ABSTRACT

Uranium deposits in the San Juan Basin occur principally in continental, fluvial sandstones of the Morrison Formation of Jurassic age. A cluster of large deposits in McKinley, Sandoval, and Valencia Counties, New Mexico, comprises the Grants Mineral Belt, the largest uranium area in the United States.

During 1948 through 1976, underground and open-pit mines in the San Juan Basin have produced 119,163 tons of uranium oxide (U3O8). This amounts to 40 percent of the total United States' uranium ore production. The discovered ore reserves and the favorable geology for undiscovered potential resources of the basin are expected to maintain New Mexico's position as the nation's principal source of uranium for years to come.

INTRODUCTION

The San Juan Basin of northwest New Mexico has been the source of more uranium production than any other area in the United States. Nearly all of the production has come from the Grants Mineral Belt (fig. 1). This paper describes the geologic setting of the ore deposits in the San Juan Basin, summarizes the growth of the uranium raw materials industry, and reviews the resource base.

GEOLOGIC SETTING

In the San Juan Basin, bedded and vein uranium deposits are in several different rock-types of Mesozoic and Tertiary age. Tabular deposits, which occur primarily in continental, fluvial sandstone of Jurassic age, are the most important. Only the more significant occurrences are discussed in this paper.

Most uranium deposits are in the Grants Mineral Belt in McKinley, Sandoval, and Valencia Counties. This cluster of large deposits extends for nearly 100 miles across the southern flank of the San Juan Basin. Although poorly defined, the belt is 10 to 20 miles wide. The four principal mining areas in the belt are Gallup, Smith Lake, Ambrosia Lake, and Laguna (fig. 1). Ore deposits occur from the surface to depths greater than 4,000 feet, although to date all production has come from deposits shallower than 2,000 feet. Deposits in the Grants Mineral Belt have been described in detail by Kelley (1963), and by Hilpert (1969).

The Todilto Limestone of Jurassic age contains uranium ore bodies along the southern margin of the Grants Mineral Belt, where the limestone has been deformed by intraformational folding and faulting. Some 2,718 tons U3O8 have been produced from 42 properties, mainly in the Ambrosia Lake area, accounting for two percent of the total output of the mineral belt. At a few places in the Todilto, ore also has been mined from the underlying Entrada Sandstone of Jurassic age where the ore bodies cross the contact between the two formations. Uranium also occurs in the Todilto in the Sanostee area of San Juan County, where small trial shipments have been made from two properties.

The Morrison Formation of Jurassic age was deposited in a continental environment. It consists of interbedded fluvial sandstone, claystone, and mudstone. In the southern San Juan Basin, the Morrison consists of three members, all of which contain ore deposits. In ascending order, they are the Recapture, Westwater Canyon, and Brushy Basin Members. In the Ambrosia Lake and Laguna areas, the Recapture contains minor sandstone beds that are hosts for small uranium deposits.

The Westwater Canyon Member consists of thick sandstones with interbedded lenses of relatively thin discontinuous claystone. This member contains large uranium deposits in the Ambrosia Lake and Gallup areas. The Brushy Basin Member consists of greenish-gray mudstone and claystone with interbedded sandstone and a few thin beds of limestone. A thick lens of sandstone, the Jackpile sandstone, occurs in the upper part of the Brushy Basin in the Laguna area, where it contains large ore deposits. The Brushy Basin also is host for deposits in the Smith Lake area, although these are smaller than those at Laguna.

Uranium deposits of the Grants Mineral Belt are irregular in shape and generally are elongated parallel to paleostream channels (fig. 2). The deposits range in size from thin pods a few feet in width and length to large masses of ore several thousand feet long, several hundred feet wide, and several tens of feet thick.

The deposits are in many different sandstone beds and form clusters along distinct trends. Some ore has been redistributed, generally in areas of faulting (fig. 3). The principal ore mineral in the Grants sandstone deposits is coffinite, a uranium silicate (U(OH)2)9.8(SiO2)x, which is intimately associated with grayish-black to brown carbonaceous humate, which impregnates the sandstone. Production from the Morrison Formation in the Grants Mineral Belt has amounted to 114,795 tons U3O8.

