Modern Geology, 1998, Vol. 23, pp. 427–439
Reprints available directly from the publisher
Photocopying permitted by license only

URANIUM MINING IN THE MORRISON FORMATION

WILLIAM L. CHENOWETH *

Research Associate, New Mexico Bureau of Mines and Mineral Resources Soccoro, NM, USA

(Received in final form 4 April 1997)

Uranium ore deposits in the Morrison Formation have been mined since the turn of the century; first for radium, then for the associated vanadium, and beginning in 1947 mainly for uranium. The ore procurement program of the US Atomic Energy Commission, for nuclear weapons, was responsible for the first "boom" of the 1950s and early 1960s. A second, short-lived, "boom" of the late 1970s and early 1980s was for fuel for nuclear power plants. Since 1947, the Morrison has yielded more uranium than any other geologic unit in the United States, and accounts for 51 percent of the domestic production. Tabular ore deposits in sandstone beds of the Westwater Canyon and Jackpile Members in the Grants, New Mexico district have been the most productive. The vanadium content of the ore deposits in the Salt Wash Member in the Four Corners area has been an important co-product.

Due to declining prices, the last mines in the Morrison closed in late 1990. Only a small amount of uranium is produced today from water circulating through mines in the Ambrosia Lake area, New Mexico. These are numerous unmined ore deposits in the Morrison, and the possibility to locate additional ores is good. Higher prices and a strong market would no doubt renew interest in these deposits.

Keywords: Mining; Uranium; History; Production

INTRODUCTION

The Morrison Formation has produced more uranium than any other geologic formation in the United States. Figures available from the Grand Junction Office of the Department of Energy indicate that between January 1, 1947 and January 1, 1983, the Morrison has yielded 419,489,000 pounds of uranium oxide (U_3O_8), or 51 percent of the total domestic uranium

* Present address: 707 Brassie Drive, Grand Junction, CO 81506, USA.

TABLE I Uranium ore production, by state, Morrison Formation, 1947–1982

State	*Pounds* U_3O_8	*Percent of state total*
New Mexico	319,632,000	98
Colorado	75,784,000	72
Utah	20,222,000	18
Arizona	3,851,000	19
Total	419,489,000	

TABLE II Uranium ore production, by member, Morrison Formation, 1947–1982

Member	*Pounds* U_3O_8	*Percent of total*
Jackpile	100,556,000	24
Brushy Basin	11,526,000	3
Westwater	207,733,000	49
Recapture	328,000	>1
Salt Wash	99,346,000	24
Total	419,489,000	100

produced during that period. This production came from mines on the Colorado Plateau in New Mexico, Colorado, Utah and Arizona (Table I). Substantial ore deposits occur in the Westwater Canyon, Jackpile and Salt Wash Members which are predominately sandstone. Sandstone beds in the Brushy Basin and Recapture Members also contain ore deposits (Table II). Outside the Colorado Plateau, some very minor production has come the Morrison Formation in Garfield County, Colorado; Harding County, New Mexico; and Big Horn County, Wyoming.

A brief review of the uranium ore deposits and the mining activities in the Morrison Formation on the Colorado Plateau is presented below. Tables I and II were compiled by me before my retirement in 1983 from the US Atomic Energy Commission, the Energy Research and Development Administration and the US Department of Energy. Due to the different sources of data, the numbers are rounded to the nearest 1,000 pounds U_3O_8.

MINING CYCLES

Uranium was first used to color glass and ceramics in the 1910s–1930s. The first large scale market did not develop until 1947 when the US Atomic Energy Commission (AEC) began its procurement program to acquire uranium for atomic weapons. Prior to the AEC program, the Manhattan Engineer District secretly recovered uranium from the tailings at vanadium mills in southwestern Colorado and southeastern Utah, for use in the early atomic bombs.

The price schedules, bonuses, and other allowances the AEC offered created a prospecting boom in the 1950s, not seen in any other metal. The search was so successful, especially in New Mexico and Wyoming, that the AEC was forced to curtail its unlimited procurement policy. On November 24, 1958, the AEC announced that beginning in 1962, it would purchase "appropriate quantities" of uranium concentrate from ores discovered prior to the 1958 date. This announcement ended the first uranium boom (Fig. 2).

Although announced in May 1958 that the AEC would allow sales of uranium to electric utilities, such sales did not begin until 1966 and the AEC procurement program ended at midnight on December 31, 1970. Beginning in 1971, all uranium concentrate produced in the United States was destined for use in nuclear power plants for the generation of electricity. It was an open competitive market, and at the beginning of 1971 the spot market price for uranium concentrate was $6.20 per pound U_3O_8.

