COAL, OIL, NATURAL GAS, HELIUM, AND URANIUM IN ARIZONA

By

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FOREWORD

This report by Dr. H. Wesley Peirce, Mr. Stanton B. Keith, and Mrs. Jan Carol Wilt presents the findings of a study made by the Arizona Bureau of Mines, University of Arizona, for the Four Corners Regional Commission. The project was initiated originally at the interest and request of the Honorable Jack Williams, Governor of the State of Arizona.

The basic purpose and scope of the program has been that of assembling and presenting basic data pertaining to the occurrence in Arizona of uranium, coal, petroleum, natural gas, and helium, with a view toward assisting in the search for additional reserves of these materials.

It is considered that the report comprehensively fulfills the objectives of the agreement which led to the establishment of the study, and the results now are being presented herewith as Bulletin 182 of the Arizona Bureau of Mines.

J. D. Forrester, Director
Arizona Bureau of Mines
University of Arizona
Tucson, Arizona
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INTRODUCTION

GENERAL STATEMENT

This report is based upon a study which was conducted during the period of March 1, 1969, through February 28, 1970. It was undertaken by the Arizona Bureau of Mines to fulfill the stipulation and conditions of a contract entered into by the Arizona Board of Regents, for the Arizona Bureau of Mines, with the Four Corners Regional Commission through the channel of a Technical Assistance Grant — Project No. FCRC 1095012 File No. 191-400-007.

Under the terms of the contract, the Arizona Bureau of Mines has assembled data that are designed to assist in developing a fundamental understanding and a geological perspective of the occurrence of coal, petroleum, natural gas, helium and uranium in Arizona. It is hoped that this effort will serve those who are interested in the search for additional supplies of these potentially economic substances, and, in addition, will constitute the base for continuing efforts by the Arizona Bureau of Mines and other agencies concerned with the orderly development of these and other natural resources.

Presentations are made in three parts, namely: (1) Coal; (2) Oil, Natural Gas, and Helium; and (3) Uranium. A unified bibliography, involving each of these commodities, is presented at the end of the report. Numerous tables and illustrations which concisely summarize significant data are included within each section, in the appendix, and as plates in the pocket at the back.

ACKNOWLEDGMENTS

In addition to the cooperative efforts of all members of the Arizona Bureau of Mines staff, special thanks are extended to Mr. John Bannister, Executive Secretary, and Mr. James Scurlock, Geologist, of the Oil and Gas Conservation Commission of Arizona, and their staff.

Appreciation is expressed also to Mr. William Chenoweth of the United States Atomic Energy Commission, to Mr. Douglas Cook and Mr. Bryan Archer of Peabody Coal Company, to Mr. Perry K. Hurlbut, Minerals Supervisor for the Navajo Tribe, and to Mr. Brian Kirby, Geologist with the Southern Union Gas Company.

PREVIOUS STUDIES

The literature that both directly and indirectly pertains to coal, petroleum, natural gas, helium, and uranium, in Arizona, is extensive. Every general geologic work in some way can be applied to one or more of these potential resources. References for reviews of the various commodities have been assembled at the end of the report.

Coal has been studied by such governmental organizations as the United States Bureau of Mines, the United States Geological Survey, and the Arizona Bureau of Mines. Statewide summaries have been made by Rubel (1916), and Averitt and O'Sullivan (1969).

Petroleum, natural gas, and helium have been discussed in many ways by individuals, company representatives, and governmental agencies. Statewide considerations have been presented by O'Sullivan (1969), Pye (1967), Stipp and Beikman (1959), the Oil and Gas Conservation Commission of Arizona (1961), Holm (1938), McKee (1950), and Butler and Tenney (1931).

Earlier studies concerning uranium in Arizona have been undertaken primarily by the United States Geological Survey and the United States Atomic Energy Commission. Much of the work has been on a format other than statewide, but two reports have statewide coverage; Granger and Raup (1962) discuss individual uranium deposits and Butler and Byers (1969) treat the general distribution of such occurrences in Arizona.

GEOLOGIC AND TOPOGRAPHIC SETTING

General Statement

Arizona is characterized by its geologic and topographic variations both large and small. On a large scale the State can be geologically divided into roughly two halves along a NW-SE diagonal that extends from near Lake Mead in the northwest to the New Mexico border northeast of Clifton. The diagonal, which is frequently referred to as the "Mogollon Rim" or the "Rim", divides the Plateau physiographic province on the northeast from the Basin and Range physiographic province on the southwest. Figure 1 shows these subdivisions and summarizes some of their respective characteristics. Fundamentally, the Plateau is a sedimentary rock province whereas the Basin and Range is a complex province containing metamorphic, igneous, and sedimentary rocks. The contrasts exhibited by these two geologic provinces reflect a differing response to geologic history and serve as a reminder that earth history has not everywhere produced identical manifestations. Arizona, geologically speaking, has a character of its own. Its understanding has been the object of much study by many earth scientists.

In Arizona, over 90 percent of the population resides in the Basin and Range province. This is related to the fact that over 97 percent of

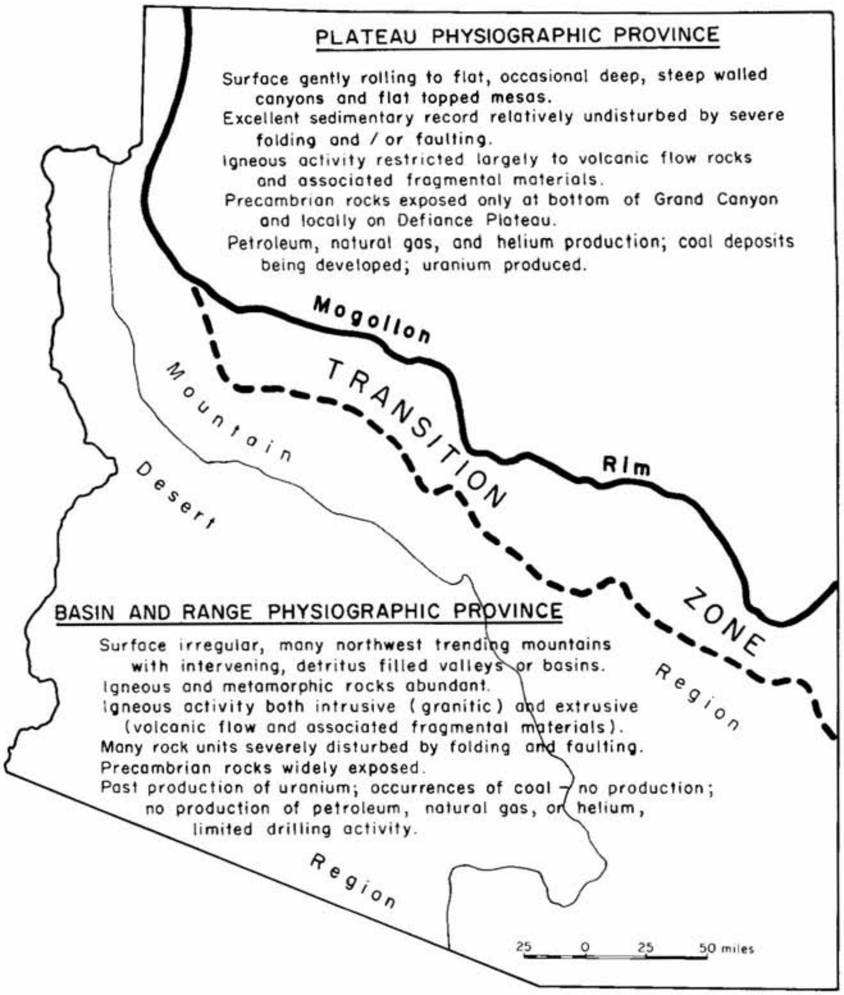

Figure 1. Major physiographic subdivisions of Arizona and their general geologic characteristics.

the agricultural acreage and over 97 percent of the value of mineral production is in the Basin and Range province. Geologically influenced factors such as climate, soil, and water here combine to form a favorable base for agriculture, and geologic history in this province has been such as to place mineral deposits, principally copper, within reach of the earth's present surface. However, most of Arizona's uranium production, coal reserves, and all of its current production of oil, natural gas, and helium is from the Plateau province. As a consequence, this study concentrates largely on the Plateau and fringing areas in the belief that additional

Eras	Periods and Epochs		Age-millions of years	Geologic Highlights of Plateau Region of Arizona	
CENOZOIC	Quaternary	Recent		Alluvial sediments; volcanics.	Volcanism. Uplift and erosion.
			.011		
		Pleistocene		Stream, river, and lake deposits; volcanics; glaciation on San Francisco Peaks near Flagstaff and in White mountains.	Local sedimentation.
			1		
	Tertiary	Pliocene		Continental sedimentation: Bidahochi and Verde Formations. Uranium occurrences.	Mogollon Rim faulting.
			12		
		Miocene		- - - - Unconformity - - - -	Regional uplift of large magnitude. Volcanism and erosion.
			23	Chuska Sandstone, "Rim" gravels, Datil Formation.	
		Oligocene			
			40	- - - - Unconformity - - - -	
		Eocene		Rock units not generally recognized.	Laramide Revolution: Folding, monoclinal flexuring. Formation of Kaibab, Monument, and Defiance uplifts, and Black Mesa basin. General uplift.
		Paleocene			
			70	Unconformity	
MESOZOIC	Cretaceous			Up to 2,000 feet upper cretaceous marine and non-marine sediments, principally sandstones and shales; important coal deposits in Black Mesa; local uranium occurrences.	
			135	Unconformity	
	Jurassic			Up to 2,000 feet largely non-marine sediments, principally sandstones. Morrison Formation important uranium host rocks.	Northward tilting of Black Mesa basin region-erosion. (Nevadan ?)
			180		
	Triassic			Up to 1,500 feet non-marine sediments, principally shales and sandstones. Contains host rocks for major Arizona uranium deposits and reservoir rocks for helium. A Black Mesa basin objective.	
			220	Unconformity	General uplift and erosion.
PALEOZOIC	Permian			Up to 2,000-3,000 feet marine and non-marine sediments. Contains principal reservoir rock for helium at Pinta. Local petroleum, natural gas, and helium potential. A Black Mesa basin objective. Locally, a host for important uranium deposits. Minor coaly occurrences.	Local basining.
			270		
	Pennsylvanian			Up to 2,000 feet of marine sediments, principally carbonates and shales. Important reserves and objectives for oil and gas in Black Mesa basin area.	Local basining.
			320	Unconformity	Regional erosion.
	Mississippian			Up to 800 feet marine sediments, principally carbonates. Local petroleum, natural gas, and helium production in Black Mesa basin area. A drilling objective throughout N. Arizona.	
			350		Local erosion.
	Devonian			Up to 600 feet marine sediments, principally carbonates with locally important sandstones. Local petroleum production and helium occurrences. A drilling objective in Black Mesa basin area.	
			400		
	Silurian			Not recognized.	General emergence.
	Ordovician			Marine sediments in extreme NW. Arizona.	
			490	Unconformity	
	Cambrian			Up to 1,500 feet marine sediments, principally sandstones, shales, and carbonates. Limited drilling objective in NW. Arizona. Sandstone beneath Devonian to SE. is a local objective.	
			600	Unconformity	Grand Canyon disturbance.
YOUNGER PRECAMBRIAN				About 10,000 feet quartzite, shale, and limestone.	
			1600	Unconformity	Mazatzal Revolution.
OLDER PRECAMBRIAN			2000+	Granitic and metamorphic rocks constitute basement rocks of region. Local outcrops in Defiance and Grand Canyon regions.	

Figure 2. Time scale with geologic highlights of the Arizona Plateau region.

resources are to be sought first in areas geologically related to known occurrences.

The geologic highlights of the Plateau and Basin and Range provinces are presented in abbreviated form in Figures 2 and 3, respectively. For a more detailed written account of the overall general geologic history and setting of Arizona the reader is referred to Darton (1925), McKee (1951), Wilson (1962), and Hayes (1969). Statewide geologic map coverage is presented by Cooley (1967), Wilson, Moore, and Cooper (1969), by the American Association of Petroleum Geologists (Oetking, Feray, and Renfro, 1967), and on the county geologic map series published by the Arizona Bureau of Mines.

A more detailed geologic discussion is presented in the sections dealing with the specific commodities.

Plateau

The elevation of the Plateau in Arizona is generally over a mile high with subordinate plateaus reaching to 9,000 feet. San Francisco Mountain, Arizona's highest point with an altitude of 12,611 feet, is a volcano remnant on the Plateau near Flagstaff. Surface rocks are Paleozoic and Mesozoic sedimentary rocks with small, but significant patches of covering Cenozoic volcanics and sediments. The thickest preserved stratigraphic section is about 9,000 feet thick, half of which is Mesozoic clastic formations and half is Paleozoic clastic and carbonate formations. Structurally, the Plateau is wavy in detail because of numerous folds and structural slopes of varying magnitudes of distortion. (See Plate 1.) The larger fold systems have been called uplifts or upwarps, e.g., Kaibab uplift, Defiance uplift, and Monument upwarp. The area of the Defiance uplift is of special interest because, thus far, all of Arizona's production of helium, natural gas, and petroleum is either on it or in proximity to it.

The uplifts are separated by structurally lower features called saddles or basins. The entire northeastern quarter of the State is frequently referred to as the Black Mesa basin region, a name derived from the Black Mesa topographic feature. Black Mesa is an important remnant of formerly more extensive rocks of Mesozoic age. These rocks have been stripped away from the structurally higher zones. This remnant, which has been relatively protected by the downwarping action that formed the basin, contains Arizona's important coal reserves. Similarly, much of Arizona's uranium production and remaining potential for additional reserves of uranium ore is associated with Mesozoic clastic sedimentary rocks preserved within the Black Mesa basin structurally depressed zone, an area of about 26,000 square miles.

