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William L. Chenoweth

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THE URANIUM-VANADIUM DEPOSITS OF THE URAVAN MINERAL BELT AND ADJACENT AREAS, COLORADO AND UTAH

WILLIAM L. CHENOWETH
U.S. Department of Energy
Grand Junction, Colorado 81502

INTRODUCTION

The Salt Wash Member of the Morrison Formation of Jurassic age contains economic deposits of uranium and vanadium minerals in western Colorado, southeastern Utah, northeastern Arizona, and northwestern New Mexico. These deposits have accounted for nearly 13 percent of the United States' uranium production. The most productive deposits are in a relatively small area in southwestern Colorado that is referred to as the Uravan mineral belt. Included with the Uravan mineral belt in this overview are the following adjacent areas: Thompson, Moab, La Sal, and Dry Valley (fig. 1).

This paper is intended to present a brief overview of the geologic setting of the deposits, to review the geologic investigations, and to summarize the development of the mining industry in the area.

GEOLOGIC SETTING

The Uravan mineral belt, as defined by the U.S. Geological Survey (USGS) in 1952, is an elongate area in southwestern Colorado wherein uranium-vanadium deposits in the Salt Wash Member of the Morrison Formation "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 in-

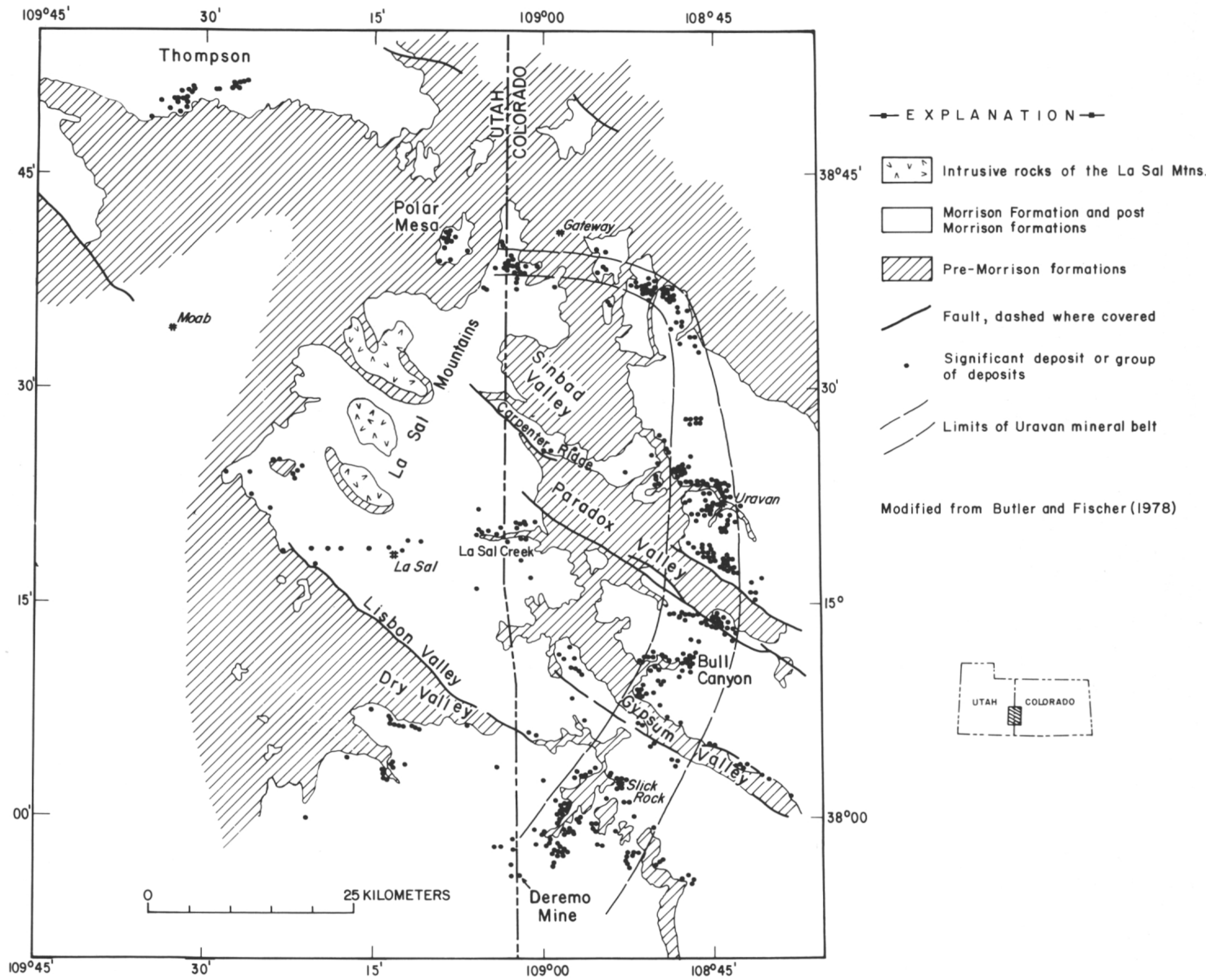

Figure 1. Index map of southwestern Colorado and southeastern Utah showing the location of uranium-vanadium deposits in the Salt Wash Member of the Morrison Formation.

cludes the Gateway, Uravan, Bull Canyon, Gypsum Valley, and Slick Rock districts (fig. 1).

The Salt Wash Member consists of interbedded fluvial sandstone and floodplain-type mudstone units. The sandstone beds crop out in three to eight cliffs or "rims" with the mudstone units forming slopes. The uppermost sandstone, or rim, contains the majority of the ore deposits, but deposits do occur in the lower sandstones. A few deposits occur in coarse conglomeratic sandstones in the lower part of the overlying Brushy Basin Member. Records of the Grand Junction Office of the U.S. Department of Energy (DOE) show that production has been derived from nearly 1,200 individual properties within the 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 which are several hundred meters wide and up to a few kilometers long. The tabular ore bodies typically are elongated parallel to sedimentary trends, and are concordant with the bedding. The ore averages about 1.2 m thick, but in a few places ore thicknesses approaching 9 m have been mined. Individual ore bodies may be connected by