New Mexico Bureau of Mines & Mineral Resources

Resource Map 18

September 1989

# Uranium resources in New Mexico

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**ABSTRACT**—The most important host rock that contains the most economic uranium deposits in New Mexico is sandstone within the Morrison Formation (Jurassic) in the Grants and Shiprock uranium districts, San Juan Basin. More than 336 million lbs of $U_3O_8$ have been produced from these uranium deposits from 1948 through 1988, accounting for 97% of the total uranium production in New Mexico and 38% of the total uranium production in the United States. Sandstone in the Morrison continues to have the most economic reserves and potential resources in New Mexico. Uranium deposits also occur in sandstone beds of Pennsylvanian, Permian, Triassic, Cretaceous, Tertiary, and Quaternary formations. Although only 468,680 lbs of $U_3O_8$ or 0.14% of the total uranium production in New Mexico have been produced from these deposits, some sandstone beds may have high potential resources. In contrast, almost 6.7 million lbs of $U_3O_8$ have been produced from uranium deposits in limestone beds of the Todilto Limestone Member of the Wanakah Formation (Jurassic) in the Grants uranium district, accounting for almost 2% of the total uranium production in New Mexico. However, limestone uranium deposits probably will not be mined in the near future because they are small in size and sporadic in distribution and are difficult to locate. Other uranium deposits in New Mexico are hosted by other sedimentary rocks or are found in fracture-controlled veins or igneous and metamorphic rocks. Production from these deposits has been insignificant (less than 0.08% of the total uranium production in New Mexico), but there may be potential for medium- to high-grade, medium-sized uranium deposits in some areas.

New Mexico has significant uranium reserves and potential resources. Future development of these reserves and resources will depend upon an increase in price for uranium and the lowering of production costs, perhaps by in-situ leaching techniques.

## Introduction

During a period of nearly three decades (1951–1980), the Grants uranium district in northwestern New Mexico (Map, #1–8) produced more uranium than any other district in the world. Additional areas in New Mexico also yielded minor quantities of ore. From 1948 through 1988, more than 171,000 tons of $U_3O_8$ were produced from more than 200 mines in 18 counties in New Mexico (Table 1). As of the spring of 1989, however, all uranium mines—except Mount Taylor, operated by Chevron Resources Co. (formerly operated by Gulf Mineral Resources Co.), and Section 23, operated by Homestake Mining Co. (formerly United Nuclear–Homestake Partners)—are closed or on standby. Uranium production in New Mexico decreased because of the major slump in uranium demand and the increased competition from other producers. At present, uranium production in New Mexico cannot compete with the production from large high-grade uranium deposits in Canada and Australia, the by-product production from gold mining in the Republic of South Africa, and the low-cost by-product recovery from domestic phosphoric acid production.

The purpose of this report is to briefly describe and locate the general types of uranium deposits and their occurrences, production, and future potential (Tables 2, 3, 4; Map). The data presented here are intended to aid exploration and mining companies in locating and developing uranium resources in New Mexico. Some occurrence areas may never constitute a major uranium district in the near future, but are included because they may contain information for determining the genesis of the more economic uranium deposits. The uranium-resource and occurrence-area data may also be useful for administrators in local, state, and federal government agencies who require this information for environmental studies, land-use decisions, and other planning actions.

The authors are optimistic that, on a long-term basis, the price for uranium will increase and that uranium production in New Mexico will also increase. However, uranium production in New Mexico will probably not reach the level of production that occurred in the 1970s.

### Definitions

The terms in this report follow international or national conventions. They are briefly defined here to aid the reader.

*Uranium resources* are naturally occurring concentrations of uranium in the earth's crust in significant quantities that can be economically extracted now or in the future (U.S. Bureau of Mines and U.S. Geological Survey, 1980). Uranium resources occur in areas of past and current production and in areas that are undeveloped. The U.S. Department of Energy (DOE) has recently adopted the international terminology that classifies uranium resources into two categories: discovered and undiscovered resources (Energy Information Administration, 1988). *Discovered resources* are divided into economic reserves and reasonably assured resources. *Economic reserves* are estimates of proven ore that can be reasonably expected to be recovered under current economic and processing conditions. The estimates of proven ore are received annually by the DOE from exploration and mining companies. *Reasonably assured resources (RAR)* are deposits that have been defined by drilling or by other direct sampling methods and that can be recovered within a given production cost range (U.S. Department of Energy, 1980; OECD Nuclear Energy Agency and the International Atomic Energy Agency, 1980, 1986, 1988). *Undiscovered or potential resources* are the concentrations of uranium in significant quantities estimated to occur in either incompletely defined or undiscovered deposits. Undiscovered resources are divided into estimated additional resources and speculative resources (Energy Information Administration, 1988).

The first step in evaluating an area for uranium resources is to inventory known uranium occurrences. For the purpose of this report, a *uranium occurrence* is any locality where uranium mineralization has been identified. Localities with uranium occurrences range from areas that have not been evaluated for economic recovery to areas that have active uranium mines. Thorium occurrences (>100 ppm Th) are included on the Map and in Table 3 because they typically contain some uranium. Uranium can be produced from some areas as a by-product of production of thorium or rare-earth elements. Specific data about individual uranium occurrences in New Mexico are in McLemore (1983a: appendix 1), Hilpert (1969), and other references cited where appropriate in this report. A *uranium mine* is any uranium occurrence from which uranium-bearing material has been shipped to a mill or buying station; individual mines with production data are listed in McLemore and Chenoweth (1988) and McLemore (1983a: appendix 3). A *uranium deposit* is a uranium occurrence that has undergone or is undergoing evaluation for economic recovery and includes subeconomic and economic orebodies as well as active mines.

Most of the areas located on the Map and listed in Table 3 are uranium occurrence areas. A *uranium occurrence area* is defined as having an accumulation of uranium equaling or exceeding 0.005% $U_3O_8$; actual size and value of an area is unknown. Where accumulations of uranium occur relatively close together, an occurrence area may include two or three types of uranium deposits. A *district* is a uranium occurrence area that has produced ore or that is located in a historic base- or precious-metal mining district. A district is typically defined by a group of spatially and geologically related uranium mines or deposits; however, some districts are characterized by only one mine or deposit.

## Methods of investigation and organization of this report

Much of the information presented in this report was obtained through an extensive literature search of published and unpublished reports and general file data from state and federal agencies and mining companies. Specific sources of data are listed in McLemore (1983a) and are referenced in this report where appropriate. Some file data from uranium mining companies used in this report have been donated to the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) and are on file for public inspection at the NMBMMR Geotechnical Information Center. All districts and most occurrence areas were examined from 1952 through 1988 by one or both authors to provide accurate information on the location, geology, and exploitation of the uranium deposits and occurrences. Samples from mine dumps and outcrops collected from 1980 through 1988 were submitted to the NMBMMR Chemistry Laboratory for chemical analyses to aid in characterizing these districts and occurrence areas. Results are included in Table 3.

The text that accompanies the Map (1) summarizes the history of uranium production in New Mexico (Table 1), (2) describes the general types of uranium deposits and occurrences found in the state (summarized in Table 2), (3) lists the major districts and occurrence areas (Table 3), and (4) briefly discusses the uranium resource potential in New Mexico by comparing published resource assessments with current economic trends and recently acquired data on New Mexico deposits.

Table 3 lists the major districts and occurrence areas by county within physiographic provinces (defined in part by New Mexico Geological Society, 1982). These districts and occurrence areas are shown on the Map, and outlines of some districts or occurrence areas are exaggerated. District boundaries on the Map are generally defined by geologic constraints (New Mexico Geological Society, 1982) and the extent of known or inferred uranium deposits. The boundaries for the subdistricts in the Grants uranium district (#1–7) are modified from Hatchell and Wentz (1981); the approximate areas of known uranium deposits are shown within the subdistrict boundaries. All uranium deposits are color-coded on the Map according to the predominant type of deposit. Individual uranium occurrences and mines are shown on the Map except where there are numerous uranium occurrences and mines. No mines in the Grants and Shiprock uranium districts are shown on the Map. More detailed locations of orebodies and uranium mines in the Grants uranium district are presented in a series of maps by McLemore and Chenoweth (1988).

Districts and occurrence areas are numbered and indexed to Tables 3 and 4, the Map, and the text (numbers are cited in parentheses in text). District and occurrence-area names are from the literature, are based on geographic locality, or are derived from the names of established base- and precious-metal mining districts (North and McLemore, 1986). The production statistics, typical grade, and period of production listed in Table 3 are from U.S. Atomic Energy Commission (AEC) files (McLemore, 1983a) and published production data. Production data from individual mines from 1971 to 1988 are confidential, and district totals and reserves are estimated in Table 3. Statistics on reserves are not available for most deposits. The geologic setting, host rocks, size, geometry, and mineralogy of deposits are briefly described in Table 3 and pertinent geochemical assays are also included. The most important sources of data and citations of geologic maps or other reports describing the geology and stratigraphy are listed in Table 3.

## Acknowledgments

This report is part of an ongoing study of uranium deposits in New Mexico. Many people have contributed to the project over the years and their help is greatly appreciated. We especially would like to thank Warren I. Finch (U.S. Geological Survey) and Harlen K. Holen (retired from the U.S. Department of Energy) for their help and discussions. Harlen K. Holen, Warren I. Finch, Richard Chamberlain, William O. Hatchell, and an anonymous reviewer critiqued this manuscript. Lynne McNeil typed various drafts of this report. Michael Wooldridge drafted the map and figures. Lynn Brandvold and associates (NMBMMR Chem-

istry Laboratory) provided geochemical analyses over the years, some of which are reported here. William O. Hatchell (New Mexico Energy, Minerals and Natural Resources Department) provided some of the production statistics used in Tables 3 and 4. Lastly, we would like to express our appreciation to Jennifer Boryta (NMBMMR editing staff) for her patience, ideas, good humor, and time required to prepare this report for publication.

**TABLE 1**—Uranium production in New Mexico and the United States from 1947 through 1988 (U.S. Department of Energy (DOE), 1983; Energy Information Administration, 1985, 1986, 1987, 1988; New Mexico Energy, Minerals and Natural Resources Department, written communication 1984, 1985, 1986, 1987; U.S. Atomic Energy Commission (AEC), ore and mill receipts tabulated by W. L. Chenoweth and E. A. Learned, DOE). Ore production from 1947 to 1970 includes *pay* and *no-pay* ores received by the AEC; shipments of ore less than 0.10% $U_3O_8$, for which the AEC did not pay, were known as *no-pay* ores. [1] Production from in-situ leaching, heap leaching, and mine-water recovery included. [2] Concentrate production from ore shipped from other states to mills in New Mexico included. [3] Average price for domestic uranium that was sold that year; not spot or market price. [4] Ore production in New Mexico in 1948 and 1949 was entirely from Carrizo Mountains, San Juan County, and was processed in Colorado. [5] Figures estimated; much of the ore produced from the Mount Taylor mine (Chevron Resources Co.) was processed in Texas and credited to Texas concentrate production. [6] Figures estimated by the authors.

| | Ore received at mills and buying stations | | | | | | Concentrate production from mills | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Production in New Mexico[1] (tons of $U_3O_8$) | Grade of production in New Mexico (% $U_3O_8$) | Production in U.S.[1] (tons of $U_3O_8$) | Grade of production in U.S. (% $U_3O_8$) | New Mexico production per U.S. total (%) | Number of operating companies in New Mexico | Production from mills in New Mexico[2] (tons of $U_3O_8$) | Production from mills in U.S. (tons of $U_3O_8$) | New Mexico production per U.S. total (%) | Average price for uranium[3] (dollar per lb $U_3O_8$) |
| 1947 | — | — | 100 | 0.25 | — | — | — | 67 | — | 7.21 |
| 1948 | 4[4] | 0.29 | 200 | 0.26 | 2 | 1 | — | 102 | — | 7.50 |
| 1949 | 8[4] | 0.17 | 200 | 0.29 | 4 | 1 | — | 177 | — | 8.77 |
| 1950 | 11 | 0.30 | 500 | 0.32 | 2 | 12 | — | 459 | — | 10.76 |
| 1951 | 9 | 0.30 | 900 | 0.32 | 1 | 14 | — | 766 | — | 10.30 |
| 1952 | 36 | 0.19 | 2,000 | 0.30 | 2 | 34 | — | 874 | — | 11.85 |
| 1953 | 215 | 0.25 | 2,405 | 0.31 | 9 | 36 | 9 | 1,163 | 1 | 12.28 |
| 1954 | 666 | 0.35 | 3,500 | 0.32 | 19 | 45 | 181 | 1,700 | 11 | 12.43 |
| 1955 | 618 | 0.23 | 4,400 | 0.29 | 14 | 58 | 847 | 2,784 | 30 | 11.94 |
| 1956 | 2,888 | 0.26 | 8,400 | 0.28 | 34 | 51 | 2,891 | 5,958 | 49 | 11.10 |
| 1957 | 2,585 | 0.22 | 9,800 | 0.27 | 26 | 49 | 2,534 | 8,482 | 30 | 9.82 |
| 1958 | 4,032 | 0.21 | 14,000 | 0.27 | 29 | 44 | 3,604 | 12,437 | 29 | 8.86 |
| 1959 | 6,829 | 0.21 | 17,400 | 0.25 | 39 | 41 | 6,772 | 16,239 | 42 | 8.64 |
| 1960 | 7,892 | 0.21 | 18,800 | 0.23 | 42 | 41 | 7,760 | 17,637 | 44 | 8.35 |
| 1961 | 7,848 | 0.22 | 18,500 | 0.23 | 42 | 34 | 7,750 | 17,348 | 45 | 7.88 |
| 1962 | 7,894 | 0.23 | 17,100 | 0.24 | 46 | 30 | 7,293 | 17,008 | 43 | 7.92 |
| 1963 | 5,132 | 0.22 | 14,700 | 0.25 | 35 | 33 | 5,512 | 14,217 | 39 | 8.00 |
| 1964 | 4,716 | 0.23 | 13,900 | 0.26 | 34 | 29 | 4,747 | 11,846 | 40 | 8.00 |
| 1965 | 4,709 | 0.23 | 10,500 | 0.24 | 45 | 20 | 4,591 | 10,442 | 44 | 8.00 |
| 1966 | 4,892 | 0.24 | 9,900 | 0.23 | 49 | 21 | 5,076 | 10,589 | 48 | 8.00 |
| 1967 | 5,816 | 0.21 | 10,900 | 0.21 | 53 | 13 | 5,933 | 11,253 | 53 | 8.00 |
| 1968 | 6,443 | 0.20 | 12,850 | 0.21 | 50 | 12 | 6,192 | 12,368 | 50 | 8.00 |
| 1969 | 6,210 | 0.20 | 12,600 | 0.20 | 49 | 11 | 5,943 | 11,609 | 51 | 5.86 |
| 1970 | 6,057 | 0.21 | 13,050 | 0.20 | 46 | 12 | 5,771 | 12,905 | 45 | 5.56 |
| 1971 | 5,464 | 0.23 | 13,100 | 0.21 | 42 | 9 | 5,305 | 12,273 | 43 | 6.00 |
| 1972 | 5,722 | 0.25 | 13,850 | 0.21 | 41 | 11 | 5,464 | 12,900 | 42 | 6.50 |
| 1973 | 4,984 | 0.23 | 13,800 | 0.20 | 36 | 6 | 4,634 | 13,235 | 35 | 7.10 |
| 1974 | 5,435 | 0.18 | 12,600 | 0.18 | 43 | 5 | 4,951 | 11,528 | 43 | 7.90 |
| 1975 | 5,484 | 0.18 | 12,300 | 0.16 | 45 | 8 | 5,191 | 11,600 | 45 | 10.50 |
| 1976 | 6,485 | 0.19 | 14,000 | 0.15 | 46 | 14 | 6,059 | 12,747 | 48 | 16.10 |
| 1977 | 7,586 | 0.18 | 16,700 | 0.15 | 45 | 12 | 6,779 | 14,939 | 45 | 19.75 |
| 1978 | 9,371 | 0.15 | 20,200 | 0.13 | 46 | 15 | 8,539 | 18,486 | 46 | 21.60 |
| 1979 | 8,198 | 0.12 | 20,700 | 0.11 | 40 | 13 | 7,423 | 18,736 | 40 | 23.85 |
| 1980 | 8,160 | 0.12 | 23,300 | 0.12 | 35 | 14 | 7,751 | 21,852 | 35 | 28.15 |
| 1981 | 6,573 | 0.12 | 19,600 | 0.11 | 34 | 13 | 6,206 | 19,237 | 32 | 38.15 |
| 1982 | 3,810 | 0.18 | 13,415 | 0.12 | 28 | 10 | 3,906 | 13,434 | 29 | 35.43 |
| 1983 | 3,058 | 0.24 | 12,406 | 0.13 | 25 | 3 | 2,830 | 10,579 | 27 | 39.10 |
| 1984 | 1,617 | 0.19 | 6,747 | 0.11 | 24 | 4 | 1,458 | 7,441 | 20 | 32.97 |
| 1985 | 810 | 0.28 | 6,140 | 0.16 | 13 | 5 | 693 | 5,657 | 12 | 34.34 |
| 1986 | 951 | 0.54 | 5,807 | 0.34 | 16 | 4 | 376 | 6,753 | 6 | 32.58 |
| 1987[5] | 1,167 | 0.49 | 4,915 | 0.28 | 24 | 3 | 350 | 6,496 | 5 | 29.16 |
| 1988[6] | 1,125 | — | 6,750 | — | 17 | 3 | 1,125 | 6,750 | 17 | — |
| TOTAL | 171,510 | | 452,935 | | 38 | | 162,446 | 423,073 | 39 | |

## Summary of uranium production in New Mexico

The U.S. Atomic Energy Commission (AEC) was created in 1946 and began its uranium procurement program in 1947 (Chenoweth, 1985c). The old vanadium mines in the Salt Wash Member of the Morrison Formation (Jurassic) in the Carrizo Mountains of New Mexico (#9) were reopened in 1948 for the recovery of both uranium and vanadium; the ore was shipped to a mill in Naturita, Colorado.