Uranium prices increased markedly in the mid 1970s and by August 1976 were over $40 per pound U_3O_8 and a second boom was underway. This boom was short lived as during 1980 the spot market price dropped from $40 to $27 per pound. The price drop was largely due to overproduction and the general non-acceptance of nuclear power as an energy source. By 1983 the second boom was over as the spot market price continued to drop (Fig. 2). Only long term contracts by the milling companies allowed the industry to continue. Mines all over the Colorado Plateau began to close. In January 1990, the last mines in the Grants, New Mexico area closed and in late 1990 the mines in the Uravan area of Colorado and Utah closed. Currently (1995), uranium is being recovered from water circulated through the mines in the Ambrosia Lake, New Mexico area.

MINING AREAS

New Mexico

New Mexico has produced more uranium than any other state and over 98 percent of the production has been derived from the Morrison Formation (Table I). The Grants uranium district, in the southern San Juan Basin (Fig. 1) has produced more uranium than any other area in the United States (Fig. 2).

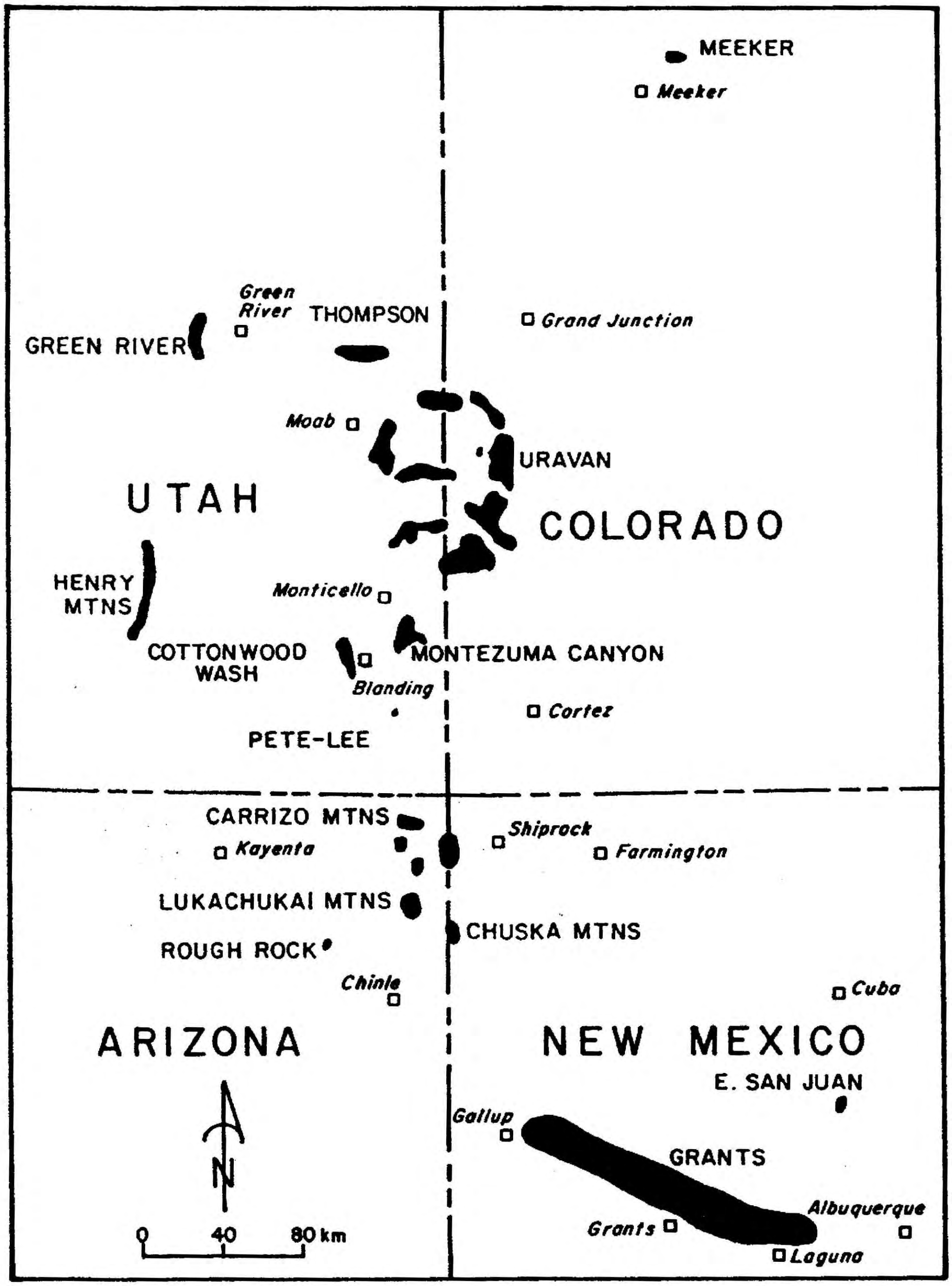

FIGURE 1 Uranium mining areas in the Morrison Formation on the Colorado Plateau.

