Uranium Resources of Northwestern New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 603

Prepared on behalf of the
U.S. Atomic Energy Commission

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Uranium Resources of Northwestern New Mexico

By LOWELL S. HILPERT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 603

Prepared on behalf of the
U.S. Atomic Energy Commission

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

A description of the stratigraphic and structural relations of the various types of uranium deposits in one of the world's great uranium-producing regions

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, ***Director***

Library of Congress catalog-card No. GS 68-390

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

Stratigraphy—Continued
  Rocks of Jurassic age—Continued
    Morrison Formation—Continued

Uranium deposits—Continued
- Peneconcordant deposits in sandstone—Continued
  - Morrison Formation—Continued
    - Laguna district—Continued

Distribution of elements in the ores—Continued
- Exceptional characteristics of some ore sample groups—Continued

ILLUSTRATIONS

[Plates 1-4 are in pocket]

TABLES

URANIUM RESOURCES OF NORTHWESTERN NEW MEXICO

By Lowell S. Hilpert

ABSTRACT

Uranium deposits in northwestern New Mexico occur in about 30 formational units that range in age from Precambrian to Quaternary. The most economically important deposits are peneconcordant and occur in sandstone, limestone, shale, and coal. Less economically important vein deposits occur in metamorphic, igneous, and miscellaneous sedimentary rocks. Of the peneconcordant deposits, the most economically important ones occur in sandstone in the Morrison Formation; others occur in limestone beds of the Todilto Limestone and in sandstone beds of the Dakota Sandstone.

From 1950 to 1964, northwestern New Mexico yielded more than 23 million tons of uranium ore, which averaged 0.22 percent U_3O_8 and had an average U : V ratio of about 2 : 1. In the Shiprock district, about 30,000 tons of vanadiferous ores averaged 2.55 percent V_2O_5.

About two-thirds of the uranium output was from the Ambrosia Lake district and nearly a third was from the Laguna district. Production reached a peak of 3.7 million tons in 1960, after which it declined to about 2.1 million tons in 1964. During the 1956–64 period, production was 42 percent of the national output. More than 95 percent of the ore came from sandstone, 4 percent come from limestone, and less than 1 percent came from carbonaceous shale, coal, and igneous rocks. More than 99 percent of the output was from rocks of Jurassic age; the remainder came from rocks that range in age from Pennsylvanian to Tertiary.

As of January 1966, mine reserves totaled 29.7 million tons of material that averaged 0.23 percent U_3O_8. About 60 percent of these reserves was in the Ambrosia Lake district, in the Morrison Formation. In addition, resources largely in the periphery of the mine reserves in the district probably total as much as several million tons of material that would average about 0.1 percent U_3O_8.

Undiscovered or potential reserves probably are several times the combined production and mine reserves estimated as of January 1966 and may amount to as much as 200 million tons of material, expected to average about 0.25 percent U_3O_8. These resources are expected to be almost entirely peneconcordant deposits, principally in large ones in sandstone lenses in the Morrison Formation, but important deposits also are anticipated in sandstone lenses in the Dakota Sandstone and in limestone beds in the Todilto Limestone. Most of these resources probably are concentrated in the southern San Juan mineral belt, now generally referred to as the Grants mineral belt. This is a geologically favorable area that is roughly 25 miles wide and about 100 miles long, extending from the Rio Grande trough westward across the south end of the San Juan Basin to near the Arizona line. Some important resources also are anticipated in the Chuska and Shiprock districts in the Morrison Formation; most of the rest probably are scattered in various formations of late Paleozoic, Mesozoic, and Tertiary ages. The resources will lie from near outcrop to several thousand feet below the surface.

Principal controls of the peneconcordant deposits were the original sedimentary basins of the host rocks, structural troughs or depressions along basin margins, and a variety of smaller scale sedimentary and tectonic structural features. Intraformational flowage structures were important controls in limestone and were minor controls in sandstone. Faults and other fractures exerted only local control on the primary deposits, but they greatly influenced the disposition of the secondary or oxidized deposits.

Structural and stratigraphic data indicate that the peneconcordant deposits were emplaced shortly after deposition of the host rocks and were localized principally along the margins of sedimentary basins. The most likely age of deposition of the deposits in the Todilto Limestone and Morrison Formation was Late Jurassic and in the Dakota Sandstone was Cretaceous.

Structural data and general age relations of the deposits indicate that the source of the uranium was the adjacent highland areas and the host rocks. Uranium probably was leached from these rocks, carried basinward in dilute solutions through unconsolidated sediments, and precipitated by the reduction of carbonaceous debris and by other unknown means. No evidence is convincing that magmatic fluids played any significant part in the emplacement of the peneconcordant deposits.

INTRODUCTION

PURPOSE AND SCOPE OF THIS REPORT

This report is an appraisal of the uranium resources of northwestern New Mexico and is one of a series of similar reports planned to appraise the uranium resources of the Colorado Plateau. The general geography, history of uranium mining, general geology, and uranium occurrences are discussed, the mineralogy and habits of the known deposits in the various districts and areas are described, and the relations of the deposits to the stratigraphy, structure, and geologic environment are reviewed. The uranium resources are appraised as to rock types and geologic environment, formations, and areas.

GEOGRAPHY

Northwestern New Mexico here is considered to be west of long 10° and north of lat 34°; it encompasses an area of about 35,000 square miles—roughly a third of the State (fig. 1). The area includes parts of three physiographic provinces. The western two-thirds is in the Colorado Plateaus province, and the eastern one-third is in the Southern Rocky Mountains province on the north and in the Basin and Range province on the south (Fenneman, 1931). The part in the Colorado Plateaus province is in the Navajo section (Fenneman, 1931) on the north and in the Datil section, also referred to as the Datil volcanic field, on the south. The dominant feature of the Navajo section is the San Juan Basin, which is a broad topographic basinlike depression characterized by broad open valleys and mesas and local deeply incised drainage features. The basin is flanked on the west by the Chuska Mountains, on the south by the Zuni Mountains, and on the east by the ranges of the Southern Rocky Mountains province. The Datil section constitutes the southeastern part of the Colorado Plateau and is characterized by lava plains, lava-capped mesas, and benches; it is dominated locally by the Zuni, Ladron, and Magdalena Mountains and by Mount Taylor. The part of the area in the Southern Rocky Mountains province is marked by the rather broad and fairly well dissected Sierra Nacimiento, by the San Pedro, Jemez, and San Juan, Mountains, and the part in the Basin and Range province by the broad valley of the Rio Grande and the northward-trending ranges, principally the Manzano and Sandia Mountains, that lie along the east margin of that valley.

The altitude of the area generally ranges from about 5,000 to 8,000 feet above sea level and the mountain crests from 8,000 to 11,000 feet above sea level. The climate is mostly semiarid, the annual precipitation ranging from 5 to 15 inches per year and averaging about 10 inches per year. The summers are generally hot, the winters moderately cold, and the mean yearly temperature ranges from about 45° to about 60°F for different parts of the area. Vegetation is sparse, and consists mostly of desert shrub species, mainly sage and juniper in the lower altitudes, and forests of pine, fir, and spruce in the higher altitudes.

Drainage is mostly confined to two basins separated by the Continental Divide, which trends northeastward through the approximate center of the area. In the western basin the drainage mostly flows into the San Juan River, and thence westward to the Colorado River in southern Utah. In the eastern basin, the drainage flows into the Rio Grande and thence southward into the Gulf of Mexico. A small area south of the Chuska Mountains and west of the Continental Divide drains westward into Arizona and into the Little Colorado River. Water is scarce except along the principal streams and in the higher parts of the mountains.

PREVIOUS INVESTIGATIONS

Northwestern New Mexico has received much attention from geologists, dating from preterritorial time (Wislizenus, 1848). During territorial time the area was visited and mapped between the years 1850 and 1880 by several of the so-called military, railroad, and territorial surveys (Simpson, 1850; Blake, 1856; Marcou, 1856, 1858; Newberry, 1861, 1876; Howell, 1875; Gilbert, 1875; Holmes, 1877; Stevenson, 1881). Since 1880, geologic work has been extensive and varied, and the reader is referred to Lindgren, Graton, and Gordon (1910), Darton (1910, 1928), Reeside (1924), Baker, Dane, and Reeside (1936), Hunt (1938, 1956), and Stearns (1953) for general bibliographic information. Other references, where pertinent, are cited in the text.

Uranium investigations in northwestern New Mexico started in the Shiprock district, San Juan County, and the area was mapped and studied by D. C. Duncan and W. L. Stokes in October and November 1942 and by Stokes and G. M. Sowers in April 1945 (Stokes, 1951). In 1948, the U.S. Atomic Energy Commission and the U.S. Geological Survey started extensive geological investigations and completed some exploration of the uranium-bearing formations to appraise the uranium resources of the Colorado Plateau. The results of some of this work have been published, other reports are forthcoming, and some work is yet in progress, particularly in the Ambrosia Lake district.

SOURCES OF DATA AND METHODS OF STUDY

Information used in this report is from records of uranium ore production and uranium reserves obtained from the Grand Junction Operations Office, Division of Raw Materials, U.S. Atomic Energy Commission; from data contained in many published reports and in the files of the U.S. Atomic Energy Commission and U.S. Geological Survey; from data obtained from many individuals and companies in the mining industry; and from data obtained by the observations of the author and his colleagues. Fieldwork was done mostly during the summers of 1954–56, and periodic field visits were made during the summers of 1957–58. The fieldwork was largely reconnaissance, but most of the more important deposits were examined and some were selectively mapped to determine their habits and geologic relations. In the more economically important districts, drilling records of literally thousands of

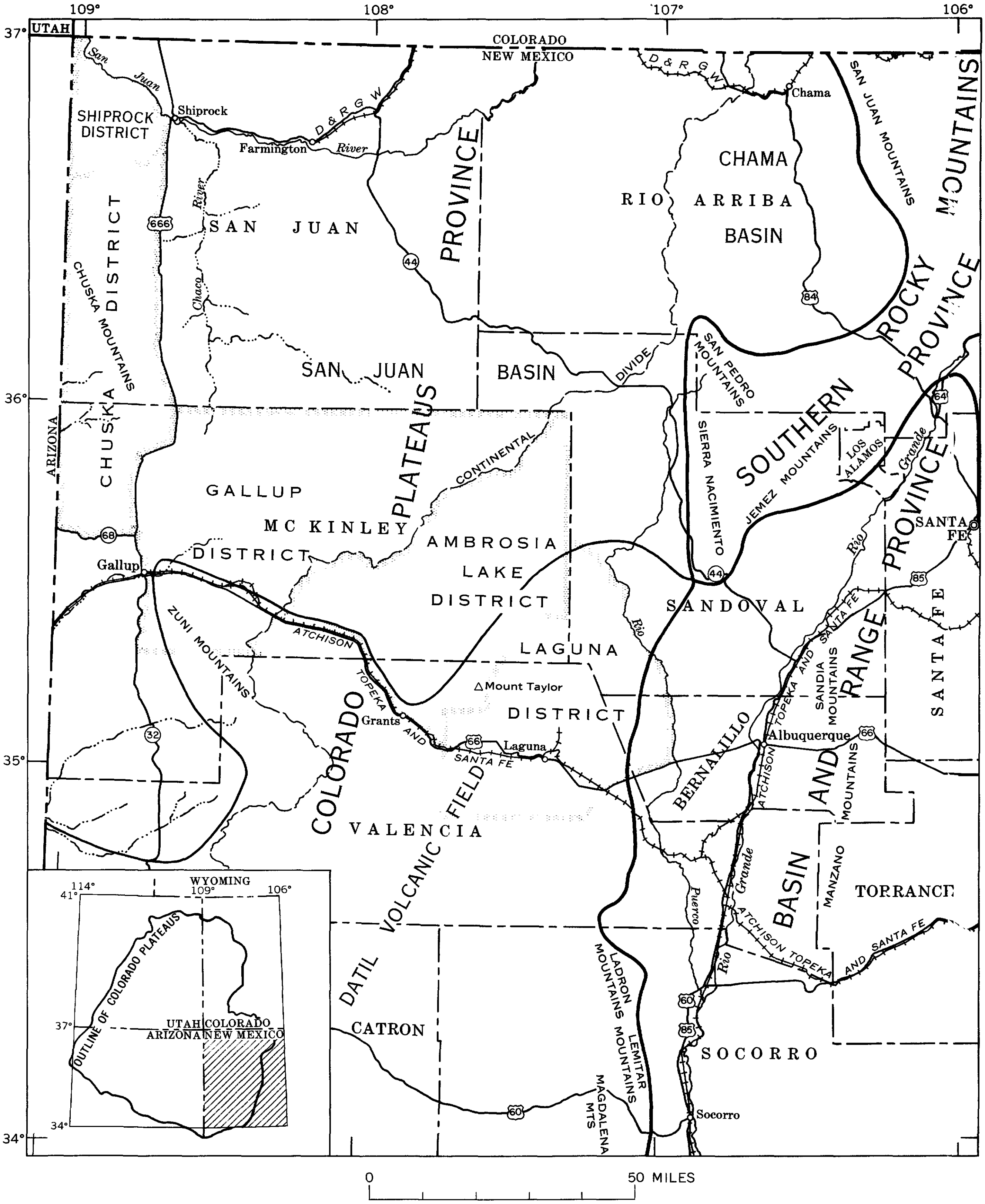


FIGURE 1.—Northwestern New Mexico.

holes were utilized for geologic information on the stratigraphic and structural relations of the deposits, and in some critical areas, stratigraphic sections were measured. During the 1955–56 field season and to some extent in 1957–58, the work was concentrated largely on abstracting the drilling records of the exploration companies in the Ambrosia Lake district.

Most of the data in this report are based on work done prior to 1959. Delay in completion of the report, however, made it desirable to update the mine production data to the end of 1964 and to locate and describe the pertinent features of deposits found after 1958. This information is shown on the illustrations as well as in the text. The text has been revised to benefit from the geologic literature published from 1959 to 1962.

GEOLOGIC NOMENCLATURE

Since this report was prepared, the age of the Ojo Alamo Sandstone has been changed from Late Cretaceous to Paleocene (Balz and others, 1966); the age of the Blanco Basin Formation has been changed from Oligocene(?) to Eocene (Steven and others, 1967); and the Potosi Volcanic Series has been changed to Potosi Volcanic Group, the name being used only near the type area in Colorado (Luedke and Burbank, 1963).

ACKNOWLEDGMENTS

It is not possible to give complete credit to the many companies and individuals whose interest and contributions make a synthesis of this type possible, and failure to acknowledge any assistance given is through oversight rather than through intent. I am especially grateful to the staffs and individuals in the following companies who were so generous in granting access to their records and properties:

American Metals Co., Ltd.
Anderson Development Co.
Calumet Hecla, Inc.
Colamer Corp.
E. J. Longyear Co.
Flat Top Mining Co.
Food Machinery & Chemical Corp. (Westvaco)
Four Corners Exploration Co.
Four Corners Uranium Corp.
Hanosh Mines, Inc.
Haystack Mountain and Development Co. (Santa Fe Railway)
Holly Minerals Corp.
Homestake Mining Co.
Homestake-Sapin Partners
Humble Oil & Refining Co.
Kermac Nuclear Fuels Corp.
Kerr-McGee Oil Industries, Inc.
L-Bar Cattle Co.
Mid-Continent Exploration Co.
Mid-Continent Uranium Corp.
National Lead Co.
New Jersey Zinc Co.
New Mexico & Arizona Land Co.
Pacific Uranium Mines Co.
Phillips Petroleum Co.
Rare Metals Corp. of America
Rimrock Mining Co.
Rio de Oro Uranium Mines, Inc.
Sabre-Pinon Corp.
Sabre Uranium Corp.
San Jacinto Petroleum Corp.
See Tee Mining Co.
The Anaconda Co.
Tidewater Oil Co.
United Nuclear Corp.
United Western Minerals Co.

Special thanks are also given the following individuals, who through their interest or involvement in the work contributed much of their time and assistance:

L. J. Reynolds and Ross Martinez, of Associated Uranium Producers; O. E. Manol and I. J. Rapaport, of Four Corners Exploration Co.; T. O. Evans, of Haystack Mountain and Development Co. (Santa Fe Railway); Paul Melancon, of Holly Minerals Corp.; E. E. Jones, of Kerr-McGee Oil Industries, Inc.; C. N. Holmes, of Phillips Petroleum Co.; J. W. Knaebel and R. D. Lynn, of The Anaconda Co.; and E. G. Robinson and Helge Laursen, of Tidewater Oil Co.

Thanks are also extended to the following individuals for their courtesy in contributing geologic information and (or) granting access to their properties:

Richard Bokum; E. P. Chapman, Jr., and J. A. Wood, of Chapman and Wood; Henry Elkins; Thomas Hyde; Malcolm Larson; Howard Major; Robert Sayre; and J. Q. St. Clair. Thanks are also extended to the Council of the Ácoma Pueblo for granting access to the Ácoma Reservation.

V. L. Freeman assisted in the work from July 1954 to June 1955, and A. F. Corey assisted from July 1955 to April 1958. H. C. Granger provided much assistance in his technical review of the manuscript. To these individuals and my other colleagues in the U.S. Geological Survey, I wish to express my appreciation for the assistance given. Special thanks are also due the many individuals on the staff of the U.S. Atomic Energy Commission, Grand Junction Operations Office, for their generous assistance. The work was done by the U.S. Geological Survey on behalf of the Division of Raw Materials, U.S. Atomic Energy Commission.

HISTORY OF MINING AND ORE PRODUCTION

Uranium minerals have been known in northwestern New Mexico for many years, but were little more than curiosities until carnotite deposits were discovered west of Shiprock in 1918. Little ore was produced from these deposits until the 1942–44 period, when several thousand tons was mined for vanadium content. In 1948, prospecting was stimulated by the U.S. Atomic Energy Commission's ore-buying schedule announced in Circulars 1 and 2 and, subsequently, by additional incentives.[1] New deposits were found in the Shiprock area and west of Sanostee, San Juan County. Discoveries of these deposits were followed by those near Grants and Laguna, in McKinley and Valencia Counties, respectively (pl. 1). Exploration for uranium in northwestern New Mexico, however, received little stimulus until the discovery of uranium in limestone in 1950 and the discovery of large uranium deposits in sandstone in 1955. Earlier discoveries were considered unimportant and were largely forgotten (Smith, 1954; Kelley, 1963). A résumé of the 1950 and 1955 discoveries and closely related events is of interest because of the effects they had on subsequent developments and the importance of these developments to the uranium industry of the United States.

In the early spring of 1950, Paddy Martinez, a Navajo Indian, found yellow coatings on the Todilto Limestone outcrop in sec. 19, T. 13 N., R. 10 W., McKinley County. He subsequently learned that the discovery site was on Santa Fe Railway Co. property, and brought the matter to the attention of T.O. Evans, a Santa Fe Railway mining engineer. Evans examined the site on September 20, and thereafter recommended an exploratory drilling program which was initiated on November 15, 1950 (T.O. Evans, written commun., 1959). The exploration shortly resulted in the development of an important ore body, later worked as the Haystack mine, which at the end of 1958 had yielded more ore than any other deposit in the Todilto Limestone. The discovery of the Haystack deposit stimulated prospecting in the region, and led to the discovery of many other deposits in the Todilto Limestone and in sandstone along the outcrop of the Morrison Formation.

The first significant discovery of uranium in sandstone in the general area was made a few miles north of Grants at Poison Canyon on the outcrop of the Morrison Formation on January 4, 1951, by T.O. Evans. This deposit was later identified by the name Poison Canyon mine.

Two later discoveries in the Morrison Formation were of outstanding significance, the Jackpile deposit near Laguna, Valencia County, and the Dysart deposit near Ambrosia Lake, McKinley County. The Jackpile deposit was discovered on November 8, 1951, from a radioactive anomaly picked up by an Anaconda Copper Mining Co. plane in which Dale Terry was the observer and Woodrow House the pilot. The anomaly was confirmed the same day by a ground check made by Terry, and the following day, House and Terry returned to the site with J.D. "Jack" Knaebel, manager of Anaconda's New Mexico operations. During the examination of the outcrop, Terry referred to the discovery as "Jack's pile," later contracted to Jackpile (R.D. Lynn, oral commun., 1958.)

Discovery of the Jackpile did not have the impact on the industry that other discoveries had, although the Jackpile by 1958 had been developed to become the largest uranium mine in the United States from the standpoint of ore produced, reserves, and magnitude of operations. The lack of impact may seem surprising, because the Jackpile was discovered nearly 8 months before Charles Steen's discovery of the Mi Vida and more than a year before Vernon Pick's discovery of the Delta deposit in southeastern Utah. The Jackpile discovery, however, was made by the employees of a large company and was not publicized; also much time elapsed before development drilling revealed the great size of the deposit.

Discovery of the Dysart deposit, however, had a great and almost immediate effect on the uranium industry, although it was found more than 3 years after the Jackpile. Early in 1955, Louis Lothman reportedly found radioactive cuttings at the site of the M. K. Wadley's Dysart well, drilled in 1952 near the SW. cor. sec. 11, T. 14 N., R. 10 W., McKinley County. Lothman and Ellis Dunn then undertook a joint drilling venture in the ground just north of the Wadley-Dysart well, where the second drill hole penetrated mineralized ground about mid-April 1955. This discovery caught the public's fancy, just as had Steen's and Pick's discoveries, because each resulted from the efforts of an individual prospector. The resulting publicity stimulated intensive exploration in the area and led to the discovery and development of several multimillion-ton deposits. By the end of 1958, a mining and milling industry of national importance flourished in the area.

Five principal uranium mining areas, or districts, in northwestern New Mexico justify description. Two

---

[1] See Atomic Energy Commission Regulations, pt. 60, Domestic Uranium Program Circulars 1 to 6, inclusive, April 9, 1948; June 15, 1948; February 7, 1949; and June 27, 1951.

of these, the Shiprock and Chuska districts, are defined by the boundaries used by the U.S. Atomic Energy Commission, and extend into adjoining parts of Arizona, Utah, and Colorado. The other three, the Gallup, Ambrosia Lake, and Laguna districts, are in the central part of the area and are the most productive parts of the larger Grants mining district as defined by the Commission. The boundaries of these five districts are shown in figure 1.

A relatively small amount of mining for uranium has been done in other metal-mining districts or areas that do not require description.

From 1950 through 1964, more than 23 million tons of ore averaging 0.22 percent U_3O_8 was produced from northwestern New Mexico (table 1). This yield came from about 175 mines and largely from the Ambrosia Lake and Laguna districts (fig. 2). The area was not an important producer of uranium ore until 1956, however, when the Jackpile mine attained large-scale operation. The ore produced by this mine in 1956–57 dwarfed the combined tonnage from all other mines, but in 1958 the Ambrosia Lake district started yielding large tonnages, and in that year northwestern New Mexico yielded about 1.9 million tons of ore—36 percent of the tonnage mined in the United States. The output continued to climb, reaching a peak in 1960 of about 3.7 million tons, after which it declined; yield was about 2.1 million tons in 1964. During the 1956–64 period, however, the output was 42 percent of that of the United States. The decline after 1960 stemmed largely from the saturated market, which resulted in the government's reduction and stretchout of mine quotas and reduction in the price offered for mill concentrates.

The district production is briefly reviewed in table 2 in order of total output. The greatest yield has been from the Ambrosia Lake district. Initial mine output in the district was in 1950, after which it progressively increased, with two minor dips, until it peaked in 1962 with an output of about 2.9 million tons. (See fig. 2.) Through 1964, the district yielded 15.3 million tons of ore, which averaged 0.22 percent U_3O_8 and 0.15 percent V_2O_5 (table 2). This tonnage was 66 percent of the total output of northwestern New Mexico. The ore came from 64 mines, of which 43 were in limestone and 21 were in sandstone. The sandstone ores however, constituted 94 percent of the total output and averaged 0.22 percent U_3O_8, 0.15 percent V_2O_5, and about 5 percent $CaCO_3$, generally referred to in the industry as lime. Through 1964, the output of limestone ores totaled about 939,000 tons, and had the same average grade for uranium and vanadium as the sandstone ores. At least one mine, the Zia, yielded a small mixed tonnage of sandstone-limestone ore.

Mining started in the Laguna district in 1952, and by the end of 1958 the district had produced about 3.3 million tons of ore (fig. 2), which was about 70 percent of the total production in northwestern New Mexico. By the end of 1964, the total output of about 7.3 million tons, which came from nine mines, was about 32 percent of the total for northwestern New Mexico. This ore averaged 0.21 percent U_3O_8 (table 2). Most of it came from the Jackpile mine, and all but about 1,000 tons was ore from sandstone; this ore during the 1952–57 period had an average content of 0.13 percent V_2O_5, and during the 1954–58 period had an average lime content of about 1 percent. Three mines in the district produced ores from limestone; one of the mines, the Sandy, yielded mixed sandstone-limestone ore. The ore from these three mines averaged 0.13 percent U_3O_8; the vanadium content probably was low, but the average content is not known.

Output in the Gallup district started in 1952, and by the end of 1964 totaled about 384,000 tons of ore that averaged 0.22 percent U_3O_8 (table 2). This yield came from 13 mines, of which 10 produced ore from sandstone and 3 produced ore from carbonaceous shale. The

TABLE 1.—*Uranium ore produced from northwestern New Mexico, 1950–64*

All data furnished by courtesy of the U.S. Atomic Energy Commission. Data for the 1950–58 period were compiled by the author from records in the Commission's files, Grand Junction, Colo. Prior to 1950, and principally during World War II, about 10,000 tons of ore was produced from the Eastside Lease, Vanadium Corp. of America. Most of this ore, however, came from Arizona; it averaged about 0.30 percent U_3O_8 and 2.50 percent V_2O_5, and during 1942–43 was mined for vanadium only]

Year	Tons	U_3O_8 Grade (weight percent)
1950	5, 813	0. 21
1951	1, 011	. 24
1952	22, 998	. 22
1953	84, 598	. 25
1954	196, 161	. 36
1955	262, 113	. 25
1956	1, 105, 655	. 26
1957	1, 185, 975	. 21
1958	1, 888, 459	. 21
1959	3, 200, 779	0. 21
1960	3, 730, 905	. 21
1961	3, 575, 589	. 22
1962	3, 450, 791	. 23
1963	2, 294, 892	. 22
1964	2, 093, 355	. 23
Total and weighted average	23, 099, 094	0. 22

ore from sandstone constituted 98 percent of the total output and had the same average grade as that of the district. Vanadium and lime assays are available only for the 1952–58 period, during which the sandstone ores averaged 0.11 percent V_2O_5 and 0.6 percent lime. The carbonaceous shale ores totaled about 6,500 tons and averaged 0.19 percent U_3O_8. About 4,400 tons of this ore averaged 0.03 percent V_2O_5, and 2,400 tons averaged 0.7 percent lime.

For the 1950–64 period, the Shiprock district yielded about 27,000 tons of ore having an average grade of 0.24 percent U_3O_8 and 2.6 percent V_2O_5 (table 2). This ore, which was entirely in sandstone, came from about 30 mines and was the only ore in northwestern New Mexico that ran consistently high in vanadium. For the 1954–58 period, about 5,000 tons had an average content of 9 percent lime. A small amount of ore was mined prior to 1950, but there are no detailed records.

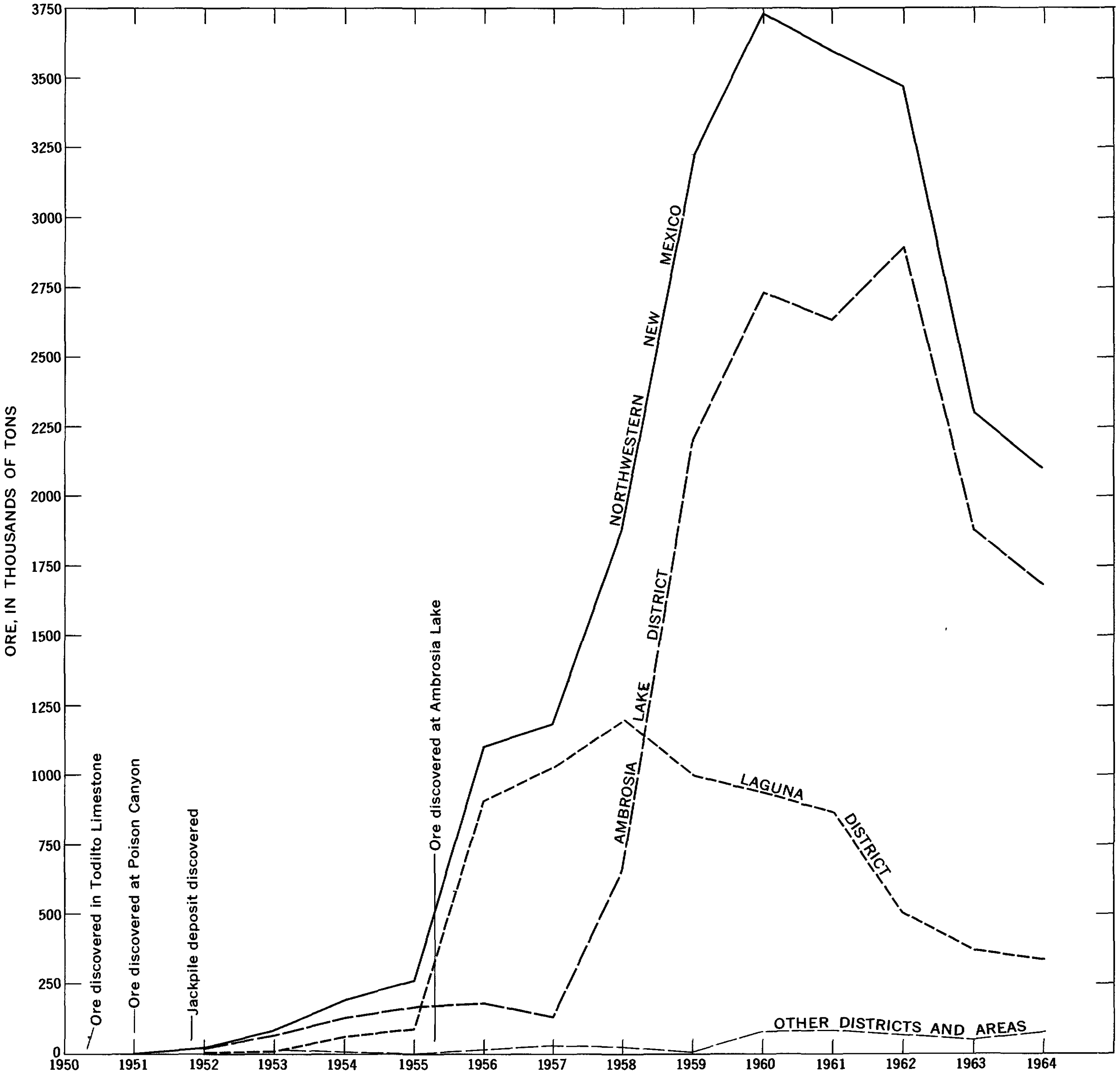


FIGURE 2.—Yearly production of uranium ores produced in the Ambrosia Lake, Laguna, and other districts and areas, and the totals for all districts and areas in northwestern New Mexico, 1950–64.

TABLE 2.—*Uranium ore produced, by district, from northwestern New Mexico, 1950–64*

[Leaders (...) indicate no production or no assay. Data furnished by courtesy of the U.S. Atomic Energy Commission; the data for 1950–58 were compiled from records in the Commission's files, Grand Junction, Colo.]

Year	Ambrosia Lake district						Laguna district						Gallup district					
	Tons	Grade (weight percent)					Tons	Grade (weight percent)					Tons	Grade (weight percent)				
		U_3O_8	V_2O_5 [1]		$CaCO_3$ [2]			U_3O_8	V_2O_5 [3]		$CaCO_3$ [2]			U_3O_8	V_2O_5 [4]		$CaCO_3$ [5]	
1950	10	0.35	0.19	(10)														
1951	779	.36	.16	(779)														
1952	14,562	.21	.20	(14,562)	1.8	(810)	1,125	0.32	0.27	(1,125)			309	0.27	0.17	(309)		
1953	66,248	.25	.17	(66,248)	1.6	(369)	10,063	.30	.20	(10,063)			3,136	.20	.14	(3,136)	5.7	(195)
1954	129,202	.26	.17	(129,202)	3.9	(36,702)	57,474	.61	.29	(57,474)	3.1	(56,574)	1,491	.17	.12	(1,491)	1.3	(625)
1955	166,859	.22	.15	(166,859)	5.0	(52,549)	86,748	.26	.16	(82,595)	2.9	(84,795)	4,428	.19	.15	(4,428)	.7	(4,408)
1956	181,593	.22	.16	(181,527)	4.8	(66,913)	906,397	.27	.14	(906,397)	.8	(906,737)	12,588	.21	.07	(12,588)	.6	(12,588)
1957	131,921	.23	.12	(118,463)	5.8	(50,453)	1,027,262	.21	.10	(1,026,815)	.8	(1,026,815)	19,421	.24	.08	(8,525)	.5	(19,421)
1958	670,035	.24	.16	(22,506)	4.0	(15,749)	1,198,291	.20			.6	(271,573)	17,459	.24	.13	(17,340)	1.0	(3,810)
1959	2,196,335	.22					1,001,680	.19					1,916	.19				
1960	2,719,065	.22					935,649	.19					75,584	.23				
1961	2,623,718	.23					868,141	.19					81,955	.21				
1962	2,883,676	.22					503,654	.24					55,880	.21				
1963	1,872,512	.22					371,331	.21					40,042	.23				
1964	1,677,285	.22					339,266	.24					69,960	.22				
Totals and weighted averages	15,333,800	0.22	0.15	(700,156)	4.8	(223,545)	7,307,081	0.21	0.13	(2,084,469)	0.9	(2,346,494)	384,169	0.22	0.11	(47,817)	0.6	(41,047)

Year	Shiprock district						Chuska district						Other districts and areas					
	Tons	Grade (weight percent)					Tons	Grade (weight percent)					Tons	Grade (weight percent)				
		U_3O_8	V_2O_5 [3]		$CaCO_3$ [2]			U_3O_8	V_2O_5 [3]		$CaCO_3$ [2]			U_3O_8	V_2O_5 [3]		$CaCO_3$ [2]	
1950	5,803	0.21	2.24	(5,803)														
1951	232	.18	2.38	(232)														
1952	5,374	.32	3.12	(5,374)			1,628	0.12	0.15	(1,628)								
1953	3,285	.25	2.71	(3,285)			1,866	.20	.23	(1,866)	3.6	(415)						
1954	3,868	.23	2.41	(3,868)	7.7	(1,828)	4,014	.15	.17	(4,014)	3.7	(3,599)	112	0.22	0.12	(98)	6.5	(90)
1955	1,656	.25	3.17	(1,656)	11.5	(1,634)	1,832	.22	.21	(1,832)	5.6	(1,832)	590	.19	.12	(57)	11.9	(57)
1956	1,195	.22	2.44	(1,195)	10.0	(920)	937	.19	.16	(937)	5.7	(937)	2,945	.21	.03	(2,446)	1.6	(592)
1957	719	.20	1.98	(719)	7.6	(698)							6,652	.37	.06	(4,782)	1.2	(6,556)
1958	480	.21	1.55	(480)	7.9	(206)	1,955	.18	.14	(1,955)	3.7	(1,955)	239	.18			2.0	(239)
1959	82	.37	2.17	(82)			444	.17					322	.14	1.29	(13)		
1960	480	.22	1.26	(480)									127	.14				
1961	136	.26	2.99	(136)			1,565	.22					74	.18				
1962	1,718	.22	1.98	(126)			4,062	.21	.12	(4,062)			1,801	.16				
1963	1,303	.20	1.49	(591)			4,214	.23	.12	(4,214)			5,490	.14				
1964	726	.12					3,996	.20					2,122	.14				
Totals and weighted averages	[6] 27,057	0.24	2.56	(24,027)	9.2	(5,286)	26,513	0.19	0.15	(20,508)	4.3	(8,738)	20,474	0.23	0.05	(7,396)	1.4	(7,534

[1] Numbers in parentheses are tons of sandstone and limestone ores assayed for V_2O_5.

[2] Numbers in parentheses are tons of sandstone ore assayed for $CaCO_3$.

[3] Numbers in parentheses are tons of sandstone ore assayed for V_2O_5.

[4] Numbers in parentheses are tons of sandstone and carbonaceous shale ores assayed for V_2O_5.

[5] Numbers in parentheses are tons of sandstone and carbonaceous shale ores assayed for $CaCO_3$.

[6] Prior to 1950, and principally during World War II, about 10,000 tons of ore was produced from the Eastside Lease, Vanadium Corp. of America. Most of this ore, however, came from Arizona; it averaged about 0.30 percent U_3O_8 and 2.50 percent V_2O_5 and during 1942–43 was mined for vanadium only.

Of a total of about 10,000 tons mined from the Eastside Lease, Vanadium Corp. of America, about 9,000 tons was mined during 1942–43 for vanadium only and about 1,000 tons was mined in 1948 for uranium and vanadium. Most of this output, however, came from Arizona; it averaged about 0.30 percent U_3O_8 and 2.50 percent V_2O_5.

The Chuska district started production in 1952, and by the end of 1964 had yielded about 26,500 tons of ore having an average grade of 0.19 percent U_3O_8 and 0.15 percent V_2O_5 (table 2). This output came from 15 mines and was ore from sandstone. Assays of about 8,700 tons mined during the 1953–58 period averaged about 4 percent lime.

In addition to the ore mined from the above-mentioned districts, about 20,500 tons was mined from other scattered districts and areas during the 1954–64 period. This ore, which averaged 0.23 percent U_3O_8 (table 2), was principally in sandstone and volcanic rocks; some was in limestone, and a small amount was in coaly shale. These ores were low in vanadium except for a 13-ton shipment of sandstone ore which was reported to have averaged 1.29 percent V_2O_5. During the 1954–57 period, about 7,400 tons of the sandstone ores had an average content of 0.05 percent V_2O_5. The lime content of the sandstone ores varied rather widely between deposits, as would be expected for the relatively small and spotty occurrences. During the 1954–58 period, the lime content ranged from about 1 to 12 percent and averaged about 1.5 percent.

The ores in northwestern New Mexico occur in sandstone, limestone, carbonaceous shale and coal, and in igneous rock—in rocks that range in age from Pennsylvanian to Tertiary. Ores that occur in sandstone are the most economically important, constituting more than 95 percent of the tonnage yielded from 1950 to

194 (table 3). Ores in limestone are second in importance, having yielded about 4 percent of the total; ores in carbonaceous shale and coal, and in igneous rocks, constitute less than 1 percent of the total.

The uranium: vanadium ratio of the ores generally is about the same regardless of the grade, type, or age of host rock. Where the average grades show marked differences from the general averages, the tonnage is small and the differences are probably not significant.

At the end of 1958, most of the uranium ores from northwestern New Mexico were being processed by six mills which had a total rated capacity of 11,075 tons per day [2]. At the end of 1964, through a property merger and the closure of one mill, the following mills were operating; they had a collective rated capacity of 9,000–10,000 tons per day:

Company	*Location*
Vanadium Corp. of America	Shiprock.
Homestake-Sapin Partners	Grants.
Kermac Nuclear Fuels Corp	Grants.
The Anaconda Co	Bluewater.

GEOLOGIC SETTING

The three physiographic units, or provinces, in northwestern New Mexico are marked by structural and lithologic as well as physiographic characteristics (fig. 1). The northern part of the area in the Colorado Plateaus province is a broad structural as well as topographic depression, the San Juan Basin. It is characterized by a sedimentary fill of marine and continental rocks that totals several thousand feet in thickness and ranges from Paleozoic to Quaternary in age. Locally around the margins of the basin there are intrusive igneous rocks of Tertiary and Quaternary ages. The southern part of the province, the Datil volcanic field, is characterized by an extensive covering of lavas and associated continental sedimentary rocks that totals several thousand feet in thickness. These rocks are mostly Tertiary and Quaternary in age and cover older marine and continental sedimentary rocks which are exposed along the east and north margins of the area.

The part of the area in the Southern Rocky Mountains province consists generally of mountain blocks that have Precambrian cores; these blocks are draped by marine and continental sedimentary rocks, mostly of late Paleozoic and Mesozoic ages, that are several thousand feet thick, and by valley fills and local volcanic piles of Tertiary and Quaternary ages that also are several thousand feet thick.

The part of the area in the Basin and Range province is characterized by northward-trending fault-block mountains and intervening basins. Along the western part of the province and extending northward into the Southern Rocky Mountains province is the Rio Grande trough, a structural depression. It is filled by several thousand feet of continental sedimentary and volcanic rocks of late Tertiary and Quaternary ages. East of the Rio Grande, the fault-block mountains are generally underlain by crystalline rocks of Precambrian age which are capped by eastward-dipping marine and continental sedimentary rocks of late Paleozoic and Mesozoic ages and by continental sedimentary rocks of Tertiary and Quaternary ages. These rocks total several thousand feet in thickness. At the north end of the province the early Tertiary and older rocks are intruded by laccolithic masses of early Tertiary age.

STRATIGRAPHY

The lithology, thickness, areal distribution, and stratigraphic relations of the uranium-bearing and as-

---

[2] U.S. Atomic Energy Commission press release 222, Feb. 1, 1959, Grand Junction, Colo.

TABLE 3.—*Uranium ores produced from northwestern New Mexico, classified by age and type of host rock, 1950–64*

Host rock		Tons of ore	Percent of total tonnage	U_3O_8 (weight percent)	V_2O_5 [1] (weight percent)		$CaCO_3$ [2] (weight percent)	
Age	Type							
Tertiary	Igneous rock	9, 285	0. 1	0. 14	0. 04	(68)	11. 3	(97)
	Sandstone	9, 036	. 1	. 33	. 03	(6, 877)	1. 2	(6, 995)
Cretaceous	Sandstone	57, 791	. 3	. 23	. 11	(43, 920)	. 6	(40, 273)
	Carbonaceous shale and coal.	6, 497	. 1	. 20	. 03	(4, 438)	. 7	(2, 434)
Jurassic	Sandstone	22, 035, 186	95. 4	. 22	. 13	[3] (2, 364, 101)	1. 2	(2, 578, 929)
	Limestone	975, 497	4. 2	. 22	. 14	(444, 965)	80. 5	(413, 325)
	Limestone and sandstone	4, 513	. 1	. 34	. 16	(999)	42. 2	(1, 848)
Permian	Sandstone	67	. 1	. 14	. 13	(67)	14. 0	(59)
	Limestone	1, 039	. 1	. 21	. 38	(803)	51. 7	(727)
Pennsylvanian	Limestone	183	. 1	. 12	. 10	(183)	11. 7	[4] (183)
Total or weighted average		23, 099, 094	100. 6	0. 22	[5] 0. 13	[5] (2, 414, 965)	[5] 1. 2	[5] (2, 626, 256)

[1] Numbers in parentheses are tons of ore assayed for V_2O_5.
[2] Numbers in parentheses are tons of ore assayed for $CaCO_3$.
[3] Excludes tonnage for Shiprock district, which for 24,027 tons averaged 2.56 percent V_2O_5.
[4] Probably silicified as well as sandy.
[5] Only the ores in sandstone are reported.

sociated formational units are described to provide the setting for the uranium deposits, which occur in about 30 formational units. The units which contain the more economically important uranium deposits, or which have the greatest potential for containing them, are described in more detail than others. Some relatively unimportant units are combined for brevity or are omitted. The outcrops of most of the exposed stratigraphic units are shown on plate 1, and the general stratigraphic relations of the principal units, including those in the subsurface, are shown on the correlation chart, plate 2.

ROCKS OF PRECAMBRIAN AGE

The oldest rocks exposed in northwestern New Mexico are Precambrian and crop out in the Zuni Mountains, in the flanks of the ranges along the Rio Grande, in the Sierra Nacimiento, in the San Pedro Mountains, and in the ranges in the eastern part of Rio Arriba County (pl. 1). These rocks consist mostly of quartzite, schist, slate, granite, rhyolite, and andesite, and include local pegmatite bodies and quartz veins. The exposed thickness of the Precambrian rocks is unknown, but probably is many thousands of feet.

ORTEGA QUARTZITE OF JUST (1937) AND ASSOCIATED ROCKS

In the vicinity of Petaca, eastern Rio Arriba County, where some uranium deposits occur, Just (1937) has subdivided the Precambrian rocks into the (older) Hopewell Series and (younger) Ortega Quartzite and included Petaca Schist. The Hopewell and Ortega intertongue with the Picuris Basalts and Vallecitos Rhyolites. All the Precambrian formations were intruded by the Tusas Granite. The Hopewell Series and Ortega Quartzite are mostly sedimentary in origin.

ROCKS OF CAMBRIAN(?) AGE

Unexposed and unnamed rocks, tentatively considered as Middle or Late Cambrian in age, occur under the San Juan Basin in northwestern San Juan County. These rocks, which consist of conglomeratic sandstone and shale, range in thickness from 0 to about 100 feet, rest on the Precambrian basement, and are considered to be near-shore marine in origin (Bass, 1944; Baars and Knight, 1957; Strobell, 1958). They apparently pinch out southeastward and thicken northwestward into Colorado, Utah, and Arizona. These rocks have been tentatively correlated lithologically with the Tapeats Sandstone of northern Arizona and the Ignacio Quartzite of southwestern Colorado, which generally are considered to be Early and Middle Cambrian in age, and Late Cambrian in age, respectively.

ROCKS OF DEVONIAN AGE

Unexposed rocks of Late Devonian age occur under the San Juan Basin in northwestern San Juan County (Bass, 1944; Baars and Knight, 1957; Strobell, 1958). They thin southeastward and probably pinch out between the Precambrian basement and overlying rocks of Mississippian or younger age. Eastward, these unexposed rocks may extend under the San Juan Basin, because correlative thin rocks occur east of the area in the Sangre de Cristo Mountains where they rest on the Precambrian basement (Baltz and Read, 1960). Northwestward, the Devonian rocks thicken into southwestern Colorado, southeastern Utah, and northeastern Arizona, where they overlie unnamed rocks of Cambrian(?) age. The Devonian rocks are considered to be extensions of the Elbert Formation and overlying Ouray Limestone of southwestern Colorado.

ELBERT FORMATION

The Elbert Formation (Cross, 1904) in northwestern New Mexico consists mostly of black, green, and maroon shale, glauconitic sandstone, and some limestone and sandy dolomite. Some of the limestone-dolomite units are as much as 100 feet thick, and are fairly uniform carbonates. The Elbert ranges from 300 to 750 feet in thickness and is considered to be a near-shore marine and littoral deposit (Strobell, 1958).

ROCKS OF MISSISSIPPIAN AGE

Rocks of Mississippian age are the oldest exposed rocks of Paleozoic age in northwestern New Mexico. They crop out locally along the flanks of the lower Rio Grande Valley and in the San Pedro Mountains and the Sierra Nacimiento, where they rest on the Precambrian basement. In the subsurface in the northwestern part of the San Juan Basin they rest on rocks of Devonian age. The Mississippian rocks, from oldest to youngest, consist of the Leadville Limestone, Caloso Formation of Kelley and Silver (1952), Kelly Limestone, and the Arroyo Penasco Formation.

LEADVILLE LIMESTONE

The Leadville Limestone (Emmons and others, 1893; Kirk, 1931) overlies the Ouray Limestone (Spencer, 1900; Kirk, 1931) in northwestern New Mexico, but is lithologically similar to and difficult to differentiate from it (Strobell, 1958). Rocks of Leadville age are of unknown extent southward under the San Juan Basin, but they may extend eastward under the northern part of the basin, for the reason that they correlate with relatively thin rocks of the same age in the Sangre de Cristo Mountains (Baltz and Read, 1960).

CALOSO FORMATION OF KELLEY AND SILVER (1952), KELLY LIMESTONE, AND ARROYO PENASCO FORMATION

The Caloso Formation crops out on the south flank of the Ladron Mountains (Kelley and Silver, 1952) and along the flanks of the lower Rio Grande Valley near Socorro (Armstrong, 1958, 1959). The Caloso generally consists of a thin basal sandstone and shale unit and an overlying unit of cherty algal limestone. It ranges in thickness from 0 to about 50 feet and rests on the Precambrian basement.

The Kelly Limestone crops out in the Magdalena and Lemitar Mountains (Herrick, 1904; Gordon, 1907a; Lindgren and others, 1910; Loughlin and Koschmann, 1942) and, according to Armstrong (1958, 1959), in the Ladron Mountains. The Kelly is a gray medium-bedded cherty limestone that contains a medial unit of dolomitic limestone and shale. The Kelly Limestone ranges in thickness from 0 to about 75 feet; it generally rests on the Precambrian basement, but locally in the Ladron Mountains it rests on the Caloso Formation (Armstrong, 1958, 1959).

The Arroyo Penasco Formation crops out in the San Pedro Mountains, in the Sierra Nacimiento (Fitzsimmons and others, 1956), and in the Sandia and Manzano Mountains (Armstrong, 1958, 1959). It consists of light-gray thin-bedded to massive fine-grained somewhat cherty limestone; it ranges in thickness from 0 to about 150 feet and rests on the Precambrian basement.

ROCKS OF PENNSYLVANIAN AGE

Rocks of Pennsylvanian age consist of the Molas, Hermosa, and Rico (part) Formations, which occur only in the subsurface in northwestern San Juan County; of the Sandia Formation and Madera Limestone of the Magdalena Group, rather widespread units in the southeastern part of the area; and of unnamed sandstone and siltstone in northeastern Rio Arriba County. These rocks are mostly marine, but they grade into near-shore continental facies around the flanks of the Zuni and Chuska Mountains in the northeastern part of the San Juan Basin.

MOLAS, HERMOSA, AND LOWER PART OF RICO FORMATIONS

Unexposed rocks of Pennsylvanian age in northwestern San Juan County are about 1,500 feet thick, rest on the Leadville and Ouray Limestones, and consists of, from base to top, the Molas, Hermosa, and Rico (part) Formations. The description that follows is taken mostly from Strobell (1958).

The Molas Formation (Cross and others, 1905) in northwestern New Mexico is a marginal marine-continental sequence that consists of dark-red, purple, and gray shale, sandy shale, and sandstone, and, in the upper part, some marine limestone. The Molas ranges in thickness from 60 to 175 feet.

The Hermosa Formation (Cross and Spencer, 1900; Roth, 1934) is mostly marine, and consists of limestone, dolomite, and gray shale, but in the northwest corner of the area it contains evaporite salt beds in the middle part of the formation. The Hermosa is about 1,000–1,350 feet thick.

The Rico Formation (Cross and Spencer, 1900) is a transitional unit between the marine Hermosa Formation and the overlying continental Permian Cutler Formation (Cross and others, 1905). The Rico consists of varicolored shale and siltstone, and some interbedded marine limestone in the lower part, and ranges in thickness from about 350 to 475 feet.

SANDIA FORMATION

Oldest of the Pennsylvanian rocks in the southeastern part of the area is the Sandia Formation, lower formation of the Magdalena Group (Herrick, 1900; Gordon, 1907b). It crops out in the ranges along both sides of the Rio Grande Valley as far north as the San Pedro Mountains. It generally ranges in thickness from about 100 to 600 feet, consists of dark shale and subordinate amounts of earthy limestone, sandstone, and quartzite, and rests on rocks of Mississippian and Precambrian ages (Loughlin and Koschmann, 1942; Read and others, 1944; Kelley and Wood, 1946; Wilpolt and others, 1946; Wilpolt and Wanek, 1951; Wood and others, 1946; Armstrong, 1959).

MADERA LIMESTONE

The Madera Limestone, middle formation of the Magdalena Group (Keyes, 1905; Gordon, 1907b), overlies the Sandia Formation, except locally in the Sandia Mountains (Read and others, 1944), in the northern part of the Sierra Nacimiento, and in the San Pedro Mountains, where it rests on Precambrian rocks (Wood and others, 1946). Rocks equivalent in age to the Madera and possibly in part to the Sandia Formation extend westward under cover into the Datil volcanic field and northward under the San Juan Basin and pinch out around the flanks of the Zuni and Chuska Mountains (Armstrong, 1959; Baars and Knight, 1957).

In most places the Madera consists of two members: A lower cherty gray limestone with minor interbeds of sandstone and siltstone and an upper member of interbedded arkosic sandstone, siltstone, and some cherty gray limestone (Loughlin and Koschmann, 1942; Read and others, 1944; Kelley and Wood, 1946; Wilpolt and others, 1946; Wilpolt and Wanek, 1951; Wood and others, 1946). The thickness of the Madera generally ranges from about 500 to 1,000 feet; it is about 1,850 feet thick in the Lucero Mesa area (Kelley and Wood, 1946), whereas it is only 80 feet thick in the La Joyita Hills where the upper member is absent (Wilpolt and others, 1946). In the Nacimiento-San Pedro Mountains area the lower limestone member is missing and the upper arkosic member rests on the Precambrian basement.

SANDSTONE AND SILTSTONE

Muehlberger (1957) described a local occurrence of Pennsylvania rocks in northeastern Rio Arriba County; these rocks are about 250 feet thick and consist of red arkosic sandstone, siltstone, and some nodular fossiliferous limestone. These rocks, which apparently wedge out eastward against Precambrian quartzite, probably represent intertonguing continental and marine debris near the northeast margin of the Pennsylvanian embayment. The finer grained, thinbedded, and calcareous material may represent or be partly equivalent to the upper arkosic member of the Madera Limestone, which crops out along the north flank of the San Pedro Mountains (Wood and others, 1946). The coarser arkosic sandstone units, which are as much as 60 feet thick, thin northeastward and presumably thicken under cover to the southeast. Their areal extent is not known, but it is rather limited. Pennsylvanian rocks are missing to the northwest and along the west side of the Chama Basin (Muehlberger, 1957), and the arkosic units would be expected to become finer grained and thinner bedded southward away from the source area.

ROCKS OF PERMIAN AGE

Rocks of Permian age crop out extensively in the ranges and mesas east of the Rio Grande, and in the Lucero Mesa area, Zuni and San Pedro Mountains, Sierra Nacimiento, southern part of the Chama Basin, and in a small area on the eastern flank of the Chuska Mountains. The Permian rocks have a maximum thickness of about 2,500 feet in the Lucero Mesa area (Kelley and Wood, 1946) and are about 1,000–1,500 feet thick in the San Pedro Mountains and the Sierra Nacimiento (Wood and others, 1946), Zuni and Chuska Mountains (Baker and Reeside, 1929, p. 1426), and in the area east of the Rio Grande (Read and others, 1944; Wilpolt and others, 1946; Wilpolt and Wanek, 1951).

In the southern part of the area, from the base upward, the Permian rocks range from the local marine Bursum Formation into the continental clastic sedimentary rocks of the Abo and Cutler Formations, through gradational continental and marine clastic and evaporite beds of the Yeso Formation and Glorieta Sandstone, to the dominantly marine beds of the uppermost part of the San Andres Limestone and the Bernal Formation. In the northern part of the area the rocks are almost entirely continental and consist of the upper part of the Rico Formation (see above) and the overlying Cutler Formation.

BURSUM FORMATION

The Bursum Formation crops out in the southeastern part of the area east of the Rio Grande where it rests on the Madera Limestone and is the upper formation of the Magdalena Group. It consists of purple-red and green shale separated by thin beds of arkose, arkosic conglomerate, and gray limestone; it ranges in thickness from 0 to 250 feet (Wilpolt and others, 1946; Wilpolt and Wanek, 1951).

ABO FORMATION

The Abo Formation (Lee and Girty, 1909, p. 12; Needham and Bates, 1943) crops out along the flanks of the Rio Grande Valley and in the Sierra Nacimiento and the Zuni and Chuska Mountains It rests on the Madera Limestone and Bursum Formation along the flanks of the Rio Grande, and on Precambrian rocks in most of the Zuni and Chuska Mountains and in the central part of the Sierra Nacimiento. North of lat 36°N., equivalents of the Abo Formation are arbitrarily included in the lower part of the Cutler Formation (Wood and others, 1946).

The Abo Formation ranges in thickness from about 300 to 900 feet and is composed mostly of dark-red and gray siltstone and dark-red and locally gray arkosic sandstone. The sandstone units are generally very lenticular, crossbedded, locally contain plant debris or impressions, and range in thickness from a few inches to as much as 75 feet (Read and others, 1944; Kelley and Wood, 1946; Wood and others, 1946; Wilpolt and others, 1946; Wilpolt and Wanek, 1951). The principal source areas for the Abo were the ancestral Zuni highlands on the west, and Joyita highlands to the south, the Pedernal highland to the east, and the San Luis-Uncompahgre highland to the north (McKee and others, 1967).

CUTLER FORMATION

The Cutler Formation (Cross and others, 1905) crops out in the central part of the Sierra Nacimiento, in the San Pedro Mountains (Wood and others, 1946), and on the east flank of the Chuska Mountains (O'Sullivan and Beaumont, 1957), where it rests on Precambrian rocks. North of lat 36°N. in the Sierra Nacimiento, equivalents of the Abo and the overlying Yeso Formations are arbitrarily included in the Cutler Formation (Wood and others, 1946). Northward from the San Pedro Mountains, the Cutler dips beneath younger rocks and is only partly exposed locally around the Chama Basin. In the Chuska Mountains only part of the De Chelly Sandstone Member of the Cutler Formation is exposed (Baker and Reeside, 1929; O'Sullivan and Beaumont, 1957). The Cutler ranges in thickness from about 500 to 1,000 feet in the Sierra Nacimiento-San Pedro Mountains area (Wood and others, 1946) and probably is about 1,000 feet thick along the flanks of the Chuska Mountains (Baker and Reeside, 1929, p. 1426; Allen and Balk, 1954, p. 63–65).

The Cutler Formation generally is similar lithologically to the Abo, but some of the sandstone units are thicker, being as much as 125 feet thick (Wood and others, 1946). The De Chelly Sandstone Member of the Cutler, in addition to being much thicker than sandstones in the Abo, is a light-red massive fine-grained quartzose unit that has large-scale crossbeds. It is generally considered to be an eolian deposit (Gregory, 1917, p. 32–33; Allen and Balk, 1954, p. 63.)

YESO FORMATION AND GLORIETA SANDSTONE

The Yeso Formation and the Glorieta Sandstone successively overlie the Abo Formation and crop out along the margins of the Rio Grande Valley (Read and others, 1944; Kelley and Wood, 1946; Wilpolt and others, 1946; Wilpolt and Wanek, 1951) and Zuni Mountains (Read, 1951, p. 83) and in the Sierra Nacimiento (Wood and others, 1946).

The Yeso Formation (Lee and Girty, 1909; Needham and Bates, 1943), is mostly an orange-red sequence of massive or crossbedded quartzose sandstone and interbedded siltstone, limestone, and gypsum. It ranges in thickness from 0 to 1,700 feet.

The Glorieta Sandstone (Keyes, 1915; Needham and Bates, 1943; Baltz and Bachman, 1956) overlies the Yeso, is 0–200 feet thick, and is mostly a white quartzose cliff-forming sandstone.

SAN ANDRES LIMESTONE

The San Andres Limestone (Lee and Girty, 1909; Needham and Bates, 1943), which rests on the Glorieta Sandstone, crops out in the ranges along the flanks of the Rio Grande trough and in the Zuni Mountains and southern part of the Sierra Nacimiento. It has a maximum thickness of about 450 feet at Lucero Mesa (Kelley and Wood, 1946), is about 400 feet thick east of the Rio Grande (Wilpolt and Wanek, 1951), 100–140 feet thick in the Zuni Mountains (Smith, 1954), and about 50 feet thick in the southern part of the Sierra Nacimiento (Wood and others, 1946).

The San Andres is mostly gray cherty limestone and interbedded gray shale, sandstone, and gypsum. The limestone units range in thickness from a few feet to more than 100 feet and are concentrated in different parts of the formation in different areas. East of the Rio Grande the limestone is mainly in the lower part (Read and others, 1944; Wilpolt and others, 1946; Wilpolt and Wanek, 1951), at Lucero Mesa in the upper part (Kelley and Wood, 1946), and in the Zuni Mountains it constitutes the entire formation except for a thin sandstone unit near the middle (Smith, 1954). In the southern part of the Sierra Nacimiento, however, the San Andres is mostly an orange-red siltstone, and only a thin wedge of limestone occurs at the base (Wood and others, 1946).

BERNAL FORMATION

The Bernal Formation (Bachman, 1953) overlies the San Andres Limestone and crops out in the ranges along the east side of the Rio Grande. The Bernal is mostly an orange-red silty sandstone that contains local thin beds of dark-gray limestone and that ranges in thickness from 5 to about 50 feet (Read and others, 1944; Wilpolt and others , 1946; Wilpolt and Wanek, 1951).

ROCKS OF TRIASSIC AGE

Rocks of Triassic age crop out along the margins of the San Juan Basin, southwest of the Zuni Mountains in the area near Zuni, in the San Pedro Mountains and in the Sierra Nacimiento, around the periphery of the Chama Basin, and along the flanks of the Rio Grande Valley. These rocks are about 1,500–2,000 feet thick along the west and south sides of the San Juan Basin (Strobell, 1956; Allen and Balk, 1954; Smith, 1954) and southwest of the Zuni Mountains (Akers and others, 1958), but they generally thin eastward and probably thin southward. They are about 1,000 feet thick in the Sierra Nacimiento and in the San Pedro

Mountains but thin to about 600 feet in the southeastern part of the Chama Basin (J. H . Stewart, written commun., 1958) and to about 400 feet in the northeastern part of the Chama Basin (Dane, 1948). South of the San Juan Basin in the vicinity of Lucero Mesa the Triassic rocks are about 1,000 feet thick (Kelley and Wood, 1946), but east of the Rio Grande they are about 500 feet (Wilpolt and others, 1946). Southward from the San Juan Basin they probably thin, but how much is uncertain because of incomplete exposures and beveling by pre-Dakota erosion (Silver, 1948).

The Triassic rocks consist of brick-red, maroon, and gray siltstone, some shale and arkosic sandstone, and local limestone-conglomerate lenses.

Only a few relatively unimportant uranium deposits are known in the Triassic rocks of northwestern New Mexico, but these rocks will be described in some detail because they contain stratigraphic equivalents of lithologically similar rocks in northeastern Arizona and southeastern Utah that contain important uranium deposits.

Along the west and south sides of the San Juan Basin and southwest of the Zuni Mountains the Triassic rocks, in ascending order, are composed of the Moenkopi(?) Formation, the Chinle Formation, and the Wingate Sandstone.

MOENKOPI(?) FORMATION

The Moenkopi Formation, which is widespread in Arizona, possibly has a limited distribution in New Mexico (McKee, 1954, p. 5–7). It may crop out along the flanks of the Zuni Mountains and can be traced eastward, questionably, at least as far as Lucero Mesa (J. H. Stewart, written commun., 1958). In New Mexico, the Moenkopi (?) consists of lenses of pale-red locally conglomeratic sandstone and interstratified gray and red siltstone. It rests on the San Andres Limestone and ranges in thickness from 0 to about 200 feet (J. H. Stewart, written commun., 1958).

CHINLE FORMATION

Most of the Triassic rocks in northwestern New Mexico are constituted by the Chinle Formation which has the same general outcrop distribution as that of the Triassic rocks, except east of the Rio Grande where the Triassic rocks are represented by the Dockum Formation.

For convenience of description the Chinle Formation is discussed by general areas along (1) the west and south sides of the San Juan Basin and (2) the east side of the San Juan Basin.

WEST AND SOUTH SIDES OF THE SAN JUAN BASIN

Along the west side of the San Juan Basin the Chinle Formation unconformably overlies the De Chelly Sandstone Member of the Cutler Formation and along the south side unconformably overlies the Moenkopi (?) Formation. Along the Arizona border the Chinle is about 1,200–1,600 feet thick and comprises, in ascending order, the Shinarump Member (0–100 ft. thick), lower red member (50–400 ft. thick), Petrified Forest Member (1,000–1,500 ft. thick), and the Owl Rock Member (0–500 ft. thick) (Akers and others, 1958; Strobell, 1956). These members as a whole consist of red, brown, purple, and gray varicolored bentonitic silty claystone and siltstone but contain some lenses of sandstone and lime-pebble and chert-pebble conglomerate.

Of the several members of the Chinle Formation that are present along the Arizona border, only the Shinarump Member, lower red member, and the Petrified Forest Member extend appreciably into northwestern New Mexico and justify description.

SHINARUMP MEMBER

Inasmuch as the Shinarump Member (Stewart, 1957) is the host for important uranium deposits in northeastern Arizona and southeastern Utah (Finch, 1959), its characteristics and extent in northwestern New Mexico are described in some detail. The description of the Shinarump including its extent in New Mexico, is based almost entirely on exposures in Arizona and Utah.

The Shinarump Member, which is present in much of southern Utah and northern Arizona (Gregory, 1917, p. 38; Akers and others, 1958, p. 90, fig. 2; Stewart and others, 1959, p. 504), ranges in thickness from 0 to 250 feet. In Monument Valley, Ariz., it is predominantly gray to buff conglomeratic sandstone (Witkind, 1956, p. 102–103) 50–100 feet thick. The pebbles are well rounded, range in diameter from granule size to 2 inches, and are composed of quartz, quartzite, and chert. The fact that the pebbles are in a quartz-sand matrix cemented by silica, calcite, clay, and iron oxide makes the Shinarump fairly resistant. Both the conglomerate and sandstone beds are lenticular and crossbedded. Plant fragments are fairly common and range in size from fine debris to logs as much as 4–5 feet in diameter and 50 feet in length. Much of the plant material is silicified, but some is degraded to black carbonaceous material. Lenses of claystone are common in the upper parts of the unit but uncommon elsewhere.

Uranium ore bodies are localized in the conglomeratic standstone where it fills stream channels scoured in the underlying Moenkopi Formation. These channels range from about 15 feet in width and 10 feet in depth to 2,300 feet in width and 70 feet in depth (Witkind, 1956, p. 114).

In the Carrizo Mountains and Fort Defiance areas, Arizona, near the New Mexico border, the Shinarump Member is similar in thickness and lithology to the Shinarump in Monument Valley, Ariz. In the Carrizo Mountains area, the thickness ranges from 20 to 95 feet, but plant material is less common, and stream channels are not apparent (Strobell, 1956). Because the exposure in that area is small and is probably near the northeast limit of the member (Stewart and others, 1959, p. 506, fig. 74), it may not be typical of the unit in this area. Near Fort Defiance, southwest of the Chuska Mountains, the Shinarump ranges in thickness from 0 to 35 feet, contains some silicified plant fragments, and is partly composed of stream-filled channels 30–50 feet wide and 5–10 feet deep (Allen and Balk, 1954, p. 65–67).

Akers, Cooley, and Repenning (1958, p. 90) show the Shinarump Member at Zuni, southwest of the Zuni Mountains, and extend it into New Mexico as far east as Thoreau but indicate that it is thin and discontinuous. East of Zuni, however, it is mostly covered and its eastward extent is uncertain, although J. H. Stewart (written commun., 1958) observed a remnant above questionable Moenkopi on the west side of Lucero Mesa which had a lithology similar to the Shinarump Member in Arizona.

The thin and discontinuous exposures of the Shinarump east of Fort Wingate probably indicate that the outcrops are near the east margin of the member. Available information, therefore, suggests that in New Mexico the east margin of the Shinarump extends from near the northwest corner of New Mexico southeastward to the Rio Grande in the vicinity of Lucero Mesa. Southwestward from this margin the extent of the Shinarump in New Mexico is speculative because it is discontinuous and generally buried under younger rocks and, south of the San Juan Basin, an unknown amount of it has been removed by pre-Dakota erosion. Because of its fluvial structures, lithology, relative thinness, wide extent, and the uncomformable nature of the contact with the Moenkopi, the Shinarump is most likely a pediment deposit (Stokes, 1950).

LOWER RED MEMBER

The lower red member of the Chinle Formation overlies the Shinarump Member, extends through the Zuni Mountains area, consists of mudstone, siltstone, and fine-grained sandstone, and is about 200 feet thick (Cooley, 1959).

PETRIFIED FOREST MEMBER AND INCLUDED SONSELA SANDSTONE BED

Of the several members of the Chinle Formation that are present along the Arizona border, only the Petrified Forest Member is widespread in northwestern New Mexico. It extends to the east side of the San Juan Basin, crops out along the south side of the basin, and may extend southward under the younger rocks of the Datil volcanic field. It overlies the Shinarump Member, lower red member, or the Moenkopi (?) Formation in different parts of the area. From base to top the Petrified Forest Member generally consists of varicolored bentonitic claystone and siltstone in the lower part, the Sonsela Sandstone Bed in the middle part, and red-brown claystone, siltstone, and some lenses of ledge-forming sandstone in the upper part. The following description of the Sonsela Sandstone Bed is mostly from Cooley (1959) and J. H. Stewart (written commun., 1958).

The Sonsela Sandstone Bed crops out in the Zuni Mountains area and along the southwest margin of the San Juan Basin. It ranges in thickness from 50 to about 150 feet and consists of yellow-gray fine- to coarse-grained conglomeratic, cherty, and quartzose sandstone and some lenses of gray and red claystone. The bedding is mostly cross-stratified and in thin to thick trough-type sets. Conglomerate is present as thin lenses and as beds as much as 20 feet thick, which locally constitute much of the lower part of the unit. The pebbles, which are mostly chert and some quartzite and quartz, range from granule size to as much as several inches in diameter. The Sonsela Sandstone Bed contains no known uranium deposits, but it is similar lithologically and in thickness to the Shinarump Member and to other uraniferous sandstone units of the Chinle Formation, and it had a similar southern source area (Cooley, 1959; Stewart and others, 1959, p. 523; Poole, 1961, fig. 199.1B). The Sonsela, however, apparently contains less fossil plant debris, fewer well-developed channel scours, and more extensive mudstone and siltstone units than does the Shinarump Member.

EAST SIDE OF THE SAN JUAN BASIN

Along the east side of the San Juan Basin the Chinle Formation is exposed in the Sierra Nacimiento and in the San Pedro Mountains and along the margins of the Chama Basin (Wood and others, 1946). The Chinle rests on the Cutler Formation in the San Pedro Mountains area and on Precambrian rocks in most of the northern part of the Chama Basin (Dane, 1948), but locally rests on sandstone and siltstone of Pennsylvanian age (Muehlberger, 1957). South of lat 36° N., the Chinle rests on the Abo Formation and on the beveled edges of younger rocks of Permian age. East of the San Juan Basin the Chinle ranges in thickness from about 1,200 feet near San Ysidro to about 400 feet in the northeastern part of the Chama Basin (Dane, 1948).

Wood, Northrup, and Cowan (1946) divided the Chinle Formation in the Sierra Nacimiento and San Pedro Mountains area, in ascending order, into the Agua Zarca Sandstone Member, Salitral Shale Tongue, Poleo Sandstone Lentil, and an unnamed shale, siltstone, and sandstone unit. In the same general area, J. H. Stewart (written commun., 1958) recognized five members—namely, the Agua Zarca Sandstone Member, Salitral Shale Tongue, Poleo Sandstone Lentil, Petrified Forest Member, and an unnamed siltstone member—and considered Wood, Northrop, and Cowan's (1946) shale, siltstone, and sandstone unit to be the Petrified Forest Member. Stewart extended his unnamed siltstone member, which occurs above the Petrified Forest Member, into the southeastern part of the Chama Basin and indicated that the unnamed siltstone member is probably equivalent to outcrops of the Chinle Formation in the northeastern part of the basin.

Except for the Agua Zarca Sandstone Member and the Poleo Sandstone Lentil, the Chinle Formation east of the San Juan Basin is a sequence of beds lithologically similar to the Petrified Forest Member along the west and south sides of the basin.

Although the Agua Zarca and Poleo contain few known uranium deposits, they are described in some detail because of their lithologic, stratigraphic, and structural similarity to the ore-bearing Shinarump and Moss Back Members in southeastern Utah.

AGUA ZARCA SANDSTONE MEMBER AND POLEO SANDSTONE LENTIL

The Agua Zarca Sandstone Member and Poleo Sandstone Lentil were recognized by Wood, Northrop, and Cowan (1946) throughout much of the west and north flanks of the Sierra Nacimiento and San Pedro Mountains area where the two units are separated by the Salitral Shale Tongue which ranges from a wedge edge to 125 feet in thickness and which is lithologically similar to Wood, Northrop, and Cowan's (1946) siltstone member. In the southern Sierra Nacimiento-Jemez Mountains area, Wood, Northrop, and Cowan (1946) indicated that the Poleo pinches out southward, and they recognized the Agua Zarca in the southern area only. J. H. Stewart (written commun., 1958), however, found that Wood, Northrop, and Cowan's Agua Zarca in the southern Sierra Nacimiento-Jemez Mountains area has characteristics more like those of the Poleo Sandstone Lentil, and he believed that the Agua Zarca in the southern area either represents a southward extension of the Poleo or is a segment of the Agua Zarca that was derived from the same general source area as the Poleo.

The Agua arca and Poleo are each cliff-forming conglomeratic sandstone units that range in thickness from about 50 to 150 feet, but the thicknesses differ considerably from place to place, largely intertonguing and intergrading with the Salitral Shale Tongue and with the Petrified Forest Member as recognized by Stewart (written commun., 1958). Each locally contains macerated and coalified plant debris and each contains generally small channel scours at the base. Although the two units resemble each other, they have the following rather distinctive features.

The Agua Zarca is generally varicolored and ranges from grayish red or purple to shades of yellowish gray. It is characteristically coarse to very coarse grained; quartzite granules, pebbles, and cobbles are common, and chert pebbles occur locally. At the north end of the Sierra Nacimiento-Chama River canyon area the basal part of the Agua Zarca contains many quartzite boulders as much as a foot in diameter and, in the same area, some coarse-textured igneous rock cobbles and boulders. Also, in the general area, grain-size distribution and a southward to southwestward dominant dip direction of the cross-strata indicate that the Agua Zarca in this area was derived from the north and northeast, probably from the ancestral Rocky Mountains (F. G. Poole, written commun., 1961).

The Poleo is generally yellowish gray, fine to medium grained, and locally contains more siltstone units than does the Agua Zarca, and the conglomerate is composed of granules and pebbles of quartz, quartzite, chert, and rarely limestone or siltstone. Chert granules, which generally typify the Poleo, increase in abundance northward whereas quartzite, in contrast to that of the Agua Zarca, is a minor constituent (J. H. Stewart, written commun., 1958).

The Poleo and Agua Zarca occupy about the same stratigraphic position in the Chinle Formation as the Shinarump and Moss Back Members, but correlation with them as continuous units is speculative because of the distance between the respective exposures and because of the lack of subsurface information. Moreover, the projected east margin the Shinarump Member is about 40 miles or more west of the Poleo and Agua Zarca outcrops, so they are probably not contiguous. Possibly the Agua Zarca is continuous with the Santa Rosa Sandstone southeast of the Rio Grande Valley and the Santa Rosa actually extends westward and is the unit identified as Shinarump in east-central New Mexico (McKee and others, 1959, p. 22, section B–B[1] and fig. 25). The present assumption is that the Shinarump, Poleo, and Agua Zarca are separate units, which had a common southern source except for the part of the Agua Zarca in the northern Nacimiento-southeastern Chama Basin area, which had a northern or northeastern source.

DOCKUM FORMATION

East of the Rio Grande, rocks of Triassic age are represented by the Dockum Formation, which crops out locally along faults. The Dockum ranges in thickness from 80 to about 500 feet, includes equivalents of the Chinle Formation and possibly of the Moenkopi Formation, and consists of maroon and light-gray sandstone, siltstone, and shale and some local limestone-pebble conglomerate lenses (Wilpolt and others, 1946; Wilpolt and Wanek, 1951; Read and others, 1944). Same sandstone units in the Dockum range in thickness from a few feet to as much as 50 feet and are similar lithologically to the Shinarump Member of the Chinle Formation.

WINGATE SANDSTONE

The Wingate Sandstone (Dutton, 1885, p. 136; Baker and others, 1947), is the only formation of the Glen Canyon Group (Gregory and Moore, 1931, p. 61) that extends appreciably into northwestern New Mexico. Although the Wingate Sandstone contains no known uranium deposits in New Mexico, is largely an eolian deposit as shown by its sweeping crossbeds, fineness, and uniformity of the sand grains, and is probably a poor host for uranium deposits, it is described to help distinguish it from the overlying Entrada Sandstone, a similar formation which is a host for some uranium deposits.

The Wingate rests on the Chinle Formation along the Arizona border, where it ranges in thickness from about 200 to 650 feet (Harshbarger and others, 1957, p. 8–12, pl. 2). In that area it consists of a lower reddish-brown silty member and an upper reddish-brown massive cliff-forming sandstone member. The siltstone member grades into the Chinle and interfingers with the sandstone member along the west side of the San Juan Basin and southwest of the Zuni Mountains. The upper sandstone member thins eastward and either pinches out southeast of Laguna or is cut out under the Entrada Sandstone southwest of Laguna. Southward from the San Juan Basin the upper member of the Wingate thins and pinches out in southern Valencia County (Silver, 1948, p. 70). The relations of the upper member of the Wingate are discussed more completely in another report (Hilpert, 1963, p. 8–9). The Wingate Sandstone also probably pinches out under the San Juan Basin because it is not recognized on the east side of the basin.

ROCKS OF JURASSIC AGE

Rocks of Jurassic age crop out in northwestern New Mexico in approximately the same areas as the Triassic rocks. South of U.S. Highway 66, however, the Jurassic rocks were beveled progressively southward by pre-Dakota erosion and their southern limit is marked by a line that extends from about 30 miles south of Laguna westward into Arizona near Zuni (Silver, 1948; Rapaport and others, 1952).

The Jurassic rocks consist of the San Rafael Group, and the overlying Cow Springs and Zuni Sandstones, and the Morrison Formation, and total about 1,000 feet in thickness. These units consist of orange, buff, and white eolian sandstone, red, buff, and gray fluvial, and some marine, sandstone and mudstone; varicolored lacustrine and fluvial claystone; and gray brackish-water limestone and gypsum.

The San Rafael Group in northwestern New Mexico consists of, in ascending order, the Carmel Formation, Entrada Sandstone, Todilto Limestone, Summerville Formation, and the Bluff Sandstone. The Carmel Formation pinches out a short distance southeast of the Four Corners (Harshbarger, and others, 1957) and deserves no further comment.

ENTRADA SANDSTONE

In northwestern New Mexico the Entrada Sandstone (Gilluly and Reeside, 1928, p. 76) generally is the basal formation of the San Rafael Group and the oldest formation of Jurassic age. It rests on the Wingate Sandstone in the western part of the area (Baker and others, 1947; Harshbarger and others, 1957), on the Chinle Formation in the eastern part (Wood and others, 1946), and on the Dockum Formation east of the Rio Grande (Read and others, 1944; Wilpolt and others, 1946; Wilpolt and Wanek, 1951). South of the Valencia-Socorro County line the Entrada is missing, partly the result of pre-Dakota beveling and partly because of nondeposition (Silver, 1948).

In northeastern Arizona, adjacent parts of Utah, and northwestern New Mexico, Harshbarger, Repenning, and Irwin (1957, p. 35–38) recognized three members—a lower sandy member that is present only in Arizona and Utah, a medial silty member, and an upper sandy member. The medial silty member and an upper sandy member, as established at Fort Wingate, have been extended eastward into the Laguna district

(Harshbarger and others, 1957; Smith, 1954; Rapaport and others, 1952) and generally extend northeastward from Laguna into north-central New Mexico (D. D. Dickey, written commun., 1963). In most places the Entrada rests on the Wingate Sandstone, but at least in the southeastern part of the Laguna district it rests on the Chinle Formation (Kelly and Wood, 1946). Elsewhere in the Laguna district, rocks that have been called Wingate might belong in the Entrada. If they do, the Entrada rests on the Chinle throughout the district (Hilpert, 1963, p. 6–9).

The upper sandy member of the Entrada constitutes the thicker part of the formation and contains the known uranium deposits. It consists of reddish-orange to white fine-grained quartz sandstone and is marked by thick sets of large-scale crossbeds. It ranges in thickness from 80 to about 250 feet, and has a tendency to weather into bold rounded cliffs. The medial silty member, the lower unit in northwestern New Mexico, consists of red and gray siltstone and ranges in thickness from 10 to about 100 feet.

TODILTO LIMESTONE

The Todilto Limestone (Gregory, 1917, p. 55) rests on the Entrada Sandstone and has about the same outcrop pattern. Southward it pinches out along a line that is 10–20 miles south of U.S. Highway 66 (Rapaport and others, 1952). This line trends westward to a point south of Grants and then swings northwestward into Arizona west of Chuska Peak (pl. 1).

The Todilto Limestone consists of two units. The basal unit, which generally ranges in thickness from 10 to 30 feet, consists of thin-bedded gray fine-grained limestone and some thin interbeds of siltstone and is present everywhere the Todilto crops out. The upper unit, which ranges in thickness from 0 to 100 feet, consists of anhydrite and gypsum and crops out along the east side of the San Juan Basin and northeast of the Sandia Mountains and extends under the central part of the basin. (See pl. 3.) Some of the debris in the Todilto consists of volcanic ash (Weeks and Truesdell, 1958). In some places the beds are nearly black, and some fine black carbonaceous material is concentrated locally along bedding planes. Wherever the limestone is pulverized it emits a fetid odor, and this characteristic coupled with the dark color, has led many to speak of the limestone as "petroliferous." Whether or not the limestone contains hydrocarbons and is petroliferous, its content of organic carbon is low, for it only locally contains as much as 1 percent organic carbon and in general averages only a few tenths of 1 percent. The relations of the organic carbon to the uranium deposits is discussed under "Distribution of Elements in the Todilto Limestone."

SUMMERVILLE FORMATION

The Summerville Formation (Gilluly and Reeside, 1928, p. 79–80) overlies the Todilto Limestone and has about the same distribution pattern as the Todilto in northwestern New Mexico (J.S. Wright, oral commun., 1958). The Summerville ranges in thickness from 50 to about 225 feet and averages about 150 feet. It consists of reddish-brown and gray fine-grained sandstone and siltstone, whose individual units range in thickness from a few inches to a few feet. South of Grants and south of Laguna, near its south margin, the Summerville contains a basal quartzite-pebble conglomerate (Silver, 1948, p. 78; Hilpert, 1963, p. 12). The bedding is mostly parallel and probably represents near-shore deposition in a shallow marine embayment.

BLUFF SANDSTONE

Overlying the Summerville Formation is the Bluff Sandstone of the San Rafael Group (Gregory, 1938, p. 58–59), which crops out along the west and south sides of the San Juan Basin (Harshbarger and others, 1957, p. 42-43; Freeman and Hilpert, 1956). The Bluff Sandstone is a pale-orange or buff fine- to medium-grained crossbedded sandstone which weathers into bold rounded cliffs similar to those of the Entrada Sandstone. The Bluff ranges in thickness from about 50 feet in western San Juan County to about 300 feet in McKinley and Valencia Counties. In southwestern McKinley County the Bluff grades into the stratigraphically more extensive Cow Springs Sandstone (Harshbarger and others, 1957, p. 48–51) which occupies the entire stratigraphic interval occupied elsewhere by the Todilto Limestone, Summerville Formation, Bluff Sandstone, and part of the overlying Morrison Formation. On plate 1 these units are mapped with Zuni Sandstone in McKinley and Valencia Counties.

MORRISON FORMATION

The Morrison Formation (Cross, 1894, p. 2; Emmons and others, 1896) is the most important host for uranium deposits in northwestern New Mexico. Its distribution is similar to the San Rafael Group, and it originally covered most of the mapped area (pl. 1) and extended into northeastern Arizona, eastern Utah, and southwestern Colorado (Craig and others, 1955, fig. 19, p. 129). The former southern extent of the Morrison in New Mexico is not known because the beds were removed by erosion prior to the deposition of the overlying Dakota Sandstone

(Silver, 1948). The southernmost outcrop of the Morrison is marked by a westward-trending line that is a few miles south of and parallel to U.S. Highway 66.

The Morrison in northwestern New Mexico generally consists of gray, maroon, and buff mudstone, varicolored claystone, and gray to reddish-brown medium- to coarse-grained sandstone. The sandstone is arkosic, locally conglomeratic, and locally contains concentrations of carbonaceous material. The Morrison ranges in thickness from 400 to about 800 feet and is comprised of, from base to top, the Salt Wash, Recapture, Westwater Canyon, and Brushy Basin Members. General descriptions of each member follow; more detailed local information is given under description of the principal mining districts.

SALT WASH MEMBER

The Salt Wash Member is present only in northwestern San Juan County where it constitutes the southern part of a fanlike unit that extends from northeastern Arizona into Utah and Colorado (Craig and others, 1955, p. 138, fig. 21). The Salt Wash rests on the Bluff Sandstone and grades into the overlying Recapture Member and, southward, interfingers with and pinches out beneath the Recapture Member along an eastward-trending line approximately at the north end of the Chuska Mountains. In northwestern New Mexico the Salt Wash Member crops out only near the Arizona line where, in the Shiprock district, it has a maximum thickness of 220 feet. Eastward from the outcrop the general lithology is the same, and the configuration of the member is only modified somewhat from the interpretation shown by Craig and others (1955). Recent work, based largely on rather sparse subsurface information, indicates that the member generally thickens northward and has a maximum thickness in New Mexico of about 300 feet in the area northeast of Shiprock near the Colorado line (L. C. Craig, written commun., July 1961).

In New Mexico the Salt Wash is mostly a reddish-brown to light-brown or gray medium-grained sandstone which is interbedded with some mudstone. The sandstone units generally range in thickness from a few feet to several tens of feet and are characteristically crossbedded. Studies of the dip directions of the cross laminae in the sandstone of the Shiprock and Chuska districts indicate a general eastward trend (Craig and others, 1955, p. 145, fig. 26). Fossil plant material, mostly in the form of coalified fragments and silicified logs, occur locally in the sandstone units.

RECAPTURE MEMBER

The Recapture Member crops out along the margins and is recognized in the subsurface of the San Juan Basin, crops out locally east of the Rio Grande, and crops out in northeastern Arizona and in adjoining parts of Utah and Colorado. The Recapture is the basal unit of the Morrison Formation in most of northwestern New Mexico, but in northwestern San Juan County and in adjoining parts of Arizona, Utah, and Colorado it is underlain by the Salt Wash Member. The Recapture generally intertongues with and grades into the Cow Springs Sandstone to the southwest, and is not recognizable south of Albuquerque and east of Santa Fe (L.C. Craig, written commun., July 1961). South of Gallup its former southern extent is unknown because it was removed by pre-Dakota erosion. South of Grants it thins abruptly and apparently either wedges out about 3 miles south of U.S. Highway 66 or is nonexistent because of removal by pre-Dakota erosion. In the vicinity of Laguna it is relatively thin and locally difficult to separate from the Westwater Canyon and Brushy Basin Members.

The Recapture is generally about 200–300 feet thick, but ranges in thickness from 0 to about 600 feet. In New Mexico it is thickest in the Chuska district in western San Juan County, where it is about 500 feet thick and consists mostly of gray and buff locally conglomeratic sandstone and some interbedded mudstone and siltstone. Elsewhere it is mostly maroon and gray, relatively thin bedded, and consists of fine-grained interbedded sandstone and siltstone. Fossil plant debris, which generally consists of coalified and macerated material, occurs locally in the Chuska district where it is principally in sandstone.

Studies of the dip directions of the cross-laminae of the sandstone of the Recapture in New Mexico are available only for a few localities along the south and west margins of the San Juan Basin. In these localities dip directions that are generally northeastward indicate a southwestern source for the Recapture sediments (L.C. Craig, written commun., July 1961). Locally, however, the dip directions may differ, as in the Chuska district where the direction of streamflow in the upper ore-bearing part of the Recapture is about N. 30° W. (J. W. Blagbrough, written commun., 1959).

WESTWATER CANYON MEMBER

The Westwater Canyon Member, which overlies the Recapture, crops out in the same general areas and has about the same distribution pattern as the Recapture Member. In New Mexico, in the vicinity of the Arizona-New Mexico border, the Westwater Canyon is about 300 feet thick, from where it grades and intertongues northward into the Brushy Basin Member in southwestern Colorado. Eastward it thins and is about 100–250 feet thick on the east side of the San Juan Basin and north of Albuquerque; it is not recognizable south of Albuquerque and east of Santa Fe (L. C. Craig, written commun., July 1961). Along its south margin the Westwater Canyon thins to extinction mostly as a result of depositional thinning and partly from removal by pre-Dakota erosion. Its former southern extent is unknown but likely was near the southernmost exposures. East of Mount Taylor, in the Laguna district, it is thin, locally absent, or inseparable from the Brushy Basin and Recapture Members (Freeman and Hilpert, 1956, p. 316; Hilpert and Moench, 1960, p. 435, fig. 3; Hilpert, 1963, p. 16, fig. 2).

The Westwater Canyon Member is mostly a reddish-brown or gray medium- to coarse-grained arkosic sandstone that includes subordinate interbeds of claystone. It is conglomeratic in southwestern San Juan and western McKinley Counties, and locally conglomeratic in eastern McKinley County. It generally becomes finer northeastward. In the southern part of the Chama Basin, Rio Arriba County, it is generally fine to medium grained. The sandstone strata are composed of many lensing, cross-laminated beds having channeled scour surfaces at their bases. Dip directions of the cross-laminae have been studied in the same general localities as the Recapture Member and show a similar northeastward trend and southeastward source of the sediments, except in the Cuchillo Arroyo area north of Albuquerque where they indicate a northwestward-dipping component (L. C. Craig, written commun., July 1961). Locally, however, the trends vary somewhat from the regional pattern and this could be a local variant.

Plant material in the Westwater Canyon consists of scattered fragments of small logs or limbs, most of which are silicified, and local concentrations of coalified fragments of plants. These fragments are rather sparse in sandstone and locally are concentrated as relatively fine debris or "trash" near the base of mudstone units. Another probable plant derivative is a fine-grained black or brownish-gray material that coats the sand grains and fills the space between the grains. This material is coextensive with the uranium deposits in the Ambrosia Lake, Laguna, and Gallup districts. It is mostly a carbon compound and is almost totally insoluble in acids, alkalies, and organic solvents; its carbon, hydrogen, nitrogen, and oxygen contents are more nearly similar to those of low-rank coals than to those of petroliferous substances, in addition, infrared absorption spectrographs of this substance are more nearly like the spectrographs of low-rank coals than to those of asphaltic materials (Granger and others, 1961, p. 1196). Moreover, the presence of this material in fluvial sandstone units is more readily explained as a derivative from nearby plant materials than as an asphaltic or petroleum residue, which would have to be brought in from an external source bed, as assumed by Zitting, Masters, Groth, and Webb (1957, p. 55–56).

BRUSHY BASIN MEMBER

The Brushy Basin Member is the uppermost member of the Morrison Formation and in Arizona, Utah, and Colorado has the same general regional distribution as the Salt Wash Member (Craig and others, 1955, p. 155, fig. 29). In New Mexico, however, the Brushy Basin extends farther south and crops out in the same general areas and has about the same distribution pattern as the Recapture and Westwater Canyon Members. It generally thickens northeastward and ranges in thickness from about 100 to 300 feet, but locally is more than 500 feet. It grades at the base into, and interfingers locally with, the Westwater Canyon Member. Because the Brushy Basin and Westwater Canyon Members interfinger, the contact between them locally is determined arbitrarily. The Brushy Basin is overlain unconformably by the Dakota Sandstone of Cretaceous age which along the south margin of the San Juan Basin rests on and southward overlaps the beveled edge of the Brushy Basin.

The Brushy Basin in New Mexico consists mostly of light-greenish-gray and some varicolored claystone. The claystone is interbedded with sandstone lenses which are lithologically similar to the sandstone lenses of the Westwater Canyon.

Along the south margin of the San Juan Basin, these sandstone lenses are described later under the principal mining districts.