The price schedules, bonuses, and other incentives offered by the AEC created a prospecting effort that spread from the Four Corners area to all parts of New Mexico. Discoveries were made in the Morrison Formation (Jurassic) in the Chuska Mountains near Sanostee in San Juan County (#10) and in the Todilto Limestone Member of the Wanakah Formation (Jurassic) near Grants (#1, #4, #5). The discovery in the Todilto Limestone spurred a significant interest in the north flank of the Zuni uplift between Gallup and Grants, and additional deposits were located in the Todilto Limestone and the Morrison and in the Dakota Sandstone (Cretaceous). Production from the limestone uranium deposits in the Todilto Limestone began in 1950 when the first ore was shipped to the AEC ore-buying station in Monticello, Utah.

The Jackpile deposit north of Laguna (#1) was discovered in 1951. Production from this deposit began the next year when the AEC established an ore-buying station in Bluewater, New Mexico, where a processing mill was being constructed. During the early 1950s, uranium in New Mexico was produced from mines in the eastern Carrizo Mountains (#9), from many deposits in sandstone and limestone between Grants and Gallup (#4–6), and from the Jackpile-Paguate mine north of Laguna (#1). A mill in Shiprock, New Mexico, began operating in 1954.

Between 1953 and 1955, rocks of every geologic age throughout the state were prospected for uranium. By the mid-1950s, nearly all uraniferous occurrences at the surface had been located. Most of these occurrences were examined by geologists from the AEC or the U.S. Geological Survey. The geologists prepared a Preliminary Reconnaissance Report (PRR) on each locality examined. These reports are listed in McLemore (1983a: appendix 5) and are on file at the NMBMMR.

During wildcat drilling near Ambrosia Lake (#4) in 1955, the Dysart deposit was discovered. The news of this large deposit in the Westwater Canyon Member of the Morrison Formation (Jurassic) was widely publicized. Numerous small companies moved into the area, and many large deposits were discovered during the next few years. The AEC established an ore-buying station in Milan, New Mexico, in July 1956 to provide a market for the newly discovered deposits and for those being mined in other parts of the state. Large companies, such as Kerr-McGee Nuclear Corp., United Nuclear–Homestake Partners (now Homestake Mining Co.), and Phillips Petroleum Co., acquired interests in the Ambrosia Lake area to develop and mine the deposits. The companies also constructed four mills in the area, which became operational in 1958.

The opening of the AEC ore-buying station in Milan in 1956 and the start up of the four mills in the Ambrosia Lake area two years later were followed by an increase in annual ore production in New Mexico. Production increased from 215 tons (0.4 million lbs) of $U_3O_8$ in 1953 to 6,829 tons (13.7 million lbs) in 1959 (Table 1). By 1958, uranium mining in New Mexico outside the San Juan Basin had ceased, except for the mining of deposits in the Rio Grande valley in Santa Fe and Socorro Counties, where sporadic production continued through 1966. During 1960 through 1962, the amount of uranium produced in New Mexico was fairly stable at approximately 7,800 tons (15.6 million lbs) of $U_3O_8$ per year (Table 1).

Two announcements by the AEC affected exploration and production of uranium in the 1960s. On November 24, 1958, the AEC stated that after April 1, 1962, it would purchase only concentrates from ores discovered before November 24, 1958. This announcement drastically curtailed uranium exploration in New Mexico and throughout the United States. On November 17, 1962, the AEC announced its stretchout program, which limited uranium production by extending the government's procurement program from January 1, 1967, to December 31, 1970. The stretchout program deferred delivery of uranium concentrates, originally contracted for delivery before 1967, to 1967 and 1968. The stretchout program also provided for the purchase of additional amounts of concentrates in 1969 and 1970 equal to the amounts deferred in 1967 and 1968.

The effect of the AEC announcements hampered the growth of the uranium industry in New Mexico. Production in New Mexico dropped to 5,132 tons (10.3 million lbs) of $U_3O_8$ in 1963 and varied between 4,700 and 4,900 tons (9.4 and 9.8 million lbs) per year through 1966 (Table 1). The United Nuclear–Homestake Partners mill closed in 1962 and the Phillips Petroleum Co. mill was shut down in 1963. Production increased to 6,443 tons (12.9 million lbs) of $U_3O_8$ in 1968 (Table 1), but declined afterwards. The mill in Shiprock, New Mexico, which processed ore mainly from Arizona, closed in 1968.

When the AEC procurement program ended on December 31, 1970, mines in New Mexico had yielded 39,227,898 tons of ore that averaged 0.22% $U_3O_8$ and contained 170,255,732 lbs of $U_3O_8$. An additional 904,482 lbs of $U_3O_8$ had been recovered by heap-leaching ore and processing mine water. The mined ores also contained 8,958,784 lbs of vanadium oxide ($V_2O_5$), which were purchased by the AEC. Not all of the vanadium was recovered by the mills; some vanadium remains in the mill tailings.

The private market for uranium for use in nuclear power plants was slow to develop, and uranium production continued to decline after the AEC procurement program ended. A sharp drop in production in 1973 to 4,984 tons (10.0 million lbs) of $U_3O_8$ (Table 1) was caused by a long labor strike against Kerr-McGee Nuclear Corp. in the Ambrosia Lake area.

By the mid-1970s, the demand for uranium accompanied by an increase in price caused production and exploration to increase. New mills began operating in Seboyeta, New Mexico, in 1976 and in Church Rock, New Mexico, in 1978. Uranium production in New Mexico reached an all-time annual high level of 9,371 tons (18.7 million lbs) of $U_3O_8$ in 1978 (Table 1). During that year, 41 separate properties were mined for uranium and two mine-water treatment plants were in operation. During 1979 and 1980, production remained high at 8,198 and 8,160 tons (16.4 and 16.3 million lbs) of $U_3O_8$, respectively.

Beginning in 1981, as the uranium market softened because of over production and a decline in the price for uranium, uranium production in New Mexico sharply declined. In the next few years, the new mills in Seboyeta and Church Rock closed and the mill in Bluewater that had been in operation for almost 30 years also shut down. In 1985, Quivira Mining Co. (formerly Kerr-McGee Nuclear Corp.) closed its mine in Church Rock and all of its mines in the Ambrosia Lake area. However, the mill in Ambrosia Lake continued to recover uranium from processing mine water.

Homestake Mining Co. (formerly United Nuclear–Homestake Partners) also continued to produce ore from the Section 23 mine in the Ambrosia Lake area and to recover uranium from mine water. The 810 tons (1.6 million lbs) of $U_3O_8$ produced in New Mexico in 1985 was the lowest level of annual uranium production since the mid-1950s (Table 1).

In 1985, Chevron Resources Co. reopened the Mount Taylor mine in the Ambrosia Lake area, which it had acquired from Gulf Mineral Resources Co. In 1986, production from the Mount Taylor mine reversed the decline in uranium production in New Mexico that had begun in 1979 and that had sharply dropped in 1981. In 1986 and 1987, Chevron Resources Co. transported the ore from the Mount Taylor mine about 900 miles by train to the Panna Maria mill near Hobson in southern Texas. In 1988, all of the ore from the Mount Taylor mine was processed in New Mexico by the Homestake Mining Co. (formerly United Nuclear–Homestake Partners) mill.

In New Mexico in the spring of 1989, one mill and two mines are in operation. The Homestake Mining Co. (formerly United Nuclear–Homestake Partners) mill is processing ore from the Section 23 mine and, since early 1988, the ore from the Mount Taylor mine. Both the Homestake Mining Co. and the Quivira Mining Co. (formerly Kerr-McGee Nuclear Corp.) are recovering uranium from water recirculated through inactive uranium mines in the Ambrosia Lake area; the mine-water recovery accounted for about 16% of the uranium production in New Mexico in 1986 (W. O. Hatchell, New Mexico Energy, Minerals and Natural Resources Department, written communication 5/11/87).

Until the price for uranium increases and the domestic production of uranium begins to compete successfully with low-cost imported uranium, uranium production in New Mexico will probably remain at levels comparable with those in the mid-1950s.

## Types of uranium deposits in New Mexico

Many classification schemes for uranium deposits have been devised over the years (Hilpert, 1969; Mickle, 1978; Mickle and Mathews, 1978; Mathews et al., 1979; Nash et al., 1981; Gabelman, 1988; OECD Nuclear Energy Agency and the International Atomic Energy Agency, 1980, 1986, 1988). The purposes of a classification for mineral deposits are (1) to be descriptive, (2) to aid in exploration and economic assessments, and (3) to aid in understanding the genesis of the deposits. Therefore, the authors have chosen to modify the internationally recognized classification for uranium deposits (OECD Nuclear Energy Agency and the International Atomic Energy Agency, 1980, 1988; Nash et al., 1981) and have classified the major uranium deposits in New Mexico on the basis of descriptive geologic characteristics and economic importance.

The uranium deposits in New Mexico can be divided into three main groups (Table 2): peneconcordant uranium deposits in sedimentary host rocks, fracture-controlled uranium deposits, and disseminated uranium deposits in igneous and metamorphic host rocks. Peneconcordant uranium deposits in sedimentary host rocks can be further divided by host rock and economic importance into four categories (Table 2): (A) Morrison Formation (Jurassic) sandstone uranium deposits, (B) other sandstone uranium deposits, (C) limestone uranium deposits, and (D) other sedimentary rocks with uranium deposits. Fracture-controlled uranium deposits and disseminated uranium deposits in igneous and metamorphic host rocks can be divided by host rock, mineralogy, genesis, and structural setting into two categories (Table 2): (E) vein-type uranium deposits and (F) igneous and metamorphic rocks with disseminated uranium deposits. The six types (A–F) of deposits in New Mexico can be further subdivided into two or more subtypes (Table 2) based on one or more of the following characteristics (in order of perceived importance): (1) host rock, (2) mineralogy, (3) structural setting, (4) process of ore formation (if known), (5) form of the deposit, and (6) economic importance. Each district or occurrence area listed in Table 3 and shown on the Map is keyed to its predominant type of deposit. The major characteristics of each type of deposit are summarized below.

### Morrison Formation (Jurassic) sandstone uranium deposits

The host rock with the most economic uranium deposits in New Mexico and the United States is sandstone within the Morrison Formation (Jurassic). The most important ore deposits in the Morrison Formation occur in the Grants and Shiprock uranium districts, San Juan Basin (#1–11). Uranium deposits also occur in the Morrison Formation in northeastern New Mexico, but they are small and low grade. Generally, Morrison Formation sandstone uranium deposits can be subdivided into four subtypes (Table 2): (1) primary (Jm-primary), (2) redistributed (Jm-redistributed), (3) remnant (Jm-remnant), and (4) tabular (Jm-tabular).

### Primary, redistributed, and remnant Morrison Formation (Jurassic) sandstone uranium deposits, Grants uranium district

More than 336 million lbs of $U_3O_8$ (including mine-water recovery) have been produced from the Morrison Formation (Jurassic) in the Grants uranium district from 1948 through 1988 (Table 4), accounting for more than 97% of the total uranium production in New Mexico and 38% of the total uranium production in the United States. All economic reserves and most potential resources in New Mexico are in the Morrison Formation in the Grants uranium district.

Uranium ore occurs mainly in the Westwater Canyon, Brushy Basin, and Jackpile Sandstone Members of the Morrison Formation (Jurassic) in the Grants uranium district. Typically, the orebodies are composed of lenticular, tabular masses of complex uranium and organic compounds that form roughly parallel trends; fine-grained, barren sandstone lie between the orebodies, which are in medium-grained sandstone (Hazlett and Kreek, 1963; Crawley et al., 1985). Three types of ore deposits occur (Table 2): (1) primary (Jm-primary), also known as prefault, trend, blanket, and black-band ores, (2) redistributed (Jm-redistributed), also known as post-fault, stack, secondary, and roll-type ores, and (3) remnant (Jm-remnant).

Exploration guides to deposits in the Westwater Canyon and Brushy Basin Members of the Morrison Formation (Jurassic) are numerous and complex. The presence of extensive grayish-green, montmorillonitic shale and mudstone above thick, permeable sandstone appears to be significant (Turner-Peterson et al., 1986; Crawley et al., 1985; Turner-Peterson and Fishman, 1986). Most primary uranium deposits occur in long narrow trends (McLemore and Chenoweth, 1988). Redistributed uranium deposits are found along the Tertiary-Quaternary oxidation front (Saucier, 1976; Crawley et al., 1985). Remnant uranium deposits are sporadically distributed and are difficult to locate.

Primary uranium deposits (Table 2: Jm-primary) in the

Westwater Canyon Member of the Morrision Formation (Jurassic) are interpreted as having formed before the Dakota Sandstone (Cretaceous) was deposited. These primary uranium deposits in the Westwater Canyon Member are characteristically less than 8 ft thick, average more than 0.20% $U_3O_8$, are low in vanadium, and have sharp ore-to-waste boundaries. Coffinite is the primary uranium mineral (Hansley, 1988), although uranium also occurs in complex uranium-organic masses. The largest deposit contains more than 30 million lbs of $U_3O_8$ (McLemore et al., 1986a; Finch and McLemore, 1989).

Some primary uranium deposits are elongate parallel to sandstone paleochannels (Chenoweth, 1976). Other primary ore forms blanket-like deposits within sandstone. The geometry of some deposits resembles the lower limbs of Wyoming roll-type ore (Harshman and Adams, 1981). Formation of the primary ore in the Grants uranium district, however, was not associated with oxidation-solution fronts as was Wyoming roll-type ore (Holen, 1982; Crawley et al., 1985; Chenoweth, 1976). The similar geometry has confused some workers who have proposed a similar origin for the two ores.

Primary ore in the Grants uranium district occurs in reduced sandstone associated with noncellular organic matter. Early workers have suggested the organic matter is a bitumen or an asphaltite (Knox and Gruner, 1957; Moench and Schlee, 1967). Studies by Hatcher et al. (1986) suggest the organic matter, which can be studied by nuclear magnetic resonance, is not hydrogen-deficient, amorphous material as described by Leventhal (1980). The nuclear magnetic resonance data and other data define properties of the organic matter that are similar to low-rank coal or humic-acid material (Hatcher et al., 1986), as previously suggested by several workers (Granger et al., 1961; Squyres, 1980; Adams and Saucier, 1981; Turner-Peterson and Fishman, 1986). The noncellular organic material probably was derived from humic acids formed by oxidation of plant debris in sandstone and mudstone. The humic acids precipitated and later coalified within sandstone, forming a perfect reducing environment for precipitating and concentrating uranium from ground water.

The primary uranium deposits in the Morrison Formation (Jurassic) differ from other known sandstone uranium deposits in the world because of their large size and relation

**TABLE 2**—Classification of uranium deposits in New Mexico. Deposits are generally classified according to their host rocks and perceived genesis, i.e. deposits hosted by sandstones are termed sandstone uranium deposits (categories A and B).

**I. Peneconcordant uranium deposits in sedimentary host rocks**

**A. Morrison Formation (Jurassic) sandstone uranium deposits**

*Jm-primary*: primary, tabular sandstone uranium-humate deposits in the Morrison Formation (Jurassic).

*Jm-redistributed*: redistributed sandstone uranium deposits in the Morrison Formation (Jurassic).

*Jm-remnant*: remnant sandstone uranium deposits in the Morrison Formation (Jurassic).

*Jm-tabular*: tabular sandstone uranium-vanadium deposits in the Morrison Formation (Jurassic), i.e. Salt Wash and Recapture Members of the Morrison Formation.

**B. Other sandstone uranium deposits**

*Kd-redistributed*: redistributed sandstone uranium deposits in the Dakota Sandstone (Cretaceous).

*K/T–roll front*: roll-front sandstone uranium deposits in Cretaceous and Tertiary sandstones, i.e. Crevasse Canyon Formation (Cretaceous), Galisteo Formation (Tertiary), and Ojo Alamo Sandstone (Tertiary).

*Sedimentary uranium*: stratabound sandstone uranium deposits associated with syngenetic organic material or iron oxides or both.

*Sedimentary copper*: uraniferous sedimentary copper deposits.

*Beach placer*: thorium-rich beach-placer sandstone uranium deposits.

**C. Limestone uranium deposits**

*Jwt*: limestone uranium deposits in the Todilto Limestone Member of the Wanakah Formation (Jurassic).

*Other limestone*: other limestone uranium deposits, i.e. Morrison Formation (Jurassic) in northeastern New Mexico and Yates, Seven Rivers, and Queen Formations (Permian).

**D. Other sedimentary rocks with uranium deposits**

*Shale*: carbonaceous shale and lignite uranium deposits.

*Surficial*: surficial uranium deposits.

**II. Fracture-controlled uranium deposits**

**E. Vein-type uranium deposits**

*Jeter type*: low-temperature vein-type uranium deposits, i.e. deposits similar to the one at the Jeter mine.

*La Bajada*: low-temperature uranium–base-metal vein deposits.

*Collapse-breccia pipe*: uraniferous collapse-breccia pipes and clastic plugs.

*Epithermal vein*: uraniferous epithermal veins in igneous and metamorphic rocks, i.e. classic veins, uraniferous fluorite veins, uraniferous opal/chalcedony veins and fracture fillings, and uraniferous sulfide veins.