In the early spring of 1950 it was announced that uranium had been discovered, northwest of Grants, in the Todilto Limestone. This created a prospecting rush in the area. In January 1951, uranium was discovered in a sandstone bed in Poison Canyon near the site of the discovery in the

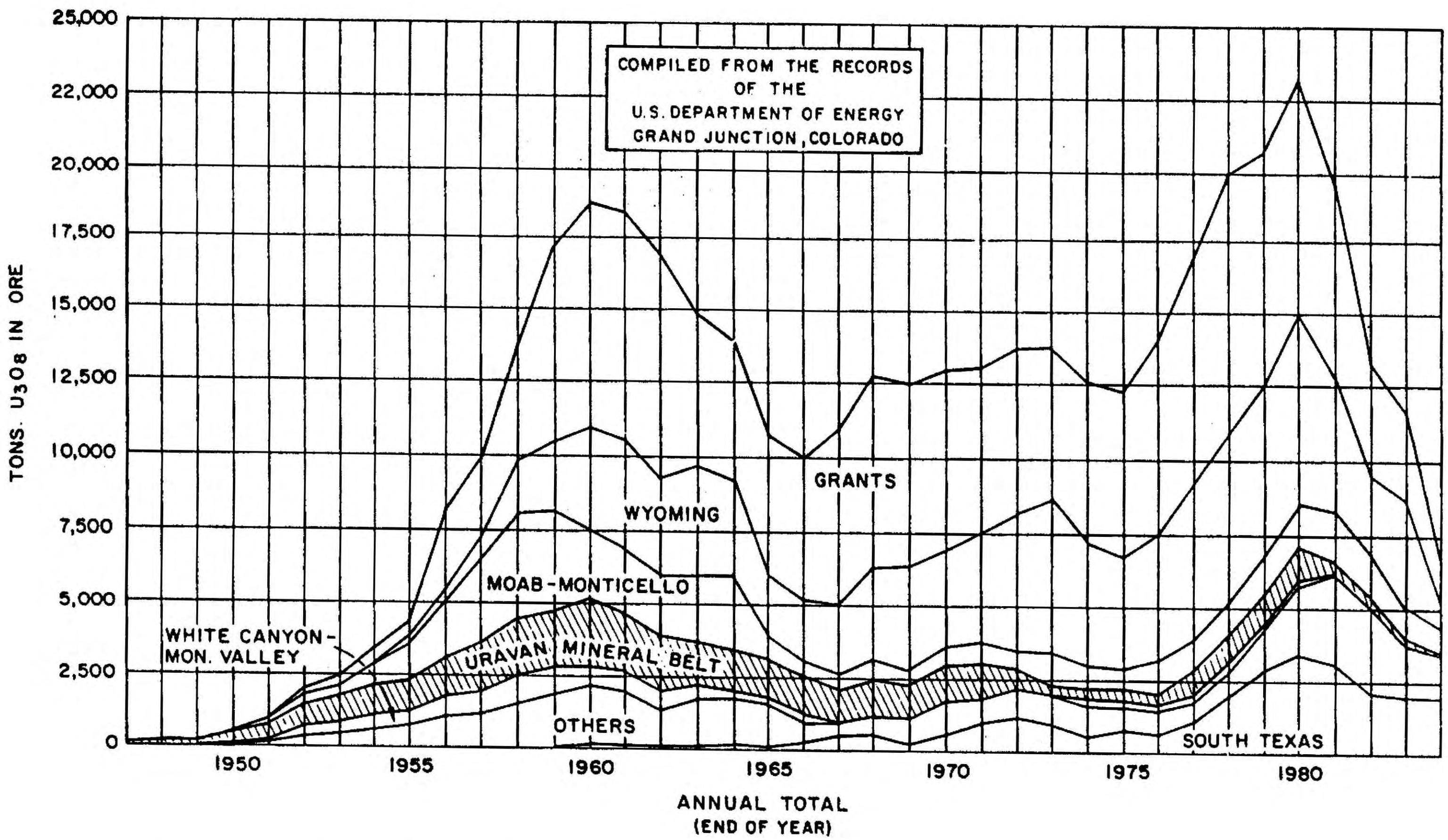

FIGURE 2 Uranium ore production by area, 1947 through 1984. "Other" indicates uranium mines not included in the indicated groups.

limestone. This discovery would become the Poison Canyon mine and exploration drilling discovered other orebodies nearby that would be known as the Poison Canyon trend. The host rock was termed the Poison Canyon sandstone, which is considered a tongue of the Westwater Canyon Member.