Another sandstone unit, which occurs at the top of the Brushy Basin in Rio Arriba County, is described because of its thickness, probable broad extent, and similarity to the other ore-bearing units. This unit directly underlies the Dakota Sandstone, and where measured at Ghost Ranch in sec. 35, T. 25 N., R. 4 E., by Craig and Freeman (Craig and others, 1959) is described as about 100 feet thick and as consisting of a white to very pale orange fine- to coarse-grained quartz sandstone that contains lenses and stringers of chert granules and pebbles and is channeled and crosslaminated. A lithologically similar unit, 124 feet thick, in the same stratigraphic position was measured by Craig (Craig and others, 1959) at Cuchillo Arroyo, near Warm Springs, on the east side of the San Juan Basin.

From available information, determination of how far north in the Chama Basin this unit might extend is somewhat speculative. Across the south margin of the basin it is apparently exposed through a distance of about 25 miles, and there is no reason to believe it extends a lesser distance to the north. Southward it could also extend continuously to the vicinity of Warm Springs and beyond, but this is only a possibility. It occurs at the same stratigraphic position as the Jackpile sandstone, an ore-bearing unit in the Laguna district, but does not connect with it. The Jackpile pinches and tongues out northward in the vicinity of Mesa Prieta, south of Warm Springs (Freeman and Hilpert, 1956; Schlee and Moench, 1961).

ROCKS OF CRETACEOUS AGE

Overlying the rocks of the Jurassic System is a sequence of near-shore marine and fluvial formations of Cretaceous age that were laid down during several southwestward transgressions and northeastward regressions of a sea that covered all of northwestern New Mexico (Sears and others, 1941). This sequence consists of gray shale, brownish-gray sandstone, and interbedded carbonaceous shale and coal and has a thickness that ranges from about 3,000 feet in Socorro and Catron Counties (Dane and others, 1957, p. 191–192) to about 7,000 feet in northern San Juan County (Reeside, 1924, p. 4–5). The complete sequence is present only in the northern part of the San Juan Basin; southward the upper formations have been removed by erosion, and east of the Rio Grande only isolated remnants crop out in the ranges and basins in Santa Fe, Sandoval, Bernalillo, and Socorro Counties.

From base to top, the formations of Cretaceous age are the Dakota Sandstone and Mancos Shale; the Gallup Sandstone, Crevasse Canyon Formation, Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone, which constitute the Mesaverde Group; and the Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, Kirtland Shale, and Ojo Alamo Sandstone. (See p. 6, this report.) The Animas Formation is described with Cretaceous formations, although it is recognized as being Late Cretaceous and Paleocene. These formations are briefly described.

DAKOTA SANDSTONE

The basal unit of Cretaceous age in northwestern New Mexico is generally referred to as the Dakota Sandstone. It crops out around the margins of the San Juan Basin and in small scattered localities in other parts of the area (Pike, 1947, p. 6–8; Dane, 1960). In the northern part of the area it rests on the Morrison Formation of Jurassic age, but in the southern part, because of pre-Dakota warping and subsequent erosion, progressively overlaps southward onto older rocks of Jurassic and Triassic ages. The Dakota consists of gray-brown quartz sandstone, some gray interbedded shale, and locally, generally near the base, conglomerate lenses and carbonaceous shale or coal. The sandstone units are crossbedded and contain numerous molds of coalified plant debris. Local scours at the base, which contain sandstone lenses that range in thickness from 20 to 50 feet and in width from 300 to 800 feet, are clustered along the outcrop in McKinley County (Mirsky, 1953). The Dakota ranges in thickness from 0 to 200 feet and averages about 100 feet. In northwestern New Mexico it was assigned a Late Cretaceous age by Cobban and Reeside (1952, chart 10b), and fossil data from the basal part near Ácoma confirm that it is not older than Late Cretaceous (Dane, 1959, p. 90). Dane and Bachman (1957b, p. 97–98), however, indicated that in the Gallup area the lower part may be Early Cretaceous in age and the upper part Late Cretaceous. They interpreted the Dakota in the Gallup area as a composite unit that is partly fluvial, partly lagoonal, and partly an offshore sandy marine unit. They interpreted the lower part as a partly fluvial deposit that may be equivalent to those deposited in marine waters that transgressed from the east and south; they interpreted the upper part as including rocks that were deposited in association with a marine transgression from the north and northeast. The age relations suggest that equivalents of the older beds near Gallup either were not deposited in the southeastern part of the area or were removed in Late Cretaceous time by the southwestward advance of the sea. The channel-filled scours at the base in McKinley County (Mirsky, 1953) probably are equivalents of the fluvial beds recognized by Dane and Bachman (1957b) in the earlier marine transgression. The highland area that contributed these sediments probably was situated west of central Arizona (Reeside, 1944).

MANCOS SHALE

The Mancos Shale (Cross, 1899) overlies the Dakota Sandstone and has a similar distribution in northwestern New Mexico (Pike, 1947). The Mancos consists of gray marine shale and subordinate amounts of fine-grained sandstone; it ranges in thickness from a few hundred feet in the southern part of the area (Dane and others, 1957, p. 186) to about 2,000 feet in the northern part (Hayes and Zapp, 1955; Wood and others, 1948).

GALLUP SANDSTONE

In the general area of the San Juan Basin and in parts of Catron and Socorro Counties, the Mancos Shale is overlain by the Mesaverde Group, which is about 1,000 feet thick and comprises, in ascending order, the Gallup Sandstone, Crevasse Canyon Formation, Point Lookout Sandstone, Menefee Formation, and the Cliff House Sandstone (Holmes, 1877, p. 244; Collier, 1919; Beaumont and others, 1956). The Gallup Sandstone (Sears, 1925), the basal formation of the group, crops out around the south and west margins of the San Juan Basin and south of the Zuni Mountains in Valencia, Catron, and Socorro Counties. It is a gray-white medium- to coarse-grained crossbedded sandstone interbedded with some shale and is locally coal bearing, generally near the top. It is about 250 feet thick near Gallup and south of the Zuni Mountains but thins northeastward and pinches out into the Mancos Shale under the San Juan Basin (Beaumont and others, 1956).

CREVASSE CANYON FORMATION

The Crevasse Canyon Formation, which overlies the Gallup Sandstone, crops out in the southern part of the San Juan Basin and in Valencia, Catron, and Socorro Counties (Allen and Balk, 1954, p. 91–92; Beaumont and others, 1956; Dane and others, 1957). It is a sequence of lenticular sandstone units, light-colored clay, and some coal beds. It has a thickness of about 750 feet in the southern part of the area, but northeastward from Gallup it thins and tongues out under the San Juan Basin (Beaumont and others, 1956). South of the basin it is only partly exposed, and in Socorro and Catron Counties most of it has been removed by erosion (Dane and others, 1957).

POINT LOOKOUT SANDSTONE

The Point Lookout Sandstone (Collier, 1919) crops out around the San Juan Basin and probably occurs as an erosional remnant in the Datil Mountains in western Socorro and eastern Catron Counties (Dane and others, 1957). The Point Lookout Sandstone is the basal formation of the Mesaverde Group in the northeastern part of the San Juan Basin where it rests on the Mancos Shale (Beaumont and others, 1956), p. 2153). In the southwestern part of the basin it rests on the Crevasse Canyon Formation which intertongues northeastward with the Mancos Shale and overlies the Gallup Sandstone, the basal formation of the Mesaverde Group in the southwestern part of the basin (Beaumont and others, 1956, fig. 3).

The Point Lookout is a gray-brown to white fine- to medium-grained thin- and parallel-bedded sandstone. It is 350 feet thick in the northeastern part of the San Juan Basin, but thins southwestward to about 100 feet along the southwestern part of the basin.

MENEFEE FORMATION

The Menefee Formation (Collier, 1919) overlies the Point Lookout Sandstone and crops out around the margins of the San Juan Basin, but has been removed by erosion farther south. From thicknesses of about 1,500 to 2,000 feet near the center of the basin the Menefee thins northward and grades into the overlying Cliff House Sandstone (Beaumont and others, 1956). The Menefee consists of gray, brown, and greenish-gray siltstone and shale, gray to buff lenticular crossbedded sandstone and coal.

CLIFF HOUSE SANDSTONE

The Cliff House Sandstone (Collier, 1919), the uppermost formation in the Mesaverde Group, overlies the Menefee Formation and crops out in western San Juan, northeastern McKinley, and northwestern Sandoval Counties, and possibly along the northeastern side of the San Juan Basin principally as the La Ventana Tongue (Beaumont and others, 1956). The La Ventana Tongue may connect westward with the Cliff House Sandstone under the basin.

Both the Cliff House Sandstone and the La Ventana Tongue are thick-bedded marine sandstone units with some shale. Both units thin northward by grading into the overlying Lewis Shale. The Cliff House Sandstone diminishes in thickness northward from about 350 feet in northeastern McKinley County, and the La Ventana Tongue thins from about 1,000 feet in northwestern Sandoval County to about 100 feet in northern Rio Arriba County.

MESAVERDE GROUP UNDIVIDED

The Mesaverde Group is shown on plate 1 in several widely separated areas as undivided. One area is in Catron and Socorro Counties and another is in southeastern and western Santa Fe Counties.

LEWIS SHALE

The Lewis Shale (Cross and Spencer, 1899) overlies the Cliff House Sandstone and crops out in San Juan, western Rio Arriba, northeastern McKinley, and northwestern Sandoval Counties. It is a gray marine shale and has a maximum thickness of about 1,500 feet in Rio Arriba County. Southwestward it grades into the Cliff House Sandstone and overlying Pictured Cliffs Sandstone (Beaumont and others, 1956; Hayes and Zapp, 1955).

PICTURED CLIFFS SANDSTONE

The Pictured Cliffs Sandstone (Holmes, 1877, p. 248; Reeside, 1924, p. 18–19) generally overlies and locally grades into the upper part of the Lewis Shale and crops out in San Juan, northern Rio Arriba, northeastern McKinley, and northwestern Sandoval Counties (Beaumont and others, 1956). It is a white to brown marine cliff-forming sandstone interbedded with some gray shale and ranges in thickness from 70 to about 400 feet (Reeside, 1924; Hayes and Zapp, 1955).

FRUITLAND FORMATION AND KIRTLAND SHALE

The Fruitland Formation, which is the lowermost, Shale crop out in San Juan, northeastern McKinley, northwestern Sandoval, and northwestern Rio Arriba Counties and overlie the Pictured Cliffs Sandstone and locally overlie the Lewis Shale (Bauer, 1916, p. 274; Reeside, 1924). Both formations are mostly fresh-water deposits and are partly fluvial.

The Fruitland Formation, which is the lowermost, ranges in thickness from 0 to about 500 feet in New Mexico and generally thins from San Juan and McKinley Counties eastward and grades out or is cut out under younger beds in Rio Arriba County (Reeside, 1924, p. 20). The Fruitland consists of gray and brown sandstone, olive-gray shale, and some coal. The sandstone units are highly lenticular, indurated, and irregularly bedded and range in thickness from a few feet to as much as 100 feet.

The Kirtland Shale ranges in thickness from 0 to about 1,200 feet in New Mexico and, like the Fruitland, thins eastward and grades out or is cut out under younger beds in Rio Arriba County (Reeside, 1924, p. 22; Dane, 1946). The Kirtland Shale overlies the Fruitland Formation in the western and southern parts of the area, but eastward and northward the two formations intergrade and are difficult to differentiate (Dane, 1946). The Kirtland is dominantly gray shale interbedded with sandstone, but contains some black carbonaceous layers. The sandstone beds are fine grained and irregularly bedded and are generally less than 20 feet thick.

OJO ALAMO SANDSTONE

The Ojo Alamo Sandstone (Brown, 1910) crops out in San Juan, northeastern McKinley, and northwestern Sandoval Counties and overlies the Kirtland Shale. The Ojo Alamo ranges in thickness from 0 to 400 feet and, from north-central San Juan County, generally thins eastward and northward and grades at the base into the underlying Kirtland Shale and into the McDermott Formation (Dane, 1936, p. 121; Hayes and Zapp, 1955). The Ojo Alamo consists of fluvial coarse-grained crossbedded buff to white arkosic sandstone interbedded with some gray and yellow shale. It is locally conglomeratic; the pebbles are well rounded and are composed of jaspery quartz, chert, vein quartz, quartzite, rhyolite, andesite, porphyry, granite, gneiss, and schist; the sandstone contains much silicified wood, largely as logs (Reeside, 1924, p. 28–30).

ANIMAS FORMATION (UPPER CRETACEOUS AND PALEOCENE)

The Animas Formation (Reeside, 1924, p. 32) crops out in western Rio Arriba County where it overlies the Fruitland Formation and overlies the Lewis Shale where the Fruitland Formation and Pictured Cliffs Sandstone are absent (Dane, 1946). In north-central San Juan County and the adjoining part of Colorado, the lower few hundred feet of the Animas, referred to by Reeside (1924, p. 24–26) as the McDermott Formation, is included in the Animas Formation as the McDermott Member (Barnes and others, 1954). On the map (pl. 1) the Animas is mapped with the Nacimiento Formation in parts of San Juan County.

In New Mexico the Animas has a maximum thickness of about 3,000 feet in Rio Arriba County near the Colorado border, from where it thins and grades southward into the Nacimiento Formation (Dane, 1946) and thins and probably grades southwestward into the Ojo Alamo Sandstone and upper part of the Kirtland Shale (Barnes and others, 1954; Hayes and Zapp, 1955). The Animas is a sequence of conglomeratic, greenish-gray, and tan sandstone, siltstone, and shale that contains considerable amounts of andesitic debris. The sandstone units, which are as much as 100 feet thick, are very lenticular, massive, coarse to fine grained, and locally contain silicified wood. The shale and siltstone contain some carbonaceous material and locally contain thin coal seams. The beds in the McDermott are generally purple, contain some well-rounded pebbles of quartz, quartzite, and chert, and are coarser grained than are other parts of the Animas.

ROCKS OF TERTIARY AGE

Rocks of Tertiary age in northwestern New Mexico are widely distributed and consist of continental sediments and igneous intrusive and extrusive rocks, locally at least several thousand feet thick. For convenience of description, the rocks are described separately for the following areas: (1) the San Juan Basin, (2) the Datil section, and (3) the Rio Grande trough and vicinity.

SAN JUAN BASIN

In the San Juan Basin the rocks of Tertiary age are all fluvial sediments and consist of the upper part of the Animas Formation (described under Cretaceous rocks), the Nacimiento Formation, and the San Jose Formation in the northeastern part of the basin and the Chuska Sandstone on the west flank of the basin.

NACIMIENTO FORMATION

The Nacimiento Formation, which includes beds equivalent to the Puerco and Torrejon Formations in the southern part of the San Juan Basin (Dane, 1936, p. 122–124; 1946), crops out in San Juan and northwestern Sandoval Counties and overlies the Ojo Alamo Sandstone. The Nacimiento is about 600 feet thick in the southern part of the area, from where it coarsens and thickens northward to about 1,000 feet and grades into the Animas Formation in Rio Arriba County (Dane, 1946). The Nacimiento Formation is a sequence of banded light- and dark-gray clay and subordinate lenses of fine- to medium-grained buff quartz sandstone. The clay is darker and somewhat carbonaceous near the base, and the sandstone is clayey, crossbedded, very lenticular, and most abundant in the upper part.

SAN JOSE FORMATION

The San Jose Formation crops out in northeastern San Juan, northwestern Sandoval, and western Rio Arriba Counties; it unconformably overlies the Nacimiento and Animas Formations and is the uppermost unit of Tertiary age in the northeastern part of the San Juan Basin. The San Jose principally is interbedded gray, purple, and varicolored shale or clay, and interbedded copper-red, gray, and white, conglomeratic sandstone units, and has a total thickness of about 3,000 feet (Dane, 1946; Simpson, 1948). The sandstone units generally are arkosic, contain some thin interbedded clays, locally contain coalified wood or plant fragments, and are massive, crossbedded, lenticular, and as much as 100 feet thick.

CHUSKA SANDSTONE

The Chuska Sandstone (Gregory, 1917, p. 80), of Pliocene (?) age, crops out near the Arizona line in the Chuska Mountains in San Juan and McKinley Counties, where it rests on the beveled edge of Cretaceous rocks. It is a light-gray to light-brown thin- to thick-bedded sandstone and contains some interbedded siltstone and shale. It ranges in thickness from about 700 to 900 feet and is fluvial and perhaps partly eolian in origin (Allen and Balk, 1954, p. 99). Carbonaceous material has not been noted in the Chuska.

DATIL SECTION

Rocks of Tertiary age in the Datil section consist mostly of the fluvial Baca Formation of Eocene(?) age and the overlying volcanic rocks of the Datil Formation of late Tertiary age and total about 3,000 feet in thickness.

BACA FORMATION

The Baca Formation crops out in northern Catron and west-central Socorro Counties as a discontinuous westward-trending belt, where it overlies beveled Cretaceous rocks. It crops out locally east of the Rio Grande, where it overlies beveled Mesozoic and Paleozoic rocks. The description of the Baca at the type section, in the north Bear Mountains, and east of the Rio Grande is taken from Wilpolt, MacAlpin, Bates, and Vorbe (1946) and Wilpolt and Wanek (1951). West of the Rio Grande, except at the type section, the description is from G. O. Bachman, E. H. Baltz, and R. L. Griggs (written commun., 1957).

At the type section and in the area east of the Rio Grande the Baca consists of coarse conglomerate, red and white sandstone, and red clay. The conglomerate contains abundant pebbles, cobbles, and boulders, which were derived from Precambrian quartzite and granite, Pennsylvanian limestone, and detritus from the Permian Abo Formation. West of the Bear Mountains the Baca consists of salmon-pink medium- to coarse-grained cross-laminated sandstone, salmon-pink to distinctive dark-red interbeds of shale and siltstone, and a few interbeds of gray shale. Pebble conglomerate, chiefly composed of quartzite, occurs near the top of the formation locally. In places, carbonaceous material is abundant in association with gray shale and as detritus in sandstone.

East of the Rio Grande the Baca Formation ranges in thickness from 80 to 140 feet, and south of the map area near Carthage, N. Mex., it is about 1,000 feet thick (Gardner, 1910, p. 454). West of the Rio Grande the Baca is about 700 feet thick at the type section and is estimated to be about 1,500 feet in the northern part of the Datil Mountains. In the vicinity of Carthage the Baca is late Eocene in age and may be the same age in other parts of Socorro County and in Catron County.

DATIL FORMATION

The Datil Formation crops out extensively in Socorro and in Catron counties; locally it is conformable on the Baca Formation in the Datil Mountains, but elsewhere overlaps the Baca and is unconformable on the beveled edges of Mesozoic and Paleozoic rocks (Winchester, 1920; Wilpolt and others, 1946; Wilpolt and Wanek, 1951; G. O. Bachman, E. H. Baltz, and R. L. Griggs, written commun., 1957).

The Datil Formation consists of purple, and lesser amounts of red and gray, volcanic flows, agglomerates, welded tuffs, and tuffs of felsic and mafic composition and some conglomerate and sandstone. It ranges in thickness from 0 to about 2,000 feet.

RIO GRANDE TROUGH AND VICINITY

Rocks of Tertiary age in the Rio Grande trough and vicinity are a heterogeneous assortment of fluvial sediments, water-laid volcanic debris, and locally, volcanic flows and breccias that are at least several thousand feet thick. These rocks are described below under "Older Volcanic Rocks of Jemez Mountains," "Galisteo Formation," "Espinaso Volcanics of Stearns (1943)," "Popotosa Formation," and "Santa Fe Group." Intrusive rocks of varied composition and form occur locally, but are described in the section that follows.

OLDER VOLCANIC ROCKS OF JEMEZ MOUNTAINS

The rocks that crop out in the Jemez Mountains area, northeastern Sandoval and southeastern Rio Arriba Counties, consist mostly of a sequence of rhyolitic to basaltic flows, pyroclastics, and intrusives, of Tertiary and Quaternary ages, and some prevolcanic sedimentary rocks. The oldest of these igneous rocks and the prevolcanic sedimentary rocks are included on plate 1 as "Older Volcanic Rocks of the Jemez Mountains."

GALISTEO FORMATION

The Galisteo Formation crops out along the east side of the Rio Grande northeast of the Sandia Mountains in southeastern Sandoval and western Santa Fe Counties, where it rests unconformably on the Mancos Shale and Mesaverde Group (Stearns, 1943). The Galisteo ranges in thickness from 900 feet along its northwest margin in Sandoval County to more than 4,000 feet along its southeast margin in Santa Fe County (Stearns, 1943, p. 309). It consists of fluvial sandstone and conglomerate, clay, and some limestone and water-laid tuff. The sandstone is gray to buff, locally pink, and is quartzose and locally arkosic. Silicified wood is abundant in many sandstone beds, and coalified plant debris occurs locally. The conglomerate pebbles consist chiefly of chert and quartzite, but locally also consist of granite, porphyry, metamorphic rocks, and some limestone (Stearns, 1943).

The Galisteo is late Eocene in age according to Stearns (1953, p. 467) and possibly correlative in age with the Baca Formation (Wilpolt and others, 1946) and may be as young as Oligocene.

ESPINASO VOLCANICS OF STEARNS (1943)

The Espinaso Volcanics of Stearns (1943), which are 400 to about 1,500 feet thick, crop out locally north and west of the Ortiz Mountains, Sandoval and Santa Fe Counties, and overlie the Galisteo Formation (Stearns, 1953, p. 467; Disbrow and Stoll, 1957, p. 11–12). The Espinaso Volcanics are latitic and consist of water-laid volcanic breccia, conglomerate, tuff, and some flows (Stearns, 1953). The Espinaso are mapped on plate 1 with the Santa Fe Group undivided. Age of the Espinaso Volcanics is uncertain. The formation is assigned to late Eocene by Stearns (1953, p. 467–468), and to Oligocene (?) by Disbrow and Stoll (1957). From indirect evidence (Sun and Baldwin, 1958, p. 7–23; Spiegel and Baldwin, 1963, p. 37), it could range from Oligocene to late Miocene.

POPOTOSA FORMATION

The Popotosa Formation, of late Miocene age, crops out along the west side of the Rio Grande trough in Socorro County, rests unconformably on volcanic breccia and consists of water-laid volcanic debris and gray and buff tuffaceous sandstone, siltstone, and conglomerate. It has a total thickness of 3,000–5,000 feet (Denny, 1940). The sandstone lenses in the Popotosa are generally crossbedded, very lenticular, and contain scattered plant remains.

SANTA FE GROUP (MIOCENE TO PLEISTOCENE?)

The Santa Fe Group (Baldwin, 1956) crops out in the Rio Grande trough and vicinity from Rio Arriba to Socorro Counties, unconformably overlies the Cieneguilla Limburgite of Stearns (1953), the Espinaso Volcanics of Stearns (1943, p. 316), and the Popotosa Formation, and has a total thickness of at least several thousand feet. The Santa Fe Group consists of fluvial, reddish-brown, buff, and gray unconsolidated sandstone, siltstone, claystone, conglomerate, and locally tuff, andesite, and other volcanic rocks. In age the group varies from place to place but probably ranges from late Miocene to late Pliocene and possibly extends locally into middle (?) Miocene and Pleistocene (?) (Spiegel and Baldwin, 1963, p. 62–63). For a more detailed description of the Santa Fe Group and its relations to the Espinaso Volcanics and Cieneguilla Limburgite, see Spiegel and Baldwin (1963, p. 21–78), Sun and Baldwin (1958, p. 7–18), and Disbrow and Stoll (1957).

INTRUSIVE ROCKS OF VARIED COMPOSITION AND FORM

Most of the larger outcrops of intrusive igneous rocks of Tertiary age in northwestern New Mexico are shown in red on plate 1. These rocks are widely distributed and are of felsic, mafic, and intermediate composition. They range from dikes and sills to irregular necklike, domelike, or laccolithic bodies and stocks; they intrude rocks that range in age from Paleozoic to Tertiary.

STRUCTURE

The principal structural features of northwestern New Mexico are roughly outlined by the boundaries of the physiographic provinces (fig. 1). These features are: (1) The San Juan basin and adjoining uplifts and the Datil-Mount Taylor volcanic field, in the Colorado Plateaus province; (2) the fault-block mountains and intervening depressions of the Basin and Range province; and (3) the domal ranges and intervening basins of the Southern Rocky Mountains province.

The San Juan basin is a broad saucer-shaped structural feature that constitutes about one-third of the mapped area and that extends northward into southern Colorado. It is characterized by Paleozoic, Mesozoic, and Tertiary sedimentary beds which are several thousand feet thick and which dip gently from the basin margins toward the center, and by relatively small elongate domes or uplifts and synclinal depressions around the margins of the basin. These uplifts and depressions have areal dimensions that are generally tens of miles across (fig. 3).

The principal uplifts are the Zuni, Defiance, Lucero, Nacimiento, and San Juan. The Nacimiento and San Juan uplifts are in the Southern Rocky Mountains province, but are included here for descriptive purposes. The Zuni uplift is on the southwestern side of the San Juan basin and is elongate northwestward; the Defiance, Nacimiento, and Lucero uplifts are on the west, east, and southeast sides of the basin, respectively, and are elongate northward; the San Juan uplift is on the northeast side of the basin, trends northwestward, and is mostly in Colorado.

The principal structural depressions around the San Juan basin are the Chama basin, the Gallup and Ácoma sags, and the McCartys syncline. The Chama basin is a synclinal structure on the northeast side of the San Juan basin; it is cradled between the north end of the Nacimiento uplift and the west flank of the San Juan uplift, and trends northward. The McCartys syncline, which is on the southeast side of the San Juan basin, lies between the Zuni and Lucero uplifts in the west side of the Ácoma sag, and plunges northward. The Gallup sag is a synclinal depression that lies between the Zuni and Defiance uplifts.

Other structural features that are marginal to the San Juan basin and adjoining uplifts are monoclinal folds, which are comparable in length to the uplifts and generally dip basinward from the flanks of the uplifts. Most prominent of these is the Hogback monocline which strikes northeastward along the northwest margin of the basin, the Defiance monocline which generally strikes northward along the east flank of the Defiance uplift, the Nacimiento monocline which strikes northward along the west flank of the Nacimiento uplift, and the Nutria monocline which strikes northwestward and dips westward along the west end of the Zuni uplift. These monoclines generally dip steeply, are overturned and faulted locally, and are crenulated by numerous cross folds.

Also marginal to the San Juan Basin are several relatively small domal or anticlinal structures which are generally a few square miles in areal dimension. Of these structures, the Ambrosia dome is of particular interest because of the uranium deposits that occur on its flanks and in its general vicinity. Numerous volcanic structures are also marginal to the basin and the adjoining domal and synclinal structures and consist of the dioritic and partly laccolithic intrusives of the Carrizo Mountains and widely distributed mafic necks, dikes, and sills.

The Datil-Mount Taylor volcanic field generally lies in the Datil volcanic section of the Colorado Plateaus province and is marked by a sequence of flat-lying lavas and some continental sediments of Tertiary and Quaternary ages. These beds total several thousand feet in thickness and generally cover flat-lying marine and continental rocks of late Paleozoic, Mesozoic, and early Tertiary ages.

The structure of the Basin and Range province is marked by northward-trending fault-block mountains and intervening depressions. The Sandia, Manzano, and Los Pinos Mountains are the principal mountain blocks. They have Precambrian cores, which are capped by marine and continental beds that are several thousand feet thick, generally dip eastward, and are mostly late Paleozoic and Mesozoic in age. The structures of the depressions are grabens, tilted fault blocks, and faulted synclinal folds. Only the upper parts of these structures, which consist of continental sedimentary and some volcanic rocks of Tertiary and Quaternary ages, are exposed. The largest of these structures is the graben of the Rio Grande trough which, in the mapped area, extends along the west side of the province northward into the Southern Rocky Mountains province and is composed of a fill that totals several thousand feet in thickness. Marginal to the Rio Grande trough and the Datil section are several monzonitic stocks and associated igneous intrusives, and also marginal to it are the monozonitic laccoliths and associated intrusives of the Ortiz Mountains and Cerrillos Hills in Santa Fe County and the Valles caldera in northeastern Sandoval County.

The principal structures in the Southern Rocky Mountains province are the archlike Sierra Nacimiento, the San Pedro and the south end of the San Juan Mountains, and the structural depression of the north end of the Rio Grande trough. The mountains in this province have Precambrian cores that are

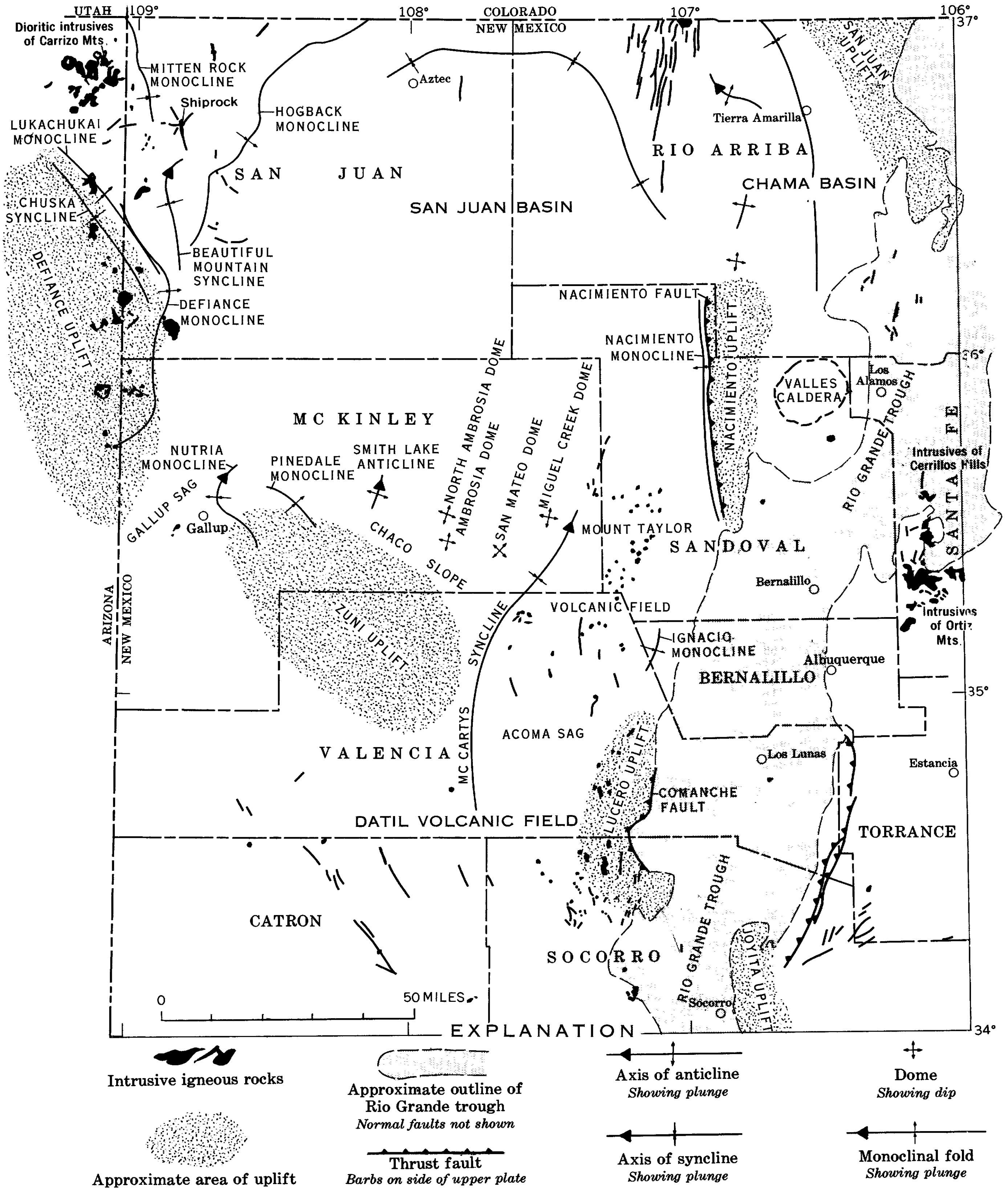


FIGURE 3.—Principal structural elements in northwestern New Mexico and adjoining areas. Modified from Kelley (1954; 1955, fig. 2); O'Sullivan and Beaumont (1957); Dane and Bachman (1957a); and O'Sullivan and Beikman (1963, sheet 2).

draped on their flanks with marine and continental beds of late Paleozoic and Mesozoic ages and some volcanic rocks of Tertiary and Quaternary ages. The rocks of the Rio Grande trough, as farther south, are composed of continental sediments and volcanic debris. The west part of the trough and the east flank of the Sierra Nacimiento are covered by the volcanic pile of the Jemez Mountains which are associated genetically with the Valles caldera.

The principal faults in northwestern New Mexico are concentrated mostly along the periphery of the Rio Grande trough, along the flanks of the ranges of the Southern Rocky Mountains province, and to a lesser extent in the east and northeast flanks of the Zuni uplift and south margin of the San Juan Basin. Most of the faults are normal and high angle and can be traced along the strike for distances of as much as several tens of miles. In the Colorado Plateaus province the faults rarely have a stratigraphic throw of more than a few hundred feet, but in the other provinces the throw on some faults is as much as several thousand feet.

Thrust faults are less common, but one occurs along the west margin of the Southern Rocky Mountains province, and several occur in the Basin and Range province. The most conspicuous thrust fault strikes northward for more than 50 miles along the west flank of the Sierra Nacimiento and the San Pedro Mountains. It dips steeply eastward and generally separates Precambrian crystalline rocks and pre-Triassic sedimentary rocks on the east from Permian and younger rocks on the west (Northrop and other, 1946). Other conspicuous thrusts occur on opposite sides of the Rio Grande trough. One skirts the east flank of Lucero Mesa for a distance of about 20 miles and, at different places along the strike, dips westward from low to high angle, and separates Precambrian and younger rocks on the west from Triassic and younger rocks on the east (Kelley and Wood, 1946). Other thrusts skirt the east flank of the Los Pinos and Manzano Mountains, generally extend along the strike for 10–15 miles, and dip steeply westward. They generally separate Precambrian rocks on the west from Paleozoic rocks on the east (Read and others, 1944; Wilpolt and others, 1946; Wilpolt and Wanek, 1951). The age relations and dating of the various structural features are discussed in the geologic history which follows.

GEOLOGIC HISTORY

The following résumé of the geologic history of northwestern New Mexico is intended to provide a background for understanding the relations of the uranium deposits to the host rocks and to the sedimentary, tectonic, and igneous structural features. Where pertinent, more detail is given under the descriptions of the mining districts and the areas containing the deposits.

The record of the Precambrian Era is obscure, but it has been long and complex and has been marked by deformation, metamorphism, and intrusion by granite and associated rocks. Associated with some of the granite in the eastern part of Rio Arriba County were injections of uraniferous pegmatite and uraniferous fluorite and quartz veins.

The Precambrian rocks subsequently were eroded to a peneplain; after this erosion period, the area was probably a stable shelf for most of the Paleozoic Era, (Kelley, 1955, p. 75). Some marine waters encroached on the northern part of the area at various times, probably during the Cambrian and again during the Devonian and Mississippian (Bass, 1944; Strobell, 1958; Baltz and Read, 1960), but the rocks that were deposited are not exposed at the surface and the record for northwestern New Mexico has been determined only from minimal well data and by projection from adjacent areas. The rocks that were deposited during this time interval comprise unnamed Cambrian(?) clastics, the Elbert Formation, the Ouray Limestone, and the Leadville Limestone.

During Mississippian time, marine waters also encroached on the eastern part of the area and the limestone and associated clastics of the Caloso Formation of Kelley and Silver (1952), Kelly Limestone, and Arroyo Penasco Formation were deposited.

During late Paleozoic time, two positive structural features began to form; these have persisted intermittently, with modifications, to the present and have had considerable influence on subsequent geologic events. One of the features, the antecedent of the San Juan uplift and generally known as the San Luis-Uncompahgre uplift, was an elongate arch which began to form in Early Pennsylvanian time (W. W. Mallory, oral commun., 1963) and which extended from the northeastern part of the area northwestward into Colorado. The other feature, the antecedent of the Zuni and Defiance uplifts, emerged as a broad upwarp about the same time and extended from about the present position of the Zuni Mountains northwestward into Arizona. Between these two uplifts a trough formed in Early Pennsylvanian time that extended northward through the central part of the area and received marine and continental sediments of Pennsylvanian and Permian ages. These sedimentary deposits include, in the southern part of the area, the Sandia Formation, Madera Limestone, Abo and Yeso Formations, Glorieta Sandstone, and San Andres Limestone, and in the northern part of the area, the Molas, Hermosa, Rico, and Cutler Formations. Locally the sedimentation of the upper part of the Madera Limestone and the overlying Abo and Yeso Formations was affected by a positive structural feature that formed in the vicinity of the Joyita Hills (Wilpolt and others, 1946).

Another positive structural feature also was elevated in Pennsylvanian time near the center of the trough and extended northward through the approximate position of the present Nacimiento and San Pedro Mountains area. This structure was antecedent to the Nacimiento uplift, and its position is marked by nondeposition of the upper part of the Madera Limestone and the interbedding of clastic materials with the limestone in the periphery of the uplift (Wood and others, 1946).

The antecedent Zuni and Nacimiento uplifts became buried by Early Permian time and, during the latter part of the Permian and Early Triassic, the Early Permian and older rocks were deformed and beveled. About Middle Triassic time, after the Moenkopi Formation was deposited, the San Juan highlands and other highlands to the southeast of the area were upwarped. Upwarping was accompanied by some volcanic activity elsewhere to the south and southeast of the mapped area (Allen, 1930; Stewart and others, 1959, p. 566).

Northwestern New Mexico at this time was part of a broad plain that sloped westward into Arizona and northwestward into Utah and Colorado. This plain received clastic debris from the highlands to the southeast and northeast and received volcanic debris from the south and southeast; the clastic and volcanic debris formed deposits that now constitute the Chinle Formation and part of the Dockum Formation. The Shinarump Member and Poleo Sandstone Lentil of the Chinle probably had a source in highlands to the south (McKee and others, 1959, p. 22). The northern part of the Agua Zarca Sandstone Member, as recognized by Wood, Northrop, and Cowan (1946), was derived from highlands to the north, and the southern part of the member from highlands to the south (F. G. Poole, written commun., 1957).

Relatively stable conditions existed during Late Triassic and Early Jurassic time and the highland areas were reduced to low relief. On the old flood plain the Wingate and Entrada Sandstones accumulated principally from wind action.

In Late Jurassic time the Zuni uplift was rejuvenated and a broad shallow basin and flood plain was formed to the north. This plain extended into northeastern Arizona, southeastern Utah, and southwestern Colorado. In the basin the Entrada Sandstone, Todilto Limestone, Summerville Formation, Bluff Sandstone (mapped with the Zuni Sandstone on pl. 1), and the Morrison Formation were deposited. The basin was above sea level, except for a time that a shallow embayment opened to the west and permitted entrance of marine waters in which the Summerville Formation and possibly the Todilto Limestone were deposited (Harshbarger and others, 1957; Anderson and Kirkland, 1960). Some volcanic activity, possibly to the southwest of the basin of deposition, accompanied the Morrison deposition.

At the time of deposition of the Jurassic rocks the junction of the uplift, or highland, and the basin areas was within a general zone now marked approximately by the southern outcrop of the Jurassic rocks. This junction is indicated by the depositional margin of the Todilto Limestone (Rapaport and others, 1952), local conglomerate facies of the Summerville on its south margin, general coarsening of the Morrison southward (Craig and others, 1955), and local pinching of the Morrison southward against the Bluff Sandstone (Thaden and Santos, 1957).

While the Jurassic sediments were being deposited, the basin receiving them slowly and differentially subsided as the highland area was rising. These movements caused flexing or broad folding. The flexures occur along the south margin of the San Juan Basin near the probable margin of the old Jurassic basin (Hilpert and Moench, 1960). They probably were concentrated along the marginal zone of the old basin because this would be the zone of maximum differential movement between the basin and the highland area. As the flexures formed, they probably partly controlled the course of the streams that deposited the Morrison sands and influenced the accumulation of the sand units because the foreset beds in the sandstone units show a dominant eastward dip and the sandstone units show an eastward elongation (Rapaport and others, 1952, p. 31–32; Mathewson, 1953; Sharp, 1955, p. 8, 11; Hilpert and Moench, 1960).

The flexing may also have formed local basins in which units like the Jackpile sandstone, of local usage, accumulated (Moench and Schlee, 1959). Such sandstone units contain the largest uranium deposits known in northwestern New Mexico. The flexing may also have helped initiate the development of the Ambrosia dome and other similar structural features in the general vicinity. Moreover, intraformational folds in the Todilto Limestone and pipelike collapse features in sandstones of the Summerville, Bluff, and Morrison Formations probably were caused by or related to this flexing.

In Late Jurassic or Early Cretaceous time the southern highland area and basin margin were tilted upward and beveled, and all formations down to the Abo Formation were progressively cut out southward. Gradual subsidence followed the beveling, and a wide seaway then encroached on the entire area of northwestern New Mexico and adjoining regions. The sea spread gradually from the southeast and the northeast and left a sequence of near-shore continental and shallow marine sediments. These sediments range from the Dakota Sandstone at the base to the Pictured Cliffs Sandstone and total several thousand feet in thickness. Deposition occurred during several transgressions and regressions of the shoreline (Sears and others, 1941); these fluctuations were accompanied by settling of the basin and differential uplift of a rather extensive highland to the southwest which contributed the sediments.

In Late Cretaceous time, as the seas gradually withdrew, the continental Fruitland Formation and Kirtland Shale were deposited. Probably late in this interval, tectonic activity, accompanied by volcanism, in the San Juan Mountains area marked the emergence of the San Juan uplift (Hayes and Zapp, 1955). About the same time or shortly thereafter, the Defiance, Zuni, Lucero, and Nacimiento uplifts emerged, which caused the initial shaping of the San Juan basin; the filling of the basin then progressed by deposition of the continental beds of the Ojo Alamo Sandstone, Animas, Nacimiento, and San Jose Formations from debris shed by the uplifts. A pulselike rise of the uplifts is indicated by the beveling of the older formations by the younger around the basin margins (Hunt, 1956, p. 23–24).

The Late Cretaceous and early Tertiary tectonic events, generally referred to as the Laramide orogeny, are important in helping establish the ages of emplacement of many of the uranium deposits. Structural features that formed during this interval are the monoclinal folds on the basin sides of the uplifts that are marginal to the San Juan Basin, the depressions, or sags, between the adjacent uplifts, and the faults related to the development of these features. These features probably formed in accompaniment with the marked rise of the uplifts that flank the basin. This interval is dated by the Nacimiento Formation of Paleocene age which was deposited during initial deepening of the basin. This deepening was largely concluded by the time of deposition of the San Jose Formation of early Eocene age which lies across the beveled beds of the Nacimiento Formation.

Structural features related to this age of tectonism are the Defiance, Nutria, and other similar monoclinal folds, the Ácoma and Zuni sags, and the McCartys syncline and the faults, fractures, and related folds along the syncline's western flank.

Thrust faults probably formed during this time (Wood and others, 1946; Kelley and Wood, 1946; Wilpolt and Wanek, 1951). Some normal faults may also have formed as early as the thrusts, but the normal faults generally are younger because they displace the thrusts (Kelley and Wood, 1946; Wilpolt and Wanek, 1951) and generally range in age from early Tertiary to Quaternary.

After the San Jose Formation was deposited, tilting of the San Juan Basin northward reversed the dip direction of the San Jose (Hunt, 1956, p. 25, 57). Some folding or faulting may have accompanied this tilting and perhaps the McCartys syncline and associated folds and fractures evolved at this time (Hunt, 1938, p. 75), and the Ambrosia dome and other similar structural features were accentuated. It seems more reasonable, however, to relate all these structural events with the preceding rise of the uplifts rather than tie them to simple tilting. The tilting and related events occurred in the post-early Eocene pre-late Miocene time interval because they postdate the San Jose Formation and precede the faulting of the Santa Fe Group along the Rio Grande trough.

In late early Tertiary time, probably during the Oligocene, volcanic activity began in the east-central part of the area and was followed in late Tertiary and Quaternary time by intermittent but widespread volcanic activity throughout much of northwestern New Mexico. The early activity left the laccolithic intrusives and associated volcanic rocks of the Ortiz Mountains and Cerrillos Hills and the dioritic intrusives of the Carrizo Mountains.

The late Tertiary and Quaternary activity left the extensive Datil-Mount Taylor volcanic field, the intrusive bodies, flows, pyroclastic rocks, and outwash debris along the Rio Grande trough, and the dikes, sills, necks, and flows around the periphery of the San Juan Basin.

The Espinaso Volcanics probably were deposited during the Oligocene, about the same time that the intrusive rocks of the Ortiz Mountains and Cerrillos Hills were emplaced (Stearns, 1943, p. 309; Disbrow and Stoll, 1957, p. 10–12, 33–34). These events were probably closely followed by emplacement of the base-metal deposits in the Los Cerrillos district (Lindgren and others, 1910, p. 167; Disbrow and Stoll, 1957, p. 46). Possibly about the same time, and somewhat later, the Datil Formation and related intrusive rocks were emplaced (Winchester, 1920, p. 9; Wilpolt and others, 1946). Late in this episode or soon thereafter, the base- and precious-metal vein and replacement deposits of the several mining districts in Socorro County were formed (Lindgren and others, 1910, p. 255; Loughlin and Koschmann, 1942, p. 56).

The dioritic and partly laccolithic intrusives of the Carrizo Mountains intrude the Mancos Shale, so are certainly Late Cretaceous or younger. More specifically their age is based indirectly on ages determined for similar intrusives elsewhere in the Colorado Plateau and adjacent areas. The oldest age for such rocks was considered to be Late Cretaceous for some of the intrusives in the La Plata Mountains of southwestern Colorado. Shoemaker (1956, p. 162) based this age on the correlation of diorite porphyry debris in the McDermott Member of the Animas Formation, assumed to have been derived from the La Platas. Other dates are younger and firmer. On geomorphic evidence, Hunt, Averitt, and Miller (1953, p. 212) inferred the Henry Mountains intrusives of south-central Utah to be middle Tertiary in age. The laccoliths of the West Elk Mountains in west-central Colorado are Eocene in age or younger because they intrude the Wasatch Formation (Godwin and Gaskill, 1964). More recently, isotopic age dates indicate that the La Sal Mountains laccoliths in southeastern Utah are late Oligocene to Miocene in age (Stern and others, 1965). The laccolithic intrusives of the Ortiz and Cerrillos Hills, which lie immediately southeast of the Colorado Plateau (fig. 3), also fit this general age pattern. They intrude the Galisteo Formation of late Eocene age (Stearns, 1943, p. 309) and are considered to be Oligocene in age (Disbrow and Stoll, 1957, p. 10–12, 33). It appears by analogy, therefore, that the dioritic, laccolithic, and related rocks of the Carrizo Mountains are most likely early to middle Tertiary in age, but could possibly be as old as Late Cretaceous.

In late Tertiary time, probably middle or late Miocene, widespread differential movements were initiated that were marked by uplift, some warping, and normal faulting, and these continued intermittently until at least the end of Tertiary time. The displacements defined the structural boundaries between the Basin and Range, Colorado Plateaus, and Southern Rocky Mountains provinces. During this time volcanic activity continued, and from the adjoining uplifts and volcanic centers the Rio Grande trough and adjoining areas received several thousand feet of alluvial and volcanic debris, including the materials in the Popotosa Formation and the Santa Fe Group.

URANIUM DEPOSITS

A uranium deposit as defined for this report is an occurrence that either has a content of 0.02 percent or more U_3O_8 by analysis or contains an identifiable uranium-bearing mineral. Such deposits occur in about 30 formational units, in seven principal lithologic types of host rocks, and in rocks of seven geologic periods. The host rocks and their ages are classified by symbols in plate 1 and, by number, the symbols show the deposits of mine rank. About 500 deposits or groups of deposits are represented, and the name, location, and a brief description of each is given in table 4. The information is summary and, between different deposits, is somewhat variable because of diverse source data and some company restrictions on publication of data on deposits, particularly subsurface data. Reference is made to the published literature for details on the more important deposits.

For descriptive purposes the uranium deposits are broadly classified as peneconcordant and vein types. By far the larger, more productive, and more abundant are the peneconcordant deposits. (Finch, 1959) which occur in sedimentary rocks and are generally concordant with the bedding, but in detail cut across it. The discordance indicates that the deposits were formed after the sediments accumulated. They differ from vein deposits in that fractures and faults have had only a subordinate or indirect influence in controlling them. The deposits occur mostly in sandstone and have been referred to as carnotite-, sandstone-, and plateau-type deposits; they also occur in limestone and in scattered localities in carbonaceous shale and coal. Vein deposits consist of fracture fillings, stockworks, mineralized breccia, and pegmatite occurrences. They occur in sedimentary, igneous, and metamorphic rocks and differ from peneconcordant deposits in their tendency to be controlled principally by fractures and in their general discordance with the bedding of the sedimentary rocks.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*

Deposit: Alternate names are shown in parentheses. Number in parentheses (*3*) is mine locality number shown on plate 1.

Location: Asterisk (*) indicates land unit is unsurveyed and projected.

Description of deposit and sample: Formal members of the Morrison Formation are abbreviated: Jms, Salt Wash; Jmr, Recapture; Jmw, Westwater Canyon; Jmb, Brushy Basin. Informal units are abbreviated: Jmj, Jackpile sandstone of economic usage; Jmpc, Poison Canyon sandstone of economic usage. Size ranges of deposits are: Small, less than 1,000 tons; medium, 1,000 to 100,000 tons; large, more than 100,000 and less than 1 million tons; and very large, 1 million tons or more. For prospects, highest grade sample data available are listed: U or U_3O_8=chemical assay; eU_3O_8=radiometric assay.

Source of data: WC, written communication; OC, oral communication; FN, author's field notes; DH, drill-hole data; AEC, U.S. Atomic Energy Comm.; publication cited refers to that listed in accompanying bibliography.