weakly mineralized rock, but generally the boundary of ore and barren rock is abrupt. Figure 2, a plan view of the Deremo Mine in the Slick Rock area, illustrates the typically erratic distribution of ore bodies and the relatively small size of individual stopes. The mineralized area at the Deremo was defined by surface holes drilled on 61-m centers, but most of the ore has been found by mining and close-spaced underground drilling (Thamm and others, 1981, p. 36). Ore bodies ranging from a few tons to large masses containing more than one million tonnes of ore tend to be clustered within elongated favorable areas a few kilometers long by several hundred meters wide. Average production from these elongated favorable areas has ranged from a few hundred thousand tonnes of ore to a few million tonnes of ore.

Although most of the mineralized zones in the Salt Wash are tabular and concordant with bedding, the ore in some deposits abruptly crosses bedding in smooth curves to form rolls. The rolls in plan view are generally narrow, not more than a few meters wide, sinuous, and decidedly elongated parallel to local sedimentary structures, major channels, or axes of greatest permeability. Most rolls are C- or S-shaped in cross section, but various other shapes have been reported.

The term "roll" was originally used by miners to describe mineralization that cuts sharply across bedding features, and was adopted by Fischer (1942). This use predated the discovery of the roll-type deposits in Wyoming, and its application to Salt Wash deposits is more descriptive than generic.

Some small, high-grade ore bodies 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 m long and 1 m in diameter.

Sedimentary features exert a strong control on the shape and distribution of the Salt Wash deposits. On a broad scale, clusters or trends of deposits are associated with major sedimentary channels and tend to occur along their margins. On a more local scale, individual deposits or lenses of mineralization commonly terminate against shale horizons, channel margins, and other sedimentary features that produces permeability changes.

In most large ore bodies and clusters of smaller ore bodies, sediments adjacent to ore-bearing, reduced sandstone are oxidized. In general, the highest grade ore in any deposit occurs next to the oxidation-reduction boundary. Where narrow, gray unoxidized zones extend into red oxidized sequences, the grade and continuity of the ore improve dramatically. These zones, bounded above and below by red sediments, do not make major mines in themselves, but contain high-grade pods of ore within larger mines (Thamm and others, 1981, p. 47).