Aerial prospecting north of Laguna, New Mexico, in November 1951, discovered a mineralized outcrop in the upper Morrison. Exploratory drilling behind the outcrop would develop the huge Jackpile mine. The host rock was informally called the Jackpile sandstone for many years until Owens and others (1984) named it the Jackpile Sandstone Member.

In March 1955, Louis Lothman, using oil well logs to determine drilling depths, drilled some wildcat uranium test holes on Ambrosia Dome, approximately 14 km northwest of the Poison Canyon mine. The second hole penetrated ore in the Westwater Canyon Member. This discovery triggered a great rush into the Ambrosia Lake area, and exploratory drilling located large orebodies. The development and mining at Ambrosia Lake has been summarized by Chenoweth (1989).

Exploration drilling spread westward to the Church Rock area, northeast of Gallup, New Mexico, where orebodies were found in both the Brushy Basin and Westwater Canyon Members. At the east end of the district, additional orebodies were found in the Jackpile and deeper deposits were also found in the Westwater Canyon. The ore deposits in the Grants district are described in Kelley (1962), and Rautman (1980), and are summarized by McLemore and Chenoweth (1989).

Typical orebodies in the Morrison Formation in the Grants district are composed of lenticular, tabular masses of complex uranium and organic compounds that form roughly parallel trends, with fine-grained, barren sandstone between orebodies. Three types of ore deposits are present: primary (also known as prefault, trend, blanket or black-band), redistributed (also known as post-fault, stack, secondary or roll-type), and remnant.

Primary uranium deposits are interpreted as having formed first and prior to deposition of the Dakota Sandstone (Upper Cretaceous). They are characteristically less than 2.4 m thick, average more than 0.20 percent U_3O_8, are low in vanadium, dark black in color, and have sharp ore-to-waste boundaries. They tend to be in tabular bodies roughly parallel to the regional stratification.

Redistributed orebodies are younger than primary orebodies, and consist of discordant, asymmetrical and irregular uranium deposits. They were formed from primary ore by an oxidation front moving through the beds during Late Cretaceous–Early Tertiary through Quaternary time. They characteristically are more than 2.4 m thick, average less than 0.20 percent

U_3O_8 in grade, have diffuse ore-to-waste boundaries, and are brownish to light gray depending on the amount of associated organic material.

Remnant ore deposits with an average grade of about 0.20 percent U_3O_8 were preserved in the oxidized sandstone after the oxidation front passed. The uranium minerals in these deposits are oxidized to yellowish and greenish colors, and the surrounding host rock is yellowish-brown to reddish-brown in color. Some remnant ore deposits were preserved by low permeability caused by local concentrations of calcite cement around the original primary deposit. Other remnant deposits occur in stratigraphically isolated sandstone lenses where oxidizing waters could not enter the beds.

Between 1951 and 1982, mines in the Morrison Formation in the Grants district produced 319,144,000 pounds of uranium oxide (U_3O_8). This accounts for 39 percent of the total domestic uranium produced up to 1983.

The Salt Wash Member has produced uranium–vanadium ore around the perimeter of the Carrizo Mountains in northwestern New Mexico and northeastern Arizona (Fig. 1). The ore deposits are relative shallow and are completely oxidized. Tyuyamunite is the principal ore mineral. Orebodies and clusters of orebodies are elongated parallel to paleostream channels. Detrital carbonaceous material is very abundant in these deposits where the vanadium to uranium ratio is 9 : 1. Orebodies generally occur 6–30 m above the base of the Salt Wash. The deposits have been described by Chenoweth and Malan (1973). Between 1948 and 1967, 31 mines in the New Mexico part of this area produced 160,000 pounds U_3O_8 and 1,643,000 pounds V_2O_5.

A small amount of uranium ore has been mined from the Morrison in the Chuska Mountains, west of Sanostee (Fig. 1). These deposits, mainly in sandstone beds in the upper part of the Recapture Member, were found by a prospector in 1951. The Enos Johnson mine produced from a series of individual orebodies that were clustered in an area 853 m long, 91 m wide, and had a thickness reaching 6 m. Uranium in this mine is associated with hematite coatings on quartz grains in reddish-brown siltstone. The uranium minerals have not been identified, although coffinite has been found in samples of black ore. Organic material is noticeably absent in the Recapture deposits, in contrast to the organic-rich deposits elsewhere in the Morrison Formation on the Colorado Plateau. The uranium deposits in the Sanostee area have been described by Chenoweth (1985). During the period 1952 through 1982 the Enos Johnson mine produced 326,900 pounds of U_3O_8. It is the largest uranium mine in New Mexico outside the Grants region. In addition to the Enos Johnson mine, there are a few other but much smaller mines in the Recapture and some in the Salt Wash in the Sanostee area.

