62 | 22 | 82 | 0.19 | 739 | 1.68 | 1:9 | 1954 |
| Fissure (Plot 5) | pits | 1.57 | 0 | 0 | — | 0 | — | — | — |
| Lookout Point (Plot 3) | 100 ft adits | ** | 2,556 | 16,327 | 0.32 | 144,337 | 2.82 | 1:9 | 1950-1956, 1959 |
| Lookout Point incline (Plot 3) | 100 ft decline | ** | 506 | 2,713 | 0.27 | 28,485 | 2.81 | 1:10 | 1960-1961 |
| East Reservation Lease | pits, adits, trenches | — | 6,758 | 29,786 | 0.22 | 311,503 | 2.30 | 1:10 | 1948-1950 |
| Shadyside 2 (Plot 3) | 350 ft adit | ** | 890 | 6,183 | 0.35 | 66,842 | 3.75 | 1:11 | 1951, 1953-1955, 1966 |
| Shadyside (Plot 3) | 600 ft adit, pits | 145.13 | 583 | 3,095 | 0.27 | 29,656 | 2.54 | 1:9 | 1950-1958, 1961, 1964-1967 |
| Shadyside Decline | 280 ft adit | ** | 1,145 | 5,746 | 0.25 | 78,933 | 3.14 | 1:12 | 1953-1955 |
| Nelson Point (Plot 3) | 800 ft adit | ** | 2,684 | 13,364 | 0.25 | 211,347 | 3.94 | 1:16 | 1942-1943, 1948-1967 |
| Tent | 70 ft adit | | 1,198 | 5,303 | 0.22 | 54,156 | 2.26 | 1:10 | 1955-1957, 1963 |
| Begay 2 | decline, pits | | 4,515 | 18,450 | 0.20 | 190,638 | 2.11 | 1:10 | 1962-1967 |
| Begay incline | decline | | 655 | 3,475 | 0.27 | 38,215 | 2.92 | 1:11 | 1955-1956 |
| Carrizo 1 | decline | | 828 | 3,426 | 0.21 | 21,917 | 1.32 | 1:6 | 1956-1958 |
| Begay 1 | adit | | 3,921 | 16,491 | 0.21 | 127,499 | 1.63 | 1:8 | 1953-1954, 1966-1967 |
| King Tutt Point (Plot 2) | 5 adits 12-40 ft long | 9.14 | 429 | 2,630 | 0.31 | 22,429 | 2.62 | 1:8 | 1950-1953, 1956 |
| King Tutt 1 | 75 ft, 150 ft adits | | 290 | 1,060 | 0.18 | 8,257 | 1.42 | 1:8 | 1951, 1953, 1956, 1958 |
| Red Wash Point (Plot 1) | pit with 2 adits | 3.53 | 249 | 1,946 | 0.39 | 14,517 | 2.92 | 1:7 | 1952 |
| Junction | cut | | 18 | 38 | 0.11 | 153 | 0.43 | 1:5 | 1953 |
| Alongo | 110 ft, 72 ft adit | — | 27 | 76 | 0.14 | 76 | 0.14 | 1:1 | 1956 |
| Red Wash (Canyon View) | adit | ** | 61 | 127 | 0.10 | 636 | 0.53 | 1:5 | 1952 |
| Horse Mesa north (Red Rock) | pits | — | 22 | 65 | 0.15 | 1,001 | 2.25 | 1:15 | 1950-1951 |
| Horse Mesa south (Red Wash) | pit, 4 ft adit | — | 27 | 137 | 0.26 | 1,176 | 2.19 | 1:19 | 1950 |
| TOTAL | — | — | 31,505 | 152,450 | 0.24 | 1,535,644 | 2.44 | 1:10 | 1948-1967 |

## GEOLOGY

The east Carrizo Mountains district lies east of the Carrizo laccolith of Tertiary age. Sedimentary beds ranging in age from Permian through Cretaceous dip gently to the east towards the San Juan Basin (Huffman, 1977). The uranium and vanadium deposits in the east Carrizo Mountains are restricted to the Salt Wash Member of the Morrison Formation of Jurassic age. The Salt Wash Member is overlain by the Brushy Basin Member (Fig. 3; Anderson and Lucas, 1992, 1995) and unconformably overlies the Bluff-Summerville Formation, using older stratigraphic nomenclature (Anderson and Lucas, 1992), or the Wanakah Formation as proposed by Condon and Peterson (1986). The Salt Wash Member consists of 190–220 ft of interbedded fluvial sandstones and floodplain mudstones, shales, and siltstones. The mudstone and siltstone comprise approximately 5–45% of the total thickness of the unit (Masters et al., 1955; Chenoweth, 1993).