Within an ore body, uranium and vanadium minerals coat sand grains, fill interstices, and replace organic material, feldspar, calcite, and quartz. In unoxidized ore bodies, the principal uranium minerals are uraninite and coffinite. The main uranium minerals in oxidized ores are tyuyamunite, metatyuyamunite, and carnotite. Although the oxidized ores are called carnotite deposits, the mineral carnotite is not as abundant as tyuyamunite (S. R. Austin, personal communication, 1978). Vanadium clays, consisting largely of chlorite and/or hydromica, are the main vanadium minerals in both oxidized and unoxidized ores and deposits. Montroseite is present in the unoxidized ores and corvusite is common in the partly oxidized deposits. The oxidation of vanadium forms a series of vanadate minerals which include: tyuyamunite, metatyuyam unite, carnotite, hewettite, metahewettite, pascoite, rauvite, rossite, metarossite, fervanite, and hummerite. The mineralogy of the Salt Wash ores is summarized by Weeks and others (1959). Generally the amount of vanadium exceeds the uranium in ratios ranging from 3:1 to 10:1. Ores mined in the area have averaged 5:1. Within the Uravan mineral belt, the vanadium increases southward from Gateway (3:1) to Slick Rock (8:1). These ratios are based on uranium production since 1947 and include both oxidized and unoxidized ores. With a few local exceptions, both oxidized and unoxidized ores are in radioactive equilibrium.

GEOLOGIC INVESTIGATIONS

Geologic investigations of the uranium-vanadium deposits of southwestern Colorado and southeastern Utah began about 1900 and have continued to the present. As a result, an extremely large number of reports have been written on the area. The majority of these reports are the results of studies by the USGS and the U.S. Atomic Energy Commission (AEC) during the uranium boom of the 1950s. Nelson-Moore and others (1978) have compiled a bibliography of uranium reports in Colorado, which includes some reports in the adjacent parts of Utah.

During World War II, the Union Mines Development Corporation, contractor to the Army Corps of Engineers, systematically studied the deposits as part of a general uranium resource apprais- al of the Colorado Plateau. This work resulted in a series of district reports complete with mine maps and detailed descriptions of in- dividuals deposits. These reports were open-filed by the AEC in the 1950s and 1960s.

Subsequent district studies include: Thompson (Stokes, 1952), La Sal Creek (Carter and Gualtieri, 1965), and Slick Rock (Shawe and others, 1959).

One of the earliest regional summaries was written by Coffin (1921) during the radium era. Included with this report was a reconnaissance geologic map of the carnotite region of southwestern Colorado. In 1958, Wood and Lekas (1958) published a brief summary of the uranium geology and economics of the Uravan mineral belt. Included with this article was a mine location map of the belt. Eleven years later, Motica (1969) prepared a fairly detailed summary of the area. Recently, Thamm and others (1981) compiled an excellent summary of the geologic features of the Salt Wash deposits.

HISTORY AND PAST PRODUCTION

The history of the mining of carnotite deposits in southwestern Colorado and southeastern Utah reflects the importance of three