In the eastern San Juan Basin, south of Cuba, New Mexico (Fig. 1), ores containing 989 pounds U_3O_8 were mined from sandstone lenses in the Brushy Basin Member in 1957–1959. Deposits in the Westwater Canyon Sandstone Member in the Ambrosia Lake area and those in the Jackpile Sandstone Member north of Laguna account for 73 percent of the total Morrison production (Table II).

Colorado

Uranium in the Salt Wash Member in Colorado has been mined in the Uravan mineral belt and in the Meeker area (Fig. 1). The Uravan mineral belt, as defined by the US Geological Survey in 1952, is an arcuate area in the eastern part of the Paradox basin in southwestern Colorado where uranium–vanadium deposits in the Salt Wash Member "generally have closer spacing, larger size, and higher grade than those in adjacent areas and the region as a whole" (Fischer and Hilpert, 1952, p. 3). The belt includes the Gateway, Uravan, Bull Canyon, Gypsum Valley and Slick Rock mining areas. The original concept of the belt has been expanded to include the Dry Valley, La Sal and Moab mining areas in Utah. The ore deposits in the Uravan area have been described by various authors, including Motica (1968) Chenoweth (1981) and Thamm and others (1981). Several attempts were made to identify the yellow mineral found on the rim rock in Paradox Valley, Montrose County, Colorado. In 1898 this material was found to contain uranium (as potassium–uranium vanadate). It was named carnotite in 1899 after the French mining engineer and chemist Adolph Carnot.

The carnotite deposits of southwestern Colorado and southeastern Utah were originally mined for their radium content during the period 1910–1925. Radium was used by the medical profession in treating cancer and in manufacture of luminous paint. For ten years, 1913–1922, the mines in the area would be the principal world source of radium. During this boom period, similar deposits were discovered in the Salt Wash Member near Meeker, Colorado and at various locations throughout southeastern Utah and around the Carrizo Mountains in northeastern Arizona and northwestern New Mexico.

From 1910 to 1923, about 67,000 tons of carnotite ore were mined in southwestern Colorado and southeastern Utah. Approximately 202 g of radium, 1,068,000 pounds of vanadium oxide, and a small amount of uranium oxide were produced (Fischer, 1968, p. 738). The same deposits were mined for their vanadium content during 1936–1945. Vanadium was used by the steel industry as a hardener, especially in armaments during the war years. During the vanadium boom many new deposits were discovered in the Salt Wash. Up to 1946, mines in the greater Uravan area are estimated to have produced over 27 million pounds of vanadium oxide (V_2O_5) (Webber, 1947). From 1943 through 1945, the Manhattan Engineer District recovered 2,698,000 pounds U_3O_8, mainly from the tailings at vanadium mills (US Department of Energy, 1982).

The AEC program created a huge mining and prospecting effort in the Uravan area. The old vanadium mines were reopened for uranium with vanadium as a byproduct. Exploratory drilling located new deposits behind existing mines and in areas with no minerals exposed on the surface. Between 1947 and 1982, the Colorado portion of the Uravan mineral belt produced approximately 75,547,000 pounds U_3O_8 and 377,735,000 pounds of V_2O_5.

The Salt Wash Member consists largely of interbedded fluvial sandstone and overbank floodplain mudstone units. The cliff-forming sandstone beds of the Salt Wash are separated by slope-forming mudstone and siltstone beds. Between three to eight cliffs, or "rims", can be present in the Salt Wash of the Uravan area. The uppermost sandstone, or rim, contains the majority of the ore deposits. Several deposits also occur in coarse conglomeratic sandstones in the lower part of the overlying Brushy Basin Member, especially in the La Sal Creek (Utah) area. Records of the Grand Junction Office of the US Department of Energy show that production has been derived from nearly 1200 individual properties within the Uravan area.

Individual deposits or groups of deposits are localized within reduced, permeable, carbonaceous Salt Wash sandstones. Many of the deposits in the Uravan area are within well-defined, sandstone-filled paleostream channels. The ore deposits are several hundred meters wide and up to a thousand meters long. The tabular orebodies typically are elongated parallel to the paleostream flows and tend to be concordant within the beds. The ore averages about 1.2 m thick, but in a few places ore thicknesses approaching 9.1 m have been mined. Uraninite and coffinite are the principal uranium minerals in the deeper, unoxidized deposits, with montrosite the primary vanadium mineral. Oxidation produced the colorful vanadates such as carnotite and tyuyamunite, which were the earliest ores to be mined.