**III. Disseminated uranium deposits in igneous and metamorphic host rocks**

**F. Igneous and metamorphic rocks with disseminated uranium deposits**

*Pegmatite*: disseminated uranium deposits in pegmatites.

*Alkalic rock*: disseminated uranium deposites in alkalic rocks, i.e. syenites.

*Granitic rock*: disseminated uranium deposits in granitic rocks.

*Carbonatite*: disseminated uranium deposits in carbonatite dikes.

*Miscellaneous*: miscellaneous types of uranium deposits in igneous and metamorphic rocks, i.e. disseminated uranium deposits in diatremes, contact-metasomatic or skarn uranium deposits, volcanogenic uranium deposits, and possibly unconformity-type uranium deposits.

**TABLE 3**—Uranium production and types of uranium deposits for districts and occurrence areas in New Mexico. Districts and occurrence areas have reported occurrences of one or more accumulations of uranium or thorium (>0.005% $U_3O_8$ or >100 ppm Th). An occurrence area with spatially and geologically related occurrences that have yielded ore production is generally termed *district*. An occurrence area in a historic base- or precious-metal mining district is named after the mining district and is also termed *district*. An occurrence area outside of a historic base- or precious-metal mining district is generally named after a nearby geographic place and is termed either *area* or *district*, depending on production. Subdistricts in the Grants and Shiprock uranium districts are defined by spatially and geologically related uranium mines and deposits. District and occurrence-area numbers refer to Map. Types of deposits are described in Table 2 and in text. Production prior to 1971 are from Atomic Energy Commission (AEC) production records (McLemore, 1983a). Cited references of the U.S. Atomic Energy Commission (AEC), U.S. Department of Energy (DOE), Phillips Uranium Corp., and Uranium Newsletter are on file at the New Mexico Bureau of Mines and Mineral Resources (NMBMMR). *Production from mine-water recovery not included. †Production from 1971 to 1988 estimated by the authors.