In the northwestern San Juan Basin, uranium-vanadium deposits occur in the Salt Wash Member of the Morrison Formation on the eastern side of the Carrizo Mountains. This member, composed of interbedded mudstones and fluvial sandstones, is the lowest member of the Morrison and is present nowhere else in the basin. Mines in the eastern Carrizo Mountains, astride the New Mexico-Arizona line, have produced 110 tons U3O8.

South of the Carrizo Mountains, in the Chuska Mountains near Sanostee, both the Salt Wash and Recapture Members have yielded ore. Sandstones in the Recapture have been the most productive host rock, from which 80 tons U3O8 have been obtained.

On the eastern flank of the San Juan Basin, the Morrison Formation has yielded 395 tons of ore, averaging 0.13 percent U3O8, from two properties on the Ojo del Espiritu Santo Grant, northwest of San Ysidro.

*Publication authorized by the U.S. Energy Research and Development Administration, Grand Junction Office.
FIGURE 1. URANIUM OCCURRENCES, MINES AND MILLS, SAN JUAN BASIN.
The Ojo Alamo Sandstone of Paleocene age and the San Jose Formation of Eocene age contain uranium in Rio Arriba and San Juan Counties. To date, no commercial deposits have been developed.

In the San Juan Basin, vein-type deposits occur in collapsed pipe structures in the mineral belt. The most significant structure is that exploited by the Woodrow mine, north of Laguna. This mine yielded 67 tons U₃O₈ during the middle 1950's.

**HISTORY OF EXPLORATION**

The first significant discovery of uranium in the San Juan Basin was in vanadium-bearing carnotite ores in the eastern Carrizo Mountains west of Shiprock by John Wade in 1918. By 1920, Wade had 41 claims in various parts of the Carrizo Mountains (personal communication, 1955), including the eastern flank. No ore was mined then, due to lack of demand for either vanadium or uranium.

One of the earliest observations of uranium minerals in the Grants area was made in 1937 when V. C. Kelley (1963, p. 1) noted carnotite in a hand specimen which had been collected by Mr. Whiteside, a local prospector. Since Kelley's observation was unrecorded, the occurrence of uranium minerals of the Grants area was overlooked for many years.

World War II increased the demand for vanadium. Early in 1942, Wade, Curran and Company leased a few plots in the east Carrizos. In July 1942, the Vanadium Corporation of America (VCA) leased 12 plots in the east Carrizo area. From 1942 to 1944, these two companies mined carnotite ore from surface exposures in the Salt Wash Member of the Morrison Formation. Although these ores were mined for vanadium content, uranium was later recovered from the mill tailings. Following the termination of vanadium mining in 1944, the Union Mines Development Corporation systematically studied the vanadium-uranium deposits in the Morrison Formation in the Carrizo Mountains as part of a general uranium resource appraisal of the Colorado Plateau by the federal government's Manhattan Engineer District. Their work was very thorough and few surface exposures of uranium known today were overlooked. Coleman (1944) and Webber (1947) of Union Mines estimated the early ore production for the eastern Carrizo Mountains as 12,000 tons, averaging 0.27 percent U₃O₈ and 3.00 percent V₂O₅.

In 1946, prospecting for uranium was stimulated by the ore-buying schedules and other incentives of the U.S. Atomic Energy Commission (AEC). In the years that followed, uranium deposits were discovered in the Sanostee area, south of the Carrizo Mountains, and in the Cuba-San Ysidro area on the eastern side of the basin. The well publicized uranium discovery by Paddy Martinez in the Todilto Limestone near Haystack Butte in Valencia County in the fall of 1950 brought a wave of prospectors into the Grants area. In January 1951, uranium was discovered nearby in the Morrison Formation in Poison Canyon. This discovery led to the subsequent delineation of the Poison Canyon trend deposits. In November 1951, an airborne radioactivity anomaly was detected north of Laguna in Valencia County, by the Anaconda Copper Mining Company, which led to the development of the Jackpile mine. Prospecting continued throughout the San Juan Basin, and by 1956 all surface occurrences had been discovered.