Some small, high-grade orebodies consist of fossil logs and pod-like accumulations of carbonaceous material replaced with uranium and vanadium minerals. Fossil logs may be as large as 15.2 m long and 0.9 m in diameter. Generally the amount of vanadium exceeds the uranium in ratios ranging from 3 : 1 to 10 : 1, with an average of 5 : 1 for ores mined in the area.

Within the Uravan mineral belt, the vanadium content increased southward from Gateway (3 : 1) to Slick Rock (8 : 1). Uranium deposits in the Salt Wash Member also occur on the White River uplift near Meeker (Fig. 1). The deposits, although smaller, are similar to those at Uravan. From 1948, through 1982, these deposits have produced 237,000 pounds U_3O_8.

During the period 1947 through 1982, the Salt Wash Member throughout Colorado produced 75,373,000 pounds U_3O_8. The Brushy Basin Member in the greater Uravan area yielded 411,000 pounds U_3O_8.

Utah

Within the Utah portion of the Paradox basin, but not included with the greater Uravan mineral belt, are four separate areas of uranium and vanadium deposits in the Salt Wash Member are called Green River, Thompson, Cottonwood Wash and Montezuma Canyon (Fig. 1). The uranium deposits in all four of these areas are similar to those in the Uravan area but are generally smaller and not as continuous. Total production from these areas has been 5,566,000 pounds U_3O_8, with 68 percent coming from the Green River area alone. The deposits in the Green River area have been described by Trimble and Doelling (1978) and those in the Thompson area by Stokes (1952) and Mobley and Santos (1955).

Deposits in the Brushy Basin Member in the above areas have produced 244,000 pounds U_3O_8. Of this total, 242,000 pounds came from the Pete-Lee mine south of the Montezuma Canyon area (Fig. 1).

Uranium–vanadium ore deposits occur in the Salt Wash Member in a large cluster on the eastern rim of the Henry Mountains Basin known as the Henry Mountains mineral belt (Fig. 1). The deposits have been described by Grundy and Kastelic (1956) and Doelling (1967, 1975). These deposits are small and oxidized and occur in carbonaceous sandstone lenses throughout the lower and middle units of the Salt Wash. The majority of the deposits are in the lower unit. The deposits are commonly called "trash piles" due to their close association with detrital organic material.

Exploration drilling in the Shootering Canyon area during the mid-1970s located a large, unoxidized deposit, downdip from the small mines on the outcrop. This deposit was unlike those being mined on the surface. The Tony M deposit was 1 km wide and 4 km long with an average thickness of 1.5 m. It is in a carbonaceous sandstone in the lower part of the Salt Wash Member (Thamm and others, 1981).

Additional deposits, the Frank M and the Bullfrog, were located in the same area. Development of the Tony M mine began in 1977, and a new mill and townsite, named Ticaboo, were built nearby. The mill ran for only a few months in the spring and summer of 1982 and was shut down due to a depressed uranium market. Development work continued at the mine, and it was put on standby in 1987. Between 1948 and 1982 the mines in the Henry Mountains produced 556,800 pounds of U_3O_8. In Utah, the Morrison Formation, mainly the Salt Wash Member, has produced 20,222,000 pounds of U_3O_8 or 18 percent of the state's total (Table I).

Arizona

The greater part of Morrison production in Arizona came from the Salt Wash Member in the Lukachukai Mountains of northeastern Arizona (Fig. 1). The Lukachukai Mountains are the northwestern spur of the Chuska Mountains. Only 33 km^2 are underlain by the Salt Wash Member. The uranium geology of the mountains has been described by Chenoweth and Malan (1973) and Chenoweth (1988). This is the only major district in the Salt Wash not discovered during the radium boom of the 1910s–1920s. Navajo prospectors discovered outcrops of yellow uranium minerals in this remote area in 1949. Drilling by the AEC and private companies located significant orebodies behind the outcrops.

Orebodies occur some 9–24 m above the base of the Salt Wash, which is roughly the middle half of the member in this area. All of the significant deposits are in a well-defined belt that trends nearly north-south across the southeast end of the mountains. This belt accounts for 99.6 percent of the total production and includes an area of 17 km^2. The orebodies are elongate and horizontally lenticular in shape and consist of one or more ore pods surrounded or separated by lower grade or mineralized rock. Tyuyamunite is the principal ore mineral. The composite length of orebodies consisting of two or more ore pods separated by lower grade material ranges up to 335 m. Individual ore pods range up to 107 m in length. The length is usually at least three times the width and is parallel to paleostream depositional trends measured in and near the orebodies. The thickness of the orebodies ranges from 0.3 to 6.7 m. Claystone and/or siltstone beds nearly always underlie and frequently overlie the ore-bearing sandstone units. Ore occurs most commonly in cross-stratified fluvial sandstone that fills scours and channels cut into underlying beds. Detrital carbonaceous material is common in the host rock. The vanadium to uranium ratio of the Lukachukai ores is 4 : 1. During the period 1950 through 1968, 53 mines in the mountains produced 3,483,000 pounds of U_3O_8 and 14,730,000 pounds V_2O_5.