The depositional fan of the Salt Wash Member forms two tongues at the south end of the ancestral Monument uplift (Fig. 1; Craig et al., 1955; Mullens and Freeman, 1957; Sanford, 1982, 1992). The southern, smaller tongue extends into northeastern Arizona and northwestern New Mexico, whereas the northern tongue extends into southeastern Utah and southwestern Colorado.

In the King Tutt Mesa area, the Salt Wash Member was divided into lower, middle and upper informal units by Huffman et al. (1980) (Fig. 4). Anderson and Lucas (1995) redefined the Salt Wash Member into two informal units. Uranium and vanadium deposits typically are restricted to the middle unit of Huffman et al. (1980) or the basal unit of Anderson and Lucas (1995). The lower unit (Huffman et al., 1980) is approximately 30 ft thick and consists predominantly of overbank deposits of red-brown siltstones and very fine-grained sandstones with white and rare pink medium-grained sandstone lenses. The sandstones are not continuous along strike and they contain fragments of reworked sandstones and shales of the underlying Bluff-Summerville or Wanakah Formation. This lower unit as defined by Huffman et al. (1980) is now reassigned to the Recapture Member of the Bluff Sandstone of the San Rafel Group based upon regional correlations (Anderson and Lucas, 1995). The middle unit of Huffman et al. (1980) is now the basal unit of the Salt Wash Member (Anderson and Lucas, 1995); it is approximately 70 ft thick and contains more sandstones than the lower unit and more siltstone lenses than the upper unit. It consists of fairly continuous fluvial sandstone beds with minor interbedded siltstones and fine-grained sandstones. Approximately 80% of this unit is composed of sandstone channels. This unit contains more organic material and clay galls then the upper unit. The upper unit is approximately 120 ft thick and consists of massive, fine-grained, flat-lying stream sandstones, with local siltstones and fine-grained sandstone lenses deposited in overbank environments.

The stratigraphic units of the Salt Wash Member represent deposition in a prograding wet alluvial fan (Galloway, 1978; Young, 1978). The lower unit is the distal-fan facies, whereas the middle and upper units belong to the midfan facies (Huffman et al., 1980).

## ECONOMIC GEOLOGY

Ore bodies in the King Tutt Mesa area are grossly similar to sandstone uranium deposits found throughout the Colorado Plateau (Hilpert, 1969; McLemore and Chenoweth, 1989). They tend to form subhorizontal clusters that are elongated and blanket-like. Ore bodies in the King Tutt Mesa area are small and irregular and only a few have yielded more than 1000 lbs of $U_3O_8$. A typical ore body in the King Tutt Mesa area is 150–200 ft long, 50–75 ft wide, and approximately 5 ft thick (McLemore and Chenoweth, 1989). A cluster of ore bodies along a trend can contain as much as 4000 tons of ore averaging 0.23% $U_3O_8$ (Chenoweth and Learned, 1984). However, unlike uranium deposits in the Grants district, the deposits at King Tutt Mesa are high in vanadium. The U:V ratio averages 1:10 and ranges from 1:1 to 1:16 (Table 2).

The ore bodies at King Tutt Mesa tend to parallel fluvial, paleostream channels in the lower third of the Salt Wash Member (Hilpert, 1969; Masters et al., 1955; Chenoweth and Malan, 1973) and are restricted to discontinuous paleostream channel sandstones that are separated by thin lenses of siltstones, shales, and mudstones (Fig. 4). The ore-bearing unit is approximately 50 ft thick (Masters et al., 1955). Paleochannel directions indicate a