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Bernalillo County	
Cerro Colorado-Archuleta prospect (LW claims).	*SW¼NW¼ 1	9 N.	1 W.	Yellow and yellow-green uranium minerals occur in limonite-stained fractures and brecciated pockets in rhyolitic mass about 2,000 ft in diameter and 300 ft high that intrudes the Santa Fe Group. Mineralized areas are small pockets in fracture zones that occur along or near eastern contact of what Wright (1943) interpreted as a central plug of quartz latite that intrudes older trachyte flows and volcanic breccia. Contact zone strikes northeastward and dips steeply northwestward. The radioactivity may be related to a smaller intrusive (about 300 ft in diameter) that occurs on the northeastern margin of what is interpreted as Wright's quartz latite. This small intrusive generally has a higher background count than other parts of the whole general mass and the generally vertical fractures in the smaller intrusive have a count that is tenfold those in the fractures of the larger intrusive body. Prospect workings consist of several shallow prospect pits and a 75-ft adit, which is immediately west of smaller intrusive. Grab sample, 0.28 percent U.	FN, 1958; Wright (1943). Analysis by J. P. Schuch and J. S. Wahlberg.
Unnamed	SE¼ 22	10 N.	5 E.	Radioactive jasperized fossil logs, about 150 ft above base of Abo Formation in pink argillaceous arkosic sandstone. Malachite and azurite occur on surface of log. Occurrence is old copper prospect. Sample of jasperized wood, 0.06 percent U.	E. H. Baltz, Jr., and H. D. Zeller (WC, 1953).
				Catron County	
Drag A Ranch	31	2 N.	9 W.	Radioactive zone in sandstone in Mesaverde Group. Grab sample of lower 3 in. of bed, 0.026 percent U.	G. O. Bachman, E. H. Baltz, and R L. Griggs (WC, 1957).
Unnamed	31	2 N.	9 W.	Radioactive black zone in massive gray sandstone of Baca Formation. Grab sample, 0.029 percent U.	Do.
Red Basin 1 (*3*)	SE¼NE¼ 19	2 N.	10 W.	Yellow-green uranium minerals, associated with carbonaceous material, occur in gray lenticular sandstone at base of Baca Formation. Deposit extends along outcrop for about ½ mile and back from outcrop several hundred feet locally. Ore mined from open pit, 1954.	Do.
Unnamed	NW¼ 19	2 N.	10 W.	Radioactive zone in lower 8 in. of sandstone in Point Lookout(?) Sandstone. Sample, 0.022 percent U.	Do.
Do	19	2 N.	10 W.	Radioactive zones in two sandstones, separated by 25-ft stratigraphic interval, in Mesaverde Group. Grab sample, 0.022 percent U. Lower zone may be stratigraphic equivalent of zone noted above.	R. L. Griggs (WC, 1953).
Red Basin 2	CW½W½ 20	2 N.	10 W.	Yellow-green uranium minerals associated with carbonaceous material in conglomeratic sandstone near base of Baca Formation. Several deposits are in vicinity, and this deposit may be extension of Red Basin 1. (See above.) Sample of drill cuttings, 0.40 percent U.	G. E. Collins (WC, 1954). G. O. Bachman, E. H. Baltz, and R. L. Griggs (WC, 1957).
Unnamed	W½SW¼ 20	2 N.	10 W.	Radioactive zone in Point Lookout(?) Sandstone. Sample of drill cuttings, 0.12 percent U.	G. O. Bachman, E. H. Baltz, and R. L. Griggs (WC, 1957).
Do	NW¼NE¼ 27	2 N.	10 W.	Radioactive zone in sandstone in Point Lookout(?) Sandstone. Grab sample, 0.14 percent U.	Do.
Do	SE¼SE¼ 27	2 N.	10 W.	Radioactive zone in sandstone in Point Lookout(?) Sandstone. Grab sample, 0.026 percent U.	Do.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Catron County—Continued	
Unnamed	CNE¼ 35	2 N.	10 W.	Radioactive zone in lower 3 in. of sandstone in Point Lookout(?) Sandstone. Sample, 0.05 percent eU.	R. L. Griggs (WC, 1954).
Do	CW½E½ 11	2 N.	11 W.	Radioactive zone in sandstone in upper part of Point Lookout(?) Sandstone. Sandstone contains carbonized fossil logs and thin lenses of carbonaceous shale. Yellow uranium mineral occurs on weathered faces of carbonaceous shale lenses, where most radioactivity detected. Grab sample of carbonaceous shale, 0.33 percent U. Grab sample of sandstone, 0.06 percent U.	G. O. Bachman, E. H. Baltz, and R. L. Griggs (WC, 1957).
Midnight 2 (*5*)	W½NW¼ 12	2 N.	11 W.	Tyuyamunite in carbonaceous sandstone of Point Lookout(?) Sandstone. U:V ratio about 1:2. Ore mined in 1957.	G. O. Bachman, E. H. Baltz, and R. L. Griggs (WC, 1957); U.S. Bur. Mines, amenability test no. 418.
Unnamed	NE¼NE¼ 14	2 N.	11 W.	Radioactive carbonaceous zone, about 3 in. thick, in sandstone at base of Point Lookout(?) Sandstone. Selected sample, 0.06 percent U.	G. O. Bachman, E. H. Baltz, and R. L. Griggs (WC, 1957).
McPhaul adit	CE½E½ 14	2 N.	11 W.	Uranium is concentrated in ferruginous zone, 1–3 in. thick, at base of Point Lookout(?) Sandstone. Radioactivity is most pronounced where carbonaceous material is concentrated. Deposit is near axis of small shallow syncline. Sample, 0.04 percent U.	Do.
Varnum	NE¼ 21	3 N.	16 W.	Mineralized sandstone in Mesaverde Group	Unknown.
Mangum	22	3 N.	16 W.	Mineralized coaly shale bed about 3 in. thick, 75 ft below top of Mesaverde Group. Sample, 0.03 percent eU.	R. L. Griggs (WC, 1954).
				McKinley County	
Unnamed	W½ 5	13 N.	8 W.	Several deposits in Jmw	AEC, DH.
Do	6	13 N.	8 W.	do	Do.
Do	SW¼ 9	13 N.	8 W.	do	Do.
Section 18	SW¼SW¼ 18	13 N.	8 W.	Deposit in Jmpc. Extends northwestward into sec. 13.	For general setting see Rapaport (1963, p. 131 and fig. 1).
Unnamed	20 and E½ 19(?)	13 N.	8 W.	Deposit in Jmw	AEC, DH.
Section 2	NW¼SE¼ 2	13 N.	9 W.	Tabular deposit in Jmw	Sabre-Pinon Corp., DH, November 1956.
Do	SW¼NE¼ 2	13 N.	9 W.	do	Do.
Do	Approx. CW½ 2	13 N.	9 W.	do	Do.
Section 5	NE¼NE¼NE¼ 5.	13 N.	9 W.	Deposit in sandstone in Jmr	National Lead Co., DH, April 1956.
Section 6	CNW¼ 6	13 N.	9 W.	Tabular deposit, or deposits, probably in Jmpc	Treasure Uranium and Resources, Inc., DH, July 1957.
Isabella (*42*)	NE¼ 7	13 N.	9 W.	Cluster of deposits along north-trending fault in Jmpc. (Much of ore probably is redistributed.) Ore mined through vertical shaft, 1959–62.	C. N. Holmes (OC, January 1959); AEC; and Rapaport (1963).
Centennial (*77*)	NW¼ 8	13 N.	9 W.	Tabular, elongate deposit that trends southeastward in Jmpc. Deposit is at southeastern end of cluster that includes the Isabella. (See above.) Ore mined through vertical shaft, 1958–64.	Colamer Corp., DH, 1956.
Section 13	S½ 13	13 N.	9 W.	Several southeastward-trending tabular deposits in Jmpc. Deposits extend into SW¼ sec. 18, T. 13 N., R. 8 W. (See above.)	Calumet and Hecla, Inc., DH, May 1957.
Hogan (*39*)	S½ 14	13 N.	9 W.	Several medium and small, amoeba-shaped, redistributed deposits in Jmpc. Deposits are concentrated along flank of anticlinal fold and parallel to San Mateo fault. Ore produced in 1959–62.	Rapaport (1963, p. 131–133 and figs. 1 and 6).
Section 16	SW¼ 16	13 N.	9 W.	Several, scattered small deposits in Jmpc	Sabre-Pinon Corp., DH, August 1956.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
McKinley County—Continued					
Beacon Hill (Gossett) (*6*).	SE¼SE¼ 18	13 N.	9 W.	Tabular deposit of fracture-controlled redistributed material in Jmpc. Ore mined through vertical shaft, 1956–60.	Holly Uranium Co., DH, October 1954; and Rapaport (1963, p. 126).
Poison Canyon (*66*).	S½NE¼ and N½SE¼ 19.	13 N.	9 W.	Two tabular, stringlike, somewhat discontinuous, medium to large deposits in Jmpc. The northern deposit extends from outcrop about N. 70° E. for about 2,000 ft; the southern deposit from the same point of outcrop S. 58° E. about the same distance into sec. 20. These deposits mined largely from open pits, 1952–62.	Haystack Mountain and Development Co., June 1955; Dodd (1956); Hilpert and Moench (1960, p. 454–455); Rapaport (1963).
Malpais (*57*)	CS½N½ 20	13 N	9 W	Irregular cluster of tabular deposits in Jmpc that extend northeastward from Dog Incline workings. Locally "stack" ore, concentrated along N. 10° W.-trending fractures, as much as 30 ft thick. Ore mined in 1958–61 through Dog Incline and Mesa Top shaft.	Four Corners Exploration Co., DH, October 1958; Rapaport (1963); AEC.
Mesa Top 7 (Moe; Davenport) (*60*).	CW½ 20	13 N.	9 W.	Eastern end of southern part of Poison Canyon deposit that extends into sec. 20. Geology is similar to Poison Canyon deposit. (See above.) Ore mined through inclined adit, 1957–61.	FN, October 1958.
Dog Incline (*27*)	SW¼SW¼NE¼ 20	13 N.	9 W.	Irregular cluster of deposits in Jmpc. Deposits are largely oxidized redistributed material, partly controlled by fracture system that trends about N. 15° W. Deposits mined in 1957–64 through inclined shaft.	Rapaport (1963, p. 126–129, and figs. 1 and 4).
Mesa Top 18 and 20 (*61*).	N½SW¼ 20	13 N.	9 W.	Irregular cluster of tabular deposits between Poison Canyon and Dog Incline deposits. Deposits are generally elongate eastward in a lower zone and irregular in plan and thickness in an upper zone of oxidized redistributed material. Deposits are in Jmpc. Ore mined in 1954–61 through vertical shaft.	Holly Minerals Corp., DH, September 1957. For details, see Rapaport (1963).
Section 21 (Doris, Doris West Extension; Doris 1, Little Doris) (*81*).	SW¼ 21	13 N.	9 W.	Several somewhat tabular, elongate deposits in Jmpc. Two oxidized parallel bodies near base of sandstone, known as Doris and Doris West Extension, extend eastward from sec. 20 into sec. 21. These bodies, or clusters, are 1,000–1,500 ft long, 10–100 ft wide, and several feet thick. Near center of sec. 21 the Doris 1, or Little Doris, consists of several small, roughly tabular deposits that are controlled by cylindrical collapse structure, which is about 100 ft in diameter. The center was displaced downward as much as 30 ft probably in pre-Dakota time. The ore, which is postfault and partly oxidized, occurs as several scattered pods and thin layers, mostly within the cylinder and largely conformable with the bedding, but some also occurs outside the structure and some partly along the fault and controlled by it. Deposits mined in 1958–61 through inclined shaft.	Food Machinery and Chemical Corp., DH, December 1955. For details, see Granger and Santos (1963), and Rapaport (1963, p. 129–130).
Marquez (*58*)	23	13 N.	9 W.	Cluster of large and medium elongate deposits in Jmpc that trend southeastward and eastward through central part of the section. Ore is mostly in lower part of sandstone beneath a disconformity and generally where sandstone thickness exceeds 40 ft. Ore-bearing sandstone is fairly clean and contains finely disseminated carbonaceous material, in contrast to relatively barren sandstone above disconformity which is clayey and contains abundant fragments of coalified wood. Deposits are partly oxidized in western part. Ore mined in 1958–64 through inclined shaft.	Calumet and Hecla, Inc., DH, May 1957; Weege (1963); Rapaport (1963, p. 131 and fig. 1).
Section 24	NE¼ 24	13 N.	9 W.	Elongate, southeastward-trending deposit in Jmpc	Rapaport (1963, p. 131 and fig. 1).
Chill Wills (*19*)	NE¼ 24	13 N.	9 W.	Elongate, southeastward-trending deposit in Jmpc. Some ore mined from adjoining sec. 13. Deposit mined from shaft, 1960–63.	AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Section 24	S½ 24	13 N.	9 W.	Eastern extension of Marquez deposit and several other deposits that extend about S. 70° E. as elongate cluster through southwestern and northeastern parts of section. Geology similar to Marquez deposit. (See above.)	Calumet and Hecla, Inc., DH, May 1957; Rapaport (1963, fig. 1).
Faith (Section 29) (*11*).	E½W½ 29	13 N.	9 W.	Cluster of medium and small, generally tabular deposits in Todilto Limestone. Cluster trends northward and individual deposits are generally elongate northward. Cluster is about 2,500 ft long and 100–300 ft wide. Deposits worked through vertical shaft, 1958–64.	Food Machinery and Chemical Co., DH, May 1957; McLaughlin (1963, p. 137, 139, 144, 145, 147).
Dalco 1 (Barbara J 2) (*8*).	E½NW¼ 30	13 N.	9 W.	Medium, rather tabular, irregular-shaped deposit that is elongate northward. Deposit is generally concentrated in middle part of Todilto Limestone. Ore worked through vertical shaft, 1957–64.	Mid-Continent Uranium Corp., April 1959; McLaughlin (1963, p. 147).
Whitecap (*51*)	CS½NW¼ 30	13 N.	9 W.	Medium deposit, elongated northward, and in approximate middle of Todilto Limestone. Deposits mined through Dalco 1 shaft, 1959–60.	Four Corners Exploration Co., DH, 1954–58; Mid-Continent Uranium Corp., DH, April 1959.
30–C	S½SE¼NW¼ 30	13 N.	9 W.	Medium deposit immediately south of Dalco 1. Deposit is irregular in outline and in approximate middle of Todilto Limestone.	Mid-Continent Uranium Corp., DH, April 1957.
Barbara J 1 (*1*)	NW¼NE¼ 30	13 N.	9 W.	Medium deposit and one or more small deposits nearby in Todilto Limestone. Deposit worked through vertical shaft, 1956–57.	Mid-Continent Uranium Corp., DH, April 1959.
Barbara J 3 (*2*)	CN½N½NE¼ 30.	13 N.	9 W.	Several medium and small deposits in Todilto Limestone. Ore worked through vertical shaft, 1959–63.	Do.
Unnamed	S½NE¼ 30	13 N.	9 W.	Several small and medium deposits in Todilto Limestone.	I. J. Rapaport (WC, 1955).
Manol (Section 30) (*22*).	S½SW¼ 30	13 N.	9 W.	Several medium and small deposits in middle and lower parts of Todilto Limestone. These deposits are generally irregular in outline and associated with diversely trending intraformational folds in the limestone. Deposits generally mined from opencuts, 1952–64.	Four Corners Exploration Co., 1954–58.
Rimrock (*29*)	N½SW¼ 30	13 N.	9 W.	Medium deposit, similar to Manol deposits (above). Ore mined through vertical shaft, 1952–58.	Four Corners Exploration Co., DH, 1954–58.
Flat Top 4 (Vilatie Hyde) (*12*).	SE¼SE¼ 30	13 N.	9 W.	Medium deposit in middle and lower part of Todilto Limestone. Is elongate northward. Extends into Vilatie Hyde on western side. Deposit mined from inclined shaft, 1955–64.	Four Corners Exploration Co., DH, 1954–58, and Flat Top Mining Co., DH, 1958.
Section 31 (*41*)	N½ 31	13 N.	9 W.	Several medium and small deposits in middle and lower parts of Todilto Limestone. Deposits mined by opencuts, 1953–62.	Haystack Mountain and Development Co., DH, August 1951.
Section 32	NW¼NW¼ NW¼ 32.	13 N.	9 W.	Small deposit in Todilto Limestone	Four Corners Exploration Co., DH, July 1956.
Do	SW¼NE¼ 32	13 N.	9 W.	Medium deposit and several nearby small deposits in middle part of Todilto Limestone.	Four Corners Exploration Co., DH, February 1957.
Section 32 (*42*)	NW¼NW¼SE¼ 32.	13 N.	9 W.	Medium deposit in lower and middle part of Todilto Limestone. Deposits mined in 1964 through inclined shaft.	Four Corners Exploration Co., DH; AEC.
Section 33 (Charlotte) (*43*).	SW¼ 33	13 N.	9 W.	Small deposit in Todilto Limestone. Ore mined from open pit, 1958. Several other small deposits in Todilto in vicinity.	Food Machinery and Chemical Corp., DH, June 1955; McLaughlin (1963, p. 147 and fig. 1).
Section 36	36	13 N.	9 W.	Deposit in Jmb	AEC.
Section 3	N½ 3	13 N.	10 W.	do	Do.
Section 4	4	13 N.	10 W.	Deposit or deposits in Jmw	Do.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Junior (*4*)	NE¼ 4	13 N.	10 W.	Mineralized zone in carbonaceous sandstone near base of Dakota Sandstone. Ore mined from opencut, 1953.	FN, November 1954.
Pat (Dakota) (*64*)	SE¼NE¼ 4 (about 300 ft from ¼ cor. secs. 3 and 4).	13 N.	10 W.	Several lenses of dark-gray radioactive material in zone about 15 ft thick in upper part of 60- to 80-ft-thick sandstone. This sandstone may be at base of Jmb or at top of Jmw. The lenses are in buff to gray crossbedded sandstone and range in thickness from a few inches to about 1 ft. In 1954, the workings were four short partly connected adits, all within an outcrop distance of about 100 ft. Mined in 1952–63 but most of ore mined since 1958.	Do.
Section 5 (Westvaco; Febco(?)) (*6*).	5	13 N.	10 W.	Probably in Dakota Sandstone, but some may occur in Jmb. Ore was mined from adit, 1958.	AEC.
Sections 10 and 11	10 and 11	13 N.	10 W.	Mineralized material in sandstone in Jmb and possibly in Jmw.	AEC, DH.
Sections 12 and 13	12 and 13	13 N.	10 W.	Mineralized material in sandstone in Jmb and possibly in Jmw. Locality is near western limit of Jmpc. Relations of the deposits to Jmpc are not known.	Do.
Section 14	NE¼ 14	13 N.	10 W.	Some mineralized sandstone and a few scattered mineralized fossil logs at outcrop, probably in Jmpc.	Mathewson (1953, p. 11).
Red Point Lode (*28*).	SW¼SW¼ NW¼ 16.	13 N.	10 W.	Small deposit in middle and lower parts of Todilto Limestone, associated with eastward-trending intraformational anticlinal fold in limestone. Deposit mined from open pit, 1952–55.	Gabelman (1956b, p. 394); McLaughlin (1963, p. 146).
Section 17	NW¼ 17	13 N.	10 W.	Several small deposits in Todilto Limestone	Food Machinery and Chemical Corp., DH, July 1955; and AEC, DH.
Do	NW¼NW¼ SW¼ 17.	13 N.	10 W.	Small deposit in Todilto Limestone	Do.
Section 18, NE¼	S½NE¼ 18	13 N.	10 W.	Northward extension of several medium deposits from SE¼ of section and several other scattered small deposits in Todilto Limestone.	AEC, DH.
Section 18, SW¼ (Williams and Thompson) (*32*).	SW¼ 18	13 N.	10 W.	Cluster of medium and small irregularly shaped deposits in Todilto Limestone. Several deposits mined from inclined shaft, others from opencuts, 1952–64.	Federal Uranium Corp., DH, June 1956; AEC.
Section 18, SE¼ (Williams) (*33*).	SE¼ 18	13 N.	10 W.	Cluster of medium and small irregularly shaped deposits in Todilto Limestone. Deposits mined from open pits, 1953.	AEC, DH.
Haystack (Haystack Butte; Section 19, NW¼) (*16*).	NW¼ 19	13 N.	10 W.	Large, irregularly shaped, roughly tabular, partly oxidized deposit approximately in middle part of Todilto Limestone. Deposit is elongate northward and associated with numerous intraformational folds in limestone, some of which include the top few feet of the Entrada Sandstone These folds have diverse trends, but the dominant trends are northward and eastward. Ore mined from opencut, 1952–57.	FN, July 1955; Haystack Mountain and Development Co., DH, 1955; Gabelman (1956b, p. 393–396).
Section 19, NE¼ (*34*).	N½N½NE¼ 19	13 N.	10 W.	Several small or medium deposits, near or at outcrop of Todilto Limestone. Deposits mined in 1959–64.	AEC.
Section 22, NE¼	NE¼ 22	13 N.	10 W.	Small deposit in Todilto Limestone. Deposit worked by open pit, but no shipments reported.	McLaughlin (1963, p. 146).
Section 23 (*38*)	S½SE¼ 23	13 N.	10 W.	Cluster of small and medium irregularly shaped deposits in middle and lower parts of Todilto Limestone. Cluster is in elongate zone about 300 ft wide that trends eastward along southern margin of SE¼ of section and into adjoining secs. 25 and 26. Ore mined from opencuts, 1957–58.	Haystack Mountain and Development Co., DH, June 1951 and January 1954.
Bob Cat (*11*)	NE¼NE¼(?) 24	13 N.	10 W.	Deposit probably in Jmpc. Ore shipped in 1955	AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Blue Peak (Garcia 1) (*10*).	SE¼NE¼ 24	13 N.	10 W.	This deposit, or deposits, consists of several medium and small, eastward-trending, tabular, lenselike layers of gray mineralized material in approximate middle of Jmpc. Relatively dense fracture sets in ore bodies and oxidized minerals indicate fracture control of ore. In 1954, exposed mineralized material ranged in thickness from 0 to about 2 ft and had been mined from two principal adits, about 600 ft apart at the outcrop. Deposit mined intermittently, 1951–64.	FN, October 1954; Rapaport (1963, p. 123–124 and fig. 1).
Divide 25, 26, 27, and 28.	SE¼SW¼ and SW¼SE¼ 24.	13 N.	10 W.	Several small scattered deposits in Todilto Limestone	Four Corners Exploration Co., DH, August 1957.
Red Rock 3 and 4	SE¼SE¼ 24	13 N.	10 W.	do	Do.
Section 25 (*40*)	25	13 N.	10 W.	Many small, medium, and large deposits generally in lower part of Todilto Limestone and in two general clusters. One cluster trends eastward through N½N½ of section; other cluster trends southeastward from central part of section into SW¼ of adjoining sec. 30, T. 13 N., R. 9 W. Deposits mined mostly from opencuts, 1952–64.	Haystack Mountain and Development Co., DH, 1954–56. For some detail, see McLaughlin (1963, p. 146–147).
Hanosh (Section 26) (*15*).	N½NE¼ 26	13 N.	10 W.	Medium, irregularly shaped deposit in middle and lower parts of Todilto Limestone. Is westward extension of cluster of deposits in northern part of sec. 25 (above). Ore contained local pockets of fine-grained fluorite. Ore mined from inclined shaft, 1952–57.	FN, July 1954.
Section 36, NE¼ (Rimrock) (*44*).	E½NE¼ 36	13 N.	10 W.	Small deposit at outcrop of Todilto Limestone. Mined from opencut, 1952–58.	AEC.
Redco	NW¼NW¼ 10	13 N.	11 W.	Small deposit in Todilto Limestone	Do.
Unnamed	SE¼NW¼ 11	13 N.	11 W.	do	AEC, DH.
Do	S½SE¼ 11	13 N.	11 W.	do	Do.
Do	SW¼SW¼ 12	13 N.	11 W.	do	Do.
Do	SW¼SE¼ 12	13 N.	11 W.	do	Do.
Do	NE¼NW¼ 13	13 N.	11 W.	Two small deposits in Todilto Limestone	Do.
Haystack 2 (*17*)	CSW¼ 13	13 N.	11 W.	Cluster of small deposits in middle and lower parts of Todilto Limestone. Cluster trends northward. Deposits mined from opencut, 1956–61.	Haystack Mountain and Development Co., DH, July 1951.
Section 13, SE¼ (Bibo) (*31*).	S½SE¼SE¼ 13	13 N.	11 W.	One or more small to medium deposits in Todilto Limestone. Ore mined, 1958–61, from opencut.	Federal Uranium Co., DH, June 1956.
Section 24 (*39*)	NE¼ 24	13 N.	11 W.	Medium deposit in Todilto Limestone. Mined from opencut, 1952–57.	AEC.
Section 31	CW½ 31	14 N.	8 W.	Probably tabular deposit in upper part of Jmw, that is extension of deposit in eastern part of sec. 36, T. 14 N., R. 9 W.	Unknown.
Section 32 (Yucca)	E½SW¼ 32	14 N.	8 W.	Large deposit in one or more tabular layers in upper part of Jmw.	E. J. Longyear Co., DH, June–December 1958.
Green Pick 20	4	14 N.	9 W.	Schroeckingerite occurs in limonite-stained sandstone near base of Hosta Tongue of Point Lookout Sandstone. Deposit extends about 50 ft along cliff face. Sample, 0.10 percent U.	I. J. Rapaport (WC, 1952).
Section 17	N½ 17	14 N.	9 W.	One or more medium and small deposits in Jmw	AEC, DH.
Section 17 (*80*)	S½ 17	14 N.	9 W.	Several large and medium tabular deposits in upper part of Jmw. Worked from vertical shaft in SW¼ of section, 1960–64. Locally, the deposits are in two stratigraphic zones, which extend into parts of adjoining secs. 18 and 20.	Kermac Nuclear Fuels Corp. DH, December 1956; AEC, DH,
Section 18	18	14 N.	9 W.	Several large and medium tabular deposits in middle and upper parts of Jmw. Locally, deposits are in two stratigraphic zones.	Do.
Section 20	NW¼ 20	14 N.	9 W.	Several medium deposits in one general zone in upper part of Jmw.	Kermac Nuclear Fuels Corp., DH, May 1957; AEC, DH.
Do	SW¼ 20	14 N.	9 W.	Medium to large deposit, or cluster of deposits, in one general stratigraphic zone in upper part of Jmw.	Do.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Canyon Mulatto	NW¼ 24	14 N.	9 W.	Mineralized lens of coaly material, about 3 in. thick, at top of Crevasse Canyon Formation. Channel sample 1.3 ft long, 0.03 percent U.	G. O. Bachman, E. H. Baltz, and R. B. O'Sullivan (WC, 1953).
Section 26 (Rio de Oro).	SW¼ 26	14 N.	9 W.	A large deposit or cluster of deposits in upper part of Jmw. Deposits occur in three general zones within stratigraphic interval of about 75 ft and extend into adjoining margins of secs. 27 and 35.	Rio de Oro Uranium Mines, Inc., DH. August 1957; Hazlett and Kreek (1963, fig. 1).
Section 26	SW¼SE¼ 26	14 N.	9 W.	Elongate deposit, probably in upper part of Jmw	Hazlett and Kreek (1963, fig. 1, p. 83).
Section 27	S½ 27	14 N.	9 W.	Large, somewhat discontinuous deposit that trends southeastward from adjoining sec. 28 and into SE¼ sec. 26. Deposit is in two or more stratigraphic zones in upper part of Jmw.	Kermac Nuclear Fuels Corp., DH, undated. For general setting see Hazlett and Kreek (1963).
Ann Lee (Section 28) (*3*).	28	14 N.	9 W.	Consists of large elongate pod and 20–30 subparallel elongate pods of prefault, "trend-type" material that generally trend N. 70° W. through center of section in a zone about 1,000 ft wide. Deposits occur throughout the Jmw, but generally ascend stratigraphically northward and less markedly westward. The larger body is markedly elongate and is closely related to enclosing channellike sandstone unit. Other bodies are also elongate and controlled by various stratigraphic features. In early 1963, about three-fourths of mine reserves had been removed through a vertical shaft.	Phillips Petroleum Co., DH, December 1957; Squyres (1963).
Section 29 (Kermac-United) (*86*).	29	14 N.	9 W.	A very large cluster of deposits and an extension of those in adjoining sec. 30. In western part of section, geologic relations are similar to those in Section 30 (Kermac-Pacific). In northern part of section the deposits are elongate eastward and are in the upper part of the Jmw. In southwestern part of section the deposits are elongate southeastward and are in the lower part of the Jmw. These two elongate parts of the cluster are "trend" type ore. During productive period of 1961–64, northern part was mined through vertical shaft in sec. 30; southern part through vertical shafts in secs. 32 and 33.	Phillips Petroleum Co., DH, March 1958; Clary and others (1963); AEC.
Section 30 (Kermac-Pacific) (*87*).	30	14 N.	9 W.	A very large cluster of irregularly shaped deposits which occur in four sandstone units within a stratigraphic range nearly 200 ft thick in Jmw. The largest and highest grade bodies are in upper two sandstone units, are crescent shaped, concave northward, and partly confined between two parallel north-trending faults. The bodies in two lower units are more linear. Both apparently conform to sedimentary structures, but upper zones are probably mostly "stack" type ore. These deposits largely occupy east-central part of sec. 30 and extend eastward into sec. 29 and southwestward through sec. 29 into sec. 32. Ore mined through vertical shaft, 1959–64.	Kermac Nuclear Fuels Corp., DH, August–October 1956; Clary and others (1963).
Section 32 (*89*)	N½ 32	14 N.	9 W.	A large tabular deposit in lower part of Jmw. Deposit is elongate eastward and locally is multilayered. Ore mined through vertical shaft, 1958–64.	San Jacinto Petroleum Corp., DH, January 1956.
Section 33 (Branson) (*91*).	33	14 N.	9 W.	A very large, somewhat discontinuous, elongate tabular cluster of deposits that trends about S. 70° E. from the northwestern part of section eastward into adjoining sec. 34. Deposits are in several sandstone units in Jmw and show a general tendency to rise stratigraphically northward. In eastern part of section, deposits are offset by north-trending graben. The general geology in this section is similar to that of adjoing sec. 34. Since 1959, deposits have been mined through a vertical shaft.	Phillips Petroleum Co., DH, March 1958; Harmon and Taylor (1963); Hazlett and Kreek (1963).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Sandstone (Section 34) (*75*).	34	14 N.	9 W.	A very large cluster of parallel, elongate, and tabular deposits in several sandstone units in Jmw. Cluster trends eastward through central part of the section into adjoining secs. 33 and 35 and generally ascends stratigraphically down dip to north. Deposits are directly associated with finely disseminated carbonaceous material, follow depositional structures, and generally thicken where enclosing sandstone units thicken. A north-trending graben in western part of section displaces ore bodies about 50 ft. No premineral faults have been recognized. Ore has been mined since 1959 through vertical shaft.	Phillips Petroleum Co., DH, December 1957; Harmon and Taylor (1963).
Cliffside (Section 36) (*21*).	SW¼ 36	14 N.	9 W.	A large, multilayered, irregular, cluster of deposits, principally in upper part of Jmw. This cluster is eastward extension of the trend of bodies from sec. 35. Most of ore is in irregular stacklike mass that has a central core 35–40 ft thick and tabular bodies that project outward in several zones. At southern edge of mass is a cylindrical collapse structure about 100 ft in diameter in which core is displaced about 20 ft. Ore in core is generally higher grade and thicker than in adjacent walls but in same stratigraphic zone. Rest of ore in smaller elongate bodies that extend to southeast and northwest. A 6,000-ton sample of ore averaged 0.52 percent U_3O_8, 0.23 percent V_2O_5, 0.012 percent Mo, and 0.029 percent Se. Body has been mined since 1960 through a vertical shaft.	Phillips Petroleum Co., DH, December 1957; Clark and Havenstrite (1963).
Section 36	CE½ 36	14 N.	9 W.	Tabular deposit in upper part of Jmw. Deposit may extend into adjoining sec. 31.	Phillips Petroleum Co., DH, December 1957.
Sections 2 and 3	2 and 3	14 N.	10 W.	Several small deposits, located by wide-spaced drilling, in Jmw.	Entrada Oil and Copper Co., DH, undated.
Section 10 (*78*)	E½ 10	14 N.	10 W.	Large deposit, or cluster of deposits, in one or more layers in upper part of Jmw. Cluster is westerly extension of Dysart 1. Deposit has been mined since 1957 through vertical shaft.	Kermac Nuclear Fuels Corp., DH, June 1957.
Mary 1 (*59*)	NW¼ 11	14 N.	10 W.	Large deposits in several zones in upper Jmw. Much of ore is fracture controlled. Ore has been mined since 1959 through a vertical shaft.	AEC.
Dysart 1 (Section 11) (*28*).	SW¼ 11	14 N.	10 W.	A cluster of large and medium deposits in upper part of Jmw. Deposits were generally elongate eastward through southern part of section and extended into adjacent parts of secs. 10 and 12. Host sandstone has bedding structures that also generally trend eastward and apparently controlled deposits, except for small linear oxidized body that followed a northeasterly striking fault. Deposits mined in 1956–62 through vertical shaft.	Rio de Oro Uranium Mines, Inc., DH, May 1957; Cronk (1963); FN.
Dysart 2 (*29*)	SE¼ 11 and SW¼ 12.	14 N.	10 W.	Large, irregularly shaped tabular deposit in upper sandstone unit of Jmw. Deposit mined through vertical shaft in SE¼ sec. 11, 1959–63.	Kermac Nuclear Fuels Corp., DH, November 1956; AEC.
Section 12	E½ 12	14 N.	10 W.	Small to large deposits in several zones in Jmw	Kermac Nuclear Fuels Corp., DH, November 1956.
Section 13	NE¼ 13	14 N.	10 W.	Several medium, generally multilayered, deposits near middle of Jmw.	Homestake Mining Co., DH, November 1957.
Do	S½ 13	14 N.	10 W.	Large multilayered deposit and several small scattered deposits in upper part of Jmw.	Do.
Bucky (Jeep 6) (*12*).	SE¼ 14	14 N.	10 W.	Several small to medium tabular deposits mainly in upper Jmw. Since 1959 deposits mined from vertical shaft.	Holly Minerals Corp., DH, November 1956.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Section 15 (*79*)	SE¼ 15	14 N.	10 W.	Large multilayered irregularly shaped deposit in Jmw. Deposit is about 1,500 ft across and as much as 50 ft thick and extends into adjoining secs. 22 and 23 to south and east. Deposit contains both "trend" ore and "stack" ore, the latter localized along fractures and oxidized. Ore mined through vertical shaft, 1958–64.	Sabre Uranium Co., and The American Metal Co., Ltd., DH, March 1956; Gould and others (1963).
Section 21	E½ 21	14 N.	10 W.	Several small scattered deposits in Jmw and lower part of Jmb.	Kermac Nuclear Fuels Corp., DH, June 1957.
Section 22	W½ 22	14 N.	10 W.	Large deposit and several scattered smaller deposits in Jmw. The large deposit may be an extension of deposit in E½ sec. 21. (See above.)	Do.
Section 22 (*82*)	E½ 22	14 N.	10 W.	Very large cluster of multilayered deposits in Jmw, largely concentrated in NE¼ but extends into adjoining quarters and into secs. 15 and 23. The continuity of this cluster and its considerable thickness suggests it is principally redistributed, or "stack" ore. Since 1958 ore has been mined through a vertical shaft.	Kermac Nuclear Fuels Corp., DH, June 1957. For general relations see Gould and others (1963).
Section 23 (*83*)	23	14 N.	10 W.	Very large multilayered deposit, or cluster of deposits, principally in the middle of the Jmw. Cluster trends eastward across northern part of section, southward across eastern part and into adjoining secs. 15, 22, 24, and 25. Consists of both "trend" ore and "stack" ore, which was deposited updip to north of trend ore along fracture system. Since 1959 deposit has been mined through vertical shaft.	Sabre-Pinon Corp., The American Metal Co., Ltd., and Homestake Mining Co., DH. March 1956; Gould and others (1963).
Section 24 (*84*)	24	14 N.	10 W.	Very large multilayered deposit, or cluster of deposits, generally in Jmw, but locally may partly occur in lower part of Jmb. Cluster is largely within W½, but locally extends into E½. General geology similar to adjoining secs. 23 and 25. Since 1959 ore has been mined through vertical shaft.	Pacific Uranium Mines Co., DH, July 1957.
Section 25 (*85*)	25	14 N.	10 W.	A very large series of lenses and pods in Jmw that extends as a linear mass southeastward across sec. 25 into secs. 23, 24, 26, and 36. Deposits are largely "stack" ore, but much trend ore near base of mass. Stack ore, some as much as 100 ft thick, is controlled by northwest-trending fracture system. Deposits mined since 1959 through vertical shaft.	Sabre-Pinon Corp., The American Metal Co., Ltd., and Homestake Mining Co., DH, March 1956; Gould and others (1963).
Section 26	NE¼ 26	14 N.	10 W.	Large multilayered cluster of deposits in Jmw. This is part of cluster described under Section 25 (see above).	Pacific Uranium Mines Co., DH, July 1957.
Section 27	NW¼ 27	14 N.	10 W.	Small and medium deposits, generally near base and middle of Jmw.	Pacific Uranium Mines Co., DH, October 1956.
Section 28	NW¼NE¼ 28	14 N.	10 W.	Medium deposit, probably in Jmw	AEC.
Section 29	29	14 N.	10 W.	One or more deposits, probably in eastern part of section, in Jmw.	AEC, DH.
Silver Spur 1 (*7*)	31	14 N.	10 W.	Deposit consists of yellow uranium minerals disseminated in basal sandstone of Dakota Sandstone. Carbonized, macerated plant debris is abundant and limonite staining conspicuous. Ore mined from open pit, 1955–58.	FN, September 1954.
Silver Spur 5 (*8*)	NE¼ 31	14 N.	10 W.	Yellow uranium minerals, including metatyuyamunite (Gruner and others, 1954), disseminated in basal sandstone of Dakota Sandstone and apparently in scour-filled channel 1,000–2,000 ft wide. Limonite staining is conspicuous and carbonized macerated plant debris is abundant. Consists of stringlike cluster of deposits that are individually and collectively elongate N. 25° E. and parallel to secondary joint set. Dip of crossbeds is about N. 30° W., and strike of principal joint set is about N. 15° W. Ore mined from several shallow open pits, 1952–59.	Mirsky, 1953; and FN, September 1954.
Small Stake (*9*)	S½SW¼ 31	14 N.	10 W.	Deposit, similar to Silver Spur deposits, occurs in scour-filled channel. Ore mined from short adit in 1952.	Mirsky, 1953; AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Section 36	NW¼ 36	14 N.	10 W.	Several scattered deposits in Jmb and in upper part of Jmw.	San Jacinto Petroleum Co., DH, September 1956.
Section 36 (United Western) (*92*).	NE¼ 36	14 N.	10 W.	Medium deposit in one or more layers in upper part of Jmw. Some ore mined in 1959 through vertical shaft.	Do.
Section 1	NW¼ 1	14 N.	11 W.	Deposits in Jmb and possibly in Jmw	Phillips Petroleum Co., DH, December 1957.
Do	SW¼ 1	14 N.	11 W.	Multilayered deposits in Jmb	Do.
Section 2	SE¼ 2	14 N.	11 W.	Deposit probably an extension from SW¼ sec. 1. (See above.)	The Superior Oil Co., DH, June 1957.
Section 4	4	14 N.	11 W.	One or more deposits, probably in Jmb and possibly in Jmw.	AEC, DH.
Unnamed	E½W½ 4	14 N.	11 W.	Radioactive anomalies in several wide-spaced drill holes. Radioactive zone probably is in upper part of Jmb.	Pacific Uranium Mines Co., DH, June 1956.
Alta (*2*)	NW¼SW¼ 5	14 N.	11 W.	Elongate tabular deposit that trends northward from the outcrop for more than 300 ft. It is mostly near the pinchout of sandstone tongue a few feet thick that splits from top of Jmw about 100 ft west of mine entry. Top foot or so of host sandstone contains abundant macerated carbonized plant fragments. Mineralized zone is immediately beneath carbonaceous material in coarser grained sandstone that is free of any obvious carbonaceous material. The northern part of deposit might be in top of the Jmw. Ore mined from adit, 1951–61.	FN, and The Anaconda Co., October 1955.
Francis (*38*)	NW¼NW¼ 8	14 N.	11 W.	This deposit, or cluster of deposits, consists of several mineralized masses in sandstone lens in upper part of Jmb. Lens ranges in thickness from few feet to about 80 ft, trends eastward, and intertongues with claystone and mudstone. Deposit is near or at outcrop at west end of lens where it is immediately beneath Dakota Sandstone, is about 40–50 ft thick, and bleached white. Deposit consists of mineralized fossil logs and tabular layers in central part of lens. Workings consists of rather short tunnel and four short adits. Deposit mined in 1953–54.	Do.
Evelyn (*34*)	NW¼ 9	14 N.	11 W.	This deposit is about 3,500 ft east of Francis (see above) and in same sandstone lens, where it is 60–80 ft thick and limonite stained. Deposit consists of several bodies, associated with abundant carbonized and macerated plant debris, mainly in central part of lens. Workings consist of main adit, about 350 ft long, and two short adits, all driven northwestward from outcrop. Outcrop of lens at mine is along north-trending east-facing fault scarp in the upthrown block of the Bluewater fault. Deposit mined in 1953–56.	Do.
Unnamed	SE¼SW¼NE¼ 17.	14 N.	11 W.	Yellow uranium minerals show at the outcrop of sandstone lens near top of Jmr.	Earl Arlin (OC, 1957).
Bottoms	S½ 18	14 N.	11 W.	Radioactive zone about 0.2–0.5 ft thick in Todilto Limestone extends along outcrop about 25 ft. Sample 0.4 ft thick, 0.07 percent eU_3O_8.	M. J. Sheridan (WC, 1950).
Section 19 (Maddox and Teague) (*36*).	19	14 N.	11 W.	One or more small deposits in Todilto Limestone; location uncertain but probably in NE¼ and N½SE¼. Ore mined from opencut, 1953.	AEC.
Glover (Private Property) (*14*).	Possibly SE¼ NW¼ 20.	14 N.	11 W.	Small deposit in Todilto Limestone. Some ore mined in 1950.	Do.
Billy The Kid (Red Top 1) (*3*).	SW¼NE¼ 19	14 N.	11 W.	Small deposit in Todilto Limestone. Some ore mined from opencut, 1952–55.	Do.
Section 19 (Greer, Warren, and McCormack) (*35*).	N½NE¼NE¼ 19.	14 N.	11 W.	Several small and medium deposits at outcrop of Todilto Limestone. One deposit may be in SW¼ of adjoining sec. 18. Deposits mined from opencuts, intermittently, 1952–58.	Do.
Section 21 (*37*)	NW¼SW¼ 21	14 N.	11 W.	Small deposit in Todilto Limestone immediately west of and in footwall of Bluewater fault. Deposit mined from opencut, 1953.	Do.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
T 2 (*45*)	W½NW¼SW¼ 28.	14 N.	11 W.	Small deposit in upper part of Todilto Limestone. Ore mined from open pit, 1952.	AEC.
T 10 (*46*)	W½NW¼SW¼ 28.	14 N.	11 W.	Probably an extension of T 2 deposit into T 10 claim. Deposit mined from open pit, 1952.	Do.
Silver Bit 7 (*95*)	N½NE¼ 10	14 N.	12 W.	Deposit at top of Jmw. Deposit probably worked as small opencut, 1955–57.	C. K. Presley (WC, 1955).
Silver Bit 15 (*96*)	SW¼NE¼ 10	14 N.	12 W.	One or more deposits at top of Jmw. Ore worked as opencuts, 1955–57.	Do.
Silver Bit 18 (*97*)	SE¼NE¼ 10	14 N.	12 W.	One or more deposits probably at top of Jmb and possibly in base of Dakota Sandstone. Ore probably mined from opencut, 1955–57.	Do.
Unnamed	10–11	14 N.	12 W.	Yellow uranium minerals in sandstone near top of Jmr.	Earl Arlin (OC, 1957).
Eagle	SW¼ 18	14 N.	12 W.	Small deposit in Todilto Limestone	AEC.
Lawrence Elkins (*20*).	SE¼NE¼ 24	14 N.	12 W.	Small deposit in Todilto Limestone. Some ore possibly mined in 1954.	Do.
Tom Elkins (*48*)	NW¼SE¼ 24	14 N.	12 W.	Small deposit in Todilto Limestone. Deposit mined in 1954–55.	Do.
Largo	N½NW¼ 14	14 N.	13 W.	Yellow uranium mineral shows in spots in bedding along outcrop of Todilto Limestone.	R. H. Olson, and J. P. Hadfield, Jr. (WC, 1957).
Last Chance 2	NW¼ 2	14 N.	14 W.	Spotty, yellow uranium minerals show in sandstone near top of Jmr. Channel sample, 0.02 percent eU_3O_8.	J. P. Hadfield and R. H. Olson (WC, 1951).
Section 27	W½SE¼ 27	15 N.	11 W.	Deposit in sandstone in Jmb	Pacific Uranium Mines Co., DH, November 1956.
Sections 32–33 (West Ranch) (*90*).	NE¼ 32 and NW¼ 13.	15 N.	11 W.	Geology unknown. Deposit 260 ft below surface, probably in Jmw. Deposit mined through inclined shaft, 1960–64.	AEC.
Section 35	NE¼ 35	15 N.	11 W.	Deposit or cluster of deposits in Morrison Formation	Phillips Petroleum Co., DH, November 1957.
Section 23	NE¼NE¼ 23	15 N.	12 W.	Deposit in sandstone in Jmb	Tidewater Oil Co., DH, October 1958.
Black Jack 1 (*8*)	N½S½ 12	15 N.	13 W.	A very large, V-shaped, complex deposit in upper part of Jmw. North arm of V trends east, is about 150 ft wide and 3,600 ft long, apparently follows sedimentary structures, and is prefault. From apex of V at east end of north arm, other arm extends southward about 3,000 ft and is about 200 ft wide. It is relatively thick and apparently is postfault, as it is oxidized and controlled, at least in part, by north- and northeast-trending fractures. Deposit mined through vertical shaft, 1959–64.	MacRae (1963); AEC.
Section 13	NE¼NE¼	15 N	13 W.	Deposit in sandstone in Jmw	Tidewater Oil Co., DH, October 1958.
Do	N½SE¼ 13	15 N.	13 W.	do	Do.
Black Jack 2 (*9*)	N½ 18	15 N.	13 W.	Several large irregularly shaped ore bodies in sandstone 18–60 ft thick near base of Jmb. Best ore occurs where sandstone is gray, crossbedded, and coarse grained; it contains mudstone splits and finely disseminated carbonaceous material. Ore pods are unoxidized (and probably prefault) and controlled by sedimentary structures, which trend southeastward. Main ore cluster is about 200–800 ft wide and 3,000 ft long. Small mineralized pods occur along same trend southeast and northwest of main deposits. Mined through vertical shaft, 1959–64.	Hoskins (1963); AEC.
Section 21	W½NW¼ 21	15 N.	13 W.	Deposit in sandstone in lower part of Jmb	Tidewater Oil Co., DH, October 1958.
Nicholson-Brown	S½ 26	15 N.	14 W.	Deposit in Jmw	AEC, DH.
Santa Fe Christ (*4*).	SW¼ 3	15 N.	16 W.	Deposit in carbonaceous shale at base of Dakota Sandstone. Ore mined in 1957–58.	AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Christian (U mine) (*2*).	SE¼ 4	15 N.	16 W.	This cluster of deposits occurs in Christian 9 and 16 claims in carbonaceous zone about 15–20 ft above base of Dakota Sandstone and, as indicated by Mirsky (1953, fig. 3), in a scour-filled channel. Zone is composed of fine-grained crenulated limonite-stained gray sandstone that contains thin seams of carbonaceous shale and macerated carbonized plant debris. Tyuyamunite identified where uranium is more concentrated, and the concentration shows a direct relation to the abundance of carbonaceous material. Principal working is 500-ft adit driven northeastward in Christian 16 claim. In adit near face, mineralized zone is 3–5 ft thick. Deposits mined in 1953–55 from Christian 16 and in 1957–58 from Christian 9.	Mirsky (1953); FN, October 1955; U.S. Bur. Mines amenability test report no. 437; R. K. Pitman (OC, 1965).
Foutz 1 (*35*)	NW¼NW¼ 4	15 N.	16 W.	Deposit in sandstone in Jmw. Ore mined from shallow pit at outcrop, 1953.	FN, October 1955; Sharp (1955, p. 9).
Foutz 2 (*36*)	NE¼NE¼ 5	15 N.	16 W.	Deposit in sandstone in Jmw. Deposit mined from south-trending adit, 1953.	FN, October 1955.
Westwater 1 (*100*)	S½ 2	15 N.	16 W.	Deposit in upper part of Jmw. Ore mined in 1957–58	AEC.
Becenti (*1*)	NW¼ 28	15 N.	17 W.	Deposit occurs in upper part of 10- to 15-ft thick sandstone at base of Dakota Sandstone and overlain by lens of carbonaceous shale. Host sandstone makes up scour-filled channel in which crossbeds dip about N. 30° E. Sandstone is limonite stained and contains seams and small pockets of carbonized plant material. Yellow uranium minerals including meta-autunite, metatyuyamunite, and uranophane (Gruner and others, 1954) are disseminated in sandstone as well as along joint and bedding surfaces. Joint sets trend N. 50° E. and N. 15° W. Ore mined from an open pit, 1952–58.	FN, October 1955; and Gabelman (1956a, p. 315–316).
Diamond 2 (Largo 2) (*3*).	NW¼NE¼ 33	15 N.	17 W.	Two medium to large deposits and several satellites, mostly in basal medium- to coarse-grained sandstone unit of Dakota Sandstone. Unit fills channel or channels scoured in Jmw. Is overlain by carbonaceous shale and interbedded fine-grained sandstone. Beds strike N. 30° W., dip about 30° SW. Two main deposits about 750 ft apart along strike. Strike length of north body about 300 ft and south body about 500 ft. Bodies pinch out along 500 level about 275 ft vertically below mine entry at outcrop. Ore occurred in podlike masses, generally crudely elongate with dip of beds and crudely parallel to axes of cross folds and to plunge of slumplike structures in host sandstone. Ore minerals uraninite, possibly coffinite, metatyuyamunite, probably tyuyamunite, and carnotite, associated with corvusite, limonite, jarosite, and a little marcasite and closely associated with carbonaceous debris. In south body much oxidation above 450 level and some between 450 and 500 level. Mine yielded about 50,000 tons of ore, 1953–64, that had U:V ratio of 3:1 and lime content of 0.5 percent.	Mirsky, 1953; Gruner and others, 1954, p. 37; FN, October 1954; Gabelman, 1956a, p. 312–316; Four Corners Uranium Corp., January 1959; Chico, 1959.
Hogback 3 (*2*) and 4 (*3*).	NE¼ 12	15 N.	18 W.	Deposit occurs in a carbonaceous coaly shale of Dakota Sandstone. Shale is lenticular and locally several feet thick and occupies same stratigraphic position as shale that overlies Becenti and Diamond 2 deposits (above). No uranium minerals are apparent except in spots in underlying sandstone which under the deposit ranges from 4 to 11 ft in thickness. Deposit apparently is related to thick part of carbonaceous shale, which thins away from vicinity of deposit, and possibly to underlying channel-type sandstone (Mirsky, 1953, p. 15). Deposit was mined, 1952–60, from open pit and prospected at southern end by 400-ft incline shaft.	FN, October 1954; Gabelman (1956a, p. 307–308); Mirsky (1953).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				McKinley County—Continued	
Unnamed	NE¼ 32	16 N.	12 W.	Radioactive zone at the top of 3-ft coal bed at top of Crevasse Canyon Formation and immediately beneath Hosta Tongue of Point Lookout Sandstone. Channel sample of upper foot of coal bed 0.019 percent U.	G. O. Bachman, E. H. Baltz, and R. B O'Sullivan (WC, 1953).
Section 21	SW¼ 21	16 N.	15 W.	Deposit in sandstone in Jmb	Tidewater Oil Co., DH, October 1958.
Section 8	SE¼ 8	16 N.	16 W.	Deposits in lower part of Jmb and upper part of Jmw	Phillips Petroleum Co., DH, January 1959.
Section 9	SE¼ 9	16 N.	16 W.	Probably similar to Section 8 (above)	Do.
Section 16	N½NW¼ 16	16 N.	16 W.	Deposits in Jmb or upper part of Jmw	Tidewater Oil Co., DH, December 1958.
Do	NW¼SW¼ 16	16 N.	16 W.	Deposit in upper part of Jmw	Do.
Church Rock (*20*)	NE¼ 17	16 N.	16 W.	Cluster of deposits in Jmb and Jmw. Deposits mined through vertical shaft, 1960–62.	Phillips Petroleum Co., DH, January 1959.
Section 17	W½ 17	16 N.	16 W.	Deposit at top of Jmw	Do.
Section 18	NW¼ 18	16 N.	16 W.	Deposit probably in upper part of Jmw	Do.
Do	SW¼ 18	16 N.	16 W.	Deposit at top of Jmw	Do.
Section 19	NW¼ 19	16 N.	16 W.	Deposit probably similar to those in adjoining sec. 18 (above).	Do.
Section 20	20	16 N.	16 W.	Deposit, or cluster of deposits, probably in Jmw	Unknown.
Section 22	22	16 N.	16 W.	Deposit, probably in Jmw	Unknown, DH.
Section 23	NW¼NE¼ 23	16 N.	16 W.	No information available	Phillips Petroleum Co., DH, January 1959.
Foutz 3 (Yellow Jacket; 3YJ) (*37*).	SE¼SE¼ 31	16 N.	16 W.	Tabular, elongate deposit near and at outcrop of 25-ft-thick sandstone in Jmb. The deposit is about 250 ft long, 10–100 ft wide, and averages about 3 ft in thickness. It was controlled in part by set of near-vertical fractures that trend about N. 30° W. Host sandstone is bounded by claystone units, is poorly sorted, crossbedded, clayey, and lacks any obvious carbonaceous material. Except for local spots of canary yellow oxide, uranium minerals are inconspicuous. Ore body was within a light-brown limonite-stained zone which in turn was within a purple hematitic envelope. These zones all within light-gray sandstone. U:V ratio about 1:1. Workings consist of four interconnected adits and two small stopes, the floors of which are about 20 ft apart vertically. Deposit was mined where fractures were concentrated, 1954–55.	FN, September 1954, October 1955.
Prospect 2	34	16 N.	16 W.	Radioactive zone in 3-ft-thick sandstone in upper part of Jmr. Sandstone is fractured and contains much carbonized plant debris. Grab sample, 0.08 percent eU_3O_8.	D. E. Mathewson and F. R. Fincher (WC, 1953).
Section 13	S½ 13	16 N.	17 W.	Deposits in Jmw	Phillips Petroleum Co., DH, January 1959.
Section 14	NW¼ 14	16 N.	17 W.	No information available	Do.
Section 24	NE¼ 24	16 N.	17 W.	Deposit probably in Jmw	AEC, DH.
CD and S (Section 35) (*13*).	SE¼ 35	16 N.	17 W.	Deposit in Jmw. Ore mined at outcrop, 1957	Do.
Delter	NW¼ 36	16 N.	17 W.	Carnotite impregnates lowermost 2-ft-thick sandstone of Dakota Sandstone. The bed constitutes basal part of a sandstone, shale, and conglomerate sequence that fills stream channel scoured in Jmw. Channel is 200 ft wide and 30 ft deep and trends N. 30° E. Host bed is carbonaceous and capped by lens of carbonaceous shale.	Gabelman (1956a, p. 316, and fig. 104).
Car-Ball 13	NE¼ 26	16 N.	18 W.	Radioactive zone about 1.5 ft thick in carbonaceous shale near base of Crevasse Canyon Formation. Channel sample 4 in. thick, 0.21 percent eU_3O_8.	P. E. Melancon and E. B. Butts (WC, 1953).
Dalton Pass	*28	17 N.	14 W.	Radioactive impure coal bed about 3 in. thick at top of Crevasse Canyon Formation and immediately beneath Hosta Tongue of Point Lookout Sandstone. Sample 0.2 ft thick, 0.025 percent U.	G. O. Bachman, E. H. Baltz, and R. B. O'Sullivan (WC, March 1953).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Rio Arriba County	
RA 1	SE¼NW¼ 11	21 N.	2 E.	Radioactive zone in bleached, arkosic, and coarse-grained sandstone of Cutler Formation. Zone is few inches thick and concentrated where sandstone contains abundant carbonized plant fragments. Azurite and malachite are present but uranium minerals are not visible. Sample from dump of prospect pit, 0.07 percent U.	FN, October 1955.
Saint Jude	NE¼SE¼ 11	21 N.	2 E.	Radioactive zone about 2–3 ft thick at base of 30-ft-thick bleached sandstone of Cutler Formation. Zone contains abundant carbonized plant debris, shows malachite and azurite, but no visible uranium minerals. Numerous small scattered deposits are exposed in general area in prospect pits and trenches. Channel sample, 0.09 percent U_3O_8.	W. L. Chenowith (WC, 1956).
RA 2	11	21 N.	2 E.	Similar to RA 1 (above). Deposit is near old caved prospect shaft, reportedly worked for copper before World War I. Sample, 0.023 percent U. Numerous other geologically similar deposits occur in general vicinity.	FN, October 1955.
Unnamed	14	21 N.	2 E.	Small deposit in arkosic sandstone of Cutler Formation. Sandstone contains carbonized plant fragments and copper carbonates. Sample of 2-ft thickness of sandstone in shallow prospect pit, 0.05 percent U.	Baltz (1955, p. 11).
Erma 1	SE¼ 14	21 N.	2 E.	Radioactive zone in gray sandstone of Cutler Formation. Zone contains carbonized plant debris and copper carbonates and shows radioactivity over area about 20-ft square. Grab sample, 0.20 percent eU_3O_8.	H. G. Brown III (WC, 1954).
Lucky Strike (Mid-Continent 1).	NE¼NE¼ 1	22 N.	2 E.	Radioactive zone in sequence of thin-bedded sandstone, siltstone, and clay in upper part of Cutler Formation. Colors are reddish purple, pale brown, and gray; no visible uranium minerals; highest radioactive readings roughly 0.20 percent eU_3O_8.	FN, October 1955.
Lola	34	22 N.	2 E.	Several small deposits in copper-bearing carbonaceous sandstone of Cutler Formation. Uranium is associated with carbonaceous material. Sample, 0.07 percent U.	L. J. Reynolds (OC, 1955).
Herrera	SW¼ 5	22 N.	3 E.	Small deposit in sandstone in lower part of Cutler Formation.	Ross Martinez (OC, 1955).
Hillfoot 1 (Serrano prospect) (*1*).	NE¼NW¼ 8	22 N.	3 E.	One or more small deposits at base of conglomeratic sandstone in lower part of Cutler Formation. Base of the sandstone is in channel scours in underlying siltstone. Mineralized zone is ferruginous, contains clay galls, and is spotted with copper carbonates but no visible uranium minerals. Some ore mined from short adit and opencut in 1954.	W. L. Chenowith (WC, 1956); AEC.
Red Head 2 (*3*)	NE¼SW¼NE¼ 8.	22 N.	3 E.	Small deposit in arkosic sandstone in lower part of Cutler Formation, in setting similar to Hillfoot and Herrera deposits—all being in same sandstone (see above). Some ore mined from opencut in 1955.	FN, October 1955; AEC.
Red Bird (Coyote Hill 2) (*2*).	SW¼NE¼ 8	22 N.	3 E.	Small deposit in same sandstone of Cutler Formation as Red Head 2. Yellow uranium minerals locally visible and disseminated in sandstone with sparse copper carbonates where sandstone locally ferruginous and gray. Some ore mined from 50-ft adit in 1954.	W. L. Chenowith (WC, 1957); AEC; FN, October 1955.
Rey	E½NW¼NE¼ 27.	22 N.	3 E.	Small deposit at outcrop in middle of Todilto Limestone. Deposit is associated with intraformational folds of several feet amplitude. Limestone in vicinity is 10–15 ft thick but about 20 ft thick where folds and deposit occur. Prospected by drill holes and opencut. Channel sample, 0.02 percent U_3O_8.	Ross Martinez and E. J. Reynolds (OC, 1955); FN, October 1955; R. K. Nestler and others (WC, 1955).
Lou	W½NE¼ 27	22 N.	3 E.	Similar to Rey deposit (above)	Do.
Jaramillo-Montoya	NW¼ 4	22 N.	4 E.	Reported as mineralized Todilto Limestone	W. L. Chenowith (WC, 1956).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Rio Arriba County—Continued	
State lease (Little prospect).	CS½ 16	23 N.	1 W.	Green uranium minerals (autunite?) occur along bedding and fracture surfaces of gray mudstone in San Jose Formation. Grab sample, 0.12 percent U_3O_8.	H. G. Brown III (WC, 1954).
Corral 3	NE¼ 25	23 N	1 W.	Uraniferous zone in gray medium-grained arkosic sandstone in Cutler Formation. Sandstone contains gray mudstone galls, carbonized plant debris, and some copper carbonate but no visible uranium minerals. Rocks are faulted and dip about 25° N. Some material mined. Sample, 0.03 percent U_3O_8.	Unknown.
Corral 1	N½NE¼NE¼ 25.	23 N.	1 W.	Yellow uranium minerals and copper carbonates impregnate and form halo around a fossil log in red medium-grained arkosic sandstone in upper part of Cutler Formation.	H. G. Brown III (WC, 1955).
E and B 1	E½SE¼NW¼ 29.	23 N.	1 E.	Yellow uranium mineral impregnates light-gray coarse-grained arkosic sandstone in middle part of Cutler Formation. Maximum thickness of mineralized zone is 4 ft and length along outcrop is 30 ft.	Do.
E and B 3	N½NE¼SW¼ 29.	23 N.	1 E.	Mineralized carbonized log, 0.35 ft in diameter and 2 ft long, in buff fine-grained arkosic sandstone in middle part of Cutler Formation. Sample of log, 0.25 percent U_3O_8.	Do.
TJBD 1	S½SW¼ 29	23 N.	1 E	Radioactive zone in light-gray arkosic sandstone in lower part of Cutler Formation. Zone contains abundant gray mudstone galls, some macerated carbonized plant fragments, limonite stains, and some visible copper carbonates. Radioactivity is between two steeply dipping fractures in sandstone. No uranium minerals are visible. Sample, 0.15 percent U_3O_8.	Do.
Whiteflo	NE¼NW¼ 30	23 N.	1 E.	A yellow uranium mineral impregnates light-gray and red arkose, siltstone, and mudstone along small channel scours in Cutler Formation. Some carbonized plant debris and copper carbonates visible. Some material mined from bulldozer cut.	Do.
Yellow Bird 2	NE¼SE¼ 30	23 N.	1 E.	An 18-in.-thick radioactive zone in middle of 3-ft-thick light-gray coarse-grained arkosic sandstone in lower part of Cutler Formation.	Do.
Pajarito Azul	SW¼NW¼ 31	23 N.	1 E.	A radioactive zone in a coarse-grained, light-gray arkosic sandstone in upper arkosic member of Madera Limestone. Zone contains some carbonized plant debris and copper carbonates and questionable visible uranium minerals.	Do.
Mesa Alta	NW¼ 19	23 N.	3 E.	Breccia pod at top of Todilto Limestone at contact between gypsum and overlying sandstone of Morrison Formation. (This sandstone is probably in Summerville(?) Formation.) Pod consists of limonite-stained limestone fragments, is 5 ft long, 3 ft wide, and 0–10 in. thick. Sample, 0.37 percent U_3O_8.	W. L. Chenowith (WC, 1956).
Resurrection (Blackhorse 3).	S½SW¼ 31	23 N.	3 E.	A series of small deposits in zone a few feet thick in red-brown siltstone in upper part of Cutler Formation. No uranium minerals visible, but spots of copper carbonates show locally in mineralized zone for a distance of about 400 ft. Grab sample, 0.02 percent eU_3O_8.	W.L. Chenowith (WC, 1957).
Wasson (Box Canyon) (*50*).	E½NE¼ 28	23 N.	4 E.	Tabular, lenticular, mineralized zone in Todilto Limestone on small intraformational fold. Fold has amplitude of several feet and width of 25–30 ft and according to Chenowith extends into base of overlying Morrison Formation. (The Summerville(?) Formation probably overlies the Todilto Limestone at this locality.) Fold axis may trend southeast. Limestone is 10–15 ft thick. Small tonnage of low-grade ore mined from shallow opencut, 1957. U:V ratio about 1:1.	W. L. Chenowith (WC, 1956); FN, Oct. 1955; AEC.
Unnamed	36	24 N.	1 W.	Radioactive zone in limonite-stained carbonaceous sandstone of Nacimiento Formation. Sample, 0.02 percent U_3O_8.	AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Rio Arriba County—Continued	
Pivot Rock	SW¼ 4	24 N.	3 E.	Thin spotty radioactive zones in lower part of Salitral Shale Tongue and top of Agua Zarca Sandstone Member of Chinle Formation. Zones are principally in mudstone and conglomerate and associated with carbonized logs and plant debris but are also in thin limestone lenses. Zones are exposed in bulldozed trenches within area about 100 ft wide and 250 ft long. Sample, 0.05 percent eU_3O_8.	P. H. Knowles and W. L. Chenowitl (WC, 1956).
Trejo and Sanches 1.	*30 and 31(?)	24 N.	6 E.	Radioactive zone in 3-ft-thick sandstone bed (probably in Poleo Sandstone Lentil of the Chinle Formation). Radioactive zone contains carbonaceous seams, malachite, and chalcocite; it extends continuously along outcrop for about 100 ft and discontinuously for about 2,000 ft. Channel sample, 0.18 percent U_3O_8.	H. G. Brown III and L. L. Werts (WC, 1954).
Carbon and Log claims.	N½NE¼ 11	25 N.	1 W.	Radioactive zones in limonite-stained carbonaceous sandstone and in carbonized logs of San Jose Formation. Grab sample of log, 0.20 percent U_3O_8.	W. L. Chenowith and L. R. Kittleman (WC, 1956).
Young prospect	19	25 N.	1 W.	Radioactive zone in limonite-stained carbonaceous sandstone of San Jose Formation. Sample, 0.04 percent U_3O_8.	AEC.
Coy claims	NE¼SW¼ 30	25 N.	1 E.	Radioactive zone in limonite-stained carbonaceous sandstone in talus block of San Jose Formation. Grab sample of float, 0.04 percent U_3O_8.	W. L. Chenowith and L. R. Kittleman (WC, 1956).
El C-B and Maxine.	SE¼ 7	25 N.	2 E.	Radioactive fossil bones occur in wide area at outcrop of lower part of Morrison Formation.	R. K. Nestler and L. R. Kittleman (WC, 1955).
Alex	N½ 31	25 N.	3 E.	Float fragments (some possibly in place) of Todilto Limestone range from 0.1 to 3.0 percent U.	L. J. Reynolds (WC, 1955).
Hornet	NW¼ 20	25 N.	5 E.	Radioactive zone and some carnotite exposed in prospect pits, probably in sandstone at top of Morrison Formation.	Unknown.
Lucky Dog (Onego?).	S½ 29	25 N.	5 E.	Yellow uranium minerals exposed along strike of beds at outcrop for about 300 ft, in white limonite-stained sandstone at top of Morrison Formation. Uranium minerals appear to follow fractures that strike N. 60° W. and N. 5°–20° E. Channel sample, 0.40 percent U_3O_8.	H. G. Brown III (WC, 1954).
Horny Toad	N½ 32	25 N.	5 E.	Similar to Lucky Dog (above)	Do.
Vargas-Jaramillo	11 (200 ft east of State Highway 111).	25 N.	8 E.	Deposit in 2-ft-thick tuffaceous sandstone in Santa Fe Group. Conspicuous but spotty yellow and green uranium minerals can be traced along strike about 500 ft. Siltstone sample, 0.18 percent eU_3O_8.	G. E. Collins and C. T. Butler (WC, 1956).
Heart 3	SW¼ 26	26 N.	2 E.	Radioactive limonite-stained sandstone immediately overlying gypsum unit of Todilto Limestone. (This sandstone is probably the Summerville(?) Formation.) Grab sample, 0.07 percent eU.	P. E. Melancon (WC, 1952).
Cebolla 2	NW¼SW¼ 26	26 N.	2 E.	Radioactive fossil bones or bone fragments in sandstone of Morrison Formation. Bone sample, 0.37 percent eU.	Do.
Beryl prospect (Lonesome deposit (?)).	Possibly NE¼ NW¼ 1.	26 N.	8 E.	A pegmatite body that contains albite, green microcline, quartz, mica, perthite, green beryl, columbite-tantalates, samarskite, uraninite, gummite, and monazite. This may be the Lonesome deposit (SW¼SW¼ sec. 36, T. 27 N., R. 8 E.).	Just (1937, p. 67); Jahns (1946, p. 137–143).
Pino Verde	SW¼NW¼ 18	26 N.	9 E.	A microcline-quartz pegmatite dike that contains garnet, green fluorite, columbite, samarskite, monazite, uraninite, and bismutite at east end.	Jahns (1946, p. 183–185).
Rancho AAA	10	27 N.	8 E.	A crystal of uraninite reportedly obtained in this general vicinity (possibily from uraniferous quartz vein). Grab sample of Ortega Quartzite of Just (1937) assayed 0.03 percent U_3O_8.	P. E. Melancon and F. R. Fincher (WC, 1952).
Kiawa	W½ 11	27 N.	8 E.	Samarskite, magnetite, and bismutite occur along fractures in massive quartz in long, thin, microcline-quartz pegmatite dike.	Jahns (1946, p. 106–115).
North Star	SW¼SW¼ 31	27 N.	9 E.	A long, sinuous, quartz-microcline pegmatite dike locally contains columbite, samarskite, monazite, and purple fluorite in albite-rich parts. Bismutite and samarskite are present in places along the quartz core of dike.	Jahns (1946, p. 144–146).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Rio Arriba County—Continued	
Tusas	NE¼ 24 and NW¼ 18 (uncertain).	28 N.	7 and 8 E.	Autunite, torbernite, and sabugalite are disseminated in Petaca Schist of Just (1937) along walls of crosscutting purple fluorite veins. Sample, 0.05 percent U_3O_8.	AEC.
JOL (Royal)	N½ 24 (uncertain).	28 N.	7 E.	Geology similar to Tusas deposit (above). Sample, 0.05 percent U_3O_8.	Do.
				Sandoval County	
Dory (Dorie; Doerrie)	*NE¼ 7	12 N.	3 W.	Small pod of mineralized, carbonaceous sandstone at base of Jmj. Prospected from adit. Sample, 0.26 percent eU_3O_8.	W. L. Chenowith (WC, 1956).
B and G	SW¼ 15	12 N.	3 W.	Mineralized zone at base of Jmj	R. D. Lynn (OC, undated).
Brookhaven	SW¼ 16	12 N.	3 W.	Deposit near or at base of Jmj	W. L. Chenowith (WC, 1956).
Unnamed (Base Metals)	*NE¼ 1	12 N.	4 W.	Deposit in Jmj. (Probably located by drill holes.)	Do.
Unnamed	NE¼ 13	12 N.	4 W.	Deposit located by drill hole in Jmj	Do.
Do	*Approx. CW½ 12.	12 N.	4 W.	do	R. D. Lynn (OC, undated).
Mimi 4	NE¼ 4	12 N.	6 E.	Autunite occurs along joints and fractures, principally near base of trachyte sill. Sill intrudes Mesaverde Group, strikes northwestward, and dips about 30° E. Grab sample, 0.13 percent eU_3O_8.	G. E. Collins (WC, 1955).
Unnamed	*E½ 25	13 N.	4 W.	Radioactive anomaly in Jmj	The Anaconda Co., DH, 1956
We Hope 4	NW¼SW¼-NW¼ 4	13 N.	6 E.	Autunite and other unidentified uranium minerals, associated with abundant selenium, occur in carbonaceous zones in sandstone in upper part of Galisteo Formation. Core sample, 2.70 percent U_3O_8.	Dial Exploration Co. (WC, 1960).
N. Blackshere Ranch.	S½ 6 (uncertain).	13 N.	6 E.	Secondary uranium minerals occur in sandstone and shale in Mesaverde Group. Grab sample, 0.54 percent eU_3O_8.	R. B. Stroud (WC, 1956).
Blackshere	10	14 N.	6 E.	Secondary uranium minerals occur sparsely with limonite and carbonized fossil logs along bedding of Santa Fe Group. Mineralized zone is 1–6 in. thick and 15 ft long. Grab sample, 0.54 percent eU_3O_8.	Do.
Unnamed	8 and 9	15 N.	1 W.	Anomaly in sandstone in upper part of Jmb	AEC, DH.
Do	SE¼ 9	15 N.	1 W.	do	Do.
Do	10 and 11	15 N.	1 W.	do	Do.
Do	SE¼ 11	15 N.	1 W.	do	Do.
Do	SE¼ 11	15 N.	1 W.	do	Do.
Do	SE¼ 14	15 N.	1 W.	do	Do.
Do	NE¼ 15	15 N.	1 W.	do	Do.
Do	SE¼ 21	15 N.	1 W.	do	Do.
Do	SE¼ 22	15 N.	1 W.	do	Do.
Do	SE¼ 23	15 N.	1 W.	do	Do.
Morris-Peters	17	15 N.	1 E.	Spotty radioactive zones along about 1,500 ft of outcrop in sandstone that is probably in upper part of Jmb. Radioactive material is concentrated around mudstone galls and lenses in limonite stained and faulted sandstone.	J. W. Allison and R. F. Nestler (WC, 1954).
Do	20	15 N.	1 E.	Same as Morris-Peters, sec. 17 (above)	Do.
Do	21	15 N.	1 E.	Same as Morris-Peters, sec. 17 (above). Sample, 0.36 percent eU_3O_8.	Do.
Burcar	*NE¼NE¼ 12	17 N.	1 W.	Radioactive zones in bands as much as 1 ft thick and in pods around large mudstone galls in Dakota Sandstone. Some carnotite visible on joint surfaces and outcrop faces. Sample, 0.04 percent U.	P. E. Melancon (WC, 1952).
Collins (*22*)	*25	17 N.	1 W.	Deposit in Jmw. Some ore mined, 1957–64	AEC, DH.
Section 25	*NW¼ 25	17 N.	1 W.	Several small deposits in Jmw	L. R. Kittleman and W. F. McConnell (WC, undated).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Sandoval County—Continued	
Section 25 (Collier).	*SW¼ 25	17 N.	1 W.	Yellow and green uranium minerals in 18-ft-thick fine-grained iron-stained sandstone in Jmb. Grab sample, 0.61 percent eU_3O_8.	A. Mirsky (WC, 1953).
Section 36	*SW¼ 36	17 N.	1 W.	Deposit in Jmw	AEC.
Peralta Canyon	*NW¼SE¼ 9	17 N.	5 E.	Torbernite and uranophane, associated with copper oxides, coat fracture surfaces and fill interstices of brecciated rhyolite.	Jones (1904, p. 342); Lindgren, Graton, and Gordon (1910, p. 162).
Unnamed	*SW¼ 13	18 N.	1 W.	Radioactive shale in Dakota Sandstone	Unknown.
Deer Creek	C. 35	18 N.	1 E.	Radioactive black carbonaceous shale lens in basal sandstone of Abo Formation. Lens is 150 ft long, 22 ft thick, and extends unknown distance back from outcrop, but is exposed to face of 24-ft adit of old copper prospect. Visible yellow-green uranium mineral associated with chalcocite, bornite, chalcopyrite, malachite, and azurite. Channel sample, reportedly 0.08 percent eU_3O_8.	W. L. Chenowith and P. H. Knowles (WC, 1956).
Unnamed	*13	18 N.	2 E.	Radioactive intermittent zone, about 10 ft thick, that extends along strike about 200 ft in basal sandstone of Abo Formation. Sandstone is about 25 ft thick, contains carbonaceous plant debris, and has spotty distribution of malachite and azurite. Exposure is in footwall of northeast-trending Jemez fault where beds dip about 45° SE. Channel sample, 0.02 percent U_3O_8.	Do.
Tex-N	*C. 34	18 N.	2 E.	Radioactive zone in shallow prospect pit immediately west of Jemez River, near base of 60-ft-thick sandstone in Abo Formation. Radioactivity is concentrated along carbonaceous seams that are 3 in. to 1 ft thick, 1–3 ft apart stratigraphically, and in zone about 10–12 ft thick but of unknown lateral extent. Copper carbonate minerals show, but no uranium minerals visible. Grab sample, 0.07 percent U_3O_8.	R. K. Nestler (WC, 1955).
Mauldian	Near junction of 1 and 2.	19 N.	1 W.	Ore-grade material mined from Dakota Sandstone	Unknown.
Cleary	E½ 14	19 N.	1 W.	Radioactive zone of carbonaceous shale 2–3 ft thick, occurs about 8–12 ft above base of Dakota Sandstone and extends about 800 ft along outcrop. Grab sample, 0.06 percent eU_3O_8. Associated small lens of impure coal assayed 0.088 percent U.	D. E. Mathewson (WC, 1953); Bachman and others (1959, p. 299–300, 306).
Butler Bros. 1 (*1*)	W½NE¼ 23	19 N.	1 W.	A carbonaceous shale, or peat, unit about 1 ft thick, at base of Dakota Sandstone is mineralized for about 100 ft along outcrop on the southeastern upthrown side of high-angle cross fault. Some ore mined in 1954 and 1957.	H. G. Brown III and Larry Werts (WC, 1954); Gabelman (1956a, p. 308, 312).
North Butte	Parts of 28, 29, 32, and 33.	19 N.	1 W.	Uranium occurs erratically near top of La Ventana Mesa in two areas, principally at North Butte and partly at South Butte, respectively. The uranium is in a zone several feet thick at top of the Menefee Formation, immediately below base of La Ventana Tongue of Cliff House Sandstone. The uranium-bearing zone includes three beds: an upper bed, 6 in.–6 ft thick, of friable gray sandstone containing fragments of carbonaceous debris; a middle bed, 2 in.–4 ft thick, of coal and impure coal; and a lower bed, as much as 10 ft thick, of carbonaceous shale. These three beds are somewhat lenticular and not always distinct. The middle bed contains the highest grade deposits, locally as much as 0.62 percent uranium. Uranium minerals are not visible, but coffinite has been identified in coal.	Bachman and others (1959); J. D. Vine, G. O. Bachman, C. B. Read, and G. W. Moore (WC, 1953).
South Butte	Parts of 2, 3, and 11; and parts of 33–35.	18 N.	1 W.	Same as North Butte (above) but not as extensive	Bachman and others (1959, p. 295–307).
Unnamed	NW¼NW¼ 35	19 N.	1 W.	Three uranium-bearing zones, each about 1 ft thick and consisting of carbonaceous shale, occur near top of Point Lookout Sandstone. Sample assayed 0.12 percent U.	Bachman and others (1959, p. 300, 306).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Sandoval County—Continued	
Houston	3	19 N.	2 W.	Radioactive zone in lower 3 ft of Ojo Alamo Sandstone. Sandstone is conglomeratic and limonite stained and contains carbonized wood fragments. Deposit is underlain by 5-ft-thick green mudstone. Grab sample of limonitic sandstone, 0.05 percent eU_3O_8.	D. E. Mathewson (WC, 1953).
Cuba 13	35(?)	19 N.	2 W.	Radioactive zone at base of La Ventana Tongue of Cliff House Sandstone. The deposit is in limonite-stained carbonaceous sandstone. Channel sample, 1 ft thick, 0.07 percent eU_3O_8.	H. G. Brown III (WC, 1954).
				San Juan County	
Kimbeto T. P	26	23 N.	10 W.	Uranium-bearing zone, 1–3 ft thick, in fine-grained carbonaceous sandstone of Ojo Alamo Sandstone. Zone immediately underlies conglomeratic sandstone containing petrified logs, is about 50 ft above the Kirtland Shale, and extends along outcrop discontinuously about 2,000 ft. Sample brought in by prospector assayed 0.12 percent U_3O_8.	W. L. Chenowith (WC, 1955).
Dodge Brothers (Airborne anomaly 1).	*Approx. 5 or 6	23 N.	19 W.	Zone of carbonaceous siltstone about 5 ft thick in upper part of Gallup Sandstone. Estimated grade as much as 0.14 percent eU_3O_8.	B. J. Archer, Jr. (WC, 1955).
Dodge-Begay	*Approx. 16	23 N.	19 W.	Mineralized bed, 1–2 ft thick, crops out for at least 2,500 ft along Dakota Sandstone hogback. Lithology not reported. Grab sample, 0.06 percent eU_3O_8.	P. E. Melancon (WC, 1952).
Dodge Brothers (Airborne anomaly 2).	*Approx. 23 or 24.	24 N.	20 W.	Mineralized carbonaceous shale 0.5–2 ft thick in upper part of Gallup Sandstone is exposed in opencut along outcrop for about 100 ft. Estimate grade as much as 0.05 percent eU_3O_8.	B. J. Archer, Jr. (WC, 1955).
Dennet Nezz *(24)*	*NE¼ 18	25 N.	20 W.	Uranium minerals in fractures in calcified fossil logs and peripheral to logs in sandstone in lower part of Jmr. Some ore mined from opencut, 1953–55.	J. W. Blagbrough and others (WC, 1959); AEC.
Dennet Nezz 2 *(25)*.	*NE¼ 18	25 N.	20 W.	Similar to Dennet Nezz (above). Some ore mined from opencut in 1955.	Do.
Dennet Nezz 3 *(26)*.	*NW¼ 18	25 N.	20 W.	do	Do.
Enos Johnson 3 (South Peak) *(33)*.	*SW¼NW¼ 19	25 N.	20 W.	Small and medium deposits in sandstone in upper part of Jmr. Ore mined from adits, 1952–64.	J. W. Blagbrough and others. (WC, 1959); AEC.
Horace Ben 1 *(41)*	*SE¼ 19	25 N.	20 W.	Small deposit in sandstone in upper part of Jmr. Some ore mined from opencut in 1952.	Do.
Carl Yazzie 1 *(15)*	*NW¼NW¼ 30	25 N.	20 W.	Small deposits in sandstone in Jms. Some ore mined from opencut in 1954. U:V ratio 1:3. No deposits have been reported in Jms south of this locality.	J. W. Blagbrough and D. A. Thieme (WC, 1954); J. W. Blagbrough (WC, 1956); AEC.
Tyler	*CE½W½ 11	25 N.	21 W.	Tyuyamunite coats fracture surfaces in folded coarsely crystalline Todilto Limestone. Deposit is about 15 ft wide and 1 ft thick.	J. W. Blagbrough (WC, 1954).
David Kee	*CS½ 11	25 N.	21 W.	Small deposits in calcified fossil logs and peripheral to logs in sandstone in lower part of Jmr.	J. W. Blagbrough and D. A. Thieme (WC, 1954).
Kee Tohe *(48)*	*NE¼SE¼ 11	25 N.	21 W.	Several small deposits in sandstone in upper part of Jmr. Some ore mined from opencut in 1954.	Do.
John Joe 1 *(46)*	*SW¼SE¼ 11	25 N.	21 W.	Small deposits in sandstone in Jms. No deposits in Jms reported north of this locality in Chuska district. Some ore mined in 1955 from opencut. U:V ratio 1:2.	J. W. Blagbrough and D. A. Thieme (WC, 1954); AEC.
Castle T'sosie *(17)*	*SE¼SE¼ 11	25 N.	21 W.	Small deposit in sandstone in upper part of Jmr. Some ore mined from opencut in 1956.	Do.
Joe Ben 1 *(44)*	*SE¼NW¼ 13	25 N.	21 W.	Small deposits in sandstone, generally around carbonized wood, in Jms. Some ore mined from opencut in 1952. U:V ratio 2:1.	Do.
Joe Ben 2	*NE¼ 13	25 N.	21 W.	Similar to Joe Ben 1 (above)	Do.
Alfred Talk	*NE¼NE¼ 14	25 N.	21 W.	Small deposit in sandstone in Jms. Channel sample 1 ft thick, 0.22 percent U_3O_8.	Do.
Joe Ben 3 *(45)*	*NE¼NE¼ 24	25 N.	21 W.	Small deposits in sandstone in Jms. Some ore mined from opencut, 1953–55; U:V ratio 1:2.5.	Do.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				San Juan County—Continued	
Enos Johnson (*30*)	*SE¼ 24(?)	25 N.	21 W.	Small to medium deposits in sandstone in Jms. Ore mined in 1952–54.	P. C. Ellsworth (WC, undated), J. W. Blagbrough and D. A. Thieme (WC, 1954), and J. W. Blagbrough and others (WC, 1959); AEC.
Enos Johnson 1 (*31*).	*SE¼ 24(?)	25 N.	21 W.	Small deposits occur in sandstone in Jms. Some ore mined, 1952–55.	J. W. Blagbrough and others (WC, 1959); AEC.
Enos Johnson 2 (*32*).	*SE¼ 24(?)	25 N.	21 W.	Similar to Enos Johnson 1 (above). Some ore mined, 1952–54.	Do.
Reed Henderson	*S½SW¼ 36	25 N.	21 W.	Tyuyamunite and metatyuyamunite occur sparsely on joint surfaces and as vug linings in recrystallized calcite in upper 5 ft of Todilto Limestone along outcrop from Reed Henderson claim to head of north branch of Sanostee Wash, a distance of about 4 miles. Deposits are principally on flanks of intraformational anticlinal folds, which have amplitudes of as much as 1–2 ft, are about 3 ft wide, and 10–15 ft long. Limestone is mineralized in areas of most intense folding, where axes of folds are subparallel. Cuprosklodowskite reported in area (Gruner and Smith, 1955). About 24 tons of subore-grade material shipped from Reed Henderson in 1954.	J. W. Blagbrough, D. A. Thieme, B. J. Archer, Jr., and R. W. Lott (WC, 1959); AEC.
H. B. Roy 2 (*40*)	*C. 14–23	26 N.	21 W.	Small deposits in sandstone in upper part of Jmr. Some ore mined from opencut in 1954.	J. W. Blagbrough and D. A. Thieme (WC, 1954).
Rocky Spring	*35	27 N.	21 W.	Two mineralized zones, each less than 1 ft thick and about 2 ft apart stratigraphically, in Jms. Deposits are in sandstone beneath 3-ft-thick mudstone and about 5 ft above Bluff Sandstone. Mineralized zone extends along the outcrop for about 1,500 ft.	K. Hatfield and J. Craig (WC, 1953).
Canyon 2	*NE¼SW¼ 2	29 N.	21 W.	Small tabular deposit in Jms in two flat-lying layers about 15 ft apart stratigraphically; each layer a few inches or more thick and exposed along outcrop about 200 ft.	K. T. Hatfield (WC, 1951).
Unnamed	*S½ 2 and N½ 11.	29 N.	21 W.	Several small deposits in Jms	AEC, DH.
Do	*NW¼ 11	29 N.	21 W.	do	Do.
Do	*SW¼ 11	29 N.	21 W.	do	Do.
Do	*S½ 11 and N½ 14.	29 N.	21 W.	do	Do.
Salt Canyon (*73*)	*NE¼ 14	29 N.	21 W.	Small deposit or deposits in Jms. Ore mined in 1952–56. U:V ratio 1:9.	AEC.
Lookout Point (*55*)	*S½SE¼ 14	29 N.	21 W.	Several deposits in Jms. Ore mined in 1952–56. U:V ratio 1:6.	Stokes (1951); AEC.
Unknown	*SW¼ 14 and NW¼ 23.	29 N.	21 W.	Several small deposits in Jms. Some ore probably produced and listed under East Side mines.	Stokes (1951).
Nelson Point (*62*)	*SE¼NW¼ 23	29 N.	21 W.	Several small and medium deposits in Jms probably about 75 ft above Bluff Sandstone. Deposits defined partly by drill holes and worked in several opencuts. Ore mined in 1952–64. U:V ratio 1:11.	J. A. Masters and others (WC, 1955); AEC, DH.
Shadyside (*93*)	*Near CN½ N½ 23.	29 N.	21 W.	Several generally small deposits in sandstone in Jms about 75 ft above Bluff Sandstone. Sandstone bed ranges from about 1 to 20 ft in thickness and is elongate southeastward. Deposits also generally are elongate southeastward. Ore has been mined from several adits in 1952–56 and in 1964. U:V ratio 1:8.	J. A. Masters and others (WC, 1955); AEC.
Shadyside 2 (*94*)	*Near CN½ N½ 23.	29 N.	21 W.	Same as for Shadyside (above); workings of two mines are probably contiguous. Ore mined in 1952–55 period. U:V ratio 1:8.	J. A. Masters and others (WC, 1955); AEC, DH.
Tent (*99*)	*E½NE¼ 23	29 N.	21 W.	Several small deposits in Jms and similar to Shadyside (above). Deposits probably worked from opencut, 1955–57. U:V ratio 1:7.	Do.

Table 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				San Juan County—Continued	
King Tutt (*51*)	*E½SE¼ 23	29 N.	21 W.	Small deposit near south margin of 50-ft-thick sandstone in lower part of Jms and probably stratigraphically below sandstone that contains Shadyside (above). Sandstone lens is elongate eastward and contains all deposits in general vicinity, most of which are also elongate eastward. King Tutt probably worked from opencut; some ore shipped in 1956. U:V ratio 1:5.	J. A. Masters and others (WC, 1955); AEC, DH.
Begay 1 and 2 (*7*)	*E½ 23 and W½NW¼ 24.	29 N.	21 W.	Numerous small and some medium deposits in Jms. Probably similar to Shadyside (above). Deposits defined by drill holes. Ore mined from short adits, 1953–64. U:V ratio 1:6.	Do.
Junction (*47*)	*NE¼ 24	29 N.	21 W.	Small deposit in Jms. Some ore mined in 1953. U:V ratio 1:3.	AEC.
King Tutt 1 (*52*)	*W½SW¼ 24	29 N.	21 W.	One or more small deposits in same 50-ft-thick sandstone in Jms as King Tutt (above). Deposits are generally elongate eastward. Ore mined in 1952–58 period. U:V ratio 1:5.	J. A. Masters and others (WC, 1955); AEC.
Alongo (*1*)	*SW¼ 25	29 N.	21 W.	One or more small deposits in Jms. Some ore mined in 1956. U:V ratio about 1:1.	AEC.
Horse Mesa	*CW½ 26	29 N.	21 W.	Several small tabular deposits crop out along rim of Horse Mesa in Jms. Some ore has been mined.	Stokes (1951).
BB (Lewis Barton) (*4*).	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1951. U:V ratio 1:9.	AEC.
BBB (Barton and Begay) (*5*).	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1950. U:V ratio 1:14.	Do.
Canyon View (*14*)	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1952. U:V ratio 1:6.	Do.
Carrizo 1 (*16*)	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1956–58. U:V ratio 1:4.	Do.
Cottonwood Butte (*23*).	*Uncertain	20–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1950–51 and 1954. U:V ratio 1:8.	Do.
King Tutt Point (*53*).	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1952–53. U:V ratio 1:5.	Do.
Plot 7 (lower Oak Springs) (*65*).	*Uncertain	29(?) N.	21 W.	Small deposits in Jms. Ore shipped in 1959–64. U:V ratio 1:5.	Do.
Rattlesnake 6 (*67*).	*Uncertain	29–30 N.	21 W.	Small deposit in Jms. Ore shipped in 1956. U:V ratio 1:2.	Do.
Red Rocks (*68*)	*Uncertain	29–30 N.	21 W.	Small deposit in Jms. Ore shipped in 1962. U:V ratio 1:6.	Do.
Red Wash Point (*69*).	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1952. U:V ratio 1:5.	Do.
Rocky mine 2 (*72*).	*Uncertain	29–30 N.	21 W.	Small deposits in Jms. Ore shipped in 1952. U:V ratio 1:8.	Do.
Sam Point (*74*)	*Uncertain	29–30 N.	21 W.	do	Do.
Jack Boyd	N½ 3	30 N.	15 W.	Uraniferous deposit at base of 30 ft-thick limonite-stained tuffaceous and crossbedded sandstone near base of Fruitland Formation. It overlies a 10-ft-thick carbonaceous claystone. Some tonnage of ore-grade material reportedly shipped in 1954–55. Deposit thickens in depressions in underlying claystone. Channel sample, 0.22 percent U_3O_8.	W. L. Chenowith and Ward Carithers (WC, 1955).
Hogback claims	15 and 22	30 N.	16 W.	Spotty scattered small limonite-stained carbonaceous thin uraniferous zones in sandstone near base of Menefee Formation. Channel sample, 0.01 percent U_3O_8, but higher grade material reportedly in drill holes.	Do.
King 6 (Troy Rose) (*60*).	*Near SW. cor. 11.	30 N.	21 W.	Small deposit in Jms. Other small deposits in vicinity along outcrop. Some ore mined in 1956. U:V ratio 1:5.	AEC.
Rocky Flats (*70*)	*E½SW¼ 14	30 N.	21 W.	Small deposit at outcrop in Jms. Some ore mined, 1953–55. U:V ratio 1:10.	Ronald Lebrecque, (WC, 1955); AEC.
Barton 1	*NE¼ 23	30 N.	21 W.	Small tabular deposit, a few inches to about 2½ ft thick, in Jms. Two other small deposits nearby.	AEC.
Hoskey Barton	*Near C. 24	30 N.	21 W.	Small deposit at outcrop in Jms. Other small deposits in vicinity along outcrop.	K. G. Hadfield (WC, 1954).
Rocky Flats 2 (*71*).	*SE¼ 26	30 N.	21 W.	Small deposit at outcrop in Jms. Many other small deposits in vicinity along outcrop. Some ore mined in 1955. U:V ratio 1:11.	AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
San Juan County—Continued					
Unknown	*S½NW¼ 35	30 N.	21 W.	Several small deposits at outcrop in Jms	Stokes (1951).
Lone Star (*54*)	*E½SW¼ 35	30 N.	21 W.	Small tabular deposit, about 1 ft thick, in Jms. Deposit is about 50 ft above top of Bluff Sandstone and near northern edge of sandstone unit that contains the Canyon 2 (above). Several other small deposits are in general vicinity in same stratigraphic zone. Ore mined in 1952 and 1962. U:V ratio 1:6.	J. A. Masters and others (WC, 1955); AEC.
King 2 (*49*)	*NW¼NW¼ 26	30 N.	21 W.	Small deposit, or deposits, in Jms. Ore mined in 1952–54 period. U:V ratio 1:12.	AEC.
Airborne anomaly 13.	*SE¼ 19	31 N.	15 W.	Radioactive zone at top of hematite-stained sandstone near base of Menefee Formation. Zone is about 1 ft thick and 30 ft in diameter and is overlain by thin coal seam. Grab sample, 0.03 percent eU_3O_8.	W. L. Chenowith (WC, 1955).
Chilton prospect	NW¼NW¼ 28	32 N.	10 W.	Radioactive zone in thin-bedded yellow-brown carbonaceous sandstone of San Jose Formation. Channel sample, 0.02 percent eU_3O_8.	R. L. Rock (WC, 1954).
Santa Fe County					
Hiser-Moore 1	*Approx. E½ 8	15 N.	7 E.	Autunite(?) locally impregnates limonite-stained joint surfaces near top of flow of Cienegilla Limburgite of Stearns (1953) which strikes northeast and dips about 20° NW. Selected chip sample, 0.15 percent U_3O_8.	FN, October 1955; R. M. Perhac (WC, 1954).
La Bajada (*1*)	*Approx. NW¼ 9.	15 N.	7 E.	Deposit occurs in Espinaso Volcanics of Stearns (1943) along brecciated footwall of limburgite dike where Espinaso is probably mostly agglomerate. Host rock is altered and impregnated with massive iron sulfides, sulfides of copper and some zinc, and possibly sulfides of nickel and molybdenum. Uranium, associated with some carbonaceous material, is localized in podlike zones with the base-metal sulfides. Mineralogy of the uranium is not known. Deposit was worked through a vertical shaft for copper in the early twenties. In 1963–64, it was being mined below level of streambed in open pit that exposed complex network of thin sulfide veins in the limburgite dike.	J. W. Hasler (WC, 1957); FN, October 1955, and May 1963.
Airborne anomaly 1.	E½ 19	15 N.	7 E.	Radioactive limonite and silica in fracture zone in Santa Fe Group. Host rocks probably sandstone. Grab sample, 0.15 percent eU_3O_8.	N. S. Mallory and G. E. Collins (WC, 1954).
Rogers No. (?)	E½NW¼ 17	20 N.	9 E.	Deposit in Santa Fe Group, similar to Airborne anomaly 1 (above).	G. E. Collins (WC, 1954); FN, October 1955.
Airborne anomaly 8.	SE¼ 17	19 N.	9 E.	Carnotite, schroeckingerite, and meta-autunite coat fracture and bedding surfaces of gray claystone and siltstone of Santa Fe Group. Mineralized zone is few feet thick and extends few tens of feet along strike of bedding. Sample, 0.04 percent U_3O_8.	Collins and Freeland (1956, p. 11); R. S. Cannon, Jr., R. L. Smith, and H. L. Cannon (WC, 1955).
Airborne anomaly 9.	SE¼ 17	19 N.	9 E.	Carnotite, schroekingerite, and meta-autunite occur in limonite-stained gray siltstone and sandstone of Santa Fe Group. Associated with abundant carbonized plant remains. Sample, 0.06 percent U_3O_8.	Collins and Freeland (1956, p. 11–12); R. S. Cannon, Jr., R. L. Smith, and H. L. Cannon (WC, 1955).
Rogers (?)	E½NW¼ 17	20 N.	9 E.	Deposit in Santa Fe Group, similar to Airborne anomaly 1 (above).	G. E. Collins (WC, 1954); FN, October 1955.
Do	300 ft SW. and 600 ft NE., respectively, of ¼ cor. 17 and 20.	20 N.	9 E.	Deposits in sandstone of Santa Fe Group, similar to those described above. Grab sample 239580, 0.03 percent U_3O_8.	FN, October 1955. Analysis by C. Angelo, J. Wahlberg, J. Schuch, G. Burrow, and J. Wilson.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Santa Fe County—Continued	
Rogers (?)	CS½S½ 20 and near C. 20.	20 N.	9 E.	Deposits in sandstone of Santa Fe Group; similar to those described above.	G. E. Collins (WC, 1954); FN, October 1955.
Do	SE¼NW¼ 29	20 N.	9 E.	Carnotite, schroeckingerite, and meta-autunite coat fracture and bedding surfaces of sandstone, siltstone, and claystone in face of shallow pit in Santa Fe Group. Uranium minerals are concentrated where sandstone contains clay galls and pockets of carbonized plant remains. Other deposits in vicinity are numerous but small. Selected grab sample 239586, 0.27 percent U_3O_8.	G. E. Collins (WC, 1954); FN, October 1955. Analysis by C. Angelo, J. Wahlberg, J. Schuch, G. Burrow, J. Wilson.
Anomaly 1	NE¼NE¼SW¼ 32.	20 N.	9 E.	Radioactive limonite in gray sandstone of Santa Fe Group. Sandstone contains clay galls and carbonaceous "trash" where radioactive. Sample, 0.02 percent U_3O_8.	Collins and Freeland (1956, p. 9–10).
				Socorro County	
"Silver Creek" prospect.	*SE¼SW¼ 15	1 N.	2 W.	Yellow uranium minerals, associated with copper oxides, coat walls of old copper prospect shaft, which is probably in Popotosa Formation. Grab sample, 0.30 percent U_3O_8.	R. D. Lynn (OC, undated).
King claim	4	1 N.	4 W.	Radioactive limonite-stained sample of sandstone float, probably from base of Baca Formation. Grab sample, 0.02 percent eU.	G. E. Collins (WC, 1954).
Hook Ranch (Airborne anomaly 5).	7	1 N.	5 W.	Radioactive zone in limonite-stained sandstone in in Mancos(?) Shale. Grab sample, 0.02 percent U.	Unknown.
Hot Shot	W½NW¼ 18	1 N.	5 W.	Radioactive anomalies in limonite-stained carbonaceous sandstone near base of Baca Formation. Sample, 0.31 percent U.	G. E. Collins (WC, 1954); Griggs and Baltz (1955, p. 211).
Hook Ranch (Airborne anomaly 4).	13	1 N.	6 W.	Similar to Hot Shot deposit (above). Sample, 3.27 percent U.	Griggs and Baltz (1955 p. 211).
Hogsett-Hust-Henderson 1–4 (Airborne anomalies 2, 3).	NW¼ 24	1 N.	6 W.	Meta-autunite(?) and unidentified uranium minerals occur in limonite-stained carbonaceous, "asphaltic" sandstone of Baca Formation. Several deposits are exposed in shallow prospect pits within area of four claims. Selected sample, 1.5 percent U_3O_8.	G. E. Collins (WC, 1954).
Hook Ranch (Jaralosa) (*2*).	24	1 N.	6 W.	Possibly one or more of Hogsett-Hust-Henderson deposits (above), or the Hust-McDonald-Brown deposit (below). Some ore shipped, 1959–61.	AEC.
Hust-McDonald-Brown.	NE¼ 24	1 N.	6 W.	Radioactive limonite-stained pod of conglomeratic sandstone, interbedded with volcanic rocks, probably in upper part of Baca Formation. Sample, 0.19 percent U.	G. E. Collins (WC, 1954); Griggs and Baltz (1955, p. 211).
Unnamed	35	1 N.	6 W.	A radioactive 1-ft-thick zone in carbonaceous sandstone in Baca Formation. Grab sample, 0.036 percent U.	G. O. Bachman, E. H. Baltz, and R. L. Griggs (WC, 1957).
Campbell	*W½ 22	1 N.	2 E.	Radioactive zone in bleached sandstone of Dockum Formation. Zone is about 20 ft thick and several hundred feet long. Secondary uranium minerals show locally. Grab sample, 0.097 percent eU_3O_8.	G. E. Collins (WC, 1955).
Rayborn prospect	N½ 6	2 N.	8 W.	Tyuyamunite occurs in limonite-stained carbonaceous sandstone of Gallup Sandstone.	AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Socorro County—Continued	
Charley 2 (*1*)	SW¼NE¼ 35	3 N.	2 W.	Carnotite, tyuyamunite, autunite, and some pitchblende are disseminated in pockets and along fractures and bedding surfaces in tabular zone, about 1–10 ft thick, of sheared dark-gray clayey material and bleached tuffaceous sandstone at base of Popotosa Formation where it is separated from underlying Precambrian by Cerro Colorado fault. Mineralized zone underlies sheared red clay zone about 5 ft thick and rests on brecciated altered granitic rock. Beds of Popotosa Formation, sheared zone, and underlying granite surface dip about 25° E. and probably mark position where fault flattens and swings abruptly from north to northwestward strike. Deposit mined from open pit and incline shaft, 1954–58.	FN, May 1956; G. E. Collins (WC, 1954); W. A. Carlson (WC, 1954); P. H. Knowles (WC, 1957); Denny (1940, fig. 1); Kelley and Wood (1946).
"Shaft" prospect	SE¼ 10	1 S.	2 W.	Torbernite(?) and carnotite(?), associated with secondary copper minerals, calcite, and quartz, occur in shear zone in trachyandesite of Datil Formation. Mineralized material noted in dump at site of flooded vertical shaft. Sample assayed 0.026 percent U.	Gott and Erickson (1952, p. 4, 13).
Agua Torres (*1*)	*SE¼ 1	1 S.	2 E.	Deposit in arkosic limestone member of Madera Limestone immediately west of steeply dipping north-trending normal fault that at the surface separates the Madera from Abo Formation. Deposit consists of fracture fillings by a yellow uranium mineral in irregular zones of siliceous limestone breccia. Breccia zones are in footwall of fault, are hematite stained, and locally as much as 100 ft in diameter but of unknown depth. Some ore was mined from shallow pits, 1955–56.	AEC.
Marie (*2*)	*12 and 13	1 S.	2 E.	Small deposit or series of deposits in geologic setting similar to Agua Torres (above). The rocks are not as brecciated, however, and deposit consists of fillings of solution cavities in limonite-stained limestone by yellow uranium mineral. Some ore mined from open pit in 1956.	Do.
Carter-Tolliver-Cook.	E½ 5	2 S.	1 W.	Carnotite and uranophane, associated with galena, pyrite, and chalcopyrite, occur in mafic dikes that crosscut diorite intrusive bodies. Igneous rocks probably intrude Santa Fe Group. Grab(?) sample, 0.25 percent U_3O_8.	Unknown.
Do	W½ 6	2 S.	1 W.	Same as E½ sec. 5 (above)	Do.
Lucky Don (Bonanza 1) (*1*).	NE¼ 35	2 S.	2 E.	Deposit in middle limestone member of San Andres Limestone immediately east of and in footwall of northeastward-trending normal fault that separates the San Andres from Yeso Formation. At deposit the San Andres is dark-gray cherty thin- to medium-bedded limestone with some interbedded white limy sandstone. Beds strike about N. 45° E., dip about* 25° E., and are locally crushed and sheared. Deposit consists of tyuyamunite and possibly carnotite disseminated along fracture and bedding surfaces and as intergranular fillings in zone that is roughly tabular, is about 300–400 ft long, 50 ft wide, and 35 ft thick. Ore has been mined from short adits and an opencut in 1955–56 and in 1960–63.	FN, May 1956; David Carter (OC, May 1956); AEC.
Little Davie (*2*)	SW¼NE¼ 35	2 S.	2 E.	Small deposit about 1,200 ft south of Lucky Don and in similar geologic setting (see above). Some ore mined in 1955.	Do.
Uranium prospect 17.	SE¼NE¼ 3	2 N.	5 E.	An unknown uranium mineral concentrated along fracture surfaces in red arkose and disseminated in carbonaceous shale in Abo Formation, closely associated with carbonized wood and with malachite, azurite, and chalcocite. This is old copper prospect and consists of two shallow shafts, a 40-ft incline, and several shallow pits. Chip sample, 0.11 percent U_3O_8.	Russell Gibson (1952, p. 22–24).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Socorro, County—Continued	
Rattlesnake	NW¼SE¼ 15	3 N.	5 E.	Radioactive zone in red and gray sandstone and conglomerate of Abo Formation. Yellow-green uranium mineral also occurs in surficial float.	G. E. Collins (WC, 1954).
Abo	SE¼ 22	3 N.	5 E.	A yellow-green uranium mineral occurs in seam about 2 in. thick along wall of short adit for distance of about 5 ft. Seam is in siliceous conglomerate lens in Abo Formation. Sample of seam, 13.0 percent U_3O_8.	H. D. Wolfe and G. E. Collins (WC, 1954).
Pioneer	23(?)	3 N.	5 E.	Yellow and green uranium minerals are visible along walls of 20-ft adit in several podlike zones and associated with carbonaceous layers in conglomeratic sandstone in lower part of Abo Formation. Podlike zones are generally an inch or less thick and traceable for few feet along bedding. Selected sample, 2.15 percent U_3O_8. This deposit may be in sec. 22 in same general zone as Abo deposit (above).	J. P. Hadfield, Jr., and H. E. Geslin (WC, 1953).
				Valencia County	
Brownlow-Heath	N½N½N½ 4	6 N.	4 W.	Radioactive zone in conglomeratic sandstone about 100 ft above base of Chinle Formation, possibly in Shinarump Member.	AEC.
Sonora	1 and 12	7 N.	5 W.	Yellow uranium minerals occur along fracture surfaces in impure nodular limestone and dark-gray shale of San Andres Limestone which is intruded with numerous igneous dikes and sills and is mineralized by copper, lead, and possibly silver and nickel minerals.	W. A. Carlson (WC, 1954).
Crackpot (*7*)	NW¼NW¼ 8	8 N.	5 W.	Medium deposit in elongate domelike fold in Todilto Limestone. The fold, which has closure of about 3–5 ft on underlying Entrada Sandstone contact, trends northwestward and is constituted in part by several minor folds that radiate from central part of dome. Deposit was concentrated in lower part of limestone, where it was about 15 ft thick near center of dome and from where it tapered and thinned irregularly toward margins near periphery of dome. Mineralogy is similar to other deposits in Todilto Limestone. (See text.) Other small deposits occur in vicinity. Ore mined from open pit in 1955.	FN, April 1955; J. M. Elias (OC, April 1955); AEC.
Unnamed	NW¼NW¼ 5	8 N.	6 W.	Small deposit exposed at outcrop of Todilto Limestone.	R. H. Moench (WC, 1960).
Do	SW¼SW¼NW¼ 5.	8 N.	6 W.	do	Do.
Do	CW½NW¼ 5	8 N.	6 W.	do	Do.
Do	SW¼SW¼ 10	8 N.	6 W.	do	Do.
Do	CW½ 11	8 N.	6 W.	do	Do.
Paisano (*23*)	SE¼NW¼ 16	8 N.	6 W.	Small deposit at outcrop of Todilto Limestone. Ore mined from open pit in 1957.	AEC.
Balo	S½ 18	8 N.	6 W.	Spotty occurrences of tyuyamunite and uraninite occur along bedding at outcrop of Todilto Limestone for distance of about 1 mile. Sample, 0.16 percent eU.	J. W. Allison (WC, 1954).
Sandy (*76*)	SE¼ 22	9 N.	5 W.	The Sandy is a cluster of several small deposits within upper 15 ft of Entrada Sandstone and, locally, in base of overlying Todilto Limestone. Cluster is more or less continuous body, roughly parallel to the bedding, elongate eastward, roughly 5–10 ft thick, 10–25 ft wide, and about 600 ft long. A diabase sill, about 25 ft thick, intrudes and displaces the upper part of deposit. The uranium is largely in finely disseminated coffinite and uraninite. Deposit was mined in 1955.	FN, 1955; The Anaconda Co., 1955; Hilpert and Moench (1960, p. 457–459); Moench (1962, p. B 67–B 69).
Unnamed	CS½N½ 27	9 N.	5 W.	Several, generally small, deposits associated with intraformational folds in Todilto Limestone. Folds are sinuous, have amplitudes as great as 15 ft, and are displaced in places by diabasic dikes and sills, which are younger than primary uranium minerals.	FN, April 1954; Hilpert and Moench (1960, p. 459 and fig. 17).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Valencia County—Continued	
Unnamed	CW½ 27	9 N.	5 W.	Several, generally small, deposits associated with intraformational folds in Todilto Limestone. Geology similar to other deposits in sec. 27 (above).	FN, April 1954.
Paraje	NW¼ 17	9 N.	6 W.	Conglomeratic sandstone at top of Jmb is mineralized just beneath northern flank of channel scour, exposed along mesa rim by bulldozer cut. Scour is at base of Dakota Sandstone. About 1,500 ft down slope a fragment of this deposit is exposed in landslide block.	FN, September 1954.
Section 4 prospect	CE½ 4	10 N.	3 W.	Deposit exposed in short adit in sandstone in Jmr	Moench and Puffett (1963b).
Chaves (*18*)	SE¼ 22	10 N.	3 W.	Deposit in medium- to coarse-grained sandstone with pockets of carbonized plant debris in Jmr in area marked by landslides and several faults. Ore was mined from shallow opencut and adit in 1955.	FN, 1955.
Unnamed	SE¼NE¼ 27	10 N.	3 W.	Two small deposits in Jmw at outcrop	Moench and Puffett (1963b).
Do	NW¼ 34	10 N.	3 W.	Small deposit in sandstone in Jmb	R. H. Moench (WC, 1960).
Do	NW¼ 34	10 N.	3 W.	do	Do.
Townsite	CE½ 3	10 N.	5 W.	Roughly tabular deposit in Jmj	The Anaconda Co., DH, 1957.
Paguate (*63*)	NW¼ 4, E½ 5, and SE¼ 33.	10–11 N.	5 W.	Very large, elongate deposit that trends northeastward, in Jmj.	The Anaconda Co., 1957; Kittel (1963, p. 174).
Oak Creek Canyon	NE¼ 10 and NW¼ 11.	10 N.	5 W.	Roughly tabular deposit in Jmj. Exposed in face of of bulldozer cut on north slope of Oak Creek Canyon.	The Anaconda Co., 1955; FN, 1955.
Unnamed	NW¼ 14	10 N.	5 W.	Small deposit at outcrop of Jmj	R. H. Moench (WC, 1960).
Horace and Quemazon.	NW¼NW¼SE¼ 4.	10 N.	9 W.	Yellow uranium minerals occur along fracture and bedding surfaces in lower part of Todilto Limestone. Mineralized zone at outcrop is several tens of feet long, a few feet wide, and several feet thick. Sample, 0.11 percent U.	Forrest Fincher (WC, 1954).
Wilcox Ranch	NE¼ 14	10 N.	15 W.	Deposit possibly in Shinarump Member of Chinle Formation. Located by drill hole. Sample assayed 0.14 percent U_3O_8.	David Carter (OC, 1956).
Unnamed	*SW¼ 18	11 N.	4 W.	Two or more small deposits near top of Jmj	The Anaconda Co., undated.
M–6 (*56*)	SW¼ 19 and NW¼ 30.	11 N.	4 W.	Large, tabular deposit near top of Jmj. Ore mined through vertical shaft, 1957–58.	Climax Uranium Corp., March 1957; AEC.
St. Anthony (Bibo).	NE¼NW¼ 29	11 N.	4 W.	One or more tabular deposits at top of Jmj	Climax Uranium Corp., March 1957.
Hanosh (M–1, M–2, and M–3).	N½ 30	11 N.	4 W.	Cluster of small and medium tabular deposits 0–100 ft below top of Jmj.	Do.
Unnamed	N½SE¼ 31	11 N.	4 W.	Tabular deposit near top of Jmj	R. H. Moench (WC, 1960).
L-Bar	*SW¼ 13 and NW¼ 24.	11 N.	5 W.	Two medium to large tabular deposits in Jmj	The Anaconda Co., DH, 1957; Kittel (1963, p. 168, 171, 174).
Unnamed	SE¼ 23 and SW¼ 24.	11 N.	5 W.	Small and medium deposits near top of Jmj	Climax Uranium Corp., March 1957.
Do	S½S½ 24	11 N.	5 W.	Several small and medium deposits near top of Jmj	Do.
Do	SE¼ 24	11 N.	5 W.	Small and medium deposits near top of Jmj	R. H. Moench (WC, 1960); Climax Uranium Corp., March 1957.
Do	NE¼ 25	11 N.	5 W.	Several small deposits near top of Jmj	R. H. Moench (WC, 1960).
Windwhip (*101*)	SW¼NW¼ 35	11 N.	5 W.	A roughly tabular deposit about 15 ft below top of Jmj. Western edge exposed at outcrop, where mined from opencut in 1954.	Hilpert and Moench (1960, p. 454).

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Valencia County—Continued	
Woodrow (*102*)	S½SE¼ 36 and N½NE¼ 1.	11 N. 10 N.	5 W. 5 W.	This deposit is in immediate periphery and in core of near-vertical pipelike structure that extends from surface to unknown depth. At least upper part is in Jmb and top 50 ft or so is in the Jmj. Pipe structure is roughly cylindrical, about 30 ft in diameter, and has known length of at least 200 and possibly more than 300 ft. The core is breccia-like and has slumped downward 30–45 ft, with respect to wallrock, along a ring fault. In upper part of structure the deposit is fairly high in grade and is mostly in fault zone and in favorable beds of the core; in lower part, deposit is mainly in core and is lower in grade. Mineralogy is similar to other deposits in the Morrison Formation in the vicinity, except principal ore mineral, coffinite, is coarse grained and the uranium and the general suite of associated elements, excepting vanadium, are roughly tenfold as abundant; the vanadium is about one-tenth as abundant. Deposit was mined in 1953–56.	FN; The Anaconda Co.; Hilpert and Moench (1960, p. 456–457); Wylie (1963).
Jackpile (*43*)	Parts of 26 and 35 and CN½ 2.	11 N. 10 N.	5 W. 5 W.	Very large, roughly tabular, multilayered deposit in upper part of Jmj. Deposit is in thickest part of sandstone, is roughly elongate northward, and is coextensive with black carbonaceous material. Deposit is closely related to sedimentary structures and may also be partly controlled by broad pre-Dakota folds. Principal ore mineral is finely disseminated coffinite. Since 1952 deposit has yielded several million tons of ore.	The Anaconda Co., 1955–57; Hilpert and Moench (1960, p. 450–454); Kittel (1963); Moench (1963c).
Tom 13 (*47*)	NW¼SE¼ 4	11 N.	9 W.	Small deposit 2–3 ft thick, in Todilto Limestone. Some ore mined 1954–55.	AEC.
Lone Pine 3 (*21*)	NE¼ 8	11 N.	9 W.	Small deposit in Todilto Limestone. Ore mined from adit, 1954–55.	Do.
Cedar 1 (Section 20; Yucca) (*5*).	NW¼SE¼ 20	11 N.	9 W.	Medium, elongate deposit, associated with east-trending intraformational fold in Todilto Limestone. Deposit mined from open pit, 1952–57. Other small deposits in vicinity.	FN, 1954–55; AEC.
Ingerson	NW¼SW¼ 7	11 N.	12 W.	Radioactive zone in basal conglomerate of Abo Formation immediately above contact with Precambrian granite. Zone contains copper carbonates, carbonaceous fossil logs, and macerated plant debris and is 1,500 ft long and 200 ft wide. Deposit has been worked for copper. Chip sample 2½ ft thick, 0.03 percent eU_3O_8.	L. H. Baumgardner (WC, 1954).
Unnamed	*Approx. CE½ 23.	12 N.	4 W.	Deposit, located by drill hole, possibly in, and near, west pinchout of Jmj.	R. D. Lynn (OC, undated); R. H. Moench (WC, 1963).
Do	*W½ 30	12 N.	4 W.	Deposit in Jmj	R. D. Lynn (OC, undated).
Do	*SE¼ 30	12 N.	4 W.	do	Do.
Do	*N½ 35	12 N.	5 W.	do	Do.
Do	*E½ 36	12 N.	5 W.	do	Do.
Double Jerry (Vallejo; Farris 1) (*9*).	NW¼NW¼ NW¼ 3.	12 N.	9 W.	Small and medium deposits occur at northeast end of stringlike cluster in the Todilto Limestone and are associated with set of intraformational folds that generally trend southwestward through sec. 4 into sec. 9. Ore mined from incline shaft, 1957–62; entry is in SW. cor. sec. 34, T. 13 N., R. 9 W.	FN, 1957; Gabelman (1956b, p. 391–393): AEC.
Red Bluff 3 (*24*)	CNE¼ 4	12 N.	9 W.	Small deposit in Todilto Limestone immediately north of Red Bluff 9. Deposit mined from open pit, 1952–56.	FN, 1954; AEC.
Red Bluff 5 (*25*)	CNE¼ 4	12 N.	9 W.	Small deposit in Todilto Limestone immediately west of Red Bluff 3. Ore mined from open pit in 1954.	Do.
Christmas Day (*6*)	SE¼NE¼ 4	12 N.	9 W.	Elongate cluster of small to medium deposits, in lower part of Todilto Limestone, that trends northeasterly, extends through area about 1,500 ft long, ranges from few feet to about 200 ft wide, and averages several feet thick. Deposits mined from open pit, 1954–56.	FN, 1955; Colamer Corp., DH, 1954; AEC.

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
				Valencia County—Continued	
Red Bluff 9 (*27*)	CNE¼ 4	12 N.	9 W.	Small deposit in Todilto Limestone immediately west of Christmas Day (above). Small amount of ore mined from open pit in 1955.	FN, 1954; AEC.
Red Bluff 7 (*26*)	SE¼SW¼ 4	12 N.	9 W.	Two or more small, elongate, westerly trending deposits in Todilto Limestone. Ore mined from open pit, 1953–58.	Gabelman (1956b, pl. 10); AEC.
Black Hawk-Bunney (*4*).	CSE¼ 4	12 N.	9 W.	Elongate, medium, and small deposits in middle of Todilto Limestone. This cluster of deposits generally trends northwesterly from the Gay Eagle. Ore mined from opencut, 1952–63.	FN, 1954; Malcolm Larson, DH, July 1954; AEC.
UDC 5 (*49*)	CSE¼ 4	12 N.	9 W.	This deposit is southern extension of adjoining Black Hawk (above). Deposit mined from opencut, 1953–54.	FN, July 1954; AEC.
Gay Eagle (*13*)	SW¼SE¼ 4	12 N.	9 W.	Elongate, rather discontinuous, medium deposit in middle of Todilto Limestone. Deposit trends northerly, is about 400–500 ft long, a few feet to several tens of feet wide, about 5–20 ft thick, and generally follows a rather complex northerly trending, intraformational fold. Deposit mined from opencut, along with Red Bluff 8 and 10, 1952–64.	FN, July 1954; Gabelman (1956b, p. 397–399); AEC.
Red Bluff 10 (*13*)	SE¼SW¼SE¼ 4	12 N.	9 W.	Southward extension of Gay Eagle deposit. (See above.)	FN, July 1954.
Red Bluff 8 (*13*)	SW¼SW¼SE¼ 4	12 N.	9 W.	Medium deposit or cluster of small deposits in Todilto Limestone immediately west of, and similar to, Red Bluff 10 (above).	Do.
UDC 1	SE¼SE¼SE¼ 4	12 N.	9 W.	Small deposit, defined by drill holes, in middle of Todilto Limestone. Highest radiometric reading about 0.10 percent eU_3O_9.	Do.
Last Chance (*19*)	NE¼NE¼ 8	12 N.	9 W.	Several small and medium deposits in Todilto Limestone. Generally irregular in outline. Ore mined from opencuts, 1952–56.	The Anaconda Co. and FN, 1954–55.
Section 9 (*30*)	NW¼ 9	12 N.	9 W.	Many small and medium deposits largely clustered and irregular in outline. Deposits are associated with intraformational folds in Todilto Limestone that have diverse trends and that range in size from folds with amplitudes of only a few inches to several feet and in length from a few feet to several hundred feet. One deposit about 1,000 ft south of north ¼ cor. is C-shaped, 300 ft in diameter, and open to west. Deposits mined from open pits, 1953–62.	The Anaconda Co., 1955.
Section 9	Near SW. cor. NE¼ 9.	12 N.	9 W.	Tabular, doughnut-shaped deposit, about 150 ft in diameter, exposed at rim in Todilto Limestone.	The Anaconda Co., DH, 1955.
Do	CW½NE¼ 9	12 N.	9 W.	Cluster of deposits, irregular in outline, in Todilto Limestone.	Do.
Do	NW¼SW¼ 9	12 N.	9 W.	Cluster of small deposits in Todilto Limestone. Generally are elongate easterly to northeasterly.	Do.
Taffy (*98*)	SW¼SW¼ 11	12 N.	9 W.	Small deposit in sandstone in Jmpc. Ore is associated with carbonized plant debris and clay galls. Some ore mined in 1961.	Eugene Berkoff (WC, 1961); AEC.
Zia (*52*)	CE½SW¼ 15	12 N.	9 W.	Deposit in lower part of Todilto Limestone and upper part of Entrada Sandstone.	AEC.
La Jara (*18*)	NW¼SE¼ 15	12 N.	9 W.	One or more small deposits in Todilto Limestone. Deposit mined with Zia, 1952–60.	Do.
F–33 (*10*)	SE¼ 33 and SW¼ 34.	12 N.	9 W.	A cluster of deposits mostly in middle and upper part of Todilto Limestone. Principal deposit is stringlike, trends about N. 70° E. along intraformational fold, is about 100 ft wide, as much as 15 ft thick, and more than 1,200 ft long. Ore mined from adit, 1954–59.	The Anaconda Co., 1957; Hilpert and Moench (1960, p. 460–461); AEC.
Unnamed	CW½ 16	13 N.	8 W.	Deposit in the Jmw	AEC, DH.
Section 30 (San Mateo) (*88*).	30	13 N.	8 W.	Several large and medium deposits in Jmpc. Deposits are generally elongate southeastward.	Rare Metals Corp., October 1957; Rapaport (1963, fig. 1).

PENECONCORDANT DEPOSITS IN SANDSTONE

The uranium mineralogy of the peneconcordant deposits in sandstone varies among deposits, districts, and areas, and stratigraphically depending principally on the contents of uranium and vanadium or uranium and copper and the degrees of oxidation. Generally the minerals consist of fine-grained and earthy assemblages of oxides and silicates of low-valent uranium and vanadates of high-valent uranium. The low-valent minerals generally are primary or early and the high-valent minerals are secondary and later. For a general background on these relations see Weeks and Thompson (1954), Botinelly and Weeks (1957), and Garrels and Larsen (1959). Because of stratigraphic differences, the mineralogy and habits of the deposits are summarized under the respective formational units. Deposits in the Morrison Formation, because of their great importance and some areal differences, are described by mining districts and areas, in the order of magnitude of the ore shipments made through 1964. The other deposits are described under the respective stratigraphic units, from oldest to youngest.

MORRISON FORMATION

AMBROSIA LAKE DISTRICT

Deposits in sandstone in the Morrison Formation in the Ambrosia Lake district occur principally in the Westwater Canyon Member, less abundantly in the Brushy Basin Member, and as small scattered occurrences in the Recapture Member. About 100 deposits or clusters of deposits are listed, of which 44 have yielded ore (pl. 1). Of these, 24 are principally or entirely in the Westwater Canyon and the others are in the Brushy Basin.

The uranium-vanadium ratio among the shipments made from 13 properties ranged from 1:1 to 3:1 and averaged 2:1. These ratios are determinations for 256,500 tons of ore shipped from 1950 to 1958. Nearly all of this ore was partly oxidized and probably averaged somewhat higher in vanadium than did the unoxidized ores. For about 219,000 tons of ore, the $CaCO_3$ (lime content) ranged from 1.5 percent to 9.2 percent among 19 different properties and averaged about 5 percent.

STRATIGRAPHY

The Morrison Formation in the district consists of the Recapture, Westwater Canyon, and Brushy Basin Members. It crops out from the Continental Divide, a few miles north of Highway 66 at the west side of the district, southeastward for about 30 miles and then swings southward and pinches out under the pre-Dakota erosion surface a few miles southeast of Grants (pl. 1). North from the outcrop the Morrison generally dips northeastward at a low angle under the San Juan Basin and eastward into the McCartys syncline. Throughout most of the district the formation is about 500 feet thick, but it tends to thicken northward and attains its greatest known thickness of about 800 feet in the central part of the district, in the western part of T. 16 N., R. 7 W.

The basal member, the Recapture, consists of distinctive alternate beds of reddish-brown, light-gray, and grayish-red sandstone and siltstone, which range in thickness from a foot or so to about 20 feet. The sandstone is mostly fine grained, soft, clayey, and poorly sorted. Crossbeds are mostly small scale, and scours, which are mostly at the base, are shallow and rarely have a relief of more than about 1 foot. In thickness, the Recapture ranges from about 50 to 300 feet, but in most places is about 150 feet. Locally, thicknesses vary considerably from adjoining localities because of intertonguing and grading of the member with the overlying Westwater Canyon Member. Few data are available on the sedimentary trends of the Recapture in the district. Regional studies (Craig and others, 1955, fig. 22) indicated that the district marks the transition between conglomeratic facies to the southwest and sandstone-mudstone facies to the northeast. Such data are largely academic because the member is barren of uranium deposits of any significance and is not considered favorable for them.

The Westwater Canyon Member is principally a light-yellow-brown to gray fine- to coarse-grained poorly sorted crossbedded sandstone. It is arkosic and locally contains small lenses of granules and small pebbles and some seams and thin beds of mudstone and siltstone. Fragments of silicified logs are present locally, but mostly are small. Crossbeds in the sandstone are small- to medium-scale trough type and dip southeastward in the lower part and northeastward in the upper part (E. S. Santos, written commun., 1963). The member ranges in thickness from a little less than 50 feet to about 300 feet and averages about 150 feet.

The Brushy Basin Member is chiefly greenish-gray mudstone and claystone, but contains much interbedded sandstone and a few thin beds of gray limestone. The sandstone beds are similar in color and lithology to the beds of the Westwater Canyon, range in thickness from a foot or so to several tens of feet, and locally extend for several miles. The Brushy Basin conformably overlies the Westwater Canyon Member and is overlain unconformably by the Dakota Sandstone. The contact with the Westwater Canyon is gradational, and because the two members intertongue, the selection of the contact is arbitrary. It is defined here as the base of the lowermost persistent mudstone or claystone unit. Along the outcrop north of U. S. Highway 66, the Brushy Basin is about 100–125 feet thick. Northeastward and eastward it thickens and is more than 300 feet thick in the central part of the district and in the central part of T. 13 N., R. 8 W., as far east as data are available.

The uranium deposits in the Brushy Basin are in several sandstone units, but most of them are in a tongue that extends eastward from the upper part of the Westwater Canyon Member and is referred to as the Poison Canyon sandstone of economic usage (Hilpert and Freeman, 1956). It extends from its westernmost outcrop in the E½ sec. 14, T. 13 N., R. 10 W., eastward into the lower part of the Brushy Basin at least 8 miles to sec. 31, T. 13 N., R. 8 W. It is exposed along the outcrop west of the San Mateo road, perhaps locally east of that road, and can be traced in the subsurface for as much as 1–3 miles northward as well as eastward. It generally ranges in thickness from 30 to 80 feet and is separated from the Westwater Canyon Member by a 15- to 25-foot-thick claystone unit.

The Poison Canyon sandstone is structurally and lithologically similar to the Westwater Canyon Member and is composed of a complex assemblage of crossbedded and locally flat-bedded sandstone units and interbedded thin and discontinuous mudstone units. It contains numerous mudstone galls and scattered fragments of silicified and coalified plant debris. Cut-and-fill structures are abundant at the base of the unit as well as at the bases of the internal crossbedded units. The Poison Canyon was deposited by eastward-flowing currents, as indicated by the crossbeds, log orientations, and heavy-mineral lineations (Rapaport 1963, p. 122).

Deposits also occur in other sandstone units, and generally in the lower part of the Brushy Basin. Some may occur in northward extensions of the Poison Canyon sandstone, but they more likely occur in unrelated units in the same stratigraphic position. In the western part of the district, north of Prewitt, the Francis and Evelyn deposits are at the top of the Brushy Basin in a sandstone unit that is about 50 feet thick, is light gray or white, and directly underlies the Dakota Sandstone. Northeastward, back from the outcrop, the host sandstone is light brown to reddish brown and is as much as 80 feet thick. Drill-hole data indicate it splits and tongues out into the claystone of the Brushy Basin within a few thousand feet northeast. East of the Bluewater fault, its extent is unknown. A similar sandstone unit at the top of the Brushy Basin crops out in sec. 34, T. 14 N., R. 12 W., as reported by Konigsmark (1955, fig. 1), but he did not specify its thickness and extent. Immediately north of the Francis deposit and beyond the limits of the host sandstone of the Francis-Evelyn, the Alta deposit occurs principally in a sandstone tongue, a few feet thick, that splits from the top of the Westwater Canyon Member and extends eastward a few hundred feet into the claystone of the Brushy Basin.

STRUCTURE

The district is on the northeast flank of the Zuni uplift on a homocline referred to as the Chaco slope in the area where the east flank of the homocline merges with the Ácoma sag (fig. 3). Throughout most of the district, the beds dip northeastward about 3°–5° into San Juan Basin, but they are flexed and faulted downward along the east side of the Chaco slope into the McCartys (Mount Taylor) syncline, a large northeastward-trending fold.

Locally the beds are broken and arched along faults, joints, and minor folds. Granger, Santos, Dean, and Moore (1961, p. 1186) arbitrarily divided the faults into three sets according to their strikes: (1) north to northeast, (2) northeast to east, and (3) northwest. All are normal faults, with the exception of a few that are east trending. The largest and most continuous faults trend north to northeast. Some can be traced for tens of miles and have as much as several hundred feet of throw. Faults of the other two sets have a much shorter strike length and a smaller displacement.

Most joints in the district are subparallel to nearby faults, but randomly oriented joints are abundant in some places (Granger and other, 1961). The fact that the joints generally are most abundant in faulted areas and are least abundant in unfaulted areas indicates that they are closely related to the faults and probably are the same age.

Most prominent of the smaller folds are the Smith Lake (Mariana) anticline in the western part of the district, the Walker dome (North Ambrosia dome or anticline) and Ambrosia dome (South Ambrosia anticline) in the central part, and the San Mateo and Miguel Creek domes in the eastern part. From east to west the long axes of these structures swing from northeast to northwest, similar to the trend of the axis of the strongest fault set. These fold structures range in width from 2 to 5 miles and in length from 4 to 10 miles, and they have a structural relief of as much as 1,000 feet.

In addition to the small domal folds, several poorly defined northeastward-trending broad anticlinal and synclinal folds are in the area just north of Grants and Bluewater. As shown by Gabelman (1956b, fig. 132), these folds are 2–4 miles wide and their axes swing from a northeastward trend in the eastern part of the area to a northward trend in the western part and are generally bounded by the principal faults of the north- to northeast-trending set. Such structures, at best, are poorly defined by the structure contours drawn on the base of the Dakota Sandstone, except for a fold shown in the area just east of the area of Gabelman's illustration (Thaden and Santos, 1963).

Less conspicuous but important structures because of their influence on the uranium deposits, are a set of rather shallow eastward-trending folds and associated pipelike structures in the Jurassic rocks. The eastward-trending folds were first noted in the district in the subsurface (Hilpert and Moench, 1960, p. 439). The larger ones have an amplitude of 100 feet or more, are a mile or more wide, and may be as much as several miles long. They are approximately parellel to the north margin of a broad highland that existed in central and southern New Mexico in Jurassic time (McKee and others, 1956). Probably associated with the eastward-trending folds are several near-vertical pipelike structural features in the Morrison Formation (Granger and Santos, 1963; Clark and Havenstrite, 1963). These pipes are 100–200 feet in diameter, have central cores that have been displaced downward about 25 feet, and have known vertical lengths of 200 feet or more. Similar pipes have been described in the Laguna district (Rapaport and others, 1952; Hilpert and Moench, 1960; Schlee, 1963) where Moench (Hilpert and Moench, 1960) has demonstrated their close association and contemporaneity with the Jurassic folds.