Other areas of Salt Wash production in Arizona are the northern, western and southern Carrizo Mountains (Fig. 1). Between 1948 and 1966, 74 mines in the Arizona part of the Carrizo's produced 365,000 pounds of U_3O_8 and 3,012,000 pounds of V_2O_5.

Some mineralized fossil logs in the Salt Wash were mined near Rough Rock Trading Post (Fig. 1) in 1952 through 1958, producing 1,823 pounds U_3O_8. Total Salt Wash production from Arizona has been 3,851,000 pounds U_3O_8, which is 19 percent of the state's total uranium production (Table I).

CONCLUSIONS

Low market prices and increased foreign competition forced the mines in the Morrison Formation to close in the late 1980s. Large tonnages remain to be mined and numerous unmined orebodies have been discovered, especially in the Grants district and the greater Uravan mineral belt. Several deposits in the Grants district are being investigated for their suitability for solution mining (*in situ* leaching) technology, which is as being used to produce uranium from Tertiary sedimentary rocks in Texas, Wyoming and Nebraska.

As long as lower cost, foreign, uranium is being purchased by the utility companies, the future of domestic production is grim. However, the potential to discover new deposits in the Morrison is good. Higher prices and a strong market would no doubt renew interest in the Morrison deposits, now closed or on standby.

Acknowledgments

Kenneth Carpenter and Fred Peterson reviewed an earlier version of this manuscript, and their comments are appreciated.

References

Chenoweth, W.L. (1981) The uranium–vanadium deposits of the Uravan mineral belt and adjacent areas, Colorado and Utah. *New Mexico Geol. Soc. Guidebook*, 32nd Ann. Field Conf., pp. 165–170.

Chenoweth, W.L. (1985) Geology and production history of the Sanostee area, San Juan County, New Mexico. *New Mexico Bur. Mines Mineral Res., Open-file Rep.*, **223**, 37 p.

Chenoweth, W.L. (1988) The geology and production history of the uranium–vanadium deposits in the Lukachukai Mountains, Apache County, Arizona. *Arizona Geol. Surv. Open-file Rep.*, **88-19**, 64 p.

Chenoweth, W.L. (1989) Ambrosia Lake, New Mexico – a Giant uranium district. *New Mexico Geol. Soc. Guidebook*, 40th Ann. Field Conf., pp. 297–302.

Chenoweth, W.L. and R.C. Malan (1973) Uranium deposits of northeastern Arizona. *New Mexico Geol. Soc. Guidebook*, 24th Ann. Field Conf., pp. 139–149.

Doelling, H.H. (1967) Uranium deposits of Garfield County, Utah. *Utah Geol. Mineral. Surv., Spec, Stud.*, **22**, 113 pp.

Doelling, H.H. (1975) Geology and mineral resources of Garfield County, Utah. *Utah Geol. Mineral. Surv. Bull.*, **107**, 175 pp.

Fischer, R.P. (1968) The uranium and vanadium deposits of the Colorado Plateau region. In Ridge, J.D. (Ed.) Ore deposits of the United States, 1933–1967. *Amer. Inst. Mining, Metal. Petr. Engineers*, **1**, 735–746.

Fischer, R.P. and L.S. Hilpert (1952) Geology of the Uravan mineral belt. *U.S. Geol. Surv. Bull.*, **988-A**, A1–A13.

Grundy, W.D. and W.R. Kastelic (1956) A summary of geologic investigations of uranium deposits in the Jurassic Morrison Formation, Henry Mountains, Utah. *U.S. Atom. Energy Com., Tech. Mem.*, **TM-206**, 21 pp.

Kelley, V.C. (1962) Geology and technology of the Grants uranium region. *New Mexico Bur. Mines Mineral Res. Mem.*, **15**, 277 pp.

McLemore, V.T. and W.L. Chenoweth (1989) Uranium resources in New Mexico. *New Mexico Bur. Mines Mineral Res., Res. Map*, **18**, 36 pp.

Mobley, C.M. and E.S. Santos (1955) Exploration for uranium deposits in the Yellow Cat and Squaw Park areas, Thompson district, Grand County, Utah. *U.S. Geol. Surv., Trace Elem. Invest. Rep.*, **448**, 124 pp.