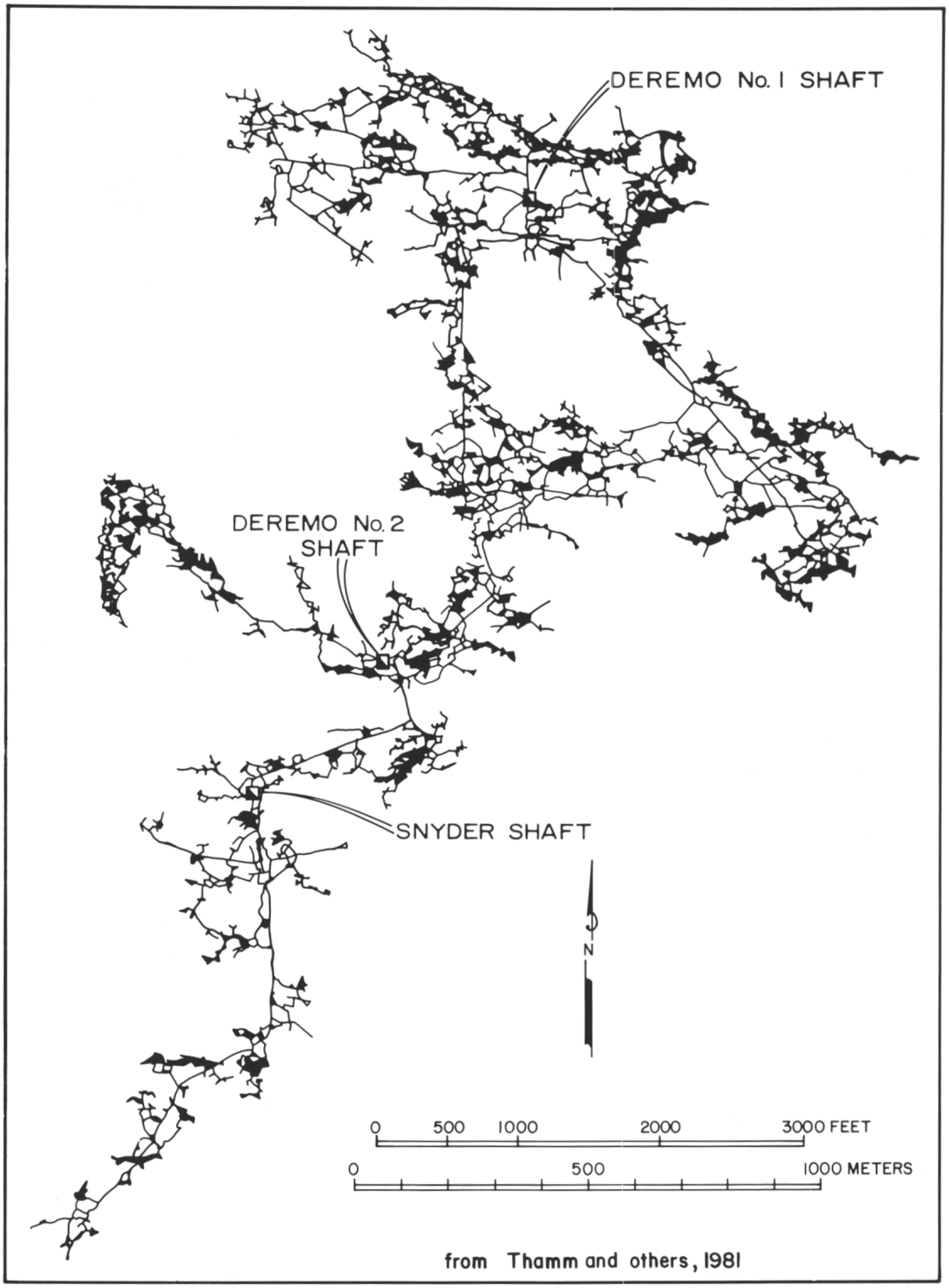

Figure 2. Plan map of the Deremo Mine, Slick Rock area, Colorado.

metals—radium, vanadium and uranium. All three are briefly reviewed in the following sections. Much of the historical material is taken from a staff report by the U.S. Atomic Energy Commission (1951).

Early Activities

The existence of a yellow substance in the Paradox Valley rimrock of Montrose County was known to the settlers prior to 1880. It is assumed that the Ute and Navajo Indians used this yellow powder as a pigment before the white settlers came to the region.

In 1881, a prospector named Tom Talbert sent some yellow material from the Roc Creek area of Montrose County to an assayer in Leadville to determine its content. This and other early attempts to detect the elements present in the yellow material were unsuccessful. About 1896 the claims on Roc Creek were relocated by Tom Dullan. Gordon Kimball and associates of Ouray, Colorado, leased the property in 1898 and sent some of the yellow material to Charles Poulot in Denver who found it contained uranium in sufficient quantity to make it valuable. During June 1898, Gordon Kimball shipped 9 tonnes of ore from the Roc

Creek property to Denver. This shipment averaged 21.5 percent uranium oxide (U308) and over 15 percent vanadium oxide (V205) for which Kimball was paid $2,600 (Kimball, 1904). The high vanadium content resulted in a penalty when the shipment was resampled in France. In 1899 Charles Poulot and another Frenchman named Voilleque sent mineral specimens to France where M. M. C. Friedel and E. Cumenge established the approximate composition of this mineral and named it carnotite, after the French mining engineer and chemist M. Adolphe Carnot.

Soon after the first shipment of carnotite it became known that the yellow mineral was marketable, and many claims were staked. Most of the claims were located along Roc Creek, along La Sal Creek, and in adjacent areas.

In 1900, Poulot and Voilleque conducted experimental work on extracting vanadium and uranium oxides from carnotite ores at the camp of the Cashin copper mine on La Sal Creek. The ores used in these experiments came from mines on Roc Creek, on La Sal Creek, and on the San Miguel River. As a result of these studies, a company formed by Poulot, Voilleque, and James McBride built an experimental mill at the mouth of Summit Creek in the Slick Rock area. About 6,800 kg of uranium-vanadium concentrates were produced at this plant before operations were transferred to the Western Refining Company in 1903 and to the Dolores Refining Company in 1904 (Lundquist and Lake, 1955). This activity created much interest in carnotite areas, and widespread claim staking occurred throughout the area between 1902 and 1905. According to Fischer (1968, p. 738), between 1898 and 1909 total production from the region was 8,200 tonnes of high-grade ore. VVith the exception of ore from the vicinity of the Summit Creek plant, all ore mined before 1906 was shipped either to the eastern part of the United States for vanadium recovery or to Europe for the recovery of radium.