Faults, though locally present, are not a Plateau characteristic except in northwestern Arizona generally north of the Grand Canyon. The

ERAS	Periods and Epochs		Age-millions of years	Geologic Highlights of Basin – Range Region of Arizona	
CENOZOIC	Quaternary	Recent	.011	Alluvial sediments.	Uplift and erosion
	Quaternary	Pleistocene	1	Stream, river, and lake deposits; basaltic volcanics.	Uplift and erosion
	Tertiary (Late)	Pliocene	12	Locally, thousands of feet of non-marine sediments including evaporitic lacustrine deposits; marine embayment in southwestern Arizona. Basaltic volcanics. Possible uranium deposits.	volcanism
	Tertiary (Middle)	Miocene	23	— Unconformity — Locally, thousands of feet of non-marine sediments and volcanics: Pantano Formation, Helmet Fanglomerate, Whitetail Conglomerate etc. Possible uranium deposits.	Basin and Range orogeny: Uplift; faulting; magmatism; erosion
	Tertiary (Middle)	Oligocene	40		
	Tertiary (Early)	Eocene		— Unconformity — Claflin Ranch Formation, Cloudburst Formation, and other unnamed units; multiple igneous rocks. Possible uranium deposits.	Laramide Revolution: Uplift; folding and faulting; granitic intrusions, volcanism; widespread mineralization.
	Tertiary (Early)	Paleocene	70		
MESOZOIC	Cretaceous		135	— Unconformity — About 15,000 feet marine and non-marine sediments, principally sandstone and shales but with thick marine carbonate zone in lower part. Volcanics – A drilling objective for oil and gas in SE Arizona. Some coal.	
	Jurassic		180	— Unconformity — Igneous rocks. Possible uranium deposits.	Nevadan Revolution: Granitic intrusions Volcanic activity Mineralization Uplift and erosion
	Triassic		220	Probable igneous rocks; possible sedimentary rocks.	
PALEOZOIC	Permian		270	— Unconformity — 2,500 or more feet of marine sediments, principally carbonates with some clastics and gypsum. Drilling objective for oil and gas in SE. Arizona.	General Uplift.
	Pennsylvanian		320	Up to 2,500 feet of marine sediments, principally carbonates and shales. Drilling objective in SE. Arizona and possibly beneath volcanics in east central Arizona	
	Mississippian		350	Up to 800 feet of marine sediments, principally carbonates. Drilling objective in SE. Arizona and possibly beneath volcanics in east central Arizona.	Uplift in central Arizona.
	Devonian		400	Up to 500 feet of marine sediments, principally carbonates. Drilling objective in SE. Arizona and possibly beneath volcanics in east central Arizona.	
	Silurian			— Unconformity — Not known in Arizona.	General Emergence.
	Ordovician		490	Up to 700 feet of marine sediments, principally carbonates. Drilling objective in extreme SE. Arizona.	
	Cambrian		600	Up to 1,500 feet of marine sediments, principally carbonates, quartzite, sandstones, and shales. Possibly a drilling objective in SE. Arizona.	
YOUNGER PRECAMBRIAN			1600	— Unconfomity — Up to 1,000 feet of Troy Quartzite in central Arizona. Up to 1,200 feet of Apache Group, principally quartzites, shales, and carbonates, probably marine. Some basalt, past uranium production in central Arizona.	Diabase intrusion some volcanism.
OLDER PRECAMBRIAN			2000 +	— Unconformity — Several thousands of feet of metamorphosed sediments and volcanics (schists and gneisses). Some quartzite, shales and volcanics relatively unaltered. Mineralization; possible uranium deposits.	Mazatzal Revolution: Granitic intrusions Folding Uplift and erosion; Earlier disturbances

Figure 3. Time scale with geologic highlights of the Arizona Basin and Range region.

Colorado River is entrenched over 5,000 feet below the general Plateau surface and exposes in its Grand Canyon the entire Paleozoic section of northwestern Arizona as well as Precambrian rocks below.

On the Plateau the Black Mesa basin region appears to offer the maximum opportunities for the development of additional reserves of uranium, coal, petroleum, natural gas, and helium.

Basin and Range

As suggested in Figures 1 and 3, the Basin and Range province is geologically complex. Its history has included numerous earth-shattering events that, combined together, confuse the restoration of geologic history. Not only is continuity disrupted by the separation of one mountain range from another by valleys that contain and hide many mysteries, but also each mountain block tends to have a character of its own. The resultant geologic picture is: unequal deposition of Paleozoic marine rocks; uplifts, igneous activity, erosion, and both continental and marine sedimentation in Mesozoic time; orogenic activity including extensive folding and faulting, granitic intrusions and volcanic episodes in the Late Mesozoic and Early Cenozoic; uplift, erosion, and continental sedimentation in local basins, and later magmatism, uplift, faulting, erosion, and sedimentation in new basins in Middle Tertiary time. Volcanism, uplift, erosion, and sedimentation have continued intermittently to the present.

Because this complex of geologic history involves the construction and destruction of many rocks, a vital question is raised concerning where in this geologic environment one should search for any of the energy materials being considered. Thus far there has not been any production of petroleum, natural gas, or helium, and only minor production of uranium. However, some recent exploration activity for oil and gas in southwestern New Mexico has stimulated interest in the petroleum possibilities of southeastern Arizona.

ENERGY — FUELS AND TRENDS

A study of fuel resources is a worthwhile activity because the overall use of energy has doubled in the last 25 years and will continue to rise rapidly in the foreseeable future. This increasing demand for energy will require greater amounts of all fuels, although use patterns may change so that each fuel is used most economically, efficiently, and conveniently. In the near future, use of coal for the generation of electricity will greatly increase, although over a longer period of time nuclear energy will probably replace all but the lowest cost coal for producing electricity. Natural gas and petroleum may be completely diverted from the generation of electricity, which now accounts for 8 percent of petroleum product uses, to household heating solely by natural gas and to the use of petroleum primarily for fuel and lubricants in transportation and industry. As reserves of natural gas become depleted most household heating will probably utilize a high-Btu gas artificially made from coal. If petroleum becomes too expensive, synthetic liquid fuels and lubricants can be manufactured from coal, oil shale, and bituminous sandstone. In the future, coal, which is a highly versatile, high-Btu chemical compound, will probably become a source of synthetic gas, liquid fuels, lubricants, and thousands of hydrocarbon chemicals used by the manufacturing industries.

In the 1800's coal was the only energy source used extensively in industry, for transportation, and for home heating. This dependence on coal continued to rise until after World War I when petroleum and natural gas began to move into the heating and transportation markets. Since 1961 when coal production reached a new low of 420 million tons, production has dramatically increased as electric power utilities have turned to coal as a cheap and efficient energy source (Averitt, 1969, p. 60). The consumption of coal by electric-power utilities has increased from 27 million tons in 1933 to 271 million tons in 1967 (U.S. Bur. Mines, 1965, p. 120, and Young and Gallagher, 1968, p. 342).

As the demand for electricity accelerates with expanding population, coal production will increase. Although coal supplied 64 percent of the energy needs of the electric utilities in 1962, this percentage has increased and will continue to increase because of the stability of coal prices f.o.b. mines, the increasing efficiency in coal production and utilization at power plants, and the lower transportation costs associated with moving coal in pipelines and by high volume unit trains. Of particular importance in the increasing utilization of coal for power generation in the West is the improvement in power transmission capabilities that allows generating plants to be placed close to coal resources.

The amounts of fossil fuel resources compared in Btu's suggests a very favorable future for coal production, since coal constitutes 73 percent of the total estimated recoverable fuel resources in the U.S., petroleum and natural gas together constitute only 9 percent and oil shale constitutes 17 percent. Such estimates of reserves are not strictly comparable since coal and oil shale occur in stratified deposits which can be accurately estimated, while petroleum and natural gas occur in a great variety of conditions which are out of sight and cannot be as readily estimated. Nevertheless, the magnitude of abundance of coal is highly significant, especially since petroleum and natural gas together are being produced and consumed at a rate 2½ times that of coal. This fact may account for the movement of oil companies toward a "total energy" company by merging with coal companies, purchasing coal reserves and leases, and forming coal mining branches within their own companies.

Coal is the only fossil fuel which now has sufficient reserves to supply foreseeable future fuel demands. As petroleum and natural gas become more scarce the accompanying rise in prices may be favorable to the coal industry. The two problems faced by coal are increasing competition from the nuclear industry in generating electric power and the possibility of pollution restrictions on coals of certain high sulfur content. These problems can be approached through research and development programs designed to reduce costs and to improve efficiency, and to reduce the sulfur content of coal, either before or during use. Future shortages of petroleum and natural gas may be offset by the conversion of coal to synthetic liquid fuels and gases. These research programs are already in practice and some of the processes are nearly economical. If a fuel-cell technology becomes dominant, synthetic gas from coal would be an ideal energy source to supplement limited reserves of natural gas (Morrison and Readling, 1968).

For the present and near future coal will continue to be the most economical fuel for the generation of electric power.

COAL — OIL, GAS, HELIUM — URANIUM IN ARIZONA

All of the commodities in this study —coal, petroleum, natural gas, helium, and uranium — figure in the future development of Arizona, the Four Corners region, the West, and the Nation. The extent of their eventual contributions depends on reserves, and the probabilities of enlarging reserves by new discoveries. The following pages outline the occurrences and developments of these commodities and consider the possibilities of discovering new reserves.

These commodities, here grouped as energy materials, are natural resources associated with rocks. Although helium is not an energy source it is included because of general similarities of occurrence to natural gas. Because the origin, distribution, and preservation of these materials are totally dependent upon earth history, it is necessary to attempt to unravel the history that has a bearing on their existence. Successfully determining exploration potential and narrowing target areas is a challenge because the narrowing process is contingent upon the degree of factual knowledge available and upon its interpretation. Geologic understanding, as with all knowledge, is evolutionary in that concepts are often modified with the acquisition of new data.

The overall consequences of geologic history are never exactly the same in any two places. The existing differences may be so minor as to be practically undetectable, but they also may be very large, even over short distances. With this in mind it can be said that Arizona is a unique portion of the earth that is unlike any other portion. On a different scale it is also true that no two portions within the State are geologically identical, therefore, geologic discussions are frequently presented by subdivisions of differing scale.

Although fundamental geologic principals are always applicable, the habit or habits of occurrence of a mineral commodity may contrast from place to place. A principal task of exploration in any region is unraveling the habits of occurrence. However, in the absence of a significant number of discoveries, one cannot always determine the likely prevailing habits. For example, Arizona's largest oil field, Dineh-bi-Keyah, is unique in that the reservoir rock is igneous and not sedimentary. This unusual situation raises several questions. In Arizona, should this be treated as one possible habit, or a rare exception? To what extent should such an occurrence encourage thought about the possible coincidence of other igneous rocks and oil? Perhaps it shouldn't in Oklahoma, Texas, or other well known oil states where other successfully established habits prevail, but in Arizona, where igneous activity is widespread in both space and time?

Another facet to exploration is that economic deposits of mineral substances must be preserved from destruction yet still be within economic reach of the surface. Many of Arizona's mineral resources were once more extensive but have suffered partial destruction and dispersement by erosional processes. At the same time erosional processes have caused some deposits to be brought within economic reach of the surface. In other areas various geologic processes have resulted in placing deposits at such depths as to be beyond economic reach with current technology.

Geologic history suggests that in certain areas optimum conditions for the occurrence and preservation of ephemeral commodities like oil, gas and helium may have obtained in the past, but that subsequent history has tended to fragment or disperse them. In such cases discovery potential may be reduced to the hope of a chance encounter. In the discussions to follow an attempt will be made to present both the geologic history generally favorable to development and preservation and that which may have been destructive.

COAL

By

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COAL IN THE WEST

The outlook for increased coal demand, both in the Nation and in Arizona, has grown since 1962 and will continue to grow because of an increasing demand for coal as a fuel base for generating electricity. This demand exists as a result of several factors: lower coal costs brought about by improved strip mining equipment, improved transportation methods, greater efficiency in producing electricity from coal, and increased transmission distances which allows generating plants to be located nearer to coal deposits. Population growth and its increasing reliance on electric appliances and other machines and manufactured products, encourages continued growth of the electric utility industry. The proximity of population centers in southern California and Arizona, which are within the range of electrical power transmission technology will necessarily encourage the continued development of coal from the Four Corners area, embracing southeastern Utah, southwestern Colorado, northeastern Arizona, and northwestern New Mexico.

According to Averitt (1969, p. 59), as of January 1, 1967, the cumulative production of coal in the United States totaled 38 billion tons, which is equivalent to about 10 cubic miles of broken coal. States west of the Mississippi are credited with 8.5 percent of the total. Of this latter production about 51 per cent came from the Rocky Mountain states, 42 percent from Western Interior states east of the Rockies, and about 6 percent from west coast states and Alaska. Of the Four Corners states, Colorado, Utah, and New Mexico have had significant production, but, to the present, Arizona has not.

An advantage of coals west of the Mississippi River is their lower sulfur content than the Pennsylvanian aged coals in the Appalachian and Interior coal basins. The sulfur of eastern coals generally occurs in the form of hard pyrite and marcasite which damages pipelines, corrodes metal and forms boiler deposits, and makes acid mine waters and spoil banks.

The economic improvements in coal usage in recent years has assured greater demands for coal by the electric utility industry. In 1920 three pounds of coal was needed to produce 1 kilowatt hour of electricity, but in 1961 only 0.86 pounds was needed to produce the same amount of electricity.

Useful articles on coal resources, technology, and outlook include: coal thicknesses in the U.S. by Young and Anderson (1947) and (1952); U.S. coal reserves by Averitt (1961); projected energy needs by Morrison and Readling (1968); regional coal supply and demand by Broderick (1969); future coal markets by Ankeny (1962); and articles concerning coal in the U.S. Bureau of Mines Mineral Facts and Problems (1965) and the 1967 Minerals Yearbook by Young and Gallagher (1968).

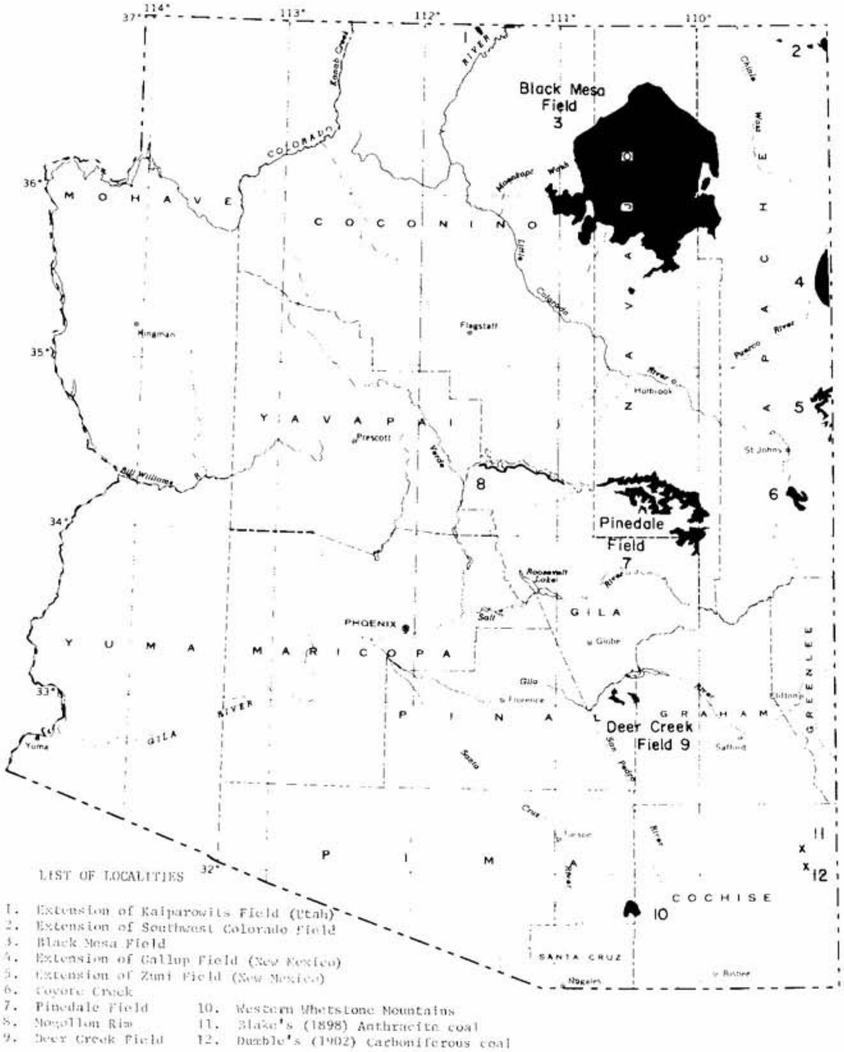


Figure 4. Coal fields and occurrences in Arizona.