Three periods of deformation are recognized in the district that have some bearing on the localization and distribution of the deposits. The first period was probably during the Late Jurassic and may have extended into Early Cretaceous time, the second period was in Late Cretaceous to middle Tertiary time, and the third period was from middle to late Tertiary and possibly extended into Quaternary time.

The first period is thought to be Late Jurassic because it involves rocks of Late Jurassic age and the folds are beveled and overlapped by relatively undeformed beds of the Dakota Sandstone of Early(?) and Late Cretaceous age. (See p. 21). The pipes and the intraformational folds in the Todilto Limestone probably formed at the same time, as they also affect only the rocks of Late Jurassic age.

Some domal structural features may also have been initiated by this deformation. The Ambrosia dome and similar structures involve the Dakota Sandstone and younger rocks, so are at least in part post-Dakota in age. A thin segment of Westwater Canyon in the Ambrosia dome, as indicated by limited drill-hole data, has been interpreted to have resulted from initial uplift in Morrison time (Hilpert and Moench, 1960, p. 439–440). Until more information is available on the lower part of the Morrison or the periphery of the dome, however, existence of this early uplift must be considered rather tentative, as the thin part of the Westwater Canyon might represent a local variation in the regional sedimentary pattern and bear no relation to the dome.

The second period of deformation started in Paleocene or possibly Late Cretaceous time and may have extended into Miocene time. It involved the initial development of uplifts marginal to the San Juan Basin, the deepening of the basin in early Eocene time, and the northward tilting of the basin in early Eocene to Miocene time. The Paleocene or possibly Late Cretaceous age of the initial uplifts is dated by the debris of the Animas Formation, of Paleocene and Late Cretaceous age, which spreads southward from the San Juan uplift (Kelley, 1955, p. 84). Debris from the Zuni and Lucero uplifts is buried, but these uplifts may have originated at the same time as the San Juan uplift (Hunt, 1965, p. 73 and fig. 54). Deepening of the basin took place in late Paleocene or early Eocene time and is dated by the overlap of the San Jose Formation of early Eocene age across nearly vertical Paleocene beds along the front of the Nacimiento uplift. Northward tilting of the San Juan Basin followed the deposition of the San Jose, which is indicated by the reversal of the original southward dip of the beds of the San Jose.

The McCartys syncline, as well as the faults, principal features, and folds in the Ambrosia Lake district, probably formed during the deepening of the basin. The syncline is thought to have formed at this time because it is the principal structural feature in the Acoma sag; the sag is an intervening structure that formed between the Zuni and Locero uplifts at the time of basin deepening. The faults, principal fractures, and folds probably originated at the same time as the syncline. Their contemporaneity is indicated by the relatively great concentration and displacement of the faults along the west limb of the syncline and the progressive decrease in numbers and in displacement westward (Hunt, 1938, p. 75). Also the rather poorly defined northeastward- to northward-trending folds fade out westward, parallel the principal fault set, and probably formed at the same time. Moreover, the fold axes and the strike of the major faults parallel the limb of the syncline.

The third period of deformation extended from middle to late Tertiary time and possibly extended into Quaternary time. It marked the formation of the Rio

Grande trough, the displacement of the beds of the Santa Fe Group, and the eruption of the volcanic rocks of the Mount Taylor volcanic field. These events were separated from the folding of the McCartys syncline by an erosional interval that beveled the gently undulating Cretaceous rocks east of the syncline. These rocks were probably folded contemporaneously with the McCartys syncline (Hunt, 1938, p. 75). Although this deformation principally involved the area east of the Ambrosia Lake district, it undoubtedly also involved the rocks in the eastern part of the district. This deformation involved renewed movement on some fractures and caused the development of some new ones, accompanied by minor folding.

MINERALOGY AND FORM

Most mineralogic work has been done on the deposits in the Westwater Canyon Member, a lesser amount on the deposits in the Brushy Basin Member, and relatively little on the ones in the Recapture Member, but all deposits appear to be similiar.

In an interim report, Granger, Santos, Dean, and Moore (1961) subdivided the minerals in the Westwater Canyon and Brushy Basin into unoxidized and oxidized suites and subdivided the unoxidized suite into prefault and postfault assemblages. Each of these suites and assemblages is associated with deposits or parts of deposits that have characteristic forms and characteristic stratigraphic and structural relations. This classification has been generally accepted and is followed here with some later modifications (Granger, 1963).

The identified unoxidized minerals are relatively few. In the prefault deposits they consist of the ore mineral coffinite ($U(SiO_4)_{1-x}(OH)_{4x}$) and accessory pyrite (FeS_2), jordisite (MoS_2) (Granger and Ingram, 1966), and ferroselite ($FeSe_2$). The coffinite is exceedingly fine grained and is coextensive with, and intimately associated with, a fine-grained dark-gray or brown carbonaceous material that coats the sand grains and fills the interstices between the grains. Where it is brown, this material has been found to just coat the sand grains. A similar gray to black material that is generally uranium deficient and lacking in carbon is associated with many of the prefault deposits either as elongate rounded zones, as much as several feet long within or adjacent to ore layers, or as more irregular ill-defined zones that generally feather out along crossbedding and occur both above and below ore layers. This material appears to be finely disseminated amorphous jordisite, but assays indicate that the gray values may partly result from vanadium minerals (Hazlett and Kreek, 1963, p. 88; Clark and Havenstrite, 1963, p. 111–113) and possibly a manganese mineral (Clark and Havenstrite, 1963, p. 111–113). This so-called barren material may actually contain small amounts of carbon, uranium, and vanadium where encompassed by ore (H. C. Granger, oral commun., 1965). In and adjacent to the prefault deposits the accessory mineral calcite occurs as a cement in the sandstone, mostly concentrated at the base of the sandstone units; some of it could be prefault in age, but it probably is largely postfault. Other minerals may be present but have not been identified, because of their sparseness and extremely small grain size.

The postfault unoxidized ore minerals are coffinite and sparse or local occurrences of uraninite (UO_2). The accessory minerals are the vanadium oxides montroseite ($V_2O_3 \cdot H_2O$), paramontroseite (V_2O_4), doloresite ($V_3O_4(OH)_6$) (Corbett, 1963), and haggite ($V_2O_3 \cdot V_2O_4 \cdot 3H_2O$); and pyrite, some marcasite, and barite. These minerals are fine grained but generally somewhat coarser than their prefault counterparts. The carbonaceous material that is coextensive with the prefault deposits is generally lacking or is quite sparse in the postfault deposits; also, the postfault deposits reportedly contain somewhat more vanadium and less molybdenum. Calcite occurs as a cement in the sandstone, as it does in association with the prefault minerals, but only where it occurs as fracture fillings can it be dated as postfault.

The oxidized suite of minerals was divided by Granger, Santos, Dean, and Moore (1961, p. 1195) into premining and postmining assemblages. The premining assemblage consisted principally of tyuyamunite ($Ca(UO_2)_2(VO_4)_2 \cdot 5\text{–}8H_2O$) and metatyuyamunite ($Ca(UO_2)_2(VO_4)_2 \cdot 3\text{–}5H_2O$) and, to a lesser extent, carnotite ($K_2(UO_2)_2(VO_4)_2 \cdot 1\text{–}3H_2O$), autunite ($Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$), meta-autunite ($Ca(UO_2)_2(PO_4)_2 \cdot 8H_2O$), and other sparse or rare minerals. In the oxidized suite, the uranium vanadates are the principal ore minerals. They occur as conspicuous canary-yellow coatings on fracture faces and as impregnations in the sandstone where the deposits are extensively oxidized. Accessory minerals are native selenium, cryptomelane, and various iron oxides. Selenium occurs as finely disseminated metallic gray crystals in the lower part of the oxidized zone and as finely dispersed red crystals in the upper part, mostly on exposed rock faces. Cryptomelane occurs locally as rather small zones of dense black cement in sandstone, as irregular small patches and short fracture fillings, and as a replacement in the outer shell of mudstone galls. Ferric oxide minerals show as light-brown, orange, and red coatings on the sand grains. Pyrite and marcasite are generally absent, but their former presence is indicated by pseudomorphs in the iron-stained zones.

Kaolinite in the form of white nests or spotty aggregates occurs pervasively in the prefault, postfault, and oxidized deposits, as well as throughout most of the barren sandstone. The spots range in diameter from a fraction of a millimeter to about 2 cm, encompass the sand grains, and are best formed in the coarser sandstone. They are generally considered to be an alteration product, but the age and relation to ore of the alteration are not completely understood. If the kaolin was deposited under a single phase of alteration, it probably was introduced prior to oxidation and followed the prefault mineralization, as suggested by kaolin spots that cement "hydrocarbon-stained" sand grains and that are coated locally in oxidized zones by yellow or green stains (Gruner and Knox, 1957, p. 15).

By their general form and distribution these suites and assemblages each make up deposits with distinctive characteristics and show close relations to the depth of burial, water table, and degree of fracturing and deformation of the host rocks.

Most distinctive and of greatest economic importance are the prefault deposits, which show no obvious relation to faults, fractures, or folds. They are tabular elongate masses that are primarily stratigraphically controlled. They range from thin layers a few feet in width and length to bodies as much as 30 feet thick, several hundred feet wide, and several thousand feet long. The long dimensions generally parallel the depositional trends, as marked by current lineations, dip of cross strata, and trend of channel scours. The shape and position of the bodies are partly controlled by intraformational disconformities, particularly those at the base of mudstone conglomerates, but away from or between disconformities the deposits may have a variety of shapes. In vertical section they are the most irregular transverse to the longest dimension and may split and occupy more than one stratigraphic zone, feather out into barren material, or end against a sharply defined curved surface, generally referred to as a "roll."

Because of their tendency to occur in elongate bodies and in beltlike clusters, these deposits are referred to as "trend" type and the included ore bodies are referred to as "trend" ore (fig. 4).

Postfault unoxidized deposits also are quite important but less so than the prefault deposits. Because of structural as well as stratigraphic control, however, they are only crudely tabular at best and have more irregular lateral limits than the prefault deposits. Where stratigraphic controls are dominant the form is similar to that of the prefault bodies, but where

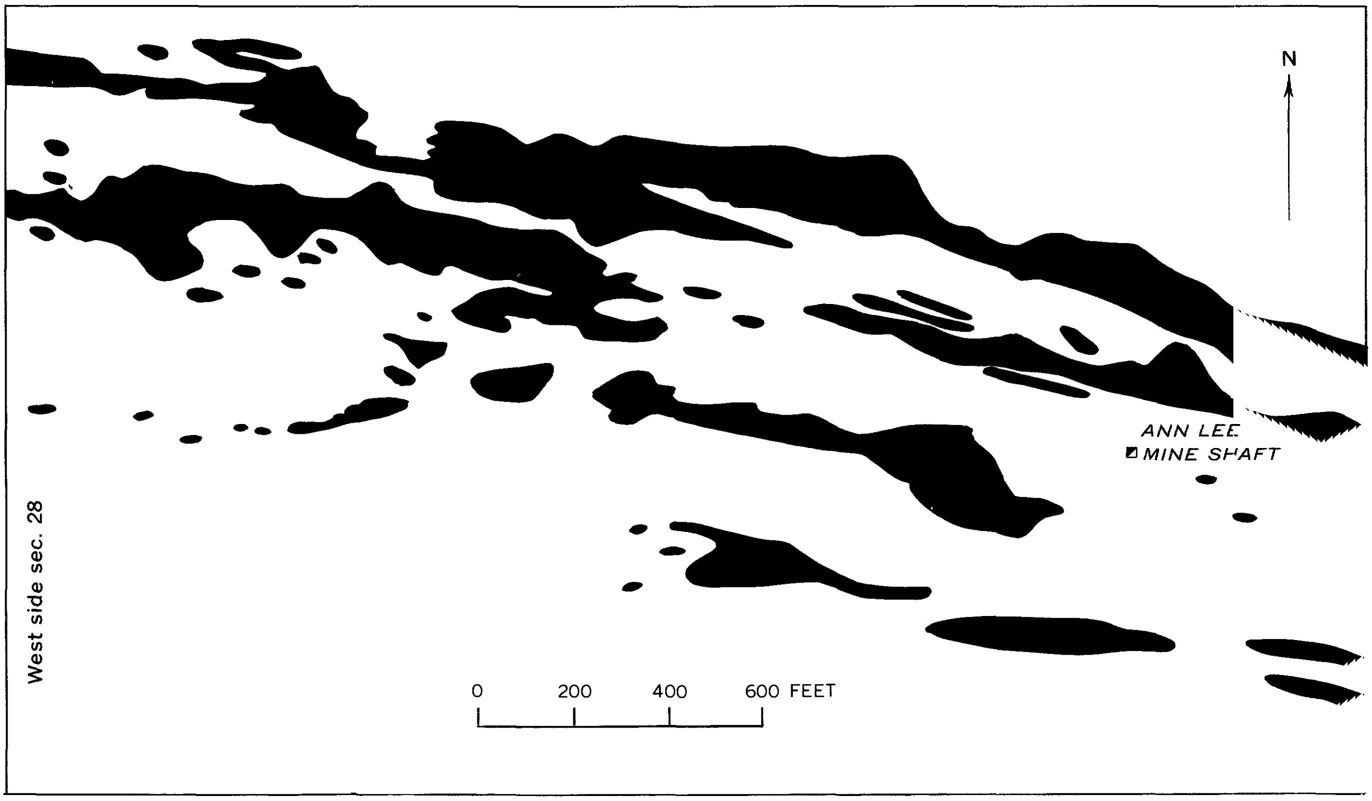


FIGURE 4.—Trend-type ore deposits (black) in sec. 28, T. 14 N., R. 9 W. Modified from J. B. Squyres (1963).

fracture control is dominant the bodies conform to the fracture pattern and have a variety of shapes, depending on the intensity of the fracturing and the angle of intersection with the prefault material. Thus, some bodies resemble very irregular or ameba-shaped masses and some are distributed through several stratigraphic intervals. The thickness of such masses is commonly several tens of feet and locally as much as 100 feet (fig. 5). The ore bodies are somewhat smaller but in places constitute a large part of the entire mass. These ore bodies are referred to as "redistributed" or "stack" ore, the first term implying that the material has been moved and the second term implying that the movement has left a body with a thickness markedly greater than that of the original prefault material, presumably at the expense of reduced lateral dimensions.

Postfault deposits are closely associated with, and generally merge into, remnants of prefault deposits. (See fig. 5.) The process of solution, movement, and redeposition has mostly removed material on the updip side of the prefault bodies and carried it downdip, although local reversals in dip show such bodies on the downdip side (fig. 5). The distance the redistributed material has moved is somewhat conjectural, but the close association with the prefault material indicates that the redistributed material generally has moved less than the original lateral dimension of the prefault material, distances that probably range from inches to perhaps as much as several thousand feet for some redistributed materials.

Postfault deposits may be oxidized or unoxidized. Where oxidized they occur mostly above the water table and generally near the surface, but the unoxidized deposits occur above and below the water table. The unoxidized deposits generally lie downdip from an encroaching oxidation front, but from place to place the relations are variable, depending on the stratigraphic and structural relations, the history of ground-water movement, and the depth to the water table. In general, however, deposits in the eastern and northern parts of the district, where they are more deeply buried, are mostly unoxidized, whereas in the western and southern parts, where they are near the outcrop, they are oxidized along the updip margins of the prefault deposits. Details on the general form and composition of the deposits may be found in several reports (Granger and others, 1961; Clary and others, 1963; Cronk, 1963; Gould and others, 1963; MacRae, 1963; Rapaport, 1963; Squyres, 1963; Weege, 1963). The broader stratigraphic and structural relations are discussed further in this report to provide the district setting.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS

Most of the uranium deposits in the Morrison Formation in the district occur in two elongate belts, referred to as the Ambrosia Lake trend and the Poison Canyon trend (fig. 6). The controls on these trends have been outlined (Hilpert and Moench, 1960) but bear repeating. In the Ambrosia Lake trend the deposits are in a sandstone mass that includes the Westwater Canyon Member and the lower part of the Brushy Basin Member. The mass is crossbedded sandstone and some discontinuous lenses of claystone and mudstone. The central part, which is about 200 or more feet thick, is rather uniform in thickness and in lithologic character parallel to the trend, except across the Ambrosia dome. (See p. 4, section *A–A′*.) The area just east of the dome that displays relatively few mudstone interbeds is similar to the area farther eastward, but reflects lack of detail as seen from noncore drill logs. Sections *B–B′* and *C–C′*, which cross the trend, show that the sandstone mass thins and splits into sandstone and interfingering claystone units southward and that it thins northward. In addition, electric-log data from the drill holes that mark the north flank indicate that the sandstone is more uniform in character and contains fewer mudstone units than that toward the south. This may indicate a northward change to more uniform conditions of sedimentation and to rocks that are less favorable for localization or uranium deposits. Somewhat arbitrarily, therefore, the sandstone mass is defined by a 150- to 200-foot-thick complex of fluvial crossbedded sandstone and discontinuous lenses of claystone and mudstone. Although the exact limits cannot be determined, the width seems to range from about 5 miles in the western part to about 2 miles at the eastern end, and it has a known length of at least 12 miles. The ends are speculative for lack of data. On the west flank of the Ambrosia dome the beds are faulted down, and information is sparse and not definitive throughout the west half of T. 14 N., R. 10 W. Available data suggest, however, that the sandstone becomes more uniform in character and contains fewer mudstone units westward, similar to the sandstone of the north flank. At the east end, the sandstone thins and grades into mudstone northward on the south and west flanks of the San Mateo dome in T. 14 N., R 8 W.; southeastward the sandstone appears to maintain a rather uniform thickness at least to the north-central part of T. 13 N., R. 8 W., but information is not available on the detailed lithology. In the northeastern part of this township the sandstone appears to interfinger with mudstone, as indicated by limited drill-hole data.

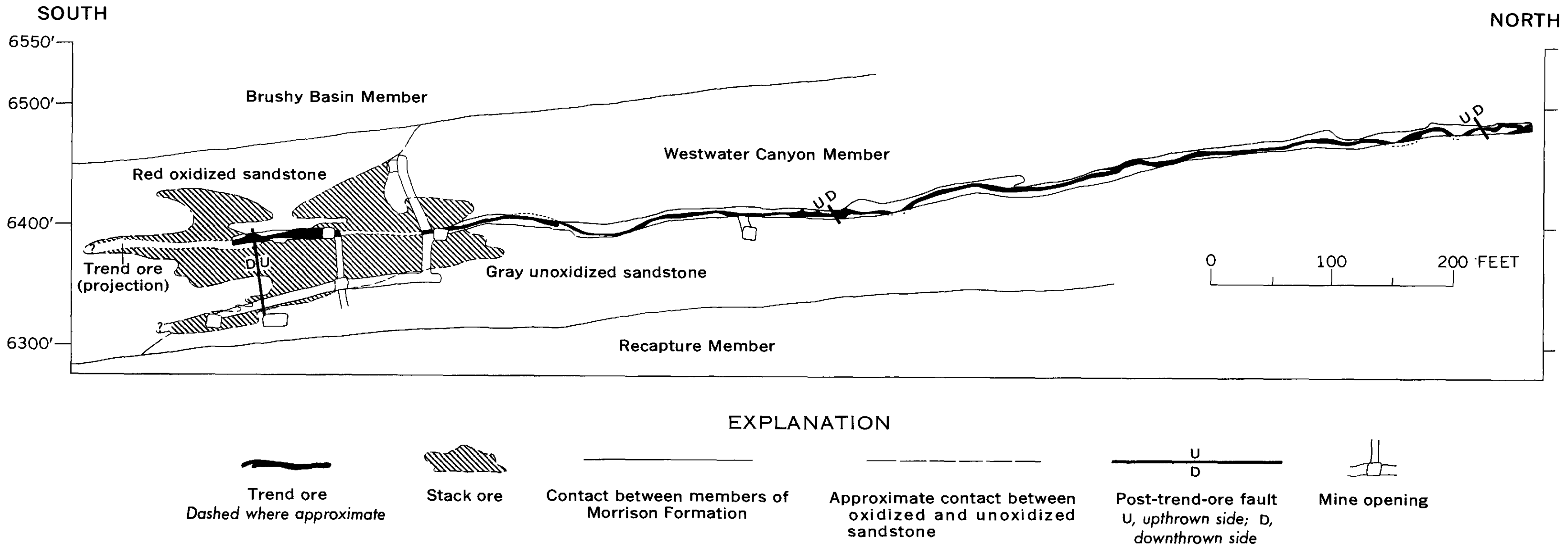


FIGURE 5.—Cross section of Section 23 ore body, showing trend ore and stack ore relations. Modified from Gould and others (1963) and R. B. Smith (oral commun., July 1965).

The Poison Canyon trend in the Poison Canyon sandstone (in lower part of the Brushy Basin Member) can be traced from its west limit, at the outcrop in sec. 14, T. 13 N., R. 10 W., eastward in the subsurface at least through sec. 30, T. 13, N., R. 8 W., and northward from the outcrop an uncertain distance in the subsurface, perhaps as much as several miles. The northern extent is uncertain because of a tendency of the sandstone to merge in places with the underlying Westwater Canyon Member and because of some uncertainty of correlation between widely spaced drill holes. If the sandstone extends as far as T. 14 N., it is most likely

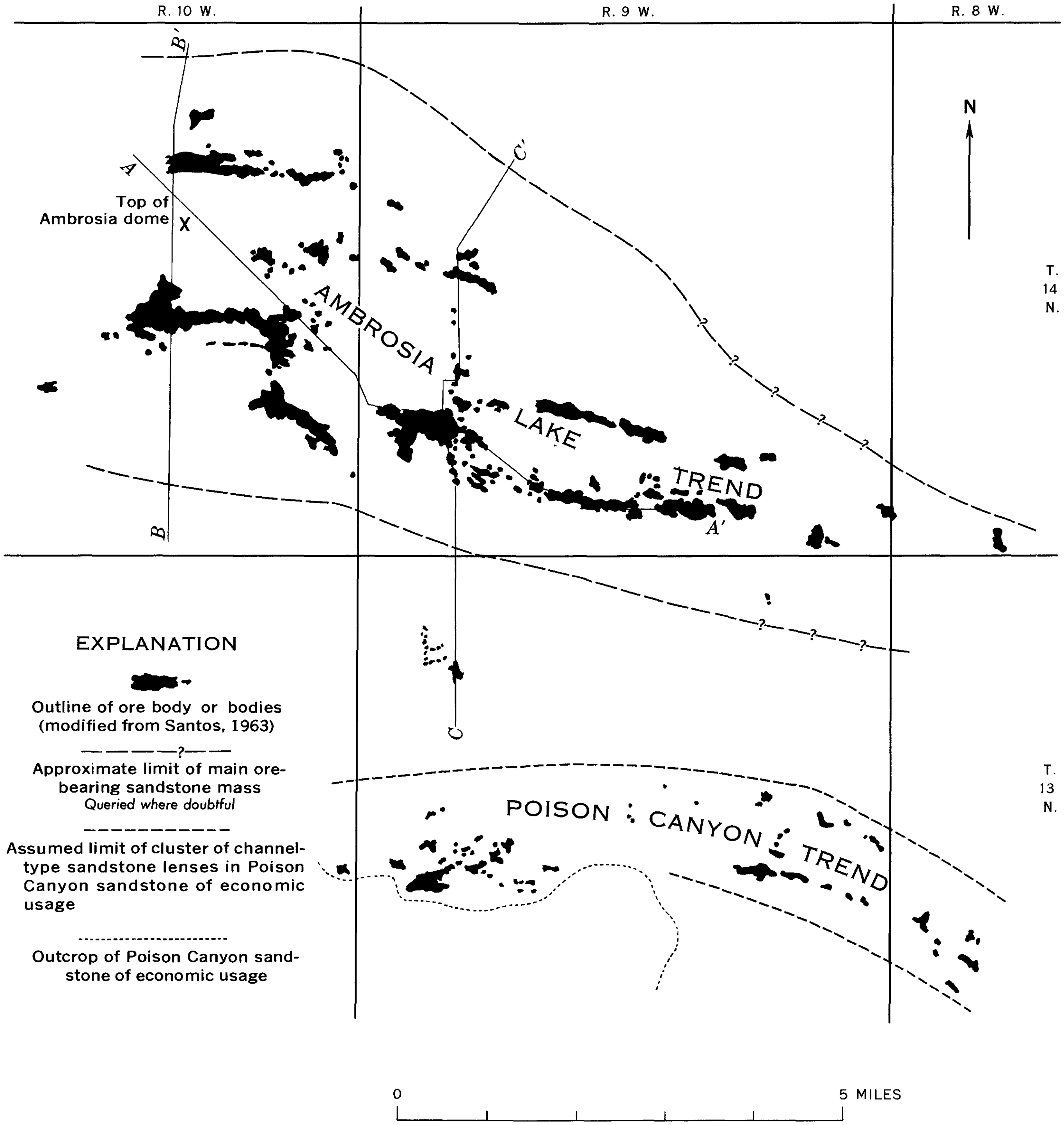


FIGURE 6.—Ore deposits and the limits of favorable belts in the Morrison Formation, Ambrosia Lake district. Geologic cross sections are shown on plate 4.

the bed that contains the deposit shown near the south end of section *C–C′* (pl. 4). North of this locality the sandstone splits, the upper unit pinching out within about 2 miles and the lower unit merging with the underlying Westwater Canyon Member within about 3 miles. Thus, the Poison Canyon sandstone may have an extreme width at the west end of about 6 miles and an eastward extent of more than 8 miles. There is general agreement that the Poison Canyon trend generally parallels the sedimentary structures of the host sandstone (Dodd, 1956; Granger and others, 1961; Rapaport, 1963), but the limits of the favorable part of the sandstone are uncertain for lack of information and the difficulty of correlating lithologic units between drill holes. The fact that the deposits parallel the sedimentary structures, however, strongly suggests that the deposits may largely be restricted to channel-type sandstone. If the deposits are restricted, the general limits of such sandstone might be expected to be near the deposits, for lack of any other apparent control on the linear arrangement. The assumed limits of the channel-type sandstones are, therefore, drawn near the periphery of the deposits, and these limits define a belt of favorable ground about 2 miles wide that trends eastward from the outcrop for at least 8 miles.

In the Ambrosia Lake trend the deposits show a general tendency to rise stratigraphically northward (Santos, 1963; Hazlett and Kreek, 1963). In the southern part of the trend they generally occur throughout the host sandstone but rise northward to where they are mostly in the upper part (pl. 4, section *B–B′* and *C–C′*). This relation is not fully understood. It could have resulted partly from the attitude of the beds at the time of emplacement, from the relative thickness and change in lithologic character of the host sandstone across the area, from the effects of oxidation and redistribution, or more likely, from the hydrologic conditions that existed at the time the deposits were emplaced.

STRUCTURAL RELATIONS OF THE DEPOSITS

As outlined earlier, the ore minerals have been subdivided into unoxidized and oxidized suites, and the unoxidized suite has been subdivided into prefault and postfault assemblages (Granger and others, 1961; Granger, 1963). Each of these suites and assemblages make up deposits that have characteristic forms and characteristic structural as well as stratigraphic relations.

Prefault-type deposits are characterized by coffinite associated with finely disseminated carbonaceous material and by tabular elongate forms and a notable lack of influence by faults, folds, or fractures.

As indicated previously, the trend of the principal belts in the district are defined largely by prefault deposits. It is notable that these belts and the elongation of the individual deposits within them do not follow the faults and folds but cross them. (See Granger and others, 1961, fig. 2.)

None of the deposits show any direct relation to the igneous rocks. As these rocks were erupted during the period of deformation of the middle Tertiary to late Tertiary they, too, probably had no influence on genesis of the prefault deposits.

In the early history of the district the arrangement of the known deposits on the flanks of the Ambrosia dome suggested an annular pattern and domal control of the deposits to some geologists. Subsequent information has shown that the deposits are arranged in eastward-trending linear belts that respectively trend across the north and south flanks of the dome and terminate on its east flank (fig. 6). Available drill-hole data show a pronounced thickening of the siltstone of the Recapture Member and a complementary thinning of the overlying sandstone of the Westwater Canyon Member in the central part of the dome (pl. 4, sections *A–A′* and *B–B′*), and show that the deposits occur in Westwater Canyon where it is about 150–200 feet thick, but generally are absent where it is less than 150 feet thick. These relations indicate the deposits are stratigraphically controlled and are not directly controlled by the domal structure. Indirectly, they may be controlled, however, by initial uplift of the dome in Jurassic time, which may have influenced the sedimentation. (See p. 62.)

The Jurassic deformation did result in forming other structural features; namely, a set of eastward-trending folds and some associated pipelike collapse features and one or more structural depressions. Of these features, only the pipelike structures directly controlled the emplacement of prefault deposits. In them the ore shows local thickening along the annular faults (Granger and Santos, 1963; Clark and Havenstrite, 1963). In summary, the prefault, or primary, deposits were emplaced after Late Jurassic deformation and prior to the deformation that probably extended from early to middle Tertiary time.

The postfault deposits are characterized by a larger suite of minerals, including uraninite as well as coffinite, some low-valent vanadium oxides, sparse carbonaceous material, and a tendency to occur in stacklike bodies. These deposits have been localized by fractures and faults, and in part by folds, as well as by stratigraphic structural features. Postfault bodies thicken adjacent to faults in many places, and strongly jointed areas contain bodies that merge with prefault bodies away from the jointed areas (Granger and others, 1961, p. 1190; Hazlett and Kreek, 1963, p. 87). Examples of such deposits are the Section 15, Section 22, Section 23, Section 24, and Black Jack 1 mines. The deposit of the Hogan mine occurs along the flank of a northeastward-trending anticlinal fold and in close association with two fracture sets, and is apparently controlled at least in part by both the fold and the fractures (Rapaport, 1963, p. 131–133). The age of these deposits is younger than that of the fractures and that of the prefault deposits, from which they apparently were derived. Their exact age, however, has not been determined; they could range from early Tertiary to Quaternary, but Pb:U ratios suggest that these deposits are post-Miocene in age (H. C. Granger, written commun., 1966).

The oxidized suite of deposits is characterized by the high-valent uranyl vanadates, by their association with fractures as well as with sedimentary structures, their irregular form, and by their general tendency to occur near the outcrop and above the water table. They postdate the prefault and postfault unoxidized deposits from which they were derived, and some or parts of some deposits are in the process of oxidation. Examples of such deposits are in the Blue Peak and Dog mines (Rapaport, 1963, p. 123, 128) and in parts of the Black Jack 1 and Section 15, Section 22, and Section 23 mines.

COLOR RELATIONS OF THE HOST ROCKS

The color relations of the host rocks to the uranium deposits in this district and others along the southern part of the San Juan Basin is incompletely understood, but a brief summary of present information may be useful.

For sandstone host rocks associated with deposits in the Morrison Formation in the Colorado Plateau, the colors have generally been considered to be gray or light brown and away from deposits to be dominantly reddish gray. These colors also have been considered "favorable" or "unfavorable" in the search for hidden deposits in the sandstone of the Westwater Canyon and Brushy Basin Members in the Ambrosia Lake district, but with notable exceptions.

In a progress report (Granger and others, 1961) the favorable colors listed for unoxidized rocks were white to light gray (*N*9–*N*7), and for weathered rocks were very pale orange to dark yellowish orange (10*YR* 8/2, 10*YR* 8/6, 10*YR* 7/4, 10*YR* 6/6). Rocks colors are from the National Research Council "Rock-Color Chart" (Goddard and others, 1948). For the gray rocks, finely disseminated pyrite was noted, but was found to be largely destroyed in the weathered rocks and replaced by films of limonite on the sand grains. These observations of color were in general agreement with earlier findings of Konigsmark (1955) and Young and Ealy (1956), except that Granger, Santos, Dean, and Moore (1961) found that the colors of some red, as well as of limonitic, sandstones are epigenetic and not necessarily original with the host rock. They noted that both colors, in association with ore, occur well below the surface and below the water table along fractured zones. The epigenetic red colors were listed as generally moderate to dusky red (5*R* 5/4–5*R* 3/4) and moderate orange pink to moderate reddish brown (10*R* 7/4, 10*R* 5/4, 10*R* 6/6, 10*R* 4/6), and the coloring agent was identified as hematite film on the sand grains. Near the outcrop they also noted moderate-red to very dark red (5*R* 4/6, 5*R* 3/4, 5*R* 2/6) sandstone closely associated with low-grade redistributed oxidized ores. The association of hematitic colors with deposits has also been noted by others (Hoskins, 1963; Gould and others, 1963; Rapaport, 1963, p. 131–133).

Gray shades may possibly not always bear a favorable relation to deposits. In some drill holes in the district, as much as 10–15 miles from the outcrop and where the host rock is as much as 3,000 feet deep, the rock is dominantly gray. These holes are more than 10 miles from a known deposit, but it is not known, of course, whether hidden deposits are in the vicinity.

Present information indicates that gray unoxidized sandstone and limonitic oxidized sandstone generally occur in the vicinity of uranium deposits, but that locally, especially along fractured zones and in close proximity to deposits, hematitic oxidized sandstone also occurs. Before more specific conclusions can be drawn, more work must be done to determine the history of the oxidation and reduction that has taken place in the host rocks before, during, and after mineralization.

LAGUNA DISTRICT

In the Laguna district 33 deposits or clusters of deposits are listed in the Morrison Formation (pl. 2 and fig. 7). Of these, 30 are in the Brushy Basin Member, 1 is in the Westwater Canyon Member, and 2 are in the Recapture Member. Of those in the Brushy Basin, 27 are in the Jackpile sandstone of economic usage. Five mines have yielded ore, and two of them, the large open-pit operations of the Jackpile and Paguate, have yielded 99 percent of all ore produced in the district. The Woodrow deposit also is in the Morrison Formation, but is discussed later with the vein deposits.

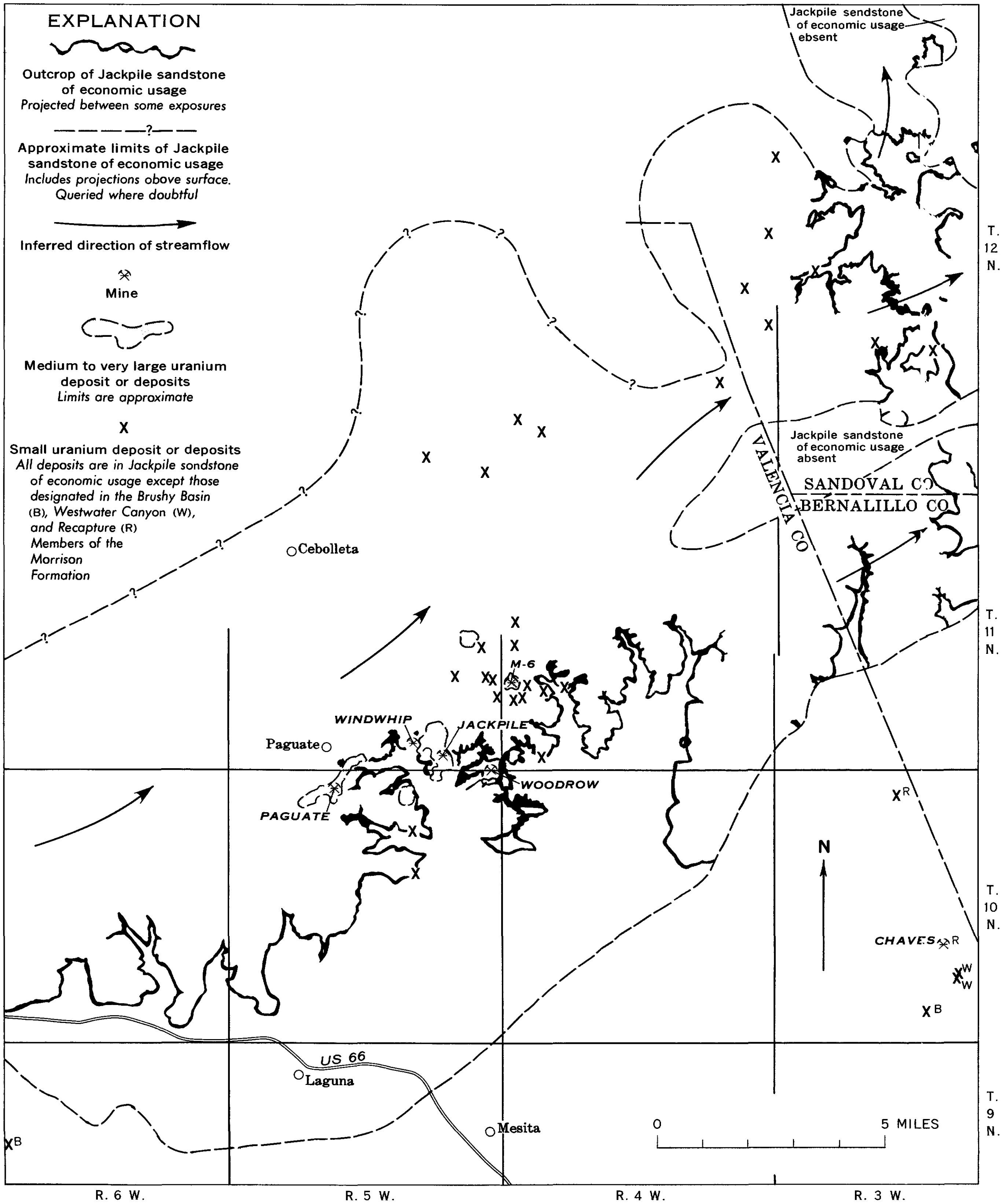


FIGURE 7.—Part of Laguna district showing the uranium deposits in the Morrison Formation. Modified from Schlee and Moench (1961, figs. 4, 10) and R. H. Moench (written commun., 1960).

The U : V ratio of about 2 million tons of ore shipped from three properties averaged 5 : 2 and ranged from 3 : 1 to 1 : 2. Except for a few thousand tons, this ore came from the Jackpile mine. During the 1954–58 period about 2.3 million tons of ore shipped from four properties averaged 0.9 percent and ranged from 0.6 to 10 percent lime. Except for a few hundred tons from one property that averaged 9 percent lime, nearly all shipments averaged less than 2 percent.

STRATIGRAPHY

Between the Ambrosia Lake and Laguna districts, the Morrison Formation is deeply buried in the McCartys syncline. Where it crops out immediately north of Laguna it has about the same thickness as in the Ambrosia Lake district, but is composed mostly of a relatively thick Brushy Basin Member and markedly thinner Westwater Canyon and Recapture Members. The stratigraphic relations of the members between the two districts are shown in figure 8. The Morrison attains its maximum thickness of about 600 feet in the central part of the Laguna district from where it thins laterally. Southward it is beveled under the pre-Dakota erosion surface, and it is missing from the southern part of the district. (See Moench, 1963a, b; 1964a, b; Moench and Puffet, 1963a, b; Moench and others, 1965; Schlee and Moench, 1963a, b.)

The lowermost member, the Recapture, ranges in thickness from 0 to about 100 feet and probably averages about 25 feet. It consists of alternating grayish-red and greenish-gray mudstone, siltstone, sandstone, and a few thin beds of limestone. It is lithologically similar to the Recapture in the Ambrosia Lake district. Locally, in the eastern part of the district, it contains two uranium deposits in a sandstone bed in close association with a pocket of coalified plant debris.

The overlying Westwater Canyon Member ranges in thickness from 0 to more than 100 feet and averages about 50 feet. It is thickest in the northern part of the district from where it thins southward. Locally it grades into the Recapture Member. It consists of grayish-yellow to very pale orange fine- to coarse-grained friable sandstone, structurally similar to the Westwater Canyon in the Ambrosia Lake district. It contains two small deposits at the outcrop.

Overlying the Westwater Canyon is the Brushy Basin Member, which composes most of the Morrison. From the central part of the district, where it is more than 300 feet thick, it thins laterally, but most markedly southward, and is cut out in the southern part of the district under the pre-Dakota erosion surface. It consists of grayish-green bentonitic mudstone and some sparse thin beds of clay-rich sandstone. In the lower part it contains lenses of sandstone similar to that of the Westwater Canyon. These are generally less than 20 feet thick, but are locally as much as 85 feet thick. In the central part of the district, it contains, in its upper part, the Jackpile sandstone of economic usage (Hilpert and Freeman, 1956), which is the main ore-bearing unit. The following description of it is largely taken from Schlee and Moench (1961).

It is a tabular body about 15 miles wide and 35 miles long that extends from the vicinity of Laguna, northeastern Valencia County, northeastward to the vicinity of Mesa Prieta, southwestern Sandoval County fig. 7). From a maximum thickness of about 200 feet a few miles north of Laguna, it tapers to its margins and, to the northeast, splits into two fingers.

The Jackpile is a yellowish-gray to white friable fine- to medium-grained fluvial sandstone that generally grades from coarser grained subarkosic material at the base to finer material at the top. The cementing material is principally calcite in the lower part and clay in the upper part. At the top the interstices of the sandstone are filled with white clay which is mostly kaolinite and probably a product of weathering of interstitial debris under the pre-Dakota erosion surface prior to Dakota deposition (Leopold, 1943;

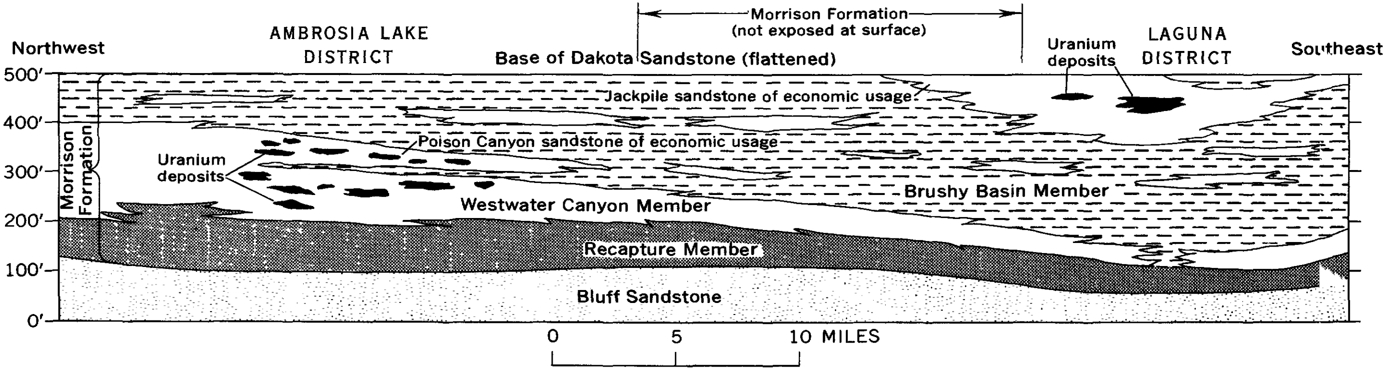


FIGURE 8.—Relations of the principal stratigraphic units of the Morrison Formation between the Ambrosia Lake and Laguna districts.

Schlee and Moench, 1961). The unit is generally thin to thick bedded and massive, but festoon crossbedding is well formed in sets as much as 4 feet thick. The crossbedding planes indicate that the sediments were transported northeastward parallel to the long axis of the unit. The truncation of the unit at the top under an unconformity indicates that former dimensions were larger than at present, but the former extent may not have been much greater, as indicated by the apparent thinning by loss of beds at the base as well as by the wedging out of the unit in places below the unconformity. The Jackpile sandstone contains nearly all the known deposits in the Brushy Basin Member and all the principal deposits in the Morrison Formation in the district (fig. 7).

STRUCTURE

The Laguna district is mainly on the east limb of the McCartys syncline, which dips gently northwestward into the San Juan Basin (fig. 3). On the east flank of the district the beds are downdropped along a north-trending faulted monocline into the Rio Grande trough. The volcanic rocks of Mount Taylor cover the western side of the district, and numerous volcanic centers, flows, dikes, and sills are distributed throughout the district and mark the northern part of the Datil volcanic field. As in the Ambrosia Lake district, three periods of deformation are recognized: Late Jurassic to Early Cretaceous, Late Cretaceous to middle Tertiary, and middle Tertiary to late Tertiary or Quaternary. The Jurassic deformation produced broad gentle folds, associated pipelike structural features, and a structural basin, all similar to those in the Ambrosia Lake district. These structural features, which are described by Moench (1963c, p. 159), are shown in figure 9.

"The Jurassic deformation produced two sets of folds of low amplitude, one trending east to northeast, the other trending north-northwest * * *. These folds are known to predate the Early Cretaceous Dakota sedimentation because folded Jurassic rocks are unconformably overlain by less-deformed beds of the Dakota. Jurassic folding was accompanied by lateral flowage of unconsolidated limestone of the Todilto Formation into the synclines, producing the variety of intraformational flowage folds that are characteristic of that unit and accounting for the thickening of limestone in the synclines. Folding was also accompanied by slumping and internal faulting of unconsolidated clastic sediments and by the formation of peculiar cylindrical subsidence structures or sandstone pipes (Hilpert and Moench [1960], p. 437-443). Folding also markedly influenced sedimentation. The fluvial Jackpile sandstone, for example, seems to have accumulated in a broad, east- to northeast-trending syncline that deepened and expanded during sedimentation (Schlee and Moench [1961], p. 147-150)."

The Late Cretaceous to middle Tertiary tilting is dated from outside the district by the same evidence as listed under the Ambrosia Lake district (p. 62). This deformation caused the tilting of the beds to the northwest.

The third period of deformation, from middle to late Tertiary time, and possibly extending into Quaternary time, marked the subsidence and sedimentation of the Rio Grande trough and produced the north-trending normal faults, the faulted monocline along the west margin of the trough, and the joints in the sedimentary rocks (Moench, 1963c). The fracturing was accompanied by the emplacement of numerous dikes and sills, for these intrusives occupy joints of the fracture system and sills are cut by joints and faults of the same system (Moench, 1963c, p. 159).

The fracture system in the main part of the Laguna district probably is younger than that in the Ambrosia Lake district. In the latter district the fractures are closely associated with the formation of the west limb of the McCartys syncline, a structural feature that probably formed early in the history of the San Juan Basin. The fractures in the Laguna district are apparently younger and occurred during formation of the Rio Grande trough, a Basin and Range structural feature.

MINERALOGY AND FORM

Most deposits in the district occur above the water table and most are oxidized to some extent, possibly more so than most descriptions have implied, for metallurgical tests of the ores from the Jackpile and Paguate deposits indicate about 75 percent of the uranium is oxidized (Kittel, 1963, p. 170).

Coffinite is the principal uranium mineral that is primary and certainly unoxidized. It is associated with the oxidized minerals, with sparsely disseminated pyrite and some marcasite, and with minute quantities of other metallic sulfides. The coffinite-bearing material contains uraninite, which might be primary, but could also be secondary after oxidized coffinite (Granger, 1963, p. 31). Vanadium generally occurs with the uranium in the ratio of about 1:2 in the ores, but few primary or unoxidized vanadium minerals have been identified, probably because of their extreme fineness. Most of the vanadium probably occurs in the unoxidized state in vanadium-bearing mica and clay.

The principal oxidized uranium minerals are the vanadates tyuyamunite and metatyuyamunite, the phosphate autunite, and the silicate uranophane

($Ca(UO_2)_2SiO_3(OH)_2 \cdot 5H_2O$). The vanadates occur chiefly as tabular bodies and small concretionary masses within the partly oxidized ore bodies and locally as fracture fillings in silicified fossil logs and in a diabase dike that intrudes the Jackpile deposit. Autunite and less common phosphates also coat fracture faces; the autunite is most abundant in the borders of the diabase intrusive. A more complete list of the uranium-bearing minerals and associated gangue minerals is given by Granger (1963, p. 32), and additional identified uranium-bearing minerals are listed by Kittel (1963, p. 170). Most deposits are closely associated with coextensive fine-grained carbonaceous material similar to that associated with the deposits in the Ambrosia Lake district. A few small deposits are associated with coalified plant debris.

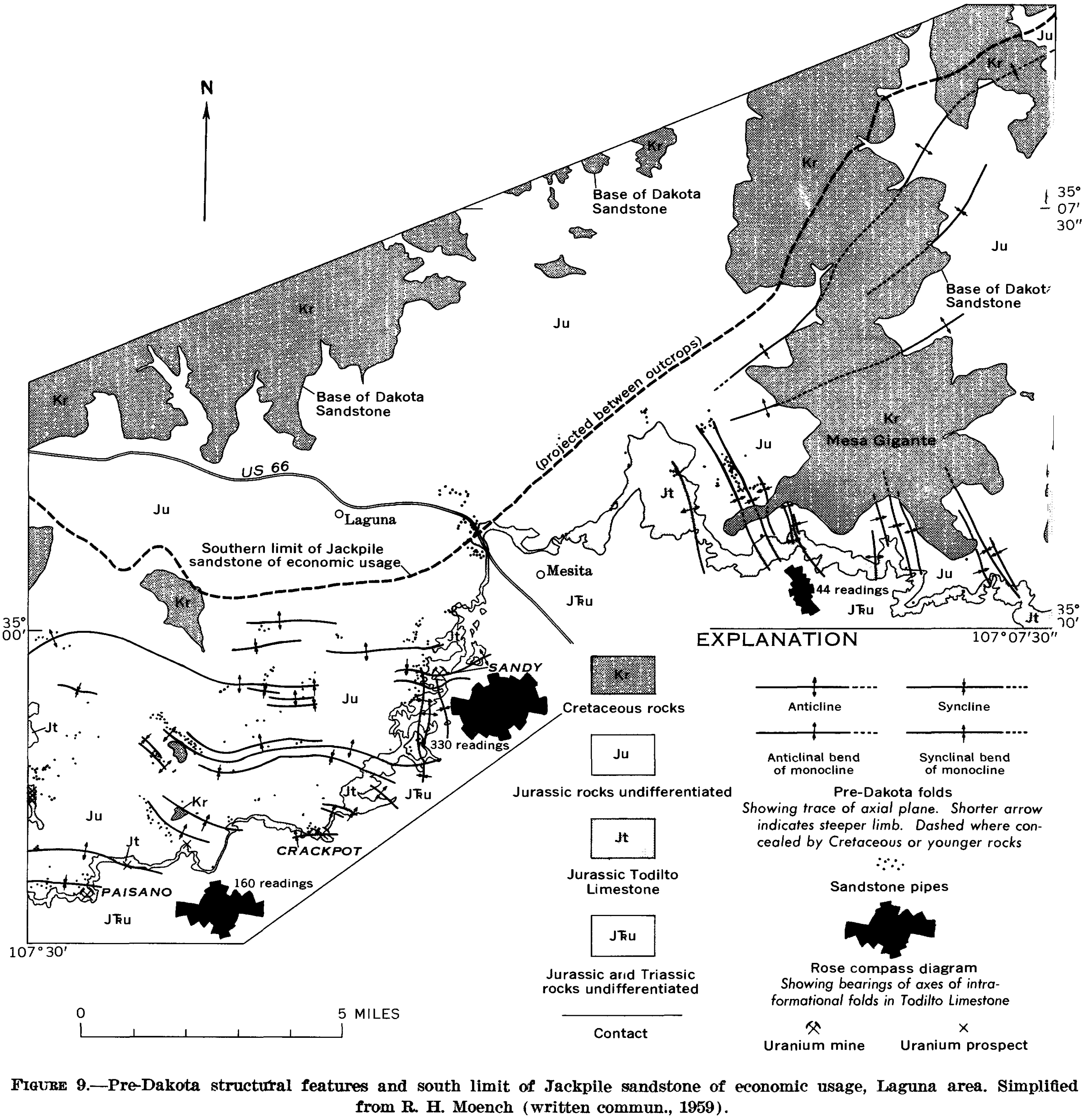


FIGURE 9.—Pre-Dakota structural features and south limit of Jackpile sandstone of economic usage, Laguna area. Simplified from R. H. Moench (written commun., 1959).

Most of the deposits are crudely tabular and have a tendency to occur in one or more layers, as elsewhere, but are generally more irregular in outline; only the larger ones are notably elongate. The layers range in thickness from only a few inches to as much as 20 feet and occur in multiple units that are as much as 50 feet thick. In lateral dimensions they range from a few feet to several thousand feet. The two largest, the Jackpile and Paguate, are elongate, the Jackpile averaging about 2,000 feet in width and having a length of about 7,000 feet, and the Paguate averaging about 1,500 feet in width and having a length of about 2 miles (fig. 7). Peculiar to the lower grade parts of some of the deposits are rodlike structures composed of uraniferous carbonaceous material, which coats sand grains and locally thoroughly impregnates the sandstone. These rods are roughly normal to bedding (Hilpert and Moench, 1960, p. 453; Moench, 1963c, p. 162, and figs. 4, 5).

STRATIGRAPHIC RELATIONS OF THE DEPOSITS

Most of the deposits, including all the larger ones, are in the Jackpile sandstone and largely concentrated within the thicker part where it ranges in thickness from about 100 to 200 feet. The margins of the deposits locally are controlled by mudstone contacts, bedding planes, diastems, and other sedimentary features, but in general the deposits figuratively float in the sandstone units within the lower and middle parts of the host sandstone (Hilpert and Moench, 1960, p. 451; Kittel, 1963, p. 170), and the Paguate extends from the lower two-thirds at the southeast end of the deposit to the upper third at the northeast end where it apparently is beveled under the pre-Dakota erosion surface (Kittel, 1963, p. 170 and fig. 4). The principal cluster of deposits in the Jackpile sandstone is elongate northeastward (fig. 7) and conforms to the dominant dip direction of the crossbedding and to the axial trends of the Jackpile sandstone body. Thus, the deposits show a direction relation to both broad and detailed stratigraphic features.

STRUCTURAL RELATIONS OF THE DEPOSITS

The uranium deposits were both indirectly and directly controlled by structures formed during Late Jurassic deformation, but obviously were not controlled by structures formed during Tertiary or later deformation, except for the oxidized material.

Indirect control is shown by clustering of the deposits in the central part of the Jackpile sandstone (fig. 7). The Jackpile occupies a structural trough that formed before, during, and after sedimentation, as evidenced by the abnormal thickness of the Morrison Formation along the axis of the Jackpile sandstone, by the pre-Dakota folds along the southeast margin, one set of which is parallel to the axis of the Jackpile sandstone (fig. 9), and by the beveled southeast and northwest flanks of the Jackpile sandstone under the pre-Dakota erosion surface (Schlee and Moench, 1961, figs. 3, 4, 11).

Direct control is shown by the occurrence of black ore in the boundary ring fault of a sandstone pipe in the Jackpile mine (Hilpert and Moench, 1960, fig. 8; Moench, 1963c, fig. 2 and p. 163). Ore also occurred in the Woodrow pipe, but the genesis of this deposit is controversial; it is discussed with the vein deposits. Locally there is evidence that the Juriassic folds may have exerted some direct control on localization of deposits. The northern part of the Jackpile ore body apparently trends northward along the axis of a pre-Dakota anticline, which is one of a set of such folds. As this trend is almost normal to the axis of the northeastward-trending sedimentary structures and to the northeastward elongation of the Paguate deposit, probably the pre-Dakota anticline exerted some control on the localization of the Jackpile deposit (Hilpert and Moench, 1960, p. 450–451, and fig. 9; Moench, 1963c, p. 163–164).

The Tertiary structures show no obvious control over the primary uranium deposits, and are apparently younger than the deposits. This is demonstrated by the relations of the deposits to the diabasic dikes and sills and to the fracture systems.

The diabasic dikes and sills, which probably are the oldest recognized intrusives in the district (Hilpert and Moench, 1960, p. 444), intrude and displace the Jackpile deposit (fig. 10) and other nearby deposits in the Todilto Limestone. If these intrusives are the same age as the fracture system, as indicated, both the fracture system and the intrusives are younger than the deposits and could not have influenced their emplacement. This relation is confirmed by the lack of any convincing alinement of the deposits with nearby fractures (Moench, 1963c, p. 161).

Oxidized uranium minerals occur along joint faces and in the chilled borders of diabasic intrusives, but the field evidence indicates that the minerals were derived from earlier black ores (Moench, 1963c, p. 161). No postfault unoxidized ores similar to those described by Granger, Santos, Dean, and Moore (1961) (see p. 63) have been recognized in the Laguna district.

Available evidence indicates that the deposits in the Laguna district were emplaced closely following or during Jurassic deformation, prior to development of the Late Cretaceous erosion surface, and prior to Late

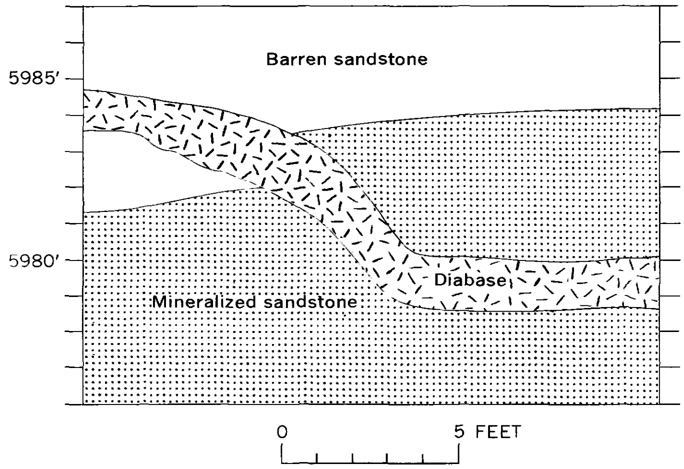


Figure 10.—Displacement of Jackpile uranium deposit by diabase sill. Geology by R. H. Moench. Datum is approximate mean sea level.

Cretaceous or early Tertiary tilting of the southern part of the San Juan Basin. As the deposits are generally widespread and show little or no obvious relation to fractures, the assumption is that they were emplaced from solutions that moved laterally and perhaps under a water table. If so, the local transection of deposits across the Jurassic folds (Hilpert and Moench, 1960, fig. 15) can be explained by emplacement during or after folding. Their pre-Cretaceous age also is supported by the apparent beveling of the Paguate deposit under the pre-Dakota, or Late Cretaceous, erosion surface (see p. 74) and by the absence of known uranium mineralization of the rocks of Cretaceous age in the district. Moreover, if the rodlike ore structures in the Jackpile sandstone ore bodies were formed by gravity control of the mineralizing solutions, as determined by Moench (1963c, p. 161–162), they would be expected originally to have had a vertical orientation. As they appear to be approximately normal to the bedding of the Dakota Sandstone, a relation confirmed by one measurement, and as the ore layers of the Jackpile conform to the dip of the Dakota Sandstone, the uranium deposits apparently were emplaced prior to tilting of the Dakota Sandstone.

Conclusions are that Late Jurassic (pre-Dakota) deformation indirectly controlled the emplacement of the deposits and likely caused some direct control on their emplacement. The emplacement probably occurred during or shortly after the Jurassic deformation and before the deposition and tilting of the Dakota Sandstone. Post-Dakota structures exerted no control on the primary deposits, but did localize some secondary minerals.

COLOR RELATIONS OF THE HOST ROCKS

Except for the Jackpile sandstone, the colors of the ore-bearing sandstones in the Morrison Formation in the district are generally light gray (*N*7) in the proximity of deposits, and range from light gray to very pale orange (10*YR* 8/2) to locally dusky yellow (5*Y* 6/4) away from deposits. The Jackpile sandstone mostly is very light gray to white (*N* 7–*N* 9). The lighter shades are at the top, the result of kaolinization by weathering of feldspar minerals under the pre-Dakota erosion surface (Leopold, 1943; Schlee and Moench, 1961; Moench, 1963c, p. 165). Darker shades, medium light gray (*N*6) to dark gray (*N*3), generally are closely associated with the deposits and result largely from the presence of carbonaceous material (Hilpert and Moench, 1960, p. 446).

Reddish hues, which generally have been found away from deposits (p. 69), occur only sparsely in the Laguna district.

GALLUP DISTRICT

About 30 deposits or clusters of deposits in sandstone are listed in the Gallup district (pl. 1). Most of them are in the Westwater Canyon Member, many are in the Brushy Basin Member, and two are recorded in the Recapture Member. Seven of the deposits or clusters have been mined, five of them are partly or entirely in the Westwater Canyon and two of them are in the Brushy Basin. Most of the ore from the Church Rock mine was produced from a body in the Dakota Sandstone, and a relatively small part was obtained from bodies in the Westwater Canyon Member.

The ore shipments made in the 1953–58 period totaled about 3,800 tons and had an average U:V ratio of 1:1 and a range among mining properties of from 1:1 to 1:2. Also, from four properties, about 3,500 tons of ore averaged 1.6 percent lime content and ranged from 0.8 to 17 percent. The 17-percent lime content represents only a few tons of ore. All the ores were partly oxidized.

STRATIGRAPHY

In the district the Morrison Formation crops out around the west and north flanks of the Zuni uplift from about 30 miles south of Gallup, where it pinches out, northward and eastward to the Continental Divide, at the east side of the district. In the western part of the district, the Recapture Member grades and intertongues with the Cow Springs Sandstone. From the general vicinity north of Thoreau the Recapture shows an increasing amount of light-gray Cow Springs material westward until it "sands up" and loses its identity immediately south of Gallup. From the northwest end of the Zuni uplift for 10–15 miles eastward, identification of the Recapture-Westwater Canyon contact is rather arbitrary or difficult in many places because of the grading and intertonguing relations with the Cow Springs.

The Recapture Member in the district is a sequence of interbedded siltstone, mudstone, and sandstone units that generally range in thickness from a foot or so to several tens of feet. The units generally consist of reddish-brown and grayish-red beds that alternate with light-gray and greenish-gray beds. Most sandstone beds are less than 15 feet thick and tend to be flat-bedded and have small-scale crossbeds, except where they intertongue with the Cow Springs. In such places the bedding locally shows sweeping cross laminations as well as some channel scours. This bedding indicates a mixture of eolian and fluvial processes. Coalified plant debris is present in the Recapture, but mostly in local and widely scattered localities.

The Recapture probably is about 500 feet thick at Twin Buttes Wash about 25 miles northwest of Gallup (Allen and Balk, 1954, p. 155–156; L. C. Craig, oral commun., 1965). Eastward it thins markedly within a few miles and, along and near the outcrop between Gallup and the east side of the district, is 150–300 feet thick but averages about 175 feet. Most of the district is in the conglomeratic facies (Craig and others, 1955, fig. 22). Dip directions of the cross laminae indicate a northeast component and a southwest source (L. C. Craig, written commun., 1961).

Between Gallup and the Continental Divide the Westwater Canyon Member ranges in thickness from 175 to 275 feet and probably averages about 225 feet. In most places it contains one or more mudstone units that range from mere partings in the sandstone to units as much as 20 feet thick. These units have rather limited lateral continuity and only some of the thicker ones may extend as much as a mile or more before grading out into sandstone or being cut out at the base of overlying sandstone units (fig. 11). Few data are available on local sedimentary trends within the sandstone units. Sharp (1955, p. 8) commented that studies on crossbedding indicate that the sedimentary trend in the Church Rock area ranges from east-northeast in the west half to southeast in the east half, but he did not indicate the extent of the studies or the units concerned. The available data indicate that the Westwater Canyon in the district is rather uniform in thickness and lithologic character along outcrop and extends from outcrop for at least several miles.

The Brushy Basin Member in the district generally ranges in thickness from 40 to 125 feet and averages about 75 feet. The range in thickness of the member is caused mostly by its intertonguing and grading at the base with the Westwater Canyon but partly by its beveling southwestward under the pre-Dakota erosion surface. The Brushy Basin consists of varicolored claystone and mudstone interbedded with some sandstone. The principal sandstone beds, which are lithologically similar to those of the Westwater Canyon, range in thickness from about a foot to as much as 60 feet, but probably average less than 25 feet. Thinner sandstone beds are present, but are generally fine grained and calcareous and grade laterally and upward into mudstone and claystone.

Two sandstone beds in the Brushy Basin contain the principal deposits, the Black Jack 2 in the eastern part of the district and the Foutz 3 in the Church Rock area in the western part of the district. Hoskins (1963, p. 49) described the host sandstone of the Black Jack 2 as ranging in thickness from 60 feet at the northwest end of the deposit to 18 feet at the south end and as pinching out from 2 to 3 miles east of the mine. He noted the sandstone is tan to dark brown except along the northeast edge of the deposit where it is brick red. He also stated that the ore follows an ancient stream pattern, which implies that the sedimentary lineation is southeastward because of the elongation of the deposit in that direction (Hoskins, 1963, p. 49, and figs. 2 and 3). He did not indicate the western extent of the host sandstone.

The host sandstone of the Foutz 3 deposit is in the approximate center of the Brushy Basin Member. Away from the deposit the lateral extent and general stratigraphy of the unit are largely taken from Sharp (1955), who referred to it as the "upper ore sand" of the Westwater Canyon Member. From measured sections along the outcrop he extended it eastward through the southern part of T. 16, N., R. 16 W., and northward from the southernmost exposures by at least 2 miles (Sharp, 1955, figs. 3–5). More northern segments of this unit, or its stratigraphic equivalents, may be the principal sandstone unit shown in the Brushy Basin in figure 11. Throughout this general area the unit ranges in thickness from 0 to 45 feet and averages about 25 feet. Where it is light brown or gray it composes an eastward-trending zone about 1 mile wide and more than 6 miles long (Sharp, 1955, fig. 2). The eastward elongation of this zone may conform with the general dip direction of the crossbeds (Sharp, 1955, p. 8).

Konigsmark (1955, p. 8 and fig. 1) showed several sandstone units at the top of the Brushy Basin at the outcrop in the Church Rock area and in the western part of T. 15 N., R. 14 W., but he gave no detailed information.

STRUCTURE

The Gallup district is largely along the southwest flank of the San Juan Basin, where the beds dip gently northward from the Zuni unlift. In the southwestern part of the district the beds warp around the northwest end of the uplift and dip steeply westward into the Gallup sag, a depression that occupies a structural position between the Defiance and Zuni uplifts similar to the position of the Ácoma sag between the Zuni and Lucero uplifts to the southeast (fig. 3). Principal folds are the Pinedale and Nutria monoclines on the north and west flanks, respectively, of the Zuni uplift. The development of these folds, which are 10–15 miles long, probably started about the same time as that of the uplifts (Kelley, 1955, p. 84). Locally the beds are fractured, but faults are sparse and the displacement along them seldom exceeds a few tens of feet. Little detailed information has been compiled on the fractures in the district. One vertical set trends northeastward through the Church Rock area; it may be part of the set having a similar trend that Kelley (1955, fig. 2) showed northeast of Gallup. Hoskins (1963) noted that in the eastern part of the district a set of fractures strikes N. 55° W. and dips steeply northeast.

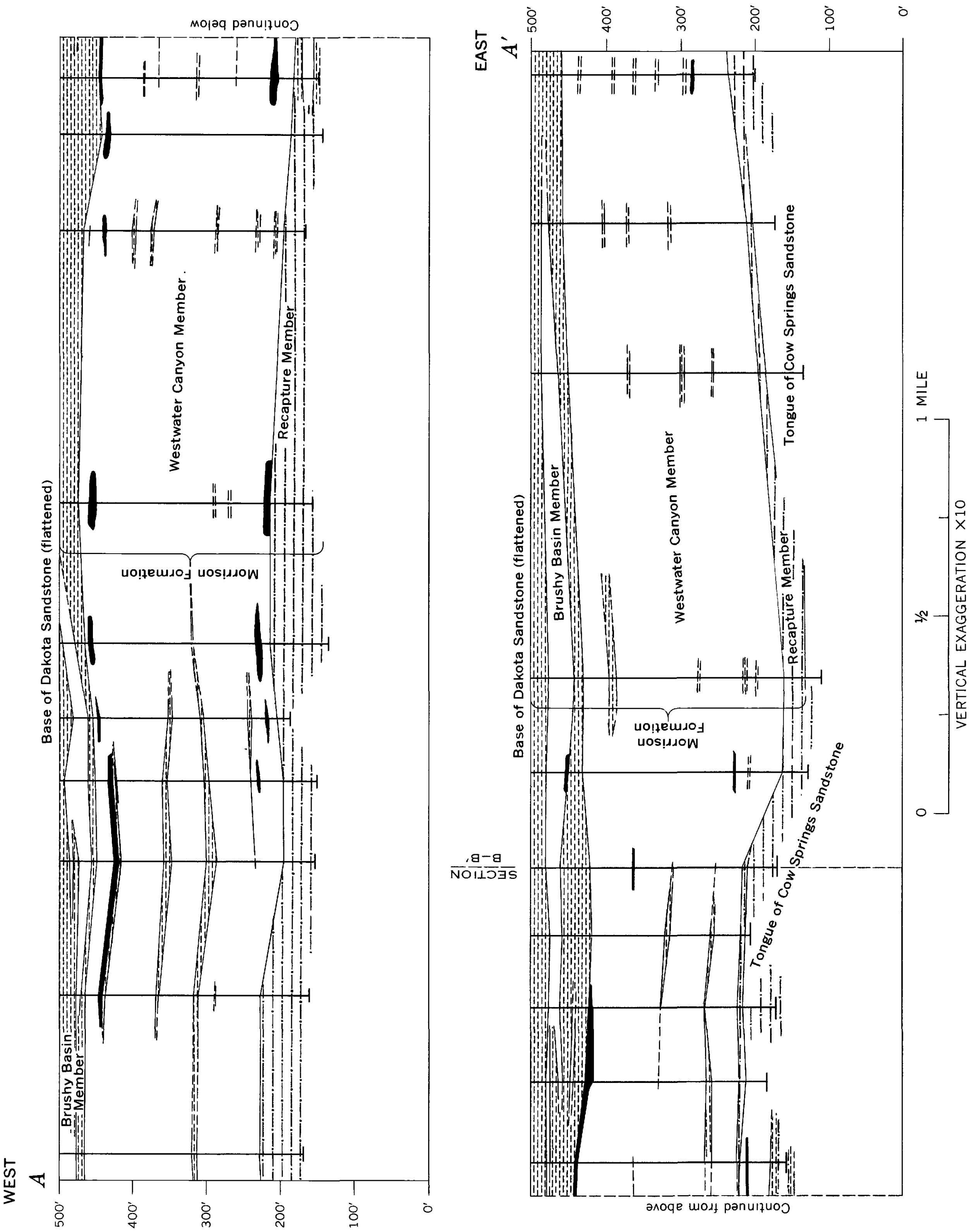
The history of deformation in the district for the Late Jurassic and early Tertiary events is probably similar to that in the Ambrosia Lake district; this premise is based on the proximity of the two districts and the similarity of their regional structural relations. No late Tertiary deformation, however, is recognized in the district. Such deformation, which involved the development of the Rio Grande trough to the east, possibly died out westward within the Ambrosia Lake district (p. 62). If so, most fractures in the Gallup district may be related to the deepening of the San Juan Basin and development of the monoclinal folds in the period of deformation of the Late Cretaceous to early Tertiary.

MINERALOGY AND HABITS

Information on the mineralogy of the deposits is fragmentary, but probably is similar to that on the deposits in the Ambrosia Lake district. The largest deposits, such as the Black Jack 2 and the Church Rock, and most of the smaller ones are closely associated with fine-grained disseminated carbonaceous material in a manner similar to the relation of the deposits in the Ambrosia Lake and Laguna districts. Some deposits are associated with coalified fossil plant debris. The large deposits and their satellites are composed mostly of black ores, which from place to place are probably prefracture, postfracture, or a combination of both, similar to the prefault and postfault deposits at Ambrosia Lake. The Black Jack 2, for example, is probably prefracture and largely unoxidized, although the tan and brown hues of the host sandstone indicate some oxidation (Hoskins, 1963, p. 49). This deposit comprises a cluster of bodies in the Brushy Basin Member that has been cut by a set of fractures that strike N. 55° W., but apparently with little effect on the deposit (Hoskins, 1963).

The Church Rock, which was flooded and abandoned in 1963, included the largest of the deposits mined from the Morrison in the western part of the district. This property included one ore body in the upper part of the Westwater Canyon Member and another, about 200 feet above, in the Dakota Sandstone. The general information on the geologic relations of the ore bodies in this property is largely from Dean Clark (oral commun., 1965) and R. K. Pitman (oral commun., 1965). Both ore bodies occurred below the water table, which was about 100 feet below the shaft collar, and the bodies were largely controlled by a strong steeply dipping fracture system that trended northeastward and along which the ore was mostly redistributed. The largest ore body in the Dakota Sandstone was roughly sombrero shaped and oriented northeastward along the fractures. Within the fracture set it was as much as 25 feet thick, but laterally away from the set it pinched abruptly to one or more layers which at most were only a few feet thick. The deposit in the Westwater Canyon contained several small ore bodies, distributed rather erratically along the fracture system, within a stratigraphic interval of 545–685 feet below the shaft collar. Laterally these bodies graded abruptly into thin blanketlike layers that were not economically minable.

Little information is available on the ore, but the ore in the Dakota seems to have been postfault and redistributed, and the ore in the Westwater Canyon prefault. When the mine was visited during its closing stages, H. C. Granger (written commun., 1966) observed that the ore in the Dakota was light colored and resembled some postfault ore in the Ambrosia Lake district; he found that along the upper level in the Westwater Canyon the ore remnants were black and identical to prefault ore at Ambrosia Lake, and that some oxidation extended at least to that level. Little information is available on most of the other deposits in the district, largely because they are in the subsurface and have not been developed.


WEST
A
500'
400'
300'
200'
100'
0'
Brushy Basin Member
Base of Dakota Sandstone (flattened)
Morrison Formation
Westwater Canyon Member
Recapture Member
Continued below
EAST
A'
Continued from above
SECTION B-B'
Base of Dakota Sandstone (flattened)
Brushy Basin Member
Westwater Canyon Member
Morrison Formation
Recapture Member
Tongue of Cow Springs Sandstone
Tongue of Cow Springs Sandstone
0
½
1 MILE
VERTICAL EXAGGERATION ×10

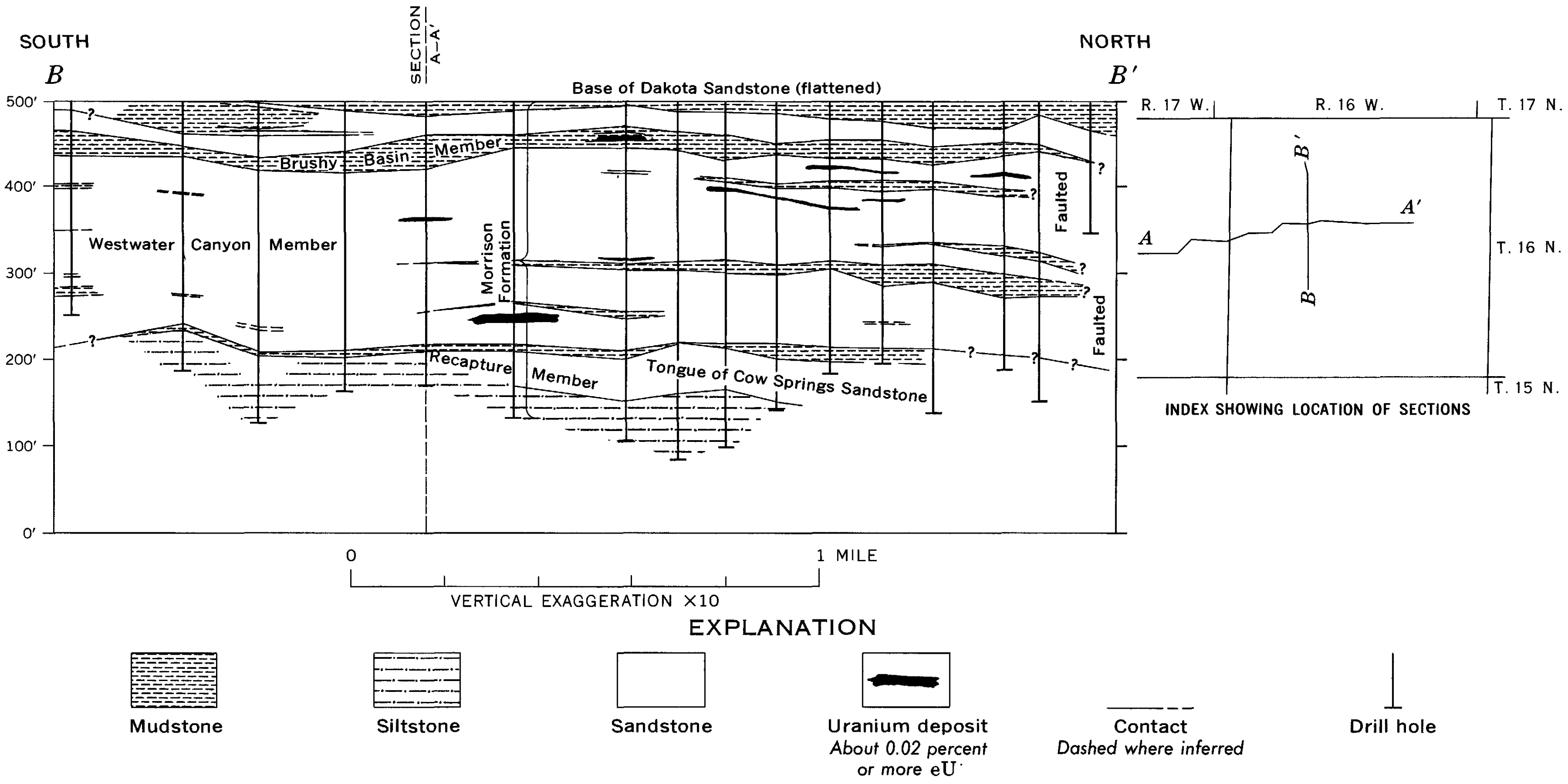


FIGURE 11.—Geologic sections in the western part of the Gallup district showing the stratigraphic relations of the uranium deposits to the members of the Morrison Formation and the Cow Springs Sandstone. Compiled from electric logs in 1957–59, provided by courtesy of Phillips Petroleum Co. and Tidewater Oil Co.

Most deposits at the outcrop are partly oxidized. The largest of these, the Foutz 3, was examined shortly after it was mined. The unusual structural relations of this deposit and the effects of Recent oxidation in part of it justify a brief description.

The Foutz 3 occurs at the north end and at the crest of a ridge capped by claystone of the Brushy Basin Member. Just under this claystone the deposit occurs at, and near, the outcrop of a 25-foot-thick sandstone unit of the Brushy Basin (fig. 12). A purple hematitic envelope encompasses the deposit and includes a central zone composed of several light-brown, light-gray to white, and purple subzones. These subzones are crudely layered, and are interfingered and intergraded. The zone and the contained deposit are partly controlled by a set of steeply dipping fractures that strike N. 30° W.

In the southern part of the deposit the ore occurred as a tabular mass at the base of a cluster of fractures that individually have strike lengths of less than 30 feet and that die out about 1–3 feet below the stope roof. The ore occurred mostly below the fractures and only locally may have been influenced by them. In the northern part of the deposit the fractures are more continuous, and a few have a strike length of as much as 80 feet and a vertical extent of as much as 15 feet. Below the floor of the workings, some of the fractures probably extend to the base of the sandstone unit. The ore bodies along the fractures were crudely elongate and generally averaged a few feet in width, were as much as 15 feet high, and ranged from several feet to as much as 100 feet in length.

Few uranium minerals were discernible in the mine when it was examined, in spite of widespread oxidation. Radiometric scanning indicated that the uranium was concentrated within the purple hematitic envelope but showed that it had no particular or consistent preference for the individual color zones. Yellow oxides, where observed, occurred as rather sparse "bloom" in the darker brown zones or limonitic material. Channel samples taken across the ore zone in the southern stope area are apparently typical of the ore, as they show no marked differences in the contents of uranium, sulfur, and iron from the pulp sample of the ore:

	Ore pulp sample	Channel samples			Local sample
	245106	239600	239601	239602	239607
Uranium [1]	0. 17(f)	0. 11(f)	0. 59(v)	0. 28(v)	0. 70(v)
Sulfur [2]	. 12	. 10	. 03	. 24	. 11
Iron [3]	1. 5	1. 5	1. 5	3. 0	10. 0

[1] Fluorimetric (f) and volumetric (v) analysis by E. J. Fennelly, J. P. Schuch, J. S. Wahlberg, and R. P. Cox.

[2] Gravimetric analysis by G. T. Burrow.

[3] Semiquantitative spectrographic analysis by R. G. Havens.

Relation of the joint pattern to the surface indicates the joints formed by surface slumping. Farthest from the outcrop the fractures appear only at the top of the sandstone unit and appear to be incipient, but they progressively become more extensive and deeper near the outcrop. (See fig. 12, section *A–A'*.) Confirming this relation is the greater degree of oxidation along the principal fractures and less conspicuous oxidation in the southern part of the mine. The conclusion is that the deposit predates the fractures except for the oxidized parts, and that the oxidation is quite late and has followed Recent surficial slumping and exposure by erosion.

The uranium in the deposit is apparently in a finely disseminated uranium vanadate. A polished section of sample 239607 (Detail section *E*, fig. 12) shows fine-grained interstitial specks of a canary yellow mineral which, from an autoradiograph (fig. 13), is indicated to be the principal uranium-bearing mineral. If uraninite or any other low-valent uranium minerals are present the concentration is too low to produce a recognizable X-ray pattern (T. E. Botinelly, written commun., March 15, 1966).

STRATIGRAPHIC AND STRUCTURAL RELATIONS OF THE DEPOSITS

In the Gallup district the uranium deposits are widely scattered within the Westwater Canyon and Brushy Basin Members and locally show a close relation to either stratigraphic or tectonic structural features. The Black Jack 2 deposit in the eastern part of the district shows a close relation to the crossbedding and coarseness of the host sandstone and to the presence in it of mudstone units, but it shows no apparent relation to fractures (Hoskins, 1963). It occurs in a sandstone unit near the base of the Brushy Basin, in the same stratigraphic position as the Poison Canyon sandstone, but as a stratigraphically discrete unit. In the Church Rock area, where most of the known deposits occur, they are widely distributed stratigraphically (fig. 11), and many show a close association with northeastward-trending fractures. At least parts of these deposits may also show a close relation to sedimentary structures, but detailed information is not available.

As indicated previously, the deposits in the Church Rock area are probably prefracture away from fractures and postfracture along fractures. One deposit is partly Recent in age where it is associated with Recent surficial slumping and fracturing. The prefracture deposits are probably the same age as the prefault deposits in the Ambrosia Lake district. As the fracturing in the Gallup district may have been restricted largely to early Tertiary deformation (Paleocene to early Eocene), the deposits probably were emplaced after Late Jurassic deformation and prior to early Eocene. The postfracture deposits are less definite in age. They might be as early as Paleocene and could be as late as Recent.

COLOR RELATIONS OF THE HOST ROCKS

Color relations of the host rocks to the deposits are quite similar to those in the Ambrosia Lake district. The deposits generally are associated with sandstone that is light gray or very pale to dark yellowish orange and that has a more pronounced reddish hue away from deposits. Locally, also, oxidized deposits are closely associated with hematitic colors that range from moderate to dusky red (Sharp, 1955, p. 10).

Two general color zones in the district can be drawn on either side of an irregular boundary that extends from the outcrop north of Wingate northeastward through the northwestern part of T. 16 N., R. 15 W. This boundary roughly follows the east flank of the fracture zone that trends through the Church Rock area. Westward from this boundary the sandstone units in the Westwater Canyon and Brushy Basin are light gray for several miles and then grade to light brown, and, in the southern part of T. 16 N., R. 17 W., are mostly light gray. East of the boundary the sandstone units in the Westwater Canyon are predominantly a pale orange to reddish brown and are light brown or gray only locally. The sandstone units in the Brushy Basin in this part are generally a light brown and locally a light gray or a pale orange.

The light shades in the Church Rock area and in the area to the west of it generally are observed where the sandstone units are in contact with the overlying pre-Dakota erosion surface (H. C. Granger, oral commun., 1966), a relation that has been observed in many other places along the south and east margins of the San Juan Basin (Leopold, 1943; Schlee and Moench, 1961; Granger, 1961). (Also see pp. 20, 61, 71.) The light-gray colors probably have resulted largely from alteration of the feldspar minerals to kaolin and partly from removal of pigmenting colors by weathering during the interval following deposition of the Morrison Formation and prior to deposition of the Dakota Sandstone (Leopold, 1943; Schlee and Moench, 1961; Granger, 1961).

Except for the Black Jack 2 deposit in the eastern part of the district, nearly all the deposits in the Morrison occur in the western light-gray to light-brown color zone.

SHIPROCK DISTRICT

Almost 40 deposits or groups of deposits are listed in the Morrison Formation in the Shiprock district (pl. 1). Most of them are clustered in a 10-mile strip along the outcrop near the State line west of Shiprock. The most productive ones are concentrated in the southern part of the area between Horse Mesa on the south and Oak Creek (also called Oak Spring Wash or Oak Spring Canyon) on the north, where they have been collectively referred to as the Eastside mines. (See Stokes, 1951; Strobell, 1956; and O'Sullivan and Beikman, 1963, sheet 2.) All the deposits occur in the Salt Wash Member and, unlike the other deposits in the Morrison in New Mexico, are high in vanadium content.

The total yield from the district has been roughly 28,000–30,000 tons or ore, which had an average U:V ratio of 1:7 and a range among mining properties of 3:2 to 1:13. The ores from three properties averaged less than 1 percent V_2O_5, but these are represented by only 50 tons of material, which averaged 0.13 percent U_3O_8. About 5,000 tons of ore shipped from 13 properties averaged about 9 percent lime, but had a range of from 1.5 to 21 percent lime. A shipment of 5 tons of material from one property contained 21 percent lime; this property was the only one on record whose ore had a total lime content exceeding 15 percent.

STRATIGRAPHY

The Salt Wash Member in the Shiprock district consists of very fine to medium-grained sandstone and about 20–30 percent interbedded sandy and silty claystone (Strobell, 1956). The Salt Wash is 220 feet thick at Oak Creek, from where it thins and grades out southward into the Recapture Member near Toadlena, thins westward into northeastern Arizona, and thins northward into southeastern Utah and southwestern Colorado where it is locally absent about 10–15 miles north of Four Corners (L. C. Craig, written commun., 1961). These data indicate the Salt Wash between Shiprock and some point west of Oak Creek composes a relatively thick elongate mass that trends eastward. This view is supported by the eastward trends of the resultant dip directions of the cross laminae in the western part of the district (Craig and others, 1955, fig. 26). Apparently the Salt Wash between Shiprock and some point in Arizona west of Oak Creek represents a relatively thick segment that was deposited in a local downwarp between the south depositional margin of the member and a local upwarp that formed about the same time north of the Four Corners area.

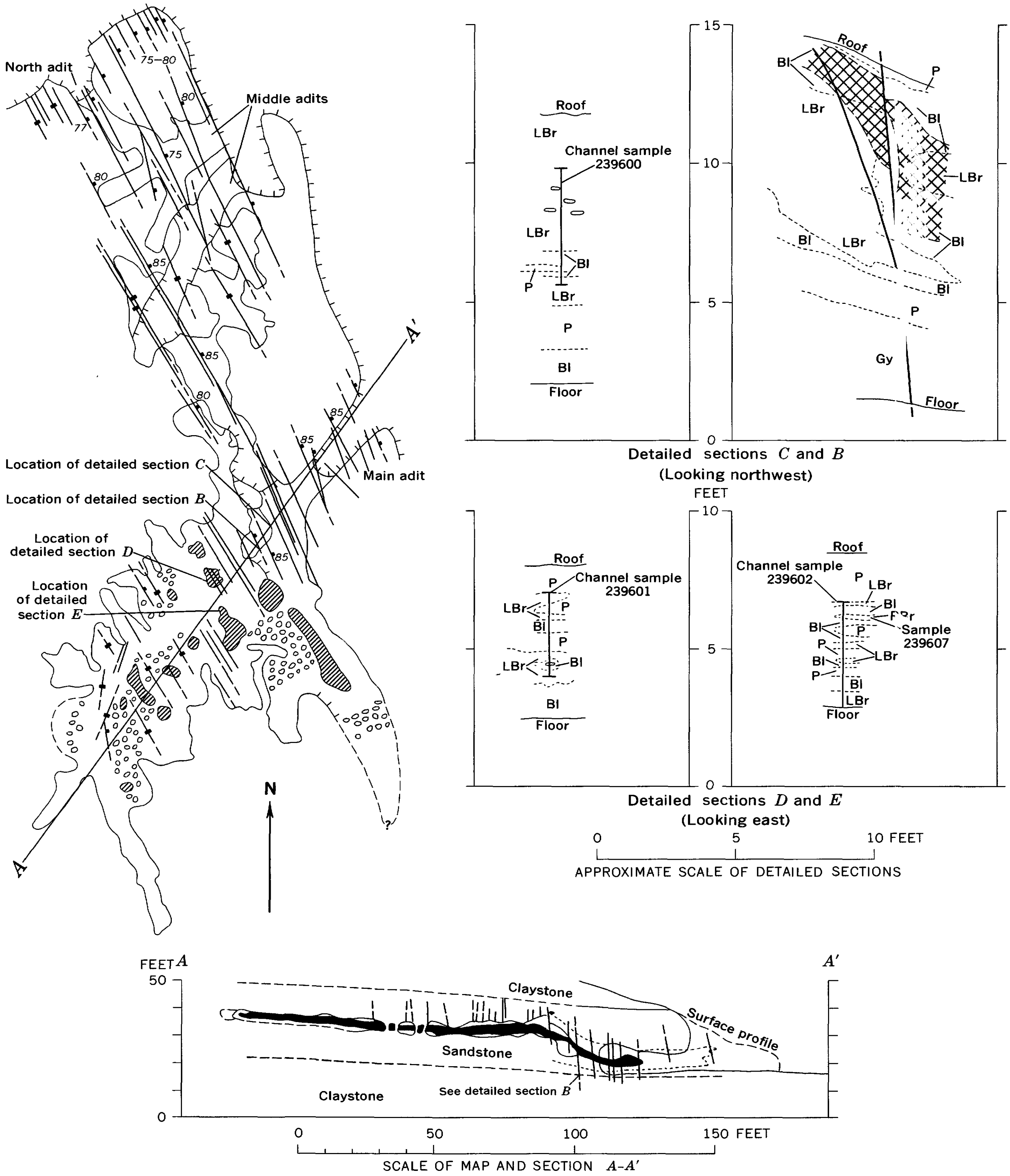


FIGURE 12.—Foutz 3 mine, Gallup district, New Mexico. Geology by L. S. Hilpert and A. F. Corey, Jr., 1955. Control by Brunton and tape. See text (p. 80) for analyses of samples.

STRUCTURE

The Shiprock district is on the northwest flank of the San Juan Basin where the beds dip eastward along the north end of the Defiance monocline, flatten east of the monocline on a structural terrace, and then plunge downward under the San Juan Basin along the northeastward-trending Hogback monocline. (See O'Sullivan and Beikman, 1963, sheet 2; this report, fig. 3.) From the outcrop along the Defiance monocline, the Morrison Formation extends eastward under younger formations. It is roughly 1,000–3,000 feet below the surface between the Defiance and Hogback monoclines, and southeast of the Hogback monocline is about 5,000 feet or more below the surface. Faults are uncommon and only a few high-angle faults of small displacement occur locally. Subsidiary structural features are principally domes and anticlines within the structural terrace, including the east flank of the Beclabito dome which is mostly in northeastern Arizona. Basaltic rocks in the form of sills, dikes, and plugs occur locally within the district.