The Radium Era

The discovery of radium by Marie and Pierre Curie in 1898 led to the realization that all uranium ores contained this new element. Experiments which showed that radium inhibited the growth of certain cancers so astonished the medical profession that an incentive to mine the carnotite ores was created.

Shortly before 1910, metallurgical processes for relatively large-scale recoveries of radium from carnotite ores were perfected. The improved processes resulted in greatly increased demands for carnotite and in accelerated prospecting in the entire area. About one gram of radium is present in every 180 to 275 tonnes of ore containing 2.0 percent U308. With development work being organized by the Radium Luminous Metals Company in 1910, and by the Radium Company of Colorado and the Standard Chemical Company in 1911, a mining rush resulted which affected the entire Colorado Plateau.

Shortly after 1910, the carnotite deposits in southwestern Colorado and southeastern Utah became one of the principal world sources of radium. For about 12 years, these deposits were mined for radium and yielded some byproducts of uranium and vanadium.

The Radium Company of Colorado treated its ore in a plant in Denver while the Radium Luminous Metals Company shipped ore to its plant in East Orange, New Jersey. The National Radium Institute built a dry-process plant in the Long Park area. This mill was later purchased by the Pittsburgh Radium Company and moved a few kilometers northwest to Saucer Basin. However, after treating some 1,814 mt of ore, the mill did not prove successful, and was dismantled.

The Standard Chemical Company treated most of its ore at the Joe Junior mill at the present-day site of Uravan. The American Rare Metals Company purchased the Summit Creek plant at Slick Rock and recovered some uranium and vanadium as well as radium. Operating costs were high because of the isolation of the mines; for example, Placerville, Colorado, about 105 km from the Joe Junior camp, was the nearest shipping point. Concentrates, ores, and supplies were hauled by freight wagon between Placerville and Joe Junior and to other points within the area. The freight rates between Joe Junior and Placerville were $27.00 per ton in 1914, but by 1922, rates had been reduced to $14.00 per ton as a result of road improvements and the introduction of motor trucks. Because of the high freight rates, the Radium Company of Colorado and the Radium Luminous Metals Company found it unprofitable to mine and ship ore assaying less than 2.0 percent U308. The Standard Chemical Company could mine and mill ore running as low as 1.25 percent U308, although the average grade of ore treated in this plant was over 1.50 percent U308. The mill recovery varied between 65 and 70 percent.

The beginning of World War I in 1914 had little effect on the mining of carnotite ores though it did affect the European market. Because of the increasing demands for vanadium, radium plants were engineered to recover quantities of vanadium as a byproduct from carnotite. With the entry of the United States into the war in 1917, emphasis slowly began to shift away from the production of radium to the production of vanadium. By 1922 Colorado Plateau ores were no longer competitive with newly developed high-grade pitchblende ores in the Belgian Congo as a source of radium.

The end of the war caused both a drop in the demand for vanadium and a resumption of production from lower cost areas. Mining and milling of carnotite ores ceased around 1923 and was not resumed in most districts of southwestern Colorado and southeastern Utah until 1936.

From 1910 to 1923, the carnotite ores are estimated to have yielded 202 grams of radium with small amounts of vanadium and uranium recovered as byproducts (Fischer, 1968, p. 738). During this period, the price of the world market for the elemental radium content in purified salts, ranged from $70,000 to $180,000 per gram (Tyler, 1930, p. 41).

The Vanadium Era

Prior to 1930, most of the vanadium produced in the United States came from roscoelite deposits near Rifle and Placerville, Colorado. In 1928, U.S. Vanadium Corporation (USV), then a subsidiary of Union Carbide and Carbon Corporation, anticipated a growing market for vanadium, and purchased from Standard Chemical the Joe Junior concentrator and 14 km' of mining claims. Between 1934 and 1935, the assets of the Colorado Radium Company and the Radium Luminous Metals Company were acquired by the Vanadium Corporation of America (VCA).

After a period of comparative inactivity, the rising demand for vanadium by the alloy-steel industry renewed interest in the deposits. Most of the established mines were reopened by 1935. VCA built a new town and mill at Vancorum, west of Naturita, Colorado. USV moved its plant from Rifle to the Joe Junior site in 1936 and altered the metallurgical process to handle carnotite ores. The townsite of Uravan was thus founded. North Continent Mines Company built a mill in the Slick Rock area, as did International Vanadium Corporation in Dry Valley, Utah.