ARIZONA

Most Rocky Mountain area coal is associated with sedimentary rocks of Cretaceous age, therefore, the presence of potentially significant coal reserves is dependent upon the preservation of significant amounts of Cretaceous strata in a position accessible to exploration.

Although much of Arizona was once covered by considerable thicknesses of Cretaceous sedimentary rocks, subsequent geologic history has acted to remove most of these strata leaving only isolated remnants that contain the existing coal potential.

Areas of outcrop of Arizona Cretaceous rocks that either are known or reported to contain carbonaceous matter are indicated in Figure 4. The largest of these, Black Mesa (No. 3, Fig. 4), in northeastern Arizona, contains the most extensive coal reserves known in Arizona. In addition some coal is known to occur in the Pinedale Field (No. 7), and the Deer Creek Field (No. 9). Smaller remnants are indicated in extreme north central Arizona (No. 1), in the northeast corner (No. 2), and in the extreme east central part of the State (Nos. 4, 5, and 6). Although Cretaceous strata are exposed in parts of certain mountain ranges in the Basin and Range province in southern Arizona apparently only three minor occurrences of carbonaceous materials are mentioned in the literature (Nos. 10, 11 and 12). The latter two localities, derived from two brief independent reports, might well prove to be the same location. Locality No. 8 is an occurrence of Paleozoic carbonaceous material and is the oldest such material known in Arizona.

Black Mesa Field

The most extensive coal reserves in Arizona occur in the northeastern part of the State in Black Mesa, a 3,200 square mile area covering parts of Apache, Navajo, and Coconino counties. (See Plates 2 and 3.) Coal seams occur in beds of Cretaceous age and crop out in cliffs around the periphery as well as on the eroded top of the mesa.

Elevations on Black Mesa range from 6,000 feet on the southern and western edges where the cliffs are only 100 to 200 feet high, to 8,000 feet on the northern side where the escarpment measures 2,000 feet. The top of the mesa slopes gently to the southwest exposing the youngest strata in the high area to the north and northeast and gradually older strata to the southwest (Plate 4, Section B-B′). Intermittent streams, such as Dot Klish, Dinnebito, Oraibi, Wepo, Polacca, and Jeddito washes, flow southwestward across the mesa and downcut into older layers where they cross gently raised, northwest trending anticlines. In the southern part of Black Mesa, Dinnebito, Oraibi, and Polacca washes have cut canyons through the resistant sandstones of the Toreva Formation leaving the cliffs of First, Second, and Third mesas of the Hopi Indian Reservation.

Although there are no large population centers near Black Mesa, several small trading posts and small towns such as Kayenta on the Navajo Reservation and Keams Canyon on the Hopi Reservation, dot the region. Larger towns such as Holbrook and Flagstaff are on the Sante Fe Railroad about 80 miles to the south and 100 miles southwest, respectively, from the center of Black Mesa. Travel on much of the mesa is generally over unimproved dirt roads and tracks that suffer during the summer rainy season. A good paved road (State 264) crosses the southern part of Black Mesa between Window Rock, Keams Canyon, Oraibi, and Tuba City. Access to the northern part is offered by U.S. 164. Kayenta, just off the northern tip of Black Mesa, is also served from Farmington, New Mexico, approximately 100 road miles to the east. A new access road in the northern portion of the mesa is being built in connection with coal developments.

PREVIOUS INVESTIGATIONS

Although the existence of coal deposits in Black Mesa has been known for several hundred years, only a few geologic investigations have been published. One of the first reports was a U.S. Geological Survey reconnaissance of Black Mesa by Campbell and Gregory (1911). This report described the stratigraphy, limits of Cretaceous rocks, and coal quality and thickness at several mines. This report is reviewed by Rubel (1915-16) in an Arizona Bureau of Mines bulletin on "Coal in Arizona." A detailed doctoral thesis by Williams (1951) describes the coal deposits and Cretaceous stratigraphy of the western part of Black Mesa. The stratigraphy of the eastern part is described in a master's thesis by Merrin (1954). The Late Cretaceous stratigraphy of all of Black Mesa is discussed by Repenning and Page (1956).

The coal mines of Black Mesa were treated in Volume I of the Mineral Resources of the Navajo-Hopi Indian Reservations by Kiersch (1955). In this report maps of the mines, proposed plans of development, and analyses of coal samples were presented by Krumlauf. The coal deposits are also summarized by O'Sullivan (1958) in the Black Mesa Basin Guidebook and by Averitt and O'Sullivan (1969) in Mineral and Water Resources of Arizona.

Articles in the Black Mesa Basin guidebook (1958) contribute much basic information about Black Mesa. The most pertinent of these to coal are the articles on Cretaceous stratigraphy by Page and Repenning (p. 115), on tectonics by Kelley (p. 137), on physiography by Cooley (p. 146), and the tectonic map by Doeringsfeld, Amuedo, and Ivey (p. 145). Stratigraphic data are available in lithologic logs, drillers logs, and stratigraphic sections compiled by Cooley, Akers, and Stevens (1964) and in the records of ground water supplies compiled by Davis and others

(1963) and by McGavock and others (1966) in the Geohydrologic Data of the Navajo and Hopi Indian Reservations. A portion of the northern part of Black Mesa has been mapped and is described by Beaumont and Dixon (1965) in a U.S. Geological Survey bulletin on the Kayenta and Chilchinbito quadrangles. Excellent geologic maps of the entire Navajo and Hopi Indian Reservations by Cooley, Harshbarger, Akers and Hardt (1969) are now available as U.S. Geological Survey Professional Paper 521-A.

Other less detailed articles about Black Mesa coal include the following: coal use by prehistoric Indians by Brew and Hack (1939); Cretaceous rocks of Black Mesa by Reagan (1925), Reeside and Baker (1929), and Keyes (1936); Cretaceous coal by Pye (1960); Coal Mine Canyon by Brady (1946); burning coal seams at Coal Mine Canyon by Brady and Greig (1939); Arizona coal fields by Andrews, Hendricks, and Huddle (1947); and stratigraphy of Black Mesa Basin by Lessentine (1965).

COAL PRODUCTION

Black Mesa coal was first exploited by prehistoric Indians without benefit of mining machinery. Coal ash from kivas, primitive stone stoves, and pottery firing pits date back at least to the year 1300 A.D., which was before coal was in general use in Europe (Brew and Hack, 1939, p. 8). The first mining may have begun as early as 900 A.D. Hack estimates that the output was about 450 pounds daily between the years 1300 and 1600 and totaled over 100,000 tons during that 300-year period.

Until the natural gas pipelines were extended through northern Arizona, more recent underground mining on Black Mesa was carried on to supply local fuel requirements. Although no official records exist between 1600 and 1925, small amounts were mined. During 1926–34, 1942, and 1944–46, recorded coal production is 88,730 tons valued at $358,800 (Wilson and Roseveare, 1949, p. 16). Since 1943 production has been less than 10,000 tons annually, most of which was mined for local use at schools on the reservations and for limited shipment to Holbrook, Winslow, and Flagstaff (Averitt and O'Sullivan, 1969, p. 67). Since 1960, coal production has been less than 1,000 tons annually (U.S. Bur. Mines, 1960–67). Arizona's total production since 1926 is estimated to have been less than 300,000 tons.

CRETACEOUS STRATIGRAPHY

The remaining Cretaceous rocks of Black Mesa total to a thickness of about 1,700 feet and include, in ascending order, the Dakota Sandstone, the Mancos Shale, and the Mesaverde Group which contains the Toreva

Formation, Wepo Formation, and Yale Point Sandstone (Plate 5). Coal seams occur in the carbonaceous member of the Dakota, in the middle carbonaceous member of the Toreva, and in the Wepo Formation. The Yale Point Sandstone contains only a minor seam or two in one small area and is therefore not considered to be of economic interest. Coal is apparently absent from the dark bluish-gray marine siltstones and claystones of the Mancos Shale. The areas of outcrop of various formations and locations of coal mines are shown on the geologic map of Black Mesa (Plate 3).

Dakota Sandstone. The Dakota Sandstone, a cliff maker, crops out around the base of Black Mesa and throughout Coal Canyon. Of the 3,200 square miles of Cretaceous outcrop in the Black Mesa area only an estimated 215 square miles are accounted for by this formation. Except along the eastern and southern margins of Black Mesa and in Coal Canyon, the Dakota Sandstone is overlain by thick sections of Mancos Shale and Mesaverde Group which bury it sufficiently (up to 1,700 feet) to have removed it from general access to investigation.

Coal seams occur in the middle carbonaceous member between the lower and upper sandstone members. The lower sandstone is a very pale orange, medium-grained quartz sandstone with trough cross bedding and thin conglomerate lenses; these indicate deposition by north flowing streams (Repenning and Page, 1956, p. 260, 282). The lower sandstone, although not present in all localities, forms a vertical, blocky cliff, capping the upper part of a large cliff of underlying Jurassic sandstones. Its thickness varies irregularly from 0 to 70 feet and averages 30–40 feet.

The middle carbonaceous member, which contains the coal, includes yellowish-gray to black carbonaceous siltstone, shale, lignite, and thin sandstones. It weathers into a smooth slope with minor ledges and varies irregularly in thickness between 20 and 80 feet; it is thickest on the eastern side of Black Mesa where the other Dakota members are absent. The better coal seams are in the upper siltstone-claystone beds of the middle member near the upper sandstone member. Most seams average 2–4 feet in thickness except in Coal Canyon and near Steamboat where they are 7–9 feet thick, (Kiersch, 1955, p. 50, and Williams, 1951, p. 85, and Merrin, 1954, p. 53). Some coal seams are lenticular; they may vary from several feet to several inches in thickness within a few hundred feet laterally as a result of deposition within local depressions or by being cut off by other channels (Williams, 1951, p. 214, and Kiersch, 1955, p. 50). Although the carbonaceous member occurs nearly everywhere in the Dakota around Black Mesa the larger and more extensive deposits are in the southwestern part where the upper sandstone member is frequently absent. Four mines have obtained coal from this formation.

Above the coal bearing unit is the yellowish-gray, medium- to fine-grained sandstone of the upper sandstone member. The thin to thick sandstone beds which have low angle cross bedding and ripple lamination, and scattered marine fossils such as *Gryphaea newberryi* in the uppermost part, indicate deposition in the foreshore beach or offshore (Williams, 1951, p. 97 and Repenning and Page, 1956, p. 261, 284). The upper sandstone ranges from 10 to 20 feet thick in the northern part of Black Mesa and is generally absent south of Tonalea on the west rim and south of Lohali Point on the east rim. Where present, the upper sandstone forms a series of thin ledges with intercalated shaly beds. The overlying Mancos Shale, apparently devoid of coal, is of marine origin and consists of 500 to 700 feet of dark gray, bluish weathering, slope forming, siltstone and claystone.

Toreva Formation. Coal seams in the 300 foot thick Toreva Formation, except in northern Black Mesa, also occur in a middle carbonaceous member between a lower and an upper sandstone member. The middle member crops out in ledges and slopes above the vertical blocky cliff of the lower sandstone and below the upper sandstone cliff which generally forms the edge of the Hopi mesas in the southern part of Black Mesa. Carbonaceous siltstones, mudstones and sandstones assigned to the Toreva Formation generally occur around the perimeter and at the surface in the southern half of Black Mesa although the middle carbonaceous member hasn't been defined in the northern part. Strata assigned to the Toreva Formation crop out over an area of about 743 square miles.

The lower and upper sandstones are both light brown to yellowish gray, and are medium to fine grained, although the lower sandstone is generally finer grained and contains some mudstone layers near a transition zone above the Mancos Shale. The lower sandstone contains low angle planar cross-bedding representing offshore deposition and high angle trough cross-bedding typical of beach deposits (Repenning and Page, 1956, p. 272, 286, 287). This is evidence for the gradual northeastward retreat of the Mancos sea as the rate of sinking was slower than the rate sediment was brought into the Black Mesa region.

The flat and thinly bedded dark mudstones, varicolored siltstones, coal, and thin yellowish gray sandstones of the middle carbonaceous member were probably deposited in marshy lagoons and swampy areas behind the beach as the sea retreated farther eastward. The upper sandstone is coarser grained than the lower sandstone, is commonly conglomeratic, and contains an abundance of altered feldspar. The medium to low angle trough crossbeds in the upper sandstone have an average dip direction of N. 32° E., indicating deposition by streams flowing from the south and southwest.

This three member subdivision has not been applied to the northern part of Black Mesa apparently because of lateral changes in the rock sequence towards the northeast (Repenning and Page, 1956, p. 264). However, coal beds or carbonaceous siltstones occur in the Toreva Formation in all measured sections throughout Black Mesa, although individual beds may not be continuous from place to place. As evidence from the upper sandstone indicates a broad coastal plain with northeastward flowing streams, the carbonaceous siltstones are probably lenses rather than continuous beds because of the shifting of streams and swampy areas between and along the sluggish parts of the streams.

The thickest and most extensive coal in the Toreva Formation has been found in the southeastern part of Black Mesa. Three mines have obtained coal from the Toreva — the Keams Canyon mine, Chinle #2 mine, and the Oraibi mine.

Wepo Formation. According to available data the Wepo Formation contains not only the highest rank and highest quality coal on Black Mesa but the largest minable reserves as well. The coal seams are thicker, more numerous, more widespread, and more accessible for strip mining. Coal occurs in an alternating sequence of dark olive-gray to brown siltstones and mudstones and yellowish gray sandstones. The Wepo Formation crops out on the northern portion of Black Mesa (Plates 3 and 4). On the extreme northeast it is capped by the massive yellowish gray Yale Point Sandstone. About 1,270 square miles of the Wepo Formation is exposed at the surface of Black Mesa.

The Wepo is 743 feet thick east of Cow Springs and over 600 feet thick in the central part of the mesa. To the north it thins to 318 feet at Rough Rock. Because the top of Black Mesa is an erosion surface the remaining Wepo thickness in a particular area depends upon its structural position and the extent of downcutting by streams. Greater thicknesses of Wepo strata and, therefore, potentially more coal, are preserved in synclines, or downwarps. The Maloney and the Black Mesa synclines are examples of such protective structures. The relatively sharp depositional thinning of Wepo strata to the northeast away from the Maloney synclinal area suggests that a downwarp existed during Wepo deposition. This downwarp and the later movement constituting the Maloney syncline, might well be closely related events. The principal coal reserves that are to be mined by the Peabody Coal Company are, in part at least, associated with the Maloney syncline (Plate 4, Sec. A-A').

