



Uranium in the San Juan Basin--An overview

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URANIUM IN THE SAN JUAN BASIN AN OVERVIEW*

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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 of U_3O_8 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 in-

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 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 ($U(SiO_4)_2 \cdot x(OH)_{4x}$), 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 U_3O_8 .

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 lowermost 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 U_3O_8 .

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 of U_3O_8 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 U_3O_8 , from two properties on the Ojo del Espiritu Santo Grant, northwest of San Ysidro.

The Dakota Sandstone of Cretaceous age has yielded 246 tons of U_3O_8 from nine properties in the Gallup and Ambrosia Lake areas. The Dakota host rocks are carbonaceous sandstone, carbonaceous shale and lignite. On the eastern flank of the basin, south of Cuba, New Mexico, 23 tons containing 0.63 percent U_3O_8 , have been mined from carbonaceous shale and lignite at one property in the Dakota Sandstone.

Uranium occurs in rocks of the Mesaverde Group of Cretaceous age, at various locations in the San Juan Basin. The most significant area is near La Ventana on the eastern flank of the basin. Here, uranium-bearing coal, carbonaceous shale and carbonaceous sandstone form a mineralized zone several feet thick in the upper part of the Menefee Formation immediately below the La Ventana Tongue. Studies by Bachman and others (1959), suggest that a resource of 132,000 tons, averaging 0.10 percent uranium is present; principally on North Butte.

A small amount of ore has been produced from a sandstone

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terbedded sandstone and a few thin beds of limestone. A thick lens of sandstone, the Jackpile sandstone, occurs in the upper