Prospecting continued, and many new mines were developed throughout the area. A small mill was built at Gateway, Colorado, by Gateway Alloys, Inc. The United States' entry into World War II in 1941 gave the vanadium industry new impetus.

In order to stimulate the production of strategic materials, the federal government formed the Metals Reserve Company in 1942. Vanadium was one of the strategic materials, and Metals Reserve began an ore purchasing program and increased the base price paid for vanadium. Mills at Monticello, Utah, and Durango, Colorado, were built and operated for Metal Reserve by VCA and USV, respectively. To insure a steady supply of ore for the mills, Metals Reserve established buying stations and stockpiled ore for distribution.

The Metals Reserve program, which lasted from 1942 through February 1944, greatly stimulated prospecting, and many new deposits were found. After the termination of the program vanadium mining all but ended in the area.

Manhattan Engineer District Studies

To evaluate the uranium resources of the Salt Wash Member of the Morrison Formation of the Colorado Plateau, the Army Corps of Engineers, as part of the Manhattan Project, contracted with Union Carbide and Carbon Corporation to create a raw-materials appraisal group. This group, known as Union Mines Development Corporation (UMDC), was formed in 1943 and was active through 1946.

UMDC geologists systematically studied the uranium-vanadium deposits of the area. All of the known outcrops of uranium-vanadium minerals, prospects, and mines were mapped and described. Their work was thorough, and few outcropping occurrences of uranium-vanadium minerals known today were overlooked by UMDC.

As part of its study, UMDC determined the amount of vanadium ore that had previously been mined. For Uravan and adjacent areas, this amounted to 639,406 tonnes of ore, averaging 1.93 percent V205, and containing 12,328,144 kg of vanadium oxide. Details of this early vanadium production are given in Table 1. These vanadium ores also were estimated to have contained 1,781,207 kg U308, much of which went into the tailings at the vanadium mills.

In 1943 UMDC began the operation of acid leach plants at Durango and Uravan for the recovery of uranium from vanadium tailings. The concentrates produced in the tailing treatment plants were shipped to a refinery at Grand Junction where a low-grade uranium concentrate and a commercial-grade fused vanadium oxide were produced. The treatment plants and refinery were in operation until late 1946.

The Atomic Energy Commission Program

In May 1947, the newly created Atomic Energy Commission signed a contract with VCA for the purchase of uranium concentrates from the Naturita mill. Deliveries to the AEC started later that year. Another contract was signed with VCA to purchase concentrates from the Durango mill, and with USV to buy concentrates from the Uravan mill; deliveries began in 1949 and 1950, respectively. The Metals Reserve mill at Monticello was altered by the AEC to permit the recovery of uranium. Climax Uranium Company began operating the first mill in the United States designed primarily for the production of uranium with vanadium as a by-product at Grand Junction in 1951.

Ore-buying schedules and other AEC incentives stimulated prospecting throughout the area. During the 1950s, the AEC and the USGS carried out extensive geologic studies and exploration programs to assist the newborn nuclear industry. These investigations resulted in the discovery and development of many deposits, and by the mid-1950s nearly all surface and near-surface deposits had been discovered.

The yearly production of uranium oxide in ore from the area is shown in Figure 3. This chart was compiled from records of the Grand Junction Office of the U.S. Department of Energy. Starting in 1947, production increased yearly until 1960 when an all-time high of 2,102 tonnes of U308 in ore were produced. The AEC announced in 1961 that purchases of uranium ore after April 1, 1962, would be limited to annual quotas allocated to individual properties. Also, from that date until the end of 1966, instead of buying concentrate at the graduated prices previously in effect, the AEC would pay $8.00 per pound for U308 in concentrates produced mostly from reserves discovered before November 24, 1958. As a result of this change, the production of uranium ore in the Uravan area and in the United States, declined in 1961 for the first time since 1947 (fig. 3). In 1962, the AEC proposed to continue the purchase of uranium until 1971 from those suppliers who would agree to defer delivery of a part of their pre-1966 quotas until 1967

Table 1. Pre–1946 vanadium production, Uravan mineral belt and adjacent areas.