Because the thickest and most continuous coal beds studied thus far are in the upper half of the Wepo Formation, the best coal prospects appear to be in the northern part of Black Mesa where the upper half of the formation has not been completely eroded away. The Wepo contains at least ten coal beds thicker than three feet in the area examined by Williams (1951, p. 214–5) along the northwest rim. Most of the coal beds occur in the siltstone units below sandstone beds (Repenning and Page, 1956, p. 278). Individual coal seams persist for hundreds to thousands of feet but invariably thin laterally to seams a few inches to a foot thick. However, another seam usually begins within a few feet, vertically. The coal seams average four to eight feet thick although individual seams may be from twelve to twenty feet thick (Kiersch, 1955, p. 51). Because some of the coal near the surface has either been burned out, cut out locally by erosion, or covered, only a detailed drilling program can indicate the presence, thickness, and depth of coal, and provide fresh samples for testing. Using such a drilling program Peabody Coal Company has found sufficient reserves of coal to justify entrance into long term contractual arrangements as a coal supplier, the first such in Arizona. More information about this development is provided in a later section.

MINES AND COAL ANALYSES

Available literature indicates that since 1900 ten small underground mines have exploited Black Mesa coals, principally for local use as fuels. Mine sites were placed as close as possible to utilization points, which were widely distributed and generally not on Black Mesa itself. Mines were developed in each of the three coal-bearing Cretaceous formations, four in the Dakota Sandstone, three in the Toreva Formation, and three in the Wepo Formation.

Although the overall total production from these mines is relatively unimportant (less than 300,000 tons) the mines serve a very useful function in that they afford some experience with the characteristics of fresh coal. Coal cannot be readily studied in natural outcrop because it weathers easily and its association with weak clays and siltstones tends to make outcrops obscure. Published analyses and detailed descriptions of coal in Black Mesa are based upon samples taken from exposures afforded by accessible mines. Considering the size of Black Mesa (3,200 square miles), the wide distribution of coal occurrences, both stratigraphically and areally, and the relatively few mine sampling points, caution should be exercised in rendering overall generalizations regarding reserves and the final distribution of coals of varying rank and quality.

Table 1 lists the mines for which there are published sample analyses. Seven mines are listed from which a total of thirty samples have been analyzed; eleven from the Dakota Sandstone, eight from the Toreva Formation, and eleven from the Wepo Formation. These thirty samples were collected at different times by different workers who frequently sampled nearly identical localities.

Table 1. — Coal analyses from mines — Black Mesa Field, Arizona. (Determinations in percent on coal samples "as received.")

Mine	Location	Formation	Ref.# No.	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	British Thermal Units	Info.* Source
Tuba City No. 3	Coal Canyon 16 mi. SE Tuba City	Dakota Ss	1	12.78	32.36	24.12	30.74	0.81	5,119	(1)
			2	13.62	43.93	16.67	25.78	0.89	5,592	(1)
			3	9.15	43.59	37.23	10.03	1.70	8,837	(1)
			4	10.01	40.09	39.90	10.00	1.57	8,914	(1)
			5	11.72	41.68	33.96	12.64	2.29	7,683	(1)
			6	11.8	36.5	40.7	11.0	2.0	10,410	(2)
			7	11.8	35.8	41.1	11.3	1.8	10,270	(2)
			8	9.1	33.3	43.9	13.7	1.28	10,490	(3)
			9	9.9	31.4	44.5	14.2	-	-	(4)
			10	10.3	33.8	42.3	13.6	-	10,550	(4)
Montezuma	Montezuma's Chair	Dakota Ss	11	7.3	33.1	43.4	11.2	0.7	10,510	(1)
Keams Canyon No. 4	Keams Canyon	Toreva Fm	12	3.4	29.8	16.0	50.8	0.6	5,430	(1)
			13	5.3	36.8	38.9	19.0	1.1	10,270	(1)
			14	11.7	32.3	47.2	8.8	1.0	11,200	(2)
			15	11.4	32.5	45.0	11.1	0.9	10,650	(2)
Chinle No. 2	6 mi. S Salina	Toreva Fm	16	5.4	37.6	42.3	14.7	1.2	10,650	(1)
			17	5.1	37.0	43.5	14.4	1.0	10,800	(1)
			18	8.62	34.31	38.87	18.20	1.30	9,807	(1)
Oraibi mine	4 mi. E Oraibi	Toreva Fm	19	9.9	32.6	46.9	10.62	1.12	10,800	(3)
Tuba City No. 4	7 mi. E Cow Springs	Wepo Fm	20	8.0	40.2	43.1	8.7	0.5	11,540	(1)
			21	8.4	39.7	45.2	6.7	0.4	11,830	(1)
			22	7.01	40.52	47.05	5.42	0.49	11,985	(1)
			23	10.4	37.3	45.8	6.5	0.4	11,590	(2)
			24	11.7	36.8	45.7	5.8	0.6	11,410	(2)
			25	17.4	37.0	41.6	4.0	-	10,450	(4)
Kayenta No. 2 or Maloney mine	30 mi. S Kayenta	Wepo Fm	26	8.2	42.4	45.5	3.9	0.5	12,060	(1)
			27	8.6	38.8	48.3	4.3	0.7	11,930	(1)
			28	11.6	40.2	44.8	3.4	0.7	11,690	(2)
			29	11.5	37.5	46.9	4.1	0.9	11,660	(2)
			30	11.0	37.7	47.1	4.2	-	11,640	(4)

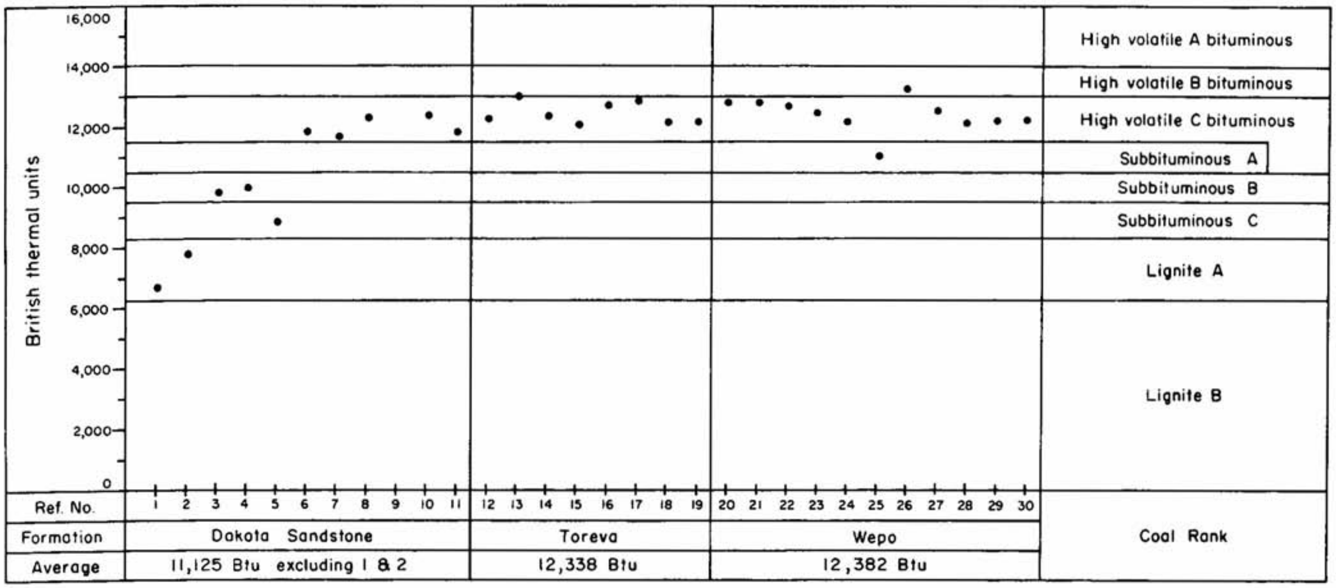
#Numbers correspond to sample numbers shown on Figures 5 and 6.

*Sources:
(1) Kiersch, 1955, p. 52, 53.
(2) Cooper, et al, 1947, p. 32-34.
(3) Campbell and Gregory, 1911, p. 237.
(4) Williams, 1951, p. 88, 188.

Two principal attributes are used in classifying coal, rank and quality. Rank considers the heat or British Thermal Unit (Btu) content of a coal, whereas quality relates to compositional content such as ash, sulfur, and other deleterious constituents. The formal method for classification by rank is given by the American Society for Testing and Materials (1966, p. 74). For classification purposes Btu content is calculated on a mineral matter (ash) free basis and for coals containing less than 14,000 Btu per pound, is the only criterion for establishing rank. The analyses in Table 1 are on coal samples "as received," which means that the indicated Btu content has not been adjusted to a mineral matter free basis. Figure 5 shows the adjusted Btu content for each sample and a plot of these values in conjunction with standard rank categories. Twenty-two of the twenty-nine samples plotted fall within the high-volatile C bituminous rank. On this basis there is little to distinguish between coals from the Wepo Formation, Toreva Formation, and five of ten samples from the Dakota Sandstone.

Kiersch (1955, p. 51) and Averitt and O'Sullivan (1969, p. 64) classify the Toreva and Wepo formations as containing high-volatile C bituminous coal. On the other hand both classify the Dakota coal as subbituminous B. Averitt and O'Sullivan's Dakota classification is based on the averaging of eight samples (individual sample anlayses not specified in text). Kiersch's classification is based on data shown in Table 1 but it is not clear just how the Dakota analyses were selected or grouped in order to draw a conclusion about rank. Williams (1951, p. 86), classes Dakota coal simply as subbituminous. Averitt (1969, p. 18) states that the Toreva and Wepo coals are of high-volatile B bituminous rank, not C, and he also classes the Dakota coals as being of subbituminous B rank. On the basis of these conclusions Averitt says that coal rank in Black Mesa is in reverse order from what is normal elsewhere, that is, in Black Mesa the lower rank coal is the older, more deeply buried, instead of the reverse. Rank tends to increase under the influence of heat (burial, geothermal gradient) and time (geologic age).

Inspection of Figure 5, which classifies Black Mesa coals as to rank as determined from all known published analyses, suggests that the proper classification of Dakota coal is subject to some discussion. Inspection of Table 1 shows that of the ten Btu analyses of Dakota coal, nine are from the single area of Coal Mine Canyon. Four of these nine indicate a rank of high-volatile C bituminous whereas the remaining five, which are all from Kiersch, are sufficiently scattered, from lignite A to subbituminous B, as to be of questionable value in judging rank. Determining which analyses are most representative of Dakota coal cannot be done with certainty but available data point to the higher rank classification. Sample number 11, from Montezuma's Chair fifty miles to the southeast of Coal



Ash-free Btu content calculated from basic data in Table 1 using the formula: $\frac{\text{As Received Btu}}{100 - 1.1(\%\text{ Ash})} \times 100$

Ref. No.	Btu	Ref. No.	Btu	Ref. No.	Btu	Ref. No.	Btu	Ref. No.	Btu	Ref. No.	Btu
1	6,700	6	11,800	11	11,900	16	12,700	21	12,800	26	13,200
2	7,800	7	11,700	12	12,300	17	12,800	22	12,700	27	12,500
3	9,900	8	12,300	13	13,000	18	12,200	23	12,500	28	12,100
4	10,000	9	–	14	12,400	19	12,200	24	12,200	29	12,200
5	8,900	10	12,400	15	12,100	20	12,800	25	11,000	30	12,200

Figure 5. Heat content and rank of Black Mesa Cretaceous coals.

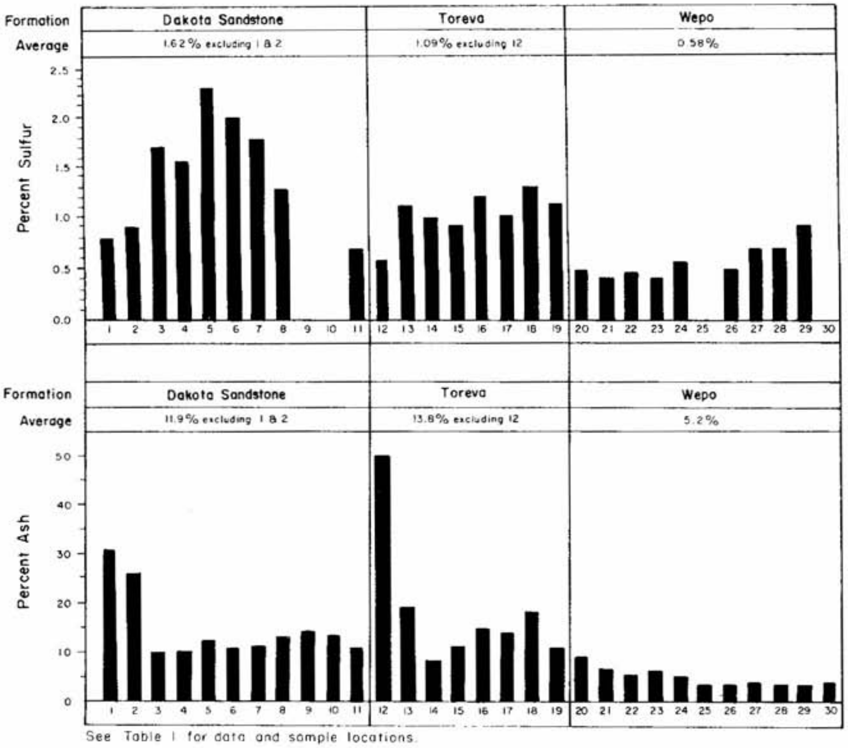


Figure 6. Quality — ash and sulfur content of Black Mesa Cretaceous coals. (Analyses on samples "as received.")

Canyon, represents high-volatile C bituminous coal, as does sample number 10 from Coal Canyon, the only sample for which Williams gives a Btu analysis. The similarity of these two analyses is striking when compared with the dissimilarities around Coal Canyon itself. Williams (pp. 88 and 188) includes tables of analyses of outcropping Dakota and Mesaverde coals for which Btu contents were not determined. Comparing fixed carbon and volatile matter contents suggests that coals from both formations are similar.

On the basis of these meager data Averitt has suggested that an abnormal reversal of coal rank occurs in Black Mesa in that the younger Mesaverde coals seem to have a higher rank than the once more deeply buried Dakota coals. However, it seems equally plausible to use these meager data to question that such a reversal actually exists and, furthermore, to suggest that all of the Cretaceous coals of Black Mesa tend to be of similar rank. Only additional new data will resolve the proper classification of coal in the Dakota Sandstone.

The quality factors of ash and sulfur in Black Mesa coal samples are compared in Figure 6. The relatively high quality of Wepo Formation coal that is indicated is consistent with informal comments made by persons knowledgeable about coal in the Four Corners region. The Wepo Formation is generally credited with containing some of the highest rank and highest quality coal available in the Four Corners coal-bearing area. It is classed as a low sulfur coal.

It seems clear that the increasing demand for coal coupled with the reserves of good coal available in the Black Mesa Field, assures Arizona of an opportunity to contribute further to economic development.

RECENT DEVELOPMENTS

In 1966, the Peabody Coal Company announced plans to initiate a large stripping operation for coal in the northern part of Black Mesa utilizing coal reserves delineated in the Wepo Formation by exploration drilling. These proven coal reserves are on the Navajo Indian Reservation and on land contested by the Navajo and Hopi Indian Tribes. Royalty payments related to coal produced from contested land will be held in escrow pending settlement of litigation. The necessary labor force will include workers from both tribes.