Using the cuttings of an oil well on the nearby Ambrosia Dome to ascertain the drilling depths to the Morrison Formation, Louis Lothman began a wildcat uranium drilling project in April 1956, in sec. 11, T. 14 N., R. 10 W. (Louis Lothman, 1956, written communication). The second hole penetrated uranium-bearing sandstone in the Westwater Canyon Member. The discovery stimulated an intensive search for uranium deposits in the Grants area.
expansion effort and led to eventual development of the multi-million-ton deposits in the Ambrosia Lake area.

During the extensive prospection that followed the initial discoveries in the Grants area in late 1951 and early 1952, several small ore bodies were discovered in outcrops of the Morrison and Dakota Formations in the Gallup and Thoreau areas. Drilling down dip from these deposits led to the discovery of the larger Blackjack and Churchrock ore bodies in 1958 by the Lance Corporation and Phillips Petroleum, respectively.

In 1962, an ore body was found by Sabre Pinon Corporation in the northeastern Churchrock area, where previous drilling had penetrated ore grade material at a depth of about 1,875 feet in the Westwater Canyon Member. Exploration by Kerr-McGee on adjacent Navajo Tribal land led to the discovery of its northeast Churchrock ore body in 1966. Following the competitive sale of Navajo leases in 1971, exploration efforts have continued in the northeast Churchrock area and have extended eastward into the Crownpoint area, where large ore bodies are currently being developed by several companies.

The discovery of ore at a depth of 2,700 feet in the Westwater Canyon Member near San Mateo by the Fernandez Joint Venture in the fall of 1968, led to the eastward extension of the Ambrosia Lake area. Nearly a year later, ore grade intercepts were found at a depth of 4,000 feet in a hole drilled by the Bokum Corporation on the flanks of Mt. Taylor. By early 1971, Gulf Oil had purchased the San Mateo and Mt. Taylor ore bodies to consolidate its holdings in the east Ambrosia area. At about the same time, exploration on the eastern side of Mt. Taylor, especially in the Marquez area, identified ore in the Westwater Canyon Member in an area previously explored only for ore in the Jackpile sandstone of the overlying Brushy Basin Member. In August 1976, Continental Oil Company announced a major find at the extreme eastern end of the mineral belt on the Bernabe Montano Grant.

In January 1974, the Exxon Company signed an agreement with the Navajo Tribe to explore 400,000 acres of tribal land in the western San Juan Basin. This agreement was approved by the Secretary of the Interior in January 1977. As a part of the agreement, the Navajo Tribe received a $6,327,300 bonus from Exxon.

In December 1975, the Phillips Petroleum Company announced the discovery of a large deposit, approximately 25 million pounds U3O8, 12 miles north of Crownpoint in McKinley County at depths of 3,000 to 3,500 feet. Since this discovery is considerably north of the present concept of the Grants Mineral Belt, it has revived deeper exploration in the San Juan Basin.

The Mobil Oil Corporation entered into an exploration agreement with the Ute Mountain Tribe in January 1976, for uranium exploration on 162,176 acres of tribal land in southwestern Colorado. This agreement brought the Ute Mountain Tribe a bonus of $2,432,640.

The magnitude of the exploration effort expended in the San Juan Basin can be measured by the amount of surface drilling that has taken place. Records of ERDA's Grand Junction Office show that from 1964 to 1977, there were 12,622 holes, having a total footage of 16,002,368 feet, drilled in the search for new deposits. In addition, 10,991 holes having a total footage of 13,059,300 feet were drilled for the development of deposits. The San Juan Basin had its peak year in 1976 when 7,104 holes having a total footage of 10,916,302 feet were drilled. This footage represents 32 percent of the total U.S. surface drilling for uranium in 1976.

PRODUCTION

ERDA records indicate that during 1948-1976, the San Juan Basin produced 65,649,500 tons of ore averaging 0.21 percent U3O8, and containing 118,018 tons U3O8. In addition, 1,145 tons U3O8 have been recovered from mine water. These totals constitute 40 percent of the domestic production through 1976. Details of this production are summarized in table 1. The most productive area is Ambrosia Lake, where the mines, shown in figure 2, have produced 62,760 tons U3O8 or 53 percent of the basin's total production.