Motica, J.E. (1968) Geology and uranium–vanadium deposits in the Uravan mineral belt, southwestern Colorado. In Ridge, J.E. (Ed.) Ore Deposits of the United States, 1933–1967. *Amer. Inst. Mining, Metal. Petr. Engineers*, **1**, 805–813.

Owen, D.E., L.J. Walters, Jr., and R.G. Beck (1984) The Jackpile Sandstone Member of the Morrison Formation in west-central New Mexico – a formal definition. *New Mexico Geol.*, **6**, 45–52.

Rautman, C.A. (1980) Geology and mineral technology of the Grants uranium region 1979. *New Mexico Bur. Mines Mineral Res. Mem*, **38**, 400 p.

Stokes, W.L. (1952) Uranium–vanadium deposits of the Thompsons area, Grand County, Utah. *Utah Geol. Mineral. Surv. Bull.*, **46**, 51 pp.

Thamm, J.K., A.A. Kovschak, Jr., and S.S. Adams (1981) Geology and recognition criteria for sandstone uranium deposits of the Salt Wash type, Colorado Plateau province. *U.S. Dept. Energy, Rep.*, **GJBX-6(81)**, 136 pp.

Trimble, L.M. and H.H. Doelling (1978) Geology and uranium–vanadium deposits of the San Rafael River mining area, Emery County, Utah. *Utah Geol. Mineral Surv. Bull.*, **113**, 122 pp.

U.S. Department of Energy (1982) American sources of uranium acquired by the Manhattan Project. *U.S. Dept. Energy, Tech. Mem.*, **TM-350**, 4 pp.

Webber, B.N. (1947) Geology and ore resources of the uranium–vanadium depositional province of the Colorado Plateau region. *Union Mines Devel. Corp., Rep.*, **RM0-437**, 279 pp.

Modern Geology, 1998, Vol. 22, pp. 235–260
Reprints available directly from the publisher
Photocopying permitted by license only

THE AGE OF THE MORRISON FORMATION

BART J. KOWALLIS[a,*], ERIC H. CHRISTIANSEN[a], ALAN L. DEINO[b], FRED PETERSON[c], CHRISTINE E. TURNER[c], MICHAEL J. KUNK[d] and JOHN D. OBRADOVICH[c]

[a] *Department of Geology, Brigham Young University, Provo, UT 84602, USA;*
[b] *Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA;*
[c] *US Geological Survey, Federal Center, Denver, CO 80225, USA;*
[d] *US Geological Survey, 981 National Center, Reston, VA 22092, USA*

(Received in final form 4 April 1997)

The Morrison Formation in Utah and Colorado contains many volcanic ash layers and ashy beds, now altered mostly to bentonite, that have yielded isotopic ages. The Brushy Basin Member, at the top of the formation, gives single-crystal, laser-fusion and step-heating, plateau $^{40}Ar/^{39}Ar$ ages on sanidine that range systematically between 148.1 ± 0.5 (1 std. error of mean) at the top of the member to 150.3 ± 0.3 Ma near the bottom. The Tidwell Member, at the base of the Morrison Formation, contains one ash bed about 3 m above the J-5 unconformity that occurs in at least two widely separated sections. This ash has been dated by $^{40}Ar/^{39}Ar$ dating of sanidine and gives ages of 154.75 ± 0.54 Ma (Deino NTM sample, laser-fusion), 154.82 ± 0.58 Ma (Deino RAIN sample, laser-fusion), 154.87 ± 0.52 (Kunk NTM sample, plateau), and 154.8 ± 1.4 Ma (Obradovich NTM sample, laser-fusion). The Morrison Formation, therefore, ranges in age from about 148 to 155 Ma and, based upon fossil evidence appears to be entirely Late Jurassic, including the latest Oxfordian(?), Kimmeridgian, and early Tithonian Ages.

Keywords: Morrison Formation; Isotopic ages; Latest Oxfordian(?); Kimmeridgian; Early Tithonian

INTRODUCTION

One of the significant unresolved problems related to the Morrison Formation is its age, both chronostratigraphically and biostratigraphically. The formation has been labeled as Jurassic, Cretaceous, and Jurassic–Cretaceous over the years (e.g., Emmons and others, 1896; Darton, 1922;

* Corresponding author.

Volume 22, Numbers 1–4 (1998)
MOGEB3 22 (1–4) 1–534 ISSN 0026-7775
ISBN 90-5699-183-3

MODERN GEOLOGY

SPECIAL ISSUE

THE UPPER JURASSIC MORRISON FORMATION: AN INTERDISCIPLINARY STUDY

Part 1