Area	Tonnes	Grade (%)	Kilograms V_2O_5
COLORADO			
Uravan	424,127	1.78	7,554,988
Slick Rock	89,541	2.38	2,133,734
Gateway	26,236	1.93	505,746
Gypsum Valley	18,779	1.90	356,802
Bull Canyon	16,928	2.18	369,212
Carpenter Ridge	2,722	1.90	51,710
UTAH			
Dry Valley	20,866	1.87	390,187
La Sal Creek	11,440	1.93	220,788
Moab	9,979	1.80	179,626
Thompson	9,616	2.79	268,295
Polar Mesa	9,172	3.24	297,057
TOTALS	639,406	1.93	12,328,145

Estimated contained kg U_3O_8—1,784,235

Modified from Webber, 1947, fig. 59

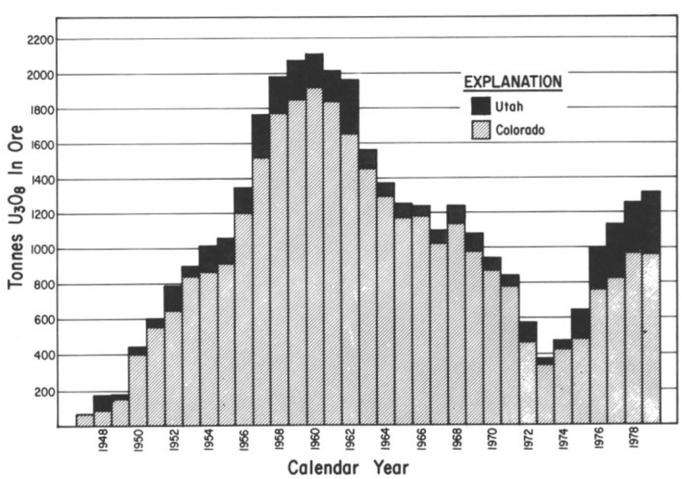

Figure 3. Uranium production, 1947–1979, Uravan mineral belt and adjacent areas.

and 1968. The price to be paid in 1969 and 1970 was not to exceed $6.70 per pound of L.1308. The Climax Uranium Company at Grand Junction elected not to participate in the AEC stretchout program and began producing uranium for private sales to utilities in 1966. The AEC procurement program ended December 31, 1970. During the period 1947 through 1970 the AEC purchased ores containing approximately 27,170 tonnes U308.

During the late 1940s and early 1950s, the AEC obtained mineral rights on 1,813 km' of land on the Colorado Plateau. Exploration was conducted on these lands by the AEC and the USGS, and when significant ore bodies were found, the land was leased for mining. By 1957, some 1,709 km2 had been returned to the public domain. Of the 104 km2 that were retained, 85 km' were in the Uravan area of Colorado and Utah. By March 1962, mining on these lands had terminated because of expired leases. During mid-1974, the lands were again leased, and mining and exploration commenced later that year. Since then, $42 million in production royalties have been paid to the federal government.

The Private Market

After the termination of the AEC purchasing program the only market for uranium was the electric utilities. Since nuclear power generation did not develop as rapidly as had been anticipated, uranium production continued to decline in the early 19705. The demand for vanadium kept the industry in the Uravan area from collapsing completely. In 1970, the Climax mill at Grand Junction closed, and most of the Climax properties were acquired by Atlas Minerals.

Production in the Uravan area reached an all time low of 371 tonnes of L.J308 in ore in 1973. Following this, the rise in uranium prices to record levels by the mid-1970s resulted in a surge of activity and increasing production. New ore bodies were located by exploration on the DOE lease blocks and outside the mineral belt in the Gypsum Valley, Dry Valley, and La Sal areas.

A buying station was established by General Electric's Nuclear Division near Naturita for independent miners. A vanadium circuit was installed by Atlas at its Moab mill in 1976. The Cotte r Corporation, a wholly-owned subsidiary of Commonwealth Edison, built a crushing and sampling plant at Whitewater, Colorado, in order to ship its ore by rail to the company mill at Canon City, Colorado. In June 1980, the Energy Fuels Nuclear mill near Blanding, Utah, began operating and now provides a market for the mines in the southern part of the area.

During the period 1947 through 1979, uranium production from Uravan and adjacent areas has amounted to 14,675,000 tonnes of ore averaging 0.24 percent U308 and containing 34,754,000 kg of U308. This represents 11 percent of the total United States' uranium production. Vanadium has been recovered from 14,589,600 tonnes with an average grade of 1.24 percent V,05 and containing 187,443,300 kg of V205. This represents 80 percent of the total domestic production of vanadium from sandstone uranium ores. Mines within the confines of the Uravan mineral belt (fig. 1) account for 85 percent of the uranium that has been pro- duced in the area.