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| **COLORADO PLATEAU** | | | | | | |
| **Grants uranium district, Cibola, McKinley, Sandoval, San Juan, Valencia, and Bernalillo Counties** | | | | | | |
| 1. Laguna subdistrict (Cibola, Sandoval, Bernalillo, and Valencia Counties) | more than 100,500,000† | 0.1–1.3 | 1951–1983 | Jm-primary | Primary uranium-humate deposits in Jackpile Sandstone and Brushy Basin Members of the Morrison Formation (Jurassic). Jackpile-Paguate mine was the largest uranium open-pit operation in the U.S. and produced over 80,000,000 lbs of $U_3O_8$ at an average grade of 0.25%. Most deposits in the subdistrict are shallow (<300 ft). The JJ-1 (L-Bar) deposit is at 650–700-ft depth with almost 12,000,000 lbs $U_3O_8$ in remaining reserves. | McLemore and Chenoweth (1988), Crawley et al. (1985), Green et al. (1982a), Jacobsen (1980), Baird et al. (1980), Beck et al. (1980), Adams et al. (1978), Nash (1968), Moench and Schlee (1967), additional references cited by McLemore (1983a) |
| | 10,651 | **0.13** | 1955–1957 | Jwt | Production from limestone uranium deposits in Todilto Limestone Member of the Wanakah Formation (Jurassic). | Green et al. (1982a), Rawson (1980a, b), Hilpert (1969), Moench and Schlee (1967) |
| | 134,014 | **1.26** | 1953–1956 | Collapse-breccia pipe | Woodrow collapse-breccia pipe is similar to collapse-breccia pipes in Arizona. | Wylie (1963), Moench (1962) |
| 2. Marquez subdistrict (Cibola, McKinley, and Sandoval Counties) | 28,000† | 0.1–0.2 | 1979–1980 | Jm-primary | Primary uranium-humate deposits in Westwater Canyon and Brushy Basin Members of the Morrison Formation (Jurassic). Combined reserves of more than 17,000,000 lbs $U_3O_8$ at depths of 800–2,100 ft are reported. | McLemore and Chenoweth (1988), Hatchell and Wentz (1981), Livingston (1980), Moore and Lavery (1980), Perkins (1979), additional references cited by McLemore (1983a) |
| 3. Bernabe Montaño subdistrict (Sandoval, Bernalillo, and Cibola Counties) | **none** | — | — | Jm-primary, redistributed | Primary and redistributed uranium deposits in Westwater Canyon Member of the Morrison Formation (Jurassic). About 10,000,000–20,000,000 lbs $U_3O_8$ with an average grade of 0.2% $U_3O_8$ at average depths of 1,500–2,000 ft are reported. | McLemore and Chenoweth (1988), McCammon et al. (1986), Kozusko and Saucier (1980) |
| 4. Ambrosia Lake subdistrict (McKinley and Cibola Counties) | 201,000,000† | 0.1–0.5 | 1951–1988 | Jm-primary, redistributed, remnant | Primary, redistributed, and remnant uranium deposits in sandstone in Westwater Canyon, Recapture, and Brushy Basin Members of the Morrison Formation (Jurassic). Deposits range from the surface in the Poison Canyon area to 3,400 ft at Mount Taylor. Grades vary but average 0.2% $U_3O_8$. Grades at Mount Taylor average 0.5% $U_3O_8$. Deposits in the Borrego Pass and West Largo areas have reported average grades of 0.15–0.35% $U_3O_8$ at depths of 1,000–2,000 ft and are undeveloped. | McLemore and Chenoweth (1988), McCammon et al. (1986), Granger and Santos (1986), Green et al. (1982a, b), Hazlett and Kreek (1963), Granger et al. (1961), additional references cited by McLemore (1983a) |
| | 6,660,718 | 0.1–0.4 | 1950–1981 | Jwt | Uranium deposits in Todilto Limestone Member of the | Gabelman and Boyer (1988), McLemore and Chenoweth |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | | Wanakah Formation (Jurassic). | (1988), Green et al. (1982a, b), Gabelman (1970) |
| | 29,595 | 0.25 | 1952–1969 | Kd-redistributed | Small redistributed uranium deposits in Dakota Sandstone (Cretaceous). | Chenoweth (1989), Green et al. (1982a, b), Pierson and Green (1980), Hilpert (1969) |
| | — | — | — | Collapse-breccia pipe | An undetermined amount of uranium was produced from collapse-breccia pipes in the Cliffside and Doris mines. These pipes are similar to collapse-breccia pipes in Arizona. | Clark and Havenstrite (1963), Granger and Santos (1963), Hilpert (1969) |
| 5. Smith Lake subdistrict (also known as Black Jack or Mariano Lake district) (McKinley County) | 13,000,000† | 0.2 | 1951–1985 | Jm-primary, redistributed, remnant | Uranium deposits in sandstone in Westwater Canyon Member of the Morrison Formation (Jurassic) at depths ranging from 300 to 825 ft. Redistributed deposits in the Westwater Canyon Member at the Black Jack No. 1 mine. | Kirk et al. (1988, 1986), McLemore and Chenoweth (1988), Fishman and Reynolds (1986, 1982), Fishman et al. (1985), McLemore (1983a), Hatchell and Wentz (1981), Ristorcelli (1980), MacRae (1963), Hoskins (1963), Hansley (1988) |
| | 151 | 0.13 | 1952–1985 | Jwt | Small uranium deposits in Todilto Limestone Member of the Wanakah Formation (Jurassic). | McLemore (1983a), Hilpert (1969) |
| 6. Church Rock–Crownpoint subdistrict (McKinley County) | 16,000,000† | 0.1–0.2 | 1953–1986 | Jm-primary, redistributed, remnant | Primary, redistributed, and remnant uranium deposits in sandstone of the Morrison Formation (Jurassic) at depths ranging from 100 to 2,800 ft. Grades average 0.10–0.20% $U_3O_8$ but may be as high as 0.40% $U_3O_8$. | Kirk et al. (1988), McLemore and Chenoweth (1988), Kirk and Condon (1986), Phelps et al. (1986), Fishman and Reynolds (1983, 1986), Vogt et al. (1982), Adams and Saucier (1981), Hackman and Olson (1977), Hazlett (1969), additional references cited by McLemore (1983a) |
| | 471,574 | 0.21 | 1952–1970 | Kd-redistributed, shale | Redistributed sandstone uranium deposits and uraniferous shale deposits in the Dakota Sandstone (Cretaceous). | Chenoweth (1989), McLemore and Chenoweth (1988), Pierson and Green (1980), Gabelman (1956a) |
| 7. Nose Rock subdistrict (McKinley County) | none | — | — | Jm-primary, redistributed, remnant(?) | Primary, redistributed, and possible remmnant uranium deposits in sandstone of the Morrison Formation (Jurassic) at depths of 2,600–3,200 ft. More than 69,000,000 lbs of $U_3O_8$ reserves at 0.10–0.15% $U_3O_8$ estimated. | McLemore and Chenoweth (1988), Phillips Uranium Corp. (written communication and general file data, 1981), Clark (1980) |
| 8. Chaco Canyon area (McKinley and San Juan Counties) | none | — | — | Jm-primary | Primary uranium-mineralized zones in sandstone of the Morrison Formation (Jurassic) at depths of 4,300–4,500 ft. Assays ranged up to 0.08% $U_3O_8$. Data insufficient to estimate uranium resource potential (Brookins, 1979). | Haddad et al. (1981), Hicks et al. (1980) |
| **Shiprock uranium district, San Juan County** | | | | | | |
| 9. Carrizo Mountains subdistrict | 159,850 | 0.23 | 1948–1967 | Jm-tabular | Shallow (<500 ft deep), tabular vanadium-uranium sandstone deposits in Salt Wash Member of the Morrison Formation (Jurassic). | Chenoweth (1985b), Green et al. (1982d), Chenoweth and Learned (1984), Hackman and Olsen (1977), additional references cited by McLemore (1983a) |
| | none | — | — | Miscellaneous (diatreme) | Minor uranium occurrences in diatremes. | Shoemaker (1956) |
| 10. Chuska Mountains subdistrict (also known as Sanostee | 333,660 | 0.12 | 1952–1982 | Jm-tabular | Shallow (<500 ft deep), tabular uranium-vanadium sandstone deposits in Recapture and Salt Wash Members of the | McLemore et al. (1988), Chenoweth (1985b), Green et al. (1982d), Hackman and Olsen (1977), Hilpert (1969), |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| subdistrict) | | | | | Morrison Formation (Jurassic). The largest deposit is at the Enos Johnson mine in the Recapture Member and yielded more than 136,000 tons of ore averaging 0.12% $U_3O_8$. | Blagbrough et al. (1959), Chenoweth (1957a), Allen and Balk (1954), additional references cited by McLemore (1983a) |
| | 25 | 0.04 | 1954 | Jwt | Minor uranium deposits in Todilto Limestone Member of the Wanakah Formation (Jurassic). Production from two properties; one 6-ton shipment averaged 0.10% $U_3O_8$. | Hilpert (1969) |
| | none | — | — | Beach placer | Uraniferous beach-placer (black) sandstone in Gallup Sandstone (Cretaceous). Sample assayed 0.032% $U_3O_8$ (NMBMMR Chemistry Lab, 8/19/85: No. 7973). | Brookins (1977), Bingler (1963), Dow and Batty (1961) |
| | none | — | — | Miscellaneous (diatreme) | Minor uranium occurrences in diatremes. | Shoemaker (1956) |
| 11. Tocito Dome area | none | — | — | Jm-primary | Small- to medium-sized orebody reported in Westwater Canyon Member of the Morrison Formation (Jurassic) by Exxon in the late 1970s at depth of about 2,000 ft. No development. | McLemore (1983a: appendix 1), Uranium Newsletter (written communication 9/78) |
| 12. Toadlena area | none | — | — | Beach placer | Uraniferous beach-placer (black) sandstone with thorium and rare-earth elements in Gallup Sandstone (Cretaceous). Sample assayed 0.024% $U_3O_8$ (NMBMMR Chemistry Lab, 8/19/85: No. 7976). | McLemore et al. (1988), Brookins (1977), Dow and Batty (1961), Chenoweth (1957a), Archer (1957) |
| **Other areas** | | | | | | |
| **Cibola County** | | | | | | |
| 13. Zuni Mountains area | none | — | — | Sedimentary copper | Uranium associated with sedimentary-copper deposits in Abo Formation (Permian). Hilpert (1969) reported an assay of 0.03% $U_3O_8$. | McLemore (1983a: appendix 1), Goddard (1966), Baumgardner (1956) |
| | none | — | — | Epithermal vein | Minor uranium in Precambrian shear zones with gold and copper; assays ranged 0.003–0.005% $U_3O_8$ (McLemore et al., 1986a: pp. 62–64). | McLemore (1983a), Goddard (1966) |
| | none | — | — | Alkalic rock | Syenites (Ordovician?) containing thorium in Precambrian rocks. Sample assayed 316 ppm Th (McLemore and McKee, 1989). | McLemore field work in progress (1989) |
| **San Juan County** | | | | | | |
| 14. Boyd prospect | 74 | 0.05 | 1955 | Sedimentary uranium | Uranium deposits in calcareous sandstone of the Kirtland or Fruitland Formations (Cretaceous). One 10-ton shipment averaged 0.10% $U_3O_8$. Sample assayed 0.182% $U_3O_8$ (McLemore, 1983a: appendix 1). Carnotite present. | Hilpert (1969), Chenoweth (1958) |
| 15. Farmington district (Hogback mine) | 3 | 0.02 | 1954 | Beach placer | Uraniferous beach-placer (black) sandstone deposits, which also contain thorium and rare-earth elements, in Point Lookout Sandstone (Cretaceous). Sample assayed 0.006% $U_3O_8$ and 280 ppm Th (NMBMMR Chemistry Lab, 5/1/88: No. 2745). Zircon and monazite present. | McLemore (1983a: appendix 1), Houston and Murphy (1977), O'Sullivan and Beckman (1963), Dow and Batty (1961), Chenoweth (1957a) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| ? Farmington area—exact location unknown (Claim No. 14) | 48 | 0.11 | 1954 | K–roll front(?) | Mystery shipment of ore in 1954 from Meadow Mining Co., presumably from the Ojo Alamo Sandstone (Tertiary). No additional information known. | AEC production records (written communication 1954) |
| **Rio Arriba and Sandoval Counties** | | | | | | |
| 16. Abiquiu area (Chama Basin) | none | — | — | K–roll front, Kd-redistributed | Low-grade roll-front sandstone uranium deposits in Burro Canyon Formation (Cretaceous) at depths of 200–600 ft. Minor sandstone uranium occurrences in Dakota Sandstone (Cretaceous). | Green et al. (1982d), Saucier (1974), Chenoweth (1974a) |
| | none | — | — | Sedimentary copper | Uraniferous sedimentary-copper deposits in basal Chinle Formation (Triassic). | Bingler (1968), Soulé (1956) |
| | none | — | — | Jwt | Uranium occurrence in Todilto Limestone Member of the Wanakah Formation (Jurassic). | Chenoweth (1974a), Hilpert (1969) |
| 17. Box Canyon mine (Chama Basin) | 253 | 0.10 | 1957 | Jwt | Uranium deposits in Todilto Limestone Member of the Wanakah Formation (Jurassic). | Chenoweth (1974a), Hilpert (1969) |
| 18. Chama Canyon area | none | — | — | Sedimentary copper | Uraniferous sedimentary-copper deposits in Cutler Formation (Permian). | Light (1982, 1983), Green et al. (1982c) |
| 19. Gallina district (Corral mine) | 19 | 0.04 | 1954–1956 | Sedimentary copper | Uraniferous sedimentary-copper deposits in shale and arkosic conglomerate of the Abo Formation (Permian) and the Madera Formation (Pennsylvanian). Samples from Max Jacque property in Abo Formation assayed 0.036 and 0.05% $U_3O_8$ (McLemore, 1983a: appendix 2). | Chenoweth (1974a), Soulé (1956), Brown (1955) |
| 20. Eastern San Juan Basin area | none | — | — | T–roll front | Ground-water anomalies, radiometric anomalies, and uranium occurrences in sandstone indicate a potential for roll-type sandstone uranium deposits at shallow depths (<500 ft) in the San Jose Formation (Eocene). Assays up to 0.20% $U_3O_8$ reported (Chenoweth, 1957b). | Chamberlin (1988; written communication May 1988), Chenoweth (1957b) |
| 21. Mesa Portales area | none | — | — | T–roll front | Low-grade uranium deposits, possibly roll-type deposits, in several blanket-like horizons in Ojo Alamo Sandstone (Tertiary). Depth to deposits could be as much as 2,000 ft. Radiometric and geochemical anomalies occur in the area. | Green et al. (1982a, c), Vizcaino and O'Neill (1977) |
| 22. Dennison Bunn area | none | — | — | Jm-redistributed | Redistributed sandstone uranium deposit in Westwater Canyon Member of the Morrison Formation (Jurassic) at the surface. Uranium content ranges from 0.002 to 0.08% $U_3O_8$ (Ridgeley, 1979, 1980; McLemore, 1983a: appendix 2). | Green et al. (1982c) |
| 23. La Ventana area | 290 | 0.63 | 1954–1957 | Shale | Irregular and scattered mineralized zones of uranium in carbonaceous shale and coal in the Dakota Sandstone (Cretaceous) and the Menefee Formation (Cretaceous) within 80 ft of the surface. One undeveloped deposit contains about 100 tons averaging 0.10% $U_3O_8$. | Chenoweth (1989), Finch and McLemore (1989), Green et al. (1982a), Bachman et al. (1959) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| 24. Collins–Warm Springs district | 989 | 0.12 | 1957–1959 | Jm-redistributed | Roll-type sandstone uranium deposits in Morrison Formation (Jurassic) at the surface. | McCammon et al. (1986), Green et al. (1982a), Santos (1975), Chenoweth (1974a) |
| 25. Ojito Spring area | none | — | — | Jm-redistributed or primary | Uranium occurrences in sandstone of the Morrison Formation (Jurassic). Mineralized drill holes and geochemical anomalies indicate potential ore deposits in subsurface. | Light (1982, 1983), Santos (1975), Chenoweth (1974a), Kittleman (1957) |
| **SOUTHERN ROCKY MOUNTAINS** | | | | | | |
| **Rio Arriba and Sandoval Counties** | | | | | | |
| 26. Coyote district | 182 | 0.13 | 1954–1957 | Sedimentary copper | Uraniferous sedimentary-copper deposits in sandstone of the Cutler Formation (Permian) and the Chinle Formation (Triassic). Sample from sec. 12 T21N R2E assayed 0.14% $U_3O_8$ (McLemore and North, 1984). | Chenoweth (1974a), Bingler (1968), Soulé (1956), Baltz (1955) |
| | none | — | — | Jwt | Minor uranium occurrences in Todilto Limestone Member of the Wanakah Formation (Jurassic). | Chenoweth (1974a), Hilpert (1969) |
| 27. Nacimiento area | none | — | — | Sedimentary copper, sedimentary uranium | Stratabound sedimentary-uranium deposits, some with copper, in the Abo Formation (Permian) and the Chinle Formation (Triassic). | McLemore (1983a: appendix 1), Chenoweth (1974a), Woodward et al. (1974), Hilpert (1969), Soulé (1956) |
| 28. Jemez Springs area | none | — | — | Sedimentary copper | Uraniferous sedimentary-copper deposits in sandstone, siltstone, and limestone of the Abo Formation (Permian). Sample from Deer Creek occurrence assayed 0.144% $U_3O_8$ (McLemore, 1983a: appendix 2; McLemore and North, 1984). | Chenoweth (1974a), Gott and Erickson (1952) |
| 29. Bromide district | 24 | 0.06 | 1954–1956 | Epithermal vein | Uranium-fluorite (± copper) veins in Moppin metavolcanic series (Precambrian). Two samples assayed 0.01% $U_3O_8$ with 3% Cu and 0.066% $U_3O_8$ (McLemore, 1983a: appendix 2) and others assayed up to 0.31% $U_3O_8$ (Goodknight and Dexter, 1984a). Uranothorite, uraninite, thorite, and other uranium minerals present (Goodknight and Dexter, 1984a). NOTE: Production corrected from McLemore (1983a) using AEC production records (written communication 1954–1956). | Wobus and Manley (1982), Chenoweth (1974b), Bingler (1968) |
| 30. Petaca district | 2 | 0.03 | 1954 | Pegmatite | Pegmatites containing uranium, thorium, and rare-earth elements in Precambrian terrane. Monazite, samarskite, euxenite, and hatchettolite present. Mine-dump samples from Nambe assayed 0.131% $U_3O_8$ and 610 ppm Th and from Globe 0.062% $U_3O_8$ and 10,332 ppm Th (McLemore, 1983a: appendix 2). | McLemore et al. (1988), Merker (1981), Robertson (1976), Chenoweth (1974b), Parker and Fleisher (1968), Bingler (1968), Redmon (1961), Wright (1948), Jahns (1946), Just (1937) |
| **Taos County** | | | | | | |
| 31. Vermejo Park area (near Costilla) | none | — | — | Possible epithermal vein, granitic rock, | Studies suggest that uranium-bearing veins(?), pegmatites, or possibly disseminated uranium deposits could occur | Zelenka (1984), McLemore (1983a: appendix 1), Reid et al. (1980) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | or pegmatite | in Costilla granite (Precambrian). Sample of microbreccia assayed 0.38% $U_3O_8$ (Goodknight and Dexter, 1984b). Uranophane, uraninite, and other uranium minerals are present (Goodknight and Dexter, 1984b). | |
| 32. Red River district (Black Copper mine) | 3 | 0.03 | 1957 | Epithermal vein | Veins with uranium in Precambrian granite near fault contact with Tertiary volcanic and intrusive rocks. Samples from Bitter Creek prospect assayed 0.03 and 0.11% $U_3O_8$ (McLemore, 1983a: appendix 2). | Reid et al. (1980) |
| 33. Picuris district (Harding mine) | none | — | — | Epithermal vein, pegmatite | Uranium-copper and uranium-quartz veins and pegmatites with uranium, thorium, and rare-earth elements in Precambrian granite. Microlite, monazite, allanite, and thorite found in pegmatite. Sample of copper vein in Ortega quartzite at Copper Hill assayed 0.02% $U_3O_8$ (DOE files, written communication 4/31/81). | McLemore (1983a: appendix 1), Brookins et al. (1979), Jahns and Ewing (1976, 1977), Taggart (1976), Parker (1965), Jahns (1946, 1953) |
| **San Miguel County** | | | | | | |
| 34. Rociada area (extends into Mora County) | none | — | — | Pegmatite, epithermal vein | Pegmatites and veins in Precambrian granite contain uranium, thorium, and rare-earth elements. | McLemore and North (1985), McLemore (1983a), Robertson (1976), Sheffer and Goldsmith (1969), Jahns (1946, 1953) |
| 35. El Porvenir area | 32 | 0.11 | 1955–1956 | Epithermal vein, pegmatite | Veins filling faults in Precambrian granite. Samples assayed up to 0.014% $U_3O_8$ (DOE files, written communication 8/3/81). Uraninite and thorium-uranium silicates present (L. Fukui and M. Dixon, written communication 3/12/82). Pegmatites contain uranium, thorium, and rare-earth elements. | McLemore et al. (1988), McLemore and North (1985), Klich (1983), McLemore (1983a: appendix 1), Reid et al. (1982), Adams et al. (1980), U.S. Geological Survey et al. (1980), Chenoweth (1979), Baltz (1972), Redmon (1961), Griggs and Hendrickson (1951), Holmquist (1946), Harley (1940) |
| | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in Sangre de Cristo Formation (Pennsylvanian-Permian). | Harley (1940) |
| 36. Tecolote area | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in Sangre de Cristo Formation (Pennsylvanian-Permian). | McLemore (1983a: appendix 1), Robertson (1976), Soulé (1956), Harley (1940) |
| | none | — | — | Pegmatite | Uranium, thorium, and rare-earth elements in pegmatites in Precambrian rocks. | McLemore (1983a: appendix 1), Harley (1940) |
| **BASIN AND RANGE** | | | | | | |
| **Santa Fe County** | | | | | | |
| 37. San Jose area (extends into Rio Arriba County) | 12 | 0.05 | 1957 | T–roll front | Small, scattered sandstone uranium occurrences are found in Tesuque Formation of the Santa Fe Group (Tertiary). One sample reported to contain 0.27% $U_3O_8$ (Hilpert, 1969). | McLemore and North (1984), Green et al. (1982c), Chenoweth (1979) |
| 38. La Bajada mine | 27,116 | 0.14 | 1956–1966 | La Bajada | Veins of base metals with silver and uranium fill a fault that cuts Cieneguilla Limburgite (Oligocene) and Espinaso Volcanics (Eocene). Uranium occurs with organic material and sulfides. Formed | McLemore and North (1984), Chenoweth (1979), Haji-Vassiliou and Kerr (1972), Elston (1967), Lustig (1958) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | | under low-temperature near-surface conditions. | |
| **Sandoval County** | | | | | | |
| 39. Hagan Basin area | none | — | — | T-roll front | Uranium-selenium deposits in sandstone of the Galisteo Formation (Eocene-Oligocene). An estimated 800,000 lbs at an average grade of 0.09% $U_3O_8$ in roll-type deposits at 10–400-ft depths. Mine-dump sample assayed 0.064% $U_3O_8$ (McLemore, 1983a: appendix 2). Core sample assayed 2.7% $U_3O_8$ (Hilpert, 1969). | Green et al. (1982a), Moore (1979), Chenoweth (1979), Perkins (1979), Hilpert (1969) |
| **Bernalillo County** | | | | | | |
| 40. Tijeras Canyon district | none | — | — | Epithermal vein, pegmatite | Uranium minerals in copper-fluorite veins along fractures and shear zones in Precambrian rocks. Uraniferous pegmatite. | Kelley and Northrop (1975), Hilpert (1969) |
| | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in the Abo Formation (Permian). Sample assayed 0.07% $U_3O_8$ (Hilpert, 1969). | Hilpert (1969) |
| **Valencia County** | | | | | | |
| 41. Manzano Mountains–Manzanitas Mountains area (extends into Bernalillo County) | none | — | — | Vein-type or disseminated magmatic deposit(?) | Radiometric anomalies and high U/Th ratios (>0.5) of NURE stream-sediment samples suggest that uranium may occur peripheral to Precambrian greenstones or in the overlying Precambrian Bosque metasediments and/or granite. | McLemore et al. (1986b) |
| **Torrance County** | | | | | | |
| 42. Lobo Hill area | none | — | — | Alkalic rock, carbonatite | Uranium in Ordovician syenite and carbonatite in Precambrian rocks. Assay of carbonatite sample ran 0.023% $U_3O_8$; assay of syenite 0.002% $U_3O_8$ and 300 ppm Th (McLemore, 1984). | Loring and Armstrong (1980), Loring et al. (1987) |
| 43. Pedernal Hills area | none | — | — | Alkalic rock, epithermal vein | Uranium in Ordovician syenite in Precambrian rocks. Sample of syenite assayed 0.001% $U_3O_8$ (McLemore, 1984) and 980 ppm Th (NMBMMR XRF Lab). Uranium with copper and gold in veins in Precambrian granite. | Loring and Armstrong (1980) |
| 44. Scholle district (extends into Socorro and Valencia Counties) | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in Bursum, Abo, and Yeso Formations (Permian). | North and McLemore (1986), McLemore (1982c, 1983a, 1984), Hatchell et al. (1982), LaPoint (1976, 1979), Soulé (1956), Collins and Nye (1957b) |
| **Socorro County** | | | | | | |
| 45. Rayo district | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in sandstone of Yeso Formation (Permian). | McLemore (1983a, b), LaPoint (1976, 1979), Soulé (1956) |
| 46. Socorro area (Agua Torres, Marie No. 1, Lucky Don, Little Davie mines) | 4,679 | 0.20 | 1955–1963 | Jeter type | Uranium veins along faults in Madera Formation (Pennsylvanian), Abo Formation (Permian), and San Andres Formation (Permian). Sample from Little Davie mine assayed 1.4% $U_3O_8$ (McLemore, 1983a: appendix 2). Secondary uranium minerals present. | McLemore (1983b), Pierson et al. (1982), Hilpert (1969) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| 47. Ladron Mountains district (also known as Sierra Ladrones) | 58,562 | 0.33 | 1954–1958 | Jeter type | Low-temperature supergene uranium-copper deposits in Precambrian granite along major fault. Not all of the ore was recovered from Jeter mine. | McLemore (1983b), Chamberlin et al. (1982), Collins and Nye (1957a), Collins and Smith (1956), Collins and Mallory (1954) |
| 48. Lemitar Mountains area | none | — | — | Carbonatite, epithermal vein | Uranium, thorium, and rare-earth elements in carbonatites and veins in Precambrian rocks. | McLemore (1987, 1983a, b, c, 1982b), Pierson et al. (1982), Collins and Smith (1956) |
| (San Lorenzo No. 1 mine) | 6 | 0.02 | 1955 | Sedimentary uranium | Uranium produced from conglomeratic sandstone of the Popotosa Formation (Tertiary). | McLemore (1983a, b) |
| 49. Chupadera Mountains area (also known as Coyote Hills) | none | — | — | Carbonatite, epithermal vein | Uranium, thorium, and rare-earth elements in carbonatites, veins, and jasper breccia zones in and along contacts with Precambrian rocks. Assays up to 0.129% $U_3O_8$ and 1,100 ppm Th reported (van Allen et al., 1986). | McLemore (1987, 1983b, c), van Allen et al. (1986) |
| 50. Hook Ranch–Riley area | 306 | 0.18 | 1954–1961 | K-roll front, sedimentary uranium | Uranium associated with oxidation-reduction interface in the Crevasse Canyon Formation (Cretaceous) and with organic material in the Baca Formation (Eocene). Drilling indicated a few hundred lbs of uranium (>0.10% $U_3O_8$) in the Baca Formation (Sargent, 1983) at depths of 250–300 ft. Production from the Baca. | Holen and Hatchell (1986), McLemore (1983a, b), Pierson et al. (1982), Chamberlin (1981), Hilpert (1969), Bachman et al. (1957) |
| **Catron County** | | | | | | |
| 51. Red Basin–Pietown area | 1,194 | 0.17 | 1954–1957 | K-roll front, sedimentary uranium | Uranium associated with organic material and oxidation-reduction interface in the Crevasse Canyon Formation (Cretaceous). Sandstone uranium deposits with organic material in the Baca Formation (Eocene). Uranium deposits probably do not exceed 500,000 lbs. | Holen and Hatchell (1986), McLemore (1983a: appendix 1), Guilinger (1982), Pierson et al. (1982), May et al. (1982), Chamberlin (1981), Hilpert (1969), Collins (1958a), Bachman et al. (1957) |
| 52. Mogollon district | 14 | 0.10 | 1956 | Epithermal vein | Uranium-fluorite vein (with gold, silver, and copper) in shear zone in Last Chance Andesite and Whitewater Creek Member of the Cooney Tuff (Tertiary) along the ring fracture zone of the Bursum and Mogollon calderas. Assays up to 3.18% $U_3O_8$ reported at the Baby mine (Collins, 1957). | White and Foster (1981), Ratté (1981), Collins (1957) |
| **Sierra County** | | | | | | |
| 53. Cuchillo district (also known as Chise or Iron Mountain district) | 85 | 0.10 | 1955–1957 | Sedimentary copper, miscellaneous (skarn) | Uraniferous stratabound sedimentary-copper deposits and skarn zones in the Abo Formation (Permian) near Tertiary intrusives. | McLemore (1983a: appendix 1), Berry et al. (1982), Boyd (1957), Jahns (1955) |
| 54. Terry prospect | 359 | 0.14 | 1955–1960 | Epithermal vein | Uranium and fluorite in veins and breccia deposits in Madera Formation (Pennsylvanian) jasper and breccia near andesite sill. Sample assayed 0.05% $U_3O_8$ (McLemore, 1983a: appendix 2). | Berry et al. (1982), Lovering (1956), Wolfe (1953), Boyd and Wolfe (1953) |
| 55. Fra Cristobal Range area | none | — | — | Sedimentary uranium | Sandstone uranium deposits in McRae Formation (Cretaceous-Tertiary). Assays up to 0.2% $U_3O_8$ reported. | Templain and Dotterer (1978) |
| 56. Caballo Mountains area | none | — | — | Alkalic rock, | Veins of thorium, uranium, and rare-earth elements | McLemore (1986), Staatz et al. (1965), Melancon (1952), |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | epithermal vein | associated with syenites in Precambrian granite. Samples assayed up to 0.498% $U_3O_8$ and 9,721 ppm Th (McLemore, 1986). | Doyle (1951) |
| 57. Derry area (Paran mine) | 9 | 0.07 | 1955 | Jeter type | Vein-type uranium deposits along Garfield fault in Permian and Pennsylvanian sedimentary rocks. | Templain and Dotterrer (1978) |
| | none | — | — | Sedimentary copper | Sedimentary-copper deposits in Abo Formation. | Templain and Dotterrer (1978) |
| **Grant County** | | | | | | |
| 58. Steeple Rock district | none | — | — | Epithermal vein | Uraniferous chalcedony veins filling fractures and faults in Oligocene volcanic rocks. Sample from Coal Creek area assayed 0.202% $U_3O_8$ (McLemore, 1983a: appendix 2). | Ratté et al. (1982), Briggs (1981, 1982) |
| 59. Telegraph district (also known as Redrock district) | none | — | — | Epithermal vein | Uranium-bearing quartz veins with some gold and silver and uranium-bearing veins with some barite in Precambrian granite. Near ring fracture zone of School House Mountain caldera. Torbernite and uraninite identified. Samples assayed between 0.09 and 0.59% $U_3O_8$ (McLemore, 1983a: appendix 2). | Richter and Lawrence (1983), O'Neill and Thiede (1982), Gillerman (1964), McAnulty (1978) |
| 60. Black Hawk district | none | — | — | Epithermal vein | Veins containing silver, tungsten, cobalt, nickel, uranium, and bismuth minerals fill fissures and faults in Precambrian quartz-diorite gneiss and granite near contact of Twin Peaks monzonite porphyry stock (Late Cretaceous). Pitchblende and other uranium minerals common. Mine-dump sample from Alhambra assayed 0.17% $U_3O_8$ (McLemore, 1983a: appendix 2). | North and McLemore (1986), Richter and Lawrence (1983), O'Neill and Thiede (1982), Hedlund (1978a, e), Gillerman (1968), Gillerman and Whitebread (1956) |
| 61. Burro Mountains district | 30 | 0.04 | 1956 | Epithermal vein | Veins containing uranium, copper, molybdenum, lead, zinc, gold, silver, fluorite, and bismuth minerals and torbernite and other secondary uranium minerals fill fissures and shear zones in Precambrian granite, Beartooth Quartzite (Cretaceous), and Tertiary volcanic rocks near Tertiary porphyry copper deposit. | McLemore (1983a: appendix 1), Richter and Lawrence (1983), O'Neill and Thiede (1982), Hedlund (1978c, d, e, 1985), Kolesar (1970), Gillerman (1968) |
| 62. White Signal district | 1,337 | 0.22 | 1953–1964 | Epithermal vein | Three district types of veins containing uranium minerals fill faults and fissures in Precambrian granite and along contacts between granite and early Tertiary rhyolite dikes; quartz-pyrite-gold veins, quartz-specularite veins, and silver and silver-lead veins. Blue Jay deposit reported to contain 2,400 tons of 0.012–0.047% $U_3O_8$ in indicated reserves; Apache Trail–Black Cat deposit reported to contain 146,000 tons of 0.012% $U_3O_8$ in inferred reserves (Granger et al., 1952). Ore from Floyd Collins averaged 0.1–0.2% | Richter et al. (1986), Richter and Lawrence (1983), O'Neill and Thiede (1982), McAnulty (1978), Hedlund (1978f), Gillerman (1968, 1964, 1953), Granger and Bauer (1952) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | | $U_3O_8$. Two carloads of radium was produced in the 1920s. Sample from Hines prospect in Bliss Sandstone (Cambrian) assayed 0.02% $U_3O_8$ (McLemore, 1983a: appendix 2). Some pegmatites contain euxenite and other minerals. | |
| 63. Malone district | none | — | — | Epithermal vein | Veins containing uranium, gold, silver, copper, lead, and zinc minerals fill faults in Precambrian granite and at the contacts of granite with Precambrian mafic dikes and Tertiary rhyolite dikes. Sample from sec. 14 T20S R16W assayed 0.02% $U_3O_8$ (O'Neill and Thiede, 1982: No. 48). | McLemore (1983a: appendix 1), Richter and Lawrence (1983) |
| 64. Gold Hill district (extends into Hidalgo County) | none | — | — | Pegmatite | Pegmatites containing uranium, thorium, and rare-earth elements intrude Precambrian granite. Minerals present include euxenite, allanite, and samarskite. Assays up to 7,200 ppm Th reported. | McLemore et al. (1988), McLemore (1983a), Staatz (1974), Hedlund (1978b), Gillerman (1964) |
| 65. Bound Ranch area (also known as Langford Hills) | none | — | — | Epithermal vein | Veins with tungsten, fluorite, gold, and uranium minerals fill faults, breccia zones, and fissures in Precambrian granite. Autunite found with fluorite. | North and McLemore (1986), Richter and Lawrence (1983), Gillerman (1964) |
| **Hidalgo County** | | | | | | |
| 66. Lordsburg Mesa area (extends into Grant County) | none | — | — | Surficial | Geophysical and geochemical studies have delineated a large anomalous limonite area, which is interpreted as the surface expression of a chemical trap that may contain surficial uranium concentrations (calcrete uranium deposits) north of Lordsburg. NURE ground-water anomalies also suggest uranium could be present (Sharp et al., 1978). | Raines et al. (1985), Carlisle et al. (1978) |
| 67. Dog Mountains area | none | — | — | Epithermal vein | Uraniferous opal veins in faults and fractures of silicified Oak Creek Tuff (Tertiary). Assays ranged from 0.02% (McLemore, 1983a: appendix 2) to 0.16% $U_3O_8$ (May et al., 1981). | Walton et al. (1980) |
| 68. Fremont district (Napane mine) | 35 | 0.19 | 1955 | Miscellaneous (skarn) | Uranium deposits along fractures and faults in limestone and sandstone of the U-Bar Formation (Cretaceous) near the ring fracture of the Apache caldera. Sample assayed 0.13% $U_3O_8$ (McLemore, 1983a: appendix 2). | May et al. (1981), Griswold (1961) |
| **Luna County** | | | | | | |
| 69. Tres Hermanas district | none | — | — | Miscellaneous (skarn) | Skarn deposits of silver, zinc, lead, copper, gold, uranium, manganese, and tungsten minerals in the Escabrosa Limestone (Mississippian) and Lower Pennsylvanian limestone adjacent to Eocene quartz-monzonite stock. Mine-dump sample assayed 0.007% $U_3O_8$ (McLemore, 1983a: appendix 2). | Griswold (1961), Balk (1962) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| **Doña Ana County** | | | | | | |
| 70. Bishop Cap district (Blue Star mine) | 14 | 0.06 | 1955 | Epithermal vein | Uranium in fluorite-barite-galena veins along fault zones in limestone of the Fusselman Dolomite (Pennsylvanian) associated with the Organ caldera. Assays up to 0.17% $U_3O_8$ reported. | McAnulty (1978), Seager (1973) |
| **Otero County** | | | | | | |
| 71. Cornudas Mountains area | none | — | — | Epithermal vein, alkalic rock | Thorium–uranium–rare-earth-element–beryllium veins in fractures of Tertiary mafic dikes and alkalic intrusives. Samples of veins assayed 0.03% $U_3O_8$ and 700 ppm Th (Collins, 1958b). Samples of silicified dike assayed 0.006 and 0.01% $U_3O_8$ (NMBMMR Chemistry Lab, 1/85: No. 7368, No. 7369). | McLemore et al. (1988), Barker and Hodges (1977), Warner et al. (1959), Zapp (1941) |
| 72. Sacramento district (also known as High Rolls district) | none | — | — | Sedimentary copper, miscellaneous (skarn) | Uraniferous stratabound sedimentary-copper deposits and copper-lead deposits in sandstone and shale of Abo Formation (Permian). Some lead deposits occur adjacent to Tertiary intrusives. Sample from Courtney mine assayed 0.01% $U_3O_8$ (McLemore, 1983a: appendix 2). | Jerome et al. (1965), Soulé (1956) |
| 73. Tularosa area | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in the Abo Formation (Permian). | Soulé (1956) |
| 74. Bent area | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in the Abo Formation (Permian). | Soulé (1956) |
| **Lincoln County** | | | | | | |
| 75. Estey district | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in arkose and limestone of the Abo Formation (Permian). | McLemore (1983a: appendix 1), Soulé (1956) |
| 76. Capitan Mountains area | 1 | 0.02 | 1954 | Epithermal vein, alkalic rock | Thorium–uranium–rare-earth-element veins and uranium-iron veins cutting Tertiary alaskite. Veins contain titanite, allanite, and smokey quartz. Sample from Bear Canyon mine assayed 0.011% $U_3O_8$ (McLemore, 1983a: appendix 2). | McLemore et al. (1988), McLemore (1983a: appendix 1), Staatz (1974), Griswold (1959), Kelley (1949), McLemore field work in progress (1989) |
| 77. Gallinas Mountains district | none | — | — | Epithermal vein | Veins of copper, rare-earth elements, thorium, uranium, fluorite, zinc, lead, and iron fill fractures and breccia zones in the Yeso Formation (Permian) and a Tertiary trachyte porphyry. Some bastnaesite was produced. | North and McLemore (1986), DeMark (1980), Perhac (1970), Perhac and Heinrich (1964), Griswold (1959), Glass and Smalley (1945), Soulé (1946) |
| | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in the Yeso Formation (Permian). | Soulé (1946) |
| **GREAT PLAINS** | | | | | | |
| **Union County** | | | | | | |
| 78. Black Mesa area | none | — | — | Collapse-breccia pipe(?) | Mineralized zones of uranium, copper, silver, and iron in clastic plugs in the Sheep Pen Sandstone (Triassic), which may indicate potential for | McLemore (1983a: appendix 1), Fay (1983), Consulting Professionals, Inc. (1982), Reynolds (1979), Baldwin and Muehlberger (1959), |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | | collapse-breccia-pipe uranium deposits similar to those at the Woodrow mine (Cibola County) and others in Arizona (McLemore and North, 1987). | Parker (1933) |
| | none | — | — | Sedimentary copper | Uraniferous stratabound sedimentary-copper deposits in Triassic rocks. | Baldwin and Muehlberger (1959) |
| 79. Northeastern Union County area | none | — | — | Other limestone | Uraniferous marlstones in the Morrison Formation (Jurassic) at depths ranging from the surface to 568 ft. Marlstones rarely exceed 3 ft in thickness. Samples assayed up to 0.018% $U_3O_8$. | Consulting Professionals, Inc. (1982), Mankin (1958) |
| **Colfax County** | | | | | | |
| 80. Laughlin Peak area (also known as Chico Hills) | none | — | — | Epithermal vein, carbonatite | Veins with thorium, rare-earth elements, and some uranium in Tertiary volcanics and Cretaceous sedimentary rocks. A carbonatite dike also contains thorium, rare-earth elements, uranium, and niobium. Samples assayed up to 0.05% $U_3O_8$ and 24,200 ppm Th (Tschanz, 1958; Staatz, 1985; McLemore, 1983a), but most samples contain less than 50 ppm U. | McLemore et al. (1988), McLemore and North (1987), Staatz (1974, 1982, 1985, 1986, 1987), Staatz et al. (1979) |
| **Mora County** | | | | | | |
| 81. Coyote Creek district | 9 | 0.04 | 1954 | Sedimentary uranium, sedimentary copper | Uraniferous stratabound sedimentary-copper deposits and sedimentary-uranium deposits in arkosic sandstone and shale of Sangre de Cristo Formation (Pennsylvanian-Permian). Assays up to 0.24% $U_3O_8$ reported (Tschanz et al., 1958). | North and McLemore (1986), May et al. (1977), Tschanz et al. (1958), Soulé (1956) |
| **Harding County** | | | | | | |
| 82. Polita No. 2 mine | 2 | 0.15 | 1955 | Jm | Uranium deposits associated with fossil-wood material in sandstone of the Morrison Formation (Jurassic). | Anderson (1981), Abbott (1979), Finch (1972), Mankin (1958) |
| **San Miguel County** | | | | | | |
| 83. Sabinoso district | 81 | 0.08 | 1956 | Sedimentary copper, sedimentary uranium | Uraniferous stratabound sedimentary-copper deposits and sedimentary-uranium deposits in channel sandstone in lower and middle members of the Chinle Formation (Triassic). | Leibold et al. (1987), McLemore and North (1985), McLemore and Menzie (1983) |
| **Quay County** | | | | | | |
| 84. Tucumcari area | none | — | — | Jm | Small, low-grade sandstone uranium deposits in the Morrison Formation (Jurassic) associated with organic material, fossil bones, and fossil logs. Sample assayed 0.04% $U_3O_8$ (Finch, 1972). | Abbott (1979) |
| 85. San Jon area | 91 | 0.05 | 1955–1958 | Sedimentary copper, sedimentary uranium | Uraniferous stratabound sedimentary-copper deposits and sedimentary-uranium deposits in middle and upper units of the Chinle Formation (Triassic). Nodules in shale assayed 0.172–0.192% $U_3O_8$ (McLemore and North, 1985). One 8-ton shipment of ore from Good Luck mine had an average grade of 0.22% $U_3O_8$. | Finch (1972) |