When AEC buying schedules for uranium went into effect in 1948, mining commenced in the King Tutt Mesa area of the eastern Carrizo Mountains and uranium production in the San Juan Basin began. The yearly production is shown graphically in figure 4.
Recent large increases in spot prices being paid for uranium have had little affect on the production in the Grants Mineral Belt during 1976. In a recent survey by ERDA, U.S. producers reported that the prices for uranium delivered in 1976 ranged from slightly over $6 to nearly $42 per pound. The average price of uranium reported for actual deliveries in 1976 was $16.10 per pound. This is due to the fact that most of the current production is tied to long-term contracts that were negotiated before the sharp rise occurred. The price of uranium sold by the producers in the Grants areas in 1976 probably is near the national average.

### PROCESSING FACILITIES

Early output from the eastern Carrizo Mountains was shipped to the Vanadium Corporation of America’s (VCA) mill at Durango, Colorado. Shipments continued to the Durango mill until it closed in March 1963. In January 1962, the AEC opened an ore-buying station at Shiprock, New Mexico, and closed it in 1954 when Kerr-McGee Oil Industries began operating a mill at Shiprock. Although this mill was built to treat ore from the Lukachukai Mountains in northeastern Arizona, it also treated ore from non-VCA properties in the eastern Carrizo Mountains. VCA acquired the Shiprock mill in March 1963, and operated it until it closed in 1968.

At first, limestone and sandstone ores from the Grants area were shipped to the AEC buying station at Monticello, Utah. In June 1962, an AEC buying station was established at Bluewater, New Mexico, and closed when the Anaconda mill went on-stream at Bluewater in mid-1953. This mill, using a carbonate-leaching circuit, was constructed to treat limestone ores and operated until May 1959. In 1955, Anaconda constructed a second mill to treat sandstone ores derived chiefly from its Jackpile mine.

Following the discovery of the Ambrosia Lake ore bodies, the AEC established a buying station at Milam, New Mexico, in mid-1956. In late-1956, the AEC contracted to purchase uranium concentrate from Homestake-New Mexico Partners. During 1957, additional purchase contracts were signed with Homestake-Sapin Partners, Kerrmac Nuclear Fuels, and Phillips Petroleum Company. The four uranium mills required to fulfill these contracts began operating in 1958.

After the consolidation of the two Homestake mills in November 1981, the Homestake-New Mexico Partners mill was shut down in April 1982. When Phillips sold its interests to United Nuclear Corporation in March 1983, the Phillips mill was shut down and United Nuclear began shipping its ore for processing, on a toll basis, to the Homestake-Sapin Partners’ mill. This is the only remaining carbonate-leach mill in the Grants area, and it is now operated by United Nuclear in partnership with Homestake Mining Company.

In 1973, Sohio Petroleum Company and Reserve Oil and Minerals Corporation announced their intention to build a 1,600-tons-per-day mill on their property near Cebolleta, New Mexico. Construction of this facility began in 1974, and the mill became operational in August 1976.

In early 1977, the four mills operating in New Mexico had a combined nominal operating capacity of 15,100 tons of ore per day, which is nearly half of the total daily national capacity. These mills and operating capacities are as follows:

<table>
<thead>
<tr>
<th>Source and Source</th>
<th>Number of Properties</th>
<th>Type of Mines</th>
<th>Years of Production</th>
<th>Production Tons U3O8</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grants Mineral Belt</td>
<td>McFarland Formation</td>
<td>Underground, Two large open pits</td>
<td>1951 to present</td>
<td>114,795</td>
<td>Molybdenum and vanadium recovered as byproducts</td>
</tr>
<tr>
<td></td>
<td>Tidbit Lime</td>
<td>Underground and 500,000</td>
<td>1957 to present</td>
<td>2,718</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dakota Silver</td>
<td>Underground</td>
<td>1951 thru 1954</td>
<td>246</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mine water</td>
<td>Underground</td>
<td>1953 thru 1956</td>
<td>1,445</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brecia pipe</td>
<td>Underground</td>
<td>1954 thru 1956</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>East Carrizo Mountains</td>
<td>Salt Wash</td>
<td>1948 thru 1956</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Morinon Formation</td>
<td>Underground</td>
<td>1951 thru 1971, 1976</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dakota Lime</td>
<td>Underground</td>
<td>1954</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monticello</td>
<td>Underground</td>
<td>1954</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dakota Lime</td>
<td>Underground</td>
<td>1957</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Farmington</td>
<td>Underground</td>
<td>1956</td>
<td>131</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL** 118,163

**RESOURCES**

Uranium resources consist of reserves and potential resources. Reserves are the finest element of resources, comprising deposits that have been delineated by drilling
or other direct sampling methods. Potential resources are the quantities of uranium estimated to be present in deposits that are incompletely defined or undiscovered. By declining order of reliability, potential resources are divided into three categories: probable, possible, and speculative. The relationship of reserves to potential resources is illustrated below.