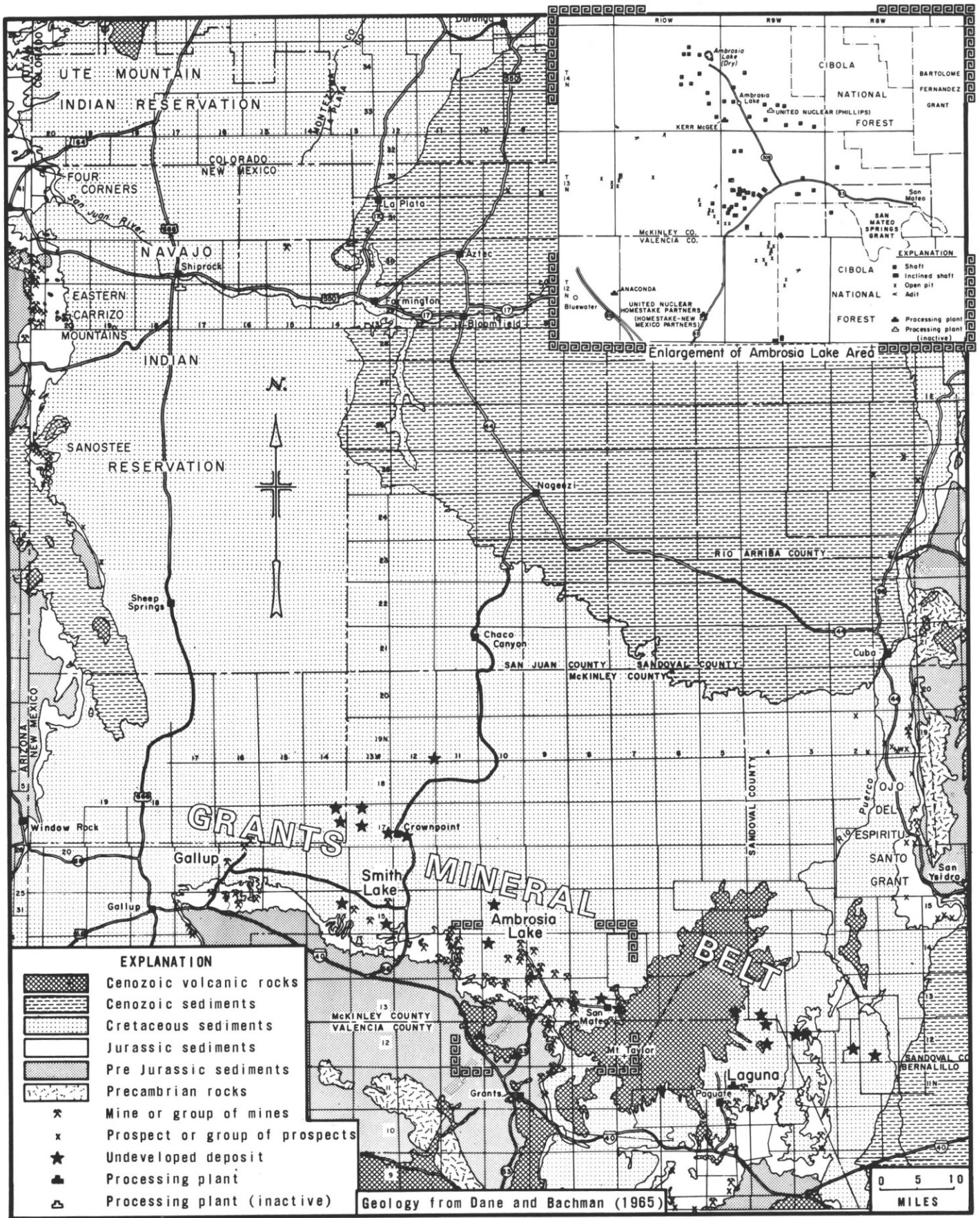


Figure 1. Uranium occurrences, mines and mills, San Juan Basin.

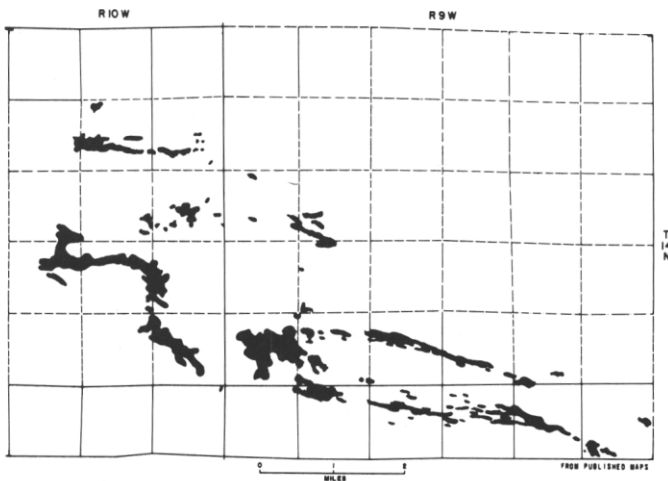


Figure 2. Plan map of ore bodies, Ambrosia Lake area.

in the lower part of the Fruitland Formation of Cretaceous age, northwest of Farmington.

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 U_3O_8 during the middle 1950s.

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.

On 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.

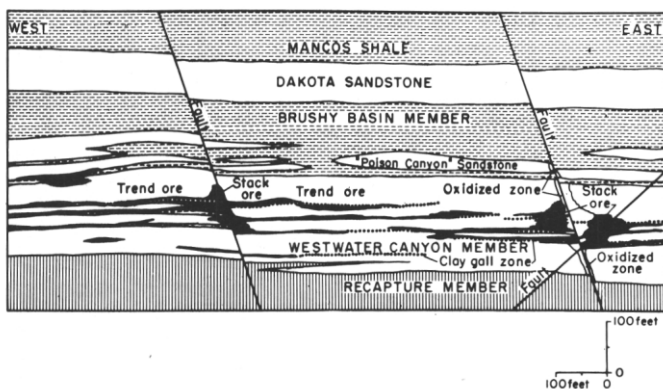


Figure 3. Generalized cross section through ore bodies, Ambrosia Lake area.

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 their 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 U_3O_8 and 3.00 percent V_2O_5 .

In 1948, 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 radioactive 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 1955, 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 exploration effort and led to eventual development of the multi-million-ton deposits in the Ambrosia Lake area.