TABLE 3 (continued)

| District or occurrence area (and Map No.) | Production* (lbs $U_3O_8$) | Typical grade of production (% $U_3O_8$) | Period of production (yrs) | Type of deposit (Table 2) | Description | References |
|---|---|---|---|---|---|---|
| | | | | | NURE geochemical ground-water anomalies (>25 ppb U) in the area (McLemore and North, 1985). | |
| **DeBaca, Curry, Roosevelt, Lea, Chaves, and Eddy Counties** | | | | | | |
| 86. Ogallala Formation | none | | — | Surficial(?) | There may be potential for surficial (calcrete) uranium deposits in the Ogallala Formation (Tertiary). Several surficial uranium deposits occur in the Ogallala in west Texas. | Otton (1984) |
| **Eddy County** | | | | | | |
| 87. Carlsbad area | none | | — | Sedimentary copper, other limestone | Small, low-grade uranium deposits in stratabound sedimentary-copper deposits and with asphaltite nodules in limestone and sandstone. Both types of deposits are in the Yates, Seven Rivers, and Queen Formations (Permian). Sample from Rocky Arroyo prospect (uraniferous asphaltite nodules in limestone) assayed 0.012% $U_3O_8$ (McLemore, 1983a: appendix 2). | Finch (1972), Waltman (1954) |

to the humate deposits. Because the size and shape of the orebodies in the Grants uranium district may be dependent upon the humate deposits (Nash et al., 1981), an explanation for the genesis of the humate deposits is critical to our understanding of uranium mineralization.

There are several explanations for the origin of the humate deposits associated with the primary uranium deposits in the Morrison Formation (Jurassic). Turner-Peterson and Fishman (1986; see also Hansley, 1988) proposed the humates were derived from overlying greenish-gray lacustrine mudstone in the Brushy Basin Member of the Morrison Formation. During compaction, formation water carrying the humic acids was expelled from the Brushy Basin mudstone into the underlying sandstone. Cations responsible for precipitation of the humic acids were scavenged from the host rock by ground water. This downward movement of the waters transporting the humic acids and cations caused flocculation of the humic acids into tabular zones (Turner-Peterson, 1985; Fishman and Turner-Peterson, 1986). During or after precipitation of the humic acids, uranium was precipitated from ground water. Granger et al. (1988; also Granger and Santos, 1986) developed a genetic model whereby uranium and humate were deposited during diagenesis by reduction at the interface of meteoric fresh water and ground-water brine. In the Section 30 mine in the Ambrosia Lake subdistrict (#4), a large uraniferous humate mass in the upper Westwater Canyon Member of the Morrison Formation can be traced to a detrital trash pile in the overlying Poison Canyon sandstone. There, the shale overlying the Westwater Canyon Member is missing, and the Poison Canyon sandstone was scoured into the upper Westwater Canyon Member. The place where the humate squeezed out of the trash pile is actually visible. Other genetic models have also been proposed.

Redistributed uranium deposits (Table 2: Jm-redistributed) are younger than primary uranium deposits and are discordant, asymmetrical, and irregularly shaped. Redistributed deposits cut across sedimentary features and have less humate than primary ore. They formed from primary ore by a regional oxidation front, where oxidizing ground water moved down dip (Saucier, 1976, 1980) during the Late Cretaceous–middle Tertiary through Quaternary. They characteristically are more than 8 ft thick, have diffuse ore-to-waste boundaries, and are brownish to light gray depending on the amount of organic material. The average deposit size has about 18.8 million lbs of $U_3O_8$ with an average grade of about 0.16% $U_3O_8$ (McCammon et al., 1986). Roll-front deposits similar to Wyoming roll-type ore (Harshman and Adams, 1981) have been observed in the Grants uranium district. Not all redistributed orebody configurations in the Grants uranium district have, however, the classic "C" shape (Green et al., 1982a). Some redistributed deposits were localized by Laramide Tertiary faults and fractures; many ore horizons are stacked along the faults.

Remnant uranium deposits (Table 2: Jm-remnant) average about 2.7 million lbs of $U_3O_8$ per deposit at an average grade of 0.20% $U_3O_8$ (McCammon et al., 1986). They were preserved in oxidized sandstone after the oxidation front that formed redistributed uranium deposits had passed. Some remnant ore deposits, such as ore in the Westwater Canyon Member of the Morrison Formation (Jurassic) at the Black Jack No. 1 mine in the Smith Lake subdistrict (#5) and ore in the Brushy Basin Member of the Morrison Formation at the Poison Canyon and Ruby mines in the Ambrosia Lake and Smith Lake subdistricts (#4, #5), were preserved because they were not very permeable. The low permeability was caused by local concentrations of calcite cement, which surrounded the deposits. Other remnant uranium deposits in the Morrison Formation occur in stratigraphically isolated sandstone lenses, which oxidizing waters did not enter (McCammon et al., 1986). Some remnant ore deposits near the oxidation front were overprinted by redistributed deposits (McCammon et al., 1986; McLemore and Chenoweth, 1988).

### Tabular Morrison Formation (Jurassic) sandstone uranium deposits, Shiprock uranium district

Tabular uranium deposits (Table 2: Jm-tabular) in the Salt Wash and Recapture Members of the Morrison Formation (Jurassic) occur in the Shiprock uranium district (#9, #10). The larger deposits are in the Carrizo Mountains subdistrict (#9) on the eastern flank of the Carrizo Mountains in both New Mexico and Arizona. The tabular orebodies are generally elongate parallel to the paleostream channels in the lower third of the Salt Wash Member. Detrital carbonized fossil plant matter is the primary ore control in this district. Classic "C"-shaped rolls have been observed; however, the origin of them is uncertain. A typical orebody in the eastern Carrizo Mountains is 150 to 200 ft long, 50 to 75 ft wide, and about 5 ft thick. A cluster of orebodies along a trend can contain as much as 4,000 tons of ore averaging 0.23% $U_3O_8$ (Chenoweth and Learned, 1984). The deposits are largely oxidized, and tyuyamunite is the principal ore mineral. Large humate masses, similar to those found in the Grants uranium district, are not known in the Shiprock uranium district.

A few small tabular uranium deposits are known in the upper part of the Salt Wash Member of the Morrison Formation (Jurassic) in the Chuska Mountains subdistrict (#10). A typical deposit there consists of a single pod of ore with a diameter of 25 to 50 ft and a thickness of 1 to 2 ft and is associated with detrital carbonaceous fossil plant material. The average grade is about 0.15% $U_3O_8$ and 0.70% $V_2O_5$.

The ores in the Salt Wash Member of the Morrison Formation (Jurassic) throughout the Colorado Plateau are well known for their vanadium content (Thamm et al., 1981). Ores shipped from the Carrizo Mountains subdistrict (#9) had an average uranium to vanadium ratio of 1:9. An exception was the Carl Yazzie No. 1 mine where the uranium to vanadium ratio was 1:5. In the Chuska Mountains subdistrict (#10), the uranium to vanadium ratios of the Salt Wash ores ranged from 1:1 to 1:3 (Chenoweth, 1985b).