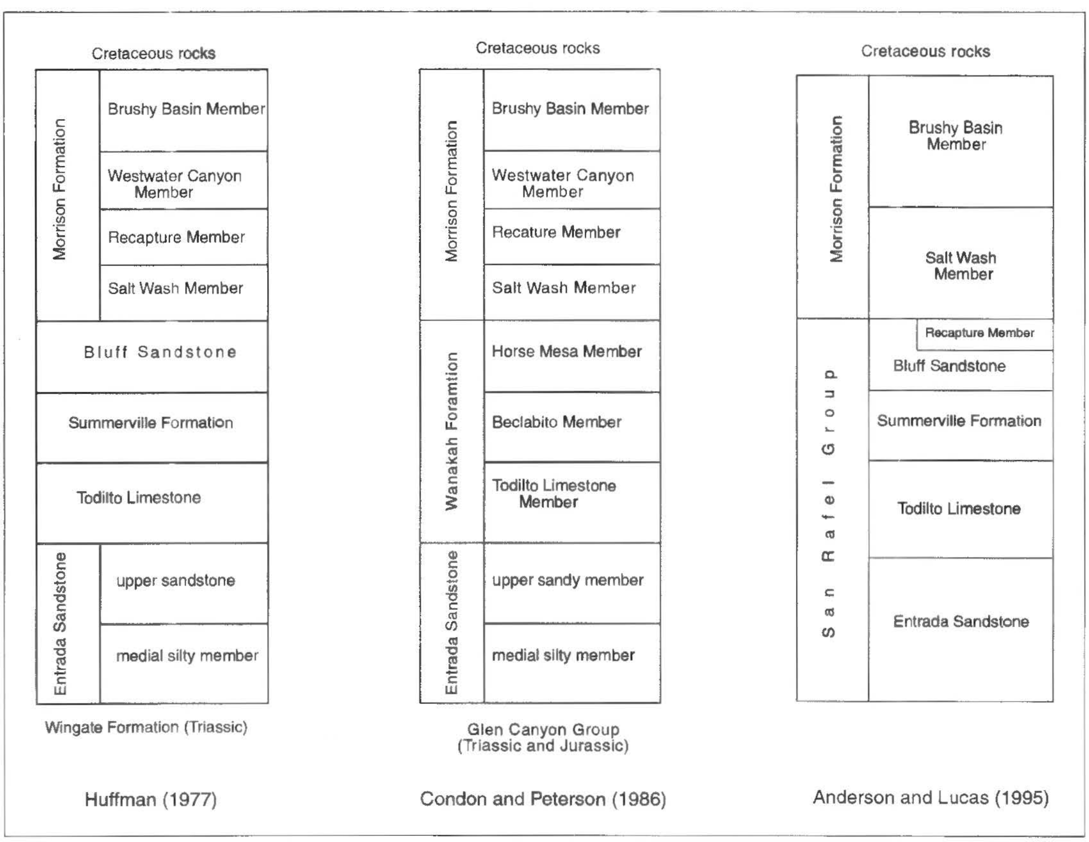


FIGURE 3. Stratigraphy in the King Tutt Mesa area, east Carrizo Mountains.

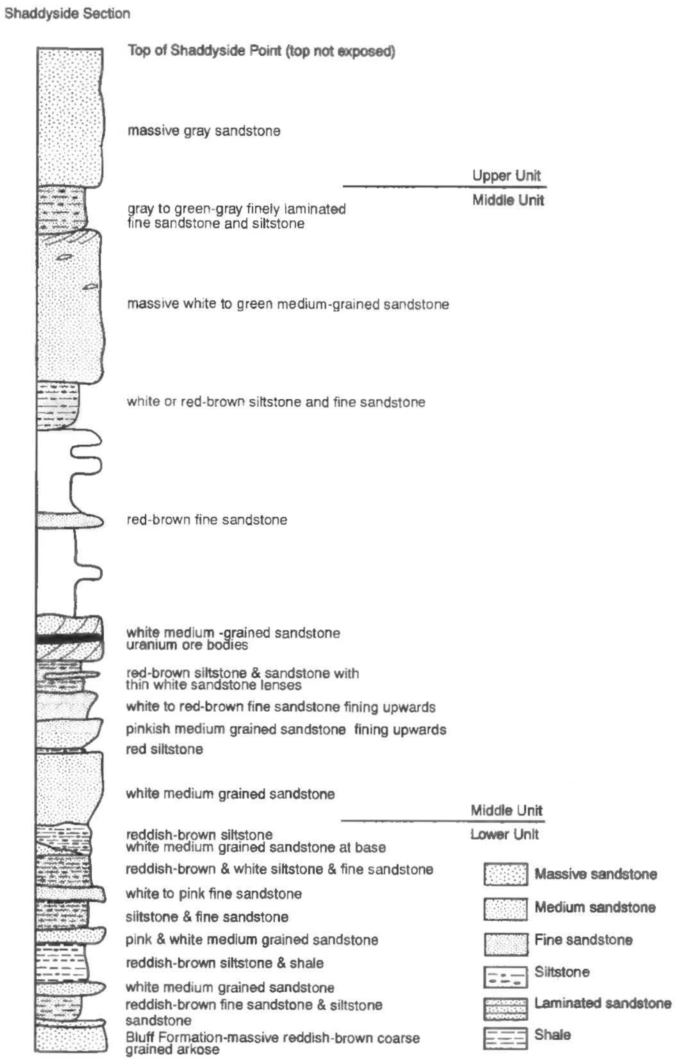


FIGURE 4. Measured stratigraphic section in the King Tutt Mesa area. Location is shown in Figure 2.

west-to-northwest direction for the streams depositing the sand containing the uranium orebodies (Stokes, 1954). The deposits are typically concordant to bedding, although discordant lenses of uranium-vanadium minerals cross-cut bedding planes locally. The ore bodies typically float in the sandstone; rarely they occur at the interface between sandstone and less permeable shale or siltstone.