OUTLOOK

Although poor market conditions and increased operating costs have forced many operations to close during the latter part of 1980 and the early part of 1981, the long term outlook for the area is favorable. An increase in the price of uranium and an expanded market would result in increased production. Significant reserves exist on the DOE lease blocks and in the La Sal trend (see paper by Kovschak and Nylund, this guidebook), and elsewhere in the area. In addition to the known reserves, the possibilities of finding additional deposits in the Salt Wash are good. Studies of the Department of Energy's National Uranium Resource Evaluation Program have estimated 43,360,000 kg of U308 of probable potential resources may be present in the area at forward costs of $30 per pound U308, or less.

The known reserves and the favorable geology for undiscovered potential resources are expected to result in the Uravan area being a source of uranium and vanadium ore for many years to come.

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REFERENCES

Butler, A. P., Jr., and Fischer, R. P., 1978, Uranium and vanadium resources in the Moab 10 x 2° quadrangle, Utah and Colorado: U.S. Geological Survey Professional Paper 988-B, p. B1-B21.

Carter, W. D. and Gualtieri, J. L., 1969, Geology of the uranium-vanadium deposits of the La Sal quadrangle, San Juan County, Utah, and Montrose County, Colorado: U.S. Geological Professional Paper 508,82 p.

Coffin, R. C., 1921, Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geological Survey Bulletin 16,231 p.

Fischer, R. P., 1942, Vanadium deposits of Colorado and Utah, a preliminary report: U.S. Geological Survey Bulletin 936-P, p. 363-394.

, 1968, The uranium and vanadium deposits of the Colorado Plateau region, in Ridge, J. D., ed., Ore deposits of the United States, 1933-1967: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 1, p. 735-746.

Fischer, R. P. and Hilpert, L. S., 1952, Geology of the Uravan mineral belt: U.S. Geological Survey Bulletin 988-A, p. 1-13.

Kimball, Gordon, 1904, Discovery of carnotite: Engineering and Mining Journal, v. 77, p. 956.

Lundquist, A. Q. and Lake, J. L., 1955, History and trends of uranium plant flowsheet: Mining Congress Journal, v.41, n. 11, p. 35-42.

Motica, J. E., 1968, Geology and uranium-vanadium deposits in the Uravan mineral belt, southwestern Colorado, *in* Ridge, J. D., ed., Ore deposits of the United States, 1933-1967: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 1, p. 805-813.

Nelson-Moore, J. L., Collins, D. B., and Hornbaker, A. L, 1978, Radioactive mineral occurrences of Colorado and bibliography: Colorado Geological Survey Bulletin 40,1,054 p.

Shawe, D. R., Archbold, N. L., and Simmons, G. C., 1959, Geology and uranium-vanadium deposits of the Slick Rock district, San Miguel and Dolores Counties, Colorado: Economic Geology, v. 54, p. 395-415.

Stokes, W. L., 1952, Uranium-vanadium deposits of the Thompsons area, Grand County, Utah, with emphasis on the origin of the carnotite ores: Utah Geological and Mineral Survey Bulletin 45,51 p.

Thamm, J. K., Kovschak, A. A., Jr., and Adams, S. S., 1981, Geology and recognition criteria for sandstone uranium deposits of the Salt Wash type, Colorado Plateau province-final report: U.S. Department of Energy Report GJBX-6(81), 136 p.

Tyler, P.M., 1930, Radium: U.S. Bureau of Mines Information Circular 6312, 55 p.

U.S. Atomic Energy Commission, 1951, Uranium exploration on the Colorado Plateau, interim staff report: U.S. Atomic Energy Commission Report RMO-1000,75 p.

Webber, B. N., 1947, Geology and ore reserves of the uranium-vanadium depositional province of the Colorado Plateau region: Union Mines Development Corp. Report RMO-437,279 p.

Weeks, A. D., Coleman, R. E., and Thompson, M. E., 1959, Summary of the ore mineralogy, pt. 5, *in* Garrels, R. M., and Larsen, E. S., 3d, compilers, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geological Survey Professional Paper 320, p. 65-79.

Wood, H. B. and Lekas, M. A., 1958, Uranium deposits of the Uravan mineral belt, *in* Guidebook to the geology of the Paradox Basin: Intermountain Association Petroleum Geologists, Ninth Annual Field Conference, p. 208-215.