The depositional fan of the Salt Wash Member of the Morrison Formation (Jurassic) divides into two tongues at the south end of the ancestral Monument uplift. The southern or smaller tongue extends into northeastern Arizona and northwestern New Mexico; the northern tongue extends into southeastern Utah and southwestern Colorado. Both tongues contain significant tabular uranium-vanadium deposits, although the larger northern tongue contains more deposits, including those in the Uravan mineral belt (Chenoweth and McLemore, 1989). Deposits in both tongues are similar. Deposits in the eastern Carrizo Mountains are near the thickest part of the southern tongue, which pinches out to the south near Toadlena, New Mexico, due to nondeposition.

The Recapture Member of the Morrison Formation (Jurassic) contains tabular uranium-vanadium deposits in the Chuska Mountains subdistrict (#10). Although production has been recorded from nine separate properties, most of the ore was produced from the the upper part of the Recapture Member in the Enos Johnson mine. From 1952 through 1982, this mine yielded 136,600 tons of ore averaging 0.12% $U_3O_8$ and containing 326,900 lbs of $U_3O_8$ (Chenoweth, 1985b). The Enos Johnson mine was the largest uranium mine (outside the Grants uranium district) in New Mexico. The mine produced ore from a series of individual up-to-20-ft-thick deposits that were clustered in an area 2,800 ft long and 300 ft wide. During the time the ore was assayed for vanadium, the uranium to vanadium ratios ranged from 1:0.42 to 1:1.75 (Chenoweth, 1985b). Uranium to vanadium ratios of shipments from the Recapture Member in other mines ranged from 1:1.05 to 1:2.80 (Chenoweth, 1985b). Uranium at the Enos Johnson mine is associated with hematite coatings on quartz grains in reddish-brown siltstone. Uranium minerals have not been identified, although coffinite has been found in samples of black ore (Chenoweth, 1985b). Organic material is noticeably absent in the Recapture deposits.

### Morrison Formation (Jurassic) sandstone uranium deposits, northeastern New Mexico

Uranium occurs with fossil bones and logs and other plant debris in sandstone, conglomerate, and shale of the Morrison Formation (Jurassic) in northeastern New Mexico (#82, #84; Abbott, 1979; Consulting Professionals, Inc., 1982; McLemore and North, 1985). The subtype of these deposits is not known because of lack of data; no economic deposits have been delineated in the Morrison Formation in northeastern New Mexico.

Clusters of ground-water anomalies containing 10–25 ppb U and greater than 25 ppb U occur north of the outcrop of the Morrison Formation (Jurassic) in southern Union County and eastern Harding County (McLemore and North, 1985). These uranium anomalies suggest other uranium accumulations are in the area, but the character and extent of such accumulations are unknown. The outcrop and subsurface extent of the Morrison Formation in northeastern New Mexico are shown on the Map.

### Other sandstone uranium deposits

Sandstone uranium deposits also occur in Pennsylvanian, Permian, Triassic, Cretaceous, Tertiary, and Quaternary formations (Hilpert, 1969; McLemore, 1983a). Many of the occurrences are small, low grade, channel controlled, and associated with carbonaceous plant material. They vary in size and grade, but are smaller in size and lower in grade than deposits in the Morrison Formation (Jurassic). Five subtypes of other sandstone uranium deposits have been recognized (Table 2); each is briefly described below. Total production from these other sandstone uranium deposits amounted to 468,680 lbs of $U_3O_8$ or 0.14% of the total uranium production in New Mexico (Table 4).

**TABLE 4**—Uranium production in New Mexico by type of deposit and district or occurrence area (Tables 2 and 3, Map) from 1948 through 1988 (U.S. Department of Energy, records tabulated by W. L. Chenoweth and E. A. Learned; statistics revised from McLemore (1983a, b) due to availability of more complete records). [1]Approximate figures rounded to the nearest 1,000 lbs. [2]Production figures from Chenoweth (1989). [3]Production figures revised from Chenoweth (1985a). *Production included with sedimentary copper.

| Type of deposit (Table 2) | District or occurrence area (and Map No.) | Production (lbs $U_3O_8$) | Period of production (yrs) | Production per total in New Mexico (%) |
|---|---|---|---|---|
| A. Morrison Formation (Jurassic) sandstone uranium deposits | | | | |
| Jm-primary, redistributed, remnant | Grants (#1, #2, #4–6) | 330,453,000[1] | 1951–1988 | 96.05 |
| | mine-water recovery | 5,708,386 | 1963–1988 | 1.66 |

TABLE 4 (continued)

| Type of deposit (Table 2) | District or occurrence area (and Map No.) | Production (lbs $U_3O_8$) | | Period of production (yrs) | Production per total in New Mexico (%) |
|---|---|---|---|---|---|
| Jm-tabular | Shiprock (#9, #10) | 493,510 | | 1948–1982 | 0.14 |
| Jm-redistributed | Collins–Warm Springs (#24) | 989 | | 1957–1959 | — |
| Jm | Polita No. 2 mine (#82) | 2 | | 1955 | — |
| | | Subtotal: | 336,656,000[1] | 1948–1988 | 97.85 |
| B. Other sandstone uranium deposits | | | | | |
| Kd-redistributed | | | | | |
| Dakota Sandstone (Cretaceous) | Grants (#4, #6) | 466,570[2] | | 1952–1970 | 0.14 |
| K/T–roll front | | | | | |
| Tesuque Formation (Tertiary) | San Jose (#37) | 12 | | 1957 | — |
| Ojo Alamo Sandstone (Tertiary) | Farmington (#15) | 48 | | 1954 | — |
| Crevasse Canyon Formation (Cretaceous) | Red Basin–Pietown (#51) | 1,194 | | 1954–1957 | — |
| Sedimentary uranium | | | | | |
| Baca Formation (Tertiary) | Hook Ranch–Riley (#50) | 306 | | 1954–1961 | — |
| Cretaceous/Tertiary sandstone | Boyd prospect (#14), Lemitar Mountains (#48) | 80 | | 1955 | — |
| Chinle Formation (Triassic) | Sabinoso (#83) | * | | 1954 | — |
| Sangre de Cristo Formation (Pennsylvanian-Permian) | Coyote Creek (#81) | 9 | | 1956 | — |
| Sedimentary copper | | | | | |
| Chinle Formation (Triassic) | Coyote (#26), Sabinoso (#83), San Jon (#85) | 177 | | 1954–1958 | — |
| Pennsylvanian/Permian sandstone | Gallina (#19), Cuchillo (#53) | 281 | | 1954–1957 | — |
| Beach placer | | | | | |
| Point Lookout Sandstone (Cretaceous) | Farmington (#15) | 3 | | 1954 | — |
| | | Subtotal: | 468,680 | 1952–1970 | 0.14 |
| C. Limestone uranium deposits | | | | | |
| Jwt | | | | | |
| Todilto Limestone Member of the Wanakah Formation (Jurassic) | Grants (#1, #4, #5) | 6,671,520[3] | | 1950–1985 | 1.94 |
| | Box Canyon (#17) | 253 | | 1957 | — |
| | Shiprock (#10) | 25 | | 1954 | — |
| | | Subtotal: | 6,671,798[3] | 1950–1985 | 1.94 |
| D. Other sedimentary rocks with uranium deposits | | | | | |
| Shale | | | | | |
| Dakota Sandstone (Cretaceous) | Grants (#6) | 34,599[2] | | 1952–1970 | 0.01 |
| Dakota Sandstone–Menefee Formation (Cretaceous) | La Ventana (#23) | 290 | | 1954–1957 | — |
| | | Subtotal: | 34,889 | 1952–1970 | 0.01 |
| E. Vein-type uranium deposits | | | | | |
| Jeter type | Ladron Mountains (#47) | 58,562 | | 1954–1958 | 0.02 |
| | Socorro (#46), Derry (#57) | 4,688 | | 1955–1963 | — |
| La Bajada | La Bajada (#38) | 27,116 | | 1956–1966 | — |
| Collapse-breccia pipe | Grants (#1) | 134,014 | | 1953–1956 | 0.04 |
| Epithermal vein | Bromide (#29), Red River (#32), Mogollon (#52), Terry (#54), Burro Mountains (#61), White Signal (#62), Bishop Cap (#70), Capitan Mountains (#76) | 1,782 | | 1953–1964 | — |
| | | Subtotal: | 226,162 | 1953–1966 | 0.06 |
| F. Igneous and metamorphic rocks with disseminated uranium deposits | | | | | |
| Pegmatite | Petaca (#30), El Porvenir (#35) | 34 | | 1954–1956 | — |
| Miscellaneous (skarn) | Fremont (#68) | 35 | | 1955 | — |
| | | Subtotal: | 69 | 1954–1956 | — |
| | | TOTAL: | 344,058,000[1] | 1948–1988 | 100.00 |

### Dakota Sandstone (Cretaceous) sandstone uranium deposits

The most important sandstone uranium deposits other than those in the Morrison Formation (Jurassic) are uranium deposits in the Dakota Sandstone (Cretaceous) in the Grants uranium district (Table 2: Kd-redistributed; #4, #6). More than 466,000 lbs of $U_3O_8$ have been produced from these deposits (Chenoweth, 1989).

Sandstone uranium deposits in the Dakota Sandstone (Cretaceous) are similar to redistributed uranium deposits in the Morrison Formation (Jurassic) and occur near primary and redistributed ore in the Morrison Formation. Orebodies in the Dakota Sandstone are typically tabular masses that range in size from thin pods a few ft long and wide to masses up to 2,500 ft long and 1,000 ft wide. The larger deposits are generally only a few ft thick, but a few are as much as 25 ft thick (Hilpert, 1969). Ore grades range from 0.12 to 0.30% $U_3O_8$ and average 0.21% $U_3O_8$. Uranium occurs with carbonaceous plant material near or at the base of channel sandstone or in carbonaceous shale and lignite (see section on shale uranium deposits). Deposits are associated with joints, fractures, or faults and with underlying permeable sandstone of the Brushy Basin or Westwater Canyon Members of the Morrison Formation.

The largest orebodies in the Dakota Sandstone (Cretaceous) are found in the old Church Rock mine in the Church Rock–Crownpoint subdistrict (#6), where uranium is associated with a major northeast-trending fault zone. More than 188,000 lbs of $U_3O_8$ have been produced from the Dakota Sandstone in the old Church Rock mine (Chenoweth, 1989). The orebodies occur in a channel in the basal Dakota Sandstone that trends N70°W. The Dakota channel scoured into a mineralized sandstone lens of the Brushy Basin Member of the Morrison Formation (Jurassic). The Dakota Sandstone is highly fractured and the orebodies are elongate in a N25°E direction, parallel to the fractures and the nearby Pipeline fault. Within the mine, subsidiary faults strike N40°E to N60°E and small orebodies are elongate parallel to these fractures. A similar, undeveloped ore deposit occurs in a Dakota channel in secs. 9 and 16, T16N R16W.

Most of the sandstone uranium deposits in the Dakota Sandstone (Cretaceous) occur along the Dakota outcrop where the Brushy Basin Member of the Morrison Formation (Jurassic) is absent or thins due to sub-Dakota erosion. Levee and crevasse-splay sandstone with carbonaceous material hosts most ore deposits (Pierson and Green, 1980). The ore was probably derived from primary uranium deposits in the Morrison Formation; the uranium had been redistributed upwards along fractures, joints, and faults or through permeable sandstone into the sandstone and shale of the Dakota Sandstone (Hilpert, 1969; Pierson and Green, 1980).

### Roll-front sandstone uranium deposits

Roll-front uranium deposits occur throughout New Mexico in Cretaceous and Tertiary sandstone (Table 2: K/T–roll front); however, production from these deposits has been small (<2,000 lbs of $U_3O_8$). Low-grade roll-front uranium deposits occur in the Galisteo Formation (Tertiary) in the Hagan Basin (#39), Burro Canyon Formation (Cretaceous) in the Chama Basin in the Abiquiu area (#16), Ojo Alamo Sandstone (Tertiary) in the Mesa Portales area (#21), and Crevasse Canyon Formation (Cretaceous) in the Hook Ranch–Riley and Red Basin–Pietown areas (#50, #51). Specific data, such as extent, size, and grade of mineralized zones, are not available for most of these deposits.

Roll-front uranium deposits occur typically in channel sandstone and are associated with carbonaceous material, clay galls, sandstone-shale interfaces, and pyrite. Associated elements include selenium, molybdenum, and vanadium. Mineralization occurred at an oxidation-reduction interface (Nash et al., 1981).

### Sedimentary sandstone uranium deposits

Sedimentary sandstone uranium deposits (Table 2: sedimentary uranium) are stratabound sandstone uranium deposits associated with syngenetic organic material or iron oxides or both, without any large concentrations of copper minerals. In New Mexico, these deposits occur in Pennsylvanian, Permian, Triassic, Cretaceous, and Tertiary rocks. Uranium contents vary, but average grades of shipments from these deposits rarely exceeded 0.10% $U_3O_8$ (#14, #48, #50, #81, #83). Some deposits occur in the vicinity of uraniferous sedimentary copper deposits. Stratabound sandstone uranium deposits tend to be small (at most they contain only a few tons of ore), and the potential for uranium production is low.

### Sedimentary-copper sandstone uranium deposits

Local, high concentrations of uranium occur in some stratabound sedimentary copper deposits (Table 2: sedimentary copper). These deposits occur within red-bed sequences deposited in intracratonic basins that lack volcanism or other magmatic activity.

In New Mexico, uraniferous copper deposits occur within specific intervals of Pennsylvanian, Permian, and Triassic fluvial to marginal-marine sedimentary rocks (Table 3). Copper concentrations are typically several percent. Uranium contents vary. Average grade of shipments from these deposits was less than 0.15% $U_3O_8$ (#19, #26, #53, #83, #85), but one 8-ton shipment of ore from the Good Luck mine in the San Jon area (#85) averaged 0.22% $U_3O_8$. The uraniferous sedimentary copper deposits tend to be small; they contain at most only several thousand lbs of ore. The potential for uranium production in these deposits is low because of low grade, low tonnage, and poor accessibility to existing mills. If in-situ leaching of copper from these deposits becomes feasible and economic, then uranium may be recovered as a by-product.

### Beach-placer sandstone uranium deposits

Heavy-mineral beach-placer sandstone deposits are concentrations of heavy minerals that formed in beaches or in longshore bars in a marginal-marine environment (Houston and Murphy, 1977). Many beach-placer sandstone uranium deposits (Table 2: beach placer) are found in the San Juan Basin (#10, #12, #15) and at least three wells have penetrated similar deposits in the subsurface (Chenoweth, 1957a).

The beach-placer sandstone uranium deposits in New Mexico occur in Cretaceous rocks and are low in tonnage and grade. Most deposits are less than 3 ft thick. Only one deposit, the Hogback deposit in the Farmington district (#15), produced ore, which had an average grade of 0.02% $U_3O_8$. Most deposits contain high concentrations of thorium, rare-earth elements, zircon, titanium, and iron. The small size, low grade, and difficulty in recovering economic minerals discourage development of these deposits in the near future.

## Limestone uranium deposits

### Todilto Limestone Member of the Wanakah Formation (Jurassic) limestone uranium deposits

The Grants uranium district is one of the few localities in the world where economic peneconcordant uranium deposits occur in limestone beds. Although yellow secondary uranium minerals had been known since the 1920s in the Todilto Limestone Member of the Wanakah Formation (Jurassic), the 1950 rediscovery by Paddy Martinez, a Navajo sheepherder, started the uranium boom in New Mexico (Melancon, 1963). From the first ore shipment (Table 2: Jwt) in December 1950 by Fred Glover (private property, sec. 9 T12N R9W, #4) to the last by Ranchers Exploration and Development Corp. in 1981 (Hope mine, sec. 19 T13N R9W, #4) almost 6.7 million lbs of $U_3O_8$ have been produced from the Todilto Limestone in the Grants uranium district, accounting for about 2% of the total uranium production in New Mexico (Table 4; Chenoweth, 1985a). Mines in sec. 30 T13N R9W (#4) produced 25% of the total uranium production from the Todilto Limestone, amounting to 1.66 million lbs of $U_3O_8$ (Chenoweth, 1985a). Production from the F-33 mine in sec. 33 T12N R9W accounted for 13% of the total uranium production from the Todilto Limestone, amounting to 205,000 tons of ore that averaged 0.21% $U_3O_8$ and contained 868,085 lbs of $U_3O_8$. Uranium orebodies are found elsewhere in the Todilto Limestone, however, only three properties outside the Grants uranium district have produced uranium: Reed Henderson No. 1 and H. B. Roy No. 2 mines in the Chuska Mountains subdistrict (#10) and Box Canyon mine in the Chama Basin (#17).

In the Grants uranium district (#1, #4, #5), the geometry of the limestone uranium deposits in the Todilto Limestone Member of the Wanakah Formation (Jurassic) are grossly similar to sandstone uranium deposits in the Morrison Formation (Jurassic); they are irregular in shape and occur in trends. The limestone uranium deposits, however, do not contain humates and are structurally controlled. They range in size from a few ft to 100s of ft long and wide and up to 20 ft thick. Occasionally mineralized zones extend into overlying or underlying sandstone. Most deposits contain less than 20,000 tons of ore averaging 0.2–0.5% $U_3O_8$ (Gabelman, 1970), although a few deposits are larger.

Three types of deposits occur in the Todilto Limestone Member of the Wanakah Formation (Jurassic): (1) unoxidized primary deposits, (2) oxidized (weathered) primary deposits, and (3) vagrant secondary deposits (Jones, 1978). Unoxidized primary deposits contain uraninite and coffinite as fine blades and fibers along grain boundaries, as veinlets, and as replacements of carbonate along bedding planes and fractures (Hilpert, 1969; Jones, 1978). Oxidized (weathered) primary deposits contain, in addition to uraninite and coffinite, secondary uranium minerals such as tyuyamunite, metatyuyamunite, and uranophane. Vagrant secondary deposits are redistributed uranium deposits consisting of only secondary uranium minerals along fractures and bedding planes.