The deposits are largely black to red, oxidized, and consist of tyuyamunite, meta-tyuyamunite, uranium/organic compounds, and a variety of vanadium minerals, including vanadium clay (Corey, 1958). Uranium and vanadium minerals are intimately associated with detrital organic material (leaves, branches, limbs and trunks), derived from adjacent sandbar, swamp, and lake deposits, and humates. Small, high-grade ore pods (>0.5% $U_3O_8$) were associated with fossil wood. The uranium-vanadium minerals form the matrix of the mineralized sandstones and locally replace detrital quartz and feldspar grains. Mineralized beds are associated with coarser-grained sandstone, are above calcite-cemented sandstone or mudstone-siltstone beds, are associated locally with mudstone galls, and are near green to gray mudstone lenses. Limonite is commonly associated with the ore bodies (Masters et al., 1955). Field and petrographic data suggests that the uranium-vanadium deposits formed shortly after deposition of the host sediments (Hilpert, 1969).

## ORIGIN OF THE URANIUM-VANADIUM DEPOSITS

Sandstone uranium deposits account for the majority of the uranium production from New Mexico (McLemore and Chenoweth, 1989), but there is no consensus on details of their origin (Sanford, 1992). Most proposed models for formation of sandstone uranium deposits suggest that deposition occurred at a ground water interface between two fluids of different chemical compositions and/or states of oxidation-reduction. Deposition involving two fluids was proposed many years ago during the early stages of exploration and production of uranium (Fischer, 1947; Shawe, 1956) and subsequent models, such as the lacustrine-humate and brine-interface models, have refined or incorporated portions of these early theories. The source of the uranium and vanadium is not well constrained, but could be derived from alteration of volcanic detritus and shales within the Morrison Formation (Thamm et al., 1981; Adams and Saucier, 1981).

In the lacustrine-humate model, ground water was expelled by compaction from lacustrine muds formed by a large playa lake into the underlying fluvial sandstones where humate or secondary organic material precipitated as a result of flocculation into tabular bodies. During or after precipitation of the humate bodies, uranium was precipitated from ground water (Turner-Peterson, 1985; Fishman and Turner-Peterson, 1986). This model indicates the humate bodies were formed prior to uranium deposition.

In the brine-interface model, uranium and humate were deposited during diagenesis by reduction at the interface of meteoric fresh water and ground water brines (Granger and Santos, 1986). In another variation of the brine-interface model, ground water flow is driven by gravity, not compaction. Ground water flowed down-dip and discharged in the vicinity of the uranium deposits. Uranium precipitated in the presence of humates at a gravitationally stable interface between relatively dilute, shallow meteoric water and saline brines that migrated up-dip from deeper in the basin (Sanford, 1982, 1992).

Modeling of the regional ground water flow in the Colorado Plateau during Late Jurassic and Early Cretaceous times supports the brine-interface model and indicates that the regional ground water flow was to the northeast in the King Tutt Mesa area (Sanford, 1982). The ground water flow was impeded by upthrown blocks of Precambrian crust and forced upwards. The zones of upwelling are closely associated with uranium-vanadium deposits throughout the Colorado Plateau (Sanford, 1982).

In the King Tutt Mesa area, the bleaching of the sandstones and the geometry of tabular uranium-vanadium bodies floating in sandstone beds supports the reaction of two chemically different waters, most likely a dilute meteoric water and saline brine from deeper in the basin. The intimate association of uranium-vanadium minerals with organic material further indicates that they were deposited at the same time. Cementation and replacement of feldspar and quartz grains with uranium-vanadium minerals are consistent with deposition during early diagenesis.

## SUMMARY

The Salt Wash Member was deposited in an eastward prograding fluvial system. During diagenesis, dilute ground water flowed down-dip in the sandy basal unit and encountered saline, basin brines from deeper in the basin. At this interface, uranium-vanadium minerals precipitated, forming tabular ore bodies. Subsequent oxidation locally occurred, forming a halo of uranium-vanadium minerals surrounding the primary deposits. All of the known deposits in the east Carrizo Mountains are above the water table and oxidized; no secondary, redistributed uranium deposits, similar to those found in the Grants district (McLemore and Chenoweth, 1989), are known to occur in the area. The King Tutt Mesa area has excellent potential for additional, small uranium deposits down-dip of the known deposits and also on nearby Horse Mesa. The mines at King Tutt Mesa are planned for reclamation in the near future.

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