<table>
<thead>
<tr>
<th>URANIUM RESOURCES</th>
<th>DEFINED</th>
<th>INCOMPLETELY DEFINED OR UNDISCOVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESERVES</td>
<td>PROBABLE</td>
<td>POSSIBLE</td>
</tr>
</tbody>
</table>

Ore reserves are calculated from drill hole data and other engineering sources which are available to the Grand Junction Office voluntarily by the uranium companies. Separate evaluations are made of the amounts of uranium that could be exploited at maximum forward costs of $15 and $30 per pound U$_{30}$O$_{8}$, using established engineering, geologic, and economic techniques and criteria.

Forward costs are those operating and capital costs yet to be incurred at the time an estimate is made. Profit and "sunk" costs, such as prior expenditure for property acquisition, exploration, and mine development, are not included. Therefore, the forward costs are independent of the market price at which the estimated resources would be sold.

Potential resources, as used by ERDA, are estimates based on geological judgement of the undiscovered tons U$_{30}$O$_{8}$ present in minable amounts in areas that are relatively unexplored in detail, but about which enough is known of the uranium geology to permit prediction of the nature and extent of favorable geologic environments. The geographic locations of potential deposits may be definable only within broad limits. Providing the subjective nature of potential is recognized and taken into account, potential plus reserves provide a more useful base for long-range predictions of domestic supply than do reserves alone.

The reliability of potential estimates varies with the classes. It is greatest in the probable class where there has been extensive exploration and where mines have been developed, thus defining ore habits, the nature and extent of the favorable host rocks, etc. The reliability is least in the speculative class where areas of favorability must be inferred solely from literature surveys, geological reconnaissances of formation outcrops, and/or the examination of the logs and cuttings of wells drilled for petroleum or other purposes.

The uranium resources of the San Juan Basin as estimated by ERDA, as of January 1, 1977, are given in Table 2.

**TABLE 2. URANIUM RESOURCES OF THE SAN JUAN BASIN**

<table>
<thead>
<tr>
<th>Tens U$<em>{30}$O$</em>{8}$</th>
<th>Cost Category</th>
<th>Ore Reserves</th>
<th>Undiscovered (Potential)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$15</td>
<td>Discorred</td>
<td>225,000</td>
<td>230,000</td>
</tr>
<tr>
<td>$30</td>
<td></td>
<td>350,000</td>
<td>355,000</td>
</tr>
</tbody>
</table>

*Includes $15

Nearly all of the reserves in both cost categories are in the Grants Mineral Belt, and most are associated with operating mines. The $15 reserves represent 55 percent of the total domestic $15 reserves, and the $30 reserves represent 52 percent of the total $30 reserves of the nation.

Probable potential resources, in the San Juan Basin, are estimated to occur in the uranium areas as extensions of known deposits or as new deposits in trends or areas of mineralization that have been identified by exploration. Possible potential resources are estimated to occur as new deposits within the Morrison Formation in areas of the basin which are not yet completely explored. Subsurface data, largely from oil and gas wells (Sears and others, 1972) have been used to determine the extent of the favorable ground. Speculative potential resources are restricted to Upper Cretaceous and Tertiary rocks which have not been productive, yet contain uranium occurrences and favorable geology for larger deposits.

Potential estimates are revised as new information becomes available. Recent increases in both the probable and possible classes are the result of new exploration which increased the size of the areas considered favorable. Speculative potential estimates are currently under review and will probably be decreased due to unfavorable exploration results. The extensive exploration currently underway within the basin is expected to convert a large proportion of the potential resources into reserves in the foreseeable future.

**ACKNOWLEDGEMENTS**

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