Peabody's Black Mesa mine is being developed to supply the fuel requirements for the $191 million, 1.5 million kilowatt Mohave electric powerplant located in southernmost Clark County, Nevada, near Davis Dam (Bullhead City) on the Colorado River (Fig. 7). The first two units of the plant, scheduled for completion in 1970 and 1971, are being built and financed by a group of 17 private and public utilities known as the Western Energy Supply and Transmission Associates (WEST Associates). The Southern California Edison Company is project manager and major investor. The contractual agreement calls for the delivery of at least 117 million tons of coal over a period of 35 years. The delivered cost of $500 million includes $30 million in royalty payments to the Indian tribes. This is the largest long-term coal mining and delivery contract ever signed.

Coal will be transported from mine to utilization point in slurry form through an 18-inch O.D. pipeline 273 miles in length. Black Mesa Pipelines, Incorporated, a subsidiary of Southern Pacific Pipe Lines, Incorporated, is building and will operate the completed line and move coal at the rate of 660 tons an hour. The line will contain 43,000 tons of coal at all times and transport time will be about 62 hours (Arnold, 1969, p. 9).

Williams (1951, p. 216, 217) suggested that Black Mesa coal would not be produced on a large scale until three problems were overcome: (1) transportation costs, (2) need for a large market and (3) adequate water supply. The first two items have been satisfied as mentioned above and the third, water supply, has apparently been overcome by the development of

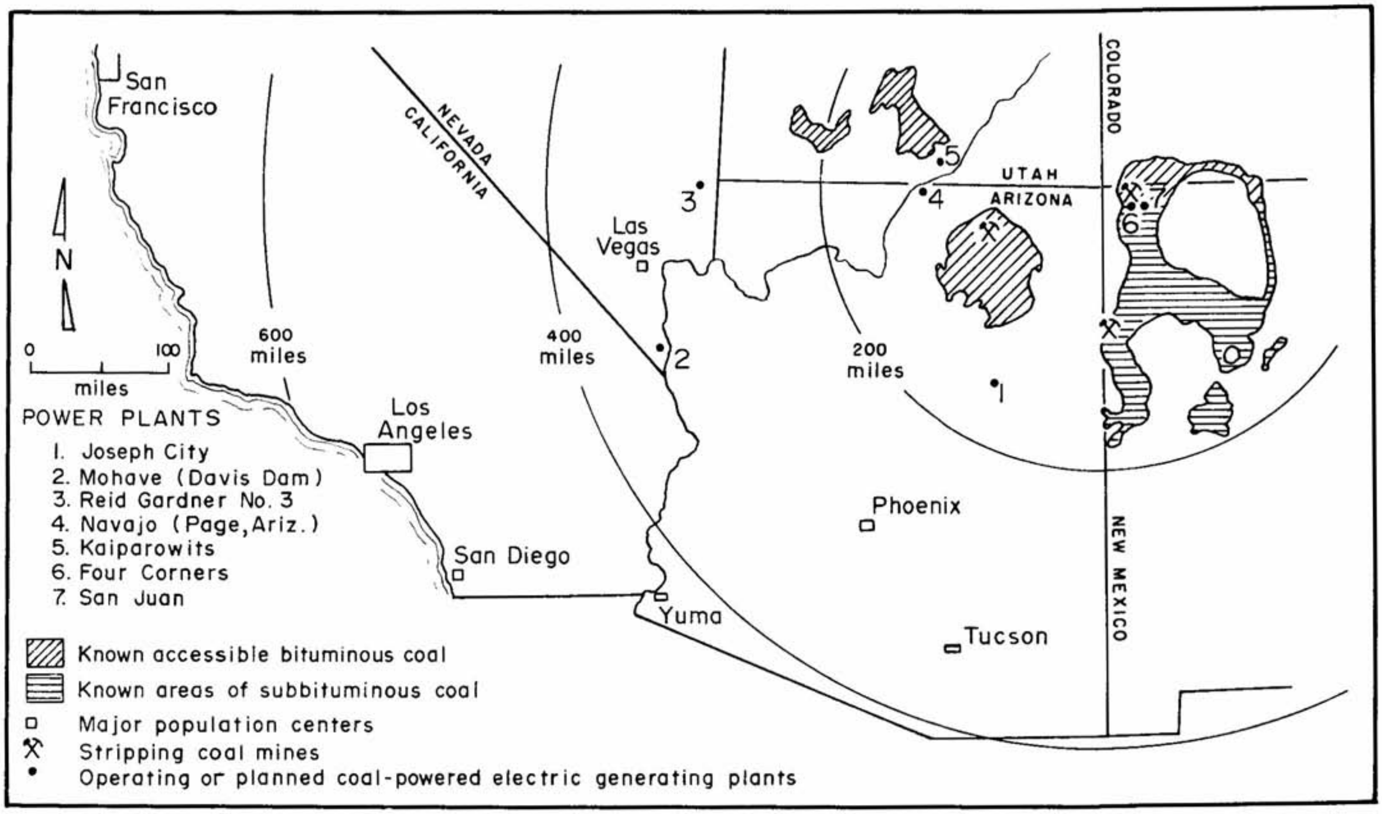


Figure 7. Operating and planned coal-fueled electrical generating plants, and major coal fields, in Four Corners region.

five water wells drilled into the Jurassic Navajo Sandstone aquifier which underlies the northern part of Black Mesa. The operation, which will require about 2,000 gallons of water per minute, will be supplied by four wells, one being held as an auxiliary or alternative source. Although the wells were drilled to depths between 3,500 and 3,800 feet the unpumped water level stands less than 1,000 feet below the surface.

The lease block held by Peabody is very irregular in nature (Plate 4) and results from the selection of lands evaluated by drilling and testing under a prospecting permit. A combination of erosion and naturally burned out coal serves to limit coal reserves to detached, irregular areas or islands. Multiple coal beds occur within a stratigraphic interval of about 400 feet. Up to four coal seams will be removed from selected stripping sites. Coal seam thicknesses are thought to range between four and twenty feet. The maximum thickness of overburden that can be economically removed to expose minable coal varies with conditions but is on the order of 130 feet for this particular operation.

In addition to supplying the Mohave generating plant Peabody is also developing additional coal reserves to provide fuel for the planned Navajo generating plant at Page, Arizona (Fig. 7). Plans are being developed to move the coal via a short railroad haul.

RESERVES

Reserves relate to coal in the ground. Reserves can be classified according to the degree of reliability of data and also according to depth of burial and mining method required for removal.

Reserve categories based upon reliability of estimates are: (1) measured, (2) indicated, and (3) inferred (Averitt, 1969, p. 25). Reserves based upon depth of burial and mining method are classified as: (1) strippable, and (2) underground. Underground reserves are subject to possible new developments such as "in place" gasification by controlled burning, as well as conventional mining techniques.

Calculations of the coal reserves of Black Mesa, a 3,200 square mile area, result largely from assumptions based on data gained by studying the coal-bearing zones exposed around its cliff-like perimeter. Only locally, as in the Peabody lease area, are data available for the interior of the mesa. As a consequence the only available approach to the inferred or gross coal reserves of Black Mesa involves assumptions about both subsurface continuity and composite thickness of coal contained in each of the coal-bearing formations. Except for the "measured" reserves of strippable coal on the Peabody lease all Black Mesa reserves are here classified as "inferred", even though it might be possible to calculate "indicated" reserves for selected small areas in the vicinity of coal-bearing outcrops.

Table 2. — Estimated coal reserves of Black Mesa, Arizona. ((In billions of short tons.)

Strippable Coal (within 130' of surface)	Formation: Dakota	Toreva	Wepo	Total strippable coal in all formations
Measured	0	0	0.35	0.35
Inferred	0.15	0	0.48	0.63
Totals	0.15	0.0	0.83	0.98

Deeper Coal (130'-1700' below surface)	Formation: Dakota	Toreva	Wepo	Total deeper coal in all formations
Measured	0	0	0	0
Inferred	9.45	6	4.82	20.27
Totals	9.45	6	4.82	20.27

All Coal	Formation: Dakota	Toreva	Wepo	Total coal in all formations
Measured	0	0	0.35	0.35
Inferred	9.6	6	5.3	20.90
Totals (Grand)	9.6	6	5.65	21.25

Table 2 summarizes the reserve status as determined for this report. An attempt here is made to arrive at an order of magnitude of coal reserves. The reader is cautioned to not forget that the numbers shown result from making assumptions that may or may not approximate reality. Some of the assumptions as well as the data on which they are based, are presented in following sections. Ideas regarding Black Mesa coal reserves presented by other workers also are summarized.

Referring to Table 2 the estimated total reserves of coal in the Black Mesa field is near 21 billion short tons and is distributed as follows: 9.6 billion tons in the Dakota Sandstone, 6.0 billion tons in the Toreva Formation, and 5.65 billion short tones in the Wepo Formation. All of this coal is judged to occur within 1,700 feet of the surface.

Campbell and Gregory (1911, p. 238) estimated that the entire Black Mesa field contains a gross quantity of 14 billion short tons of coal and considered that about 8 billion short tons might be "recoverable" under ordinary conditions. Furthermore, they thought these estimates were on the low side. It was not until Kiersch (1955, p. 51) that another attempt was made to judge coal reserves of Black Mesa. Citing Williams' (1951) demonstration that coal seams tend to be lense-like Kiersch revised downward, rather arbitrarily it seems, "minable" reserves to 2 billion tons. He also suggests that of Campbell and Gregory's 8 billion tons of minable (recoverable) coal, only 60 million tons were assigned by them to coal in the Dakota Sandstone. Actually, Campbell and Gregory attributed 6 billion tons to the latter interval, or nearly 43 percent of their estimated gross reserves of Black Mesa. In turn they estimated that at least half, or 3 billion tons, was "recoverable". Because Kiersch does not present any supporting data, one cannot determine if the apparently missing 3 billion tons is involved in his revised estimates of minable reserves. He did not calculate gross or inferred reserves.

Stating that data are scarce, Averitt (1969, p. 43) includes a figure of 4 billion tons for the inferred coal resources of Black Mesa, and states that the estimate is "based on statements by G. A. Williams (1951) and Kiersch [1955]." The distinction between Kiersch's 2 billion and Averitt's 4 billion tons is that between minable versus inferred resources. Up to the present time only Campbell and Gregory have adequately stated the assumptions on which reserve estimations were based. It appears that the magnitude of the later downward revisions in estimated reserves is not well supported. In summary, estimates for inferred coal reserves of Black Mesa range from 4 to 21 billion short tons.

The reserves that are significant are those that stand some chance of future development. The strippable coal reserves are of immediate interest because they offer the largest volume at the least cost.

Averitt (1968, p. C14) has estimated Arizona's stripping coal resources, in beds generally less than 100 feet below the surface, to be 100 million short tons. Recently, in a personal communication to the Arizona Bureau of Mines, Averitt was revising this figure upward to about 400 million short tons.

Peabody officials have stated (Coal News, 1965, p. 2) that company ground on Black Mesa contains a proven reserve estimated at near 400 million tons. Because Peabody plans a stripping operation it seems logical to conclude that this reserve applies to strippable coal, which in this case is coal within about 130 feet of the surface. If so, Peabody has proved up almost as much strippable coal under less than 140 square miles as thus far has been attributed to Black Mesa or the State as a whole. Information available suggests that the stripping coal resources of Black Mesa are considerably more than has thus far been suggested.

Estimates of the total coal reserves summarized in Table 2 credit the Wepo Formation with 5.65 billion tons. Of this amount 1.4 billion tons is too deep for stripping because 1 billion tons is below the Yale Point Sandstone and 0.4 billion tons is deeper than 130 feet on the Peabody lease; this leaves 4.25 billion tons in the remainder of the Wepo Formation. Considering that this coal is within 650 feet of the surface it seems reasonable to assume that one-fifth of these reserves, or .85 billion tons, occurs within 130 feet of the surface. This figure is obviously conservative because it includes the known .35 billion tons of stripping coal within the 140 square mile Peabody lease. The estimate thus requires that only 1.4 times the coal (.5 billion tons) occur in 8 times the area (1,130 square miles) of the Peabody lease. This estimate of .85 billion short tons in the Wepo plus an estimate of .15 billion short tons in the Dakota yields a total strippable reserve of over 1 billion short tons.

As previously mentioned, three of the five Cretaceous formations on Black Mesa are coal-bearing; they are the basal, third, and fourth formations in sequence. The stratigraphic interval between the lowest and highest remaining coal is about 1,400 feet at the north end and about 60 feet at the south end. The maximum thickness of remaining Cretaceous strata is about 1,700 feet at the north end of the mesa. Because only Cretaceous strata are at the surface, no where on the mesa can the lowest coal in the Dakota Sandstone be buried more than 1,700 feet. Similarly, given a combined thickness of 750 feet for both the Dakota Sandstone and Mancos Shale, the coal in the Toreva Formation cannot be buried more than about 1,000 feet. Assuming a thickness of 200 feet for the Toreva Formation all of the remaining coal in the Wepo Formation cannot be buried more than 800 feet. If the Wepo Formation has a maximum thickness of 650 feet and much of the coal is in the upper half, then the base of the upper half cannot be buried more than 325 feet.

The lowest coal-bearing formation, the Dakota Sandstone, crops out all around the edges of Black Mesa and is, therefore, believed to underlie the entire mesa. Campbell and Gregory (1911, p. 238) calculated the gross reserves of this "lower group" as being 6 billion short tons by assuming that half of the area of Black Mesa was underlain by enough coal to make a bed 3 feet thick. At the time of their estimate they did not know of coal at this horizon in the northern part of the mesa. Subsequent work demonstrates that there are coal-bearing Dakota sections on all sides of Black Mesa such that, on the basis of Campbell and Gregory, gross reserves can be increased twofold to 12 billion tons.

The current study has record of 56 separate stratigraphic measurements of the Dakota Sandstone including both well and outcrop sections. Of these 56 sampling localities, which are scattered throughout Black Mesa, 22 contain no mention of coal while 34 do. The sections with and without coal are interspersed in such a way as to suggest that some of the seemingly barren localities probably contain coal that went unrecorded for one reason or another. The average thickness of coal per section, including 22 zeros for coal in the 22 sections with no record of coal, is 4.4 feet. These data suggest that the Campbell and Gregory assumption of a bed of coal 3 feet thick is a valid assumption and only the total area underlain by coal-bearing Dakota Sandstone is subject to revision, as previously mentioned.

In the current study the area of Black Mesa is considered to be 3,200 square miles. Three feet of coal under this area indicates a gross reserve of 9.6 billion short tons in the Dakota Sandstone.