Unoxidized and oxidized primary uranium deposits occur in the Todilto Limestone of the Wanakah Formation (Jurassic) within intraformational folds where an overlying gypsum bed is absent. The largest orebodies occur in the anticlinal portions of the folds where the intraformational folds are clustered and have a similar northeasterly trend (Hilpert, 1969; Green et al., 1982a).

The origin of the intraformational folds that appear to control uranium mineralization in the Todilto Limestone Member of the Wanakah Formation (Jurassic) is controversial. Rapaport (1952a, b) and Hilpert and Moench (1960) attributed these folds to soft-sediment slumping or creep down a depositional slope on the flanks of anticlines. Gabelman (1956b) attributed the folds to volumetric changes due to dehydration and diagenesis. Perry (1963) suggested some folds were a result of differential loading and compaction near either a subsiding reef or biohermal structures. Rawson (1980a, b) and Green (1982) suggested the folds are a result of the migration of overlying Summerville dunes, which locally deformed the underlying Todilto muds. After the Todilto muds had folded, uraniferous waters were pumped by hydraulic and evaporative processes from the permeable Entrada Sandstone (Jurassic) into the overlying organic-rich layers of the Todilto Limestone. The intraformational folds acted as conduits and structural traps for the mineralization. Some deposits were oxidized during the Tertiary and Quaternary by ground water. Locally, subsequent remobilization of primary uranium deposits in the Todilto Limestone (and possibly the overlying Morrison Formation) occurred during the Tertiary and Quaternary along fractures and formed vagrant deposits (Saucier, 1976).

Mineralized horizons in the Todilto Limestone Member of the Wanakah Formation (Jurassic) were intersected by drilling in the Ambrosia Lake subdistrict (#4; Young, 1960: p. 270; I. Rapaport, Four Corners Exploration Company, written communication 11/11/82; H. Holen, U.S. Department of Energy, written communication 1983). However, orebodies of economic size have not been delineated in the subsurface, except in the Poison Canyon area of the Ambrosia Lake subdistrict (McLemore and Chenoweth, 1988). Deeper Todilto Limestone uranium deposits probably will not be mined in the near future because of their small size, low grade, sporadic distribution, and difficulty in locating and developing.

### Other limestone uranium deposits

Uraniferous limestone, other than the Todilto Limestone Member of the Wanakah Formation (Jurassic), is rare in New Mexico . The two significant areas in the state where peneconcordant uranium occurs in limestone other than the Todilto Limestone (Table 2: other limestone) are northeastern New Mexico (#79) and the Carlsbad area (#87). Uraniferous marlstones occur in the Morrison Formation (Jurassic) in Union County in northeastern New Mexico (#79) and extend into west Texas and Oklahoma, and uraniferous asphaltite nodules occur in the Yates, Seven Rivers, and Queen Formations (Permian) in the Carlsbad area, Eddy County (#87). These deposits have not been developed and are small and low grade. Sandstone uranium deposits are also found in the Morrison Formation in northeastern New Mexico and in the Yates and Seven Rivers Formations in the Carlsbad area. Most other uranium occurrences in limestone are vein-type uranium deposits (Table 2: Jeter type, epithermal vein); they are discussed separately in this report under vein-type uranium deposits.

## Other sedimentary rocks with uranium deposits

Many uranium occurrences and a few deposits are found in other sedimentary rocks, including carbonaceous shale, lignite, and possibly surficial (calcrete) deposits.

### Shale uranium deposits

Some ore from carbonaceous shale and lignite (Table 2: shale) has been produced from the Dakota Sandstone (Cretaceous) in the Grants uranium district (#6) and in the La Ventana district (#23). Uranium production from these areas from 1952 to 1960 totalled 34,889 lbs of $U_3O_8$ or about 0.01% of the total uranium production in New Mexico (Table 4).

### Surficial uranium deposits

The potential for surficial (calcrete) uranium deposits (Table 2: surficial) in the Lordsburg Mesa area in southwestern New Mexico (#66; Carlisle et al., 1978) and the Ogallala

Formation (Tertiary) in southeastern New Mexico (#86; McLemore, 1983a; Otton, 1984) is highly speculative. Groundwater anomalies suggest uranium deposits may be present in these areas; however, mineralized zones high in uranium have *not* been discovered. The host rocks may be lenticular deposits of alluvium, soil, or detritus that have been cemented by carbonate. Uranium minerals, typically carnotite, are found in voids and fractures of such lenticular surficial deposits elsewhere in the world (Nash et al., 1981).

### Vein-type uranium deposits

Vein-type uranium deposits are structurally controlled, generally vertically oriented, tabular or sheet-like deposits in which uranium minerals fill cavities, cracks, fissures, faults, breccias, and stockworks. These uranium deposits occur in a variety of host rocks and have different mineral assemblages, but are similar in form and tectonic setting. The majority of vein-type uranium deposits in New Mexico can be grouped into four subtypes (Table 2): (1) Jeter type, (2) La Bajada, (3) collapse-breccia pipe, and (4) epithermal vein. Each subtype is briefly described below. Vein-type uranium deposits in New Mexico have produced only 226,162 lbs of $U_3O_8$ or 0.06% of the total uranium production in New Mexico (Table 4).

#### Jeter-type uranium deposits

One of the largest vein-type uranium deposits in New Mexico is at the Jeter mine (Table 2: Jeter type) in the Ladron Mountains (#47)—also known as Sierra Ladrones. From 1954 to 1958, 58,562 lbs of $U_3O_8$ were produced from this mine from ore with an average grade of 0.33%. Production from similar deposits in Socorro and Sierra Counties (#46, #57) from 1955 to 1963 amounted to 4,688 lbs of $U_3O_8$ (Table 4).

At the Jeter mine, uranium, vanadium, and copper minerals occur within a red to black carbonaceous mudstone breccia along the footwall of a fault that separates Precambrian granite from the Tertiary Santa Fe Group (Chamberlin et al., 1982; Hilpert, 1969; Collins and Nye, 1957a). The principal uranium mineral is coffinite (Collins and Nye, 1957a). Argillic alteration is about one ft thick in Santa Fe fanglomerate and 6–15 ft thick in the Precambrian granite (Chamberlin et al., 1982). The origin of the deposit at the Jeter mine is controversial. It has been described as a hydrothermal uranium deposit (Collins and Nye, 1957a; U.S. Department of Energy, 1980), as a vein-type uranium deposit (Hilpert, 1969; Pierson et al., 1982), and as a supergene uranium deposit (Chamberlin et al., 1982).

Many vein-type uranium occurrences similar to the Jeter deposit are present along the Rio Grande valley in Socorro and Sierra Counties (#46, #57). Most of these occurrences are in silicified and recrystallized limestone and sandstone along the footwall of major faults. Mineralized zones are small and discontinuous along these faults. The origin is speculative and further work will be needed to define and classify these Jeter-type occurrences (McLemore, 1983a).

#### La Bajada uranium deposit

La Bajada deposit at La Bajada mine (#38) is a low-temperature, uranium–base-metal vein deposit (Table 2: La Bajada) that formed during the Oligocene or Miocene (Hilpert, 1969; Haji-Vassiliou and Kerr, 1972). Thin veins of uranium and sulfide minerals occur along a north-trending fault in the Espinaso Volcanics (Eocene). This deposit is unusual because petroliferous material is associated with the mineralized veins, yet the adjacent volcanic rocks and Cieneguilla Limburgite (Oligocene) were intensely altered by hydrothermal solutions (Haji-Vassiliou and Kerr, 1972).

Lustig (1958) described 23 minerals from La Bajada deposit. Because of the complex association of uranium and carbonaceous material, however, specific uranium minerals have yet to be identified. Uranium, copper, zinc, cobalt, nickel, molybdenum, germanium, and gold occur in appreciable amounts (Hilpert, 1969). A dump sample assayed 0.09% $U_3O_8$, 1.51% Cu, 19 ppm Th, 600 ppm Pb, 300 ppm Zn, and 0.54 oz/ton (19 ppm) Ag (McLemore and North, 1984). From 1956 through 1966, 27,116 lbs of $U_3O_8$ were produced from La Bajada mine from ore with an average grade of 0.14% $U_3O_8$. In 1928 and 1929, 5,345 lbs of copper and 52 oz of silver were also produced (Lustig, 1958; McLemore and North, 1984).

#### Collapse-breccia-pipe and clastic-plug uranium deposits

Collapse-breccia pipes and clastic plugs are grouped together in this report (Table 2: collapse-breccia pipe). Uraniferous collapse-breccia pipes in the Grants uranium district (#1, #4) are vertical or steeply dipping cylindrical features bounded by ring fractures and filled with a heterogeneous uraniferous mixture of brecciated wallrocks. The pipes are not associated with any volcanic rocks, although a volcanic origin was previously proposed (Wylie, 1963). The pipes were probably formed by solution collapse of underlying limestone or evaporites or both (Hilpert and Moench, 1960; McLemore, 1983a; Wenrich, 1985). Clastic plugs in the Black Mesa area in northeastern New Mexico (#78) also have circular brecciated features. Similarities with the collapse-breccia pipes in the Grants uranium district and in northwestern Arizona suggest an analogous solution-collapse origin for the plugs (McLemore and North, 1987). Upward intrusion of underlying sandstone has also been suggested as having formed the plugs (Parker, 1933).

Mineralized collapse-breccia pipes in northwestern Arizona are currently being developed and mined where average production grades of 0.5–0.7% $U_3O_8$ are common. Production from the Woodrow pipe in the Laguna subdistrict (#1) in New Mexico amounted to 134,014 lbs of $U_3O_8$ from ore with an average grade of 1.26% $U_3O_8$ (McLemore, 1983a). Minerals from the Woodrow pipe include uraninite, coffinite, secondary uranium minerals, chalcopyrite, galena, and barite. Pyrite and marcasite are common (Wylie, 1963). Anomalous amounts of silver, cobalt, copper, iron, nickel, lead, sulfur, and arsenic from the Woodrow pipe are also reported (Hilpert, 1969).

More than 600 collapse-breccia pipes are known in the Laguna and Ambrosia Lake subdistricts (#1, #4) in the Grants uranium district (Moench amd Schlee, 1967; Nash, 1968: p. 739; Hilpert, 1969), but only a few contain anomalous uranium. These collapse-breccia pipes range from 5 to 200 ft in diameter and are up to 360 ft or more in height, although the depths of the collapse-breccia pipes have not yet been penetrated (Megrue and Kerr, 1965). The Woodrow pipe is 24–34 ft in diameter and has a vertical extent of at least 360 ft (Wylie, 1963). In northwestern Arizona, collapse-breccia pipes tend to be larger; the Orphan Lode pipe is 150–500 ft in diameter and has a vertical length of at least 1,500 ft (Gornitz and Kerr, 1970; Chenoweth, 1986).

Several other collapse-breccia pipes in the Jackpile-Paguate mine in the Laguna subdistrict (#1) and the Cliffside and Doris mines in the Ambrosia Lake subdistrict (#4) yielded uranium when sandstone uranium deposits were mined. The size and grade of these collapse-breccia-pipe uranium deposits are unknown (Clark and Havenstrite, 1963; Granger and Santos, 1963; Hilpert, 1969).

More than 120 circular brecciated features known as clastic plugs (Table 2: collapse-breccia pipe) are located in the Black Mesa area (#78) in northeastern Union County and adjacent parts of southeastern Colorado and western Oklahoma (Parker, 1933; Baldwin and Muehlberger, 1959; Reynolds, 1979; Fay, 1983), but only a few are mineralized with copper, silver, iron, and locally uranium at the surface. None of these clastic plugs have been explored at depth. The clastic plugs range in size from 9 to 300 ft in diameter and have a vertical extent of as much as 380 ft (Parker, 1933). Most clastic plugs are capped by limonite and hematite, which often obscure brecciated features.

The potential for uranium deposits in the clastic plugs is uncertain because mineralized zones high in uranium have not been discovered but could lie at depth. Mineralogical and geochemical studies and drilling are required to evaluate the uranium potential of the plugs.

### Epithermal-vein uranium deposits

Many areas in New Mexico are listed in Table 3 as having uraniferous epithermal veins (Table 2: epithermal vein). This subtype as classified in this report includes classic veins, uraniferous fluorite veins, uraniferous opal/chalcedony veins and fracture fillings, and uraniferous sulfide veins.

Several hundred uraniferous epithermal veins occur in the Burro Mountains district (#61). Most of the veins are small and rarely exceed 500 ft in length. None of the veins has been explored to depths exceeding 206 ft. The age of mineralization is uncertain, but field relations tend to indicate a Tertiary age (Gillerman, 1968). The source of the uranium is unknown. The area is considered favorable for uranium deposits; however, additional drilling and geochemical studies will be required to adequately assess the potential.

Elsewhere in New Mexico, most epithermal-vein uranium deposits are thin (less than one foot wide) and discontinuous and have sporadically distributed uranium minerals. Some select samples contained significant concentrations of uranium and thorium (Table 3), but rarely in quantities sufficient to favor development.

## Igneous and metamorphic rocks with disseminated uranium deposits

More than 100 uranium occurrences are hosted by igneous and metamorphic rocks in New Mexico; a few have yielded minor ore production (Table 4). Uranium occurs in pegmatites, alkalic rocks, granitic rocks, carbonatite dikes, and other miscellaneous rocks (diatremes, contact-metasomatic, volcanogenic). Disseminated uranium deposits in igneous and metamorphic host rocks are therefore subdivided into five subtypes (Table 2): (1) pegmatite, (2) alkalic rock, (3) granitic rock, (4) carbonatite, and (5) miscellaneous.

### Pegmatite uranium deposits

Pegmatites are coarse-grained granitic dikes, lenses, or veins and represent the last and most hydrous portion of a magma (Table 2: pegmatite). They occasionally contain uranium and thorium minerals, but are poor mining targets because uranium and thorium minerals are dispersed throughout them (Gabelman, 1977: pp. 89–90; Adams et al., 1980). Only two pegmatites in New Mexico have yielded minor uranium production (Table 4): Sparks Stone in the El Porvenir area (#35) and Pineapple No. 1 in the Petaca district (#30). At least 77 pegmatites in New Mexico contain uranium and thorium minerals; select samples ranged as high as 0.13% $U_3O_8$ (Nambe, Petaca district, #30) and 10,332 ppm Th (Globe, Petaca district, #30; McLemore, 1983a). New Mexico pegmatites, however, will probably not constitute a major source of uranium or thorium unless expensive hand-sorting techniques are used.

### Alkalic-rock uranium deposits

Alkalic rocks throughout the world are known for their anomalously high concentrations of uranium, thorium, rare-earth elements, niobium, beryllium, and zirconium (Table 2: alkalic rock); a few contain economic uranium deposits (Nash et al., 1981). Host rocks include alaskites, syenites, and peralkaline granite. Uranium and thorium minerals are disseminated throughout the host rock or occur in veins.

In New Mexico, several areas have potential for disseminated magmatic uranium deposits in alkalic rocks (#13, #42, #43, #56, #71), although there may be more potential for thorium than uranium. More detailed geologic mapping and petrologic and geochemical studies in these areas will be required to properly characterize and assess the uranium and thorium potential.

### Granitic-rock uranium deposits

Granitic rocks tend to contain uranium (Table 2: granitic rock), but no economic uranium deposits of magmatic origin are known in granites in New Mexico (Nash et al., 1981). The Vermejo Park area in northern Taos County (#31), however, contains uranium anomalies in stream-sediment samples, pegmatites, and soil samples. These uranium anomalies suggest uranium may be disseminated in Precambrian granite or in epithermal veins (Goodknight and Dexter, 1984b, Reid et al., 1980). More geochemical and geologic work will be needed to characterize the uranium occurrences in this area.

### Carbonatite uranium deposits

Carbonatites are carbonate-rich rocks of apparent magmatic derivation and typically contain uranium and thorium minerals (Table 2: carbonatite). Uranium has been produced from the Palabora carbonatite in South Africa. Uranium has been produced as a by-product of mining copper from this carbonatite at the rate of 300–400 tons of $U_3O_8$ per year. Uranium reserves are estimated at 10,000 tons of ore with an average grade of 0.004% $U_3O_8$ (Nishimori and Powell, 1980).

In New Mexico, carbonatites occur as dikes and associated veins and stockworks in five areas: Lemitar and Chupadera Mountains (#48, #49), Lobo Hill (#42), Laughlin Peak (#80), and the Monte Largo area in Bernalillo County (Lambert, 1961; Kelley and Northrop, 1975; McLemore, 1983c). The Monte Largo carbonatite is not significantly radioactive and is not included in Table 3 nor on the Map. Uranium and thorium concentrations in other carbonatites are sporadic and rarely exceed 0.01% $U_3O_8$ and 100 ppm Th, although uranium concentrations up to 0.25% $U_3O_8$ are found in some carbonatites in the Lemitar Mountains (McLemore, 1982b). The dikes are only 3–5 ft wide and up to 1,500 ft long; larger deposits may occur at depth. Uranium can be produced only as a by-product of production of thorium or rare-earth elements (McLemore et al., 1988).

### Miscellaneous uranium deposits

Minor uranium occurrences are associated with igneous and metamorphic rocks throughout New Mexico (McLemore, 1983a) and are classed as miscellaneous types of uranium deposits (Table 2: miscellaneous). Locally, diatremes in the Shiprock uranium district (#9, #10) contain uranium minerals. Uranium is occasionally found in volcanogenic deposits near Tertiary calderas, such as the Nogal Canyon caldera in Socorro and Sierra Counties (Map). Some porphyry copper deposits in southwest New Mexico contain anomalous amounts of uranium, but not enough to recover as a by-product.