During the extensive prospecting 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 downdip from these deposits led to the discovery of the larger Blackjack and Church Rock 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 northeast Church Rock 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 lands led to the discovery of its northeast Church Rock ore body in 1966. Following the competitive sale of Navajo leases in 1971, exploration efforts have continued in the northeast Church Rock area and have been 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 efforts expended in the San Juan Basin can be measured by the amount of surface drilling that has taken place. Records of ERDA's Grand Junc

tion 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 55,649,500 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.

As the mines in the Ambrosia Lake area came into production, the amount of uranium ore produced increased rapidly (fig. 4). Production reached an all-time high of slightly more than 7,900 tons of U₃O₈ in 1962, but declined sharply in 1963 during the AEC's stretchout program. This program, announced November 17, 1962, extended the government's procurement program from January 1, 1967, to December 31, 1970. It deferred delivery to 1967 and 1968 of some uranium concentrates which were originally contracted for delivery before 1967, and provided for purchase of additional amounts of concentrates in 1969 and 1970 equal to the amounts deferred to 1967 and 1968.

Since January 1, 1971, when the AEC ceased its procurement program, most uranium purchases have been made by

Table 1. Summary of uranium production, San Juan Basin.

Area and Source	Member	Number Of Properties	Type Of Mines	Years Of Production	Production Tons U ₃ O ₈	Remarks
Grants Mineral Belt						
Morrison Formation	Westwater Canyon, Brushy Basin minor Recapture	129	Underground. Two large open pits	1951 to present	114,795	Molybdenum and vanadium recovered as by-products
Todilto Limestone	-	42	Underground and open pit	1951 to present	2,718	
Dakota Sandstone	-	9	Underground	1951 thru 1970	246	
Mine water	-	-	-	1963 to present	1,145	
Breccia pipe	-	1	Underground	1953 thru 1956	67	
East Carrizo Mountains						
Morrison Formation	Salt Wash	45	Underground	1948 thru 1968	110	1,141 tons V ₂ O ₅ produced as a co-product
Sanostee						
Morrison Formation	Recapture, minor Salt Wash	11	Underground	1951 thru 1971, 1976	81	
Todilto Limestone	-	2	Open pit	1954		
Nacimiento						
Morrison Formation	Brushy Basin	2	Open pit	1957, 1959	1	
Dakota Sandstone	-	1	Open pit	1954, 1957		
Farmington						
Fruitland Formation	-	1	Open pit	1955		
TOTAL					119,163	

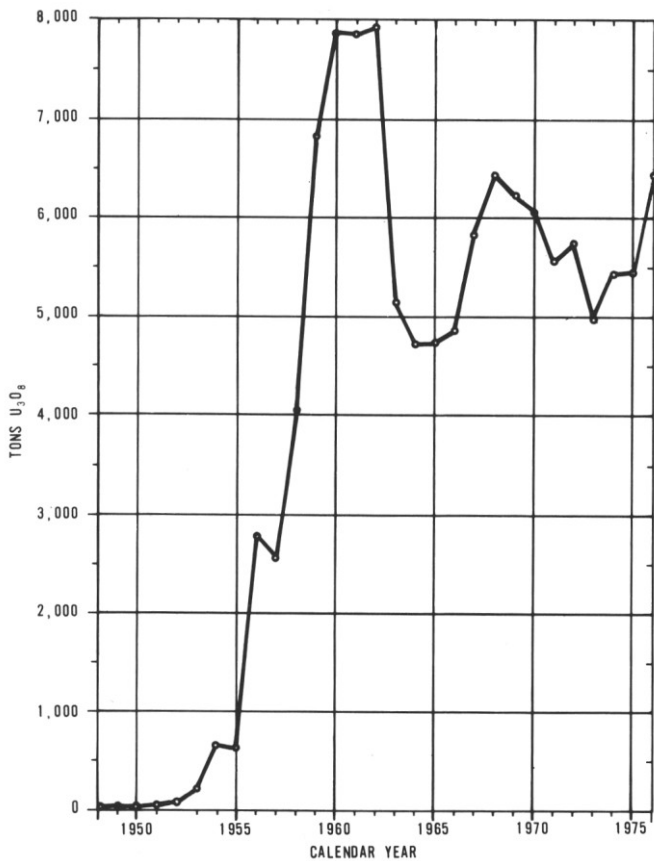


Figure 4. San Juan Basin uranium production, 1948 through 1976.

the nuclear electrical power industry. The decline in uranium sales in the early 1970s was due to a saturated market and was accentuated in 1973 by a long strike against Kerr-McGee. The rise in production in recent years reflects increased demand by the electric-power utility companies.