Stripping possibilities are limited principally to the southwestern edge of Black Mesa where the Dakota Sandstone is at the surface or overlain by varying thicknesses of the erosional edge of the Mancos Shale. Isolated mesas with a thin capping of Mancos Shale offer potential stripping sites. In the coal mine area of Coal Canyon there is only 12.0 feet of Mancos Shale immediately overlying Dakota coal (Agasie, 1967, p. 13, 81). A portion of Agasie's measured section follows:

UNIT	THICKNESS (Feet)
Mancos Shale	12.0
Unconformity	
Dakota Sandstone	
(upper portion of middle carbonaceous member)	
5.14 Coal, sub-bituminous, black, friable, contains sulfur and stringers of gypsum	2.5
5.13 Silty carbonaceous zone, grayish	0.3
Coal, like No. 5.14	0.7
Like No. 5.13	0.1
Coal, like No. 5.14	4.3
Shale, grayish brown	0.1
Coal, like No. 5.14	1.0
Shale, black	0.3
Coal, like No. 5.14	0.7
Shale, grayish-brown	0.1
Coal, like No. 5.14	0.6
Thickness this portion	10.7
Thickness coal	9.8

About 11 miles to the southeast, on the south side of a mesa continuous with the coal mine area, Williams (1951, p. 265) measured the following about 3 miles south of Howell Mesa:

UNIT	THICKNESS (Feet)
Mancos Shale	60.0
Dakota Sandstone	
Coal: contains bone layers	8.0

That coal of similar thickness underlies the Mancos Shale at these two localities about 11 miles apart suggests lateral continuity. The main area of the mesa between these two localities covers more than 50 square miles. Assuming half of this area is capped by 130 feet or less of Mancos Shale there are 25 square miles of potentially strippable country. Assuming that 1 foot of coal under 10 square miles weighs 11,520,000 short tons, 5 feet of coal under 25 square miles weighs 144 million short tons. Although data are lacking it is probable that many millions of tons of Dakota coal along the rim of its southernmost outcrop could be added to strippable reserves.

The foregoing treatment of coal in the Dakota Sandstone was presented because Dakota coal may have been underrated in the past, especially in regard to rank. In comparison with Wepo coal it may suffer in quality, but there are methods for cleaning coals. Although past workers have largely discredited Dakota coal, more data are needed before its place in the future development of Arizona energy resources can be judged objectively.

The Toreva Formation, like the Dakota Sandstone, crops out all around the edges of Black Mesa and is, therefore, believed to everywhere underlie the Wepo Formation in the subsurface. Although it crops out in an area of more than 700 square miles, likely stripping sites are not known because of the massive sandstone sequence that generally overlies the coal-bearing middle member in the southern part of the mesa. Under present and foreseeable circumstances it is believed that Toreva coal reserves should be classified in an underground category. Other workers have not isolated Toreva coal for reserve calculations, but it is possible to estimate gross reserves on the same basis as was done for coal in the Dakota Sandstone.

The current study has record of 62 separate stratigraphic measurements of the Toreva Formation including both well and outcrop sections. Of these 62 sampling localities, which are scattered throughout Black Mesa, 37 do not reflect coal while 25 do. As with the Dakota sections, the Toreva sections are interspersed with no consistent pattern of coal-no coal. It is suspected that coal may have been overlooked during the course of some water well drilling or section measuring. The best information is derived from sections measured along the edge of the mesa. Enough of these contain coal on all sides of the mesa to suggest the continuance of coal into the subsurface. The average thickness of coal per section, including 37 zeros for coal in the 37 sections with no record of coal, is 3.2 feet. Sections with coal contain from 1 to 3 beds varying in thickness from 1 to 22 feet. Assuming 3 feet of coal over the projected extent of the Toreva Formation, 2,150 square miles, it would contain over 6 billion short tons. These gross or inferred reserves occur between the surface and a depth not greater than 1,000 feet.

Because the general setting of coal in the Toreva Formation does not appear to favor large scale stripping operations it is difficult to foretell the arrival of circumstances that would permit the development of these coals on a large scale. Although large tonnages might be classed as ultimately recoverable there is not sufficient data to pick and choose large areas that contain beds of known thickness and quality that might be developed by underground techniques.

The Wepo Formation is the coal-bearing unit of principal immediate significance to Arizona. It is exposed on the surface of Black Mesa over an area of 1,270 square miles, and is overlain by the Yale Point Sandstone over an additional area of only 140 square miles.

Data pertaining to Wepo coal are concentrated in the northern part of Black Mesa north of a line between Yale Point on the east and Tonalea just off the mesa to the west. Within this information zone the Wepo occupies a surface area of approximately 440 square miles, of which approximately 140 square miles has been explored and drilled by Peabody Coal Company.

Within this 440 square mile area the remnant thickness of Wepo strata, because of folding and erosion from structurally higher areas, varies from zero to over 600 feet. In the area of the Peabody lease isolated well information indicates that as much as 650 feet of Wepo is preserved locally. Because coal will be mined by stripping procedures, only coal above general drainage levels is potentially minable. Furthermore, because there is a limit to the amount of overburden that can be economically removed, the position of stripping locations tends to be on ridge tops. With these factors in mind inspection of the sections in Plate 4 suggests that the coal to be removed generally occurs within the upper half of the formation.

As previously mentioned, officials of Peabody Coal Company have announced proven reserves of at least 350 million tons. These reserves are assumed to belong to the "strippable" reserves category and thus far represent the only proven or measured reserves of any magnitude within the State. Gross reserves within the Wepo Formation of the 440 square mile sector, because of erratic erosion at the surface and depositional variations, cannot be estimated with any precision.

This study has record of 13 measured sections along the northern rim of Black Mesa of which 7 have measured specific coal beds whereas 6 simply refer to "carbonaceous" occurrences. The seven with specific coal beds are sufficiently scattered that, combined with Peabody data in the central region, it seems reasonable to assume that Wepo strata were once coal-bearing throughout their lateral extent. However, indications are that Wepo strata thin and thicken depositionally with more coal present where the Wepo was originally thickest. Therefore, the Wepo may not be a blanket-like deposit.

Along the northeast edge of the mesa, where the Wepo Formation is overlain by the Yale Point Sandstone, it is approximately 300 feet thick and apparently contains from 2 to 6 coal beds ranging from 1 to 15 feet in thickness and averaging 4 feet. The average aggregate thickness of coal in 12 sections, including no coal for six sections, is 7 feet. Assuming there is 7 feet of coal under 140 square miles, results in reserves of about 1 billion short tons, none of which is more deeply buried than about 600 feet and much of which is exposed along the mesa scarp.

Within and around the area of the Peabody lease there is little information as to the distribution of coal within the Wepo below general wash level. Measured section information gathered from rim exposures suggests that coal in the Wepo is dispersed throughout the unit. South of the Peabody lease water wells indicate that remaining Wepo strata range up to 650 feet in thickness. Considerable coal is undoubtedly present but there is not sufficient information on which to base well qualified assumptions. Such regions remain open for general geologic study and reserve estimations. Of considerable interest is a northwest trending elongate belt of Wepo strata preserved along the Black Mesa syncline that roughly parallels the southwest edge of Black Mesa. This outcrop belt is over 30 miles in length and about 8 miles in average width. At the extreme northwest end Williams' (1951) measured sections indicate that the remnant thickness of the Wepo is as much as 650 feet and that the Wepo contains at least 6 coal-bearing zones or coal beds. It is in this area that the Tuba City No. 4 mine was developed in a coal seam about 5 feet thick. The topography, particularly in the northern part where the higher parts of the Wepo are exposed, may provide numerous stripping sites. This region, as well as the general area of the Black Mesa syncline, appears to warrant additional exploration effort and evaluation.

Arriving at a meaningful gross figure for coal reserves in the Wepo Formation is difficult. Two figures already have been stated: 350 million tons within the Peabody lease (140 square miles) and 1 billion tons in that part of the Wepo underlying Yale Point Sandstone on the northeast (140 square miles). Considering that the Wepo in the north zone covers about 440 square miles, 160 square miles remain to be estimated. Available stratigraphic data suggest that an assumption of a 5 foot coal bed under this unexplored region would be conservative. On this basis the 160 square mile area would contain about 900 million short tons of coal, none of which is buried more than 650 feet and much of which should be in stripping position.

This treatment of reserves in the Wepo Formation has not considered the 970 square miles underlain by Wepo in the south portion nor has it considered that part of the Wepo in the Peabody lease that is below present stripping limits. Data about coal within these latter two zones are so meager as to again make assumptions difficult.

Regarding the southern area, a section of the Wepo Formation was measured along Wepo Wash, the type area of the formation, by Page and Akers (Repenning and Page, 1956, p. 291). The highest unit is described as a "carbonaceous" siltstone 314 feet thick; a second unit 73 feet thick is similarly described. Numerous water wells have been drilled but existing driller's logs contain no mention of coal. Considering the probability that Wepo strata are coal-bearing throughout their distribution, it does not seem excessive to assume that the unknown areas are underlain by an average of at least 3 feet of coal. On this basis the southern 970 square miles would contain about 3 billion short tons of coal within 650 feet of the surface. Similarly, 3 feet of additional coal under Peabody's lease of about 140 square miles would add about 400 million tons. In summary, the estimated gross reserves within the Wepo Formation is conservatively estimated to be 5.65 billion tons, all of which is within about 650 feet of the surface.

Pinedale Field

A remnant of coal-bearing Cretaceous strata, ranging up to 500 feet in thickness and covering about 175 square miles, crops out along the southeastern portion of the Mogollon Rim (Fig. 4, No. 7). The general area of outcrop is in southern Navajo County west and south of Show Low and extends into the northern portion of the Ft. Apache Indian Reservation. Darton (1925) describes the geologic highlights; Finnell (1966) mapped part of the immediate region on a scale of 1:62,500; and the Arizona Bureau of Mines mapped the entire region on a scale of 1:375,000 (Wilson, Moore, O'Haire, 1960). Veatch (1911) describes the coal deposits near Pinedale; Cooper, *et al* (1947, p. 32) provides analyses of three samples taken from the Pinedale Field of Veatch; Averitt and O'Sullivan (1969, p. 64–65) summarize the coal aspects of the overall Cretaceous outcrop and call it the Pinedale Field, thus extending the original Pinedale Field of Veatch; and the Arizona Bureau of Mines briefly discusses coal on the Ft. Apache Indian Reservation (Moore, 1968).

This sequence of Cretaceous strata, including both marine and near marine deposits of Mesaverde Group aspect, principally sandstones, has not received formal stratigraphic designation. Its precise relationship to the sequence in Black Mesa regarding formational correlation is not known with certainty. However, on the basis of paleontologic data, Miller (1962, p. 93) suggests the possibility that these strata are at least partially equivalent to the Mancos Shale of Black Mesa. If so, the Mesaverde Group becomes older toward the Rim, or south. Carbonaceous materials are associated with shales that occur in the lowest 100 feet of the sequence.

In 1909 all public lands in T. 10 N. and 11 N., R. 18 E. and 19 E., west of Pinedale, were withdrawn from public entry pending classification and valuation regarding coal. Veatch (1911, p. 239, 240), representing the U.S. Geological Survey, made a general examination and found prospect pits that exposed two beds of coal 10 to 15 feet apart. In his judgment only half of the 12-foot thick upper bed could even be called dirty coal. He found the lower bed thinner, but of better quality, showing 2 to 3 feet of very good "subbituminous" coal.

About 30 miles southeast of Pinedale the Indian Service operated a coal mine near Cottonwood Creek on the Ft. Apache Indian Reservation. The coaly material is on the order of 3 to 4 feet thick and is very impure. This, or a similar coaly horizon has been sampled intermittently over a distance of about 25 miles toward to northwest and is consistently thin and high in waste material (Moore, 1968, p. 81).

The only known published analyses of coaly materials from this region are provided by the U.S. Bureau of Mines (Cooper, *et al,* 1947, p. 32). Three samples were taken from three separate portions of a coal occurrence exposed in an adit on the Merwin prospect in NE¼, NE¼, Sec. 36, T.11N., R.18E. The results are shown below:

	Ref. No.	Mois- ture	Vola- tile matter	Fixed carbon	Ash	Sulphur	Btu	Btu Ash-Free Basis
Top 16″	1	6.8	37.8	38.8	16.6	3.1	10,430	12,800
Mid 28″	2	3.7	29.6	25.6	41.1	2.2	7,100	12,900
Low 28″	3	5.9	34.2	37.3	22.6	3.3	9,630	12,800

According to these data the coal is low quality high volatile C bituminous with a high sulfur content.

Considering the elongate nature of the outcrop of these Cretaceous strata and the almost continuous exposure along its southern edge, it seems doubtful that there is much chance for the blind occurrence of better coal than is presently known. Although local uses are possible, it seems doubtful that the coal reserve potential in the extended Pinedale Field will encourage significant development in the foreseeable future.

Deer Creek Field

Because of its inaccessibility this field (Fig. 4, No. 9) was not reexamined during the present study. However, it was recently summarized by Averitt and O'Sullivan (1969, p. 65–66) as follows:

> The small and unimportant Deer Creek field is in eastern Pinal County far removed from other Rocky Mountain coalfields. It was examined on a reconnaissance basis by Devereaux (1881), Walcott and Bannon (1885),

Campbell (1904), and Ross (1925). The field is a small synclinal basin, 10 or 12 miles long east-west, and 3 to 4 miles wide, in which coal-bearing rocks of Cretaceous age have been preserved. These Cretaceous rocks consist of a lower, unnamed sedimentary formation as much as 500 feet thick containing coal beds in the basal 50 feet, and an upper unnamed volcanic and sedimentary formation as much as 3,000 feet thick (Willden, 1964, p. E25–E27). The lower sedimentary formation is mainly of non-marine origin, but locally contains thin beds of marine rock of early Late Cretaceous age (Simons, 1964, p. 37). The Cretaceous rocks dip 30 to 60 degrees at the outcrop, but flatten to approximately horizontal in the center of the basin. They are also cut by many andesite dikes.

The coal-bearing sequence at the base of the Cretaceous contains two impure coalbeds individually 24 to 30 inches thick and several additional thin beds of no commercial importance. The two best coalbeds commonly contain several partings, and benches of pure coal are typically no more than 10 to 15 inches thick. The coal is also high in ash. Of five analyses presented by Campbell (1904, p. 254–256) the ash contents range from 18.7 to 54.4 percent. The lower figure was from a selected 10-inch bench of "clean" coal. The coal is of bituminous rank and will make a low-grade coke, which is of no current commercial value because of its high ash content. This coal will probably not be developed except for local use because of the thinness of the beds, the high ash content, and the relative inaccessibility of the area.

Campbell (1904, p. 257), assuming 24 inches of coal throughout a basin 3 by 10 miles in extent, estimated gross reserves at 60,000,000 tons and further suggested that half might be recoverable. Averitt (1969, p. 43) and Averitt and O'Sullivan (1969, p. 68) carry a figure of 10 million tons for the estimated original coal resources of the Deer Creek Field, the figure being credited to Campbell (1929), an unavailable informal reference.

According to Willden (1964, p. E-50) local ranchers report that one or more of the coal deposits is visited two or three times a year by persons interested in the coal exploration potential of the region. However, it appears as though no serious efforts have been made since about 1907 to explore the coal either by drilling or shaft sinking (Ross, 1925, p. 117).