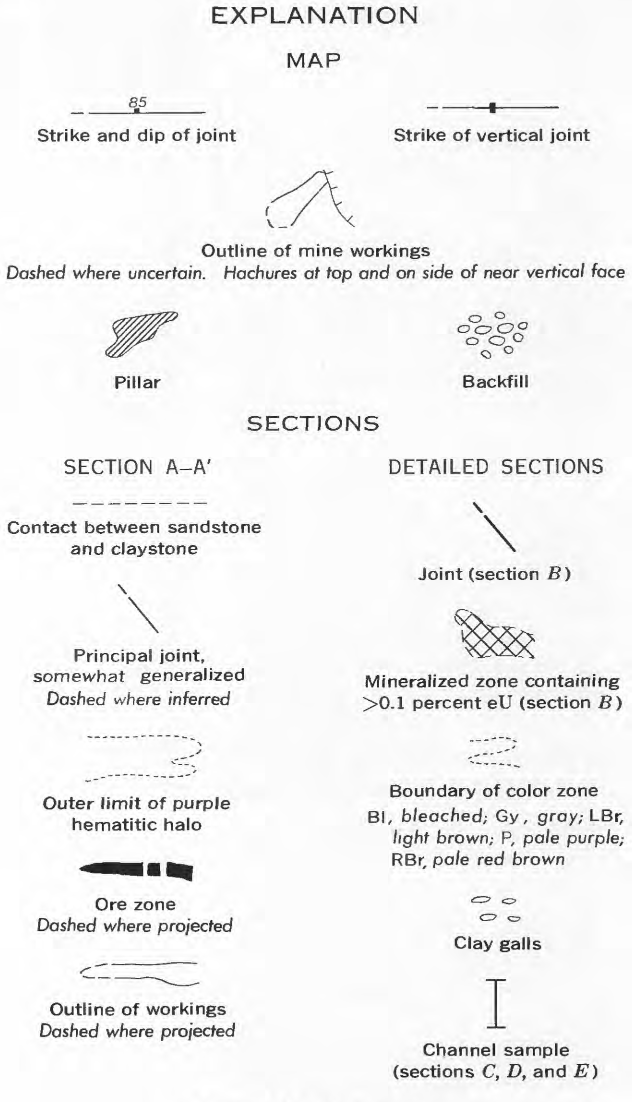


FIGURE 12.—Continued.

MINERALOGY AND HABITS

Few specific ore mineral determinations have been recorded for the district. As the deposits occur largely at the outcrop and are oxidized they are conspicuous by the prevalence of yellow uranyl vanadates, generally reported as carnotite. These vanadates, however, probably are a mixture of carnotite and tyuyamunite because of the fairly high content of calcium carbonate

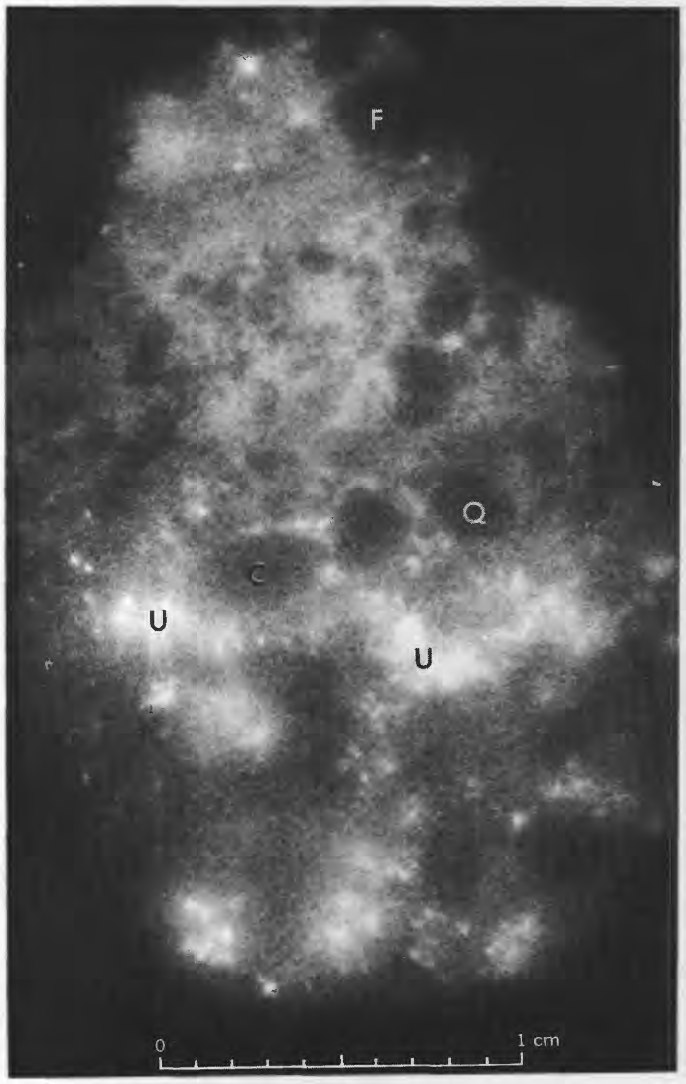


FIGURE 13.—Autoradiograph of ore specimen, Foutz 3 mine. White areas correlate with a canary-yellow mineral, probably a uranium vanadate (U), which probably also is in a finely disseminated material represented by the gray areas. Dark areas are mostly grains of quartz (Q), feldspar (F), and chert (C). Exposure 18 hours on Kodak medical X-ray no-screen film, by Mary H. Strobell. From polished section.

in the ore and host rock (Weeks and others, 1959, p. 73). According to the classification of Botinelly and Weeks (1957), which is based on the U: V ratio in the ore and the degree of oxidation, hewettite should also be abundant, and vanadium clay (vanadium chlorite or vanadium hydromica) should be present. Associated gangue minerals are largely finely disseminated calcite, gypsum, and ferric oxide. The unoxidized or low-valent ore minerals to be expected are coffinite, uraninite, and montroseite, and an associated gangue of calcite and some pyrite; the partly oxidized ore minerals to be expected are rauvite, corvusite, doloresite, hewettite, and vanadium clay (Botinelly and Weeks, 1957, p. 4, and pl. 1).

Most deposits in the district are small; only a few have yielded more than a thousand tons of ore. The deposits consist of sandstone impregnated with ore minerals and some fossil plant material. High-grade replacements of fossil plants are uncommon, and fossil logs are scarce and generally small, and rarely attain a diameter of as much as a foot.

The deposits form blanketlike layers that follow the bedding in general, but cross it locally at low angles. These mineralized layers are gray or greenish gray, but in places are colored by bright yellow uranyl vanadates. Individual layers pinch and swell markedly within short distances, but rolls are less common and less well formed than in the deposits in the Salt Wash in southwestern Colorado. The layers range in thickness from 0 to as much as 15 feet and in width and length from a few feet to several hundred feet. In places, deposits comprise one or more layers that are separated by barren sandstone and locally they merge laterally to form podlike masses. Most deposits tend to occur in clusters, which generally are a few thousand feet across.

The ore bodies are the rather vaguely defined higher grade parts of the mineralized masses, except for a small number of isolated ore bodies. Within the clusters of deposits many of the ore bodies are connected by thin or weakly mineralized layers. The ore bodies range in thickness from about a foot to 5 feet or more and probably average about 3 feet, and they range in width from several feet to a few hundred feet.

The deposits occur where the sandstone and encompassed mudstone is gray; away from deposits the sandstone and mudstone are a general reddish color.

STRUCTURAL RELATIONS OF THE DEPOSITS

Deposits in the district show only an indirect relation to Late Jurassic deformation and no apparent relation to later periods of deformation or to igneous rocks in the district. These relations will be reviewed, however, for the bearing they have on deposits elsewhere in the Morrison, as well as in the Shiprock district.

As indicated above, the deposits occur in a relatively thick part of the Salt Wash Member where the sedimentary structures and thickness data indicate that it occupies an eastward-trending structural depression. Because this depression formed in Late Jurassic time, the deposits contained in the host rocks are indirectly related to the deformation of Late Jurassic age, similar to the deposits in the Jackpile sandstone in the Laguna district.

The oldest recognizable post-Jurassic structural features in the district are the Defiance and Hogback monoclines, which probably formed about the same time as the uplifts marginal to the San Juan Basin, which are considered to be Late Cretaceous or early Paleocene in age (Kelley, 1955, p. 84). The deposits show no obvious relations to these monoclines and could possibly predate them.

Intrusive igneous rocks in the district and in adjacent parts of northeastern Arizona are of two ages. The dioritic intrusives are probably early to middle Tertiary but are possibly as old as Late Cretaceous (see p. 31); the basaltic intrusives are Pliocene or Quaternary in age. The deposits show no relation to any of these rocks and are probably older, but dating is uncertain.

The basaltic igneous rocks intrude the Chuska Sandstone, south of the Shiprock district. The Chuska Sandstone rests on the beveled edge of Upper Cretaceous rocks (O'Sullivan and Beikman, 1963) and is generally considered to be late Tertiary in age through correlation of the underlying erosion surface with a similar surface under the Pliocene Bidahochi Formation (Hack, 1942). Because the basaltic rocks intrude the Chuska, they are considered to be Pliocene or younger in age. Masters (1955, p. 115) indicated that a basaltic dike in the east Carrizo area intersects uranium deposits and that the ore is prebasalt, but he gave no details.

CHUSKA DISTRICT

About 18 deposits or groups of deposits are listed in the Morrison Formation in the Chuska district (pl. 1). Most of them are clustered along the outcrop west of Sanostee in a relatively small area along Peña Blanca Creek, generally referred to as the Sanostee Wash area, where they are about equally distributed in the Salt Wash and Recapture Members (fig. 14). Most of the deposits have yielded some ore, but the total district yield of about 26,500 tons has come largely from the Enos Johnson 3 deposit in the upper part of the Recapture Member. The ores from the various mines range in U: V ratio from 1: 3 to 5: 1 and

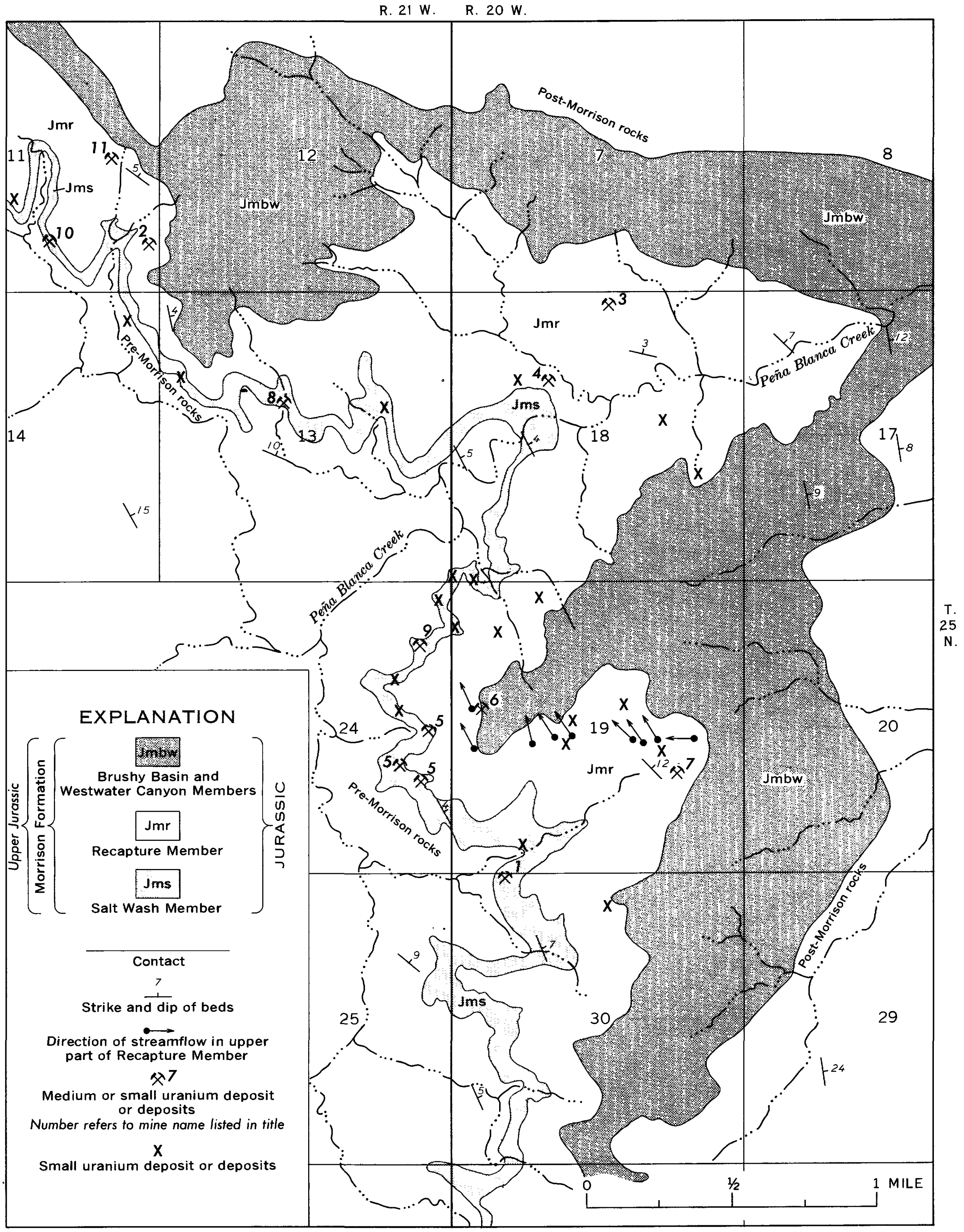


FIGURE 14.—Main part of Chuska district showing the uranium deposits in the Morrison Formation. Modified from J. W. Blagbrough, D. A. Thieme, B. J. Archer, Jr., and R. W. Lott (written commun., 1959). List of mines: 1, Carl Yazzie 1; 2, Castle T'sosie; 3, Dennet Nezz and Dennet Nezz 2; 4, Dennet Nezz 3; 5, Enos Johnson, or Enos Johnson 1 or 2; 6, Enos Johnson 3 (South Peak); 7, Horace Ben 1; 8, Joe Ben 1; 9, Joe Ben 3; 10, John Joe 1; 11, Kee Tohe. Land net unsurveyed and projected.

average 2:1, similar to the ores in the Gallup, Ambrosia Lake, and Laguna districts. During the 1952–58 period, 8,700 tons of ore yielded from 13 mining properties averaged 4.3 percent lime and among the individual properties ranged from 0.8 to 30.6 percent lime. The ores from four properties averaged more than 10 percent lime, but these ores represent only about 250 tons of material. The high lime values probably represent ores largely from calcified fossil logs.

STRATIGRAPHY

The Sanostee Wash area is near the south margin of the Salt Wash Member. At Sanostee Wash the Salt Wash is about 50 feet thick; northward it thickens to about 200 feet at the outcrop west of Shiprock. Southward it interfingers with and pinches out beneath the Recapture Member about 15 miles south of Sanostee. Cross-laminae studies in the upper part at Sanostee Wash (on north slope of Peña Blanca Creek, in fig. 14) and in the lower part at Horse Mesa, about 20 miles to the north, indicate a resultant dip direction of S. 75°–85° E. (Craig and others, 1955, fig. 26). Uranium deposits in the Salt Wash Member occur in a gray sandstone, generally less than 30 feet thick, in the upper part of the member along a 3-mile strip of outcrop from the Carl Yazzie 1 northward to the John Joe 1 (fig. 14).

Sanostee Wash is at the north end of the conglomeratic facies and near the northeast end of the thick part of the Recapture fan, which centers in northeastern Arizona (Craig and others, 1955, fig. 22). From Sanostee Wash, where the Recapture Member is about 500 feet thick, the Recapture thins northward and grades into a sandstone-mudstone facies in the Shiprock district. Cross-laminae studies by L. C. Craig (written commun., 1961) indicate that the resultant dip directions are generally northeastward. The northwestward direction of stream flow shown in the Sanostee Wash (fig. 14) area may represent a local variation from the regional pattern. It is not known what specific sedimentary structures are represented.

Uranium deposits in the Recapture crop out between the prospect immediately east of the Carl Yazzie 1 and the H. B. Roy 2, about 5 miles to the northwest. The largest deposits are in a light-gray sandstone in the upper part of the member. The sandstone, which has a maximum thickness of about 60 feet, occurs in a gray zone about 10 to 170 feet below the top of the member. This zone thins northward and southward from the vicinity of the Enos Johnson 3 and interfingers at its margins with red sandstone units in the general vicinity of the Dennet Nezz and Carl Yazzie mines (J. W. Blagbrough, written commun., 1959). The eastward extent of the gray zone, back from the outcrop, is not known.

STRUCTURE

The Chuska district is on the east flank of the Defiance uplift and west flank of the San Juan Basin, where the beds are upturned along the Defiance monocline, a sinuous northward-trending structural feature (pl. 1 and fig. 3). (See Kelley, 1955, p. 64, figs. 2, 5, and 10; O'Sullivan and Beikman, 1963, sheet 2.) At the outcrop west of Sanostee, the Morrison Formation and bounding formations dip about 5°–10° NE. Five to six miles east of the outcrop, on the crest of the Beautiful Mountain anticline, approximately at Sanostee and about 2 miles east of the axis of the Beautiful Mountain syncline, the base of the Morrison is about 1,500 feet below the surface. Eastward from this locality, the beds dip into the San Juan Basin on the Hogback monocline (O'Sullivan and Beikman, 1963).

J. W. Blagbrough (written commun., 1959) reported two well-developed joint sets in the Sanostee area, both approximately normal to the regional dip and roughly normal to each other. He indicated that one set was parallel to the "northwest trend of the Defiance uplift [probably more specifically referring to the Defiance monocline]" and the other "essentially parallel to the regional dip [northeasterly]." (See O'Sullivan and Beikman, 1963, sheet 2.) The parallel and normal relations of the joint sets to the monocline indicate that they probably were formed at the same time as the monocline. As discussed earlier under other districts, the monoclinal folds on the flanks of the uplifts are probably Late Cretaceous to Paleocene in age, so the joint sets are likely the same age.

An older, Late Jurassic, trough apparently trends eastward through the main part of the district. The evidence for it is stratigraphic. The Recapture in the main part of the district is at the north end of the conglomeratic facies and near the northeast end of the Recapture fan, and though the data are rather sparse, they suggest that the beds of the Recapture occupy a local structural trough somewhat similar to the troughs in the Laguna and Shiprock districts. This is indicated by the greater thickness of the Morrison Formation, the high ratio of thickness of stream deposits to thickness of flood-plain deposits, and the eastward trend of the trough from northeastern Arizona where the Recapture is thickest (Craig and others, 1955, figs. 22, 24, 30).

MINERALOGY AND FORM

Little is known about the specific mineralogy of the deposits. Carnotite has been reported as the most obvious mineral in most of the deposits, but tyuyamunite is probably also abundant. Schroekingerite was reported by Droullard and Jones (1951) and uranophane by Gruner and Smith (1955, p. 36), but no low-valent ore minerals have been identified. According to the classification of Botinelly and Weeks (1957), the expected low-valent ore minerals having U : V ratios from 3 : 1 to 1 : 5 principally would be coffinite, uraninite, and montroseite. These minerals might be expected in the unoxidized zone back from the outcrop and, intermediate between these suites, the partly oxidized ores would be expected to consist mostly of rauvite associated with some vanadium minerals such as corvusite and doloresite. The principal gangue minerals consist of finely disseminated calcite, some gypsum, and a mixture of iron oxides.

Several deposits in the Salt Wash have yielded ore, perhaps totaling as much as 2,000 tons, but the tonnage is uncertain because of mixed production records and the uncertainty of location of the Enos Johnson and Enos Johnson 1 and 2 mines. The ores, however, apparently are similar to those in the Recapture because the U:V ratio is the same as that of the ores that can be identified and is unlike that of the vanadiferous ores of the Shiprock district.

General habits of the deposits are largely taken from J. W. Blagbrough (written commun., 1959). Deposits in the Salt Wash Member are in the upper part where they occur as thin tabular bodies in sandstone. The bodies generally bound mudstone beds, impregnate sandstone around concentrations or pockets of carbonized plant debris, fill fractures within carbonized logs, and are disseminated as halos in the surrounding sandstone. The deposits that bound the mudstone beds and that are associated with the plant debris range in thickness from a few inches to about 2 feet, and in length and width from a few feet to as much as 50 feet. They generally are smaller than the deposits in the Shiprock district. The mineralized logs are about 1–2 feet in diameter and 3–4 feet long.

Deposits in the Recapture Member occur in the lower part as fracture fillings in calcified logs and as impregnations of the enclosing sandstone; in the upper part they occur in sandstone as one or more crudely tabular layers along mudstone beds, as halos around mudstone galls and calcareous pods, and as halos around lenslike hematitic zones. The mineralized logs are from 2 to 3 feet in diameter and range in length froom 5 to 15 feet. Deposits in the upper part of the Recapture range in width from 150 to 200 feet, in length from 500 to 600 feet, and in thickness from 1 to 20 feet. Orientation is not known. Only the higher grade parts are minable, and the configuration of the ore is rather ill defined as in the Shiprock district.

In general the deposits occur where the sandstone and mudstone are gray; no deposits are known where the host rocks are red. Locally some deposits in the upper part of the Recapture encompass pods of purple-red sandstone.

STRUCTURAL RELATIONS OF THE DEPOSITS

As in the Shiprock district, two periods of deformation may have influenced the emplacement of the uranium deposits—Late Jurassic and Late Cretaceous to early Tertiary. Stratigraphic evidence indicates that Late Jurassic deformation produced an eastward-trending troughlike structure through the main part of the district. The deformation may be assumed to have formed in Recapture time and to have died out prior to Dakota time because the thickness relations of the Salt Wash Member and the structure contours at the base of the Dakota Sandstone show no effect from it. The uranium deposits are indirectly related to this structure because they occur approximately on its axis, where the Recapture Member, the principal host rock, is thickest. This relation is similar to that in the deposits in the Jackpile sandstone in the Laguna district and in the deposits in the Salt Wash Member in the Shiprock district.

No evidence has been found, perhaps because of limited exposures, that indicates the deposits were influenced or controlled by the Late Cretaceous to early Tertiary deformation. Just west of the Sanostee area in Arizona, however, where rather extensive exposures of deposits in the Salt Wash Member occur, Masters (1955, p. 117) found no apparent relation in the position or trend of the deposits to the Lukachukai anticline and adjacent syncline. These structural features, which are also referred to as the Lukachukai monocline and Chuska syncline (Kelley, 1955) and the Toadlena anticline and Chuska syncline (O'Sullivan and Beikman, 1963), are similar structurally to the Defiance monocline and probably formed during the same period of deformation. The deposits in the Chuska district apparently, therefore, where emplaced during or after Late Jurassic deformation and prior to or during Late Cretaceous to early Tertiary deformation.

OTHER DISTRICTS OR AREAS

Aside from the districts described, few deposits have been found in the Morrison Formation. Of about two dozen that are recorded, most of them are clustered in west-central Sandoval County on the southeast margin of the San Juan Basin, and the others are scattered in south-central Rio Arriba County near the south margin of the Chama Basin.

In Sandoval County, the deposits occur in two clusters. The larger one, in T. 15 N., Rs. 1 E. and 1 W., consists of several scattered subsurface radioactive anomalies and several scattered radioactive zones at the outcrop. All are apparently in sandstone lenses in the Brushy Basin Members. Uranium minerals have not been identified in these deposits. The radioactive material at the surface is mostly concentrated around mudstone galls and lenses in fractured and limonite-stained sandstone. The smaller cluster, in the southeastern part of T. 17 N., Rs. 1 E. and 1 W., consists of several small deposits at the outcrop and in the subsurface. Most of them are in the Westwater Canyon Member and one is in an 18-foot-thick sandstone unit in the Brushy Basin Member. The latter deposit contains yellow and green uranium minerals associated with limonite, jarosite, pyrite cubes, and carbon in an iron-stained sandstone (A. Mirsky, written commun., 1953). The mineralogy of the other deposits is not known. Most of them are described as radioactive anomalies around mudstone galls and along mudstone seams. Several hundred tons of ore was mined from one deposit in the Westwater Canyon Member in the 1957–64 period.

In Rio Arriba County, five deposits are listed (table 4), of which two consist of scattered radioactive bones and bone fragments. The other three are occurences of yellow uranium minerals, probably carnotite or tyuyamunite, in a white sandstone unit at the top of the Morrison Formation. The minerals occur on joint surfaces and as spotty disseminations in sandstone at the outcrop and in prospect pits.

PENNSYLVANIAN, PERMIAN, AND TRIASSIC ROCKS

About three dozen uranium deposits occur in stratigraphic units that range in age from Pennsylvanian to Triassic. These units contain a high percentage of fluvial material that largely composes the characteristic red beds of the Southwest. These contain the red-bed copper deposits, as well as uranium deposits, which are similar except for variations in their respective metal contents. Most of the deposits occur in the Cutler and Abo Formations of Permian age, and a few are in the Chinle and Dockum Formations of Triassic age and in the Madera Limestone of Pennsylvanian age. Most of them (27) are clustered in south-central Rio Arriba County; the others are dispersed in Torrance (4), Valencia (3), Sandoval (2), Bernalillo (1), and Socorro (1) Counties (pl. 1).

Uranium ore shipments were made in 1954–55 from three properties in the Cutler Formation, Rio Arriba County. The total was less than 100 tons and averaged 0.14 percent U_3O_8 and 0.13 percent V_2O_5. Shipments from two of the properties averaged 8 percent and 17 percent lime, and about 0.3 percent copper.

MINERALOGY AND HABITS

The mineralogy of these deposits is incompletely known, partly because little work has been done on them and partly because the uranium minerals are fine grained, sparse, and not readily identifiable in the field. Where noted, they have been reported as yellow and green oxides associated with the copper carbonates malachite and azurite and the copper sulfides chalcocite, bornite, and chalcopyrite. These deposits are uraniferous variants of red-bed copper deposits; some of them were worked for copper ores before they were prospected for uranium. The primary uranium minerals, where present, probably are coffinite and uraninite, which are similar to the other nonvanadiferous ores in sandstone. For more detailed mineralogy of uraniferous copper deposits see Weeks, Coleman, and Thompson (1959).

Most of the deposits consist of tabular or lenticular zones of finely disseminated material in sandstone. They are roughly parallel to the bedding, range in thickness from thin layers or seams to as much as 20 feet, and in lateral dimensions from a few feet to as much as 200 feet in width and 2,000 feet in length. Most of them probably average about a foot in thickness and only a few feet in lateral dimensions. Nearly all are low grade; high-grade material occurs only in local spots, generally as concentrations around carbonaceous plant debris.

Most deposits are closely associated with plant debris, and a few occur as coatings or halos around coalified or silicified logs. A few occur as local concentrations along and in the margins of claystone seams and galls and in siltstone.

Nearly all the deposits occur in a host rock of coarse-grained locally conglomeratic arkosic sandstone which is light gray and locally stained light brown. Barren sandstone generally is reddish or reddish purple. The sandstone units generally range in thickness from a foot or so to as much as 60 feet, and they display conspicuous fluvial-type crossbeds and local channel scours at their base.

STRATIGRAPHIC AND STRUCTURAL RELATIONS

The deposit in the Madera Limestone occurs in the upper arkosic limestone member (sec. 31, T. 23 N., R. 1 E., Rio Arriba County). This member wedges out northward against Precambrian rocks and generally grades southward into thinner bedded clastics and marine limestone. The arkosic sandstone units are generally thin bedded and are representative of a continental environment near the south margin of the San Luis highland. (See p. 28.)

As indicated under the section on stratigraphy, the Cutler Formation is approximately equivalent to the Yeso and the underlying Abo Formation to the south. The principal source area for the Cutler was the San Luis highland to the north, and the principal sources for the Abo were the ancestral Zuni highland to the west, the Joyita highland to the south, and partly the San Luis highland to the north (McKee and others, 1967). From north to south, the arkosic sandstone units generally become thinner and their grain size somewhat finer, but these relations are reversed in the proximity of the two southern highlands. The principal uranium deposits in both the Cutler and Abo are concentrated along the flanks of the respective highlands that contributed most of the coarser clastic debris. (See McKee and others 1967.)

The late Paleozoic uplifts became buried by Early Permian time and, during Late Permian and Early Triassic time, the Lower Permian and older rocks were deformed and beveled. About Middle Triassic time, after Moenkopi deposition, the San Juan element to the north and the highlands to the south and southeast were upwarped and contributed clastic sediments southward and northward. These sediments formed the segments of the Chinle and Dockum Formations that are represented in northwestern New Mexico. Of the principal sandstone units, the Shinarump Member, Sonsela Sandstone Bed, and Poleo Sandstone Lentil probably were derived from the southeastern and southern highlands (Cooley, 1959; Stewart and others, 1959; Poole, 1961; McKee and others, 1959, p. 22) and the Agua Zarca Sandstone Member from the San Juan highlands to the north and probably also in part from the south (McKee and others, 1959, p. 22). It is possible that the Agua Zarca and Shinarump are a continuous unit in the subsurface in the southeastern part of the San Juan Basin area (McKee and others, 1959, p. 22 and section *B–B′*, pl. 4).

Deposits in the Shinarump Member are probably near its east margin; the ones in the top of the Agua Zarca and base of the Salitral Shale Tongue are near the Agua Zarca source area, and those in the Poleo Sandstone Lentil are near the northern known limit of the unit and are remote from the southern source area.

Relations of the deposits to local structural features are little know. The southeast margin of the mineralized zone in the Poleo Sandstone Lentil terminates against a northward-striking steeply dipping fracture (H. G. Brown 3d, and L. L. Werts, written commun., 1954), but the relative ages of the fracture and the mineralization are not known.

CRETACEOUS ROCKS

Several dozen uranium deposits or clusters of deposits are listed in stratigraphic units of Cretaceous age. These units were formed largely under marine environment, and the deposits contained in them are almost entirely in rocks formed under near-shore or marginal continental conditions. The deposits are widely distributed throughout the area and in many places are closely associated with or make up parts of similar deposits in carbonaceous shale and lignitic shale or coal. Although the deposits in sandstone and in shale and coal are similar and in some places can be separated only arbitrarily, they are treated separately because of some differences in their ores and in the character of their host rocks.

The stratigraphic host unit and number of deposits in sandstone, by counties, are as follow (see table 4 and pl. 1):

Stratigraphic unit	Number of deposits	County
Ojo Alamo Sandstone	1	Sandoval.
	1	San Juan.
Fruitland Formation	1	Do.
Mesaverde Group:		
Cliff House Sandstone	1	Sandoval.
Menefee Formation	2	San Juan.
Point Lookout Sandstone	1	McKinley.
Point Lookout(?) Sandstone [1]	10	Catron.
Gallup Sandstone	1	San Juan.
	1	Socorro
Mesaverde Group undivided	3	Catron.
	1	Sandoval.
Mancos(?) Shale	1	Socorro.
Dakota Sandstone	[2] 11	McKinley.
	1	San Juan.
	2	Sandoval.

[1] Possibly in part the Crevasse Canyon Formation.

[2] One deposit, the Church Rock, is partly in the Morrison Formation.

Most of the deposits and all the productive ones, except one, occur in the Dakota Sandstone. Of 14 that are listed, 9 yielded a total during the 1952–64 period of about 110,000 tons of ore that ranged from 0.12 to 0.30 percent U_3O_8 and averaged about 0.22 percent U_3O_8. More than 90 percent of this ore was mined from the Church Rock and Diamond 2 mines. About 43,500 tons of this material, which was representative of seven properties, averaged 0.11 percent V_2O_5. The U : V ratio averaged 3 : 1 and ranged from 4 : 1 to 1 : 1 among properties. The lime content from five properties for a total of about 40,000 tons of ore ranged from 0.5 to 1.8 percent and averaged about 0.5 percent.

The Midnight 2 (sec 12, T. 2 N., R. 11 W., Catron County) is the only productive deposit in Cretaceous rocks, other than the deposits in the Dakota Sandstone. It occurs in the Point Lookout(?) Sandstone or possibly in the Crevasse Canyon Formation. It yielded a few hundred tons of low-grade ore in 1957 that had a U:V ratio of 1:2 and a lime content of about 2.5 percent. The Jack Boyd mine (sec. 3, T. 30 N., R. 15 W., San Juan County) in the Fruitland Formation reportedly yielded a small tonnage of ore-grade material, but is not listed in the official records as a producer.

MINERALOGY AND HABITS

Few data are available on the mineralogy of uranium deposits in rocks of Cretaceous age. The secondary uranium minerals carnotite, tyuyamunite, and metatyuyamunite have been reported in many of the deposits and generally described as impregnations and as coatings along joint faces and bedding surfaces in close association with limonite, jarosite, calcite, and locally gypsum. Meta-autunite and a variety of uranophane were identified in the "Desanti [Becenti]" deposit by Gruner, Gardiner, and Smith (1954, p. 39), but they gave no details. These, however, may have been the yellow uranium minerals observed in the deposit by the writer as disseminations in sandstone and as coatings on joint and bedding surfaces.

In the Diamond 2, carnotite was reported as the principal ore mineral in the workings above the 200 level and pitchblende the principal ore mineral in two ore bodies that probably occurred along the 300 level (Gabelman, 1956a, p. 306). The principal black ore mineral in the deeper levels probably also was pitchblende, but could have been coffinite or a mixture of the two minerals.

In about half the deposits listed, the close association of the uranium minerals or radioactive material with carbonaceous material is noted. Where uranium minerals were observed they generally were intimately mixed with plant debris or occurred immediately above or below a carbonaceous bed. A few minerals consist of radioactive material associated with limonite, and a few occur at the contact of sandstone with clay or shale. The Jack Boyd deposit occurs in a tuffaceous sandstone unit that overlies a carbonaceous claystone.

In rocks of Cretaceous age the deposits consist of tabular masses that range from thin seams a few feet in width and length to crudely tabular masses as much as 2,500 feet in length and at least 1,000 feet in width. The larger deposits range from a few inches to as much as 25 feet in thickness, but generally average a few feet. Roll surfaces are less common, and the deposits are more blanketlike than the ones in Jurassic sandstone. This may stem partly from the close association of the uranium minerals with the carbonaceous debris, which is generally distributed in crude bedlike zones within the sandstone units, and partly from the tendency of the uranium minerals to accumulate on relatively impervious claystone or shale units. Ore bodies, which generally compose the high-grade parts of deposits, range from small masses that comprise only a few tons of material to masses that include as much as or more than 50,000 tons of material. They range in thickness from a foot or so to 25 feet, but most of them are only a few feet thick and comprise only a few hundred tons of material.

STRATIGRAPHIC AND STRUCTURAL RELATIONS

Nearly all the deposits occur near or at the base of sandstone units, and most of them at the base of formational units. In the Dakota Sandstone most are in sandstone lenses that occupy channel scours at the base of the formation. These lenses range in thickness from 20 to 50 feet at the center and in width from 300 to 800 feet; they consist mostly of fine- to medium-grained sandstone and contain crossbeds that dip from 8° to 25° (Mirsky, 1953). Locally these lenses are conglomeratic (Gabelman, 1956a, p. 316).

Trends of the lenses generally have not been determined, but the lenses apparently are clustered along the outcrop on the south flank of the San Juan Basin where Mirsky (1953, p. 8–9, 10–11) mapped about 30 and noted their concentration in the area and their general absence elsewhere. Within the lenses the uranium deposits generally are closely associated with the distribution of carbonaceous material and, in at least two, the deposits underlie lenses of carbonaceous shale.

The principal ore bodies of the Diamond 2 mine (fig. 15) are apparently in one or more sandstone lenses (Mirsky, 1953; Gabelman, 1956a). Although the geology of the mine is incompletely known, it is reviewed for the stratigraphic and structural relations that bear on the ore controls and age relations of the uranium deposits in the Dakota Sandstone. The geology is abstracted and interpreted mostly from Gabelman (1956a) for the upper workings adjacent to the main incline, and partly from a later report by Chico (1959).

In the upper workings along the main incline, Gabelman (1956a) showed the ore bodies in a crossbedded sandstone at the base of the Dakota where it occupied a channel scour in the underlying Westwater Canyon Member of the Morrison Formation. He also showed the ore bodies as near the south margin of the host sandstone and under an overlying carbonaceous shale near its southward pinchout into thin-bedded sandstone. The dip direction of the crossbeds in the host sandstone has a southward trend (Mirsky, 1953, p. 19). Gabelman showed that the ore bodies were controlled by shallow folds and to some extent by shallow

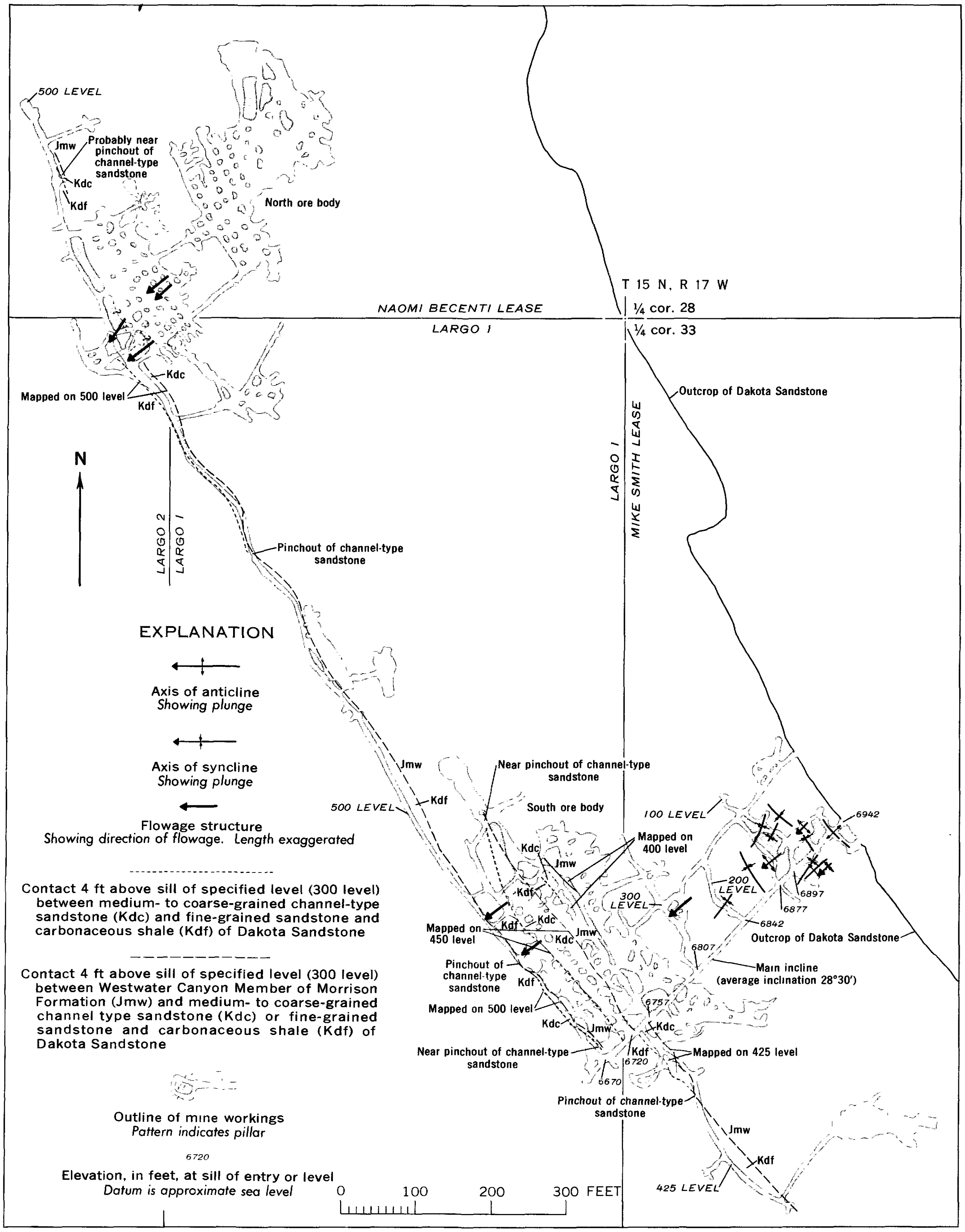


FIGURE 15.—Diamond 2 mine. Shows local tectonic folds and flowage structures and stratigraphic relations of principal ore bodies to the host sandstone. Geology abstracted and modified from Gabelman (1956b) and Chico (1959). Base and mine map from Four Corners Uranium Corp., January 1959. Publication by permission of Four Corners Oil and Minerals Co.

cross folds, the axes of which trended southwestward and northwestward, respectively, parallel to the dip and strike of the beds. He also indicated that the principal joints trended eastward and N. 10° W., and that a minor set trended northeastward, and stated that the prominent joints controlled the ore by acting as barriers. Presumably the structural control referred to carnotite bodies, as the only mention of low-valent uranium minerals in the mine is in the statement, "* * * two ore bodies recently discovered below the oxidized zone * * * are composed entirely of primary pitchblende ore." (Gabelman, 1956a, p. 306). These bodies were not included in his reference to the structural control by the folds and joints.

Later work by Chico (1959) in the deeper levels of the mine also showed that the principal ore bodies were in the basal sandstone and that the sandstone pinched laterally away from the margins of the bodies and pinched downward below the south ore body. His level maps show that the host sandstone is 10 feet or more thick in the central part of the south ore body, pinches out near the southeast limit of the body on the 425 level, and is at most only a few feet thick near the northwest limit of the body on the 450 level. On the 500 level the sandstone has a maximum thickness of about 7–8 feet and wedges out along the level near the main incline and about 150 feet north of it.

The host sandstone is missing along about 600 feet of the 500 level between the south and north ore bodies, but also likely occurs on the level under the north ore body. From a pinchout about 300 feet southeast of the body, it thickens northwestward to about 12 feet at the south margin. About 50 feet north of the body, it has a thickness of only a few feet; at this point it seems to be pinching northward. The exposures under the north ore body could represent a segment of the same channel sandstone that contains the south body or possibly a segment of the channel sandstone that crops out at the Becenti deposit about half a mile to the northwest (Mirsky, 1953, fig. 3 p. 9). The north ore body apparently was controlled by a channel sandstone similar to one that controlled the south ore body; whether the sandstone pinches out below the 500 level, as it does along the 425 level, is not known. In addition to the folds described by Gabelman in the shallow workings, Chico described flowage structures in the deeper workings that may be useful in dating the emplacement of the ore.

Chico's description of the flowage structures indicates that they have a variety of shapes. Their direction of flowage is southwestward, parallel to the structural dip of the beds (fig. 15), but their internal structure is incompletely known and their range in size is uncertain. They probably are, however, as much as several feet thick and several tens of feet wide and long; they are bounded by undisturbed beds and show crumpling and folding back of the more disturbed beds over or around the nose of some folds. They are probably similar to the folds referred to as diagenetic by Gabelman (1956a, p. 306).

Age relations of the black ore to those structures and to later fractures indicate that the ore was emplaced after flowage and prior to fracturing. Pockets of coalified plant debris that were distorted by flowage of the sandstone are intersected by fractures. The coalified material is mineralized by black ore minerals, but the fact that crosscutting fractures are barren indicates that the mineralization was prefracture (Chico, 1959, p. 63, fig. 22).

Age of the flowage structures is probably Cretaceous and about the same as or slightly younger than the deposition of the host rocks. The flowage took place prior to compaction and probably during initial uplift, because the direction of flowage is parallel to the dip of the Nutria monocline. The fractures formed after compaction, possibly about the time the initial fractures formed in the Ambrosia Lake district—during the development of the McCartys syncline. If so, the black ore in the Diamond 2 was emplaced during Cretacous or Paleocene time, probably shortly after the initial uplift of the beds.

Relations of the other deposits in the Dakota Sandstone to tectonic structures are not clear. The oxidized minerals have a tendency to occur along fractures and under small folds and crenulations, but the relations of any low-valent or primary minerals is uncertain since none have been recognized. The association of the Dakota ore body in the Church Rock mine with the northeastward-trending fracture system suggests that the ore here is postfracture and perhaps redistributed, similar to the postfault unoxidized ore of the Ambrosia Lake district.

Little information is available on the stratigraphic and structural relations of the deposits that occur in formations above the Dakota Sandstone other than their tendency to occur at the base of sandstone units above a rather impermeable clay or shale bed and to generally show an intimate relation to carbonaceous debris or carbonaceous shale. Somewhat exceptional is the McPhaul deposit, in Catron County; it occurs in a small shallow syncline that may have partly controlled its emplacement.

TERTIARY AND QUATERNARY ROCKS

About two dozen deposits or clusters of deposits are listed in stratigraphic units of Tertiary and Quaternary ages, all of which were deposited in a continental environment. From oldest to youngest the units and the number of deposits which they contain are as follows: Nacimiento, 1; San Jose, 4; Galisteo, 1; Baca, 10; and Santa Fe, 10. The deposits principally occur in the northern part of Santa Fe County and in western Socorro County; others are scattered in Rio Arriba, Catron, and Sandoval Counties (pl. 1). A small tonnage of moderately low grade ore was shipped from the Red Basin 1 deposit in 1954; this ore had a U:V ratio of 1:1 and a content of about 15 percent lime. A small amount was also shipped from the Hook Ranch (Jaralosa) mine in 1959–60. The Red Basin 1 is in the Baca Formation, probably also the host formation of the Hook Ranch mine deposit.

MINERALOGY AND HABITS

Information on the mineralogy of the deposits is meager. Except for those deposits in the Santa Fe Group, most have been reported simply as radioactive or uraniferous zones, closely associated with carbonaceous material or limonite. Yellow-green uranium minerals and meta-autunite(?) occur in deposits in the Baca Formation, and autunite occurs in a deposit in the Galisteo Formation. In the Santa Fe Group, carnotite, schroekingerite, and meta-autunite coat fracture and bedding surfaces of sandstone, siltstone, and claystone and are generally concentrated where the sandstone contains clay galls and pockets and seams of coalified plant debris. Radioactive opal locally occupies fractures, and some of the higher grade deposits are within opal-cemented halos.

The deposits are generally surficial, small, and low grade. They range from seams or small pockets, an inch or so thick and a few feet wide and long, to crudely lenticular masses as much as several feet thick and 100 feet long. Exceptionally large ones are the Red Basin 1 (sec. 19, T. 2 N., R. 10 W.), in the Baca Formation, which extends along the outcrop for about half a mile and back from the outcrop for several hundred feet, and the We Hope 4 (sec. 4, T. 13 N., R. 6 E.), in the Galisteo Formation. According to a private report, the We Hope 4 deposit is a few hundred feet long and wide and as much as 25 feet thick, and it is within a radioactive seleniferous zone that can be traced along the outcrop for about 1 mile.

STRATIGRAPHIC AND STRUCTURAL RELATIONS

Host rocks containing the deposits were laid down in four separate basins or depressions. The Nacimiento and San Jose Formations were deposited in the San Juan Basin during its early development and were derived from debris shed from highlands to the east and north. (See p. 30.) Northward tilting and some folding, faulting, and intrusion by lamprophyric dikes, sills, and other igneous bodies followed the deposition of the San Jose. These tectonic events probably were intermittent from early Eocene until Quaternary time (Dane, 1946, 1948), but they had little apparent influence on the uranium deposits in the San Jose and Nacimiento Formations. Mineralogic and surficial relations of the deposits indicate that they probably formed as shallow accumulations from ground water in and around carbonaceous debris.

The Galisteo Formation was deposited in a depression that resulted from late Eocene warping and was derived from debris shed principally from the Nacimiento uplift area to the northwest and the southern part of the Sangre de Cristo Mountains area to the north (Stearns, 1943). The Galisteo in the Cerrillos Hills, Ortiz, San Pedro, and South Mountains was intruded during Oligocene time by stocks and laccoliths and in peripheral areas by dikes and sills. The intrusions were accompanied by some normal faulting. Differential subsidence and faulting in late Tertiary and Quaternary time formed the Rio Grande trough across the northwest flank of the Galisteo basin of deposition. Erosion, attendant to these events, left partly exposed remnants of the Galisteo through the deeper part of the basin, roughly in the area between Algodones on the west and Lamy on the east, a distance of about 35 miles (Stearns, 1953, pl. 1). In spite of the long sequence of tectonic events, the uranium deposit in the Galisteo and the radioactive zone with which it is associated show no apparent relation to faults, folds, igneous rocks, or other tectonic structural features. The deposit may be a near-surface accumulation of uraniferous material that precipitated from downdip-migrating meteoric water. This possibility is suggested by the dip of the beds, about 30° E., the solubility of autunite, and the concentration of the higher grade part of the deposit roughly 50–200 feet below the outcrop and nearly parallel to the bedding.

The Baca Formation accumulated in a basin or several interconnected depressions that formed during late Late Cretaceous to early Eocene time in the area roughly outlined by Socorro and the eastern part of Catron Counties. The basin resulted from compressive forces that caused warping and some reverse faulting along north-trending lines in the south-central part of the area. Extensive regional erosion followed the warping and furnished the material found in the Baca; some of it was derived from the south (Wilpolt and Wanek, 1951) and some from the Lucero uplift area to the north

(Kelley and Wood, 1946). Deposition of the Baca was succeeded by volcanic and intermittent sedimentary activity that produced the Datil Formation of probably late Tertiary, possibly Miocene, age. The Datil is conformable on the Baca Formation in the central part of the area (G. O. Bachman, E. H. Baltz, and R. L. Griggs, written commun., 1957), but overlaps the beveled edge of older rocks to the east (Wilpolt and Wanek, 1951). It is overlain unconformably by the Santa Fe Group and is more complexly faulted than the Santa Fe (Wilpolt and others, 1946).

The following stratigraphic and structural relations of the principal uranium deposits in the Baca are abstracted from G. O. Bachman, E. H. Baltz, and R. L. Griggs' (written commun., 1957) reconnaissance studies of the upper Alamosa Creek valley, Catron County.

In the general region of the deposits the beds dip about 3° SW. and locally are folded gently along fold axes that trend roughly parallel to the regional dip. Faults are uncommon, are of normal type, and have displacements of less than 100 feet (fig. 16).

Host rock of the principal deposits, the Red Basin 1 and 2, is a lenticular sandstone unit that apparently fills an old stream channel cut into the Point Lookout(?) Sandstone (fig. 17). To the southwest this basal sandstone unit apparently wedges out between shale in the Point Lookout (?) and the overlying shale of the Baca Formation. To the northeast the basal unit thins rapidly and wedges out about 1,500 feet northeast of the southwestern pinchout.

The southwestern pinchout can be observed in a prospect cut, and its projection is based partly on drill-hole data. The northeastern pinchout is based on exposures in, and projections from, two outliers of the basal sandstone unit.

Since deposition, the rocks have been tilted to the southwest so that the southwestern part of the channel, the part containing the deposits, is topographically lower than the northeastern part. Tilting must be post-Datil in age, because the Datil shows about the same regional dip as the older rocks. (See fig. 16.) Bachman, Baltz, and Griggs (written commun., 1957) believed that ground water carried uranium in solution into the basal sandstone of the Baca Formation and that the uranium was deposited where this aquifer wedges out between shale units.

Apparently the only tectonic features to which the deposits can be related are the synclinal folds that trend roughly parallel to the regional dip. These folds were noted in the Crevasse Canyon Formation and Point Lookout(?) Sandstone, but not in the overlying Baca Formation, so it is possible that they are pre-Baca or Late Cretaceous to early Tertiary in age. If so, they may have partly controlled the development of the stream channel cut in the Point Lookout (?) Sandstone and the subsequent filling of that channel by the basal sandstone of the Baca. If the uranium deposits were emplaced after regional tilting, their age is certainly post-Baca and probably post-Datil and can range from Miocene to Recent.

The youngest of the Tertiary structural depressions, the Rio Grande trough, probably originated in late Miocene time and cut across earlier structures, such as the Galisteo and Baca basins. Its development attended periodic faulting, depression, and filling with clastic debris and some fine volcanic debris from marginal uplands more or less intermittently and from place to place until Recent time. As a result, the beds dip at various angles from place to place, but generally from the flanks toward the central part of the trough at moderately low angles. The fill in the basin also varies in thickness from place to place but probably in the central part averages several thousand feet. Because the fill is generally unconsolidated, it serves as a highly permeable aquifier that permits southward flow of ground water.

Known uranium deposits in the Santa Fe Group are nearly all concentrated in a small area between Espanola and Santa Fe within a stratigraphic interval of a few hundred feet. The beds are in the Tesuque Formation, of middle(?) Miocene to early Pliocene age, and were derived largely from Precambrian crystalline rocks to the east (Spiegel and Baldwin, 1963, p. 39–40) and partly from volcanic debris from the Jemez volcanic center to the west and the San Juan volcanic center to the north (R. L. Cannon, R. L. Smith, and H. L. Cannon, written commun., 1955).

The deposits show no apparent relations to faults or folds and are surficial. They likely represent accumulations of radioactive material from the present cycle of circulating ground water. This possibility is suggested by the highly soluble uranium minerals; small size and low grade of the deposits; the envelopment of some deposits by radioactive opal; the close association of the deposits with carbonaceous debris, claystone, and limonite; the high uranium content of the host rocks; and the young age of the deposits. The radioactive opela is related to the present cycle of weathering because it occurs as films and coatings on boulders and concretions at the surface, as a cement at the tops of beds of relatively fresh vitric ash, and as a cement in sands just beneath the ash (R. L. Cannon, R. L. Smith, and H. L. Cannon, written commun., 1955).

The high uranium content of the host rock is demonstrated by a suite of 10 samples collected between Abiquiu and Santa Fe (fig. 18). Uranium content of these samples ranged from 2 to 12 ppm (parts per million) and averaged >5 ppm. Eight of the samples were sandstone and two were siltstone. Although they were collected roughly parallel to the strike of the beds, they likely represent several hundred feet of stratigraphic section, including the part that contains the uranium deposits, because the coverage is about 40 miles.

The high uranium content of the Tesuque Formation can most likely be attributed to the high uranium concentrations in the volcanic ash, as shown by the following five samples:

Sample	Locality	Description	Uranium content (ppm)	
			U	eU[1]
2A [2]	Center E½ sec. 33, T. 19 N., R. 9 E. (≈1 mile south of locality of sample 252605, fig. 18).	Top 3 in. of 42-in.-thick exposure of ash bed.	18. 1	(3)
2B [2]	do	28 in. above base of ash bed described for sample 2A.	10. 7	(3)
2 [2]	do	6 in. above base of ash bed described for sample 2A.	5. 6	(3)
239584	NW¼SE¼ sec. 17, T. 20 N., R. 9 E.	Channel across 4-ft-thick white tuff bed.	(3)	20
239585	Center SW¼ sec. 17, T. 20 N., R. 9 E. (≈3,500 ft northeast of locality of sample 252603, fig. 18, and 1,700 ft west of locality of sample 239584 (see above).	do	(3)	30

[1] Analyst, C. G. Angelo.
[2] Data from R. L. Cannon (oral commun., 1965).
[3] No data.

These samples show a range in content of 5.6–30 ppm U or eU and, although the eU values may be high because of disequilibrium, the tuffs probably average more than the entire host rock.

The uranium deposits postdate the Tesuque Formation. Their surficial relations and envelopment within radioactive opal, which also coats surficial debris, indicate that they were probably formed in the present cycle of weathering.

PENECONCORDANT DEPOSITS IN TODILTO LIMESTONE AND ADJACENT FORMATIONS

About 100 deposits or clusters of deposits are listed in the Todilto Limestone, of Jurassic age, on plate 1. Deposits occur in other limestone units, but are uncommon; nearly all of them are associated with faults and are classified as vein deposits. A few others are segments of deposits that are primarily in sandstone; they have been described previously. Most of the deposits in the Todilto Limestone are in the Ambrosia Lake and Laguna districts, McKinley and Valencia Counties. A few are scattered in the southern part of the Chama Basin, Rio Arriba County, and in the Chuska district, San Juan County.

From 1950 to 1964, about 980,000 tons of ore was produced from 52 mines in the Todilto Limestone. This ore had an average grade of 0.22 percent U_3O_8 but ranged from 0.10 to 0.43 percent U_3O_8 among the mines. Prior to 1959, 445,000 tons of this ore averaged 0.14 percent V_2O_5 and had a U:V ratio of about 5:2, similar to that of most of the deposits in sandstone. All but a few thousand tons was mined in the Ambrosia Lake District; the remainder came from three mines in the Laguna district and one mine in Rio Arriba County.

The ores ranged fro 25 to 98 percent lime and averaged 80 percent. Ores from only a few mines averaged less than 50 percent $CaCO_3$; these were mostly mixed ores that came from deposits that extended into the underlying Entrada Sandstone or overlying Summerville Formation, such as the Sandy, Zia, and Haystack 2.

STRATIGRAPHY

Regional stratigraphy of the Todilto Limestone and its relations to the underlying Entrada Sandstone and overlying Summerville Formation were outlined previously (p. 18), but the local stratigraphy in the Ambrosia Lake and Laguna districts will be discussed in more detail to explain the relationships of the deposits.

In the Ambrosia Lake district only the limestone member crops out, but the gypsum-anhydrite member has been penetrated by drill holes about 8 miles north of the outcrop (J. C. Wright, written commun., 1957). The limestone member, which contains all the deposits, ranges in thickness from about 5 to 30 feet and averages about 15 feet. It comprises three units which are referred to locally as the basal "platy," medial "crinkly," and the upper "massive" zones. The platy and crinkly zones are about equal in thickness and compose about half the total thickness of the member. They consist of fine-grained laminated and thin-bedded limestone, which contains thin siltstone partings and locally seams of gypsum. Black fine-grained films of carbon-rich material are conspicuous locally, especially along the partings in the crinkly unit. Bedding in the platy unit is undisturbed, but in the crinkly unit is intensely crenulated. The massive unit is more coarsely crystalline and indistinctly bedded limestone, and it varies markedly in thickness from place to place.

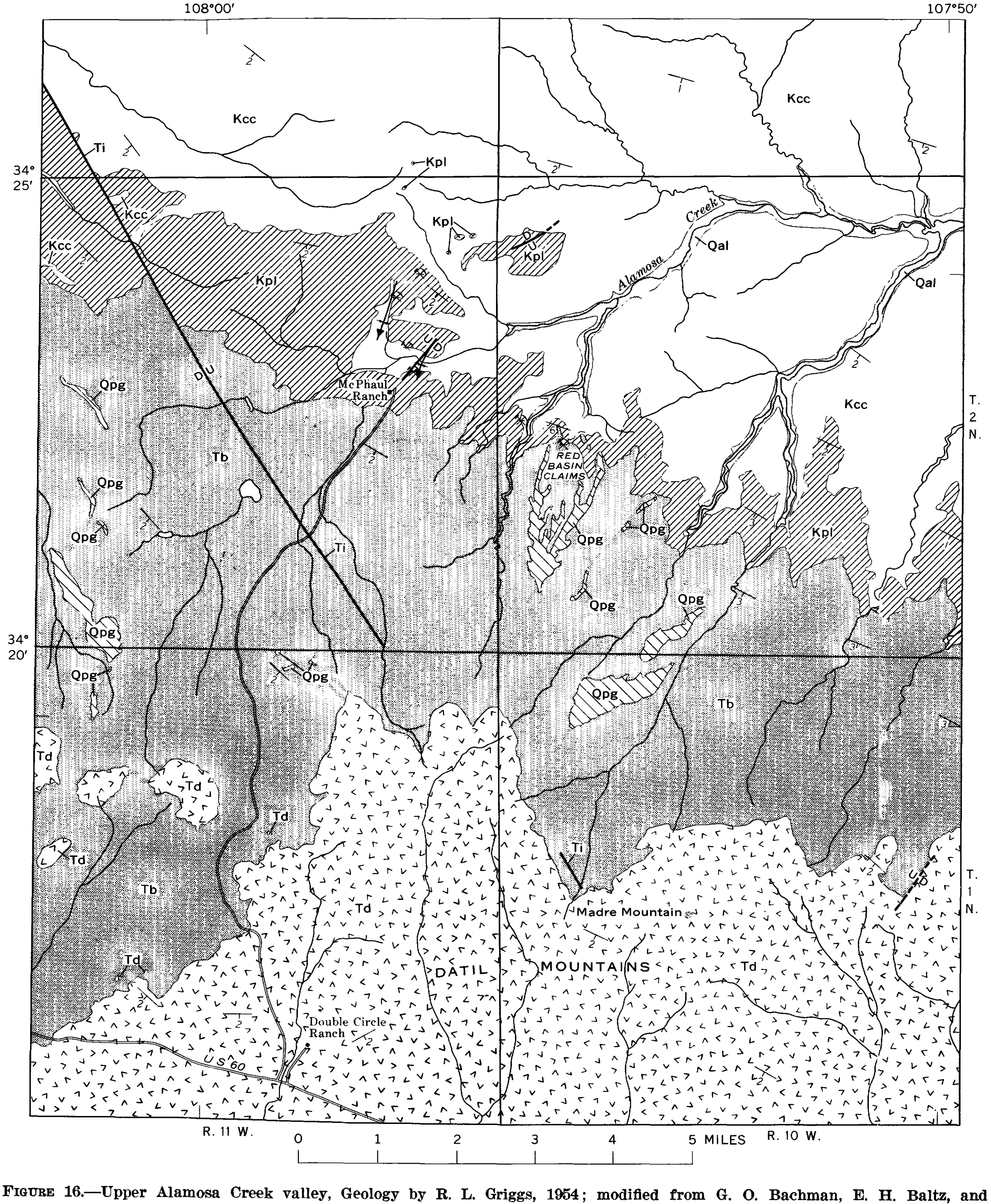


FIGURE 16.—Upper Alamosa Creek valley, Geology by R. L. Griggs, 1954; modified from G. O. Bachman, E. H. Baltz, and R. L. Griggs (written commun., 1958). Base compiled from planimetric maps of U.S. Department of Agriculture. Soil Conservation Service.

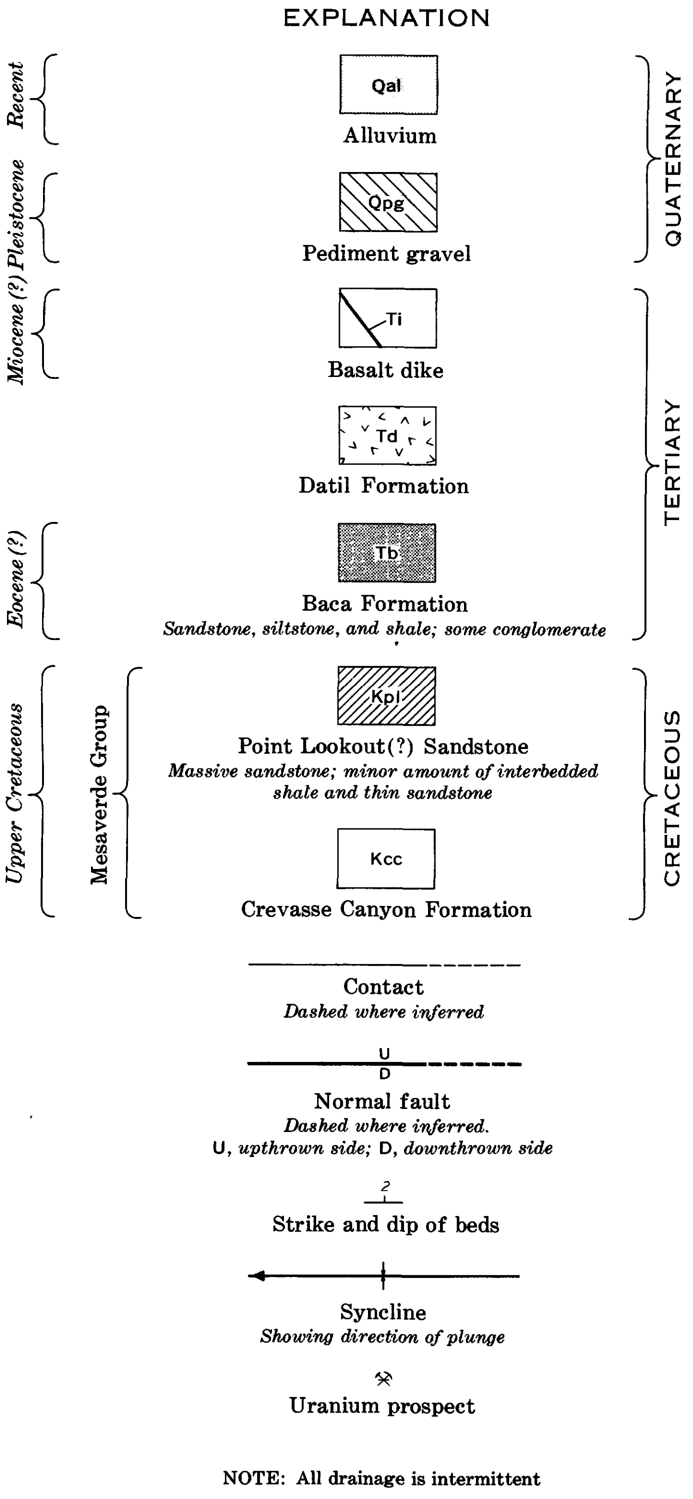


Figure 16.—Continued.

In many places it contains limestone breccia cemented by calcite, and locally the top of the unit is a breccia with fragments of limestone embedded in sand derived from the overlying Summerville Formation. Lenses of siltstone also occur in the massive unit and indicate the gradational relations of the Todilto with the overlying Summerville Formation.

Both the limestone and the gypsum-anhydrite members are exposed in the Laguna district. The limestone member is as much as 35 feet thick at the outcrop in the southern part of the district, but to the north, where it is overlain by the gypsum-anhydrite member, it is only about 10 feet thick. The limestone member consists of two units of about equal thickness, a lower bedded unit and an upper massive unit that are lithologically and structurally similar to the platy and massive units in the Ambrosia Lake district. The lower, or bedded unit, ranges in thickness from a few feet to as much as 35 feet and probably averages about 10 feet. The massive unit is discontinuous and highly variable in thickness from place to place, but is locally as much as 15 feet thick.

Where the gypsum-anhydrite member is missing, the massive limestone unit and basal sandstone beds of the Summerville Formation in many places are intimately mixed, and thin layers of sandstone and siltstone are tightly folded. These relations suggest flowage after deposition but before consolidation of the sediments (R. H. Moench, written commun., 1963). Brecciation and mixing in the same stratigraphic zone in the Ambrosia Lake district is probably the result of similar flowage. The gypsum-anhydrite member crops out in the Laguna district where it ranges in thickness from 0 to 75 feet. This exposure is the south end of the thick part of the member (pl. 3), which extends northward along the east side of the San Juan Basin.

STRUCTURE

Structures that bear on the occurrence of the uranium deposits in the Ambrosia Lake and Laguna districts were formed during three periods of deformation: (1) Late Jurassic to Early Cretaceous, (2) Late Cretaceous to middle Tertiary, and (3) middle Tertiary to late Tertiary or Quaternary. Most of the uranium deposits in these districts occur in the Todilto Limestone, where they are mostly in, or closely associated with, intraformational folds that formed during the first period of deformation and, thus, are allied with the pre-Dakota folds and pipelike structures. (See page 68). Similar intraformational folds also occur in the Chuska district and in the southern part of the Chama Basin. They also probably formed during the first period of deformation and likewise contain uranium deposits.

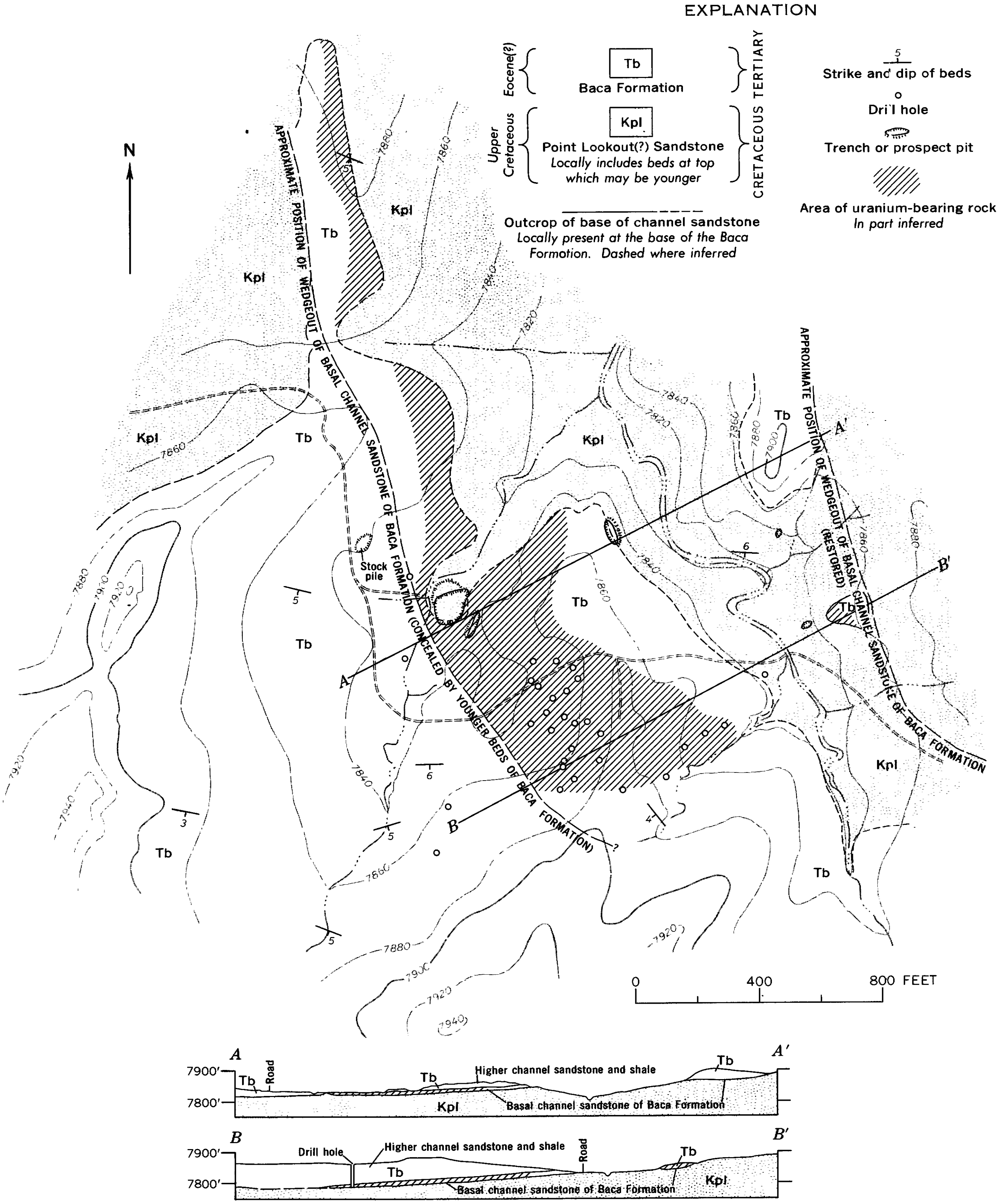


FIGURE 17.—Red Basin claims, NE¼ sec. 19 and NW¼ sec. 20, T. 2 N., R. 10 W. Geology and topography by G. O. Bachman and E. H. Baltz, Jr.; modified from G. O. Bachman, E. H. Baltz, and R. L. Griggs (written commun., 1958).

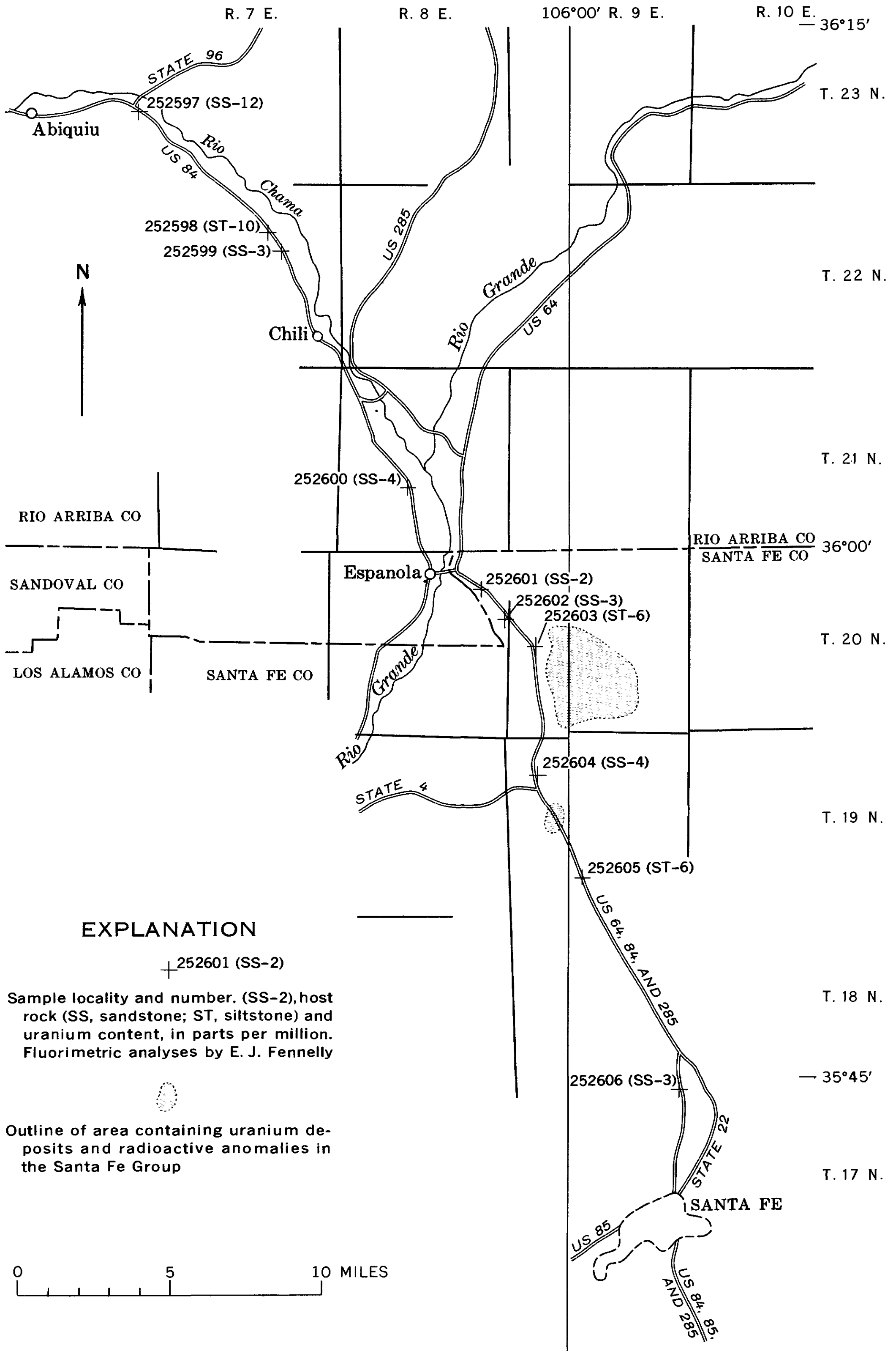


Figure 18.—Sample localities and sample contents of uranium in Santa Fe Group, Rio Arriba and Santa Fe Counties, N. Mex.

Rapaport, Hadfield, and Olson (1952) first described the intraformational folds and dated their development as shortly after deposition of the Todilto sediments. Gabelman (1956b) described some of them in detail and drew similar conclusions regarding the age of their formation, and Hilpert and Moench (1960) described their association and probable contemporaneity with the larger pre-Dakota folds in the Ambrosia Lake and Laguna districts.

The intraformational folds occur in a great variety of shapes, ranging from open and closed anticlines to recumbent folds, chevron folds, and fan folds. They are mostly anticlinal and asymmetric, but some are synclinal, open, and symmetrical. Most of the folds are small, pronounced structural features that have amplitudes generally less than their breadths. The largest have a breadth of as much as 50 feet and an amplitude of about 25 feet and involve the entire thickness of the Todilto and basal part of the overlying Summerville Formation. The smallest are measured in inches or fractions of an inch and commonly bear a drag relation to larger folds. In length the folds range from a few feet to hundreds of feet. They mostly are somewhat sinuous and elongate, but some are rather tortuous in plan or are simply domal.

The folds generally tend to be concentrated or clustered, and in both the Ambrosia Lake and Laguna districts the fold axes in the clusters generally trend eastward or northward. Others show an almost random arrangement.

All the folds are fractured or jointed and some are faulted. The associated faults, however, are almost invariably intraformational and die out within the folds or within the Todilto Limestone and basal part of the Summerville Formation. Many faults are reverse type and closely follow the axial plane of tight or recumbent folds. All the related faults, however, show little displacement, seldom more than a foot or so and generally not more than a few inches.

Most joints are nearly vertical and comprise many sets. The principal set is longitudinal to the folds and probably formed with the folds or shortly after, similar to the intraformational faults. Other subsidiary joints make up an almost random pattern, although in some deposits in the Ambrosia Lake district a minor set is roughly normal to the fold axes. Many of the joints probably formed during later periods of deformation. The complexity of the fold and fracture patterns is illustrated by the structures in the Haystack, Gay Eagle, and Black Hawk deposits (Gabelman, 1956b, figs. 135–137).

In the Laguna district the intraformational folds are localized along the flanks and troughs of broad eastward- and northward-trending pre-Dakota synclines, and the dominant trends of the axes of the intraformational folds are likewise eastward and northward (Moench, 1963c, p. 159). (See fig. 9, this report.)

The Todilto Limestone in the Laguna district is also somewhat thicker in the synclines than on the crests of the adjoining folds. This fact suggests that the intraformational folds formed by flowage down the limbs of the pre-Dakota folds. This flowage apparently occurred under cover in post-Todilto time because the intraformational folds are not truncated by bedding planes.

Similar relations are indicated in the Ambrosia Lake district. Where data are available, particularly where uranium deposits have been mined, the intraformational folds also tend to trend eastward and northward and to make up clusters with similar trends (Gabelman, 1956b, figs. 134–138; Hilpert and Moench, 1960, p. 460–461, fig. 18). The pre-Dakota folds in the overlying rocks likewise trend eastward; others might also trend northward, as in the Laguna district, but more detailed information is needed to determine this.

In the Chuska district small anticlinal intraformational folds occur along a 4-mile strip of outcrop west of Sanostee in the upper part of the Todilto. The largest folds have amplitudes of as much as 2 feet, a width of 3 feet, and a length of 15 feet. Where concentrated or most highly developed they are subparallel, but show no relation to Laramide structures (J. W. Blagbrough, D. A. Thieme, B. J. Archer, Jr., and R. W. Lott, written commun., 1959).

In the south part of the Chama Basin, similar intraformational folds have been noted in the Todilto Limestone at the outcrop south and east of Coyote. Some of these folds have amplitudes of as much as several feet and widths of as much as 25 or 30 feet, but their lengths and trends are not known.

Structural features that formed principally during the second period of deformation in the Ambrosia Lake district consist of the Chaco slope or homocline, west flank of the McCartys syncline, a set of fractures and folds that range in trend from northeast to north, and some domal and anticlinal structures. (See p. 61–62). In the Laguna district they consist of the east limb of the McCartys syncline, a north-trending faulted monocline, and a set of faults and fractures that were intruded in many places by diabasic dikes and sills. (See p. 72).

MINERALOGY AND FORM

Mineralogy of the uranium deposits in the Todilto Limestone has been partly described by Rapaport, Hadfield, and Olson, (1952, p. 9–12), Laverty and Gross (1956, p. 200), and Truesdell and Weeks (1960), and has been summarized by Granger (1963, p. 33–35) and by McLaughlin (1963, p. 140).

The deposits in the Todilto differ from the ones in sandstone principally in their relative sparseness of metallic sulfide minerals and in the occurrence of fluorite.

Unoxidized minerals that have been identified are uraninite, coffinite, paramontroseite, haggite, fluorite, pyrite, marcasite, and galena. Barite, specular hematite, vanadium clay, and recrystallized calcite are closely associated with these minerals and probably are also primary.

Uraninite is more abundant than coffinite and occurs as colloform coatings on grain boundaries, as veinlets in limestone, and as replacements of the limestone grains along bedding planes and along the walls of veinlets. Coffinite at least locally coats uraninite and fills shrinkage cracks in uraninite.

The formation of haggite, paramontroseite, and vanadium clay generally preceded that of uraninite. The haggite occurs as fine blades and fibers along grain boundaries and solution channels in limestone, and some as intergrowths with paramontroseite. The vanadium clay in some places forms irregular spherical aggregates.

Fluorite has been observed in several deposits and likely is a constituent of most of them. It generally is purple and occurs as a fine-grained replacement of the limestone along bedding surfaces, as veinlets, and locally as irregular replacements of limestone that form masses as much as 6 inches in diameter. The fluorite generally is closely associated with and in places is replaced by uraninite.

Pyrite, marcasite, and galena are the only sulfide minerals identified in the deposits in the Todilto. Pyrite occurs as an early mineral which is generally corroded and replaced by later minerals but is most abundant as a late mineral which fills solution cavities and fractures and which replaces detrital grains. Marcasite has been identified only as a late mineral. Galena occurs as fine-grained cubes deposited with and after uraninite and coffinite and as a replacement of early pyrite and haggite.

Coarse-grained calcite occurs along bedding planes, fractures, and solution cavities as a replacement of limestone or as recrystallized limestone in and near the uranimum deposits. The coarse-grained calcite is both earlier and later than most other minerals.

Fine-grained hematite occurs in most of the deposits and generally is associated with the uraniferous zones. Specular hematite has been noted with vanadium clay. Hematite also occurs as pseudomorphs after pyrite and as stains along fractures and bedding planes in oxidized zones.

Barite occurs in most deposits as a resinous yellow to clove-brown tabular mineral that lines solution cavities and forms veinlets or irregular globelike replacements of coarse-grained calcite or local disseminations along the bedding.

Most of the deposits in the Todilto occur at or near the surface and so have been subjected to oxidation which has led to the rather widespread occurrence of the conspicuous yellow and green secondary minerals tyuyamunite, metatyuyamunite, uranophane, and probably sklodowskite. Less common secondary minerals are carnotite, cuprosklodowskite, gummite, santafeite, liebigite, and various oxides of manganese and iron. Also, the dark-olive green fibrous vanadyl vanadate, grantsite, was identified in the F-33 mine (Weeks and others, 1961) and probably occurs in other deposits in the Todilto.

Early field-examination reports generally mentioned carnotite as a constituent of most deposits and created the impression that the mineral was one of the more common ones. Most of the reported occurrences, however, were probably tyuyamunite, which is more likely to form in limestone in which calcium is in excess of sodium. Tyuyamunite and carnotite are both canary yellow and difficult to distinguish in the field.

Uranium deposits in the Todilto are roughly tabular bodies having an irregular form similar to the forms of the deposits in sandstone. Most of them occur along the flanks of the folds and some along the fold axes roughly parallel to the bedding, but locally the deposits cut across the bedding. Many of them are near the base of the Todilto, but others are near the middle or top, and a few occupy the entire limestone interval. Many are not confined to the limestone, but extend a few inches and in some places several feet into the underlying Entrada Sandstone, and in many deposits as much as several feet into the overlying siltstone of ths Summerville Formation. A few deposits are mostly, or entirely, in the basal part of the Summerville or top of the Entrada Sandstone. Although these deposits have a relationship to bedding that is similar to that of deposits in other sandstones, they are dissimilar in their association with folds in the overlying or underlying Todilto Limestone.

Dimensions of the deposits in the Todilto range from a few feet in width and length to several hundred feet in width and more than 1,000 feet in length, and in thickness from mere seems to as much as 20 feet. They probably average a few tens of feet in width, a hundred feet or so in length, and about 10 feet in thickness.

The largest deposits occur where the folds in the limestone are clustered and have a similar trend. Because of the clustering, the deposits associated with individual folds interconnect or merge into relatively large masses that in some places are rather irregular or oblong, such as the Haystack (Gabelman, 1956b, figs. 133, 135) and Flat Top 4-Vilatie Hyde deposits. Others merge and interconnect to form stringlike masses having a length many times their width, such as the F-33 (Hilpert and Moench, 1960, fig. 18), the Faith (McLaughlin, 1963, fig. 6), and the Section 25. The dominant trends of these masses are eastward or northward, similar to the trends of the intraformational folds, but many are heterogeneous.

Ore bodies generally constitute the central parts of the deposits where the deposits are thicker and higher in grade. Away from ore, the deposits feather out or grade into barren host rock along rather irregular or vaguely defined zones. Ore bodies range from masses with dimensions of only a few feet that contain several tons of ore to masses that are hundreds of feet wide, more than 1,000 feet long, and several feet thick, and contain as much as 100,000 tons of ore. Most ore bodies, however, average about 25 feet in width, 100 feet in length, and 5–7 feet in thickness, and contain about 1,000 tons of ore. McLaughlin's (1963, fig. 6) map of the Faith deposit is a good example of the general relations of ore to mineralized ground.

Grade of the ore ranges from 0.10 U_3O_8 to at least 10.0 percent U_3O_8.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS

Uranium deposits in the Todilto Limestone show no direct relation to the stratigraphy of the formation but possibly are indirectly related to the gypsum-anhydrite member and probably are indirectly related to the original thickness of the limestone member.

From place to place the deposits occur at the base, middle, top, or throughout the limestone member and, in many places, extend into the top of the underlying Entrada Sandstone or base of the overlying Summerville Formation. No known deposits occur in the gypsum-anhydrite member, but all the principal deposits are near its outcrop. (See pl. 3.) This position of the deposits in relation to the member probably stems from chance exposure, but for some unknown physical or chemical reason, the gypsum-anhydrite member may have influenced the emplacement of the deposits near its margin.

Near the principal deposits the limestone member is about 15–25 feet thick (pl. 3). Elsewhere it is generally less than 15 feet thick. This occurrence of deposits near thicker limestone may also be a result of fortuitous exposure—the Todilto Limestone has been explored at most only a few miles from the outcrop—but more probably it expresses some relation of the deposits to the original thickness of the limestone.

STRUCTURAL RELATIONS OF THE DEPOSITS

Primary uranium deposits in the Todilto were directly controlled by structures that resulted from the first period of deformation (Late Jurassic to Early Cretaceous), but show few effects, except secondary ones, from later deformation.

The deposits are closely related to intraformational folds in the limestone and these folds are related to broader open folds in the Jurassic rocks, which are dated as post-Todilto and pre-Dakota. The deposits are postsyngenetic because they cross the limestone bedding (fig. 19), and are postintraformational folding because they transect the intraformational folds (Gabelman, 1956b, fig. 136, cross section *L–K*) and at least locally transect the broader pre-Dakota folds (Hilpert and Moench, 1960, p. 458, fig. 15; Moench, 1963c, p. 163–164).

The original thickness of the limestone (see above) probably had a direct bearing on the localization and development of the intraformational folds. Confinement of the folds largely within the limestone indicates its relative incompetence; it should follow that where the limestone is thickest it would have a tendency to absorb a greater percentage of the stresses exerted on the rock column. Thus, the degree of deformation expressed by the folds would most likely be a direct result of the original thickness of the limestone member. The deposits are directly related to the folds and generally to their degree or intensity of development: thus they are indirectly related to the original thickness of the limestone.

No convincing evidence supports the possibility that localization of the primary deposits was influenced by the second (Late Cretaceous to middle Tertiary) or third (middle Tertiary to late Tertiary or Quaternary) periods of deformation. Present information indicates that the oldest structural features resulting from these periods of deformation are the faults and folds that formed contemporaneously with the development of the McCartys syncline. As indicated above, the syncline and the associated smaller features probably formed during development of the Zuni and Lucero uplifts and the Acoma sag, and probably prior to the northward tilting of the San Juan Basin (pre-San Jose, or pre-early Eocene time).

In the Ambrosia Lake district, deposits do not occupy fault zones except for the intraformational faults within the Todilto Limestone. Where faults

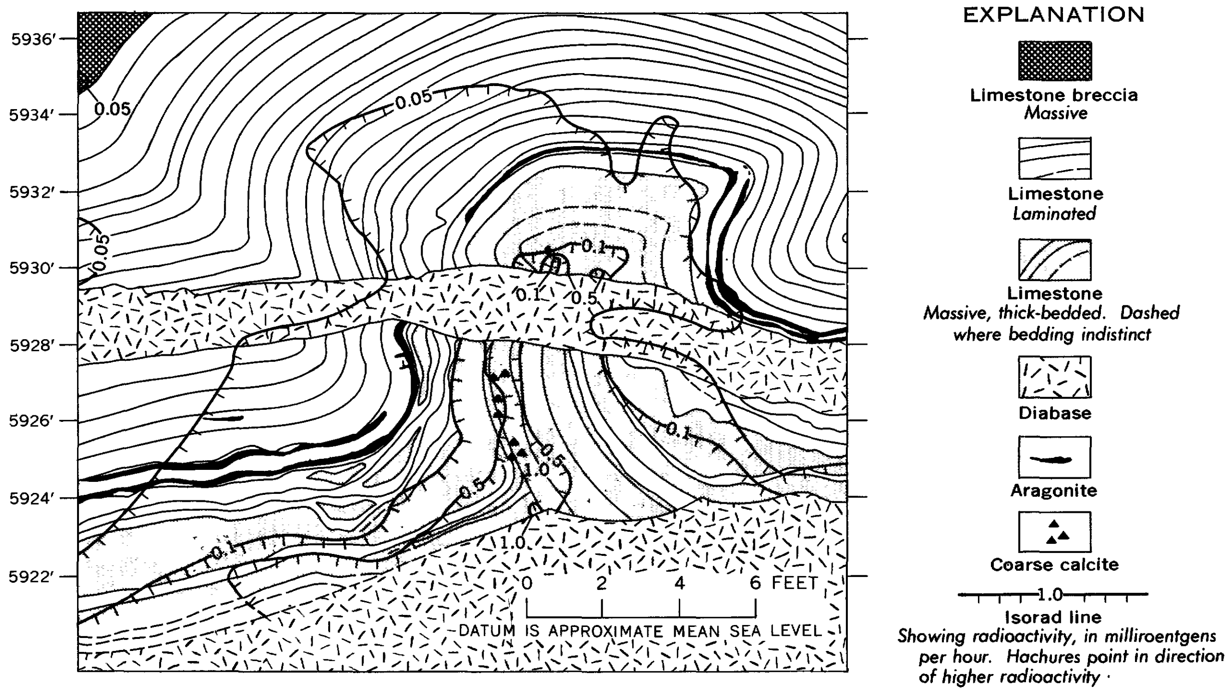


FIGURE 19.—Geologic section across uranium deposit in Todilto Limestone, showing displacement by diabase intrusive, Sandy mine area. Geology by Frank Hensley.

intersect deposits, the deposits are displaced and therefore must be older.

Gabelman (1956b, p. 391–392, fig. 132), however, implied that the deposits may be younger than the faults and folds by noting that the deposits occur within the area of strongest faulting and along the axes of northeastward-trending folds, both of which are on the flank of the Zuni uplift and within the sharpest bend of the strike of the Thoreau homocline (meaning the bend of the Chaco slope southeastward around the Zuni uplift and southward along the west flank of the McCartys syncline).

Gabelman's northeastward-trending folds probably are related to the subparallel faults (see p. 61), and both probably are the same age. Because the faults displace the deposits, both the folds and the faults must be younger than the deposits and could not have influenced their emplacement.

The oldest recognizable structural features that are certainly younger than the deposits are the fractures in the Laguna district that formed contemporaneously with the Rio Grande trough during the third period of deformation. These fractures are intruded by diabasic dikes and sills which, in turn, are broken by the same set of fractures, a relation that indicates their contemporaneity. The deposits show no relation to the fractures, and the diabasic intrusives displace and metamorphose the uranium deposits (Moench, 1962; 1963c, p. 161) (fig. 19). These facts demonstrate that the deposits are clearly older than the fractures and the intrusives.

Field relations indicate the fractures and intrusives probably formed mostly in middle to late Tertiary time, and probably prior to the Mount Taylor eruptions. Inclusions of the diabase were found in a volcanic pipe that probably supplied one of the earliest basaltic flows (Hilpert and Moench, 1960, p. 444). The fact that these flows were extruded during the latest stages of the Mount Taylor eruptions indicates the diabasic rocks are at least older than what may be the oldest basaltic flows. Because the entire sequence of Mount Taylor probably formed during an eruptive cycle, a relatively short period of time, the diabasic intrusions probably took place before the Mount Taylor cycle, as well as before the basaltic extrusions. Conclusions are that the deposits are older than any of the intrusive igneous rocks within the Laguna and Ambrosia Lake districts and that their emplacement could not have been influenced by them.