At the Napane mine in the Fremont district (#68) a contact-metasomatic uranium deposit (i.e. skarn) yielded some production (Table 4). This area may have potential for additional contact-metasomatic uranium deposits.

The Precambrian and Tertiary terranes in New Mexico have not been adequately examined for potential disseminated magmatic, pegmatitic, and contact-metasomatic uranium deposits. Unconformity-type uranium deposits similar to those being mined in Canada and Australia (Nash et al., 1981) may occur in some Precambrian terranes in New Mexico (McLemore, 1982a). Detailed geologic mapping and geochemical studies in these areas will be needed to properly assess the uranium potential.

## Uranium resource potential

The U.S. Department of Energy (DOE) released their latest evaluation of uranium resources in the United States in 1980 (U.S. Department of Energy, 1980). The DOE has not updated this 1980 assessment. A discussion of the DOE (1980) assessment of uranium resources in New Mexico was presented by McLemore (1981), and areas favorable for uranium resource potential as assessed by the DOE (1980) are shown in Fig. 1. Fig. 2 shows favorable areas of uranium potential resources in New Mexico based on the DOE (1980) assessment, but revised by the authors. The additions and changed in Fig. 2 are based on recent trends in the uranium industry and newly acquired data presented in Table 3 and shown on the Map. The authors are not able to revise the resource and endowment figures for each area as presented by the DOE (1980; see also McLemore, 1981) because much of the information required for calculating resource and endowment figures is confidential and not available.

The DOE classifies reasonably assured resources (RAR) into forward-cost categories of $30, $50, and $100 per lb. Forward costs are operating and capital costs (in current dollars) that are still to be incurred to produce uranium from estimated resources. Previous expenditures (before the time of resource estimation) for such items as property acquisition, exploration, mine development, and mill construction are excluded from forward-cost determination. Income taxes, profit, and cost of money are also excluded. Thus, forward costs are generally lower than the market prices required to make production and sale of uranium economical for the producer. Hence, a market price of about $45 per lb for uranium is necessary to make production and sale of RAR viable at $30 per lb.

Clearly the highest resource potential for economic uranium deposits is in sandstone uranium deposits in the Morrison Formation (Jurassic) in the Grants uranium district (Figs. 1, 2; #1–8). Most of the economic reserves and RAR are in the Grants uranium district (Table 5). Many mineralized trends in the Grants uranium district may be more extensive, especially in areas where land acquisition has been a problem that resulted in little or no exploratory drilling (i.e. Church Rock–Crownpoint, Nose Rock, Bernabe Montaño; McLemore and Chenoweth, 1988). Additional undiscovered trends may also occur. Although not all the ground is mineralized, the entire area where the Morrison Formation occurs, except at depths below the 5,000-ft-depth contour at the top of the Morrison (Map), is favorable for sandstone uranium deposits. Other areas with excellent potential for sandstone uranium deposits in the Morrison Formation include the area located south of the Carrizo Mountains (#9; deposits in the Salt Wash Member in the King Tutt Mesa area) and Tocito Dome (#11; deposits in the Westwater Canyon Member). Some areas in northeastern New Mexico may also have potential for uranium deposits in the Morrison Formation; however, present data suggest that deposits in these areas are low grade and small.

Uranium deposits probably occur at depth in the Todilto Limestone Member of the Wanakah Formation (Jurassic) in the Grants uranium district (#1, #4, #5), but because of their small size and sporadic distribution, they are difficult to locate and mine and may not be economic. Additional deposits probably occur along faults in the Dakota Sandstone (Cretaceous) in the Gallup area (#6). Potential low-grade sandstone uranium deposits may occur in the Burro Canyon Formation (Cretaceous) in the Chama Basin, Abiqui area (#16) and in the Ojo Alamo Sandstone (Tertiary) in the Mesa Portales area (#21).

Outside of the San Juan Basin in the Colorado Plateau, the potential for medium- to high-grade, large-tonnage uranium deposits are not as good (Fig. 2). Sandstone uranium deposits have been found in the Galisteo Formation (Tertiary), Hagan Basin (#39; Fig. 2), but the deposits are medium in size and low in grade (about 900,000 lbs of $U_3O_8$ at an average grade of 0.09%; Moore, 1979). Small and low-grade sandstone uranium deposits (<50,000 lbs of $U_3O_8$; Holen and Hatchell, 1986) also occur in the Crevasse Canyon Formation (Cretaceous) and the Baca Formation (Eocene) in the Hook Ranch–Riley and Red Basin–Pietown areas (#50, #51; Fig. 2). The DOE (1980) considered sandstone uranium deposits in the Chinle Formation (Triassic) and Sangre de Cristo Formation (Pennsylvanian-Permian) in eastern New Mexico and in the Chinle Formation in west-central New Mexico as speculative potential resources (Fig. 1). Because of their low grade, small size, and sporadic distribution, these sandstone uranium deposits are probably difficult to locate and mine and may not be economic and, therefore, are not shown in Fig. 2.

Three additional areas in New Mexico were considered by the DOE (1980) as containing speculative potential resources (Fig. 1), but are not included in Fig. 2. The Nogal Canyon caldera in Socorro and Sierra Counties was thought to be favorable for volcanogenic uranium deposits (Map; Berry et al., 1982). Available data, however, does not support the presence of economic uranium deposits there and the area has been dropped from consideration by the DOE (J. Olsen, DOE, Albuquerque Field Office, oral communication 1981). A small area in the Caballo Mountains was also identified by the DOE (1980) as having speculative potential resources, but the DOE did not include an assessment report on the area. Minor uranium occurrences are found in Precambrian rocks and in the Abo Formation (Permian), Mesaverde Formation (Upper Cretaceous), and McRae Formation (Cretaceous-Tertiary; Templain and Dotterer, 1978), but none of these occurrences constitutes a significant uranium resource (McLemore, 1981).

Speculative uranium potential resources were thought to

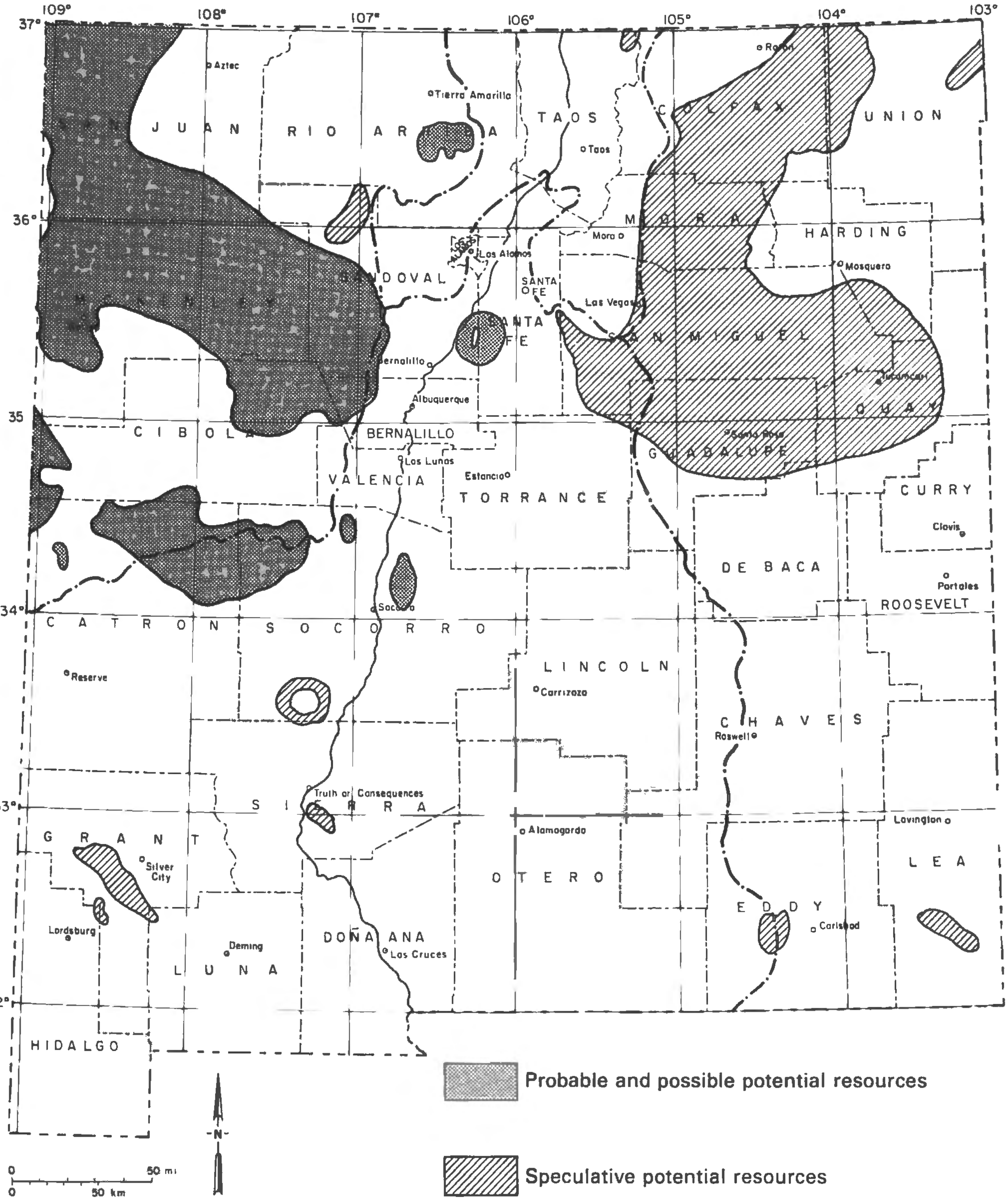

FIGURE 1—Uranium potential in New Mexico according to the U.S. Department of Energy (1980).

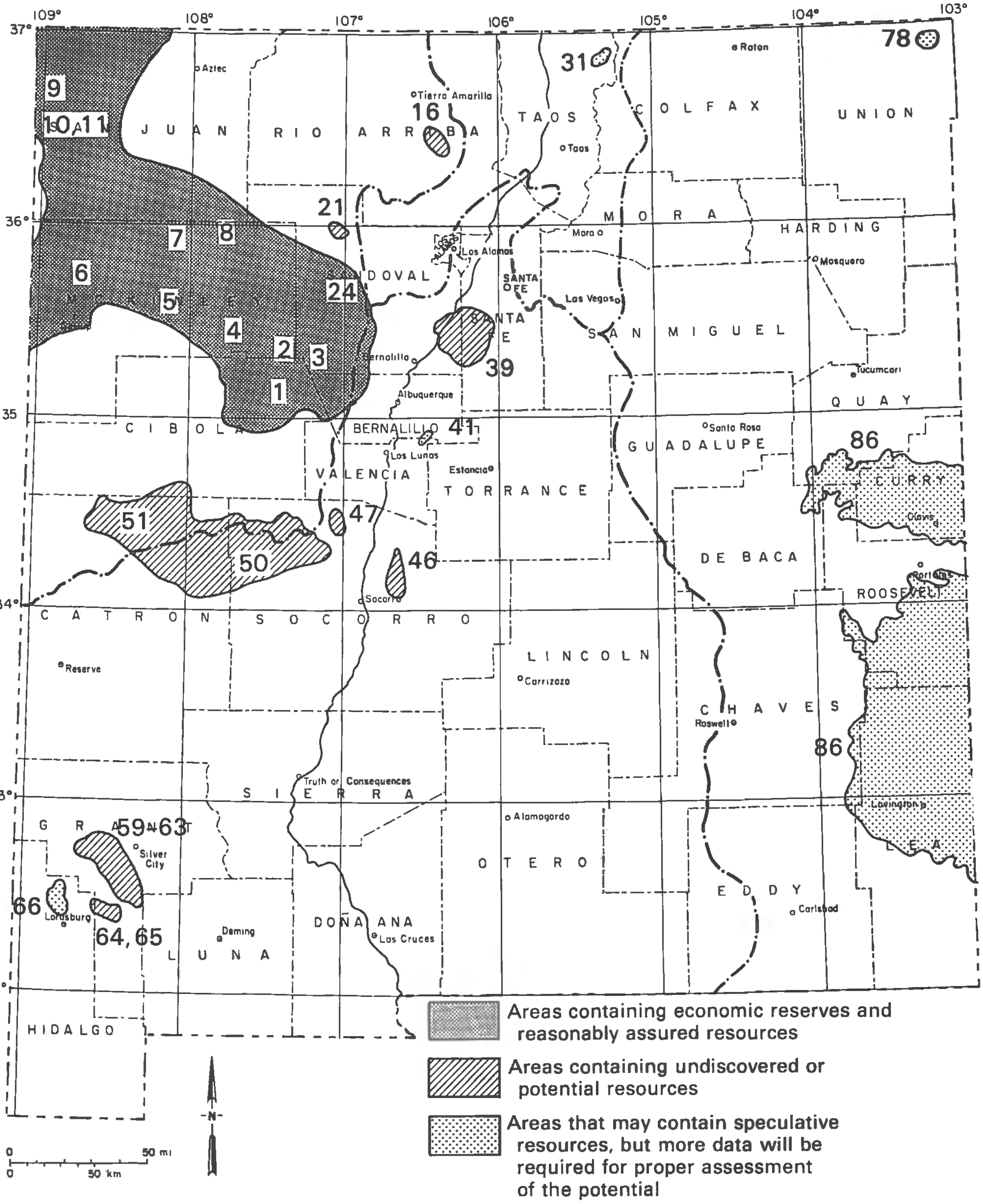

FIGURE 2—Uranium potential in New Mexico in 1988 (portions modified from U.S. Department of Energy, 1980). Location numbers refer to Table 3 and Map. The international terminology for the classification of uranium resources, recently adopted by the DOE, is used in this figure (Energy Information Administration, 1988).

**TABLE 5**—Economic reserves and reasonably assured resources (RAR) by state as of December, 31, 1987 (Energy Information Administration, 1988). The U.S. Department of Energy (DOE) has adopted the International Atomic Energy Agency (IAEA) terminology. [1] It is the authors' opinion that these figures are too low, possibly not including the Mount Taylor mine. [2] Economic reserves included with others. Note: totals do not equal sum of components because of independent rounding.

| | Discovered resources | | | | | |
|---|---|---|---|---|---|---|
| | Economic reserves | | | Reasonably assured resources (RAR) Forward-cost categories | | |
| | Quantity (thousand tons of ore) | Grade (% $U_3O_8$) | Quantity (million lbs $U_3O_8$) | \$30/lb (million lbs $U_3O_8$) | \$50/lb (million lbs $U_3O_8$) | \$100/lb (million lbs $U_3O_8$) |
| New Mexico[1] | 30,500 | 0.145 | 88.2 | 178 | 450 | 679 |
| Wyoming | 76,330 | 0.129 | 197.4 | 70 | 350 | 610 |
| Texas | 17,005 | 0.089 | 30.1 | 13 | 36 | 64 |
| Arizona, Colorado, Utah[2] | — | — | — | 21 | 105 | 146 |
| Others | 8,353 | 0.315 | 52.7 | 22 | 64 | 93 |
| U.S. TOTAL: | 131,188 | 0.139 | 368.5 | 304 | 1,005 | 1,592 |
| Reserves/RAR in New Mexico per U.S. total (%) | — | — | 24 | 59 | 45 | 43 |

occur in limestone in the Yates Formation (Permian) in the Carlsbad area (Fig. 1). Small and low-grade uranium deposits occur in limestone and sandstone of the Yates, Seven Rivers, and Queen Formations (#87), but not in sufficient quantities to be economic.

Collapse-breccia-pipe uranium deposits, similar to the Woodrow deposit near Laguna (#1) and others in northern Arizona, may occur in the Grants uranium district and northeastern New Mexico (#78), but their economic potential is unknown. Fracture-controlled, supergene(?) uranium deposits may occur in the Ladron Mountains and Socorro areas (#47, #46) and may have potential for medium- to high-grade, medium- to low-tonnage deposits (Pierson et al., 1982).

Surficial uranium deposits similar to calcrete uranium deposits in Australia and Namibia may occur in southwestern and southeastern New Mexico. Geochemical, geophysical, and alteration patterns suggest such calcrete uranium deposits may occur near Lordsburg (#66; Fig. 2; Raines et al., 1985). Calcrete uranium deposits may also occur in the Ogallala Formation (Tertiary) in southeastern New Mexico (#86; Fig. 2; Otton, 1984). More data are required to properly assess these areas.

Vein-type uranium deposits occur in Precambrian rocks in the Burro Mountains and additional deposits may be present in the area (#59–65; Fig. 2). Other areas with Precambrian rocks, such as the Vermejo Park area (Costilla massif; #31) and Manzano Mountains–Manzanitas Mountains (#41), may contain vein-type or even Proterozoic unconformity-type uranium deposits.

New Mexico has significant uranium reserves and resources, especially in the Grants uranium district. Compared to Proterozoic unconformity-type uranium deposits in Canada and Australia, however, the uranium deposits in New Mexico are lower in grade and deeper. Future development of uranium resources in New Mexico will depend upon (1) an increase in price for uranium, (2) the lowering of production costs of uranium in New Mexico, perhaps by including the use of in-situ leaching techniques (Holen and Hatchell, 1986), (3) discovery of higher grade deposits or a raise in the mining-grade cutoff, and (4) assistance to potential mining companies with the complexities of processing the permits and licenses and applying the environmental regulations that are required to mine uranium in the state.

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