Stratigraphically, available faunal data indicate that the coal-bearing strata of the Deer Creek region are closely related to the Upper Cretaceous deposits of the Colorado Plateau region to the north (Miller, 1962, p. 93). Pike (1947, p. 93) considers that the Deer Creek locality probably marks the approximate maximum southwesterly extent of the Upper Cretaceous sea.

Kaiparowits Field

The Kaiparowits coal field is extensively developed in southwest Utah but one small outlier of the Dakota Sandstone extends into northern Arizona at a point slightly west of the Colorado River (Fig. 4, No. 1). According to Averitt and O'Sullivan (1969, p. 67) the Dakota Sandstone here contains only thin beds of coal that are not of known economic value.

Southwestern Colorado Field

The coal-bearing Dakota Sandstone crops out extensively in southwestern Colorado. According to Averitt and O'Sullivan (1969, p. 66) some coal mining has been done near Cortez, Colorado. Only remnants of the Dakota are left in the Four Corners portion of Arizona (Fig. 4, No. 2) and apparently contain coal beds of insufficient thickness to encourage serious exploration.

Gallup Field

Cretaceous strata are preserved in the San Juan Basin of New Mexico, and an edge encroaches slightly into Arizona preserving some Cretaceous strata south of Window Rock (Fig. 4, No. 4) on the Navajo Indian Reservation. Although the Pittsburg and Midway Coal Company operates the McKinley coal mine a few miles east of the Arizona border, coal deposits of economic interest are not known to occur in the part of the Gallup Field that extends into Arizona. Coal from the McKinley mine is shipped to Arizona Public Service's Cholla generating plant at Joseph City, Arizona; it is the only coal-fired generating plant currently operating in Arizona.

Zuni Field

A belt of locally coal-bearing Cretaceous strata extends southward from Gallup, New Mexico, some 90 miles. According to Kottlowski and Beaumont (1965, p. 106) some coal occurs in the lower parts of the Mesaverde Group, although the upper part has been removed by erosion. In adjacent Arizona only remnants of the Dakota Sandstone and the Mancos Shale remain (Fig. 4, No. 5). Akers (1964, p. 35) indicates that coal occurs in "scattered irregular lenses from a few inches to several feet thick." However, specific localities are not presented and there is no suggestion that any serious attempts at exploration for coal have been undertaken in central Apache County.

Coyote Creek Area

Several miles of undifferentiated Cretaceous strata are exposed in the vicinity of Coyote Creek south of St. Johns, Arizona (Fig. 4, No. 6). The principal exposures are sandstone but some carbonaceous shale is exposed in cuts along U.S. Highway 60. However, discrete coal beds are not known to have been reported from this remnant.

Southern Arizona

Although significant quantities of coal are not known to be associated with the thousands of feet of Lower Cretaceous strata in southern Arizona, mention has been made in the geologic literature of occurrences of carbonaceous materials in Cochise County. Blake (1898) and Dumble (1902) reported on coal of "Paleozoic" and "Carboniferous" age, respectively, and Schrader (1915) mentions reported occurrences of "coal or lignite" in "apparently Mesozoic" strata in or about the Whetstone Mountains.

Blake (1898, p. 345, 346) describes "glossy black graphitic anthracite over twelve feet in thickness" as occurring in the vicinity of Cochise Head at the northern end of the Chiricahua Mountains (Fig. 4, No. 11). The material is associated with shales and Blake states further that "it cannot be claimed that any of this material has much value as a fuel. It is hard to ignite. The percentage of ash is large . . ." Most likely the carbonaceous material is associated with Cretaceous strata known to occur in the general region. There is no indication that this occurrence has stimulated significant exploration activity.

Dumble (1902, p. 270) also reported on a "Carboniferous" coal in the Chiricahua Mountains of Cochise County (Fig. 4, No. 12). His principal interest was the apparent discovery of Paleozoic coal so far to the west in the United States. He states that "there can be no question as to the Carboneferous age of this particular coal deposit" and " . . . while it may be that this deposit has no commercial value, its occurrence is of scientific interest . . ." There appears to be a strong probability that Blake and Dumble were dealing with very similar, if not identical, occurrences. According to Hayes (Averitt and O'Sullivan, 1969, p. 67), Dumble's occurrence is now believed to be of Cretaceous age. Apparently, faulting in the region gives the impression that the coal-bearing strata are overlain by Paleozoic carbonate rocks.

Schrader's comments (1915, p. 360–361) relate to reports of ranchers. Strata of Lower Cretaceous age crop out extensively in southeastern Pima County on the southwestern flank of the Whetstone Mountains (Fig. 4, No. 10). He says that according to reports a 40-foot shaft was sunk on a low grade coal occurrence but that there was no perceptible improvement with depth. In addition "associated with the deposit are reported to be plentiful remains of petrified trees, some being about 100 feet in length." Another report relates that 4 inches of coal of "good grade" was found but that exploration work was unsuccessful in developing thicker coal. Creasey (1967) has measured and described more than 7,000 feet of Cretaceous strata in the Whetstone Mountains. However, he did not encounter recognizable coal or lignite.

Mogollon Rim

The Mogollon Rim is a prominent high escarpment in central Arizona that forms the dividing line between Gila County on the south and

Coconino County on the north. This important topographic feature also forms the topographic boundary between the Plateau province to the north and the Basin and Range province to the south. Although the term "Mogollon Rim" is generally applied to the total extent of this topographic boundary, the portion to be discussed lies between Fossil Creek Canyon to the northwest and Canyon Creek to the southeast, a distance of approximately 70 miles (Fig. 4, No. 8). This specific segment of the escarpment exposes in excess of 2,500 feet of Paleozoic sedimentary rocks of Pennsylvanian and Permian age consisting, from the base upward, of the Naco and Supai formations, the Coconino Sandstone, and the Kaibab Limestone.

The following quote is from Ransome (1916, p. 160): "about 6 miles west of Pine the mail trail between Payson and Camp Verde crosses the canyon of Fossil Creek and affords a fairly good section of the Supai Formation, which here consists chiefly of bright-red friable, very fine grained calcareous and gypsiferous sandstones, with a few beds of soft light-gray sandy limestone. One bed of such limestone, about 20 feet thick, is well exposed on the trail about 50 feet below the east rim of the canyon and is regarded as the top most bed of the Supai. About 800 feet below this bed is a layer of gray limestone conglomerate, about 12 feet thick, with pebbles of limestone as much as 2 inches in diameter. A seam of very impure lignite, reported to be in places 20 inches thick, lies just under this conglomerate and is said by prospectors to be accompanied by some native copper."

Subsequent investigation of this general stratigraphic horizon (McGoon, 1962, p. 89) indicates that at least three thin "coaly" units occur within a 30 foot section of light gray shales. The maximum thickness measured of coaly material was about 15 inches. Ransome thought the horizon occurred about 800 feet below a 20 foot limestone. The limestone referred to is today known as the Ft. Apache Member of the Supai Formation (Gerrard, 1964, p. 33). Mapping the coaly horizon suggests that it is between 600–800 feet below the Ft. Apache Member. According to Frederiksen of Socony Mobil Oil Company (1962, written communication) coal samples from Fossil Creek Canyon submitted by H. W. Peirce contained pollen and spores suggestive of a Lower Wolfcamp age. Prior to this dating no fossil information was available in the 1,300 feet between the Naco Formation below and the Ft. Apache Member of the Supai Formation above. Thus the spore-pollen study provides a tentative date at about the middle of this previously undated interval.

Recently, in the vicinity of Promontory Butte about 30 miles along the Mogollon Rim east of Fossil Canyon, the Supai Formation was being explored for possible uranium deposits. The zone of interest includes a limestone pebble conglomerate that contains carbonaceous material and a carbonaceous shale that contains remains of fossil plants. This general horizon is estimated to occur about 600 feet below the Ft. Apache Member, a stratigraphic position that at least approximates the position of the conglomerate and coaly units in Fossil Canyon. Averitt and O'Sullivan (1969, p. 67), in writing about the Fossil Creek occurrence, state that "the coal is noteworthy because it is the westernmost occurrence of coal in Paleozoic rocks in the United States and indicates that conditions suitable for the formation of coal existed this far west in Paleozoic times."

Available data suggest that some of the Supai Formation that was deposited during Lower Permian time accumulated in swamps adjacent to streams capable of transporting limestone pebbles of uncertain derivation. Thus far, although this general condition may have prevailed over hundreds of square miles, there is no evidence to indicate that the condition persisted long enough to result in the development of coal beds of sufficient thickness to be economically exploited as a large volume fuel source. However, the common association of uranium bearing minerals and certain metallic sulfides with carbonaceous materials makes these carbonaceous occurrences, and their possible extensions, of some practical interest (see section on uranium deposits).

CONCLUSIONS

The Nation's coal deposits, particularly those east of the Mississippi River, have been a vital asset in the past. Stimulated by a growing population, vast reserves in the West are being developed on a large scale as an energy source for the generation of electricity.

Large reserves of coal are present in the Four Corners states. The coal deposits of northwestern New Mexico are already being used as fuel in electrical generating plants serving both Arizona and southern California. Until recently, Arizona's coal deposits were relatively untouched. Because of an ever increasing market for electricity, feasible transportation by pipeline, and an adequate water source, large reserves of stripping coal of high rank and good quality, have been blocked out on Black Mesa.

It is estimated that Black Mesa contains coal reserves, within 1,700 feet of the surface, amounting to approximately 20 billion short tons. These reserves are contained in three formations of Cretaceous age; the Dakota, Toreva, and Wepo formations. The higher, or Wepo Formation, contains an estimated 5 billion tons of coal of which .35 billion tons has been blocked out for stripping by the Peabody Coal Company, in order to supply coal to the Mohave plant in southeastern Nevada and the Page plant in northern Arizona. Wepo coal is excellent coal as it has high rank and quality and contains low amounts of sulphur and ash. Black Mesa reserves are on the Hopi and Navajo Indian reservations and are subject to their management.

Although there are other occurrences of coal in Arizona none is believed to contain sufficient reserves of adequate quality to warrant large scale development in the foreseeable future.

Other possible future uses of coal in the West are many and include the manufacture of other hydrocarbon fuel forms including gasoline products and gas. Existing natural gas pipelines cross Black Mesa so that a major distribution system is already present should the conversion of Black Mesa coal to gas become a practical reality.

Although most of the coal reserves of Black Mesa are below currently economical stripping range it is probable that large additional stripping reserves could be developed, especially in the northern end of the Black Mesa syncline.

The Four Corners region, including Arizona, appears destined to become one of the world's large energy producing centers.

OIL, NATURAL GAS, AND HELIUM

By
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GENERAL STATEMENT

Oil, natural gas, and helium are commercially produced in Arizona only in Apache County. Oil and natural gas are produced from wells on the Navajo Indian Reservation and helium is produced principally from wells just south of the Reservation. Natural gas and helium may or may not mingle within the same reservoir. The relatively high grade helium occurrences at Pinta and Navajo Springs near U.S. Highway 66 are not associated with natural gas, therefore, helium is a commodity that can be subject to exploration efforts independent of any association with oil or natural gas. Ultimately, helium is believed to be derived by radioactive disintegration of uranium and thorium bearing minerals, an origin quite dissimilar from that generally postulated for the organic compounds that combine to form oil and natural gas. The geologic habitat of helium varies from that of oil and natural gas in all of the factors that relate to contrasting sources. Whereas it is common to associate oil and gas with marine environments rich in organic matter, helium is commonly considered to be influenced by the proximity of a radioactively disintegrating source such as a basement granitic mass. Subsequent concentration by migration and accumulation might take place in any rock, regardless of initial origin. Sedimentary rocks of marine origin need not be an intervenor as regards source, but may provide reservoir space. To this extent oil and natural gas, and helium can be unrelated, separately occurring commodities.

BLACK MESA BASIN

In its broadest concept the Black Mesa basin embraces about 26,000 square miles, the northeastern two-thirds of which is Indian Reservation. It includes almost all of Navajo and Apache counties and the eastern half of Coconino County. It contains 80 percent of all of the exploration drilling done in the Plateau province.

Drilling has resulted in the commercial production of petroleum and natural gas only in the extreme 600 square miles in the Four Corners sector of the Navajo Reservation. This production flanks production in the three adjacent states of Utah, Colorado, and New Mexico, and is largely an outgrowth of the encouragement offered by these previously known petroleum occurrences. Wells with a history of production are shown in Table A of the Appendix.

Helium, although present in the immediate Four Corners area, is currently being produced commercially only in the southeastern corner of the Black Mesa basin southwest of the Defiance uplift just to the south of the Reservation boundary (Plate 6). This helium production is about 100 miles south of the nearest oil production established in 1967 at the Dineh-bi-Keyah field at the north end of the Defiance uplift, Apache County.

Plate 6 indicates the positions of exploration holes in Navajo and Apache counties and symbolizes the deepest units penetrated. It must be remembered that exploration drilling is a three-dimensional problem and that the density of drilling activity is meaningless without knowledge of the third dimension, or penetration factor. Drilling activity tends to concentrate in and around known production and there is considerably more area that has not been drilled than has. Explorationists tend to exhaust known possibilities first, hesitate, then venture forward into the realm of new ideas and hopes. Ideas are the forerunner of drilling activity and someone is always first to step out. It may be that in Arizona the time has come to again consider whether Arizona has a petroleum potential in addition to that which remains by virtue of being in close proximity to favorable geology that supports larger production in adjacent states.

The overall Black Mesa basin reflects a geologic history that seems only partially understood. The essence of geologic understanding is derived from a knowledge of the interplay of stratigraphic and structural events that point to the recognition of conditions leading to the origin, migration, accumulation, and preservation of significant concentrations of oil, gas, or helium. However, in actual practice, it is the recognition of a potential trapping mechanism that appears likely to contain appropriate rocks in the subsurface that usually prompts a drilling venture.

General Stratigraphy and Structure

Outcrop data coupled with well information permit a general stratigraphic framework to be constructed. Stratigraphic nomenclature and sedimentary sequences are indicated in Plates 7, 8, 9, and 10, which are generalized sections through various parts of the Black Mesa basin and adjacent features, and Table F summarizes Plateau stratigraphic and formational characteristics.

The southern limit of the Black Mesa basin is formed by the Mogollon slope. Although the Mogollon slope is often applied to surface geomorphology between the Rim and the Little Colorado River, Plate 8 suggests that an apparent component of the structural tilt is continuous for 140 miles to a position below Black Mesa. The average slope in this north-south direction is about 34 feet per mile. Eight feet per mile or less appears to be Laramide deformation and about 26 feet per mile is pre-Laramide tilting, a fact that accounts for the southward wedge-out of Triassic-Jurassic rocks beneath Cretaceous strata (Plate 8).

Maximum structural relief is near 3,000 feet. The northeast-southwest section shown in Plate 9 is more nearly parallel to the regional northeast dip direction of the slope therefore the slope gradient is greater, averaging about 46 feet per mile over a distance of 80 miles. In this section the basin appears symmetrical with the low point near the north-south center line of the Black Mesa topographic feature. The northeast limb, the Defiance uplift, is largely a Laramide structure because, beyond the section, Cretaceous rocks are folded and the Tertiary Chuska Formation (Miocene?) truncates the structure. To the southwest Cretaceous rocks have been removed by erosion but it is likely that the northeast tilting is still largely pre-Cretaceous in origin. The Defiance uplift may have been imposed upon a previously existent northeast dip. At least it seems clear that the basin shape results from a composite of more than one significant structural episode.