PENECONCORDANT DEPOSITS IN SHALE AND COAL

Deposits in shale and coal are quite similar in mineralogy and form to those in sandstone and, in some instances, where they occur in nearly equal proportions in both rock types, are classified rather arbitrarily. The host rocks, however, are different, so the deposits are separated for descriptive purposes. The deposits occur in shale and coal of Permian, Cretaceous, and Tertiary ages; undoubtedly others have been arbitrarily included with the deposits in sandstone, through lack of information. The deposits occur around the periphery of the San Juan Basin in seven stratigraphic units and four counties, as follows:

Stratigraphic unit	Number of deposits or clusters of deposits	County
San Jose Formation	1	Rio Arriba.
Menefee Formation	2	Sandoval.
Point Lookout Sandstone	1	Do.
Crevasse Canyon Formation	4	McKinley.
Gallup Sandstone	1	San Juan.
Dakota Sandstone	3	Sandoval.
Do	2	McKinley.
Abo Formation	1	Sandoval.

Nine of the deposits are principally in carbonaceous shale, five are in low-grade coal or peat, and one is in mudstone, which can be considered the same as shale. Three of the deposits have been mined: the Butler Bros. 1 in northwestern Sandoval County and the Hogback 3 and 4, and the Santa Fe Christ in southwestern McKinley County. These deposits, which are in the Dakota Sandstone, yielded 6,497 tons of ore that averaged 0.20 percent U_3O_8 during the 1952–60 period. Of this material, 4,438 tons averaged 0.03 percent V_2O_5 and 2,434 tons averaged 0.7 percent lime. Among the three properties, the ores ranged from 0.17 to 0.63 percent U_3O_8, 0.03 to 0.12 percent V_2O_5, and 0.5 to 5.2 percent lime. Undoubtedly some inclusion of sandstone ore in shipments caused the higher lime values and probably the higher vanadium values. The average ratio of uranium to vanadium, in the 4,438 tons of material for which there are data, was 10:1.

MINERALOGY AND HABITS

Uranium minerals are not visible in the deposits, and few identifications have been attempted in the laboratory. Nearly all deposits have been reported only as radioactive zones or anomalies. Exceptions are the Deer Creek deposit in the Abo Formation, reported as an occurrence of a yellow-green uranium mineral associated with various copper sulfides and carbonates, and the State lease deposit in the San Jose Formation, reported as autunite (?) coatings on bedding and fracture surfaces of mudstone. The uranium in most of the deposits, however, probably occurs as coffinite or uraninite. Gruner (in Bachman and others, 1959, p. 302) identified coffinite in coal in the North or South Butte deposit of La Ventana Mesa, Vine (1962, p. 150) reported uraninite and coffinite in lignitic shale samples from South Dakota, and Nekrasova (1958) identified pitchblende (uraninite) as the principal primary mineral in some Russian coals. In the fine-grained highly carbonaceous materials like coal and carbonaceous shale these low-valent minerals are likely protected from oxidizing solutions by the low permeability of the shales and coals. The minerals also are protected from oxidation by the reducing effects of organic material. In the Cave Hills and Slim Buttes areas of northwestern South Dakota, autunite, zeunerite, torbernite, and metatyuyamunite have been identified in lignite and carbonaceous sandstone (Denson and others, 1959, p. 28). This suite is essentially the same as the high-valent secondary uranium minerals that are found in the sandstone deposits, where the minerals are obviously derived from coffinite or uraninite.

Deposits in shale and coal generally are smaller and thinner and tend to be more tabular than the ones in sandstone, and they tend to occur in single rather than multiple layers. They range in size from small layers, an inch or so thick and a few feet long, to masses, as much as 10 feet or more thick and more than 1,000 feet long. The general configuration of many deposits is not known, as they have been observed only at outcrop. They probably, however, are mostly crudely equidimensional in plan, as suggested by their close association with carbonaceous beds or shale lenses and the general absence of bedding structures such as crossbeds and cut-and-fill features that cause the elongation of the deposits in sandstone. The largest deposit or cluster of deposits is at North Butte in the La Ventana Mesa area, where as much as several hundred thousand tons of material, generally containing more than 0.02 percent uranium, forms a crudely tabular mass that ranges in thickness from about 1 foot to 4 feet and that averages about 1½ feet (Bachman and others, 1959; J. D. Vine, G. O. Bachman, C. B. Read, and G. W. Moore, written commun., 1953). The uranium is mostly in impure coal and is partly in carbonaceous shale and sandstone.

STRATIGRAPHIC AND STRUCTURAL RELATIONS

Nearly all the known deposits occur at or near the base of sandstone units and above shale, claystone, or mudstone units. A few occur at or near the top of sandstone units. Sedimentary structural features seem to have little effect on most of the deposits, although some bedding planes or seams show local control. Mirsky (1953) noted that the Hogback 3 and 4 deposit was underlain by a channel type sandstone that thinned southward, presumably away from the deposit.

Tectonic structures influence the deposits locally. The Butler deposit occurs in the hogback about 1 mile west of the Nacimiento thrust fault where the Dakota and adjacent formations are offset along a northward-trending high-angle normal fault of uncertain age. The deposit is in a peat bed at the base of the Dakota and is confined east of the normal fault, which is unmineralized (Gabelman, 1956a, p. 310–312). If the fault is related to the Nacimiento thrust it could be as old as Paleocene; however, it could be related to faulting in the Rio Grande trough and be as young as Pliocene (Wood and others, 1946). Because the deposit terminates downdip against the fault, it may have been emplaced against the fault barrier after Tertiary tilting (Gabelman, 1956a).

In La Ventana Mesa the deposits are controlled by several structural features, as noted by Bachman, Vine, Read, and Moore (1959, p. 300–301). The fact that the two largest deposits are near the axis of the La Ventana syncline suggests that the deposits may have been controlled by the syncline during emplacement. In addition, local tent-shaped thickenings of sandstone beds at the top of the uranium-bearing zone, minor synclinal crenualtions within the zone, and joints in the overlying La Ventana Tongue of the Cliff House Sandstone all locally control uranium concentrations. The tent-shaped structures are thought to have formed by plastic deformation and the synclinal structures by flowage of the incompetent coaly or shaly material under indurated sandstone units. Joint control of the uranium is shown by the downdip concentrations below the joints and uranium-bearing opal found on a joint surface. Age of these structures and their mineralization is uncertain. The La Ventana syncline is related to the deformation that caused the San Juan Basin, so could range in age from Late Cretaceous to late Tertiary, but the fact that the syncline occupies a structural position on the flank of the San Juan Basin that is similar to the monoclinal folds would more likely indicate the age of the folds to be Late Cretaceous or early Tertiary. The joints formed after the beds consolidated, perhaps in early Tertiary time. The deposits postdate these structures, so probably are post-early Tertiary.

Stratigraphic and structural evidence indicates that the deposits were derived from descending solutions. The deposits tend to concentrate in the uppermost bed of coal or carbonaceous material; stratigraphically lower carbonaceous beds are practically barren; and there is little evidence that the mineralized areas are associated with faults. The uranium may have been derived by downward leaching from the Bandelier Tuff (Smith, 1938), of Pleistocene age—as postulated by Bachman, Vine, Read, and Moore (1959)—a wide spread unit in the Jemez Mountains to the east. (See pl. 1.) The tuff contains an average of 0.003 percent uranium and may have formerly extended over the La Ventana Mesa area. It is an ash-flow unit, however, and more likely was confined east of the Sierra Nacimiento divide, which is higher than the general surface of the Bandelier Tuff. The uranium, therefore, was probably leached from the overlying La Ventana Tongue. If so, the leaching and emplacement must have taken place in late Tertiary and Quaternary time, after uplift and removal of the younger and relatively impervious Lewis Shale.

Many of the other deposits in shale and coal could be youthful, as suggested by their occurrence at outcrop and their possible association with the Recent cycle of weathering. This Recent age is uncertain, however, and at least some deposits such as the Hogback 3 and 4, could be much older than Recent. The Hogback 3 and 4 and others, such as the Diamond 2 and Becenti, which occur in sandstone, are found at or near the outcrop of the Nutria monocline. If this monocline influenced emplacement of the deposits, as indicated by the structural relations of the Diamond 2 (see p. 92), the deposits may be as old as Late Cretaceous.

VEIN DEPOSITS

About two dozen vein deposits in sedimentary, igneous, and metamorphic rocks in northwestern New Mexico are listed on plate 1. They comprise fracture fillings, stockworks, mineralized breccia, and fillings or disseminations of uranium minerals in pegmatite bodies. All are in or along the flanks of the Rio Grande trough, but those in metamorphic rocks and in pipelike structures are older than the trough structures and not related to them.

Several mineralized pipes also occur in the Ambrosia Lake and Laguna districts, but they constitute parts of peneconcordant deposits in sandstone. Pipe structures in the Cliffside, Doris 1, and Jackpile deposits probably yielded several thousand tons of ore, but the exact tonnage and grade are not known.

Seven of the listed vein deposits yielded about 25,000 tons of ore during 1954–64, the productive period. Ninety-five percent of this ore was produced by the La Bajada, Charley 2, and Woodrow mines. The Woodrow yielded the highest grade ore, which annually ranged from 0.32 to 1.70 percent U_3O_8 and averaged 1.26 percent U_3O_8. This ore averaged 0.04 percent V_2O_5; the La Bajada ore averaged 0.04 percent, and the Charley 2 ore averaged 0.03 percent. The other deposits ranged from 0.10 to 0.38 percent V_2O_5, and had average U:V ratios that ranged from 2:1 to 1:1, similar to most of the peneconcordant deposits.

For descriptive purposes, the vein deposits are classified according to their occurrences in sedimentary, igneous, and metamorphic rocks, and the general mineralogy, habits, and stratigraphic and structural relations of each type are summarized below.

DEPOSITS IN SEDIMENTARY ROCKS

MINERALOGY AND HABITS

Eight vein deposits are listed in sedimentary rocks: the Agua Torres and Marie in the Madera Limestone; the Lucky Don, Little Davie, and Sonora in the San Andres Limestone; the Woodrow in the Morrison Formation; and the Charley 2 and Silver Creek prospect in the Popotosa Formation. The uranium in all except the Woodrow is mostly in the yellow uranyl vanadates autunite, meta-autunite, and metatorbernite (?), which occur as coatings on fracture faces and bedding planes, as fillings in open spaces, and as disseminations in the host rock. At the Silver Creek prospect, the uranium minerals are associated with copper oxides, and at the Sonora prospect they are probably associated with copper and lead, and possibly silver and nickel minerals. Mineralogy of the Woodrow deposit is similar to that of other deposits in the Morrison Formation of the Laguna district, except that some of the principal ore mineral is coarse-grained coffinite and the deposit contains a much higher grade of uranium as well as of sulfides of associated metals.

Host rocks of these deposits generally show alteration effects similar to those of the host rocks of the peneconcordant deposits. The Charley 2 may be an exception, in that the deposit is overlain by a hanging wall of sheared clay and is on a footwall of altered granitic rock (P. K. Knowles, written commun., 1957). Most of the deposits are small and irregular in form, and range from breccia fillings along fault zones (such as the Woodrow and Agua Torres) to crudely tabular disseminated masses in the hanging wall or footwall of faults (such as in the Charley 2 and Lucky Don).

STRATIGRAPHIC AND STRUCTURAL RELATIONS

Most of the known deposits are surficial and, at most, extend a few tens of feet below the surface. The Woodrow, however, extends at least 240 feet below the surface, below which it has not been explored.

Host rocks of these deposits are either sandy or shaly limestone or sandstone ranging in age from Pennsylvanian to Tertiary. The limestone generally is broken or brecciated, and the sandstone is fractured and locally crushed and sheared. All the deposits except the Woodrow are associated with fractures that probably formed contemporaneously with the development of the Rio Grande trough and are middle Tertiary or younger in age. Fracture control of the mineralization, therefore, indicates that the deposits were emplaced during or after formation of the trough structures.

DEPOSITS IN IGNEOUS ROCKS

MINERALOGY, HABITS, AND STRUCTURAL RELATIONS

Eight deposits are listed in igneous rocks: the La Bajada in the Espinaso Volcanics of Stearns (1943); the Cerro Colorado, at the contact of a rhyolitic intrusive with trachyte flows; and the Mimi 4, Hiser-Moore, Peralta Canyon, "Shaft" prospect, and the two Carter-Tolliver-Cook deposits, all of which occur in various sills, flows, and other intrusives of felsic and mafic composition. Of these deposits, only the La Bajada has been productive.

Most of the deposits are probably surficial, and consist of fracture or joint fillings or coatings of the uranium minerals autunite, torbernite, uranophane, and carnotite (?), and various other associated minerals. The "Shaft" occurrence contains torbernite (?) and carnotite (?) associated with secondary copper minerals, calcite, and quartz; the Carter-Tolliver-Cook deposits contain carnotite and uranophane associated with galena, pyrite, and chalcopyrite. The uranium minerals in these deposits may be coatings derived from the recent cycle of circulating ground waters, or they may be secondary after earlier primary minerals, such as uraninite. The La Bajada, and probably the Cerro Colorado, however, more certainly are older and are related to igneous intrusions.

The La Bajada consists of a complex network of thin sulfide mineral veins in a mafic dike and an impregnation of fine-grained sulfide minerals in the brecciated footwall of the dike where it is altered to clay. Some of the uranium occurs in tyuyamunite, but it may principally be in fine-grained uraninite. Except for pyrite, the sulfide minerals have not been identified, but they probably represent sulfides of several metals; for example, one pulp sample of the ore contained about 1.5 percent copper, 0.3 percent nickel, 0.13 percent arsenic, and 18.4 percent sulfur.

The size of the deposit is uncertain, but it must be at least several hundred feet deep, several tens of feet wide, and probably a little more than 200 feet long, as indicated by a vertical shaft and an open pit. The deposit is one the west side of the Cerrillos Hills district, and probably is related to the base-metals mineralization of the district and to intrusives considered to be Oligocene in age. (See p. 30–31.) The La Bajada deposit is emplaced in the Espinaso Volcanics, considered to be Oligocene(?) in age by Disbrow and Stoll (1957, p. 10–12, 33). Mineralization of the La Bajada deposit probably closely followed emplacement of the Espinaso Volcanics, and therefore may be Oligocene in age.

The Cerro Colorado deposits consist of several prospects in which unidentified yellow and yellow-green uranium minerals coat limonite-stained fractures and brecciated pockets along the contact of a rhyolitic intrusive body with trachytic flows. The uranium is probably genetically related to the rhyolitic intrusive. It is radioactive at the surface, and vertical fractures within it are roughly 10 times as radioactive as other parts of the volcanic body. Because the rhyolitic rocks intrude the Santa Fe Group, their age can be determined as late Tertiary or possibly Quaternary, which indicates a late Tertiary or Quaternary age for the uranium mineralization.

DEPOSITS IN METAMORPHIC ROCKS

MINERALOGY, HABITS, AND STRUCTURAL RELATIONS

At least seven deposits are listed in metamorphic rocks, of which four are in quartz-microcline pegmatite bodies, two are in crosscutting veins, and one or more possibly are in quartz veins. All are in the Ortega Quartzite of Just (1937), and most of them are in the Petaca Schist [Member] of the Ortega or in schistose quartzite.

In the pegmatite bodies, the uranium minerals occur as sparsely disseminated crystals of dull fine-grained masses of samarskite and uraninite and as thin coatings of gummite, autunite, and sabugalite. They are associated with purple or green fluorite, bismutite, monazite, columbite and other columbate-tantalates, ilmenite, magnetite, molybdenite, and garnet.

Deposits in veins consist of sparse disseminations of autunite, torbernite, and sabugalite in the walls of schist bounding crosscutting veins of purple fluorite; one or more deposits consist of uraniferous quartzite in which the uranium may be associated with quartz veins. A crystal of uraninite was reportedly found in the vicinity of the uraniferous quartzite (P. E. Melancon and F. R. Fincher, written commun., 1952), but details of the occurrence are not known.

The pegmatite bodies and the fluorite and quartz veins are thought to be related to the Precambrian Tusas Granite of Just (1937), and are also considered to be Precambrian in age (Jahns, 1946, p. 22–25).

DISTRIBUTION OF ELEMENTS IN THE ORES

PURPOSE AND METHODS OF ANALYSIS

Spectrographic analyses of about 70 elements and chemical analyses of a few selected elements and oxides were obtained from mill pulp samples from the uranium ores of 66 deposits. (See pl. 1 and tables 5, 6.) Radiometric analyses also were obtained routinely to determine whether the ores were in radioactive equilibrium. All analyses were obtained to determine the similarities and differences in the ores as related to stratigraphic position, rock type, tectonic structure, and areal distribution as a means to help classify the deposits geologically and to aid in the appraisal of the uranium resources.

Individually, the samples represent substantial tonnages of ore from the larger deposits and all the ore from the smaller deposits. Each sample generally represents ore mined during the 1951–57 period. One sample (246891, table 6) represents a 10-ton shipment that was substantially below ore grade but is included to provide data on a deposit in limestone in a part of the area that has been unproductive.

If an element or oxide was detected in two or more ore sample groups, the sample data were plotted in graphs (tables 7–9) for comparative purposes. Eight of the twelve most abundant elements in the earth's crust (Fleischer, 1953, p . 3) are shown in table 7. Of the other four elements, oxygen and hydrogen are excluded, phosphorus is not shown because it was undetected, and silicon is not shown because it constituted more than 10 percent of each sample and was not specifically measured. Table 8 lists the minor elements as determined spectrographically, and table 9 lists the data on the elements and oxides as determined chemically. On each table the ore sample groups are listed by host rock, generally from youngest to oldest. Those in the Espinaso Volcanics of Stearns (1943), although older, are listed above the Popotosa Formation so that the groups in Tertiary sandstones can be listed contiguously. The ore groups are broken down to separate the ores by types of host rocks and to flag their associations with the more obvious tectonic structures. The types of host rocks and the tectonic structures are identified by symbols, which are described in the explanations of the tables.

The graphs, which were prepared to give the reader a rapid visual comparison between sample groups, show the ranges in concentration between samples (horizontal bar) and their geometric means (vertical intersection of bar). The geometric means are logarithmic averages which are sample medians on a log scale. These show a better central tendency than arithmetic averages when applied to asymmetric distributions (Krumbein and Pettijohn, 1938, p. 240; Miesch and Riley, 1961, p. 248).

TABLE 5.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from volcanic rocks, sandstone, and shale, northwestern New Mexico*

Italic numbers are mine numbers shown on plate 1. Spectrographic determinations are semiquantitative and were made by the rapid visual comparison method. Comparsons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, 0.15 and are coded as follows: >10=1, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7, 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15, 0.00015=16, 0.00007=17, 0.00003=18, 0.000015=19. Figures reported as less than (<1) are coded: <1.0=a, <0.05=b, <0.02=c, <0.01=d, <0.005=e, <0.002=f, <0.001=g, <0.0005=h, <0.0002=i, <0.00005=j. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (--), not looked for; number enclosed in parentheses is near threshold of detectability; ND, no data

[Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded]

Sample [1]	Name of mine or prospect	Spectrographic [2]																	
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu
	Espinaso Volcanics																		
254107	La Bajada 1 *(1)*	14	3	7	0	0	8	0	0	4	0	9	9	10	------	4	0	0	0
254108	La Bajada 2 *(1)*	16	2	0	0	0	7	0	0	2	0	9	10	10	------	4	0	0	0
	Popotosa Formation																		
229396	Charley 2 *(1)*	(19)	1	0	0	g	8	15	0	5	0	0	12	12	ND	9	0	0	ND
254045	do	0	1	0	0	11	7	15	0	7	0	0	11	12	------	8	0	0	0
	Baca Formation																		
229399	Red Basin 1 *(3)*	(18)	3	0	0	g	5	(17)	0	3	0	0	15	13	ND	12	0	0	ND
	Dakota Sandstone																		
229365	Becenti *(1)*	0	3	0	0	12	10	0	0	6	0	0	14	13	ND	13	0	0	ND
229368	Christian 16 (U) *(2)*	0	3	0	0	12	9	0	0	7	0	0	14	13	ND	12	0	0	ND
229366	Diamond 2 *(3)*	0	4	0	0	13	10	0	0	7	0	0	15	14	ND	13	0	0	ND
254044	do	0	3	0	0	0	10	0	0	7	0	0	14	13	------	9	0	0	0
229364	Hogback 4 *(3)*	0	2	0	0	12	8	16	0	7	0	0	14	12	ND	12	0	0	ND
229367	Silver Spur 5 *(8)*	0	3	0	0	13	9	0	0	5	0	0	15	14	ND	12	0	0	ND
	Morrison Formation																		
229369	Alta *(2)*	0	3	0	0	13	7	(17)	0	3	0	0	15	13	ND	12	0	0	ND
254048	Beacon Hill *(6)*	0	2	0	0	12	7	0	0	3	0	0	13	12	------	11	0	0	0
254040	Begay 1 *(7)*	0	3	0	0	0	9	0	0	2	d	0	14	13	------	11	0	0	0
229372	Blue Peak (Garcia 1) *(10)*	0	3	0	0	g	7	16	0	5	0	0	15	13	ND	12	0	0	ND
245226	Chaves *(18)*	0	3	0	0	12	8	0	0	2	0	0	14	11	------	11	0	0	------
254046	Dysart 1 *(28)*	0	2	0	0	12	7	0	0	2	0	0	14	12	------	11	0	0	0
245225	Enos Johnson 3 *(33)*	0	2	0	0	12	8	16	0	3	0	0	13	13	------	11	0	0	------
229370	Evelyn *(34)*	0	3	0	0	13	8	16	0	5	0	0	13	13	ND	12	0	0	ND
229371	Foutz 1 *(35)*	0	2	0	0	13	7	16	0	3	0	0	14	13	ND	12	0	0	ND
254106	Foutz 3 YJ *(37)*	0	2	0	0	0	8	16	0	6	0	0	g	14	------	11	0	0	0
254036	Francis *(38)*	0	1	0	0	12	7	15	0	5	0	9	12	13	------	11	0	0	0
229373	Jackpile *(43)*	0	4	0	0	13	9	16	0	6	0	0	14	13	ND	12	0	0	ND
254047	Mesa Top 7 *(60)*	0	1	0	0	0	7	16	0	2	0	0	14	13	------	11	0	0	0
254037	Pat *(64)*	0	1	0	0	0	7	0	0	3	0	0	15	13	------	11	0	0	0
229374	Poison Canyon *(66)*	0	3	0	0	g	8	16	0	4	0	0	15	14	ND	12	0	0	ND
254038	Silver Bit 7 *(95)*	0	3	0	0	12	7	15	0	6	0	0	12	11	------	11	0	0	0
254039	Silver Bit 15 *(96)*	0	3	0	0	12	7	15	0	6	0	0	12	13	------	12	0	0	0
229375	Windwhip *(101)*	0	3	0	0	13	8	16	0	6	0	0	15	14	ND	12	0	0	ND
239460	Woodrow *(102)*	15	3	8	0	0	7	Tr.	0	6	0	0	10	13	ND	10	0	0	ND
	Cutler Formation																		
229397	Hillfoot 1 *(1)*	(18)	2	0	0	13	8	16	0	3	0	0	13	12	ND	6	0	0	ND
245224	Red Head 2 *(3)*	0	1	0	0	12	8	15	0	2	0	0	12	11	------	6	0	0	------
229400	Whiteflo	(18)	2	0	0	13	7	(17)	0	1	12	0	13	12	ND	11	0	0	ND

See footnotes at end of table.

TABLE 5.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from volcanic rocks, sandstone, and shale, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued																
		F	Fe	Ga	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn	Mo
Espinaso Volcanics																		
254107	La Bajada 1 (*1*)		2	Tr.	0	12	0	0	0	0	0	4	10	0	0	4	8	10
254108	La Bajada 2 (*1*)		3	Tr.	0	0	0	0	0	0	0	5	10	0	0	3	7	13
Popotosa Formation																		
229396	Charley 2 (*1*)	ND	4	14	0	0	0	0	ND	0	0	3	12	0	ND	6	7	12
254045	do		3	14	0	0	0	0	0	0	0	3	12	0	0	5	6	12
Baca Formation																		
229399	Red Basin 1 (*3*)	ND	4	(15)	0	0	0	0	ND	0	0	3	0	0	ND	6	6	14
Dakota Sandstone																		
229365	Becenti (*1*)	ND	5	i	0	0	0	0	ND	0	0	5	12	0	ND	7	11	12
229368	Christian 16 (U) (*2*)	ND	5	i	0	0	0	0	ND	0	0	4	0	0	ND	7	11	14
229366	Diamond 2 (*3*)	ND	6	i	0	0	0	0	ND	0	0	0	0	0	ND	8	11	14
254044	do		4	0	0	0	0	0	0	0	0	0	0	0	0	8	8	12
229364	Hogback 4 (*3*)	ND	5	13	0	0	0	0	ND	0	0	4	12	0	ND	6	11	13
229367	Silver Spur 5 (*8*)	ND	5	i	0	0	0	0	ND	0	0	4	0	0	ND	8	11	0
Morrison Formation																		
229369	Alta (*2*)	ND	4	i	0	0	0	0	ND	0	0	3	0	0	ND	6	7	12
254048	Beacon Hill (*6*)		3	14	0	0	0	0	0	0	0	3	0	0	0	5	7	8
254040	Begay 1 (*7*)		4	16	0	0	0	0	0	0	0	4	0	0	0	5	8	10
229372	Blue Peak (Garcia 1) (*10*)	ND	4	(15)	0	0	0	0	ND	0	0	3	0	0	ND	6	9	11
245226	Chaves (*18*)		4	Tr.	0	0	0	0	------	0	0	3	0	0	------	5	8	11
254046	Dysart 1 (*28*)		4	15	0	0	0	0	0	0	0	3	0	0	0	7	6	10
245225	Enos Johnson 3 (*33*)		3	14	0	0	0	0	------	0	0	3	0	0	------	4	7	11
229370	Evelyn (*34*)	ND	4	i	0	0	0	0	ND	0	0	3	0	0	ND	6	8	10
229371	Foutz 1 (*35*)	ND	4	(15)	0	0	0	0	ND	0	0	3	12	0	ND	6	7	12
254106	Foutz 3 YJ (*37*)		4	Tr.	0	0	0	0	0	0	0	3	0	0	0	8	10	14
254036	Francis (*38*)		4	14	0	0	0	0	0	0	0	3	10	0	0	6	7	11
229373	Jackpile (*43*)	ND	5	i	0	0	0	0	ND	0	0	4	0	0	ND	6	9	15
254047	Mesa Top 7 (*60*)		4	15	0	0	0	0	0	0	0	3	0	0	0	6	7	8
254037	Pat (*64*)		4	15	0	0	0	0	0	0	0	3	0	0	0	8	8	0
229374	Poison Canyon (*66*)	ND	5	i	0	0	0	0	ND	0	0	3	0	0	ND	7	8	9
254038	Silver Bit 7 (*95*)		4	14	0	0	0	0	0	0	0	3	0	0	0	6	6	14
254039	Silver Bit 15 (*96*)		4	14	0	0	0	0	0	0	0	3	0	0	0	6	6	13
229375	Windwhip (*101*)	ND	5	i	0	0	0	0	ND	0	0	4	0	0	ND	7	9	14
239460	Woodrow (*102*)	ND	2	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	6	9	12
Cutler Formation																		
229397	Hillfoot 1 (*1*)	ND	3	14	0	0	0	0	ND	0	0	3	12	0	ND	4	7	15
245224	Red Head 2 (*3*)		3	12	0	0	0	0	------	0	0	3	11	0	------	3	7	0
229400	Whiteflo	ND	4	15	0	0	0	0	ND	0	0	3	12	0	ND	4	7	11

See footnotes at end of table.

TABLE 5.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from volcanic rocks, sandstone, and shale, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued																
		Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc	Si
Espinaso Volcanics																		
254107	La Bajada 1 (*1*)	6	12	10	6	0	0	13	0	0	0	------	0	0	0	0	13	1
254108	La Bajada 2 (*1*)	5	12	Tr.	9	0	0	13	0	0	0	------	0	0	0	0	12	1
Popotosa Formation																		
229396	Charley 2 (*1*)	4	13	0	12	0	0	11	0	ND	0	ND	0	0	0	0	12	1
254045	do	7	12	0	11	0	0	9	0	0	0	------	0	0	0	0	13	1
Baca Formation																		
229399	Red Basin 1 (*3*)	4	0	0	13	0	0	12	0	ND	0	ND	0	0	0	0	15	1
Dakota Sandstone																		
229365	Becenti (*1*)	7	0	0	(14)	0	0	13	0	ND	0	ND	0	0	0	0	15	1
229368	Christian 16 (U) (*2*)	6	0	0	14	0	0	14	0	ND	0	ND	0	0	0	0	14	1
229366	Diamond 2 (*3*)	9	0	0	13	0	0	0	0	ND	0	ND	0	0	0	0	0	1
254044	do	0	12	0	12	0	0	0	0	0	0	------	0	0	0	0	0	1
229364	Hogback 4 (*3*)	7	0	0	13	0	0	13	0	ND	0	ND	0	0	0	0	13	1
229367	Silver Spur 5 (*8*)	5	0	0	14	0	0	(15)	0	ND	0	ND	0	0	0	0	0	1
Morrison Formation																		
229369	Alta (*2*)	4	0	0	14	0	0	12	0	ND	0	ND	0	0	0	0	15	1
254048	Beacon Hill (*6*)	4	13	0	12	0	0	10	0	0	0	------	0	0	0	0	14	1
254040	Begay 1 (*7*)	6	13	0	13	0	0	11	0	0	0	------	0	0	0	0	0	1
229372	Blue Peak (Garcia 1) (*10*)	4	0	0	14	0	0	12	0	ND	0	ND	0	0	0	0	14	1
245226	Chaves (*18*)	5	0	0	14	0	0	12	0	------	0	------	0	0	0	0	0	1
254046	Dysart 1 (*28*)	4	0	0	11	0	0	11	0	0	0	------	0	0	0	0	0	1
245225	Enos Johnson 3 (*33*)	4	13	0	14	0	0	12	0	------	0	------	0	0	0	0	0	1
229370	Evelyn (*34*)	4	0	0	13	0	0	13	0	ND	0	ND	0	0	0	0	15	1
229371	Foutz 1 (*35*)	4	0	0	13	0	0	10	0	ND	0	ND	0	0	0	0	15	1
254106	Foutz 3 YJ (*37*)	5	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0	1
254036	Francis (*38*)	6	13	10	12	0	0	10	0	0	0	------	0	0	0	0	14	1
229373	Jackpile (*43*)	6	0	0	13	0	0	11	0	ND	0	ND	0	0	0	0	0	1
254047	Mesa Top 7 (*60*)	4	13	0	12	0	0	11	0	0	0	------	0	0	0	0	0	1
254037	Pat (*64*)	4	13	0	13	0	0	13	0	0	0	------	0	0	0	0	0	1
229374	Poison Canyon (*66*)	4	0	0	13	0	0	12	0	ND	0	ND	0	0	0	0	0	1
254038	Silver Bit 7 (*95*)	5	0	0	13	0	0	9	0	0	0	------	0	0	0	0	0	1
254039	Silver Bit 15 (*96*)	5	0	0	13	0	0	10	0	0	0	------	0	0	0	0	0	1
229375	Windwhip (*101*)	7	0	0	13	0	0	12	0	ND	0	ND	0	0	0	0	0	1
239360	Woodrow (*102*)	5	0	0	11	0	0	9	0	ND	0	ND	0	0	0	0	14	1
Cutler Formation																		
229397	Hillfoot 1 (*1*)	3	0	0	12	0	0	11	0	ND	0	ND	0	0	0	0	13	1
245224	Red Head 2 (*3*)	3	13	Tr.	12	0	0	10	0	------	0	------	0	0	0	0	12	1
229400	Whiteflo	3	0	11	13	0	0	7	0	ND	0	ND	0	0	0	0	13	1

See footnotes at end of table.

TABLE 5.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from volcanic rocks, sandstone, and shale, northwestern New Mexico*—Continued

Sample[1]	Name of mine or prospect	Spectographic[2]—Continued																
		Sn	Sr	Sm	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Espinaso Volcanics																		
254107	La Bajada 1 (*1*)	0	8	0	0	0	0	0	5	0	0	7	11	ND	12	15	Tr.	10
254108	La Bajada 2 (*1*)	0	7	0	0	0	0	0	6	0	0	7	10	ND	12	15	0	10
Popotosa Formation																		
229396	Charley 2 (*1*)	0	11	0	0	ND	0	0	5	0	ND	8	10	0	12	15	0	10
254045	do	0	9	0	0	0	0	0	6	0	0	7	10	0	12	f	9	9
Baca Formation																		
229399	Red Basin 1 (*3*)	0	10	0	0	ND	0	0	8	0	ND	7	7	0	11	g	0	10
Dakota Sandstone																		
229365	Becenti (*1*)	0	13	0	0	ND	0	0	7	0	ND	6	9	0	13	g	0	8
229368	Christian 16 (U) (*2*)	0	12	0	0	ND	0	0	7	0	ND	7	9	0	13	g	0	9
229366	Diamond 2 (*3*)	0	16	0	0	ND	0	0	8	0	ND	6	9	0	14	g	0	10
254044	do	0	14	0	0	0	0	0	7	0	0	6	9	0	14	f	0	9
229364	Hogback 4 (*3*)	0	12	0	0	ND	0	0	6	0	ND	7	11	0	12	14	0	10
229367	Silver Spur 5 (*8*)	0	12	0	0	ND	0	0	8	0	ND	6	7	0	14	g	0	11
Morrison Formation																		
229369	Alta (*2*)	0	10	0	0	ND	0	0	7	0	ND	6	8	0	12	g	0	10
254048	Beacon Hill (*6*)	0	10	0	0	0	0	0	6	0	0	5	8	0	13	f	0	9
254040	Begay 1 (*7*)	0	10	0	0	0	0	0	7	0	0	7	5	0	0	f	0	9
229372	Blue Peak (Garcia 1) (*10*)	0	10	0	0	ND	0	0	7	0	ND	7	9	0	13	g	0	10
245226	Chaves (*18*)	0	10	0	0	------	0	0	7	0	------	7	6	0	12	f	0	10
254046	Dysart 1 (*28*)	0	9	0	0	0	0	0	7	0	0	6	8	0	13	f	0	10
245225	Enos Johnson 3 (*33*)	0	9	0	0	------	0	0	7	0	------	7	8	0	12	f	0	11
229370	Evelyn (*34*)	0	11	0	0	ND	0	0	7	0	ND	7	7	0	12	g	0	9
229371	Foutz 1 (*35*)	0	10	0	0	ND	0	0	8	0	ND	6	6	0	12	g	0	11
254106	Foutz 3 YJ (*37*)	0	10	0	0	0	0	0	8	0	0	7	8	0	0	------	0	11
254036	Francis (*38*)	0	10	0	0	0	0	0	6	0	0	6	6	0	10	f	0	10
229373	Jackpile (*43*)	0	12	0	0	ND	0	0	7	0	ND	6	7	0	14	g	0	9
254047	Mesa Top 7 (*60*)	0	9	0	0	0	0	0	6	0	0	6	8	0	13	f	0	9
254037	Pat (*64*)	0	10	0	0	0	0	0	7	0	0	7	7	0	13	f	0	10
229374	Poison Canyon (*66*)	0	10	0	0	ND	0	0	7	0	ND	6	8	0	13	g	0	11
254038	Silver Bit 7 (*95*)	0	10	0	0	0	0	0	7	0	0	5	6	0	13	f	0	10
254039	Silver Bit 15 (*96*)	0	9	0	0	0	0	0	7	0	0	6	6	0	13	f	0	10
229375	Windwhip (*101*)	0	12	0	0	ND	0	0	8	0	ND	6	8	0	12	g	0	10
239460	Woodrow (*102*)	0	10	0	0	ND	0	0	7	Tr.	ND	4	10	0	12	g	0	10
Cutler Formation																		
229397	Hillfoot 1 (*1*)	0	10	0	0	ND	0	0	6	0	ND	7	8	0	12	g	0	10
245224	Red Head 2 (*3*)	0	9	0	0	------	0	0	6	0	------	7	7	0	11	14	0	10
229400	Whiteflo	0	10	0	0	ND	0	0	7	0	ND	8	7	0	11	g	8	11

See footnotes at end of table.

TABLE 5.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from volcanic rocks, sandstone, and shale, northwestern New Mexico*—Continued

Sample[1]	Name of mine or prospect[2]	Radiometric	Chemical							
		eU[3]	U[4]	V_2O_5[5]	S[6]	C[7] (organic)	As[8]	F[9]	Se[10]	Zn[11]
		Percent					Parts per million			
				Espinaso Volcanics						
254107	La Bajada 1 (*1*)	0.13	0.16	<0.05	18.4		1,300	480	<0.5	200
254108	La Bajada 2 (*1*)	.11	.12	<.05	.86		100		<.5	70
				Popotosa Formation						
229396	Charley 2 (*1*)	0.11	0.10				40		1	100
254045	do	.15	.17	0.05	0.11	0.3	30	920	25	280
				Baca Formation						
229399	Red Basin 1 (*3*)	0.28	0.14				30		5	50
				Dakota Formation						
229365	Becenti (*1*)	0.16	0.21				60		18	50
229368	Christian 16 (U) (*2*)	.12	.12				50		250	10
229366	Diamond 2 (*3*)	.13	.16				40		4	20
254044	do	.14	.16	0.05	0.10	1.4	22	<20	75	10
229364	Hogback 4 (*3*)	.15	.18				10		75	50
229367	Silver Spur 5 (*8*)	.14	.18				40		3	10
				Morrison Formation						
229369	Alta (*2*)	0.18	0.20				60		625	20
254048	Beacon Hill (*6*)	.41	.50	0.21	1.30	0.8	92	230	500	70
254040	Begay 1 (7)	.16	.19	2.24	.15	<.3	35	<20	100	10
229372	Blue Peak (Garcia 1) (*10*)	.11	.12				20		150	20
245226	Chaves (*18*)	.14	.20	.56	.49		83	90	50	21
254046	Dysart 1 (*28*)	.21	.24	.10	.58	<.3	26	210	100	20
245225	Enos Johnson 3 (*33*)	.15	.18	.17	.16		19	40	50	39
229370	Evelyn (*34*)	.13	.15				250		125	40
229371	Foutz 1 (*35*)	.23	.27				150		100	40
254106	Foutz 3 YJ (*37*)	.16	.17	.24	.12		34	50	25	10
254036	Francis (*38*)	.32	.35	.86	.09	.4	85		100	60
229373	Jackpile (*43*)	.33	.31				20		1	20
254047	Mesa Top 7 (*60*)	.16	.17	.13	.70	.5	46	170	125	30
254037	Pat (*64*)	.10	.10	.16	.18	<.3	14		2	10
229374	Poison Canyon (*66*)	.25	.20				50		250	20
254038	Silver Bit 7 (*95*)	.85	.96	1.28		.3	24		12	50
254039	Silver Bit 15 (*96*)	.29	.35	.65		.3	16		4	60
229375	Windwhip (*101*)	.26	.28				20		18	10
239460	Woodrow (*102*)	.87	1.16		6.64		890	220	8	35
				Cutler Formation						
229397	Hillfoot 1 (*1*)	0.10	0.12	ND	ND	ND	50	ND	4	70
245224	Red Head 2 (*3*)	.13	.13	5	.07	ND	65	320	<.5	87
229400	Whiteflo	.07	.06	ND	ND	ND	50	ND	10	1,000

---

[1] Spectrographic analyses, chemical analyses for As, Se, U, and Zn, and radiometric analyses for U for samples 229364–229375 and 229396–229400 inclusive requested by A. T. Miesch.

[2] Analyses of samples 245224–245226 and 254106–254108 inclusive by N. M. Conklin; others by R. G. Havens.

[3] Analysts: C. G. Angelo and others under the direction of L. F. Rader, Jr.

[4] Analysts: R. P. Cox, E. J. Fennelly, H. H. Lipp, J. S. Wahlberg, and others under the direction of L. F. Rader, Jr. Fluorimetric method.

[5] Analysts: H. H. Lipp and others under the direction of L. F. Rader, Jr. Volumetric method.

[6] Analysts: G. T. Burrow, E. C. Mallory, and others under the direction of L. F. Rader, Jr. Gravimetric method.

[7] Analysts: E. J. Fennelly and Wayne Mountjoy. Rapid scanning, CO_2 method.

[8] Analysts: R. R. Beins, H. E. Crowe, W. D. Goss, Claude Huffman, J. P. Schuch, and others under the direction of L. F. Rader, Jr. Colorimetric method.

[9] Analysts: R. P. Cox, W. D. Goss, and L. F. Rader, Jr. Colorimetric method.

[10] Analysts: G. T. Burrow and others under the direction of L. F. Rader, Jr. Colorimetric method.

[11] Analysts: R. R. Beins, G. T. Burrow, H. E. Crowe, Claude Huffman, J. S. Wahlberg, and others under the direction of L. F. Rader, Jr., Colorimetric method.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*

Material within brackets is descriptive, not part of mine name. Italic numbers are mine numbers shown on plate 1. Spectrographic determinations are semiquantitative and were made by the rapid visual comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, 0.15, and are coded as follows: >10=1, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7, 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15. Figures reported as less than (<) are coded: <1.0=a, <0.05=b, <0.02=c, <0.005=d, <0.002=e, <0.001=f, <0.0005=g, <0.0002=h, <0.00005=i. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (----), not looked for; number enclosed in parentheses is near threshold of detectability; ND, no data

[Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded]

Sample[1]	Name of mine or prospect	Spectrographic[2]																
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
	Ore in the Todilto Limestone																	
256424	Barbara J 1 (*1*)	0	3	0	0	0	9	0	0	1	0	b	14	13	......	12	0	0
256425	Billy The Kid (*3*)	0	4	0	0	0	9	0	0	1	0	b	15	14	......	12	0	0
256426	Black Hawk (*4*)	0	4	0	0	0	9	0	0	1	0	b	14	14	......	12	0	0
256427	Bunney (*4*)	0	4	0	0	0	9	0	0	1	0	b	14	14	......	12	0	0
229390	Cedar 1 (*5*)	i	5	0	0	b	9	0	0	1	0	b	(15)	12	ND	13	0	0
256428	Christmas Day (*6*)	0	5	0	0	0	9	0	0	1	0	b	14	14	......	13	0	0
245228	Crackpot (*7*)	0	4	0	0	0	10	0	0	1	0	......	0	13	......	12	0	0
256429	Flat Top 4 (*12*)	0	3	0	0	0	9	0	0	1	0	b	15	13	......	13	0	0
256430	Gay Eagle (*13*)	0	4	0	0	0	9	0	0	1	0	b	15	14	......	13	0	0
229393	Hanosh (Section 26) (*15*)	i	4	0	0	b	9	0	0	1	0	b	(15)	13	ND	13	0	0
256431	Haystack 2 (*17*)	0	3	0	0	0	8	0	0	1	0	b	15	13	......	13	0	0
256432	Last Chance (*19*)	0	4	0	0	0	8	0	0	1	0	b	14	14	......	12	0	0
256433	Red Bluff 3 (*24*)	0	5	0	0	0	9	0	0	1	0	b	14	15	......	13	0	0
256434	Red Bluff 5 (*25*)	0	4	0	0	0	8	0	0	1	0	b	14	14	......	13	0	0
256435	Red Bluff 7 (*26*)	0	4	0	0	0	9	0	0	1	0	b	15	14	......	12	0	0
256436	Red Bluff 8 (*13*)	0	3	0	0	0	8	0	0	1	0	b	14	13	......	12	0	0
229391	Red Bluff 10 (*13*)	i	4	0	0	b	9	0	0	1	0	b	(15)	14	ND	13	0	0
256437	Red Point Lode (*28*)	0	5	0	0	0	8	0	0	1	0	b	15	14	......	13	0	0
246891	Reed Henderson	0	5	0	0	0	9	0	0	1	0	......	0	13	......	13	0	0
256438	Rimrock (*29*)	0	5	0	0	0	9	0	0	1	0	b	15	14	......	12	0	0
256439	Section 18 (*32*)	Tr.	3	0	0	0	7	0	0	1	0	b	14	13	......	12	0	0
256440	Section 18 (*33*)	0	3	0	0	0	8	0	0	1	0	b	15	13	......	12	0	0
229395	Section 19 (*34*)	i	5	0	0	b	11	0	0	1	12	b	g	15	ND	13	0	0
256441	Section 21 (*37*)	0	2	0	0	0	9	0	0	1	0	b	15	14	......	12	0	0
256442	Section 24 (*39*)	0	3	0	0	0	8	0	0	1	0	b	15	14	......	12	0	0
229392	Manol (Section 30) (*22*)	i	4	0	0	b	10	0	0	1	0	b	(15)	12	ND	13	0	0
256443	Manol (Section 30, T-8) (*22*)	0	4	0	0	0	9	0	0	1	0	b	15	13	......	12	0	0
256444	Manol (Section 30, T-19) (*22*)	0	3	0	0	0	9	0	0	1	0	b	14	13	......	12	0	0
229394	T 2 (*45*)	i	5	0	0	b	10	0	0	1	(12)	b	g	14	ND	13	0	0
256445	Tom Elkins (*48*)	0	2	0	0	0	7	0	0	1	0	b	15	14	......	12	0	0
256446	UDC 5 (*49*)	0	4	0	0	0	9	0	0	1	0	b	14	14	......	12	0	0
	Ore in the Todilto Limestone and Entrada Sandstone																	
245229	Sandy (*76*)	0	3	0	0	Tr.	9	0	0	1	0	0	13	12	......	12	0	0
	Ore in the San Andres Limestone																	
245227	Lucky Don (*1*)	0	4	0	0	Tr.	11	0	0	1	0	0	13	12	......	12	0	0
	Ore in the Madera Limestone																	
254110	Agua Torres (*1*)	0	3	0	0	12	7	0	0	3	0	0	14	12	......	11	0	0
254109	Marie (*2*)	14	3	5	0	12	8	0	0	2	0	0	12	11	......	9	0	0

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued																
		Eu	F	Fe	Ga	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn
Ore in the Todilto Limestone																		
256424	Barbara J 1 (*1*)	0	------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
256425	Billy The Kid (*3*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256426	Black Hawk (*4*)	0	------	5	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256427	Bunney (*4*)	0	------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	8
229390	Cedar 1 (*5*)	ND	ND	5	h	0	0	0	0	ND	0	0	a	0	0	ND	6	9
256428	Christmas Day (*6*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
245228	Crackpot (*7*)			6	0	0	0	0	0	------	0	0	4	0	0	------	6	9
256429	Flat Top 4 (*12*)	0	------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	8
256430	Gay Eagle (*13*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
229393	Hanosh (Section 26) (*15*)	ND	ND	6	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	8
256431	Haystack 2 (*17*)	0	------	5	0	0	0	0	0	0	0	0	3	0	0	0	6	8
256432	Last Chance (*19*)	0	------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	7
256433	Red Bluff 3 (*24*)	0	------	5	0	0	0	0	0	0	0	0	0	0	0	0	7	7
256434	Red Bluff 5 (*25*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	7
256435	Red Bluff 7 (*26*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256436	Red Bluff 8 (*13*)	0	------	5	0	0	0	0	0	0	0	0	5	0	0	0	6	8
229391	Red Bluff 10 (*13*)	ND	ND	6	h	0	0	0	0	ND	0	0	a	0	0	ND	6	8
256437	Red Point Lode (*28*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	7	8
246891	Reed Henderson			7	0	0	0	0	0	------	0	0	4	0	0	------	5	8
256438	Rimrock (*29*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256439	Section 18 (*32*)	0	------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
256440	Section 18 (*33*)	0	------	5	0	0	0	0	0	0	0	0	3	0	0	0	5	8
229395	Section 19 (*34*)	ND	ND	7	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	6
256441	Section 21 (*37*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256442	Section 24 (*39*)	0	------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
229392	Manol (Section 30) (*22*)	ND	ND	6	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	8
256443	Manol (Section 30, T-8) (*22*)	0	------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	8
256444	Manol (Section 30, T-19) (*22*)	0	------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
229394	T 2 (*45*)	ND	ND	6	h	0	0	0	0	ND	0	0	a	0	0	ND	6	8
256445	Tom Elkins (*48*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256446	UDC 5 (*49*)	0	------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
Ore in the Todilto Limestone and Entrada Sandstone																		
245229	Sandy (*76*)			5	Tr.	0	0	0	0	------	0	0	3	0	0	------	5	8
Ore in the San Andres Limestone																		
245227	Lucky Don (*1*)			5	0	0	0	0	0	------	0	0	4	0	0	------	2	
Ore in the Madera Limestone																		
254110	Agua Torres (*1*)	0	------	4	Tr.	0	0	0	0	0	0	0	4	0	0	0	5	8
254109	Marie (*2*)	0	------	2	14	0	0	0	0	0	0	0	3	0	0	0	6	9

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued																
		Mo	Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc
	Ore in the Todilto Limestone																	
256424	Barbara J 1 *(1)*	13	5	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0
256425	Billy The Kid *(3)*	0	6	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
256426	Black Hawk *(4)*	14	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256427	Bunney *(4)*	14	6	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
229390	Cedar 1 *(5)*	14	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	f
256428	Christmas Day *(6)*	14	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
245228	Crackpot *(7)*	0	6	0	0	14	0	0	12	0	------	0	------	0	0	0	0	0
256429	Flat Top 4 *(12)*	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256430	Gay Eagle *(13)*	14	6	0	0	15	0	0	11	0	0	0	------	0	0	0	0	0
229393	Hanosh (Section 26) *(15)*	12	6	0	0	14	0	0	10	0	ND	0	ND	0	0	0	0	f
256431	Haystack 2 *(17)*	13	5	0	0	15	0	0	11	0	0	0	------	0	0	0	0	0
256432	Last Chance *(19)*	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256433	Red Bluff 3 *(24)*	13	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256434	Red Bluff 5 *(25)*	12	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256435	Red Bluff 7 *(26)*	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256436	Red Bluff 8 *(13)*	14	6	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0
229391	Red Bluff 10 *(13)*	13	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	f
256437	Red Point Lode *(28)*	0	6	0	0	15	0	0	12	0	0	0	------	0	0	0	0	0
246891	Reed Henderson	0	6	0	0	14	0	0	14	0	------	0	------	0	0	0	0	0
256438	Rimrock *(29)*	0	6	0	0	14	0	0	13	0	0	0	------	0	0	0	0	0
256439	Section 18 *(32)*	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256440	Section 18 *(33)*	0	5	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
229395	Section 19 *(34)*	f	7	0	0	15	0	0	13	0	ND	0	ND	0	0	0	0	f
256441	Section 21 *(37)*	0	6	0	0	15	0	0	13	0	0	0	------	0	0	0	0	0
256442	Section 24 *(39)*	0	6	0	0	15	0	0	11	0	0	0	------	0	0	0	0	0
229392	Manol (Section 30) *(22)*	f	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	f
256443	Manol (Section 30, T-8) *(22)*	0	6	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0
256444	Manol (Section 30, T-19) *(22)*	14	6	0	0	13	0	0	10	0	0	0	------	0	0	0	0	0
229394	T 2 *(45)*	f	7	0	0	14	0	0	13	0	ND	0	ND	0	0	0	0	f
256445	Tom Elkins *(48)*	0	6	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
256446	UDC 5 *(49)*	13	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
	Ore in the Todilto Limestone and Entrada Sandstone																	
245229	Sandy *(76)*	13	4	0	0	14	0	0	12	0	------	0	------	0	0	0	0	0
	Ore in the San Andres Limestone																	
245227	Lucky Don *(1)*	13	6	0	0	11	0	0	11	0	------	0	------	0	0	0	0	0
	Ore in the Madera Limestone																	
254110	Agua Torres *(1)*	12	7	0	0	12	0	0	12	0	0	0	------	0	0	0	0	14
254109	Marie *(2)*	10	6	0	0	12	0	0	5	0	0	0	------	0	0	0	10	14

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued																	
		Si	Sn	Sr	Sm	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Ore in the Todilto Limestone																			
256424	Barbara J 1 (*1*)	1	0	9	0	0	0	0	0	8	0	0	6	9	0	14	d	0	11
256425	Billy The Kid (*3*)	3	0	8	0	0	0	0	0	9	0	0	8	7	0	0	d	0	12
256426	Black Hawk (*4*)	2	0	9	0	0	0	0	0	8	0	0	7	9	0	Tr.	d	0	11
256427	Bunney (*4*)	2	0	9	0	0	0	0	0	8	0	0	8	8	0	0	d	0	12
229390	Cedar 1 (*5*)	3	0	10	0	0	ND	0	0	9	0	ND	6	9	0	0	h	0	12
256428	Christmas Day (*6*)	3	0	9	0	0	0	0	0	9	0	0	7	8	0	0	d	0	12
245228	Crackpot (*7*)	3	0	9	0	0	......	0	0	11	0	......	8	7	0	0	e	0	12
256429	Flat Top 4 (*12*)	2	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	11
256430	Gay Eagle (*13*)	3	0	9	0	0	0	0	0	9	0	0	7	8	0	0	d	0	11
229393	Hanosh (Section 26) (*15*)	7	0	10	0	0	ND	0	0	8	0	ND	6	8	0	14	f	0	11
256431	Haystack 2 (*17*)	1	0	10	0	0	0	0	0	8	0	0	7	9	0	0	d	0	10
256432	Last Chance (*19*)	2	0	9	0	0	0	0	0	9	0	0	7	7	0	0	d	0	12
256433	Reb Bluff 3 (*24*)	3	0	9	0	0	0	0	0	10	0	0	7	10	0	0	0	0	13
256434	Reb Bluff 5 (*25*)	2	0	8	0	0	0	0	0	9	0	0	7	9	0	0	0	0	12
256435	Red Bluff 7 (*26*)	2	0	9	0	0	0	0	0	9	0	0	7	8	0	0	d	0	12
256436	Red Bluff 8 (*13*)	1	0	8	0	0	0	0	0	8	0	0	7	7	0	0	d	0	11
229391	Red Bluff 10 (*13*)	3	0	10	0	0	ND	0	0	9	0	ND	7	8	0	0	f	0	12
256437	Red Point Lode (*28*)	3	0	9	0	0	0	0	0	8	0	0	8	8	0	0	d	0	12
246891	Reed Henderson	3	0	9	0	0	......	0	0	9	0	......	0	8	0	0	......	0	12
256438	Rimrock (*29*)	3	0	8	0	0	0	0	0	9	0	0	8	7	0	0	d	0	11
256439	Section 18 (*32*)	1	0	8	0	0	0	0	0	9	0	0	7	7	0	0	d	0	11
256440	Section 18 (*33*)	1	0	9	0	0	0	0	0	8	0	0	8	7	0	14	d	0	11
229395	Section 19 (*34*)	4	0	10	0	0	ND	0	0	10	0	ND	7	7	0	0	f	0	13
256441	Section 21 (*37*)	3	0	8	0	0	0	0	0	9	0	0	7	7	0	0	d	0	13
256442	Section 24 (*39*)	1	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	10
229392	Manol (Section 30) (*22*)	3	0	10	0	0	ND	0	0	9	0	ND	6	7	0	0	f	0	12
256443	Manol (Section 30, T-8) (*22*)	1	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	12
256444	Manol (Section 30, T-19) (*22*)	1	0	9	0	0	0	0	0	8	0	0	6	9	0	Tr.	d	0	11
229394	T 2 (*45*)	3	0	10	0	0	ND	0	0	10	0	ND	7	7	0	0	f	0	12
256445	Tom Elkins (*48*)	3	0	8	0	0	0	0	0	9	0	0	7	7	0	0	d	0	12
256446	UDC 5 (*49*)	2	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	12
Ore in the Todilto Limestone and Entrada Sandstone																			
245229	Sandy (*76*)	1	0	10	0	0	......	0	0	8	0	......	8	9	0	13	15	0	11
Ore in the San Andres Limestone																			
245227	Lucky Don (*1*)	1	0	11	0	0	......	0	0	8	0	......	7	7	0	0	e	7	11
Ore in the Madera Limestone																			
254110	Agua Torres (*1*)	1	0	7	0	0	0	0	0	7	0	0	8	9	ND	13	15	9	11
254109	Marie (*2*)	1	0	9	0	0	0	0	0	6	10	0	7	9	ND	13	15	7	10

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample[1]	Name of mine or prospect	Radiometric	Chemical								
		eU[3]	U[4]	V_2O_5[5]	S[6]	P_2O_5[7]	C[8] (organic)	As[9]	F[10]	Se[11]	Zn[12]
		Percent						Parts per million			
	Ore in the Todilto Limestone										
256424	Barbara J 1 (*1*)	0.23	0.23	0.09	0.07	0.026	0.11	16	50	5	20
256425	Billy The Kid (*3*)	.09	.09	.30	.03	.003	.08	3	50	1	10
256426	Black Hawk (*4*)	.12	.12	.08	.04	.015	.07	23	340	3	10
256427	Bunney (*4*)	.08	.08	.11	.03	.003	.08	11	30	2	10
229390	Cedar 1 (*5*)	.21	.24	------	------	.024	------	60	290	5	20
256428	Christmas Day (*6*)	.16	.16	.13	.04	.003	.10	18	290	4	10
245228	Crackpot (*7*)	.07	.10	.33	.11	.011	------	18	160	3	7
256429	Flat Top 4 (*12*)	.19	.20	.13	.03	.003	.09	18	630	3	10
256430	Gay Eagle (*13*)	.16	.18	.15	.03	.003	.06	20	190	4	10
229393	Hanosh (Section 26) (*15*)	.31	.34	------	------	.031	------	50	1,700	5	20
256431	Haystack 2 (*17*)	.15	.16	.13	.08	.015	.14	8	60	8	10
256432	Last Chance (*19*)	.12	.13	.23	.03	.003	.06	6	50	2	10
256433	Red Bluff 3 (*24*)	.17	.16	.05	.04	.015	.05	33	90	4	10
256434	Red Bluff 5 (*25*)	.16	.16	.05	.03	.018	.06	21	90	3	10
256435	Red Bluff 7 (*26*)	.13	.13	.09	.04	.003	.07	12	120	2	10
256436	Red Bluff 8 (*13*)	.13	.14	.14	.03	.003	.08	19	150	3	10
229391	Red Bluff 10 (*13*)	.17	.18	------	------	.017	------	60	440	5	10
256437	Red Point Lode (*28*)	.11	.11	.07	.03	.005	.06	20	30	3	10
246891	Reed Henderson	.03	.03	.12	.05	.015	.92	8	80	.5	4
256438	Rimrock (*29*)	.10	.11	.28	.03	.003	.06	8	110	3	10
256439	Section 18 (*32*)	.15	.16	.33	.03	.003	.06	9	20	5	20
256440	Section 18 (*33*)	.10	.10	.23	.03	.003	.07	8	20	4	10
229395	Section 19 (*34*)	.14	.14	------	------	.004	------	10	160	5	10
256441	Section 21 (*37*)	.10	.11	.30	.03	.003	.06	2	20	2	10
256442	Section 24 (*39*)	.19	.18	.15	.03	.003	.06	2	20	1	30
229392	Manol (Section 30) (*22*)	.19	.23	------	------	.019	------	50	460	2	10
256443	Manol (Section 30, T–8) (*22*)	.17	.19	.11	.04	.007	.12	19	240	3	10
256444	Manol (Section 30, T–19) (*22*)	.28	.31	.07	.04	.029	.10	16	130	3	10
229394	T 2 (*45*)	.12	.13	------	------	.004	------	10	130	1	20
256445	Tom Elkins (*48*)	.12	.11	.19	.04	.003	.06	4	20	3	10
256446	UDC 5 (*49*)	.14	.14	.06	.04	.011	.06	29	370	5	10
	Ore in the Todilto Limestone Limestone and Entrada Sandstone										
245229	Sandy (*76*)	0.09	0.10	0.13	0.08	0.024	------	15	60	15	12
	Ore in the San Andres Limestone										
245227	Lucky Don (*1*)	0.17	0.22	0.43	0.06	0.011	------	41	240	10	830
	Ore in the Madera Limestone										
254110	Agua Torres (*1*)	0.06	0.08	0.11	0.46	------	------	172	------	50	37
254109	Marie (*2*)	.17	.17	.05	3.27	------	------	6,200	890	75	2,100

---

[1] Spectrographic analyses, chemical analyses for As, Se, U, and Zn, and radiometric analyses for U for samples 229390–229395 inclusive requested by A. T. Miesch.

[2] Analysis of sample 246891 by N. M. Conklin; all others by R. G. Havens.

[3] Analysts: C. G. Angelo, R. P. Cox, G. S. Erickson, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg.

[4] Analysts: C. G. Angelo, R. P. Cox, E. J. Fennelly, D. L. Ferguson, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller and J. S. Wahlberg. Fluorimetric method.

[5] Analysts: W. D. Goss, H. H. Lipp, and J. S. Wahlberg. Volumetric method.

[6] Analysts: G. T. Burrow, D. L. Ferguson, and E. C. Mallory. Gravimetric method.

[7] Analysts: D. L. Ferguson and L. F. Rader, Jr. Volumetric method.

[8] Analysts: Wayne Mountjoy and J. P. Schuch. Rapid scanning, CO_2 method.

[9] Analysts: R. R. Beins, H. E. Crowe, E. J. Fennelly, Claude Huffman, J. P. Schuch, and J. E. Wilson. Colorimetric method.

[10] Analysts: R. P. Cox, W. D. Goss, and L. F. Rader, Jr. Colorimetric method.

[11] Analysts: C. G. Angelo, G. T. Burrow, R. P. Cox, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg. Colorimetric method.

[12] Analysts: R. R. Beins, G. T. Burrow, and H. E. Crowe. Colorimetric method

ORE SAMPLE GROUPS AND THEIR CHARACTERISTICS

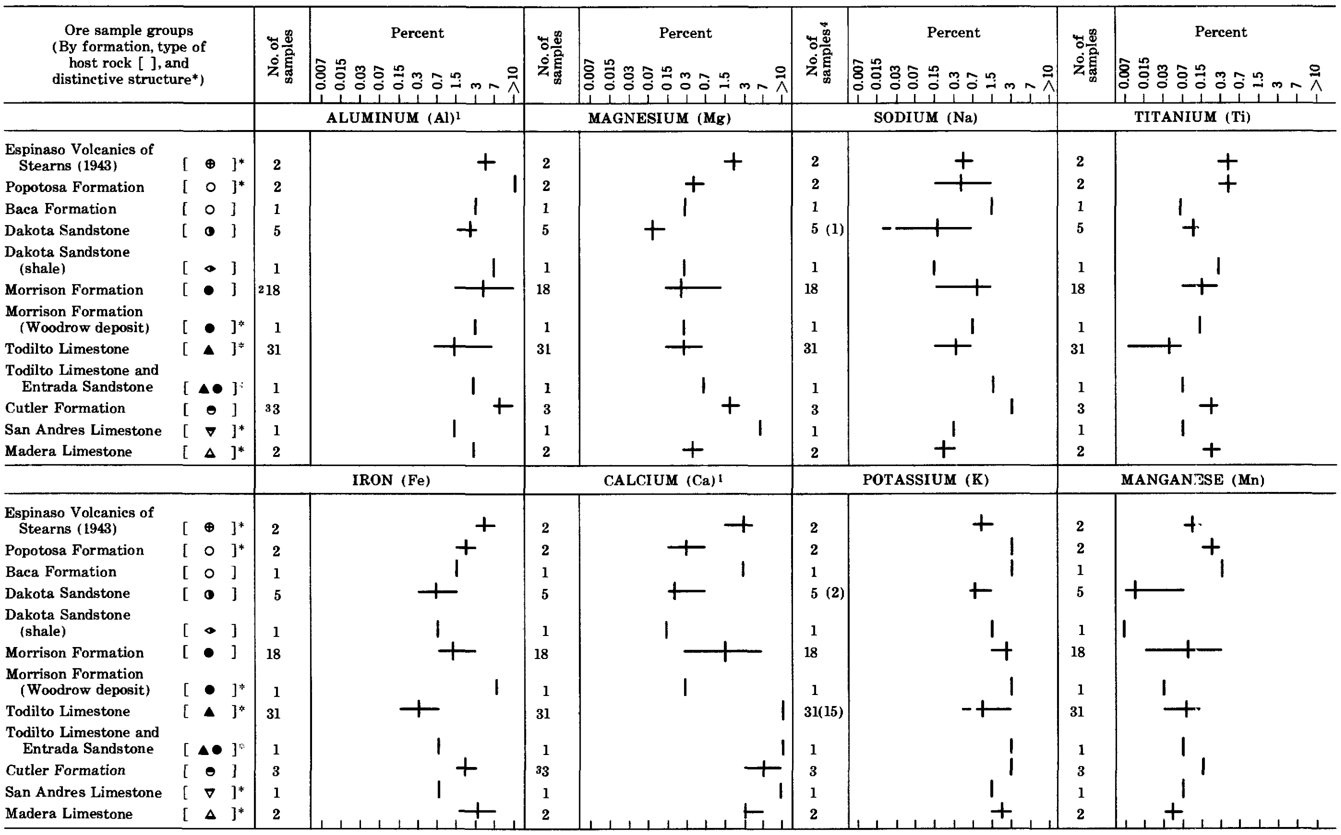
Tables 5 and 6 indicate that the ores are generally in radioactive equilibrium and, with the exception of the Woodrow, are of about the same grade; tables 7–9 reveal, however, some differences that can be related to the stratigraphic position, to rock type, and to tectonic structure, but areal differences within stratigraphic units generally are not notable. The various differences, plus what is known of the geology of the deposits, support the following twofold classification of the ore groups, listed by stratigraphic host unit:

Class 1 ore sample groups	*Class 2 ore sample groups*
Baca Formation	Espinaso Volcanics of Stearns (1943)
Dakota Sandstone	Popotosa Formation
Dakota Sandstone (shale)	Morrison Formation (Woodrow deposit)
Morrison Formation	San Andres Limestone
Todilto Limestone	Madera Limestone
Todilto Limestone and Entrada Sandstone	
Cutler Formation	

A discussion of these ore sample groups and their geologic relations must be prefaced by an understanding of the inherent limitations of the assay methods, especially for the spectrographic data, and of the near-threshold quantities and the varying limits of detection among different samples. For these reasons it is assumed that differences between means generally are not significant unless they differ by at least a factor

TABLE 7.—*Ranges of concentration and the geometric means of eight major elements in 12 sample groups of the uranium ores, northwestern New Mexico*

[All analyses are spectrographic]



[1] Samples reported as >10 are assumed to be 15, which is the next higher number in the series 1.5, 3, 7, etc.

[2] Includes 3 samples reported as >10.

[3] Includes 1 sample reported as >10.

[4] Number in parentheses is the number of samples below the limit of detection.

EXPLANATION

Range in content of samples
Dashed where uncertain

Geometric mean of all samples in which element detected

Ore sample groups

[⊕]*	Tertiary igneous breccia; in footwall of igneous dike
[○]*	Tertiary sandstone; in hanging wall of low-angle fault
[○]	Tertiary sandstone
[◑]	Cretaceous sandstone
[◆]	Cretaceous shale
[●]	Jurassic sandstone
[●]*	Jurassic sandstone (Woodrow deposit); in near-vertical breccia pipe
[▲]*	Jurassic limestone
[▲●]*	Jurassic limestone and sandstone
[◒]	Permian sandstone
[▽]*	Permian limestone; in footwall of high-angle fault
[△]*	Pennsylvanian limestone; in footwall of high-angle fault

of 2. The above classification, therefore, as far as elemental assembladges are concerned, is restricted to about 20 of the approximately 70 elements detected. With this in mind, the assemblages in the ores and the geology of the respective deposits yield the following characteristics of each class of ore sample groups.

Characteristics of the ore sample groups

Class 1 groups	*Class 2 groups*
1. Similar elemental assemblages.	1. Diverse elemental assemblages.
2. Similar mineralogy.	2. Diverse mineralogy.
3. Similar and rather mild alteration effects.	3. Diverse and generally more intense alteration effects.
4. Occurrence in sedimentary rocks.	4. Occurrence in sedimentary and igneous rocks.
5. Peneconcordance.	5. Generally veinlike.
6. Generally not directly related to tectonic structures, except to intraformational structures.	6. Direct relationship to fractures.
7. Wide stratigraphic and areal distribution, principally in the Colorado Plateaus and Rocky Mountains provinces.	7. Wide stratigraphic but rather limited areal distribution, principally in the Rio Grande trough, of the Basin and Range province.

Class 1 includes most of the ore samples from deposits of the so-called sandstone or peneconcordant type (Finch, 1959). Class 2 includes ore samples that generally have a relatively high content of various base and ferrous metals and of sulfur, arsenic, fluorine, and thallium (in two samples); all ores are from deposits that are closely associated with faults and from host rocks that generally are sheared or brecciated.

Some deposits which do not quite fit these criteria or which are somewhat exceptional are discussed below under their respective groups.

EXCEPTIONAL CHARACTERISTICS OF SOME ORE SAMPLE GROUPS

ESPINASO VOLCANICS OF STEARNS (1943)

Most distinctive of the ore sample groups is that in the Espinaso Volcanics of Stearns (1943) because of its exceptional assemblage of elements—a relatively high content of iron (table 7), silver, cerium, cobalt, chromium, copper, germanium, molybdenum, nickel, strontium, lanthanum, and neodymium (tables 5, 8), arsenic, fluorine, and sulfur (table 9) and a relatively low content of vanadium and selenium (table 9). The strontium and germanium, and possibly the lanthanum and neodymium, may in large part be original constituents of the host rock. The rest of the assemblage, especially iron, silver, cobalt, chromium, copper, nickel, arsenic fluorine, and sulfur, probably was introduced during the ore-forming process and is strikingly more abundant than in the groups of class 1, and the first six of these elements generally are more abundant than in the other groups of class 2, except for the group in the Woodrow deposit. The geometric means of these elements in the Espinaso range from about 3 times to more than 10 times those in any of the groups of class 1, as shown in summary table 10. The opposite is true for vanadium, which is quite low and generally less than in each of the groups of class 1, except for the group in the shale of the Dakota Sandstone. The low vanadium content in the Espinaso is what would be expected in a sulfide-rich deposit of magmatic affinities (Goldschmidt, 1954, p. 490).

Deposits in the Espinaso Volcanics are within and along the side of a near-vertical mafic dike in sulfide-mineral veinlets and in a hydrothermally altered, sulfide mineral-impregnated clayey matrix (table 4). The locality is the west side of the Los Cerrillos mining district, an area that is characterized by base-metal vein deposits. Although the mineralogy of the deposits in the Espinaso is incompletely known, the assemblage of elements and general structural relations of the deposits indicate that they are related to the other base-metal deposits of the Los Cerrillos district.

POPOTOSA FORMATION

Classification of the group in the Popotosa Formation and of some of the other groups in class 2 is less certain because some of them, and the deposits they represent, have characteristics of both classes.

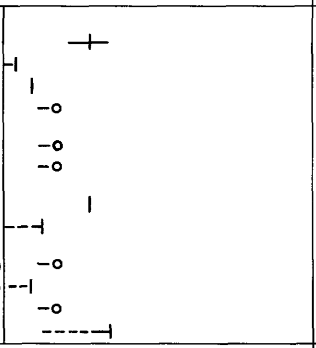
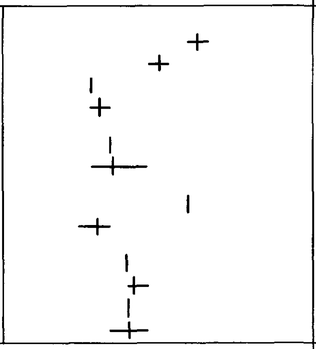
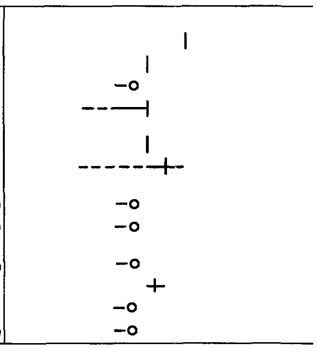
Table 10 shows that the group generally is appreciably higher in aluminum, cobalt, copper, nickel fluorine, and zinc (with some single exceptions) than are the ores in the groups of class 1. The aluminum content may not be meaningful, as it could represent in large part the original host rock or fault gouge and not have been introduced with the ore. The concentrations of the other elements may partly be related to the occurence of the deposit in the Popotosa in the hanging wall of the Cerro Colorado fault, a fault that bounds the west side of the Rio Grande trough (Denny, 1940, fig. 1; Kelley and Wood, 1946), and partly to the association of the ore with what may be hydrothermally altered rocks. Clay, which apparently occurs only locally in beds in the Popotosa (Denny, 1940), is a principal constituent of the ore. Much of the clay could be gouge, an attrition product of faulting, but a several-foot-thick bed of dark-gray clay occurs at the outcrop of the ore body and is interbedded with tuffaceous sandstone. Because the sandstone is bleached but the bedding not visibly disturbed or broken, the clay may be a hydrothermal product.

TABLE 8.—*Ranges of the geometric means of 19 minor elements in 12 sample groups of the uranium ores, northwestern New Mexico*

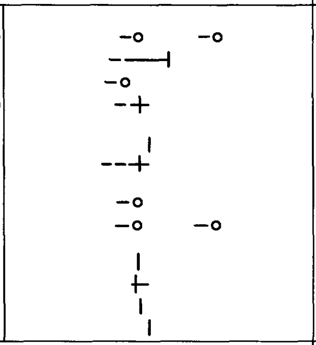
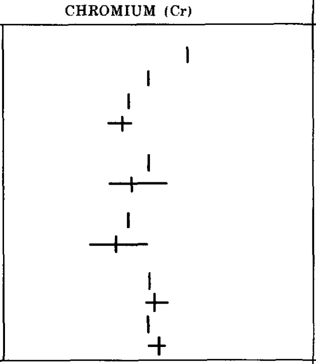
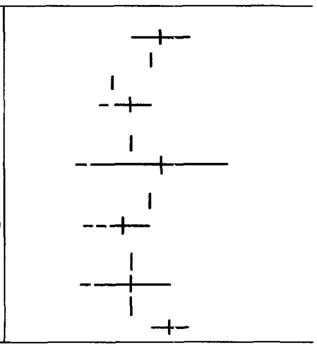
[All analyses are spectrographic. Numbers in parentheses are samples below limit of detection]

Percent scale (each element panel): 0.000015, 0.00003, 0.00007, 0.00015, 0.0003, 0.0007, 0.0015, 0.003, 0.007, 0.015, 0.03, 0.07, 0.15, 0.3, 0.7, 1.5

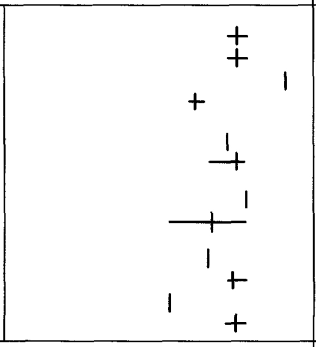
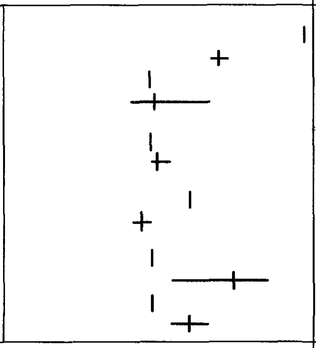
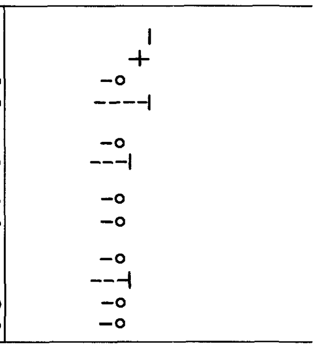
Ore sample groups (By formation, type of host rock [ ], and distinctive structure*)		SILVER (Ag) No. of samples	COBALT (Co) No. of samples	LANTHANUM (La) No. of samples
Espinaso Volcanics of Stearns (1943)	[⊕]*	2	2	2
Popotosa Formation	[○]*	2 (1)	2	2
Baca Formation	[○]	1	1	1 (1)
Dakota Sandstone	[◑]	5 (5)	5	5 (4)
Dakota Sandstone (shale)	[◈]	1 (1)	1	1
Morrison Formation	[●]	18 (18)	18 (1)	18 (16)
Morrison Formation (Woodrow deposit)	[●]*	1	1	1 (1)
Todilto Limestone	[▲]*	[1]31 (30)	31 (4)	31 (31)
Todilto Limestone and Entrada Sandstone	[▲●]*	1 (1)	1	1 (1)
Cutler Formation	[⊖]	3 (1)	3	3
San Andres Limestone	[▽]*	1 (1)	1	1 (1)
Madera Limestone	[△]*	2 (1)	2	2 (2)

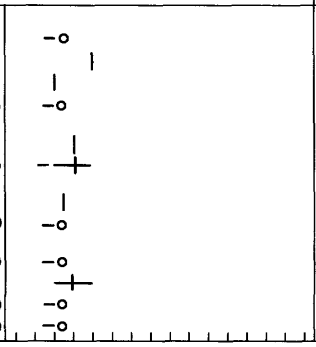
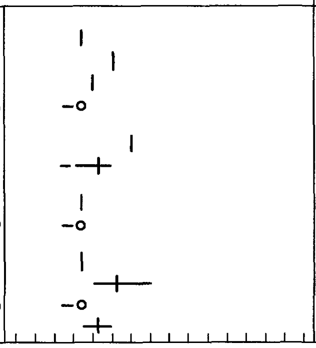
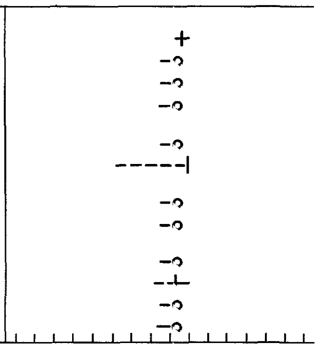
Ore sample groups		BORON (B) No. of samples	CHROMIUM (Cr) No. of samples	MOLYBDENUM (Mo) No. of samples
Espinaso Volcanics of Stearns (1943)	[⊕]*	2 (2)	2	2
Popotosa Formation	[○]*	[2]2 (1)	2	2
Baca Formation	[○]	[2]1 (1)	1	1
Dakota Sandstone	[◑]	5 (1)	5	5 (1)
Dakota Sandstone (shale)	[◈]	1	1	1
Morrison Formation	[●]	18 (6)	18	18 (1)
Morrison Formation (Woodrow deposit)	[●]*	1 (1)	1	1
Todilto Limestone	[▲]*	31 (31)	31	31 (17)
Todilto Limestone and Entrada Sandstone	[▲●]*	[3]1 (1)	1	1
Cutler Formation	[⊖]	3	3	3 (1)
San Andres Limestone	[▽]*	[3]1 (1)	1	1
Madera Limestone	[△]*	2	2	2

Ore sample groups		BARIUM (Ba) No. of samples	COPPER (Cu) No. of samples	NIOBIUM (Nb) No. of samples
Espinaso Volcanics of Stearns (1943)	[⊕]*	2	2	2
Popotosa Formation	[○]*	2	2	2
Baca Formation	[○]	1	1	1 (1)
Dakota Sandstone	[◑]	5	5	5 (4)
Dakota Sandstone (shale)	[◈]	1	1	1 (1)
Morrison Formation	[●]	18	18	18 (12)
Morrison Formation (Woodrow deposit)	[●]*	1	1	1 (1)
Todilto Limestone	[▲]*	31	31	31 (31)
Todilto Limestone and Entrada Sandstone	[▲●]*	1	1	1 (1)
Cutler Formation	[⊖]	3	3	3 (2)
San Andres Limestone	[▽]*	1	1	1 (1)
Madera Limestone	[△]*	2	2	2 (2)

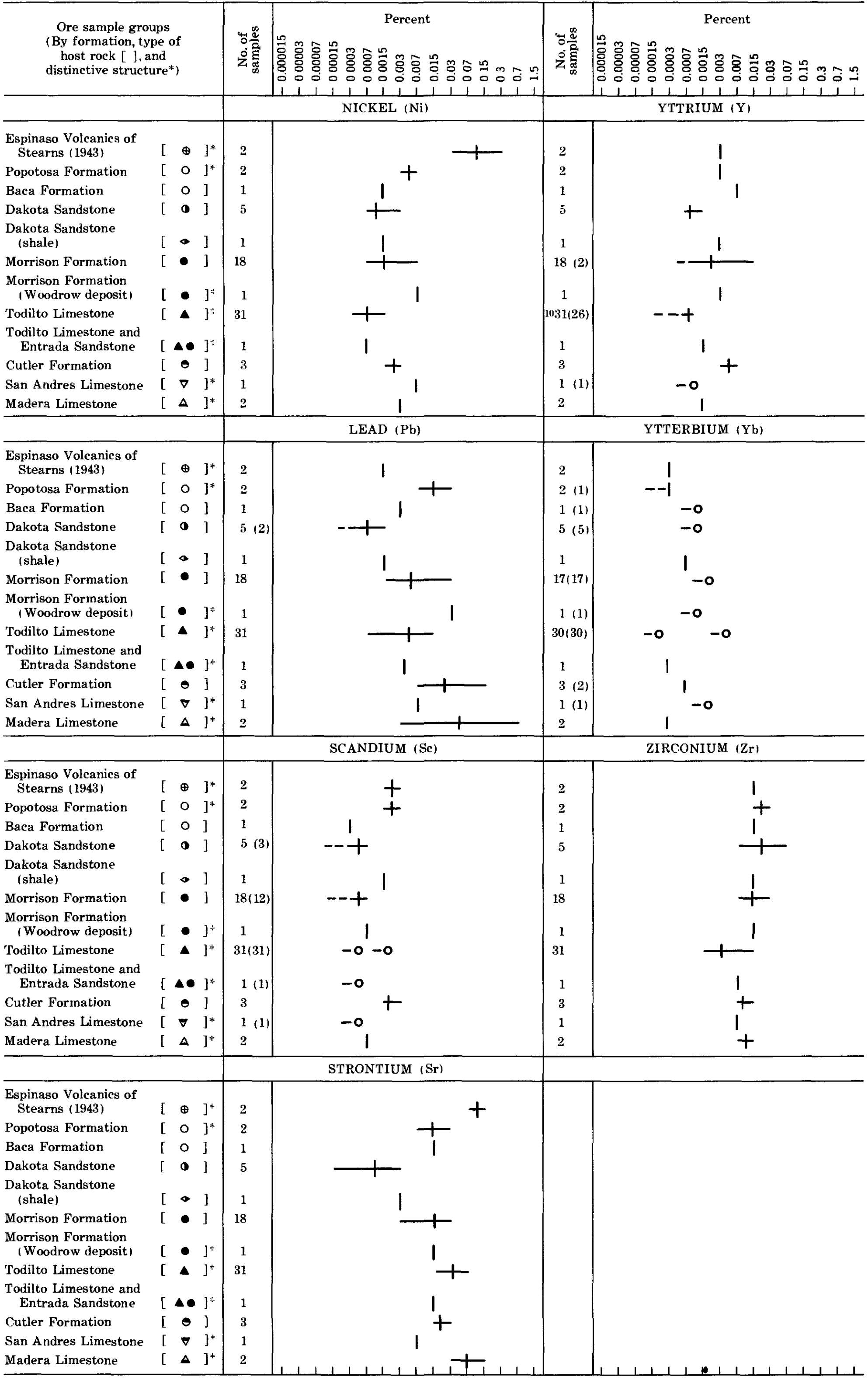




Ore sample groups		BERYLLIUM (Be) No. of samples	GALLIUM (Ga) No. of samples	NEODYMIUM (Nd) No. of samples
Espinaso Volcanics of Stearns (1943)	[⊕]*	2 (2)	[5]2	[9]2
Popotosa Formation	[○]*	2	2	2 (2)
Baca Formation	[○]	1	1	1 (1)
Dakota Sandstone	[◑]	5 (5)	5 (5)	5 (5)
Dakota Sandstone (shale)	[◈]	1	1	1 (1)
Morrison Formation	[●]	18 (5)	[6]18 (5)	18 (17)
Morrison Formation (Woodrow deposit)	[●]*	[4]1	[7]1	1 (1)
Todilto Limestone	[▲]*	31 (31)	31 (31)	31 (31)
Todilto Limestone and Entrada Sandstone	[▲●]*	1 (1)	[7]1	1 (1)
Cutler Formation	[⊖]	3	3	[9]3 (1)
San Andres Limestone	[▽]*	1 (1)	1 (1)	1 (1)
Madera Limestone	[△]*	2 (2)	[8]2	2 (2)

[1] One sample reported as trace, assumed to be 0.00005.
[2] One sample reported as 0.001.
[3] One sample reported as trace, assumed to be 0.002.
[4] Sample reported as trace, assumed to be 0.0001.
[5] Both samples reported as trace and assumed to be 0.0002.
[6] Includes 2 samples reported as trace and assumed to be 0.0002.
[7] Sample reported as trace, assumed to be 0.0002.
[8] Includes 1 sample reported as trace and assumed to be 0.0002.
[9] Includes 1 sample reported as trace and assumed to be 0.01.

TABLE 8.—*Ranges of the geometric means of 19 minor elements in 12 sample groups of the uranium ores, northwestern New Mexico*—Continued



Ore sample groups (By formation, type of host rock [ ], and distinctive structure*)		No. of samples, Nickel (Ni)	No. of samples, Yttrium (Y)	No. of samples, Lead (Pb)	No. of samples, Ytterbium (Yb)	No. of samples, Scandium (Sc)	No. of samples, Zirconium (Zr)	No. of samples, Strontium (Sr)
Espinaso Volcanics of Stearns (1943)	[⊕]*	2	2	2	2	2	2	2
Popotosa Formation	[○]*	2	2	2	2 (1)	2	2	2
Baca Formation	[○]	1	1	1	1 (1)	1	1	1
Dakota Sandstone	[◑]	5	5	5 (2)	5 (5)	5 (3)	5	5
Dakota Sandstone (shale)	[◆]	1	1	1	1	1	1	1
Morrison Formation	[●]	18	18 (2)	18	17(17)	18(12)	18	18
Morrison Formation (Woodrow deposit)	[●]*	1	1	1	1 (1)	1	1	1
Todilto Limestone	[▲]*	31	[10]31(26)	31	30(30)	31(31)	31	31
Todilto Limestone and Entrada Sandstone	[▲●]*	1	1	1	1	1 (1)	1	1
Cutler Formation	[◓]	3	3	3	3 (2)	3	3	3
San Andres Limestone	[▼]*	1	1 (1)	1	1 (1)	1 (1)	1	1
Madera Limestone	[△]*	2	2	2	2	2	2	2

---

[10] Includes 2 samples reported as trace and assumed to be 0.001.

EXPLANATION

|←—Range in content of samples—→|
Dashed where uncertain
- - - ———+———

Geometric mean of all samples reported as trace or more. Questioned where doubtful

—o

Approximate limit of sensitivity where the element is undetected in all samples

—o —o

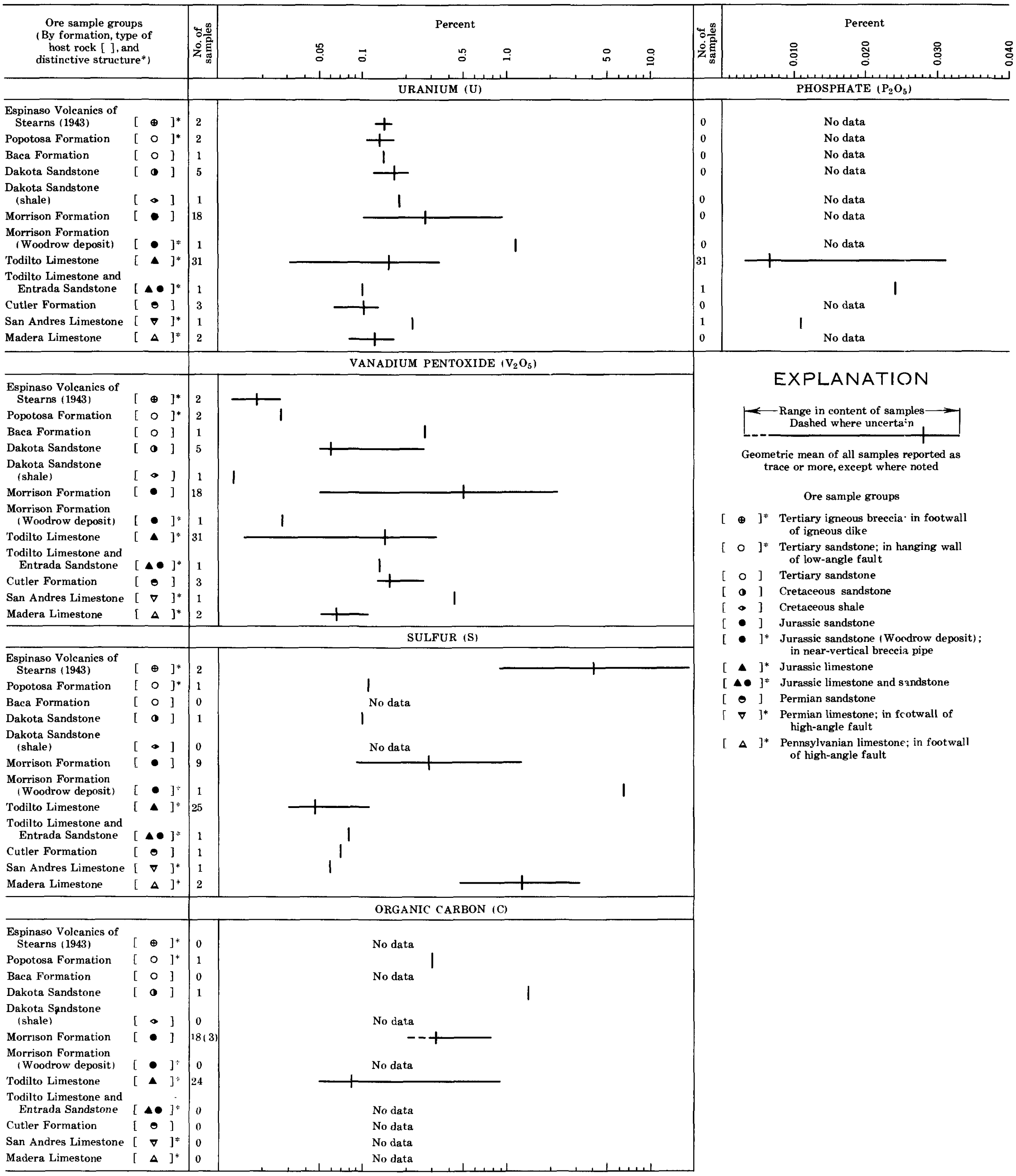
Approximate limits of sensitivities where they vary between samples. All samples undetected and below either or both limits

Ore sample groups

[⊕]*	Tertiary igneous breccia; in footwall of igneous dike
[○]*	Tertiary sandstone; in hanging wall of low-angle fault
[○]	Tertiary sandstone
[◑]	Cretaceous sandstone
[◆]	Cretaceous shale
[●]	Jurassic sandstone
[●]*	Jurassic sandstone (Woodrow deposit); in near-vertical breccia pipe
[▲]*	Jurassic limestone
[▲●]*	Jurassic limestone and sandstone
[◓]	Permian sandstone
[▼]*	Permian limestone; in footwall of high-angle fault
[△]*	Pennsylvanian limestone; in footwall of high-angle fault

TABLE 9.—*Ranges of concentration and the geometric means of uranium, vanadium pentoxide, sulfur, phosphate, organic carbon, arsenic, fluorine, selenium, and zinc in 12 sample groups of the uranium ores, northwestern New Mexico*

[Analyses are chemical except for some samples of V_2O_5. Where no chemical analyses are available or show an assay of <0.10 percent V_2O_5, spectrographic analyses are used by conversion of V to V_2O_5.]