Recent large increases in spot prices being paid for uranium have had little effect 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 area 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 1952, 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 north-eastern 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 1952, an AEC buying station was established at Blue-water, 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 Milan, 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, Kermac 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 1961, the Homestake-New Mexico Partners mill was shut down in April 1962. When Phillips sold its interests to United Nuclear Corporation in March 1963, 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:

Tons of Ore Per Day

The Anaconda Company	3,000
Kerr-McGee Nuclear Corporation	7,000
Sohio Petroleum Co.-Reserve Oil and Minerals Corp.	1,600
United Nuclear-Homestake Partners	3,500
T o t a l	1 5 , 1 0 0

United Nuclear announced plans to build a mill in the northeast Church Rock area in the early 1970s. In November 1975, ground was broken and the construction of this 3,000 TPD mill commenced; the target date for operations is the summer of 1977. United Nuclear and the Sohio-Reserve mills are the first to be constructed in New Mexico without benefit of government concentrate-purchase contracts.

During the latter part of 1976, Phillips Petroleum announced plans for a mill on its Nose Rock property and the Anaconda Company announced plans to enlarge its plant to a capacity of 6,000 TPD.

RESOURCES

Uranium resources consist of reserves and potential resources. Reserves are the firmest 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.

URANIUM RESOURCES				
DEFINED	INCOMPLETELY DEFINED OR UNDISCOVERED			
RESERVES	POTENTIAL RESOURCES			
	PROBABLE	POSSIBLE	SPECULATIVE	

Ore reserves are calculated from drill hole data and other engineering sources which are made 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 U₃O₈, 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 expenditures 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 judgment of the undiscovered tons of U₃O₈ 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 reconnaissance 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.

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

Table 2. Uranium resources of the San Juan Basin.

\$/lb. U ₃ O ₈ Cost Category	Discovered Ore Reserves	Tons U ₃ O ₈ Undiscovered (Potential)		
		Probable	Possible	Speculative
\$15	225,800	230,000	250,000	50,000
\$30*	356,400	395,000	455,000	65,000

*Includes \$15

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 population of the potential resources into reserves in the foreseeable future.

ACKNOWLEDGEMENTS

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REFERENCES

- Coleman, A. H., 1944, A report on the geology and ore deposits of the B'Cla B'Toh (Beclabito) district, Carrizo uplift area, New Mexico, Arizona: Union Mines Development Corp. RMO-469, AEC open-file rept., 23 p.
- Bachman, G. O., Vine, J. D., Read, C. B., and Moore, G. W., 1959, Uranium-bearing coal and carbonaceous shale in the La Ventana Mesa area, Sandoval County, New Mexico: U.S. Geol. Survey Bull. 1055-J, p. 295-307.
- Dane, C. H., and Bachman, G. O., 1965, Geologic map of New Mexico: U.S. Geol. Survey, scale 1:500,000.
- Hilpert, L. S., 1969, Uranium resources of northwestern New Mexico: U.S. Geol. Survey Prof. Paper 603, 166 p.
- Kelley, V. C., chm., 1963, Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, 227 p.
- Sears, R. S., Marjaniemi, D. K., and Blomquist, J. T., 1974, Study of the Morrison Formation in the San Juan Basin, New Mexico and Colorado: U.S. Atomic Energy Comm. G J0-912-20, 416 p.; Appendices volume, 374 p., open-file rept.
- Webber, B. N., 1947, Geology and ore resources of the uranium-vanadium depositional province of the Colorado Plateau region: Union Mines Development Corp. RMO-437, AEC open-file rept., 279 p., 73 figs.