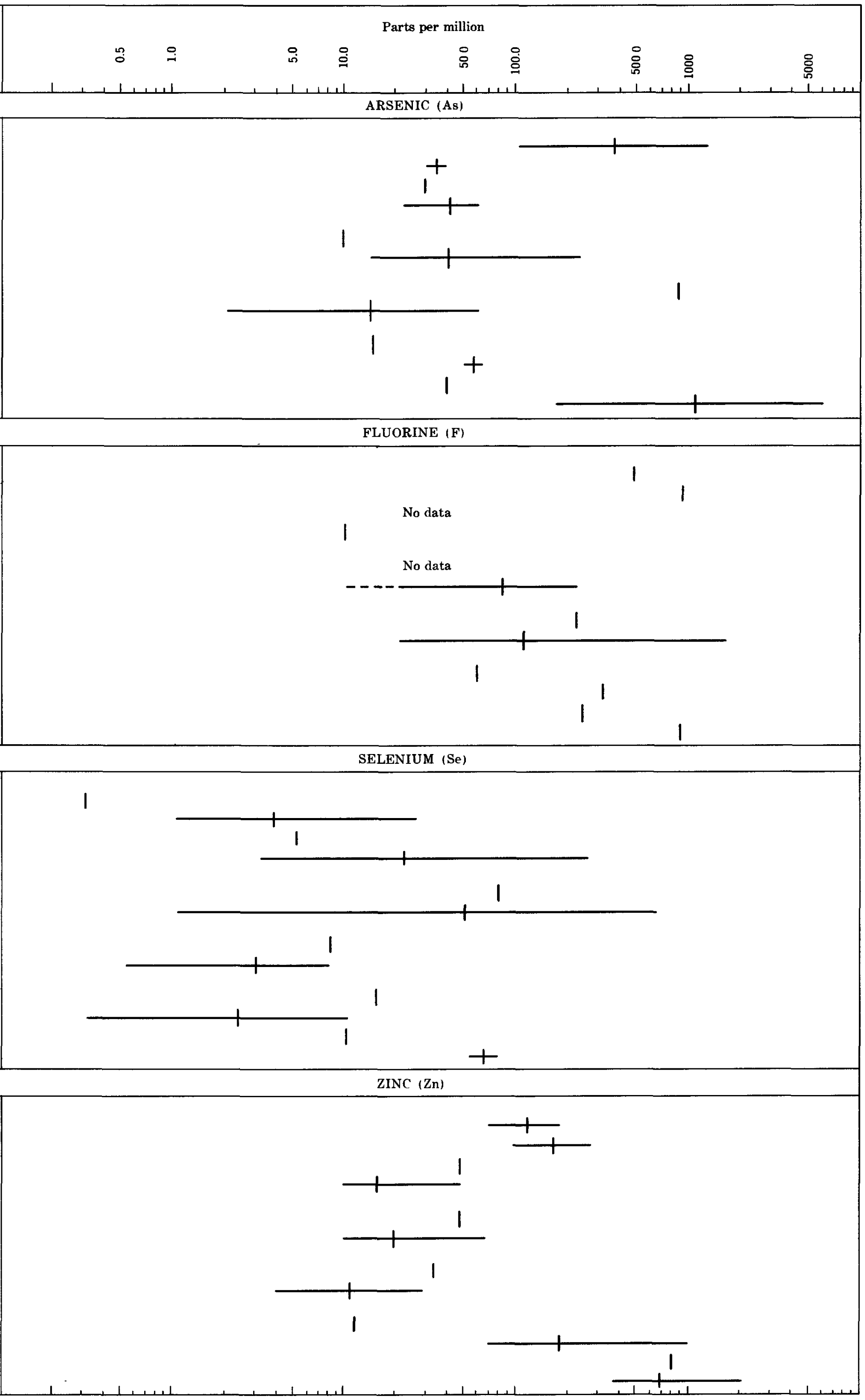


---

[1] Number in parentheses is samples below limit of detection, each reported as <0.3 and assumed to be 0.2 ppm.

TABLE 9.—*Ranges of concentration and the geometric means of uranium, vanadium pentoxide, sulfur, phosphate, organic carbon, arsenic, fluorine, selenium, and zinc in 12 sample groups of the uranium ores, northwestern New Mexico*—Continued

Ore sample groups (By formation, type of host rock [ ], and distinctive structure*)		No. of samples
ARSENIC (As)		
Espinaso Volcanics of Stearns (1943)	[⊕]*	2
Popotosa Formation	[○]*	2
Baca Formation	[○]	1
Dakota Sandstone	[◑]	5
Dakota Sandstone (shale)	[◆]	1
Morrison Formation	[●]	18
Morrison Formation (Woodrow deposit)	[●]*	1
Todilto Limestone	[▲]*	31
Todilto Limestone and Entrada Sandstone	[▲●]*	1
Cutler Formation	[◓]	3
San Andres Limestone	[▽]*	1
Madera Limestone	[△]*	2
FLUORINE (F)		
Espinaso Volcanics of Stearns (1943)	[⊕]*	1
Popotosa Formation	[○]*	1
Baca Formation	[○]	0
Dakota Sandstone	[◑]	[2]1
Dakota Sandstone (shale)	[◆]	0
Morrison Formation	[●]	[2]7
Morrison Formation (Woodrow deposit)	[●]*	1
Todilto Limestone	[▲]*	31
Todilto Limestone and Entrada Sandstone	[▲●]*	1
Cutler Formation	[◓]	1
San Andres Limestone	[▽]*	1
Madera Limestone	[△]*	1
SELENIUM (Se)		
Espinaso Volcanics of Stearns (1943)	[⊕]*	[3]2
Popotosa Formation	[○]*	2
Baca Formation	[○]	1
Dakota Sandstone	[◑]	5
Dakota Sandstone (shale)	[◆]	1
Morrison Formation	[●]	18
Morrison Formation (Woodrow deposit)	[●]*	1
Todilto Limestone	[▲]*	31
Todilto Limestone and Entrada Sandstone	[▲●]*	1
Cutler Formation	[◓]	[4]3
San Andres Limestone	[▽]*	1
Madera Limestone	[△]*	2
ZINC (Zn)		
Espinaso Volcanics of Stearns (1943)	[⊕]*	2
Popotosa Formation	[○]*	2
Baca Formation	[○]	1
Dakota Sandstone	[◑]	5
Dakota Sandstone (shale)	[◆]	1
Morrison Formation	[●]	18
Morrison Formation (Woodrow deposit)	[●]*	1
Todilto Limestone	[▲]*	31
Todilto Limestone and Entrada Sandstone	[▲●]*	1
Cutler Formation	[◓]	3
San Andres Limestone	[▽]*	1
Madera Limestone	[△]*	2



---

[2] One sample reported as <20, assumed to be 10 ppm.
[3] Both samples reported as <0.5, assumed to be 0.3 ppm.
[4] One sample reported as <0.5, assumed to be 0.3 ppm.

TABLE 10.—*Geometric means of 16 selected elements in the ore sample groups of classes 1 and 2*

[0, looked for but not found; <, less than amount shown; leaders (..), not looked for; ~, approximate amount shown. Analyses are in percent, except as otherwise indicated]

Ore sample groups (by host rock)	Ag	Al	Co	Cr	Cu	Fe	Mo	Ni	Pb	U	V₂O₅	S	As	F	Se	Zn
													Parts per million			
Groups of class 1																
Baca Formation	0.00003	3	0.0003	0.0015	0.003	1.5	0.0007	0.0015	0.003	0.14	0.27	......	30	......	5	50
Dakota Sandstone	0	2.6	.0005	.001	.004	.7	.0015	.001	<.0007	.16	.06	0.10	40	~10	21	16
Dakota Sandstone (shale)	0	7	.0007	.003	.003	.7	.0015	.0015	.0015	.18	.01	......	10	......	75	50
Morrison Formation	0	4.8	.0008	.002	.004	1.4	.005	.0015	.006	.26	.50	.3	40	83	48	20
Todilto Limestone	<.00005	1.6	.0004	.001	.002	.3	<.0011	.0007	.005	.14	.14	.04	14	108	2.9	11
Todilto Limestone and Entrada Sandstone	0	3	.0015	.003	.003	.7	.0009	.0007	.003	.10	.13	.08	15	60	15	12
Cutler Formation	~.00003	~9	.002	.004	.09	2.4	<.0014	.002	.025	.10	.15	.07	55	320	2.3	183
Groups of class 2																
Espinaso Volcanics of Stearns (1943) [1]	0.0003	4.6	0.02	0.015	1.5	4.6	0.005	0.09	0.0015	0.14	0.02	4.0	360	480	<.5	118
Popotosa Formation	<.000015	15	.005	.003	.05	2.1	.003	.005	.015	.13	.03	.11	35	920	3.7	167
Morrison Formation (Woodrow) deposit [2]	.0003	3	.015	.0015	.015	7	.003	.007	.03	1.16	.03	6.6	890	220	8	35
San Andres Limestone	0	1.5	.0015	.003	.003	.7	.0015	.007	.007	.22	.43	.06	41	240	10	830
Madera Limestone [3]	~.0004	3	.0015	.0046	.014	3.2	.007	.003	.05	.12	.06	1.2	1.033	890	61	703

[1] This sample group also contains 0.03 Ce, 0.015 La, ~0.01 Nd, and 0.12 Sr; 1 sample contains 0.003 Ge.

[2] This sample group also contains a trace of Tl.

[3] One sample in this sample group also contains 0.015 Sb and 0.015 Tl.

MORRISON FORMATION

Most data were obtained for the ore sample group of the Morrison Formation, the most important ore group in the area, from the standpoint of ore production and mine reserves. With the exception of some redistributed deposits in the Ambrosia Lake district and possibly the Gallup district, this ore group shows no direct relation to tectonic structures and, with the exception of the ores in the Salt Wash Member, no stratigraphic or geographic differences.

In general, the ore group in the Morrison shows a somewhat greater range in content of many elements than most other groups of class 1. This is principally the result of the greater number of samples, as indicated by the similar geometric means for the respective elements among the several sample groups (tables 7–9). An exception is vanadium, which has a relatively wide range and an average content that is much greater than that of any of the other groups. (See vanadium pentoxide, table 9.) These differences are reflected mostly by sample 254040 (table 5), which was taken from the northwestern part of the area where ores in the Salt Wash Member have an average U : V ratio of 1 : 7 (See table 2, Shiprock district.) Because the Salt Wash has a rather limited distribution in northwestern New Mexico, the ores that have a high vanadium content are restricted geographically as well as stratigraphically.

MORRISON FORMATION (WOODROW DEPOSIT)

The Woodrow deposit in the Morrison Formation differs from the groups in class 1 in its high content of 10 elements, the presence of coarse-grained coffinite in the ore, and the close association of the deposit with a faulted pipelike structural feature. These differences justify assignment of the Woodrow deposit to class 2.

The contents of each of the following nine elements in the Woodrow deposit are greater than the highest respective contents of the sample groups in class 1 by the following multiples: silver, >6×; cobalt, 7½×; copper, 3½×; iron, 3×; nickel, 3½×; lead, 5×; uranium, 4½×; sulfur, 22×; and arsenic, 16×. The contents of lead and copper in the Woodrow are about the same or less than in the group in the Cutler Formation, which contains an appreciably higher content of these and some other elements than the groups in class 1. This matter is discussed below under Cutler Formation. The Woodrow also contains a trace of thallium, which is rarely detected in deposits of the peneconcordant type, and it also has a relatively high sulfide mineral content, which is expressed in the ore principally as pyrite and marcasite; this content is indicated by the high amounts of iron and sulfur (table 10). Conversely, the Woodrow is low in vanadium.

The mineralogy of the Woodrow deposit is similar to that of the group in the Morrison Formation, with two exceptions: one is its relatively high sulfide mineral content, and the other is the presence of coarse-grained coffinite (Hilpert and Moench, 1960, p. 446) which occurs only in a fine-grained or earthy form in other deposits in the Morrison Formation as well as in all other peneconcordant deposits. Thus, the significant differences between the Woodrow deposit and groups of class 1 are the high grade of the deposit, the presence of coarse-grained coffinite in the ore, and the association of the deposit with a faulted pipelike structural feature.

TODILTO LIMESTONE

Unlike the other deposits of class 1, the deposits in the Todilto Limestone are closely associated with intraformational folds, the elemental assemblage differs from that of the other groups in class 1 in its somewhat lower amounts of iron, sulfur, and selenium (table 10), and there are other differences which are to be expected from a limestone rather than a sandstone or shale host rock (tables 5, 6). The smaller amounts of iron and sulfur probably reflect a lesser amount of sulfide minerals, and the relatively small amount of selenium is a corollary condition because selenium generally occurs in the sulfide minerals (Coleman and Delevaux, 1957).

The wider range in content of many elements in the group in the Todilto is similar to the range in the group in the Morrison and likewise is attributable to the greater number of samples rather than to the widespread distribution of samples (pl. 3).

CUTLER FORMATION

The elemental assemblage of the group in the Cutler Formation is similar to that of the class 1 groups, with the exception of copper, lead, zinc, and fluorine, which occur in substantially larger amounts and, in some places, are roughly comparable in quantities with the groups of class 2 (table 10). These relatively larger amounts are peculiar to deposits in the Pennsylvanian, Permian, and Triassic rocks of the region, particularly the Abo, Dockum, Chinle, and Cutler Formations. Many of these deposits are notable for their high content of copper, which may run as much as several percent. Little is known of their content of lead, zinc, and fluorine, at least in the subject area, but data on nearby areas indicate that at least lead and zinc occur in some of them in large amounts (Tschanz and others, 1958, p, 372–377). Where copper is abundant, it generally occurs in chalcocite, bornite, and chalcopyrite in close association with fossil plant debris (Lindgren and others, 1910, p. 76–79). Such deposits are generally known as red-bed copper deposits, and, with minor variations, are worldwide in distribution.

Uranium is associated with many of the red-bed deposits and where substantial amounts have been mined as uranium ore the mineralogy of the deposits is known (Finch, 1954; Trites and Chew, 1955; Trites and others, 1959, p. 185–195). In northwestern New Mexico, although only the more conspicuous yellow and green uranium oxides have been reported, the mineralogy probably is similar to that of deposits of this type in adjoining areas. If so, the lead and zinc are probably also associated with galena and sphalerite, as elsewhere in the region (Garrels and Larsen, 1959, p. 71).

Conclusions are that the deposits in the group in the Cutler have an elemental assemblage that is similar to that of the other groups in class 1, except for the high content of some base metals and fluorine, which is peculiar to deposits in the Pennsylvanian, Permian, and Triassic rocks.

SAN ANDRES LIMESTONE

The group in the San Andres Limestone, which is represented by only one sample, is noteworthy because of its exceptionally high content of zinc and somewhat high content of nickel (table 10). The zinc concentration ranges from 4.5 to 75 times the geometric mean concentrations in the groups in class 1, and the concentration of nickel ranges from 3.5 to 10 times the mean concentrations in the same group. What these somewhat anomalous concentrations mean is speculative and, by themselves, they are rather meaningless; the mineralogy of the deposit is incompletely known, and the lack of alteration of the host rock suggests a similarity to the deposits in the Todilto Limestone.

MADERA LIMESTONE

The group in the Madera Limestone is notable for its high content of iron, lead, sulfur, arsenic, fluorine, zinc, antimony, and thallium. These elements, especially lead, arsenic, and zinc, are more highly concentrated here than in any group of class 1. (See table 10.) Moreover, the group in the Madera is the only one in which antimony was detected and in which thallium was found in more than trace amounts. The moderately high content of iron and sulfur is probably indicative of the sulfide-mineral content; little is known of the mineralogy.

SUMMARY AND CONCLUSIONS

The elemental assemblages in the ore sample groups show differences that can be related in some instances to stratigraphic position, type of host rock, and tectonic features, but areal differences of the ores within stratigraphic units are less apparent.

In class 1, three general groupings by stratigraphic units can be made, principally on the basis of relative contents of vanadium and copper. Ores that are low in these two elements occur in the Baca Formation, Dakota Sandstone, Morrison Formation (except the Salt Wash Member), Todilto Limestone, and Entrada Sandstone. Ores that are low in vanadium but high in copper occur in the Cutler Formation. These ores also probably are relatively high in lead, zinc, and fluorine. Ores that are high in vanadium and low in copper occur in the Salt Wash Member of the Morrison

Formation. The differences among rock types in class 1 ores are not marked, and the class is notable for the general uniformity of ores in sandstone, shale, and limestone. The most apparent difference is the relatively low contents in the Todilto Limestone of iron, sulfur, and selenium, which collectively are indicative of a low sulfide content. The ores in this class, except for the ones in the Todilto Limestone, show no close relation to tectonic features; these ores are almost invariably related to intraformational folds.

The ores of class 2 have rather marked differences among groups, but sample data are generally too few to determine the relations as to stratigraphic position, type of host rock, structural features, or area. As a class, the assemblage of elements is relatively high in base and ferrous metals, in sulfur, arsenic, and fluorine, and probably in thallium, and it is relatively low in vanadium. The one characteristic that is common to all groups in this class is the close association of the deposits with faults. Moreover, the faults all occur within or along the margins of the Rio Grande trough (pl. 1). Most of these faults formed contemporaneously with the Rio Grande trough, except for the Woodrow pipe. Although it occurs near the margin of the trough, it probably formed earlier than the trough and probably is intraformational, whereas the other fault structures are interformational.

The characteristics listed above for the two classes of ore sample groups and related deposits, when applied to the other uranium deposits in northwestern New Mexico, indicate that most deposits belong in class 1, some belong in class 2, and relatively few—specifically the ones in pegmatite—do not belong in either class. Although this application is based on incomplete information, particularly regarding the elemental assemblages, it is helpful in the subsequent appraisal of the resources.

Of the deposits that belong in class 1, the largest number is low in both vanadium and copper and constitutes most, if not all, of the deposits in the Santa Fe Group, Galisteo, San Jose, Baca, and Nacimiento Formations, Ojo Alamo Sandstone, Fruitland Formation, Mesaverde Group, Mancos(?) Shale, Dakota Sandstone, Morrison Formation (except for the Salt Wash Member), Summerville Formation, Todilto Limestone, and Entrada Sandstone. Next in abundance are the deposits that are high in copper and low in vandium; they constitute all those in the Chinle, Dockum, Cutler, and Abo Formations and include a deposit in the Madera Limestone in Rio Arriba County. Deposits that are high in vanadium and low in copper occur only in the Salt Wash Member of the Morrison Formation.

Class 2 deposits comprise those in the intrusive rocks of varied composition and form, the older volcanic rocks of the Jemez Mountains, Popotosa and Datil Formations, and other rocks in the San Andres and Madera Limestones.

DISTRIBUTION OF ELEMENTS IN THE TODILTO LIMESTONE

PURPOSE AND METHODS OF ANALYSIS

In addition to the ore samples taken from the Todilto Limestone (table 6) and discussed in the preceding section, samples of the mineralized and barren Todilto were taken in the vicinity of and away from ore deposits. The purpose of the sampling was to determine the spatial relations of the deposits to the various elements in the Todilto and to determine the relations of the deposits to the Todilto gypsum unit, as a means of helping to appraise the uranium resources.

Of 54 selected samples, 51 were taken from the limestone unit and three from the gypsum unit at the sample localities shown on plate 3, which also shows the known uranium deposits in the Todilto and isopach lines drawn on the limestone and gypsum units.

The samples were taken at outcrop and from drill holes. Of the 51 from the limestone unit, 22 were from drill-hole cuttings, 21 were chip-channel samples from the outcrop, and eight were grab samples from quarries and outcrop. Each sample weighed about 5 pounds. Most samples represent the entire thickness of the limestone unit. Exceptions were samples 252610 and 252609, which represent the basal 5-foot and overlying 4-foot stratigraphic intervals, respectively, at the same locality; sample 252616, which represents the basal 4-foot interval; and sample 252615, which represents a 1-foot interval 4 feet above the base at different nearby localities. The three samples of the gypsum unit (pl. 3) were taken near or at the base; samples 252608 and 252612 were composite chunk samples taken within the basal 10-foot interval, and sample 252617 represents the basal 4-foot interval. This latter interval is rather calcareous at the sample locality.

Semiquantitative spectrographic and chemical analyses were made of the Todilto samples for the same elements that were determined for the Todilto ores. The analytical data for the ores and for four zones away from ore are listed in tables 6 and 11, and, for comparative purposes, the ranges in concentration and the geometric means are plotted in graphs in tables 12–14 in the same manner as was done for the ores in the formational groups. Analytical data for the gypsum unit are listed in table 15.

TABLE 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone, northwestern New Mexico and northeastern Arizona*

Spectrographic determinations are semiquantitative and were made by the rapid visual-comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, 0.15, and are coded as follows: >10=1, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7, 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15, 0.00015=16. Figures reported as less than (<) are coded as follows: <1.0=a, <0.05=b, <0.02=c. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (..), not looked for; number enclosed in parentheses near threshold of detectability; ND, no data.

[Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded]

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Spectrographic [1]																
			Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
Mineralized ground																			
238805	Drill-hole cuttings.	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	0	3	0	0	0	10	0	0	1	0	0	0	11	ND	13	0	
238810	do	do	0	4	0	0	0	10	0	0	1	0	0	14	13	ND	13	0	0
238840	do	NW¼NW¼NE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	0	3	0	0	0	10	0	0	1	0	0	0	13	ND	13	0	0
238847	Chip channel.	SE¼NE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	0	4	0	0	0	10	0	0	1	0	0	0	15	ND	13	0	0
238849	do	SW¼SW¼SE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	0	4	0	0	0	10	0	0	1	0	0	0	13	ND	13	0	0
>25 feet and <500 feet from known uranium deposit																			
238819	Drill-hole cuttings.	SE¼SE¼ sec. 23, T. 13 N., R. 10 W., McKinley County.	0	4	0	0	Tr.	9	0	0	1	0	0	0	13	ND	13	0	0
238848	do	SW¼SW¼SW¼ sec. 3, T. 12 N., R. 9 W., Valencia County.	0	3	0	0	Tr.	8	0	0	1	0	0	0	13	ND	12	0	0
238806	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	0	3	0	0	0	10	0	0	1	0	0	0	13	ND	13	0	0
238809	do	do	0	3	0	0	0	8	0	0	1	0	0	0	13	ND	13	0	0
238828	do	do	0	3	0	0	0	10	0	0	1	0	0	14	12	ND	13	0	0
238829	do	do	0	3	0	0	Tr.	10	0	0	1	0	0	0	13	ND	13	0	0
238830	do	do	0	3	0	0	Tr.	10	0	0	1	0	0	14	12	ND	13	0	0
238831	do	do	0	3	0	0	Tr.	10	0	0	1	0	0	0	12	ND	13	0	0
238832	do	do	0	3	0	0	Tr.	10	0	0	1	0	0	0	12	ND	13	0	0
238833	do	do	0	3	0	0	Tr.	10	0	0	1	0	0	0	13	ND	13	0	0
238834	do	do	0	3	0	0	Tr.	8	0	0	1	0	0	0	12	ND	13	0	0
238835	do	do	0	3	0	0	Tr.	7	0	0	1	0	0	0	12	ND	11	0	0
238823	Chip channel.	SW¼ sec. 8, T. 8 N., R. 5 W., Valencia County.	0	5	0	0	0	11	0	0	1	0	0	0	13	ND	14	0	0
>500 feet and <1 mile from known uranium deposit																			
239622	Chip channel.	By road, west side Horse Mesa, Apache County, Ariz.	0	6	0	0	0	11	0	0	1	0	b	0	14	......	12	0	0
246069	do	Roadcut ±1,000 feet northwest of Joe Ben 3, San Juan County (unsurveyed).	0	4	0	0	0	10	0	0	1	0	......	0	13	......	10	0	0
238841	do	NW¼NE¼ sec. 33, T. 9 N., R. 5 W., Valencia County.	0	4	0	0	0	9	0	0	1	0	0	0	13	ND	13	0	0
238850	do	Center S½ sec. 22, T. 9 N., R. 5 W., Valencia County.	0	3	0	0	0	8	0	0	1	0	0	0	13	ND	12	0	0
238814	Drill-hole cuttings.	Sec. 23, T. 13 N., R. 10 W., McKinley County.	0	3	0	0	0	8	0	0	1	0	0	14	12	ND	12	0	0
238815	do	do	0	3	0	0	0	7	0	0	1	0	0	0	12	ND	12	0	0
238816	do	do	0	4	0	0	0	8	0	0	1	0	0	0	13	ND	13	0	0
238817	do	do	0	4	0	0	0	8	0	0	1	0	0	0	13	ND	13	0	0
238818	do	do	0	4	0	0	0	8	0	0	1	0	0	0	13	ND	13	0	0
238836	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	0	3	0	0	0	10	0	0	1	0	0	0	12	ND	12	0	0
238837	do	do	0	3	0	0	0	8	0	0	1	0	0	0	12	ND	12	0	0

See footnote at end of table.

TABLE 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone, northwestern New Mexico and northeastern Arizona*—Continued

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Spectrographic [1]																
			Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
			>1 mile from known uranium deposit																
239623	Chip channel	South side Todilto Wash, Todilto Park, McKinley County (unsurveyed).	0	5	0	0	0	12	0	0	1	0	b	0	13	......	13	0	0
238838	do	NW¼ sec. 12, T. 15 N., R. 17 W., McKinley County.	0	6	0	0	0	11	0	0	1	0	0	0	12	ND	14	0	0
238820	Grab	In pit, center W½W½ sec. 17, T. 14 N., R. 12 W., McKinley County.	0	4	0	0	0	10	0	0	1	0	0	0	13	ND	13	0	0
238821	do	do	0	4	0	0	0	10	0	0	1	0	0	14	13	ND	13	0	0
238822	do	do	0	4	0	0	Tr.	9	0	0	1	0	0	14	13	ND	13	0	0
238843	do	do	0	3	0	0	0	9	0	0	1	0	0	0	13	ND	13	0	0
238812	do	In pit, SE¼SE¼NW¼, sec. 28, T. 10 N., R. 9 W., Valencia County.	0	5	0	0	0	10	0	0	1	0	0	0	12	ND	14	0	0
238813	do	do	0	5	0	0	0	11	0	0	1	0	0	0	14	ND	14	0	0
238824	Chip channel	NW¼SE¼ sec. 4, T. 8 N., R. 5 W., Valencia County.	0	6	0	0	0	9	0	0	1	0	0	0	14	ND	13	0	0
238825	do	SW¼ sec. 34, T. 9 N., R. 5 W., Valencia County.	0	5	0	0	0	9	0	0	1	0	0	0	13	ND	14	0	0
238839	Grab	Center S½S½S½ sec. 14, T. 9 N., R. 5 W., Valencia County.	0	4	0	0	0	11	0	0	1	0	0	0	13	ND	13	0	0
252607	Chip channel	NE¼NW¼ sec. 7, T. 9 N., R. 4 W., Valencia County.	0	5	0	0	0	10	0	0	1	0	b	0	13	......	14	0	0
252609	do	NE¼ sec. 12, T. 9 N., R. 5 W., Valencia County.	0	4	0	0	0	8	0	0	1	0	b	0	13	......	14	0	0
252610	do	do	0	5	0	0	0	11	0	0	1	0	b	0	13	......	14	0	0
252616	do	SW¼ sec. 13, T. 15 N., R. 1 E., Sandoval County.	0	5	0	0	0	12	0	0	1	0	b	0	13	......	13	0	0
252613	do	SW¼ sec. 13, T. 16 N., R. 1 W., (projected), Sandoval County.	0	3	0	0	Tr.	10	0	0	1	0	b	0	12	......	12	0	0
252614	do	do	0	5	0	0	0	10	0	0	1	0	b	0	14	......	13	0	0
252615	Grab	do	0	5	0	0	0	11	0	0	1	0	b	0	14	......	13	0	0
239624	Chip channel	NW¼ sec. 17, T. 23 N., R. 1 E., Rio Arriba County.	0	5	0	0	0	11	0	0	1	0	b	0	14	......	13	0	0
252611	do	NE¼NW¼ sec. 8, T. 24 N., R. 4 E., Rio Arriba County.	0	5	0	0	0	11	0	0	1	0	b	0	14	......	13	0	0
246068	do	NE¼ sec. 25, T. 11 N., R. 5 E., Bernalillo County.	0	4	0	0	0	9	0	0	1	0	......	0	13	......	12	0	0
246070	do	SE¼ sec. 28, T. 25 N., R. 4 E., Rio Arriba County.	0	5	0	0	0	12	0	0	1	0	......	0	13	......	12	0	0

Sample	Type of sample	Location	Spectrographic [1]																	
			Eu	F	Fe	Ga	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn	Mo
			Mineralized ground																	
238805	Drill-hole cuttings.	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	6	8	0
238810	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	5	0	0	ND	5	7	0
238840	do	NW¼NW¼NE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238847	Chip channel	SE¼NE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	ND	ND	6	0	0	0	0	0	ND	0	0	0	0	0	ND	5	7	0
238849	do	SW¼SW¼SE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	5	0	0	ND	6	8	0
			>25 feet and <500 feet from known uranium deposit																	
238819	Drill-hole cuttings.	SE¼SE¼ sec. 23, T. 13 N., R. 10 W., McKinley County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238848	do	SW¼SW¼SW¼ sec. 3, T. 12 N., R. 9 Valencia County.	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238806	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	7	0
238809	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
2388[illegible]8	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238829	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238830	do	do	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238831	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238832	do	do	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238833	do	do	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	6	8	0
238834	do	do	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	7	0
238835	do	do	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	6	7	0
238823	Chip channel	SW¼ sec. 8, T. 8 N., R. 5 W., Valencia. County.	ND	ND	7	0	0	0	0	0	ND	0	0	0	0	0	ND	5	9	0

See footnote at end of table.

Table 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone, northwestern New Mexico and northeastern Arizona*—Continued

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Spectrographic [1]																	
			Eu	F	Fe	Ga	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn	Mo
>500 feet and <1 mile from known uranium deposit																				
239622	Chip channel	By road, west side Horse Mesa, Apache County, Arizona.	......	......	8	0	0	0	0	0	......	0	0	0	0	0	......	6	8	0
246069	do	Roadcut± 1,000 feet NW¼ Joe Ben 3, San Juan County (unsurveyed).	......	......	6	0	0	0	0	0	......	0	0	4	0	0	......	5	8	0
238841	do	NW¼NE¼ sec. 33, T. 9 N., R. 5 W., Valencia County.	ND	ND	6	0	0	0	0	0	ND	0	0	5	0	0	ND	4	8	0
238850	do	Center S½ sec. 22, T. 9 N., R. 5 W., Valencia County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	4	7	0
238814	Drill-hole cuttings.	Sec. 23, T. 13 N., R. 10 W., McKinley County.	ND	ND	5	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	5	8	0
238815	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	5	8	0
238816	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	6	8	0
238817	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	5	8	0
238818	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	5	8	0
238836	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	5	8	0
238837	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	5	8	0
>1 mile from known uranium deposit																				
239623	Chip channel	South side Todilto Wash, Todilto Park McKinley County (unsurveyed).	......	......	7	0	0	0	0	0	......	0	0	0	0	0	......	5	8	0
238838	do	NW¼ sec. 12, T. 15 N., R. 17 W., McKinley County.	ND	ND	7	0	0	0	0	0	ND	0	0	0	0	0	ND	6	7	0
238820	Grab	In pit ,center W½W½ sec. 17, T. 14 N., R. 12 W., McKinley County.	ND	ND	7	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	5	8	0
238821	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	4	8	0
238822	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	3	0	0	ND	4	7	0
238843	do	do	ND	ND	6	Tr.	0	0	0	0	ND	0	0	4	0	0	ND	4	8	0
238812	do	In pit, SE¼SE¼NW¼, sec. 28, T. 10 N., R. 9 W., Valencia County.	ND	ND	7	0	0	0	0	0	ND	0	0	0	0	0	ND	5	8	0
238813	do	do	ND	ND	7	0	0	0	0	0	ND	0	0	0	0	0	ND	5	7	0
238824	Chip channel	NW¼SE¼ sec. 4, T. 8 N., R. 5 W., Valencia County.	ND	ND	7	0	0	0	0	0	ND	0	0	0	0	0	ND	5	9	0
238825	do	SW¼ sec. 34,T. 9 N., R.5 W., Valencia County.	ND	ND	7	0	0	0	0	0	ND	0	0	0	0	0	ND	4	8	0
238839	Grab	Center S½S½S½ sec. 14, T. 9 N., R. 5 W., Valencia County.	ND	ND	6	0	0	0	0	0	ND	0	0	5	0	0	ND	5	7	0
252607	Chip channel	NE¼NW¼ sec. 7, T. 9 N., R. 4 W., Valencia County.	0	......	7	0	0	0	0	0	0	0	0	0	0	0	0	6	7	0
252609	do	NE¼ sec. 12, T. 9 N., R., 5 W., Valencia County.	0	......	6	0	0	0	0	0	0	0	0	0	0	0	0	5	8	0
252610	do	do	0	......	7	0	0	0	0	0	0	0	0	4	0	0	0	6	8	0
252616	do	SW¼ sec. 13, T. 15 N., R. 1 E., Sandoval County.	0	......	6	0	0	0	0	0	0	0	0	5	0	0	0		9	0
252613	do	SW¼ sec. 13 T. 16 N., R. 1 W., (projected), Sandoval County.	0	......	6	Tr.	0	0	0	0	0	0	0	3	0	0	0	5	9	0
252614	do	do	0	......	7	0	0	0	0	0	0	0	0	0	0	0	0	5	9	0
252615	Grab	do	0	......	7	0	0	0	0	0	0	0	0	0	0	0	0	6	8	0
239624	Chip channel	NW¼ sec. 17, T. 23 N., R. 1 E., Rio Arriba County.	......	......	7	0	0	0	0	0	......	0	0	0	0	0	......	5	9	0
252611	do	NE¼NW¼ sec. 8, T. 24 N., R. 4 E., Rio Arriba County.	0	......	7	0	0	0	0	0	0	0	0	0	0	0	0	5	9	0
246068	do	NE¼ sec. 25, T. 11 N., R. 5 E., Bernalillo County.	......	......	6	0	0	0	0	0	......	0	0	a	0	0	......	4	9	0
246070	do	SE¼ sec. 28, T. 25 N., R. 4 E., Rio Arriba County.	......	......	6	0	0	0	0	0	......	0	0	4	0	0	......	5	9	0

Sample	Type of sample	Location	Spectrographic [1]																	
			Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc	Si	Sn
Mineralized ground																				
238805	Drill-hole cuttings.	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238810	do	do	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	3	0
238840	do	NW¼NW¼NE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	5	0	0	14	0	0	13	0	ND	0	ND	0	0	0	0	0	2	0
238847	Chip channel	SE¼NE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	6	0	0	0	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	3	0
238849	do	SW¼SW¼SE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	6	0	0	14	0	0	12	0	ND	0	ND	0	0	0	0	0	3	0

See footnote at end of table.

TABLE 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone, northwestern New Mexico and northeastern Arizona*—Continued

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Spectrographic [1]—Continued																	
			Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc	Si	Sn
>25 feet and <500 feet from known uranium deposit																				
238819	Drill-hole cuttings.	SE¼SE¼ sec. 23, T. 13 N., R. 10 W., McKinley County.	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238848	do	SW¼SW¼SW¼ sec. 3, T. 12 N., R. 9 W., Valencia County.	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238806	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238809	do	do	5	0	0	0	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238828	do	do	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238829	do	do	4	0	0	14	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238830	do	do	4	0	0	14	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238831	do	do	4	0	0	14	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238832	do	do	4	0	0	14	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238833	do	do	4	0	0	14	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238834	do	do	4	0	0	13	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238835	do	do	4	0	0	14	0	0	13	0	ND	0	ND	0	0	0	0	0	1	0
238823	Chip channel	SW¼ sec. 8, T. 8 N., R. 5 W., Valencia County.	6	0	0	Tr.	0	0	0	0	ND	0	ND	0	0	0	0	0	4	0
>500 feet and <1 mile from known uranium deposit																				
239622	Chip channel	By road, westside Horse Mesa, Apache County, Ariz.	7	0	0	0	0	0	0	0	------	0	------	0	0	0	0	0	4	0
246069	do	Roadcut ±1,000 feet northwest of Joe Ben 3, San Juan County (unsurveyed).	6	0	0	14	0	0	Tr.	0	------	0	------	0	0	0	0	0	2	0
238841	do	NW¼NE¼ sec. 33, T. 9 N., R. 5 W., Valencia County.	4	0	0	14	0	0	13	0	ND	0	ND	0	0	0	0	0	3	0
238850	do	Center S½ sec. 22, T. 9 N., R. 5 W., Valencia County.	3	0	0	13	0	0	0	0	ND	0	ND	0	0	0	0	0	3	0
238814	Drill-hole cuttings.	Sec. 23, T. 13 N., R. 10 W., McKinley County.	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238815	do	do	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238816	do	do	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238817	do	do	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238818	do	do	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238836	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	1	0
238837	do	do	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	
>1 mile from known uranium deposit																				
239623	Chip channel	South side Todilto Wash, Tedilto Park, McKinley County (unsurveyed).	6	0	0	0	0	0	0	0	------	0	------	0	0	0	0	0	3	
238838	do	NW¼ sec. 12, T. 15 N., R. 17 W., McKinley County.	6	0	0	0	0	0	0	0	ND	0	ND	0	0	0	0	0	3	0
238820	Grab	In pit, center W½W½ sec. 17, T. 14 N., R. 12 W., McKinley County.	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238821	do	do	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238822	do	do	4	0	0	14	0	0	Tr.	0	ND	0	ND	0	0	0	0	0	1	0
238843	do	do	5	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	2	0
238812	do	In pit, SE¼SE¼NW¼, sec. 28, T. 10 N., R. 9 W., Valencia County.	7	0	0	0	0	0	0	0	ND	0	ND	0	0	0	0	0	4	0
238813	do	do	5	0	0	0	0	0	0	0	ND	0	ND	0	0	0	0	0	3	0
238824	Chip channel	NW¼SE¼ sec. 4, T. 8 N., R. 5 W., Valencia County.	6	0	0	Tr.	0	0	0	0	ND	0	ND	0	0	0	0	0	4	0
238825	do	SW¼ sec. 34, T. 9 N., R. 5 W., Valencia County.	6	0	0	Tr.	0	0	0	0	ND	0	ND	0	0	0	0	0	4	0
238839	Grab	Center S½S½S½ sec. 14, T. 9 N., R. 5 W., Valencia County.	4	0	0	14	0	0	0	0	ND	0	ND	0	0	0	0	0	3	0
252607	Chip channel	NE¼NW¼ sec. 7, T. 9 N., R. 4 W., Valencia County.	7	0	c	0	0	0	0	0	------	0	------	0	0	0	0	0	3	0
252609	do	NE¼ sec. 12, T. 9 N., R. 5 W., Valencia County.	6	0	c	14	0	0	0	0	------	0	------	0	0	0	0	0	2	0
252610	do	do	6	0	c	15	0	0	0	0	------	0	------	0	0	0	0	0	3	0
252616	do	SW¼ sec. 13, T. 15 N., R. 1 E., Sandoval County.	6	0	c	14	0	0	0	0	------	0	------	0	0	0	0	0	3	0
252613	do	SW¼ sec. 13, T. 16 N., R. 1 W., (projected), Sandoval County.	5	0	c	13	0	0	0	0	------	0	------	0	0	0	0	0	2	0
252614	do	do	7	0	c	14	0	0	0	0	------	0	------	0	0	0	0	0	3	0
252615	Grab	do	7	0	c	0	0	0	0	0	------	0	------	0	0	0	0	0	3	0
239624	Chip channel	NW¼ sec. 17, T. 23 N., R. 1 E., Rio Arriba County.	7	0	0	0	0	0	0	0	------	0	------	0	0	0	0	0	4	0
252611	do	NE¼NW¼ sec. 8, T. 24 N., R. 4 E., Rio Arriba County.	7	0	c	15	0	0	0	0	------	0	------	0	0	0	0	0	3	0
246068	do	NE¼ sec. 25, T. 11 N., R. 5 E., Bernalillo County.	6	0	0	14	0	0	14	0	------	0	------	0	0	0	0	0	3	0
246070	do	SE¼ sec. 28. T. 25 N., R. 4 E., Rio Arriba County.	6	0	0	14	0	0	Tr.	0	------	0	------	0	0	0	0	0	4	0

See footnote at end of table.

TABLE 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone, northwestern New Mexico and northeastern Arizona*—Continued

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Spectrographic [1]—Continued															
			Sr	Sm	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
		Mineralized ground																
238805	Drill-hole cuttings.	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	10	0	0	ND	0	0	8	0	ND	0	7	0	0	......	0	11
238810	do	do	9	0	0	ND	0	0	9	0	ND	0	8	0	0	......	0	11
238840	do	NW¼NW¼NE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	8	0	0	ND	0	0	8	0	ND	0	9	0	Tr.	0	0	10
238847	Chip channel	SE¼NE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	8	0	0	ND	0	0	9	0	ND	0	9	0	0	0	0	12
238849	do	SW¼SW¼SE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	9	0	0	ND	0	0	9	0	ND	7	8	0	0	......	0	12
		>25 feet and <500 feet from known uranium deposit																
238819	Drill-hole cuttings.	SE¼SE¼ sec. 23, T. 13 N., R. 10 W., McKinley County.	9	0	0	ND	0	0	8	0	ND	0	8	0	0	......	0	11
238848	do	SW¼SW¼SW¼ sec. 3, T. 12 N., R. 9 W., Valencia County.	9	0	0	ND	0	0	8	0	ND	0	12	0	Tr.	0	0	11
238806	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	10	0	0	ND	0	0	8	0	ND	0	9	0	Tr.	16	0	11
238809	do	do	9	0	0	ND	0	0	8	0	ND	0	8	0	0	......	0	11
238828	do	do	9	0	0	ND	0	0	8	0	ND	0	9	0	13	16	0	10
238829	do	do	9	0	0	ND	0	0	8	0	ND	0	9	0	13	16	0	11
238830	do	do	9	0	0	ND	0	0	8	0	ND	0	9	0	13	15	0	9
238831	do	do	9	0	0	ND	0	0	8	0	ND	0	10	0	13	16	0	11
238832	do	do	9	0	0	ND	0	0	8	0	ND	0	10	0	Tr.	16	0	11
238833	do	do	9	0	0	ND	0	0	8	0	ND	0	8	0	Tr.	......	0	10
238834	do	do	9	0	0	ND	0	0	8	0	ND	0	10	0	13	16	0	9
238835	do	do	9	0	0	ND	0	0	8	0	ND	0	10	0	13	16	0	11
238823	Chip channel	SW¼ sec. 8, T. 8 N., R. 5 W., Valencia County.	8	0	0	ND	0	0	10	0	ND	0	11	0	0	0	0	13
		>500 feet and <1 mile from known uranium deposit																
239622	Chip channel	By road, west side Horse Mesa, Apache County, Ariz.	10	0	0	......	0	0	11	0	......	0	13	0	0	0	0	13
246069	do	Roadcut ±1,000 feet northwest of Joe Ben 3, San Juan County (unsurveyed).	9	0	0	......	0	0	9	0	......	0	10	0	0	0	0	12
238841	do	NW¼NE¼ sec. 33, T. 9 N., R. 5 W., Valencia County.	8	0	0	ND	0	0	9	0	ND	0	11	0	0	0	0	12
238850	do	Center S½ sec. 22, T. 9 N., R. 5 W., Valencia County.	8	0	0	ND	0	0	8	0	ND	0	12	0	0	0	0	10
238814	Drill-hole cuttings.	Sec. 23, T. 13 N., R. 10 W., McKinley County.	8	0	0	ND	0	0	8	0	ND	0	11	0	Tr.	0	0	11
238815	do	do	8	0	0	ND	0	0	8	0	ND	0	11	0	Tr.	0	0	11
238816	do	do	10	0	0	ND	0	0	8	0	ND	0	10	0	0	0	0	11
238817	do	do	8	0	0	ND	0	0	8	0	ND	0	11	0	Tr.	0	0	11
238818	do	do	8	0	0	ND	0	0	8	0	ND	0	8	0	0	......	0	10
238836	do	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	8	0	0	ND	0	0	8	0	ND	0	11	0	Tr.	......	0	11
238837	do	do	8	0	0	ND	0	0	8	0	ND	0	9	0	Tr.	0	0	11
		>1 mile from known uranium deposit																
239623	Chip channel	South side Todilto Wash, Todilto Park, McKinley County (unsurveyed).	9	0	0	......	0	0	10	0	......	0	13	0	0	0	0	12
238838	do	NW¼ sec. 12, T. 15 N., R. 17 W., McKinley County.	9	ND	0	ND	0	0	11	0	ND	0	12	0	0	0	0	11
238820	Grab	In pit, center W½W½ sec. 17, T. 14 N., R. 12 W., McKinley County.	8	ND	0	ND	0	0	8	0	ND	0	12	0	0	0	0	11
238821	do	do	8	ND	0	ND	0	0	8	0	ND	0	12	0	0	0	0	11
238822	do	do	9	ND	0	ND	0	0	8	0	ND	0	11	0	13	16	0	10
238843	do	do	8	ND	0	ND	0	0	8	0	ND	0	12	0	Tr.	0	0	11
238812	do	In pit, SE¼SE¼NW¼, sec. 28, T. 10 N., R. 9 W., Valencia County.	9	ND	0	ND	0	0	10	0	ND	0	12	0	0	0	0	13
238813	do	do	9	ND	0	ND	0	0	9	0	ND	0	12	0	0	0	0	11
238824	Chip channel	NW¼SE¼ sec 4, T. 8 N., R. 5 W., Valencia County.	9	ND	0	ND	0	0	10	0	ND	0	12	0	0	0	0	13
238825	do	SW¼ sec. 34, T. 9 N., R. 5 W., Valencia County.	8	ND	0	ND	0	0	9	0	ND	0	12	0	Tr.	0	0	12
238839	Grab	Center S½S½S½ sec. 14, T. 9 N., R. 5 W., Valencia County.	8	ND	0	ND	0	0	9	0	ND	0	12	0	0	0	0	11
252607	Chip channel	NE¼NW¼ sec. 7, T. 9 N., R. 4 W., Valencia County.	9	0	0	0	0	0	10	0	0	0	13	0	0	0	0	0
252609	do	NE¼ sec. 12, T. 9 N., R. 5 W., Valencia County.	9	0	0	0	0	0	8	0	0	0	12	0	0	0	0	11

See footnote at end of table.

TABLE 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone, northwestern New Mexico and northeastern Arizona*—Continued

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Spectrographic [1]—Continued															
			Sr	Sm	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
		>1 mile from known uranium deposit—Continued																
252610	Chip channel	NE¼ sec. 12, T. 9 N., R. 4 W., Valencia County.	8	0	0	0	0	0	9	0	0	0	13	0	0	0	0	12
252616	do	SW¼ sec. 13, T. 15 N., R. 1 E., Sandoval County.	9	0	0	0	0	0	10	0	0	0	12	0	0	0	0	12
252613	do	SW¼ sec. 13, T. 16 N., R. 1 W., (projected), Sandoval County.	8	0	0	0	0	0	7	0	0	0	11	0	13	16	0	11
252614	do	do	7	0	0	0	0	0	10	0	0	0	12	0	0	0	0	13
252615	Grab	do	7	0	0	0	0	0	10	0	0	0	12	0	0	0	0	13
239624	Chip channel	NW¼ sec. 17, T. 23 N., R. 1 E., Rio Arriba County.	9	0	0		0	0	10	0		0	13	0	0	0	0	14
252611	do	NE¼NW¼ sec. 8, T. 24 N., R. 4 E., Rio Arriba County.	8	0	0	0	0	0	9	0	0	0	12	0	0	0	0	12
246068	do	NE¼ sec. 25, T. 11 N., R. 5 E., Bernalillo County.	9	0	0		0	0	9	0		0	11	0	0	0	0	12
246070	do	SE¼ sec. 28, T. 25 N., R. 4 E., Rio Arriba County.	9	0	0		0	0	9	0		0	12	0	0	0	0	13

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Radiometric	Chemical								
			eU [2]	U [3]	V_2O_5 or V [4]	S [5]	P_2O_5 [6]	C [7] (organic)	As [8]	F [9]	Se [10]	Zn [11]
			Parts per million		Percent				Parts per million			
		Mineralized ground										
238805	Drill-hole cuttings.	SE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	60	55	ND	0.03	0.032	ND	<5	100	2.0	<10
238810	do	do	10	9	ND	.05	.029	ND	<5	120	1.0	<10
238840	do	NW¼NW¼NE¼ sec. 30, T. 13 N., R. 9 W., McKinley County.	30	58	ND	.05	.020	ND	<5	150	12.0	20
238847	Chip channel	SE¼NE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	50	58	ND	.07	.029	ND	<5	420	.5	<10
238849	do	SW¼SW¼SE¼ sec. 4, T. 12 N., R. 9 W., Valencia County.	1,300	1,600	ND	.11	.044	ND	50	240	8.0	10
		>25 feet and <500 feet from known uranium deposit										
238819	Drill-hole cuttings.	SE¼SE¼ sec. 23, T. 13 N., R. 10 W., McKinley County.	20	12	ND	0.09	0.027	ND	<5	70	0.5	<1
238848	do	SW¼SW¼SW¼ sec. 3, T. 12 N., R. 9 W., Valencia County.	<10	8	ND	.07	.025	ND	<5	660	<.5	<10
238806	do	SE¼ sec. 30, T. 13 N., R. 9 W., Kinley County.	20	19	ND	.05	.038	ND	<5	100	<.5	<10
238809	do	do	25	25	ND	.05	.035	ND	<5	100	2.0	<10
238828	do	do	10	9	ND	.04	.033	ND	5	70	<.5	<10
238829	do	do	20	10	ND	.03	.037	ND	<5	100	<.5	10
238830	do	do	30	4	ND	.05	.044	ND	<5	150	<.5	20
238831	do	do	<10	29	ND	.05	.030	ND	6	90	.5	20
238832	do	do	<10	8	ND	.05	.035	ND	6	90	<.5	30
238833	do	do	<10	8	ND	.04	.038	ND	5	90	<.5	10
238834	do	do	10	10	ND	.04	.038	ND	6	60	1.0	10
238835	do	do	<10	12	ND	.05	.033	ND	8	280	2.0	10
238823	Chip channel	SW¼ sec. 8, T. 8 N., R. 5 W., Valencia County.	<10	3	ND	.08	.024	ND	<5	170	<.5	<10
		>500 feet and <1 mile from known nranium deposit										
239622	Chip channel	By road, westside Horse Mesa, Apache County, Ariz.	<100	9		0.07	0.017	0.27		80	<0.5	
246069	do	Road cut ±1,000 feet northwest of Joe Ben 3, San Juan County (unsurveyed).	60	60	<0.05	.09	.030	.20	24	130	<.5	<1
238841	do	NW¼NE¼ sec. 33, T. 9 N., R. 5 W., Valencia County.	<10	4	ND	.02	.024	ND	<5	120	1.0	<10
238850	do	Center S½ sec. 22, T. 9 N., R. 5 W., Valencia County.	10	14	ND	.07	.026	ND	<5	120	.5	10
238814	Drill-hole cuttings.	Sec. 23, T. 13 N., R. 10 W., McKinley County.	10	5	ND	.06	.040	ND	<5	140	<.5	<10
238815	do	do	10	5	ND	.09	.038	ND	<5	220	<.5	
238816	do	do	30	29	ND	.07	.036	ND	<5	140	2.0	<10
238817	do	do	<10	4	ND	.07	.035	ND	<5	140	<.5	<10
238818	do	do	<10	6	ND	.06	.039	ND	<5	230	.5	<10
238836	do	SE¼ sec. 30, T. 13 N., R. 9 W., Kinley County.	20	9	ND	.07	.039	ND	<5	110	25.0	<10 30
238837	do	do	<10	24	ND	.07	.027	ND	<5	130	12.0	20

See footnotes at end of table.

TABLE 11.—*Semiquantitative spectrographic, radiometric, and chemical analyses of samples of barren and uraniferous Todilto Limestone northwestern New Mexico and northeastern Arizona*—Continued

Sample	Type of sample	Location (Counties are in New Mexico unless otherwise indicated. See pl. 3.)	Radiometric	Chemical								
			eU [2]	U [3]	V_2O_5 or V [4]	S [5]	P_2O_5 [6]	C [7] (organic)	As [8]	F [9]	Se [10]	Zn [11]
			Parts per million		Percent				Parts per million			
			>1 mile from known uranium deposit									
239623	Chip channel	South side Todilto Wash, Todilto Park, McKinley County (unsurveyed).	<10	2	......	0.07	0.017	0.55	......	120	0.5	......
238838	do	NW¼ sec. 12, T. 15 N., R. 17 W., McKinley County.	<10	1	ND	.03	.016	ND	<5	30	<.5	<10
238820	Grab	In pit, center W½W½ sec. 17, T. 14 N., R. 12 W., McKinley County.	<10	2	ND	.10	.038	ND	<5	220	<.5	<10
238821	do	do	<10	2	ND	.05	.038	ND	<5	200	<.5	<10
238822	do	do	<10	6	ND	.05	.033	ND	<5	160	.5	<10
238843	do	do	<10	1	ND	.06	.037	ND	<5	150	.5	10
238812	do	In pit, SE¼SE¼NW¼ sec. 28, T. 10 N, R. 9 W., Valencia County.	<10	4	ND	.07	.019	ND	<5	60	<.5	10
238813	do	do	<10	2	ND	.06	.022	ND	<5	60	<.5	<10
238824	Chip channel	NW¼SE¼ sec. 4, T. 8 N., R. 5 W., Valencia County.	<10	3	ND	.08	.022	ND	<5	70	<.5	<10
238825	do	SW¼ sec. 34, T. 9 N., R. 5 W., Valencia County.	<10	2	ND	.10	.030	ND	<5	90	2.0	30
238839	Grab	Center S½S½S½ sec. 14, T. 9 N., R. 5 W., Valencia County.	<10	2	ND	.06	.031	ND	<5	90	.5	10
252607	Chip channel	NE¼NW¼ sec. 7, T. 9 N., R. 4 W., Valencia County.	<10	8	<.05	.11	.018	<.3	30	<20	1	9
252609	do	NE¼ sec 12, T. 9 N., R. 5 W., Valencia County.	<10	3	<.05	1.23	.048	.5	<5	120	1	10
252610	do	do	<10	5	<.05	.21	.037	.6	<5	90	1	4
252616	do	SW¼ sec. 13, T. 15 N., R. 1 E., Sandoval County.	<10	5	<.05	.38	.027	.9	<5	80	.5	18
252613	do	SW¼ sec. 13, T. 16 N., R. 1 W., (projected), Sandoval County.	<10	5	<.05	.30	.029	.5	<5	420	2	10
252614	do	do	<10	6	<.05	.40	.026	.9	<5	40	1	14
252615	Grab	do	20	4	<.05	.19	.029	.9	<5	40	2	3
239624	Chip channel	NW¼ sec. 17, T. 23 N., R. 1 E., Rio Arriba County.	<10	2	......	.22	.026	.40	......	170	<.5	......
252611	do	NE¼NW¼ sec. 8, T. 24 N., R. 4 E., Rio Arriba County.	<10	3	<.05	.84	.033	1.0	<5	80	.5	11
246068	do	NE¼ sec. 25, T. 11 N., R. 5 E., Bernalillo County.	ND	6	(<.001)	.98	<.05	.51	800	140	<1.0	14
246070	do	SE¼ sec. 28, T. 25 N., R. 4 E., Rio Arriba County.	20	......	<.05	.45	.037	1.59	8	230	<.5	6

[1] Analysts: N. M. Conklin, sample 246068; R. G. Havens, samples 239622–239624, inclusive; all other samples by J. C. Hamilton.

[2] Analysts: C. G. Angelo, samples 246069–246070 and 252607–252617, inclusive; all other samples by personnel under the general direction of L. F. Rader, Jr.

[3] Analysts: R. P. Cox, samples 252607–252617, inclusive; D. L. Ferguson, sample 246068; H. H. Lipp, samples 246069 and 246070; all other samples by personnel under the general direction of L. F. Rader, Jr. Fluorimetric method.

[4] Analysts: C. A. Horr, sample 246068; H. H. Lipp, samples 246069 and 246070; J. S. Wahlberg, samples 252607–252617, inclusive; all other samples by personnel under the general direction of L. F. Rader, Jr. Volumetric method.

[5] Analysts: G. T. Burrow, samples 252607–252617, inclusive; C. A. Horr, sample 246068; E. C. Mallory, samples 246069–246070 and 238805–238850, inclusive; all other samples by personnel under the general direction of L. F. Rader, Jr. Gravimetric method.

[6] Analysts: D. L. Ferguson, samples 252607–252617, inclusive: L. F. Rader, Jr., samples 239622–239624, inclusive, and sample 246069; L. F. Rader, Jr., and H. H. Lipp, samples 238805–238850, inclusive; J. P. Schuch, samples 246068 and 246070. Volumetric method.

[7] C. A. Horr, sample 246068; Wayne Mountjoy, samples 246069–246070 and 252607–252617, inclusive; all other samples by personnel under the general direction of L. F. Rader, Jr. Rapid scanning, CO_2 method.

[8] Analysts: C. A. Horr, sample 246068; Claude Huffman, samples 252607–252617 and 238805–238850, inclusive; J. E. Wilson, samples 246069 and 246070. Colorimetric method.

[9] Analysts: R. P. Cox, samples 238805–238850 and 246068–246069, inclusive; W. D. Goss, samples 252607–252617, inclusive; all other samples by personnel under the general direction of L. F. Rader, Jr. Colorimetric method.

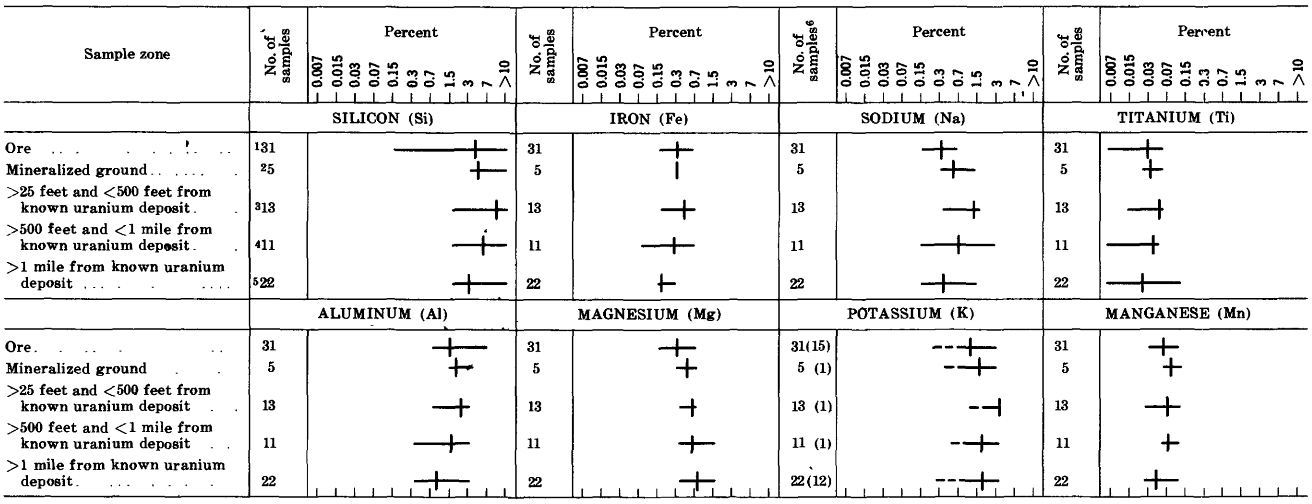
[10] Analysts: G. T. Burrow, samples 246069–246070 and 252607–252617, inclusive; C. A. Horr, sample 246068; all other samples by personnel under the general direction of L. F. Rader, Jr. Colorimetric method.

[11] Analysts: G. T. Burrow and H. H. Lipp, samples 238805–238850, inclusive; C. A. Horr, sample 246068; Claude Huffman, samples 252607–252617, inclusive; J. S. Wahlberg samples 246069 and 246070. Colorimetric method.

The samples for the graphs of tables 12–14 are arranged in five groups or zones, ranging from the ore zone to a zone more than 1 mile from known uranium deposits. This outer zone is presumed to contain the average concentrations of uranium and other elements that were originally included in the host rock. The ore zone is represented by the mill pulp samples listed in table 6 and referred to in the preceding section. Samples representing the other four zones are listed in table 11. The mineralized zone is represented by samples taken within 25 feet of known limits of a mined ore body or within 25 feet of a sample containing at least 0.1 percent uranium. This rather narrow zone was selected to show significant changes in the immediate periphery of ore—in what might be considered part of the uranium deposit. The other zones (>25 feet and <500 feet, >500 feet and <1 mile, and >1 mile from known uranium deposits) were selected rather arbitrarily to obtain as many sample zones between ore and nearly barren rock as possible. The number of such zones is limited by the number of samples taken. Obviously, the exact limiits of ore are rather indeterminate, and certainly not all uranium deposits or ore bodies were known when the samples were selected. Moreover, the limits of the three zones between ore and barren ground are rather sketchy because of the limited number of samples. Nevertheless, the sample control should be adequate (see pl. 3) to show significant contrasts for most elements in the different zones.

TABLE 12.—*Ranges of concentration and the geometric means of eight major elements in the ores and in four zones away from ore in the Todilto Limestone*

[All analyses are spectrographic. Samples reported as >10 are assumed to be 15, which is the next higher number in the series 1.5, 3, 7]



[1] Includes 8 samples reported as >10.
[2] Includes 1 sample reported as >10.
[3] Includes 11 samples reported as >10.
[4] Includes 2 samples reported as >10.
[5] Includes 1 sample reported as >10.
[6] Number in parentheses is the number of samples below the limit of detection.

EXPLANATION

|←Range in content of samples→|
Dashed where uncertain
Geometric mean of all samples in which element detected

The graphs show a few elements that progressively decrease in concentration outward from ore, a few that increase outward, and numerous elements that show a relatively high concentration in the three zones between ore and barren ground. (See tables 12–14).

ELEMENTS THAT DECREASE IN CONCENTRATION AWAY FROM ORE

Vanadium shows the most uniform or progressive decrease outward from ore, and somewhat similar relations are shown by selenium, zinc, arsenic, and lead. In many samples these elements were below the limits of detection in the outer zones, however, so the results are somewhat speculative. Selenium (table 14) occurs principally, and in relatively high concentrations, in the sulfide minerals in most uranium ores in the sedimentary rocks of the Colorado Plateau (Coleman and Delevaux, 1957). The relatively low content of selenium in the Todilto ores (table 6), therefore, probably reflects the low sulfide content of the ores and perhaps also the low content of volcanic debris in the Todilto. Such debris is the principal source to which Coleman and Delevaux (1957) ascribe the selenium in most of the deposits in the sedimentary rocks of the Colorado Plateau. About 45 percent of the samples tested for zinc, 75 percent tested for arsenic, and 88 percent tested for lead that were peripheral to ore contained less than detectable amounts, so the suggested outward decrease of these elements away from ore is speculative. The discrepant graph for arsenic in the outer zone stems mostly from one sample (246068) that contained an anomalous 800 ppm. If this sample is disregarded, the mean concentration in the outer zone rather than being 12 ppm is 3.5 ppm, which is less than the maximum concentrations in the other four zones.

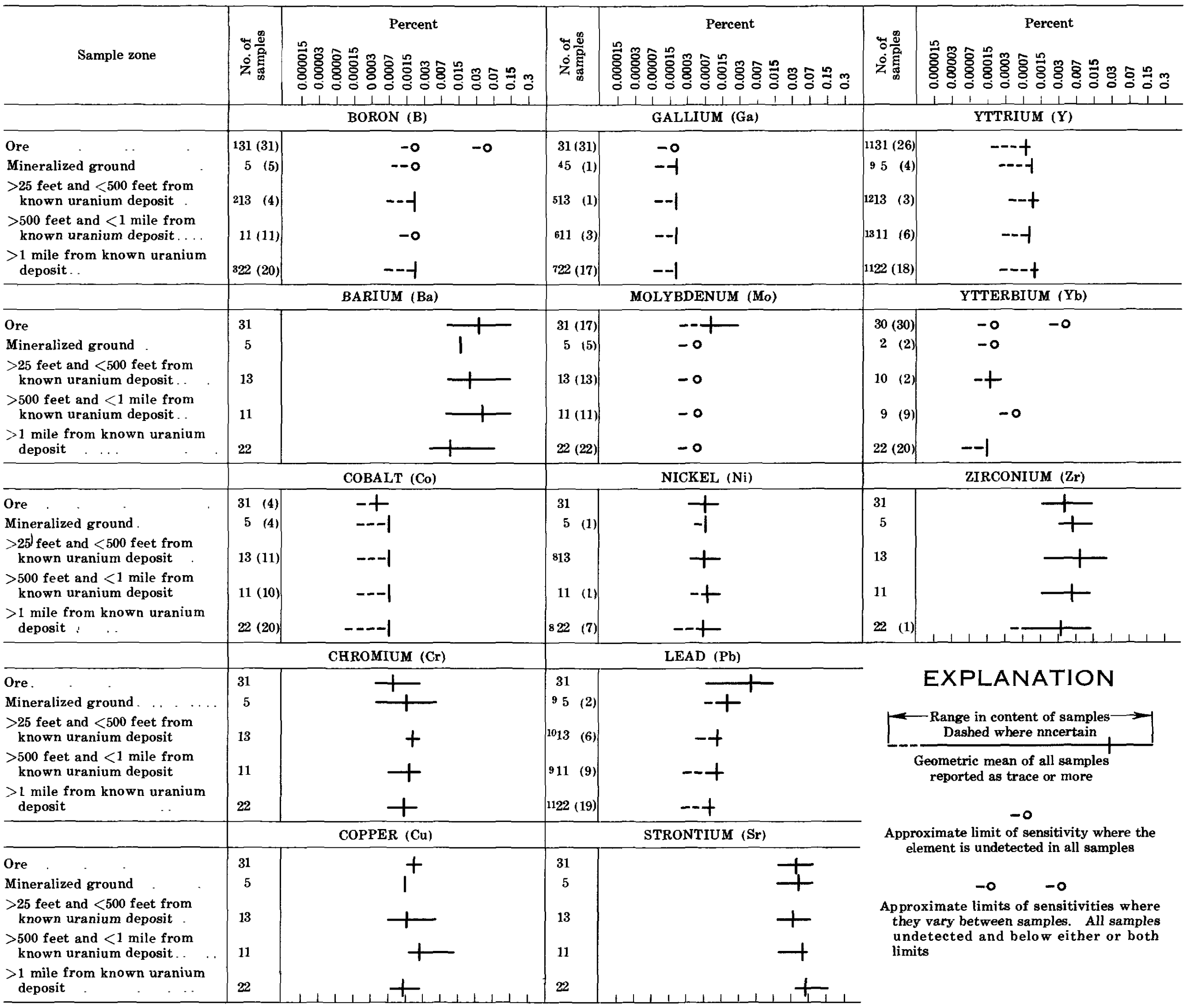
ELEMENTS THAT INCREASE IN CONCENTRATION AWAY FROM ORE

Elements that show an increase in concentration outward from ore are magnesium (table 12), organic carbon, sulfur (table 14), and possibly boron, cobalt, gallium, and ytterbium (table 13). Such relations for the latter four elements, however, are more apparent than real because of the lower sensitivity of these elements in ore to spectrographic analysis and because in many samples from the other zones these elements were below the limits of detection. The relations for magnesium are also rather uncertain because of the small range in median concentrations between zones. The relations of organic carbon deserve some comment, although the sample data pertain to only the ore zone and the two outermost zones away from ore.

Organic carbon in the form of carbonized plant debris is recognized as a precipitant or collector of uranium in many deposits in sandstone in the Colorado

TABLE 13.—*Ranges of concentrations and the geometric means of 13 minor elements in the ores and in four zones away from ore in the Todilto Limestone*

[All analyses are spectrographic. Numbers in parentheses are the number of samples below the limit of detection.]



Sample zone	No. of samples	No. of samples	No. of samples
	BORON (B)	GALLIUM (Ga)	YTTRIUM (Y)
Ore	[1]31 (31)	31 (31)	[11]31 (26)
Mineralized ground	5 (5)	[4]5 (1)	[9]5 (4)
>25 feet and <500 feet from known uranium deposit	[2]13 (4)	[5]13 (1)	[12]13 (3)
>500 feet and <1 mile from known uranium deposit	11 (11)	[6]11 (3)	[13]11 (6)
>1 mile from known uranium deposit	[3]22 (20)	[7]22 (17)	[11]22 (18)
	BARIUM (Ba)	MOLYBDENUM (Mo)	YTTERBIUM (Yb)
Ore	31	31 (17)	30 (30)
Mineralized ground	5	5 (5)	2 (2)
>25 feet and <500 feet from known uranium deposit	13	13 (13)	10 (2)
>500 feet and <1 mile from known uranium deposit	11	11 (11)	9 (9)
>1 mile from known uranium deposit	22	22 (22)	22 (20)
	COBALT (Co)	NICKEL (Ni)	ZIRCONIUM (Zr)
Ore	31 (4)	31	31
Mineralized ground	5 (4)	5 (1)	5
>25 feet and <500 feet from known uranium deposit	13 (11)	[8]13	13
>500 feet and <1 mile from known uranium deposit	11 (10)	11 (1)	11
>1 mile from known uranium deposit	22 (20)	[8]22 (7)	22 (1)
	CHROMIUM (Cr)	LEAD (Pb)	
Ore	31	31	
Mineralized ground	5	[9]5 (2)	
>25 feet and <500 feet from known uranium deposit	13	[10]13 (6)	
>500 feet and <1 mile from known uranium deposit	11	[9]11 (9)	
>1 mile from known uranium deposit	22	[11]22 (19)	
	COPPER (Cu)	STRONTIUM (Sr)	
Ore	31	31	
Mineralized ground	5	5	
>25 feet and <500 feet from known uranium deposit	13	13	
>500 feet and <1 mile from known uranium deposit	11	11	
>1 mile from known uranium deposit	22	22	

EXPLANATION

Range in content of samples
Dashed where nncertain

Geometric mean of all samples reported as trace or more

-o

Approximate limit of sensitivity where the element is undetected in all samples

-o -o

Approximate limits of sensitivities where they vary between samples. All samples undetected and below either or both limits

[1] Six samples reported as <0.05; others undetected and presumably <0.002.
[2] Nine samples reported as trace, assumed to be 0.002.
[3] Two samples reported as trace, assumed to be 0.002.
[4] Eight samples reported as trace, assumed to be 0.0002.
[5] Twelve samples reported as trace, assumed to be 0.0002.
[6] Eight samples reported as trace, assumed to be 0.0002.
[7] Five samples reported as trace, assumed to be 0.0002.
[8] Includes 1 sample reported as trace and assumed to be 0.0003.
[9] Includes 1 sample reported as trace and assumed to be 0.001.
[10] Includes 6 samples reported as trace and assumed to be 0.001.
[11] Includes 2 samples reported as trace and assumed to be 0.001.
[12] Includes 4 samples reported as trace and assumed to be 0.001.
[13] Five samples reported as trace, assumed to be 0.001.

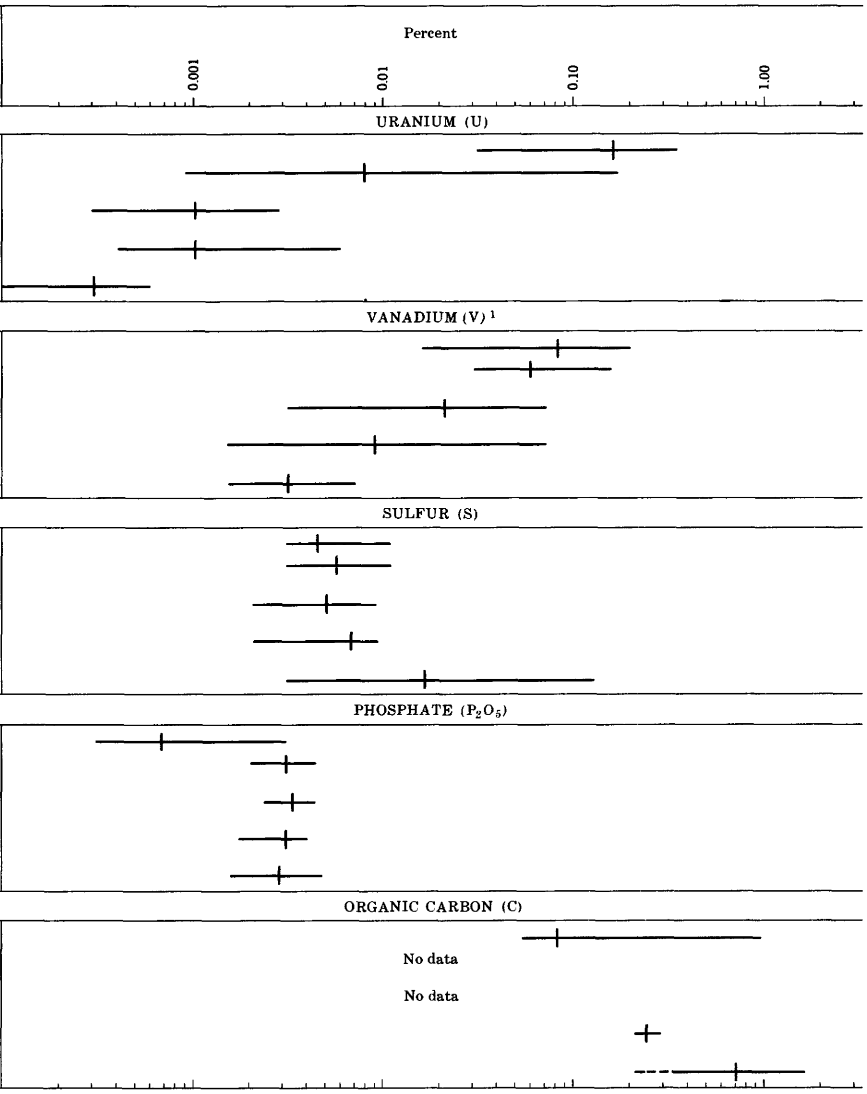
Plateau, and sedimentary rocks containing an abundance of such material are considered favorable hosts for uranium deposits. Since the time commercial uranium deposits were discovered in the Todilto Limestone there has been much speculation about the influence the carbonaceous content of the limestone had on emplacement of the deposits. This speculation was nourished by the dark-gray or nearly black color and the fetid odor emitted by the limestone when crushed. These facts led many to refer to it as petroliferous and thus to consider it carbonaceous.

As a help in clarification of this problem, all samples were analyzed for organic carbon. Unfortunately, the method used to analyze the first samples was not accurate enough to determine their content, so there are no data for the two zones near ore, and there are data for only two samples from the zone that is > 500 feet and <1 mile from uranium deposits. The results, however, show a much lower organic carbon content in ore than in each of the two outermost zones (table 14). This contrast is even more striking when the range in concentration for organic carbon in ore is

TABLE 14.—*Ranges of concentration and the geometric means of uranium, vanadium, sulfur, phosphate, organic carbon, arsenic, fluorine, selenium, and zinc, in the ores and in four zones away from ore in the Todilto Limestone*

[All analyses are chemical except for vanadium, as noted]

Sample zone	No. of samples
	URANIUM (U)
Ore	31
Mineralized ground	5
>25 feet and <500 feet from known uranium deposit	13
>500 feet and <1 mile from known uranium deposit	11
>1 mile from known uranium deposit	21
	VANADIUM (V)[1]
Ore	31
Mineralized ground	5
>25 feet and <500 feet from known uranium deposit	13
>500 feet and <1 mile from known uranium deposit	11
>1 mile from known uranium deposit	22
	SULFUR (S)
Ore	25
Mineralized ground	5
>25 feet and <500 feet from known uranium deposit	13
>500 feet and <1 mile from known uranium deposit	11
>1 mile from known uranium deposit	22
	PHOSPHATE (P_2O_5)
Ore	31
Mineralized ground	5
>25 feet and <500 feet from known uranium deposit	13
>500 feet and <1 mile from known uranium deposit	11
>1 mile from known uranium deposit	[2]22 (1)
	ORGANIC CARBON (C)
Ore	24
Mineralized ground	0
>25 feet and <500 feet from known uranium deposit	0
>500 feet and <1 mile from known uranium deposit	2
>1 mile from known uranium deposit	[3]12



[1] Sample data are spectrographic, except for ore samples which are chemical and assay 0.10 percent or more V_2O_5; these are converted from V_2O_5 to V.

[2] Number in parentheses is number of samples below limit of detection and not used.

[3] Includes 1 sample reported as <0.3 and assumed to be 0.2 percent.

[4] Includes 4 samples reported as <5 and assumed to be 3 ppm.

[5] Includes 7 samples reported as <5 and assumed to be 3 ppm.

[6] Includes 9 samples reported as <5 and assumed to be 3 ppm.

[7] Includes 17 samples reported as <5 and assumed to be 3 ppm.

[8] Includes 1 sample reported as <20 and assumed to be 10 ppm.

[9] Includes 8 samples reported as <0.5 and assumed to be 0.3 ppm.

[10] Includes 5 samples reported as <0.5 and assumed to be 0.3 ppm.

[11] Includes 8 samples reported as <0.5 and assumed to be 0.3 ppm; and 1 sample reported as <1.0 and assumed to be 0.5 ppm.

[12] Includes 3 samples reported as <10 and assumed to be 5 ppm.

[13] Includes 6 samples reported as <10 and assumed to be 5 ppm.

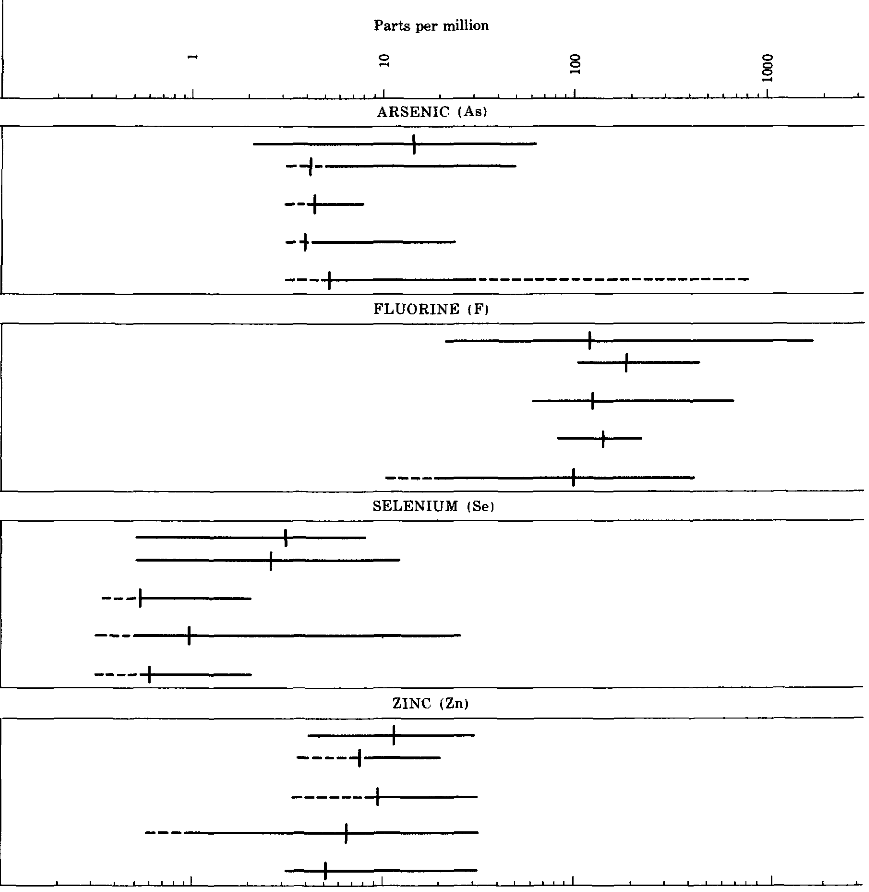
[14] Includes 6 samples reported as <10 and assumed to be 5 ppm; and 1 sample reported as <1 and assumed to be 0.5 ppm.

only from 0.05 to 0.14 percent when sample 246891 is disregarded. (See table 6.) This sample represents a deposit that contained less than 0.1 percent U_3O_8.

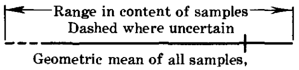
The low organic carbon content in the ore can be explained by (1) the removal of organic carbon from the sites of deposition by the ore-bearing solutions, (2) the ore favoring the limestone where it is deficient in organic carbon, or (3) simply a fortuitous relation. The favored explanation is that organic carbon was removed during emplacement of the deposits. There is no apparent reason why the ores should select the rocks that were deficient in organic carbon and there is no reason to believe that the indicated relations are fortuitous. Removal of carbon from the sites of deposition, therefore, seems reasonable, perhaps as a result of oxidation. It is doubtful that concentrations of organic carbon caused localization of the uranium deposits, but the organic carbon may have caused precipitation of the uranium at favorable structural sites by reducing the uranyl ion and by precipitating the

TABLE 14.—*Ranges of concentration and the geometric means of uranium, vanadium, sulfur, phosphate, organic carbon, arsenic, fluorine, selenium, and zinc, in the ores and in four zones away from ore in the Todilto Limestone*—Continued

Sample zone	No. of samples
ARSENIC (As)	
Ore	31
Mineralized ground	[4]5
>25 feet and <500 feet from known uranium deposit	[5]13
>500 feet and <1 mile from known uranium deposit	[6]10
>1 mile from known uranium deposit	[7]20
FLUORINE (F)	
Ore	31
Mineralized ground	5
>25 feet and <500 feet from known uranium deposit	13
>500 feet and <1 mile from known uranium deposit	11
>1 mile from known uranium deposit	[8]22
SELENIUM (Se)	
Ore	31
Mineralized ground	5
>25 feet and <500 feet from known uranium deposit	[9]13
>500 feet and <1 mile from known uranium deposit	[10]11
>1 mile from known uranium deposit	[11]22
ZINC (Zn)	
Ore	31
Mineralized ground	[12]5
>25 feet and <500 feet from known uranium deposit	[13]13
>500 feet and <1 mile from known uranium deposit	[14]10
>1 mile from known uranium deposit	[13]20



EXPLANATION



Geometric mean of all samples, except where noted

uranium in pitchblende. Apparently enough organic carbon is present to cause such reduction, provided it is in a form that is as effective a reducing agent as lignite (Garrels and Pommer, 1959, p. 163–164; and table 3).

Sulfur shows about the same range in concentration and mean concentration for each of the four inner zones. The outer or barren zone shows a much greater range in concentration and a mean concentration which is about three times that of each of the other zones. These differences may not have any significance as far as uranium is concerned because they probably are mostly a reflection of differences in the sulfate content of the host rock in different areas; the analyses represent the sulfur in both sulfides and sulfates. Relatively high concentrations of gypsum and anhydrite, particularly along the east side of the San Juan Basin, could account for the relatively high sulfur content in the outer zone. Moreover, the outer zone shows no attendant increase in iron content, which would be expected if the sulfur occurred in the sulfide pyrite.

ELEMENTS CONCENTRATED BETWEEN ORE AND BARREN GROUND

Elements that have a relatively high concentration between ore and barren ground are silicon, iron, sodium, titanium, aluminum, manganese, and potassium (table 12), chromium and zirconium (table 13), and phosphorus (shown as phosphate) and fluorine (table 14). Many of these elements are major constituents of the host rock, and such an original arrangement would hardly be expected—especially in a rather monolithic host like the Todilto. The simplest explanation for the arrangement is that many of the constituents of the host rock were leached from the sites of the ore bodies and redeposited in their periphery at the time

TABLE 15.—*Semiquantitative spectrographic, radiometric, and chemical analyses of gypsum and limy gypsum from the Todilto Limestone, northwestern New Mexico*

Semiquantitative spectrographic determinations were made by the rapid visual-comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations.

The following elements were looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Co, Cr, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, K, La, Li, Lu, Mo, Nb, Ni, Os, P, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, W, Y, Yb, Zn, and Zr. Also, Cs, F, Pr, and Rb were not looked for. 0, looked for but not found; >, greater than amount shown; <, less than amount shown, standard detectability does not apply.

[Analyses are in percent, except as otherwise indicated]

Sample	Type of sample	Location (see pl. 3)				Spectrographic [1]														
		County	Sec.	T.	R.	Al	Ba	Ca	Ce	Cr	Cu	Fe	Mg	Mn	Na	Nd	Si	Sr	Ti	V
252608	Chunk	Valencia	NW¼ 12	9 N.	5 W.	.015	0.0007	>10	<0.05	0	0.00015	0.007	0.015	0.0007	0	<0.02	0.07	0.03	0.0003	0.0015
252612	do	Rio Arriba	NE¼NW¼ 8	24 N.	4 E.	.015	.0007	>10	<.05	0	.00015	.007	.015	.0015	0	<.02	.03	.03	.0003	.0015
252617	Chip channel.	Sandoval	SW¼ 13	15 N.	1 E.	.03	.0003	>10	<.05	.00015	.0003	.007	.015	.003	.07	0	.3	.03	.0015	.0015

Sample	Type of sample	Location (see pl. 3)				Radiometric	Chemical								
		County	Sec.	T.	R.	eU[2]	U[3]	V_2O_5[4]	S[5]	P_2O_5[6]	C[7]	As[8]	F[9]	Se[5]	Zn[8]
						Parts per million		Percent			(organic)	Parts per million			
252608	Chunk	Valencia	NW¼ 12	9 N.	5 W.	<10	3	<0.05	17.8	<0.003	<0.3	<5	<20	<0.5	<1
252612	do	Rio Arriba.	NE¼NW¼ 8.	24 N.	4 E.	<10	7	<.05	17.3	<.003	<.3	<5	<20	.5	<1
252617	Chip channel.	Sandoval	SW¼ 13	15 N.	1 E.	<10	1	<.05	13.7	.004	<.3	<5	30	.5	3

[1] Analyst: J. C. Hamilton.

[2] Analyst: C. G. Angelo.

[3] Analyst: R. P. Cox.

[4] Analyst: J. S. Wahlberg.

[5] Analyst: G. T. Burrow.

[6] Analyst: D. L. Ferguson.

[7] Analyst: Wayne Mountjoy.

[8] Analyst: Claude Huffman.

[9] Analyst: W. D. Goss.

of uranium mineralization. A lack of detailed sample control precludes making any estimate of the quantity of the materials removed and redeposited or determining the size and shape of the affected zones. Phosphorus and fluorine, however, deserve further comment because of their possible bearing on localization of the deposits.

In some sediments the phosphatic mineral fluorapatite may contain uranium in concentrations as high as about 1 percent (Altschuler and others, 1958, p. 50–51). Thus, the phosphate content in the limestone unit of the Todilto was determined to find the role fluorapatite might have played in the presence of the uranium deposits. The results show that the phosphate content of the limestone is quite low and is actually lowest in ore, where it has a median concentration of only 0.007 percent. Obviously, any fluorapatite in the Todilto could contain only a minute part of the uranium present in the rock. For this reason, and because the phosphate content is lowest in ore, conclusions are that the phosphate had no influence on localization of the deposits.

Local spotty concentrations of fluorite in some deposits and of rather finely disseminated, but conspicuous, fluorite in others in the Todilto have led to much speculation about the origin of the fluorite and its bearing on the source of the ore-bearing solutions. If the fluorite was largely derived externally, such as magmatically, it should show a relatively high concentration in the ores. The analytical results, however, do not support this assumption. In fact, the geometric means of the five zones show a narrow range from 90 to 180 ppm fluorine, and the mean content in the ores is only about 100 ppm fluorine. Actually, the mean concentration in each of the zones is no more than might be expected originally in limestone, of which fluorine and fluorite are common constituents (Goldschmidt, 1954, p. 579).

The ore samples show a range in concentration of fluorine of from 20 to 1,700 ppm, but only two samples contained more than 500 ppm (table 6). Rather than make a special case and imply a magmatic origin for these relatively high concentrations, it seems more reasonable to explain them as a rearrangement of the fluorine in the host rock (Goldschmidt, 1954, p. 574).

ELEMENTS IN THE GYPSUM UNIT

Although uranium deposits have not been found or anticipated in the gypsum unit of the Todilto Limestone, three samples (252608, 252612, 252617) were selected from three widely separated localities (pl. 3) to determine whether the gypsum contained any unusual elemental concentration that might have some bearing on the localization of the deposits in the limestone unit. The results, as shown in table 15, show nothing unusual. Somewhat higher values shown for some metals and fluorine in sample 252617 are most likely a reflection of a somewhat higher content of limestone than for the other two samples.

SUMMARY AND CONCLUSIONS

The distribution of elements in the limestone unit of the Todilto Limestone shows a zonal decrease for vanadium and selenium outward from ore and probably a similar distribution for arsenic, lead, and zinc. Elements that show an increase outward from ore are organic carbon and probably magnesium. The increase of sulfur is most likely the result of the relatively high sulfate in the outer zones caused by a regional increase of gypsum in the eastern part of the Todilto basin.

Many elements show a relatively high concentration in the zones between ore and barren ground. These are principally major rock constituents and include silicon, iron, sodium, titanium, aluminum, manganese, potassium, chromium, zirconium, phosphorus, and fluorine. The arrangement of this assemblage is most likely the result of a rearrangement of the original constituents of the host rock by the mineralizing solutions.

The low content of selenium, relative to other uraniferous host rocks in northwestern New Mexico and the Colorado Plateau, probably reflects a low sulfide content in the ores and a low content of volcanic debris in the host rock. The low phosphate content indicates the presence of little if any fluorapatite; it also indicates that the phosphate, in turn, had little if any influence on localization of the uranium deposits. The low content of organic carbon in the ores and the relatively high content in barren rock indicates that the carbon likewise had no significant influence on localization of the deposits but may have caused precipitation of uranium at favorable structural sites.

Fluorine occurs in the ores and in the host rock in concentrations that are considered normal for limestone, and some local relatively high concentrations probably are the result of rearrangement within the host rocks by mineralizing solutions.

Nothing in the concentrations or distribution of the various elements indicates that the gypsum-anhydrite unit, or the content of such material in the limestone unit, influenced the localization of the uranium deposits. Likewise, nothing could be determined in the limestone unit that could have influenced the localization of the deposits. As a corollary, the zonal concentrations of the various elements offer little help in broadly classifying the ground for uranium potential. The zonal relations of some of the elements, however, should be helpful in guiding exploration within a mile or less of deposits. In addition to uranium, which is the most readily detectable of the elements, vanadium and, less certainly, selenium, zinc, and lead should be useful guides because of their direct relation to uranium concentrations. Indirectly, organic carbon might also be useful, but more data on the zones near ore are needed to be certain of the relations.

The outer limit of detection of anomalous amounts of these elements appears to be somewhere between 500 feet and 1 mile from known ore deposits. Because of the ranges in concentration among samples, the mean concentration of several samples obviously should be more reliable and effective than the concentration in single samples. Likewise, the collective use of the concentrations of several elements is more meaningful than the concentration of one element.

AGES OF EMPLACEMENT

The uranium deposits occur in many formations of various lithologies and ages and under various structural conditions in the respective districts and areas. A review of the ages of emplacement and the general geologic relations that bear on them for the peneconcordant and vein deposits will be helpful in evaluating the resources and establishing guides to ore.

Peneconcordant deposits, by their probable ages of emplacement, can be grouped in three categories: (1) those in Pennsylvanian, Permian, and Triassic rocks; (2) those in Jurassic and some Cretaceous rocks; and (3) those in Tertiary and Quaternary rocks. Deposits in the first category are tentatively considered to have been emplaced in Pennsylvanian to Lake Triassic time; those in the second, in Late Jurassic to early Tertiary time; and those in the third, in mid-Tertiary to Recent time.

Age of emplacement of deposits in Pennsylvanian, Permian, and Triassic rocks in highly tentative. The earliest tectonic events that may have influenced the emplacement were uplift of the San Luis, Zuni, and Joyita highlands in late Paleozoic time; Late Permian and Early Triassic deformation and beveling of the highlands; and subsequent upwrap of the San Luis highland and highlands to the south and southeast in later Triassic time. Deposits occur in arkosic debris shed from these highlands and incorporated into rocks of Pennsylvanian, Permian, and Triassic ages, but the detailed structural relations are not known. Most deposits, however, occur along or near the margins of the old depositional basins, similar to the mode of occurrence of the principal deposits in the Jurassic and Cretaceous rocks. Because the latter deposits probably were emplaced during initial deformation of the basins of deposition, the assumption seems plausible that the deposits in the Pennsylvanian to Triassic rocks experienced a similar but earlier history.

Deposits in rocks of Jurassic and Cretaceous age initially were emplaced in Late Jurassic to early Tertiary time, and probably the principal primary mineralization occurred in pre-Tertiary time. The deposits are no older than Late Jurassic because they occur in intraformational folds in the Todilto Limestone and in sandstone pipes that formed during Late Jurassic deformation. They are older than the earliest fracturing that is correlated with the McCartys syncline and the early development of the monoclinal folds on the flanks of the San Juan Basin. This folding occurred principally during the initial deepening of the basin in Paleocene time, so the deposits must have been emplaced at least by Paleocene time to precede the fracturing. Some evidence, however, suggests that they were earlier, and that the deposits in the Cretaceous rocks possibly were emplaced after the ones in the Jurassic rocks.

In the Laguna district, for example, where Moench (in Hilpert and Moench, 1960, p. 458) has demonstrated control of the deposits in the Todilto Limestone and Entrada Sandstone by pre-Dakota folds, the deposits transect the formational boundary across the steep flank and anticlinal and synclinal bends of a monocline. The folding is interpreted to have occured shortly after deposition of the limestone, because the limestone is markedly thicker in the synclinal trough than on the flank and probably resulted from flowage during folding, prior to consolidation. Moench (1963c, p. 163–164) interpreted the emplacement of the deposits to have occurred during folding, because the deposits are controlled by the fold but dip toward the trough of the fold at a lower angle than the host formations. These data suggest that the deposits were emplaced prior to consolidation of the host rocks, probably in Late Jurassic time.

Deposits in the Morrison Formation also probably were emplaced in Late Jurassic time, but later than the deposits in the Todilto. Some of the Morrison deposits were emplaced in sandstone pipes. Because the pipes are the same age as the enclosing sedimentary rocks, the deposits must be Morrison in age or younger. It is doubtful that they are much younger, however, and most likely they are pre-Dakota in age. None of the primary deposits in the Morrison are known to transect the Morrison-Dakota contact, and some data suggest that such deposits locally are beveled under the pre-Dakota erosion surface (Kittel, 1963, fig. 4). It is concluded, therefore, that the deposits in the Morrison also are Late Jurassic in age, but younger than the ones in the Todilto. If the deposits in the Todilto Limestone and Morrison Formation were emplaced in Late Jurassic time, as these data suggest, the deposits in the Dakota Sandstone, which is Cretaceous in age, must be younger.

The earliest that such emplacement in the Dakota Sandstone could have taken place would have been Early Cretaceous and would likely have occurred in the southwestern part of the area; it is in this area that the Dakota may be partly Early Cretaceous in age—probably older than elsewhere. (See p. 21.) In the southwestern part of the Gallup district, the black ore in the Diamond 2 mine was apparently emplaced after slumps formed at the base of the Dakota and prior to fracturing. If the fracturing formed in Paleocene time, the age of emplacement of the ore would have been restricted to Early Cretaceous to Paleocene. Again, where evidence can be found to date the earliest mineralization, ore minerals are found in association with structural flowage features that must have formed shortly after the rocks were deposited, a relation that is similar to the one in the Todilto Limestone and Morrison Formation. The data suggest, therefore, that the primary deposits in the Jurassic and Cretaceous rocks were emplaced in Late Jurassic time and Cretaceous to Paleocene time, respectively.

Deposits in rocks of Tertiary and Quaternary ages probably were emplaced in mid-Tertiary time or later, but the evidence is mostly indirect; some could have formed as early as Paleocene. The younger age is favored for most of them because of the more intensive tectonism in mid-Tertiary time and later. The older age is speculative because most of the deposits are surficial, are associated with fractures, and are highly oxidized. The mid-Tertiary to Recent tectonism more or less climaxed deformation that was intermittent throughout Tertiary time; this tectonism caused the development of the Galisteo basin in early Eocene time, the deepening and northward tilting of the San Juan Basin, the southward tilting of the Datil Mountains area, and the widespread fracturing that culminated in development of the Rio Grande trough. During this deformation, dioritic and monzonitic rocks were intruded, most likely in early to middle Tertiary time, and rather extensive volcanism occurred throughout the rest of Tertiary and Quaternary time. Few deposits show an obvious relation to structural features formed during this period except for the secondary minerals which are controlled by fractures. A few deposits, as in the Baca and Galisteo Formations, are unoxidized at the outcrop but are in highly carbonaceous material. None show any obvious relation to the intrusive igneous rocks. Conclusions are that most deposits probably are mid-Tertiary or younger in age, but some may be as old as Paleocene.

Vein deposits were emplaced during four periods: (1) Precambrian, (2) Late Jurassic to early Tertiary, (3) early Tertiary, and (4) mid-Tertiary to Recent.

During the Precambrian, vein deposits in metamorphic rocks and in pegmatite bodies were formed. The deposits are considered to be Precambrian in age because of their association with the Precambrian Tusas Granite (Just, 1937; Jahns, 1946). Deposits in sandstone pipes in the Morrison Formation were emplaced contemporaneously with the peneconcordant deposits in the same rocks, probably during the late Jurassic. During the third period, probably in Oligocene time, the La Bajada deposit was emplaced in the Espinaso Volcanics of Stearns (1943). Probably at the same time the monzonitic bodies and base-metal deposits, similar to the La Bajada deposit, were emplaced in the Los Cerrillos and Ortiz Mountain districts. During the fourth period, most of the deposits along faults in miscellaneous sedimentary rocks and in fractures in igneous rocks along the Rio Grande trough were formed. The ages of most of these deposits probably are young, similar to those of the peneconcordant deposits in rocks of Tertiary and Quaternary ages. Faults in the Rio Grande trough formed during the development of the trough, so are Miocene(?) or younger. Deposits associated with faults therefore also are Miocene(?) or younger. Most of the deposits bottom within a few tens of feet below the surface and are largely made up of oxidized minerals, mainly yellow and green uranyl vandates and phosphates. Thus, they appear to be surficial, similar to many of the peneconcordant deposits in the Tertiary and younger rocks, and probably are Quaternary or Recent in age. Most of the vein deposits in igneous rocks also contain surficial oxides and probably are Recent in age, although some of them could be remnants of older primary deposits; a few, such as the Cerro Colorado, may be related to volcanism and would therefore be somewhat older.

In conclusion, the emplacement of the uranium deposits in northwestern New Mexico can be grouped into five different ages: (1) Precambrian, (2) late Paleozoic to Late Triassic, (3) Late Jurassic to early Tertiary, (4) early Tertiary, and (5) mid-Tertiary to Recent. Peneconcordant deposits may be referred to the second, third, and fifth ages, and vein deposits may be referred to the first, fourth, and fifth ages. Vein deposits that formed during the third age in sandstone pipes in the Morrison Formation are the same age as the peneconcordant deposits that formed in the Morrison. These deposits were formed at about the same time as the peneconcordant deposits in the Todilto Limestone, probably during the Late Jurassic. Peneconcordant deposits in the Dakota Sandstone and in some other Cretaceous rocks were formed later, but locally may be as old as Early Cretaceous. Peneconcordant deposits in Tertiary and Quaternary rocks, and vein deposits along faults in various sedimentary rocks and in fractures in most igneous rocks, were nearly all formed during the fifth age. Many of them probably are Recent.

GEOLOGIC CONTROLS

The foregoing sections indicate that the deposits are related to, or controlled by, various lithologic, stratigraphic, and structural features. As an aid to resource appraisal and a guide to exploration, the broader and more important of these features that affect peneconcordant and vein deposits are summarized.

Peneconcordant deposits occur in sandstone, limestone, and shale and coal. Of these, the ones in sandstone are most important economically because of size and abundance. The host sandstones have similar lithologic, sedimentary, and structural characteristics. They mostly are medium- to coarse-grained crossbedded arkoses that are carbonaceous and contain volcanic debris. Cut-and-fill structural features, including mudstone lenses, interstitial clay, and high-angle crossbedding, indicate a fluvial environment. The sandstones are thicker and more concentrated along the margins of depositional basins and generally comprise a complex of discontinuous channel sands. In the Morrison Formation they locally are abnormally thick in structural depressions along the margins of and within the sedimentary basin. These depressions and their contained sandstone units range from several miles to several tens of miles in width and length. The principal uranium deposits occur in the central parts of the sandstone masses that occupy these troughs in the Laguna, Ambrosia Lake, Chuska, and Shiprock districts, where the sandstone masses range in thickness from about 200 feet to more than 500 feet. Host sandstone lenses within the masses generally are 30 feet or more thick.

In the Dakota Sandstone the principal deposits occur at the base of the formation in channel sands that range in thickness from 20 to 50 feet at the center and in width from 300 to 800 feet. Little is known of their lengths, as they have been explored only a few hundred feet back from outcrop.

Within the host sandstones, deposits are controlled in detail by miscellaneous sedimentary structures and concentrations of carbonaceous matter, which have been widely described and need not be itemized. They also are controlled by tectonic structures, indirectly and directly.

Indirectly, the deposits are controlled by the sedimentary basins that received the host sandstones and by subsidiary structural features along the flanks and within the basins. Most important of these basins was the old Jurassic basin. The segment of this basin that is represented in northwestern New Mexico, largely within the San Juan Basin, has remained in large part as a closed structure since its inception. All the other basins have been breached, a factor that could either have influenced the nondeposition of deposits or have permitted their leaching and removal after formation.

Important subsidiary structural features that indirectly controlled deposits are the Late Jurassic troughs, depressions, and folds in the Morrison Formation. These features controlled the thickness and trends of the host sandstone units during deposition and may have caused thinning of the host sands over domes such as the Ambrosia and San Mateo domes.

More directly, anticlinal and synclinal folds of this age locally may also have partly controlled some deposits, such as the Jackpile in the Laguna district. Monoclinal folds of Cretaceous age or early Tertiary age possibly partly controlled some deposits in the Dakota Sandstone and in some of the other Cretaceous formations.

Fractures directly control many deposits, but mostly the deposits that are oxidized. Most important are the fracture sets of Late Cretaceous to early Tertiary age in the Ambrosia Lake district that control the postfault deposits in the Morrison Formation. Similar sets may control postfault deposits in the Morrison Formation and Dakota Sandstone in the Gallup district. Other fractures of similar and younger ages largely control the oxidized parts of deposits in rocks of pre-Tertiary age; fractures of mid-Tertiary age, and younger, control most of the deposits in rocks of post-Cretaceous age.

Controls on the deposits in limestone are primarily structural and partly sedimentary and possibly chemical but of unknown nature. They are controlled principally by intraformational folds and partly by broader folds of probable Late Jurassic age. Fractures show little apparent effect on them, except for the oxidized minerals. These folds are best formed in the Ambrosia Lake and Laguna districts but also occur on a smaller scale in the Chuska district, in San Juan County, and in Rio Arriba County. It is noteworthy that the principal deposits are associated with the best formed structural features, which occur along the south margin of the old Jurassic basin. These features may be directly controlled by the thickness of the limestone in the Todilto Limestone (fig. 5). Smaller deposits are associated with the smaller scale features.

The precipitating agent of the uranium in limestone is not known. It was not fluorapatite but possibly was organic carbon or may have been S^{--} or HS^{-} ions, as implied by Bell (1963, p. 17).

Controls on the deposits in shale and coal are principally carbonaceous material and, to a lesser extent, sedimentary and tectonic structural features. A few unimportant occurrences in noncarbonaceous shale are apparently controlled by the clay minerals which served as precipitants of the uranium. Where deposits are least carbonaceous, the sedimentary and structural controls are more dominant and show the same controls and relations to the host rocks as the deposits in sandstone. Where they are highly carbonaceous, however, the sedimentary and age relations and some structural relations are obscure. In some, as in the Cretaceous rocks of La Ventana Mesa, the deposits are controlled partly by folds and joints. Most of the deposits, however, occur at the surface and, because of their tendency to remain in a reduced state, their age relationship to sedimentary and tectonic structural features is difficult to determine. Probably many of them, especially those in rocks of post-Cretaceous age, are late Tertiary to Quaternary in age.

Controls on most vein deposits in metamorphic and igneous rocks are direct and fairly obvious, but in sedimentary rocks they are both direct and indirect. In metamorphic rocks the deposits are controlled by fissures and fractures of Precambrian age. In igneous rocks they likewise are controlled by similar structural features and breccia zones. At the La Bajada such features are probably Oligocene in age; at most others they are Miocene(?) or later in age. Most of these deposits are oxidized and probably are surficial accumulations of Pleistocene or Recent age. In sedimentary rocks the controls are mostly tectonic features but are partly sedimentary and locally are chemical features. The oldest deposits are in sandstone pipes in the Morrison Formation, which are controlled principally by the bounding faults, of Late Jurassic age, but partly by sedimentary structural features next to the faults and partly by finely disseminated carbonaceous material, similar to the peneconcordant deposits in sandstone. Indirectly, these deposits also probably are controlled by the old Jurassic basin and subordinate folds of the same age that formed on the basin margin. Other vein deposits in sedimentary rocks are controlled by faults and fractures and partly by sedimentary structural features. They occur in and along the Rio Grande trough, so are controlled by the trough as well as by the subsidiary faults with which they are associated. These structural features are Miocene(?) to Recent in age. The vein deposits also are partly controlled by sedimentary structural features near the fractures and locally by pockets or concentrations of coalified plant debris.

ORIGIN

Origin of the uranium deposits, which in general is controversial, is of interest because it has a direct bearing on the estimation of the resources, particularly for the peneconcordant deposits because of their great potential. Vein deposits have little potential and their origin is better understood, so are treated briefly.

Because stratigraphic relations of the peneconcordant deposits demonstrate that the deposits were emplaced after the host rocks, the source of the uranium was either from some other part of the host rocks or was external to them. The original source is of interest, but the direction of transport is of greater concern because of its bearing on the final disposition and distribution of the deposits. Attention will be focused on the deposits in the Upper Jurassic rocks along the south margin of the San Juan Basin, which are most important and about which the geology is better understood than elsewhere.

The geologic setting during Late Jurassic time was a broad southern highland area that shed clastic debris into a broad shallow basin to the north. During deposition the highland was uplifted and the basin differentially sank. This sinking permitted an accumulation of Jurassic sediments that now total about 1,000 feet in thickness. Near the close of Jurassic time the highland area as well as the remainder of the entire region was beveled prior to encroachment by Cretaceous seas from the southeast and northeast.

Some time following deposition of the sediments, the uranium deposits were emplaced. Before the source and direction of transport can be discussed, two basic assumptions must be made. First, the transporting solutions were dilute and, second, the fact that the solutions were dilute would require the passage of large volumes of such solutions past the points or areas of precipitation. The first assumption is generally accepted, and the second assumption is a necessary corollary for the precipitation of enough uranium to build the large deposits that occur in the Jurassic rocks.

If the source of the uranium was from within the host rocks, the direction of transport had to be largely lateral, or roughly parallel to the bedding. If it was external, the transport could have been by ascending, descending, or laterally migrating solutions, or some combination of such movements. Of these various possibilities most probably the solutions moved laterally and downdip, as indicated by the hydrologic conditions that can be reconstructed from the structural setting, age of emplacement, and the general stratigraphic relations of the deposits.

The deposits occur along or near the south margin of the basin of deposition. This was the principal area of recharge during sedimentation and most likely was the locale of greatest flow of water per unit area within the basin sediments. Basinward from the recharge area the waters would eventually ascend toward the surface but only after a loss in velocity and a decreased rate of flow per unit area. Loss in velocity would result from friction, which would cause the waters to spread and flow through a greater cross-sectional area. The friction must have been intensified by the increasing fineness and decreasing permeability of the sediments away from the basin margins.

No structural or hydrologic evidence suggests that the solutions could have moved from the basin toward the margins, or that the principal direction of movement was downward or upward. Downward movement of any appreciable volume would have required a breached structure prior to Tertiary time, of which there is no evidence. Upward movement would have required hydraulic pressures at depth great enough to overcome the hydrostatic head and the friction of transmission to cause and maintain flow. Possibly such flow could have been caused by magmatic pressure beneath the deposits, but this condition would have required a fracture system. No evidence indicates such a system older than Laramide age, which would have been predated by the primary uranium deposits. Furthermore, no evidence indicates igneous intrusions between Precambrian and mid-Tertiary time along or even near the south margin of the Jurassic basin. Such intrusion would be expected if magmatic pressures great enough to have caused flow had existed.

One possible alternative process that might have induced some upward flow was dewatering of the sediments by compaction. Such a process, however, would have generated only a small volume of flow—hardly the amount necessary to satisfy the needs.

Conclusions are, therefore, that the uranium-bearing solutions flowed basinward from a recharge area along the south margin of the sedimentary basin. Under these circumstances the uranium could have originally been derived from the highland bedrock or leached from the host rocks, possibly in large part from the contained volcanic debris. Characteristics of the ore-sample groups and the distribution of trace elements in the Todilto Limestone support this conclusion. The general uniformity in the contents of the elemental assemblages in the ore sample groups and the zonal arrangement of the elements in and around the deposits in the Todilto Limestone are not only compatible with the derivation of the deposits from the host rocks or highland bedrock, but also some elemental concentrations in the ore, such as fluorine, for example, are more readily explained by a rearrangement within the host rock, rather than by a derivation from magmatic fluids or some other external source.

If these premises are correct, the general hydrologic conditions during sedimentation and the relations of the uranium deposits to the Jurassic structures and stratigraphy deserve further consideration for they reflect the chronology of emplacement.

Under the general hydrologic conditions that would be expected during sedimentation in a basin, water entering the recharge area first would fall stratigraphically as it entered the basin, then would pass more or less parallel to the bedding and, finally, would rise stratigraphically as it approached the central part of the basin. The rate of flow per unit area would be progressively slower with distance from the recharge area, so the maximum flow per unit area would be maintained within the upper part of the sedimentary column throughout the depositional history of the basin. Because of continued sedimentation, the maximum rate of flow per unit area would progressively rise from older to younger stratigraphic zones; for example, the older zone of the Todilto Limestone to the younger zone of the Morrison Formation.

As indicated previously under the section on ages of emplacement (p. 139), the structural relations of the deposits in the Todilto Limestone in the Laguna district indicate that they were emplaced during Late Jurassic folding. It was also noted that the deposits in the Todilto Limestone and in the Morrison Formation were both closely associated with flowage structures and that there was some reason to believe the time of emplacement closely followed the flowage of the sediments in the intraformational folds and in the sandstone pipes. Admittedly, the reasoning is rather tenuous, but coupled with that on the hydrology involved during sedimentation and on the probable direction of transport, indications are not only highly probable that the deposits were emplaced during Late Jurassic sedimentation but that the deposits in the Todilto Limestone were emplaced somewhat earlier than the ones in the Morrison Formation.

Conclusions are, therefore, that the deposits were emplaced by solutions that moved northward and mainly laterally through the host rocks in Late Jurassic time. The deposits in the Todilto Limestone were emplaced first, then the deposits in the Morrison Formation. Most probably the uranium was derived from the highland bedrock or from volcanic debris within the host rocks, or from both.

Origin of the deposits in other parts of the Jurassic basin probably was similar to that of the ones along the south margin. The deposits in the Jurassic basin also apparently predate the Laramide structures, and, except for possibly being emplaced farther within the basin, had a similar geologic history. The ones in the Chuska and Shiprock districts, for example, are nearest the old basin margin in northwestern Arizona and were probably derived from that source. If so, the fact that the deposits rise stratigraphically from the Salt Wash Member in the Lukachukai district in Arizona to the Recapture Member in the Chuska district in New Mexico is perhaps noteworthy. This would be the expected general relation along the line of flow within the basin where the uraniferous solutions would be rising.

Origin of the deposits in the other sedimentary basins probably was similar, but these deposits most likely were emplaced at different times from late Paleozoic to Quaternary. As indicated previously, the more important deposits in the Pennsylvanian, Permian, and Triassic rocks and the principal ones in the Dakota Sandstone of the Cretaceous rocks nearly all occur near the margins of the depositional basins. The similar structural relations of these deposits to the ones in the Jurassic basin of deposition strongly suggest that the deposits in each basin also were emplaced shortly after the respective host rocks were deposited and by solutions that flowed basinward from the adjoining highlands. Credence is added to this general relationship by the structural relations of the Diamond 2 deposits in the Dakota Sandstone of the Gallup district.

The Diamond 2 deposits apparently were emplaced after flowage structures were formed and may have been controlled partly by Laramide folds, but they predate fractures of probable Laramide age. These structural limitations more or less fix the age of emplacement in early Laramide time and possibly early in the Cretaceous shortly after deposition of the sediments.

Of all the principal deposits in the sedimentary basins, only those in the Shinarump Member of the Chinle Formation are situated within the central part of the basin of deposition. (The deposits are largely within southeastern Utah and northeastern Arizona.)

This relationship probably was caused partly by the low permeability of the Moenkopi Formation—which underlies the Chinle Formation and, in many places, directly underlies the Shinarump Member—and partly by the uplift and northward tilting of the basin following Moenkopi deposition. Uplift and tilting resulted in dewatering and compaction of the Moenkopi. These factors added to its impermeability and formed the broad planelike or pedimentlike suface on which the Shinarump was subsequently deposited (Stokes, 1950). In this setting, water moving from the recharge area during and following Shinarump deposition was largely confined within the Shinarump Member and moved into the central part of the basin before being evaporated at the surface.

Origin of the deposits in the Tertiary basins is more speculative. Many of the deposits are certainly surficial and Recent. Possibly the deposits were formed in these basins during the early history of the basins and were similar in emplacement to the ones in the older basins, but such deposits perhaps were not preserved, as all of the basins were breached at least in part and were subjected to leaching by ground waters, especially after mid-Tertiary time. The fact that the older deposits are preserved, however, casts doubt on similar deposits of younger age having been removed. Conclusions are that deposits probably formed in the Tertiary basins that are similar to the deposits in the older basins, but they are hidden. The known deposits are interpreted to be superficial accumulations and Recent in age.

The vein deposits in sandstone pipes in the Morrison Formation in the Laguna and Ambrosia Lake districts are the same age and probably were derived from the same solutions as were the peneconcordant deposits in the same rocks. As indicated previously, the pipes probably are intraformational and of Late Jurassic age. If they served as conduits for mineralizing solutions they could have connected beds only within the Jurassic sediments. Vein deposits along faults in the sedimentary rocks along the Rio Grande trough probably are similar in origin to the peneconcordant deposits in the same rocks. This is indicated by their superficial character, oxidized minerals, and general lack of alteration that would be expected if they were associated with more deep seated solutions. A possible exception is the Charley 2 deposit. Vein deposits in metamorphic rocks were derived from magmatic solutions in Precambrian time. The La Bajada deposit was derived from magmatic solutions in Oligocene time. A few other scattered vein deposits in igneous rocks along the Rio Grande trough also probably were derived from magmatic solutions during late Tertiary and Quaternary time.

URANIUM RESOURCES

Uranium resources are the materials in the ground that are minable now plus materials that are likely to become minable in the future. The resources include reserves and ore. Reserves are materials that may or may not be completely explored but which may be estimated quantitatively and are considered to be economically exploitable at the time of estimation. Ore is material that can be mined at a profit. The term "ore reserves," or "mine reserves," applies to deposits currently being mined, or to deposits known to be of such size and grade that they may be mined profitably.

This resource estimate is based largely on the habits, trends, and geology of the known deposits, on recent ore-reserve estimates, on records of past production, and partly on origin of the deposits. Because of the somewhat erratic occurrence of uranium deposits and because of the diverse geologic controls of those deposits, the estimate cannot be exact but is an expression of a general order of magnitude.

As of January 1, 1966, the U.S. Atomic Energy Commission estimated the uranium mine reserves in northwestern New Mexico to be 29.7 million tons of ore averaging 0.23 percent U_3O_8 and containing about 70,000 tons of U_3O_8.[3] During 1965 about 2 million tons of ore was mined which, totaled with the previous output, amounts to about 25 million tons that has been extracted through 1965. At the 1965 rate of extraction, the mine reserves would sustain a yield for 15 years or until about the end of 1980. About 99 percent of these reserves are in Morrison Formation; the remaining 1 percent is mostly in the Todilto Limestone and Dakota Sandstone. About 60 percent of the reserves are in the Ambrosia Lake district; most of the remainder is in the Laguna district.

An appreciable tonnage of material of submarginal grade occurs on the periphery of the known ore deposits, particularly in the deeper deposits in the Morrison Formation in the Ambrosia Lake district. This material has not been thoroughly sampled and its tonnage has not been calculated, but it probably amounts to several million tons of material averaging about 0.1 percent U_3O_8.

In contained uranium this submarginal material greatly exceeds all other known submarginal uranium resources. The only other submarginal material of much importance in northwestern New Mexico is mostly

---

[3] Robert K. Pitman (written commun., Apr. 4, 1966). Publication by permission of the U.S. Atomic Energy Commission.

in impure coal at the top of the Menefee Formation in the La Ventana Mesa area. The coal is estimated to contain 132,000 tons of material 1 foot or more thick and containing at least 0.1 percent uranium and about 400,000 tons of material that ranges from 0.01 to 0.1 percent uranium (Bachman and others, 1959, p. 307).

As of January 1966, the total uranium resources probably amounted to several times the total past mine output plus mine reserves. These resources may amount to as much as 200 million tons of material averaging about 0.25 per cent U_3O_8. Most of these resources are in peneconcordant deposits several hundred to several thousand feet below the surface. They are mostly in sandstone masses that occupy structural depressions of Late Jurassic age. These structures probably occur mostly in the periphery of the San Juan Basin and largely within the southern San Juan Basin mineral belt, now generally referred to as the Grants mineral belt. More than 90 percent of the resources are probably in the Morrison Formation. Most of the rest probably are in the Todilto Limestone and Dakota Sandstone, but a small percentage may occur in other formations. In addition, a small percentage of the resources is in vein deposits in rocks of diverse lithology and age.

A general breakdown of these resources is made by formational units, from oldest to youngest, under which the general size and abundance of the known deposits and the resource potential and disposition are discussed; mine reserves are listed where figures are available from the Atomic Energy Commission. These data are summarized in table 16.

PRECAMBRIAN ROCKS

Ortega Quartzite of Just (1937) and others rocks.—A few scattered occurrences of uranium minerals have been found in association with fluorite veins and in pegmatite bodies in the Ortega Quartzite of Just (1937). None of these occurrences are of commercial importance, as far as uranium is concerned, and the outlook is poor for the Ortega or other rocks of Precambrian age to contain any resources of much value. This estimation is based on the sparseness of the known occurrences and their lean values and on the poor general outlook for pegmatite bodies to contain substantial or recoverable quantities of uranium (Page, 1950, p. 33).

CAMBRIAN(?) ROCKS

Unnamed conglomeratic sandstone and shale.—No uranium deposits are known in the Cambrian(?) rocks, which are deeply buried under the northwestern part of the San Juan Basin and are unexplored except by test wells for oil. These rocks might possibly contain some uranium resources, but any uranium contained in them would not be economically recoverable in the foreseeable future.

DEVONIAN ROCKS

Elbert Formation.—Shale, glauconitic sandstone, and some sandy carbonate rocks, which are probably extensions of the Elbert Formation, are deeply buried under the northern part of the San Juan Basin. They also are largely unexplored and contain no known uranium deposits. It is unlikely they contain any uranium resources as they are near-shore marine, or littoral, in origin, and are rocks that rarely contain any appreciable amount of uranium, thus their resource potential is poor.

MISSISSIPPIAN ROCKS

Leadville Limestone, Caloso Formation of Kelley and Silver (1952), Kelly Limestone, and Arroyo Penasco Formation.—Mississippian rocks also are barren of known uranium deposits and their resource potential also is poor. Limestone in general is a poor host rock for uranium, except where deformed or fractured (Hilpert, 1961) or, in a few occurrences, where it is in solution cavities in karst terrains (Bell, 1963). Possibly a few small deposits might be found in these rocks where they are faulted, particularly along the Rio Grande trough.

PENNSYLVANIAN ROCKS

Molas, Hermosa, and lower part of Rico Formations.—These rocks, also, do not contain known uranium deposits and are buried under the northern part of the San Juan Basin. They are marine and marginal marine-continental fine-grained clastics, carbonates, and some evaporites, all of which are poor hosts for uranium. The uranium potential for these rocks is poor and they likely contain no uranium resources.

Sandia Formation.—The Sandia Formation, which is a near-shore marine deposit of fine-grained clastics and earthy limestone, contains no known uranium deposits. Its resource potential is poor for the same reasons given for the Molas, Hermosa, and lower part of the Rico Formations.

Madera Limestone.—The Madera Limestone contains two small deposits along faults on the east side of the Rio Grande trough and one occurrence is in arkosic sedimentary rocks in the San Pedro Mountains. The resource potential of the Madera is fair to poor. A few additional small deposits might occur where the Madera is faulted along the Rio Grande trough. Elsewhere it is unfavorable, except along its north margin where the marine beds grade northward into unnamed continental facies along the old northern highland area. Here, where arkosic beds dip southward under the Chama Basin, the potential for the occurrence of some small or possibly medium-sized deposits in the thicker coarser grained sandstones may be considered to be fair. Except along the north margin of the Chama Basin, the favorable beds are several thousand feet below the surface; they become less favorable southward where they grade into marine beds.

PERMIAN ROCKS

Bursum Formation.—The Bursum Formation in northwestern New Mexico is barren of known uranium deposits and probably contains few, if any, uranium resources. Some deposits may possibly occur in arkosic sandstone lenses in Torrance County, which is just west of the Pedernal highland area, the source of the arkosic material.

Abo Formation.—The Abo Formation contains a few small deposits in arkosic carbonaceous sandstone beds. The resource potential of the formation is fair and it probably contains numerous small deposits and possibly some medium-sized deposits back from the outcrop. The best potential is in the relatively thick coarse-grained arkosic sandstone lenses near the ancestral highland areas in western Torrance and eastern Socorro and Valencia Counties.

Cutler Formation.—Several small uranium deposits occur in the Cutler Formation near the base in arkosic carbonaceous sandstone lenses. The resource potential is fair to possibly good in similar sandstone lenses where they are about 30 feet or more thick. Most of the resources probably occur from the San Pedro Mountains area northward to the north margin of the Chama Basin, which is marginal to the ancestral highland. Elsewhere the Cutler is finer grained and more thin bedded or is largely aeolian in origin and unfavorable.

Yeso Formation and Glorieta Sandstone.—The Yeso Formation and the Glorieta Sandstone are barren of known uranium deposits and probably contain no uranium resources. They consist of marine fine-grained sandstone, siltstone, limestone, and some evaporites, all generally considered unfavorable for uranium deposits.

San Andres Limestone.—A few small uranium deposits occur in the San Andres Limestone where it is faulted. The San Andres Limetone probably contains a few additional small deposits where it is faulted, especially along the Rio Grande trough, but the resource potential generally is poor. It is a marine deposit of limestone, shale, thin-bedded sandstone, and some evaporites, rocks that are considered unfavorable for uranium.

Bernal Formation.—The Bernal Formation contains no known uranium deposits and probably has poor resource potential, for the same reasons as the San Andres Limestone.

TRIASSIC ROCKS

Moenkopi(?) Formation.—The Moenkopi(?) Formation contains no known uranium deposits in New Mexico and has a poor resource potential. It is mostly siltstone, which generally is unfavorable for uranium deposits.

Chinle Formation.—The Chinle Formation in New Mexico contains only a few scattered small deposits of uranium. These mostly are in fairly thick arkosic carbonaceous sandstone units, namely the Shinarump Member, Poleo Sandstone Lentil, and Agua Zarca Sandstone Member. The resource potential for the Chinle is fair. The formation probably contains numerous small deposits and possibly back from the outcrop some medium-sized deposits. These resources probably are mostly in the Shinarump Member, but some are expected in the Agua Zarca and possibly some in the Poleo Sandstone Lentil and Sonsela Sandstone Bed. The potential of these units is rather speculative because of their limited exposures and questions regarding their source areas. The potential for the Shinarump is considered the best for the members because of its rather uniform regional extent and the pediment conditions that probably influenced the widespread distribution of the uranium deposits away from, or remote from, the highland source area. The limited exposures of the Shinarump in New Mexico probably are not representative of the unit under cover in the western part of the area. The northern part of the Agua Zarca is obviously near the highland source area and is the most favorable of the other sandstone units. The Poleo Sandstone Lentil and the Sonsela Sandstone Bed, where they are preserved, may lie farther from the highland sources and are therefore, possibly less favorable.

Dockum Formation.—One uranium occurrence is known in the Dockum Formation, which is lithologically similar to the Chinle Formation. The resource potential of the Dockum is poor to fair. The formation locally contains arkosic sandstone lenses as much as 50 feet thick, and these are similar to the arkosic sandstone units of the Chinle Formation, which is a partial stratigraphic equivalent. In the periphery of the highland source area the thicker lenses might contain some uranium deposits of small to medium size.

Wingate Sandstone.—The Wingate Sandstone contains no known uranium deposits in New Mexico and probably contains no uranium resources. It is largely an eolian deposit and generally considered unfavorable for uranium deposits.

TABLE 16.—*A listing of the relative size and abundance of known uranium deposits, relative magnitude of mine or submarginal reserves, and potential for undiscovered resources, in the formational units of northwestern New Mexico*

[Uranium deposits: Abundance and size: small, <1,000 tons; medium, 1,000-100,000 tons; large, >100,000 to 1 million tons; very large, more than 1 million tons]

Era	System or Period		Formational unit	Uranium deposits	Mine or submarginal reserves	Potential
Cenozoic	Quaternary and Tertiary		Intrusive rocks of varied composition and form.	Few; small	None	Poor.
	Tertiary	Rio Grande trough and vicinity	Santa Fe Group	Many; small	Small	Poor to good.
			Popotosa Formation	Few; small to medium	Small	Poor to good.
			Espinaso Volcanics and Cieneguilla Limburgite	Few; small	Small	Fair.
			Galisteo Formation	Few; small to medium	Small	Poor to good.
			Older volcanic rocks of Jemez Mountains	Few; small	None	Poor.
		Datil volcanic field area	Datil Formation	Few; small	None	Poor.
			Baca Formation	Many; small to medium	Small	Fair.
		San Juan Basin	Chuska Sandstone	None	None	Poor.
			San Jose Formation	Few; small	None	Poor to fair.
			Nacimiento Formation	Few; small	None	Poor to fair.
Mesozoic	Cretaceous		Animas Formation	None	None	Poor to fair.
			Ojo Alamo Sandstone	Few; small	None	Poor to fair.
			McDermott Formation	None	None	Poor to fair.
			Kirtland Shale	None	None	Poor.
			Fruitland Formation	Few; small	Small	Poor.
			Pictured Cliffs Sandstone	None	None	Poor.
			Lewis Shale	None	None	Poor.
			Mesaverde Group, undivided	Few; small	None	Poor.
			Cliff House Sandstone	Few; small	None	Poor.
			Menefee Formation	Few; small to large	Moderate	Fair.
			Point Lookout Sandstone	Few; small	Small	Poor.
			Crevasse Canyon Formation	Few; small	Small	Poor.
			Gallup Sandstone	Few; small	Small	Poor.
			Mancos Shale	None	None	Poor.
			Dakota Sandstone	Many; small to medium	Moderate	Good.
	Jurassic		Morrison Formation	Many; small to very large	Moderate to very large	Good to excellent.
			Brushy Basin Member	Many; small to very large	Very large	Fair to excellent.
			Westwater Canyon Member	Many; small to very large	Very large	Fair to excellent.
			Recapture Member	Many; small to medium	Moderate	Good.
			Salt Wash Member	Many; small to medium	Moderate	Good.
			Bluff Sandstone	None	None	Poor.
			Summerville Formation	Many; small	Small	Poor to fair.
			Todilto Limestone	Many; small to large	Large	Good.
			Entrada Sandstone	Many; small	Small	Poor to fair.

TABLE 16.—*A listing of the relative size and abundance of known uranium deposits, relative magnitude of mine or submarginal reserves and potential for undiscovered resources, in the formational units of northwestern New Mexico*—Continued

Era	System or Period		Formational unit	Uranium deposits	Mine or submarginal reserves	Potential
Mesozoic	Triassic		Wingate Sandstone	None	None	Poor.
			Dockum Formation	Few; small	Small	Poor to fair.
		Eastern side of the San Juan Basin	Chinle Formation	Few; small	None	Poor to good.
			Petrified Forest Member, including Poleo Sandstone lentil	Few; small	None	Poor to fair.
			Agua Zarca Sandstone Member	Few; small	None	Fair to good.
		Western and southern sides of the San Juan Basin	Chinle Formation	Few; small	Small	Poor to good.
			Petrified Forest Member, including Sonsela Sandstone Bed	None	None	Poor to fair.
			Shinarump Member	Few; small	Small	Fair to good.
			Moenkopi Formation	None	None	Poor.
Paleozoic	Permian		Bernal Formation	None	None	Poor.
			San Andres Limestone	Few; small	Small	Fair to poor.
			Glorieta Sandstone	None	None	Poor.
			Yeso Formation	None	None	Poor.
			Cutler Formation	Few; small	Small	Fair to possibly good.
			Abo Formation	Few; small	Small	Fair.
			Bursum Formation	None	None	Poor.
	Pennsylvanian		Madera Limestone and unnamed arkosic sediments	Few; small	Small	Fair to poor.
			Sandia Formation	None	None	Poor.
			Molas, Hermosa, and Rico Formations	None	None	Poor.
	Mississippian		Arroyo Penasco Formation	None	None	Poor.
			Kelly Limestone	None	None	Poor.
			Caloso Formation	None	None	Poor.
			Leadville Limestone	None	None	Poor.
	Devonian		Elbert Formation	None	None	Poor.
	Cambrian(?)		Unnamed conglomeratic sandstone and shale	None	None	Poor.
Precambrian	Precambrian		Ortega Quartzite and other rocks	Few; small	None	Poor.

JURASSIC ROCKS

Entrada Sandstone.—The Entrada Sandstone contains numerous small deposits or parts of deposits at the top. A few have been mined, but the reserves are small. The uranium in the Entrada is associated with deposits in the overlying Todilto Limestone. The Entrada is an eolian sandstone and partly a marine siltstone, both rocks generally being unfavorable for uranium. Except for parts of the Entrada that directly underlie deposits in the Todilto Limestone, the resource potential is poor. Immediately under favorable Todilto structural features, however, the Entrada has a fair potential for containing parts of some small to medium-sized deposits.

Todilto Limestone.—The Todilto Limestone contains many deposits that mostly range from small to medium size. Mine reserves total about 200,000 tons of material that averages about 0.30 percent U_3O_8 and is in ore bodies that average a few feet in thickness. These reserves are almost entirely in the Ambrosia Lake district. Total resources in the Todilto are probably many times the total of past mine production and mine reserves, perhaps 5 to 10 times as much. Although the potential resource outlook for the Todilto is good, the deposits are mostly deeply buried and will be costly to find and exploit. These resources most likely are in the southern San Juan Basin mineral belt in the Ambrosia Lake and Laguna districts where the limestone unit is 15 or more feet thick. This is nearest the old highland area where tectonic activity was most intensive during deposition and caused the intraformational folds which control the deposits. The resources probably occur in deposits of about the same size and grade as those that have been found, but they mostly will be found below the surface and will be progressively deeper back from the outcrop, the deepest being several thousand feet below the surface. A small part of the Todilto resources likely occurs in some small deposits in the Chuska district and in and near the southern part of the Chama Basin.

Summerville Formation.—The Summerville Formation contains numerous small deposits or parts of deposits at the base. A few have been mined, but the reserves are small. Deposits in the Summerville are associated with the deposits in the underlying Todilto Limestone, similar to the ones in the Entrada Formation. The resource potential of the Summerville is likewise poor. The host rocks are mostly marine thin-bedded sandstone and siltstone, generally considered unfavorable for uranium deposits. Just overlying the favorable Todilto Limestone structures, the base of the Summerville has a fair potential for containing parts of some small to medium-sized deposits. These resources will occur in the same areas as the Todilto Limestone resources.

Bluff Sandstone.—The Bluff Sandstone is barren of known uranium deposits and probably contains no uranium resources of any consequence. It is an eolian deposit and generally considered unfavorable for uranium.

Morrison Formation.—Deposits ranging in size from small to very large occur in the Morrison Formation. It has been the most prolific producer of uranium and has the greatest potential for containing substantial resources. The mine reserves total more than 29 million tons of material which has an average content of about 0.23 percent U_3O_8 and which occurs in ore bodies that range in thickness from a few to several tens of feet. About 60 percent of these reserves are in the Ambrosia Lake district; most of the remainder is in the Laguna district.

The resource outlook for the Morrison is fair to excellent in the various members and localities. Overall it probably contains resources that are several times as great as the total of the past production and presently known mine reserves. At least 90 percent of this material is expected in the southern San Juan Basin mineral belt in the Ambrosia Lake, Gallup, and Laguna districts. The remainder is expected to be mostly in the eastern parts of the Chuska and Shiprock districts.

Most of the resources are expected to be in relatively thick sandstone masses that occupy structural depressions of Late Jurassic age in the following districts: (1) Laguna district, mostly in the Brushy Basin Member in the Jackpile sandstone of economic usage; (2) Ambrosia Lake and Gallup districts, mostly in the Westwater Canyon Member and partly in the Brushy Basin Member; (3) Chuska district, mostly in the Recapture Member; and (4) Shiprock district, mostly in the Salt Wash Member. A relatively small amount of the total resources is expected in numerous small deposits and perhaps a few of medium size in other areas in the Westwater Canyon Member and in sandstone lenses in the Brushy Basin Member where they exceed about 25 feet in thickness.

Most of the resources in the Morrison probably occur in deposits of about the same size and grade as those that have been mined and developed in the various districts and areas but at greater depths. Most resources in the principal mining districts range in depth from a few hundred to several thousand feet below the surface.

CRETACEOUS ROCKS

Dakota Sandstone.—Numerous small and some medium-size deposits occur in the Dakota Sandstone, several of which have been mined. Few mine reserves were known at the end of 1965. The uranium resources in the Dakota are expected to be roughly 10 times the total of those that have been discovered and mined. Most of these resources occur back from the outcrop in the Gallup and Ambrosia Lake districts, principally in channel-type sandstone at the base of the formation. Some occur in low-grade coal and in carbonaceous shale in these districts and elsewhere. Most of the resources probably occur within the western part of the southern San Juan Basin mineral belt; this part is nearest the highland area that contributed the sediments, and it contains the largest and thickest channel-type sandstones. These resources are a few hundred to several thousand feet below the surface.

Mancos Shale, Gallup Sandstone, Crevasse Canyon Formation, Point Lookout Sandstone, Menefee Formation, Cliff House Sandstone, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, Kirtland Shale, Ojo Alamo Sandstone, and Animas Formation (Upper Cretaceous and Paleocene).—Scattered uranium deposits occur in some of these formations but are mostly surficial occurrences. A few are small and several are medium in size. Except for the submarginal reserves at the base of the La Ventana Tongue of the Cliff House Sandstone, the known resources in these rocks are small.

The resource potential for most of these rocks is poor. They are nearly all marine or near-shore marine clastic sediments, except for the Ojo Alamo and Animas (in part of Paleocene age) Formations, and generally are unfavorable for uranium. Most of the known deposits are accumulations at the top or base of sandstone units, are surficial, and are associated with lenses or beds of carbonaceous debris. Locally, however, the potential for some small and medium-sized deposits in low-grade coals and highly carbonaceous materials is fair. These deposits most likely occur near the surface in structural depressions or where the beds may be faulted.

The Ojo Alamo and Animas Formations are continental clastic sedimentary rocks, including arkosic sandstone units, that are several thousand feet thick, but they are barren of known uranium deposits except for some minor occurrences in the Ojo Alamo. The resource potential for these formations is uncertain but probably ranges from poor to fair. The general lack of any deposits of much substance in the widely exposed surface indicates a poor outlook, but the presence of fairly thick lenses of arkosic sandstone and some included woody debris is a favorable indication that uranium deposits of substantial size might occur in the subsurface.

TERTIARY ROCKS

Nacimiento and San Jose Formations.—Several small deposits similar to the ones in the Ojo Alamo have been noted in the Nacimiento and San Jose Formations. The resource potential is uncertain but is rated poor to fair, similar to that of the Ojo Alamo and Animas Formations. Because of its fine grain size, most of the Nacimiento is considered potentially poor. In its northern part, largely under the San Jose Formation, it is considered potentially fair because of its coarser grain size. The San Jose is composed of material that is coarser grained than that in the Nacimiento, and many of the units in it appear to be favorable hosts for uranium deposits. The potential of the formation is rated no better than fair, however, because of its widespread exposure and the sparseness in it of known deposits, all of which are small.

Chuska Sandstone.—The potential for uranium deposits in the Chuska Sandstone is poor. This is indicated by the lack of uranium in rather widespread exposures, the paucity of carbonaceous material, and the possibility that much of the Chuska may be eolian in origin.

Baca Formation.—The potential for the Baca Formation to contain substantial uranium resources is fair. These resources most likely occur in channel-type sandstone lenses along synclinal folds, similar to the occurrence of the known deposits.

Datil Formation.—No deposits of much substance occur in the Datil Formation, and its resource potential is poor. The Datil consists mostly of volcanic debris and some fluvial clastic material, which are considered unfavorable for uranium deposits.

Galisteo Formation.—The resource potential of the Galisteo Formation is considered to range from poor at the outcrop to good in the unexposed parts. The Galisteo is rather widely exposed, but only one uranium deposit is known. This deposit, however, is medium size, much of the formation is lithologically favorable for containing deposits, and most of it is unexposed and unexplored. The unexplored parts are therefore considered potentially good for containing deposits that may range in size from small to large.

Popotosa Formation.—Several small occurrences and one medium-sized deposit, which is associated with a fault, occur in the Popotosa Formation. The resource potential of the Popotosa Formation is considered to range from poor to good for the same reasons that are given for the range for the Galisteo Formation.

Santa Fe Group (Miocene to Pleistocene?).—Several uranium deposits are known in rocks of the Santa Fe Group, but they generally are small and superficial. The resource outlook, however, is considered to range from poor at the outcrop to good in the subsurface, similar to the Galisteo and Popotosa Formations. The Santa Fe Group is widely exposed, but in most places only the upper few hundred feet of the sequence is represented; elsewhere the beds are covered by alluvium and surficial debris. Little, if any, exploration has been done for deposits in the unexposed beds. The great extent and thickness of these beds, and the favorableness of many of them for containing uranium deposits, offer a good potential for deposits that may range in size from small to large.

Older volcanic rocks of Jemez Mountains, Espinaso Volcanics of Stearns (1943), Cieneguilla Limburgite of Stearns (1953), and intrusive rocks of varied composition and form.—One medium-sized vein deposit occurs in the Espinaso Volcanics of Stearns (1943) on the eastern side of the Los Cerrillos district; a few other scattered small deposits, which are mostly surficial accumulations, occur in various types of intrusive and extrusive igneous rocks, mainly along the Rio Grande trough. The uranium resources in these rocks are small and the outlook is poor for finding more than a few small, or possibly medium-sized, deposits in them. The best potential is in the Los Cerrillos and Ortiz mining districts, where some uraniferous vein deposits might be found in association with the base-metal deposits.

AREAS RECOMMENDED FOR EXPLORATION

The principal uranium resources in northwestern New Mexico are in peneconcordant deposits, mostly in sandstone, partly in limestone, and to some extent in carbonaceous shale and coal. Most of these resources are along the margins of sedimentary basins, the most important of these areas being the southern and western parts of the San Juan Basin.

Of greatest importance is the southern part of the basin. On the basis of the frequency of distribution of the known deposits and their geologic relations, the deposits in this area are restricted to a zone or belt north of the outcrop of the Jurassic rocks which is at least 20 miles wide and which has been referred to as the southern San Juan Basin mineral belt (Hilpert and Moench, 1960). The northern limit of the belt is adjusted here to include the known areas of most intensive structural deformation during Late Jurassic time. This deformation is recognized as the prime control on the uranium deposits in the Morrison Formation and Todilto Limestone. As drawn, the northern limit of the belt extends from near the northern pinchout of the Jackpile sandstone northwestward, parallel to the reconstructed boundary of the Jurassic basin of deposition, to the outcrop of the Morrison Formation on the western side of the San Juan Basin (fig. 20). Included in the belt are the Jackpile trough in the Laguna district (roughly marked by the Jackpile sandstone) and the main ore-bearing sandstone mass in the Ambrosia Lake district (areas C and D, respectively, fig. 20). Other structurally deformed areas probably occur in the western part of the belt and along its north margin. Certainly such areas will not be expected to end abruptly where the north margin is indicated. The boundary is drawn to show approximately where the deformation became less intensive northward.

Included in the belt is the part of the limestone unit of the Todilto Limestone that is 15 feet or more thick. This part includes almost all the mine reserves, has yielded almost all the ore, and probably contains most of the uranium resources in the Todilto. Where the limestone unit of the Todilto was thickest, it probably received the most intensive deformation and thus is considered most favorable for deposits. The Todilto generally lies about 400–500 feet below the base of the Morrison Formation. Because of this general depth and the smaller deposits in it, the Todilto is not of immediate economic interest except where it is not deeply buried.

The mineral belt also contains the most favorable ground for uranium deposits in the Dakota Sandstone, although the Jurassic deformation probably had little, if any, influence on them. The best ground is in the western part of the belt, where channel-type sandstone lenses are largest and thickest. This area is near the margin of the Dakota basin of deposition. Depths to the base of the Dakota will generally be about 500 feet nearer the surface than the base of the Morrison. Although the size of the deposits in the Dakota is about the same as the size of the ones in the Todilto, the deposits in the Dakota are more amenable to exploration and development, which can be coordinated with exploration for the deeper but generally larger deposits in the Morrison Formation.

In the western part of the San Juan Basin substantial resources may also be found in the Shiprock district in the Salt Wash Member of the Morrison Formation and in the Chuska district in the Recapture Member of the Morrison (fig. 20, areas A and B, respectively). Each of these areas defines the thicker part of the respective members where they apparently occupy eastward-trending structural depressions. Deposits in these rocks are expected to range from small to medium in size, similar to the ones at the

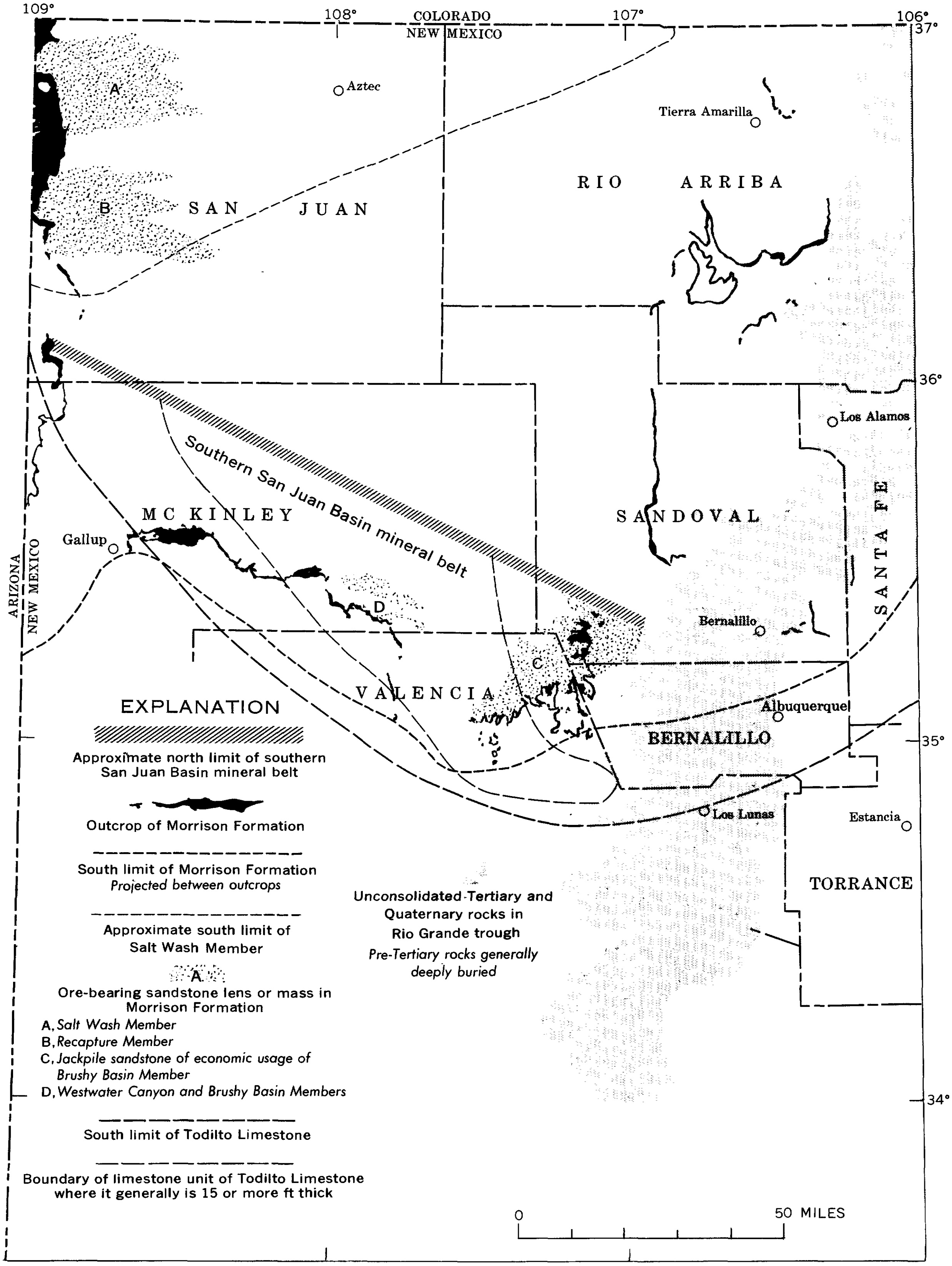


FIGURE 20.—Areas recommended for exploration.

outcrop. Eastward from the outcrop they will lie progressively deeper below the surface. In the Salt Wash the most favorable ground (area A) is largely on a structural terrace between the Mitten Rock and Hogback monoclines (fig. 3) where the member ranges from 0 to about 3,000 feet below the surface. In the Recapture the most favorable ground (area B) is largely in the Beautiful Mountain syncline, between the Defiance and Hogback monoclines (fig. 3) where the member ranges from 0 to about 3,000 feet below the surface. (See O'Sullivan and Beikman, 1963, sheet 2.)

In addition to the south and west sides of the San Juan Basin a few other areas offer some potential for finding deposits of economic interest. These areas include Rio Arriba County, the western part of Torrance County, and eastern Catron County.

In Rio Arriba County some deposits may be found in arkosic sands in unnamed Pennsylvanian rocks along the north margin of the Chama Basin and in arkosic sands in the Cutler Formation and Agua Zarca Member of the Chinle Formation along the south margin of the Chama Basin. In western Torrance County the Abo Formation might contain deposits in similar rocks. Some deposits might also be found in the Baca Formation in eastern Catron County, probably along synclinal structural features.

Deposits also may occur in the deeper parts of the Galisteo basin and within structurally closed segments of the Rio Grande trough, but many such deposits might be too deeply buried to be of immediate economic interest.

LITERATURE CITED

Akers, J. P., Cooley, M. E., and Repenning, C. A., 1958, Moenkopi and Chinle formations of Black Mesa and adjacents areas, *in* New Mexico Geol. Soc. Guidebook 9th Field Conf., Black Mesa Basin, northeastern Arizona, October 1958, p. 88–94.

Allen, J. E., and Balk, Robert, 1954, Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 36, 192 p.

Allen, V. T., 1930, Triassic bentonite of the Painted Desert: Am. Jour Sci., 5th ser., v. 19, p. 282–288.

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geol. Survey Prof. Paper 314–D, p. 45–90.

Anderson, R. Y., and Kirkland, D. W., 1960, Origin, varves, and cycles of Jurassic Todilto formation, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 1, p. 37–52.

Armstrong, A. K., 1958. The Mississippian of west-central New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 5, 32 p.

——— 1959, Mississippian strata on the east side of the Datil Plateau, *in* New Mexico Geol. Soc. Guidebook 10th Field Conf., West-central New Mexico, October 1929: p. 52–56.

Atwood, W. A., and Mather, K. F., 1932, Physiography and Quaternary geology of the San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 166, 176 p.

Baars, D. L., and Knight, R. L., 1957, Pre-Pennsylvanian stratigraphy of the San Juan Mountains and Four Corners area, *in* New Mexico Geol. Soc. Guidebook 8th Field Conf., Southwestern San Juan Mountains, Colorado, September 1957: p. 108–131.

Bachman, G. O., 1953, Geology of a part of northwestern Mora County, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM–137.

Bachman, G. O., Vine, J. D., Read, C. B., and Moore, G. W., 1959, Uranium-bearing coal and carbonaceous shale in the La Ventana Mesa area, Sandoval County, New Mexico: U.S. Geol. Survey Bull. 1055–J, p. 295–307.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlations of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geol. Survey Prof. Paper 183, 66 p.

——— 1947, Revised correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 9, p. 1664–1668.

Baker, A. A., and Reeside, J. B., Jr., 1929, Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 13, no. 11, p. 1413–1448.

Baldwin, Brewster, 1956, The Santa Fe group of north-central New Mexico, *in* New Mexico Geol. Soc. Guidebook 7th Field Conf., Southeastern Sangre de Cristo Mountains, New Mexico, October 1956: p. 115–121.

Baltz, E. H., Jr., 1955, A reconnaissance for uranium in carbonaceous rocks in southwestern Colorado and parts of New Mexico: U.S. Geol. Survey TEM–915, issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Baltz, E. H., Ash, S. R., and Anderson, R. Y., 1966, History of nomenclature and stratigraphy of rocks adjacent to the Cretaceous-Tertiary boundary, western San Juan Basin, New Mexico: U.S. Geol. Survey Prof. Paper 524–D, p. D1–D23.

Baltz, E. H., Jr., and Bachman, G. O., 1956, Notes on the geology of the southeastern Sangre de Cristo Mountains, New Mexico, *in* New Mexico Geol. Soc. Guidebook 7th Field Conf., Southeastern Sangre de Cristo Mountains, New Mexico, October 1956: p. 96–108.

Baltz, E. H., Jr., and Read, C. B., 1960, Rocks of Mississippian and probable Devonian age in Sangre de Cristo Mountains, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 11, p. 1749–1774.

Barnes, Harley, Baltz, E. H., Jr., and Hayes, P. T., 1954, Geology and fuel resources of the Red Mesa area, La Plata and Montezuma Counties, Colorado: U.S. Geol. Survey Oil and Gas Inv. Map OM–149.

Bass, N. W., 1944, Correlation of basal Permian and older rocks in southwestern Colorado, northwestern New Mexico, northeastern Arizona, and southeastern Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 7.

Bauer, C. M., 1916, Stratigraphy of a part of the Chaco River valley: U.S. Geol. Survey Prof. Paper 98–P, p. 271–278.

Beaumont, E. C., Dane, C. H., and Sears, J. D., 1956, Revised nomenclature of Mesaverde group in San Juan Basin, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 9, p. 2149–2162.

Bell, K. G., 1963, Uranium in carbonate rocks: U.S. Geol. Survey Prof. Paper 474–A, 29 p.

Blake, W. P., 1856, General report upon the geological collections [made on Whipple's reconnaissance near the 35th parallel], U.S. Pacific R.R. Explorations: U.S. 33d Cong., 2d sess., Senate Exec. Doc. 78 and House Exec. Doc. 91, v. 3.

Botinelly, Theodore, and Weeks, A. D., 1957, Mineralogic classification of uranium-vanadium deposits of the Colorado Plateau: U.S. Geol. Survey Bull. 1074–A, p. 1–5.

Brown, Barnum, 1910, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus *Kritosaurus:* Am. Mus. Nat. History Bull., v. 28, p. 267–274.

Chico, R. J., 1959, The geology of the uranium-vanadium deposit of the Diamond No. 2 mine, near Gallup, New Mexico: Missouri School of Mines M.S. thesis, Rolla, Mo.

Clark, D. S., and Havenstrite, S. R., 1963, Geology and ore deposits of the Cliffside mine, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 108–116.

Clary, T. A., Mobley, C. M., and Moulton, G. F., Jr., 1963, Geological setting of an anomalous ore deposit in the Section 30 mine, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 72–79.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1043.

Coleman, R. G., and Delevaux, M. H., 1957, Occurrence of selenium in sulfides from some sedimentary rocks of the Western United States: Econ. Geology, v. 52, no. 5, p. 499–527.

Collier, A. J., 1919, Coal south of Mancos, Montezuma County, Colorado: U.S. Geol. Survey Bull. 691–K, p. 293–310.

Collins, G. E., and Freeland, R. E., 1956, Airborne and ground reconnaissance in the Espanola area, Santa Fe County, New Mexico: U.S. Atomic Energy Comm. RME–1075.

Cooley, M. E., 1959, Triassic stratigraphy in the state line region of west-central New Mexico and east-central Arizona, *in* New Mexico Geol. Soc. Guidebook 10th Field Conf., West-central New Mexico, October 1959: p. 66–73.

Corbett, R. G., 1963, Uranium and vanadium minerals occurring in Section 22 mine, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 80–81.

Craig, L. C., and others, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geol. Survey Bull. 1009–E, p. 125–168.

Craig, L. C., Holmes, C. N., Freeman, V. L., Mullens, T. E., and others, 1959, Measured sections of the Morrison Formation and adjacent beds in the Colorado Plateau region, Arizona, Colorado, New Mexico, and Utah: U.S. Geol. Survey open-file report.

Cronk, R. J., 1963, Geology of the Dysart No. 1 mine, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 60–65.

Cross, C. W., 1894, Description of the Pikes Peak sheet [Colo.]: U.S. Geol. Survey Geol. Atlas, Folio 7.

——— 1899, Description of the Telluride quadrangle [Colo.]: U.S. Geol. Survey Geol. Atlas, Folio 57.

——— 1904, A new Devonian formation in Colorado: Am. Jour. Sci., 4th ser., v. 18, p. 245–252.

Cross, C. W., Howe, Ernest, and Ransome, F. L., 1905, Description of the Silverton quadrangle [Colo.]: U.S. Geol. Survey Geol. Atlas, Folio 120.

Cross, C. W., and Spencer, A. C., 1899, Description of the La Plata quadrangle [Colo.]: U.S. Geol. Survey Geol. Atlas, Folio 60.

——— 1900, Geology of the Rico Mountains: U.S. Geol. Survey 21st Ann. Rept., pt. 2, 1899–1900, p. 7–165.

Dane, C. H., 1936, The La Ventana-Chacra Mesa coal field, pt. 3 *of* Geology and fuel resources of the southern part of the San Juan Basin, New Mexico: U.S. Geol. Survey Bull. 860–C, p. 81–161.

——— 1946, Stratigraphic relations of Eocene, Paleocene, and latest Cretaceous formations of eastern side of San Juan Basin, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 24.

——— 1948, Geologic map of part of eastern San Juan Basin, Rio Arriba County, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 78.

——— 1959, Historical background of the type locality of the Tres Hermanos Sandstone Member of the Mancos Shale, *in* New Mexico Geol. Soc. Guidebook 10th Field Conf., West-central New Mexico, October 1959: p. 89–91.

——— 1960, The boundary between rocks of Carlile and Niobrara age in San Juan Basin, New Mexico and Colorado: Am. Jour. Sci., v. 258–A (Bradley volume), p. 46–56.

Dane, C. H., and Bachman, G. O., 1957a, Preliminary geologic map of the northwestern part of New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I–224.

——— 1957b, The Dakota Sandstone and Mancos Shale in the Gallup area [N. Mex.], *in* Four Corners Geol. Soc. Guidebook 2d Field Conf., Geology of southwestern San Juan Basin, 1957: p. 95–98.

Dane, C. H., Wanek, A. A., and Reeside, J. B., Jr., 1957, Reinterpretation of section of Cretaceous rocks in Alamosa Creek Valley area, Catron and Socorro Counties, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 2, p. 181–196.

Darton, N. H., 1910, A reconnaissance of parts of northwestern New Mexico and northern Arizona: U.S. Geol. Survey Bull. 435, 88 p.

——— 1928, "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U.S. Geol. Survey Bull. 794, 356 p.

Denny, C. S., 1940, Tertiary geology of the San Acacia area, New Mexico: Jour. Geology, v. 48, no. 1, p. 73–106.

Denson, N. M., and others, 1959, Uranium in coal in the Western United States: U.S. Geol. Survey Bull. 1055, 315 p.

Disbrow, A. E., and Stoll, W. C., 1957, Geology of the Cerrillos area, Santa Fe County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 48, 73 p.

Dodd, P. H., 1956, Some examples of uranium deposits in the Upper Jurassic Morrison formation on the Colorado Plateau, *in* Page, Stocking, and Smith, compilers, 1956: U.S. Geol. Survey Prof. Paper 300, p. 243–262.

Droullard, R. F., and Jones, E. E., 1951, Investigation of uranium deposits near Sanastee, New Mexico: U.S. Atomic Energy Comm. RMO–909, Tech. Inf. Service, Oak Ridge, Tenn.

Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau [N. Mex.], *in* Powell, J. W., Sixth Annual Report of the United States Geological Survey, 1884–85: p. 105–198.

Emmons, S. F., Cross, Whitman, and Eldridge, G. H., 1894, Description of the Anthracite-Crested Butte quadrangle, Colorado: U.S. Geol. Survey Geol. Atlas, Folio 9.

——— 1896, Geology of the Denver Basin in Colorado: U.S. Geol. Survey Mon. 27, 556 p.

Fenneman, N. M., 1931, Physiography of the Western United States: New York and London, McGraw-Hill Book Co., Inc., 534 p.

Finch, W. I., 1954, Geology of the Shinarump No. 1 uranium mine, Seven Mile Canyon area, Grand County, Utah: U.S. Geol. Survey Circ. 336, 14 p.

——— 1959, Peneconcordant uranium deposit—a proposed term: Econ. Geology. v. 54, no. 5, p. 944–946.

Fitzsimmons, J. P., Armstrong, A. K., and Gordon, Mackenzie, Jr., 1956, Arroyo Peñasco formation, Mississippian, north-central New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 1935–1944.

Fleischer, Michael, 1953, Recent estimates of the abundances of the elements in the earth's crust: U.S. Geol. Survey Circ. 285, 7 p.

Freeman, V. L., and Hilpert, L. S., 1956, Stratigraphy of the Morrison formation in part of northwestern New Mexico: U.S. Geol. Survey Bull. 1030–J, p. 309–334.

Gabelman, J. W., 1956a, Uranium deposits in paludal black shales, Dakota sandstone, San Juan Basin, New Mexico, *in* Page and others: U.S. Geol. Survey Prof. Paper 300, p. 303–319.

——— 1956b, Uranium deposits in limestone, *in* Page and others: U.S. Geol. Survey Prof. Paper 300, p. 387–404.

Gardner, J. H., 1910, The Carthage coal field, New Mexico: U.S. Geol. Survey Bull. 381, p. 452–460.

Garrels, R. M., and Larsen, E. S. 3d, compilers, 1959, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, 236 p.

Garrels, R. M., and Pommer, A. M., 1959, Some quantitative aspects of the oxidation and reduction of ores, pt. 14 *of* Garrels and Larsen, compilers, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, p. 157–164.

Gibson, Russell, 1952, Reconnaissance of some red bed copper deposits in the southwestern United States: U.S. Atomic Energy Comm. RMO–890, Tech. Inf. Service, Oak Ridge, Tenn.

Gilbert, G. K., 1875, Geology of portions of New Mexico and Arizona, explored and surveyed in 1873, *in* G. M. Wheeler, Geological surveys west of the 100th meridian, v. 3, pt. 5, p. 503–567.

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U.S. Geol. Survey Prof. Paper 150–D, p. 61–110.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council (repub. by Geol. Soc. America, 1951), 6 p.

Godwin, L. H., and Gaskill, D. L., 1964, Post-Paleocene West Elk laccolithic cluster, west-central Colorado, *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501–C, p. C66–C69.

Goldschmidt, V. M., 1954, Geochemistry: London, Oxford, Clarendon Press, 730 p.

Gordon, C. H., 1907a, Mississippian (Lower Carboniferous) formations in the Rio Grande Valley, New Mexico: Am. Jour. Sci., 4th ser., v. 24, p. 58–64.

——— 1907b, Notes on the Pennsylvanian formations in the Rio Grande Valley, New Mexico: Jour. Geology, v. 15, p. 805–816.

Gott, G. B., and Erickson, R. L., 1952, Reconnaissance of uranium and copper deposits in parts of New Mexico, Colorado, Utah, Idaho, and Wyoming: U.S. Geol. Survey Circ. 219, 16 p.

Gould, Walter, Smith, R. B., Metzger, S. P., and Melancon, P. E., 1963, Geology of the Homestake-Sapin uranium deposits, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 66–71.

Granger, H. C., 1963, Mineralogy, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 21–37.

Granger, H. C., and Ingram, B. L., 1966, Occurrence and identification of jordisite at Ambrosia Lake, New Mexico, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B120–B124.

Granger, H. C., and Santos, E. S., 1963, An ore-bearing cylindrical collapse structure in the Ambrosia Lake uranium district, New Mexico, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C156–C161.

Granger, H. C., Santos, E. S., Dean, B. G., and Moore, F. B., 1961, Sandstone-type uranium deposits at Ambrosia Lake, New Mexico—An interim report: Econ. Geology, v. 56, no. 7, p. 1179–1210.

Gregory, H. E., 1917, Geology of the Navajo country—a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 93, 166 p.

——— 1938, The San Juan country, a geographic and geologic reconnaissance of southeastern Utah, *with contributions by* M. R. Thorpe and H. D. Miser: U.S. Geol. Survey Prof. Paper 188, 123 p.

Gregory, H. E., and Moore, R. C., 1931, The Kaiparowitz region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U.S. Geol. Survey Prof. Paper 164, 161 p.

Griggs, R. L., and Baltz, E. H., Jr., 1955, [Reconnaissance for uranium in the United States] New Mexico, *in* Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI–540, p. 211–212, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Gruner, J. W., Gardiner, Lynn, and Smith, D. K., Jr., 1954, Mineral associations in the uranium deposits of the Colorado Plateau and adjacent regions—Interim report: U.S. Atomic Energy Comm. RME–3092, Tech. Inf. Service, Oak Ridge, Tenn.

Gruner, J. W., and Knox, J. A., 1957, Annual report for April 1, 1956 to March 31, 1957: U.S. Atomic Energy Comm. RME–3148, Tech. Inf. Service, Oak Ridge, Tenn.

Gruner, J. W., and Smith, D. K., Jr., 1955, Annual report for April 1, 1954 to March 31, 1955: U.S. Atomic Energy Comm. RME–3020, Tech. Inf. Service, Oak Ridge, Tenn.

Hack, J. T., 1942, Sedimentation and volcanism in the Hopi Buttes, Arizona: Geol. Soc. America Bull., v. 53, no. 2, p. 335–372.

Harmon, G. F., and Taylor, P. S., 1963, Geology and ore deposits of the Sandstone mine, southeastern Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 102–107.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country [Colorado Plateau]: U.S. Geol. Survey Prof. Paper 291, 74 p.

Hayes, P. H., and Zapp, A. D. 1955, Geology and fuel resources of the Upper Cretaceous rocks of the Barker dome-Fruitland area, San Juan County, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM-144.

Hazlett, G. W., and Kreek, Justin, 1963, Geology and ore deposits of the southeastern part of the Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 82–89.

Herrick, C. L., 1900, The geology of the white sands of New Mexico: Jour. Geology, v. 8, no. 2, p. 112–128.

——— 1904, Laws of formation of New Mexico mountain ranges: Am. Geologist, v. 33, p. 301-312.

Hilpert, L. S., 1961, Structural control of epigenetic uranium deposits in carbonate rocks of northwestern New Mexico, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B5–B8.

——— 1963, Regional and local stratigraphy of uranium-bearing rocks, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 6–18.

Hilpert, L. S., and Freeman, V. L., 1956, Guides to uranium deposits in the Morrison Formation, Gallup-Laguna area, New Mexico, *in* Page and others: U.S. Geol. Survey Prof. Paper 300, p. 299–302.

Hilpert, L. S., and Moench, R. H., 1960, Uranium deposits of the southern part of the San Juan Basin, New Mexico: Econ. Geology, v. 55, no. 3, p. 429–464.

Holmes, W. H., 1877, Geological report on the San Juan district [Colo.], *in* Geology, Pt. 1 *of* Hayden, F. V., Ninth Annual Report of the United States Geological and Geographic Survey of the Territories, embracing Colorado and parts of adjacent territories, being a report of progress of the exploration for the year 1875: p. 241–276.

Hoskins, W. G., 1963, Geology of the Black Jack No. 2 mine, Smith Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 49–52.

Howell, E. E., 1875, Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in the years 1872–1873, *in* Wheeler, G. M., Report upon geographical and geological exploration and surveys west of the 100th meridian: v. 3, pt. 3, p. 227–301.

Hunt, C. B., 1938, Igneous geology and structure of the Mount Taylor volcanic field, New Mexico: U.S. Geol. Survey Prof. Paper 189–B, p. 51–80.

——— 1956, Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279, 99 p.

Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region: U.S. Geol. Survey Prof. Paper 228, 235 p.

Jahns, R. H., 1946, Mica deposits of the Petaca district, Rio Arriba County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 25, 289 p.

Jones, F. A., 1904, New Mexico mines and minerals: Santa Fe, N. Mex., The New Mexican Printing Company, World's Fair ed.

Just, Evan, 1937, Geology and economic features of the pegmatites of Taos and Rio Arriba Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 13, 73 p.

Kelley, V. C., 1954, Tectonic map of a part of the upper Rio Grande area, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM–157.

——— 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: New Mexico Univ. Pubs. Geology, no. 5, 120 p.

——— 1963, Preface, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 1–2.

Kelley, V. C., and Silver, Caswell, 1952, Geology of the Caballo Mountains: New Mexico Univ. Pub. Geology, no. 4, 286 p.

Kelley, V. C., and Wood, G. H., Jr., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim Map 47.

Keyes, C. R., 1905, Geology and underground water conditions of the Jornada del Muerto, New Mexico: U.S. Geol. Survey Water-Supply Paper 123, 42 p.

——— 1915, Foundation of exact geologic correlation: Iowa Acad. Sci. Proc., v. 22, 249-267.

Kirk, Edwin, 1931, The Devonian of Colorado: Am. Jour. Sci., 5th ser., v. 22, p. 222-240.

Kittel, D. F., 1963, Geology of the Jackpile mine area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 167-176.

Konigsmark, T. A., 1955, Color changes and uranium deposits of the upper Morrison formation, northeast flank of the Zuni uplift, New Mexico: U.S. Atomic Energy Comm. RME-76, pt. 1, Tech. Inf. Service, Oak Ridge, Tenn.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, Appleton-Century-Crofts, Inc., 265 p.

Larsen, E. S., Jr., and Cross, C. W., 1956, Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.

Laverty, R. A., and Gross, E. B., 1956, Paragenetic studies of uranium deposits of the Colorado Plateau, *in* Page and others: U.S. Geol. Survey Prof. Paper 300, p. 195–201.

Lee, W. T., and Girty, G. H., 1909, The Manzano group of the Rio Grande valley, New Mexico: U.S. Geol. Survey Bull. 389, 141 p.

Leopold, L. B., 1943, Climatic character of the interval between the Jurassic and Cretaceous in New Mexico and Arizona: Jour. Geology, v. 51, no. 1, p. 56–62.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., 1910, The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, 361 p.

Loughlin, G. F., and Koschmann, A. H., 1942. Geology and ore deposits of the Magdalena mining district, New Mexico: U.S. Geol. Survey Prof. Paper 200, 168 p.

Luedke, R. G., and Burbank, W. S., 1963, Tertiary volcanic stratigraphy in the western San Juan Mountains, Colorado, *in* Geological Survey research 1963: U.S. Geol. Survey Prof. Paper 475–C, p. C39–C44.

McKee, E. D., 1954, Stratigraphy and history of the Moenkopi formation of Triassic age: Geol. Soc. America Mem. 61, 133 p.

McKee, E. D., and others, 1956, Paleotectonic maps of the Jurassic System: U.S. Geol. Survey Misc. Geol. Inv. Map I–175.

McKee, E. D., and others, 1959, Paleotectonic maps of the Triassic System: U.S. Geol. Survey Misc. Geol. Inv. Map I–300.

——— 1967, Paleotectonic maps of the Permian System: U.S. Geol. Survey Misc. Geol. Inv. Map I–450.

McLaughlin, E. D., Jr., 1963, Uranium deposits in the Todilto Limestone of the Grants district, *in* Kelley, V. C.. chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 136–149.

MacRae, M. E., 1963, Geology of the Black Jack No. 1 mine, Smith Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 45–48.

Marcou, Jules, 1856, Résumé of a geological reconnaissance extending * * * to the Pueblo de los Angeles in California, U.S. Pacific R.R. Explorations: U.S. 33d Cong., 2d sess., Senate Executive Doc. 78 and House Executive Doc. 91, v. 3, pt. 4, p. 165–171.

——— 1858, Geology of North America, with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California: Zurich, 144 p.

Masters, J. A., 1955, Geology of the uranium deposits of the Lukachukai Mountains area, northeastern Arizona: Econ. Geology, v. 50, no. 2, p. 111-126.

Mathewson, D. E., 1953, Reconnaissance for uranium in the Morrison formation north of Bluewater, McKinley County, New Mexico: U.S. Atomic Energy Comm. RME–57, Tech. Inf. Service, Oak Ridge, Tenn.

Miesch, A. T., and Riley, L. B., 1961, Basic statistical measures used in geochemical investigations of Colorado Plateau uranium deposits: Am. Inst. Mining Metall. and Petroleum Engineers Trans., v. 220, p. 247–251.

Mirsky, Arthur, 1953, Preliminary report on uranium mineralization in the Dakota sandstone, Zuni uplift, New Mexico: U.S. Atomic Energy Comm. RME–47, 21 p., Tech. Inf. Service, Oak Ridge, Tenn.

Moench, R. H., 1962, Vanadium-rich garnet from Laguna, New Mexico, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–B, p. B67–B69.

——— 1963a, Geologic map of the Seboyeta quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–207.

——— 1963b, Geologic map of the Laguna quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–208.

——— 1963c, Geologic limitations on the age of uranium deposits in the Laguna district, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 157–166.

——— 1964a, Geology of the Dough Mountain quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–354.

——— 1964b, Geology of the South Butte quadrangle, New Mexico—Valencia County: U.S. Geol. Survey Geol. Quad. Map GQ–355.

Moench, R. H., and Puffett, W. P., 1963a, Geologic map of the Arch Mesa quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–211.

——— 1963b, Geologic map of the Mesa Gigante quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–212.

Moench, R. H., and Schlee, J. S., 1959, Laguna district, New Mexico, *in* Geologic investigations of radioactive deposits, semiannual progress report for December 1, 1958 to May 31, 1959: U.S. Geol, Survey TEI–751, p. 14–32, issued by the U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Moench, R. H., Schlee, J. S., and Bryan, W. B., 1965, Geologic map of the La Gotera quadrangle, Sandoval and Valencia Counties, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–371.

Muehlberger, W. R., 1957, Pennsylvanian outcrops along Brazos uplift, Rio Arriba County, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 1, p. 140–145.

Murphy, J. F., 1956, Preliminary report on titanium-bearing sandstone in the San Juan Basin and adjacent areas in Arizona, Colorado, and New Mexico: U.S. Geol. Survey open-file report.

Needham, C. E., and Bates, R. L., 1943, Permian type sections in central New Mexico: Geol. Soc. America Bull., v. 54, no. 11, p. 1653–1667.

Nekrasova, Z. A., 1958, The form of the occurrence of uranium in some coals, *in* Second United Nations International Conference on the Peaceful Uses of Atomic Energy, v. 2, Survey of Raw Material Resources: p. 412–419.

Newberry, J. S., 1861, Geological report, *in* Ives, J. C., Report upon the Colorado River of the West: U.S. 36th Cong. 1st sess., Senate Executive Doc. and House Executive Doc. 90, pt. 3, p. 65–66.

——— 1876, Geological report, *in* Macomb, J. N., Report on the exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the Great Colorado of the West in 1859: U.S. Army Eng. Dept., p. 9–118.

Northrop, S. A., Sullwold, H. H., Jr., McAlpin, A. J., and Rogers, C. P., Jr., 1946, Geologic maps of a part of the Las Vegas Basin and of the foothills of the Sangre de Cristo Mountains, San Miguel and Mora Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 54.

O'Sullivan, R. B., and Beaumont, E. C., 1957, Preliminary geologic map of western San Juan Basin, San Juan and McKinley Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM–190.

O'Sullivan, R. B., and Beikman, H. M., 1963, Geology, structure, and uranium deposits of the Shiprock quadrangle, New Mexico and Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–345.

Page, L. R., 1950, Uranium in pegmatites: Econ. Geology, v. 45, no. 1, p. 12–34.

Page, L. R., Stocking, H. E., and Smith, H. B., compilers, 1956, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, 739 p.

Pike, W. S., Jr., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. America Mem. 24, 103 p.

Poole, F. G., 1961, Stream direction in Triassic rocks of the Colorado Plateau, in Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C139–C141.

Rapaport, Irving, 1963, Uranium deposits of the Poison Canyon ore trend, Grants district, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 122–135.

Rapaport, Irving, Hadfield, J. P., Jr., and Olson, R. H., 1952, Jurassic rocks of the Zuni Uplift, New Mexico: U.S. Atomic Energy Comm. RMO–642, Tech. Inf. Service, Oak Ridge, Tenn.

Read, C. B., 1951, Stratigraphy of the outcropping Permian rocks around the San Juan Basin, *in* New Mexico Geol. Soc. 2d Field Conf., Guidebook of the south and west sides of the San Juan Basin, New Mexico and Arizona, 1951: p. 80–84.

Read, C. B., Wilpolt, R. H., Andrews, D. A., Summerson, C. H., and Wood, G. H., Jr., 1944, Geologic map and stratigraphic sections of Permian and Pennsylvanian rocks of parts of San Miguel, Santa Fe, Sandoval, Bernalillo, Torrance, and Valencia Counties, north-central New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 21.

Reeside, J. B., Jr., 1924, Upper Cretaceous and Tertiary formations of the western part of the San Juan Basin of Colorado and New Mexico: U.S. Geol. Survey Prof. Paper 134, p. 1–70.

——— 1944, Map showing thickness and general character of the Cretaceous deposits in the western interior of the United States: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 10.

Ross, C. S., and Smith, R. L., 1961, Ash-flow tuffs—their origin, geologic relations, and identification: U.S. Geol. Survey Prof. Paper 366, 81 p.

Roth, R. I., 1934, Type section of Hermosa formation, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 18, no. 7, p. 944–947.

Santos, E. S., 1963, Relation of ore deposits to the stratigraphy of the Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 53-59.

Schlee, J. S., 1963, Sandstone pipes of Laguna area, New Mexico: Jour. Sed. Petrology, v. 33, no. 1, p. 112–123.

Schlee, J. S., and Moench, R. H., 1961, Properties and genesis of "Jackpile" sandstone, Laguna, New Mexico, *in* Geometry of sandstone bodies—a symposium, 45th Ann. Mtg., Atlantic City, N.J., 1960: Am Assoc. Petroleum Geologists, p. 134–150.

——— 1963a, Geologic map of the Moquino quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–209.

——— 1963b, Geologic map of the Mesita quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–210.

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U.S. Geol. Survey Bull. 767, 52 p.

Sears, J. D., Hunt, C. B., and Hendricks, T. A., 1941, Transgressive and regressive Cretaceous deposits in southern San Juan basin, New Mexico: U.S. Geol. Survey Prof. Paper 193-F, p. 101–121.

Sharp, J. V. A., 1955, Uranium deposits in the Morrison formation, Church Rock area, McKinley County, New Mexico: U.S. Atomic Energy Comm. RME–79, Tech. Inf. Service, Oak Ridge, Tenn.

Shoemaker, E. M., 1956, Structural features of the central Colorado Plateau and their relation to uranium deposits *in* Page and others: U.S. Geol. Survey Prof. Paper 300, p. 155-170.

Silver, Caswell, 1948, Jurassic overlap in western New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 32, no. 1, p. 68-81.

Simpson, G. G., 1948, The Eocene of the San Juan Basin, New Mexico, pt. 1: Am. Jour. Sci., v. 246, no. 5, p. 257–282.

Simpson, J. H., 1850, Journal of a military reconnaisance from Santa Fe, New Mexico, to the Navajo country: U.S. 31st Cong., 1st sess., Senate Executive Doc. 64, p. 56–138, 146–148.

Smith, C. T., 1954, Geology of the Thoreau quadrangle, McKinley and Valencia Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 31, 36 p.

Smith, H. T. U., 1938, Tertiary geology of the Abiquiu quadrangle, New Mexico: Jour. Geology, v. 46, no. 7, p. 933–965.

Spencer, A. C., 1900, Devonian strata in Colorado: Am. Jour. Sci., 4th ser., v. 9, p. 125–133.

Spiegel, Zane, and Baldwin, Brewster, 1963, Geology and water resources of the Santa Fe area, New Mexico: U.S. Geol. Survey Water-Supply Paper 1525, 258 p.

Squyres, J. B., 1963, Geology and ore deposits of the Ann Lee mine, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 90–101.

Stearns, C. E., 1943, The Galisteo formation of north-central New Mexico: Jour. Geology, v. 51, no. 5, p. 301–319.

——— 1953, Tertiary geology of the Galisteo-Tonque area, New Mexico: Geol. Soc. America Bull., v. 64, no. 4, p. 459–507.

Stern, T. W., Newell, M. F., Kistler, R. W., and Shawe, D. R., 1965, Zircon uranium-lead and thorium-lead ages and mineral potassium-argon ages of La Sal Mountains rocks, Utah: Jour. Geophys. Research, v. 70, no. 6, p. 1503–1507.

Steven, T. A., Mehnert, H. H., and Obradovich, J. D., 1967, Age of volcanic activity in the San Juan Mountains, Colorado, *in* Geological Survey research 1967: U.S. Geol. Survey Prof. paper 575–D, p. D47–D55.

Stevenson, J. J., 1881, Geological examinations in southern Colorado and northern New Mexico, during the years 1878 and 1879, *in* Wheeler, G. M., U.S. Geographical surveys west of the 100th meridian, v. 3, Geology 420 p.

Stewart, J. H., 1957, Proposed nomenclature of part of Upper Triassic strata in southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 3, p. 441–465.

Stewart, J. H., Williams, G. A., Albee, H. F., and Raup, O. B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geol. Survey Bull. 1046–Q, p. 487–573.

Stewart, J. H., and Wilson, R. F., 1960, Triassic strata of the salt anticline region, Utah and Colorado, *in* Geology of the Paradox Basin fold and fault belt: Four Corners Geol. Soc. 3d Field Conf., 1960 [Guidebook], p. 98–106.

Stokes, W. L., 1950, Pediment concept applied to Shinarump and similar conglomerates: Geol. Soc. America Bull., v. 61, no. 2, p. 91–98.

——— 1951, Carnotite deposits in the Carrizo Mountains area, Navajo Indian Reservation, Apache County, Arizona, and San Juan County, New Mexico, U.S. Geol. Survey Circ. 111, 5 p.

Strobell, J. D., Jr., 1956, Geology of the Carrizo Mountains area in northeastern Arizona and northwestern New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM–160.

——— 1958, Salient stratigraphic and structural features of the Carrizo Mountains area, Arizona-New Mexico, *in* Intermountain Assoc. Petroleum Geologists Guidebook 9th Ann. Field Conf., Geology of the Paradox Basin, 1958: p. 66–73.

Sun, M. S., and Baldwin, Brewster, 1958, Volcanic rocks of the Cienega area, Santa Fe County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 54, 80 p.

Thaden, R. E., and Santos, E. S., 1957, Grants area, New Mexico, *in* Geologic investigations of radioactive deposits—semiannual progress report, June 1 to November 30, 1956: U.S. Geol. Survey TEI–640, p. 73–76, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1963, Map showing the general structural features of the Grants district and the areal distribution of the known uranium ore bodies in the Morrison Formation, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, between p. 20 and 21.

Trites, A. F., and Chew, R. T., 3d, 1955, Geology of the Happy Jack mine, White Canyon area, San Juan County, Utah: U.S. Geol. Survey Bull. 1009–H, p. 235–248.

Trites, A. F., Chew, R. T. 3d, and Lovering, T. G., 1959, Mineralogy of the uranium deposit at the Happy Jack mine, San Juan County, Utah, pt. 16 *of* Garrels and Larsen, compilers, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, p. 185-197.

Truesdell, A. H., and Weeks, A. D., 1960, Paragenesis of uranium ores in Todilto Limestone near Grants, New Mexico, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B52–B54.

Tschanz, C. M., Laub, D. C., and Fuller, G. W., 1958, Copper and uranium deposits of the Coyote district, Mora County, New Mexico: U.S. Geol. Survey Bull. 1030–L, p. 343–398.

Vine, J. D., 1962, Geology of uranium in coaly carbonaceous rocks: U.S. Geol. Survey Prof. Paper 356–D, p. 113–170.

Weege, R. J., 1963, Geology of the Marquez mine, Ambrosia Lake area, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 117–121.

Weeks, A. D., Coleman, R. G., and Thompson, M. E., 1959, Summary of the ore mineralogy, pt. 5 *of* Garrels and Larsen, compilers, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, p. 65–79.

Weeks, A. D., Lindberg, M. L., and Meyrowitz, Robert, 1961, Grantsite, a new hydrated sodium calcium vanadyl vandate from New Mexico and Colorado—a preliminary description, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B293.

Weeks, A. D., and Thompson, M. E., 1954, Identification and occurrence of uranium and vanadium minerals from the Colorado Plateau: U.S. Geol. Survey Bull. 1009–B, p. 13-62.

Weeks, A. D., and Truesdell, A. H., 1958, Mineralogy and geochemistry of the uranium deposits of the Grants district, New Mexico [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1658–1659.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, Georges, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and Northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 61.

Wilpolt, R. H., and Wanek, A. A. 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM–121.

Winchester, D. E., 1920, Geology of the Alamosa Creek valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas: U.S. Geol. Survey Bull. 716–A, p. 1–15.

Wislizenus, A., 1848, Memoir of a tour to northern New Mexico: U.S. 30th Cong., 1st sess., Senate Misc., Doc. 26.

Witkind, I. J., 1956, Uranium deposits at base of the Shinarump conglomerate, Monument Valley, Arizona: U.S. Geol. Survey Bull. 1030–C, p. 99–130.

Wood, G. H., Kelley, V. C., and MacAlpin, A. J., 1948, Geology of southern part of Archuleta County, Colorado: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 81.

Wood, G. H., Northrop, S. A., and Cowan, M. J., 1946, Geology of the Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 57.

Wright, H. E., Jr., 1943, Cerro Colorado, an isolated non-basaltic volcano in central New Mexico: Am. Jour. Sci., v. 241, no. 1, p. 43–56.

Wylie, E. T., 1963, Geology of the Woodrow breccia pipe, *in* Kelley, V. C., chm., Geology and technology of the Grants uranium region: New Mexico Bur. Mines and Mineral Resources Mem. 15, p. 177–181.

Young, R. G., and Ealy, G. K., 1956, Uranium occurrences in the Ambrosia Lake area, McKinley County, New Mexico: U.S. Atomic Energy Comm. RME–86, Tech. Inf. Service, Oak Ridge, Tenn.

Zitting, R. T., Masters, J. A., Groth, F. A., and Webb, M. D., 1957, Geology of the Ambrosia Lake area uranium deposit, McKinley County, New Mexico: Mines Mag., v. 47, no. 3, p. 53–58.

INDEX

[Italic page numbers indicate major references]

U.S. GOVERNMENT PRINTING OFFICE: 1969 C—329-381