Although it is generally recognized that the Black Mesa basin is a structural basin, it does not appear to have resulted from a simple subsidence event. It results from uplift imposed upon a pre-existent structural slope that is most probably related to the rise of the so called Mogollon Highland to the south. Maximum structural relief is about 4,400 feet.

An east-west section across the northern segment of northeastern Arizona illustrates several structural zones within the overall Black Mesa basin region, which is considered to lie between the summit of the Kaibab uplift to the west and the summit of the Defiance uplift to the east. Although Cretaceous strata are absent in the immediate region, the flexuring is believed to have occurred largely during the Laramide interval. Maximum structural relief is about 4,700 feet along this line of section.

Maximum relief on the Precambrian surface approximates 8,700 feet as indicated on Plate 7, a north-south generalized section along the Defiance uplift. About 1,000 feet of this relief was established in a Late Mississippian-Early Pennsylvanian adjustment interval.

With this general structural framework in mind, it is useful to examine and summarize the associated stratigraphic framework. Lessentine (1969) presents an excellent stratigraphic synthesis of the Black Mesa basin region as well as flanking areas in adjacent Utah.

The maximum, in place, stratigraphic section beneath Black Mesa is 9,000 feet thick and consists of about equal parts of Mesozoic and Paleozoic sedimentary rocks. The Mesozoic section is composed almost wholly of siliceous clastics. Paleozoic rocks, approximating 4,500 feet in maximum total thickness, consist largely of siliceous clastics in the upper part and carbonate rocks in the lower portion (Plate 8).

The Paleozoic section is thinnest on the Defiance uplift where about 1,300 feet of Permian clastics rest unconformably upon Older Precambrian quartzite in outcrop near Ft. Defiance (section 7, Plate 7). It thickens northward, southwestward and westward to between 3,500-4,500 feet, eventually picking up, within the basin region, representatives of the Pennsylvanian, Mississippian, Devonian, and Cambrian periods.

Relationships in the Defiance region seem to be of particular interest because, to the present, all of Arizona's oil, gas, and helium production is on or near it.

The term "Defiance" lends itself to a plateau, an uplift, and a region of positive tendencies and sedimentational influence throughout much of Paleozoic and Mesozoic time. The plateau is atop the uplift, a Laramide feature well expressed at the surface today. The uplift is elongated north-south, rises to above 7,000 feet, and older rocks plunge beneath younger rocks at both ends approximately 75 miles apart. An oil test (section 8, Plate 7) drilled in 1927 at the south end spudded in the Triassic Moenkopi Formation and entered Precambrian granite at about 1,500 feet. Fifty years later, in 1967, about 75 miles to the north at the north end, Kerr-McGee Company discovered oil in a Tertiary igneous sill in Pennsylvanian strata. Subsequently, by the end of 1969, nineteen wells had produced over 8,000,000 barrels of oil from the Dineh-bi-Keyah Field, Arizona's most exotic and most prolific (Plate 6, Table A).

"Defiance," as applied to paleogeographic phenomena, can be rather loosely used to describe numerous stratigraphic patterns that are reflected both on the surface and in the subsurface. In Arizona a positive tendency commonly has been invoked to explain the southeasterly and northerly wedge out of Cambrian, Devonian, and Mississippian strata; the southward and eastward thinning of Pennsylvanian and Permian strata; the eastward, northward, and northwestward wedge out of the Permian Kaibab-San Andres limestone; the southeasterly thinning of the DeChelly Sandstone; and the eastward and northward wedge out of the Triassic Moenkopi Formation, and other such phenomena in the Mesozoic and Cenozoic. Some of these features take place within the area of the present limited uplift and others take place laterally distant, but within the Black Mesa basin. In other words, the Defiance as a repeatedly active paleogeographic influence cannot be tied down with a rigid boundary. When a larger region is considered it is common to link the Defiance with other influential paleogeographic features such as the Zuni to the southeast in New Mexico and the Kaibab in the Grand Canyon, Flagstaff, Jerome area.

It is of interest, although often annoying, to speculate as to the causes of stratigraphic variances in the Defiance region, whether facies change, non-deposition, erosion, or combinations of these features are involved.

Although the thinning to absence of lower Paleozoic strata (especially Devonian and Mississippian) has customarily been ascribed to thinning against a Defiance positive, the subsurface patterns of distribution are suggestive of some erosional removal beneath Pennsylvanian and Permian strata.

For this report the Black Mesa basin is subdivided into the following sections: Defiance uplift, Mogollon slope, Black Mesa, and Central Arizona.

DEFIANCE UPLIFT

Lower Paleozoic stratigraphy. Subsurface relationships at the northern end of the Defiance uplift, or plateau, in the vicinity of Canyon DeChelly, appear to be quite interesting (Plate 7). Whereas the Paleozoic section above the Devonian thins by half (1,700 feet) between well sections 1 and 6, largely because of thinning of the Pennsylvanian Hermosa Group, the Devonian maintains relative thickness and apparently, lithologic continuity as well. The Mississippian carbonates appear to wedge out to the north of the Devonian as if truncation occurs beneath the Pennsylvanian. The Devonian in well section 6 also appears to be truncated. It is likely that the Precambrian quartzite in outcrop section 7 stood high in Devonian time but probably was not a regionally extensive feature.

Following the line of sections to the south and southwest the Devonian is absent for a distance of over 80 miles. Relationships in the subsurface of southern Apache County suggest that the Devonian-Mississippian-Pennsylvanian relationships with the Defiance positive are similar to those just described. Such a relationship is hinted at between well sections 11 and 12. Had the Precambrian granitic rocks been in positive relationship to Mississippian seas one might think that Mississippian strata should contain more sand than they do. Quartzites of the Older Precambrian type are not good sand sources but granites are. It is suggested that Mississipian strata and to some extent Devonian, were once more extensive in the Defiance uplift region than they now are.

A well developed Devonian section with some Mississippian, constituting a 700 foot section of lower Paleozoics, encroaches upon the Defiance uplift region from the west (well sections 4 and 5, Plate 9). An undrilled zone of up dip wedge out of this section extends for some 90 miles to the southwest towards Winslow. Some oil is produced from Devonian and Mississippian strata in Arizona and both contain helium in the vicinity of the Defiance uplift.

Pennsylvanian-Permian. Combined Pennsylvanian-Permian strata dominate the Paleozoics of the Black Mesa basin region. In the vicinity of the Defiance uplift they constitute between 75 and 100 percent of the Paleozoic section. The interval ranges in thickness between 1,300-3,500 feet, the variation being the result, principally, of thinning of Pennsylvanian strata against a positive, the Defiance in this region. Fetzner (1960) considers Pennsylvanian structural and stratigraphic history in detail, relating the influence of the positive on facies distribution.

Pennsylvanian strata are, at the present time, apparently the most important sources of petroleum products in southern Utah and northern Arizona. If Dineh-bi-Keyah is assumed to represent Pennsylvanian oil then approximately 95 percent of Arizona's production of 9,000,000 barrels of oil is associated with Pennsylvanian strata, the remaining 5 percent coming from Devonian and Mississipian reservoir rocks.

The Pennsylvanian Paradox basin was centered north of Arizona. However, a southwest shelf edge extends across the northeast corner of the State and it is this feature that contains the petroliferous carbonate zones that have stimulated drilling in the northeast corner.

For the purposes of this general report, these rocks are lumped into the Hermosa Group. The group is subdivided differently by different organizations but it is frequently divided into three formations, from bottom to top, the Pinkerton Trail, Paradox, and Honaker Trail formations (Wengerd, 1958). The Paradox Formation contains the principal zones of exploration interest and they have been called, from bottom to top, the Barker Creek, Akah, Desert Creek, and Ismay zones, and they consist principally of carbonates and shales.

In the immediate Four Corners area, the Hermosa Group is about 1,700 feet thick. It thins southward to near 800 feet thick in the Dineh-bi-Keyah field and 200 feet thick in well section 6 (Plate 7), and it is absent in outcrop at section 7. According to McKenny and Masters (1968), the productive sill in the Dineh-bi-Keyah field occurs about 180 feet above the base of the Hermosa Group in the lower part of the Paradox Formation beneath a section equivalent to the Akah, Desert Creek, and Ismay zones. The source of the oil is an interesting question because insight into the habits of oil formation and movement hinges upon the answer. It is quite possible that the oil was originally contained in an unrecognized Paleozoic reservoir. Of particular importance is the role played by igneous activity and associated thermal and fracturing phenomena. The Tertiary sill is in juxtaposition with a black shale, a potential "source" rock. Apparently, fracturing is essential but the role of thermal activity is debatable.

As with the lower Paleozoic rocks the Pennsylvanian carbonates are absent over a large stretch of country that trends southwest into undrilled territory. Well sections 3, 4 and 5 (Plate 9) to the west of the Defiance uplift contain from 200–600 feet of Hermosa Group sedimentary rocks in which the carbonates are thin and redbeds are dominant. Clastic rock porosities might be associated with up dip pinch out on the west flank of the Defiance uplift, especially if onlap onto the Defiance positive is the reason for thinning. Because evidence for petroliferous Pennsylvanian strata along this zone is lacking, it seems more likely that helium occurrences offer a realistic potential. The origin of the helium in the Pinta Field (well section 10, Plate 7) is not known. However, it is possible that some of it has or is migrating outward from deeper parts of the Black Mesa basin.

The remaining Paleozoic section above the Hermosa Group is generally clastic in nature. An unknown amount of the lower part above the somewhat arbitrarily established top of the Hermosa Group, is probably Pennsylvanian in age. Between the Hermosa Group and the Permian DeChelly Sandstone is an undifferentiated section of Pennsylvanian-Permian redbeds assigned to the Cutler Group but generally equivalent to the Organ Rock, Cedar Mesa Sandstone, and Halgaito units of the Monument Valley region.

The Cutler undifferentiated portion of the section thins southward from 1,500 feet to 600 feet at Ft. Defiance (section 7, Plate 7) where it rests unconformably upon Older Precambrian quartzite. The Cutler wraps around the Defiance positive so that it also thins to the east from beneath Black Mesa (sections 4 and 5, Plate 9) where it is 1,400 feet thick. A nomenclature change then takes place, and from Ft. Defiance southward the Cutler interval is referred to the Supai Formation.

The Permian DeChelly Sandstone is the uppermost unit of the Paleozoic in the northern sector of the Defiance uplift. It is the only Paleozoic formation that does not thin southward in the northern portion of the Defiance uplift, being 350 feet thick near the Four Corners (well section 1, Plate 7) and 800 feet thick at well section 6 near the east end of Canyon DeChelly. Northward thinning is caused by a combination of factors including the loss of lower sands that are equivalent to some of the undifferentiated Cutler redbeds and to nondeposition of the sands that constitute the upper part.

To the west beneath Black Mesa (Plate 9) the DeChelly also thins, perhaps again by losing its lower, primarily water-deposited sands, as is suggested between well sections 4 and 5. Relationships in outcrop on the Defiance uplift have been discussed by Peirce (1967). The 800 feet of DeChelly completely disappears southward where 200 feet of Coconino-Glorieta sandstone underlies Triassic sedimentary rocks (Plate 7). Westward, in similar fashion, the Coconino Sandstone replaces the DeChelly Sandstone beneath the Triassic Moenkopi Formation (Plate 9). Lateral relationships are not clear but regional data consistently indicate that the Coconino and/or Glorieta sandstones tend to be younger than the DeChelly Sandstone. Nowhere, however, is there a sedimentation interval that separates these two sandstone groupings. Baars (1962) has suggested that there is an intervening "Yeso" interval.

The DeChelly Sandstone thins and is lost southward beneath Triassic rocks, both in outcrop and in the subsurface. Whereas the DeChelly in the central and northern part of the Defiance uplift is overlain by sandstone and conglomerate of the basal Chinle Formation, southward and westward it is overlain by finer grained rocks of the Moenkopi Formation. The Moenkopi forms a relatively impervious cap over the Coconino-Glorieta sandstones in the Pinta-Navajo Springs helium fields (well section 10, Plate 7). The Moenkopi is expected to pinch out northeastward along a northwest-southeast trend in the subsurface. Should the northeastward thinning Moenkopi overlie the southward thinning DeChelly in the subsurface along the southwest side of the Defiance uplift, trapping conditions could prevail. As stated earlier, present information suggests that helium is a likely objective in this region. Trapping conditions also could prevail in the up dip sandstone wedges that are likely to be associated with DeChelly Sandstone thinning to complete absence.

Some oil has been produced from the DeChelly Sandstone in the Boundary Butte Field in extreme southern Utah (Heylmun, *et al,* 1965, p. 394). The production, however, is assigned to the "Coconino" Sandstone.

Prior to the drilling of the Dineh-bi-Keyah discovery, a water well drilling effort at Lukachukai apparently encountered sufficient "petroleum" contamination to warrant exceptional efforts to try to locate the offending zone so that it could be sealed off. Side wall samples were taken in the DeChelly-Shinarump (basal Chinle) contact zone. Information as to final results is vague but the incident may be indicative of the possibility that petroleum migration in the Dineh-bi-Keyah area may have been more widespread, stratigraphically and geographically, than is now known.

In summary, the Paleozoic petroleum and helium possibilities in the region of the northern and western portions of the Defiance uplift are twofold: (1) those remaining in the northern part of Apache County that are principally associated with Pennsylvanian stratigraphy and (2) those that exist in the large unexplored regions to the south and west in which the lower Paleozoics will become primary targets for oil, natural gas and helium, and the Permian clastics targets principally for helium concentrations.

Explorationists will encounter a relatively complex structural condition resulting from the interplay of the Defiance positive, the pre-Upper Cretaceous regional northeast dipping structural slope, the Defiance uplift, and the general involutions that are associated with the west side of the Defiance uplift. Further to the south at least 800 square miles of the surface is capped with Tertiary sediments that obscure structure and only test drilling and geophysical techniques will unravel the hidden subsurface trends (Plate 1).

A general summary of stratigraphic names and formational characteristics for northeastern Arizona is given as part of Table F and generalized isopachs for the State are shown on Plates 11–13.

MOGOLLON SLOPE

The Mogollon slope region embraces the area between Flagstaff on the west and the New Mexico-Arizona state line on the east and between the southern part of the Navajo Indian Reservation on the north and the Mogollon Rim on the south. This region, occupying part of southern Coconino, Navajo, and Apache counties, constitutes an area of approximately 10,000 square miles.

Of the several hundred holes that have been drilled for oil, gas, helium, potash, and water in the region, only 27 have been drilled to basement (Plates 6 and 14), an average of one basement test per 370 square miles. The drilling has not been distributed evenly regarding either areal distribution or stratigraphic penetration. Wells drilled strictly for helium tend to cluster in a small area and usually bottom in the upper part of the Permian Coconino Sandstone, the principal reservoir rock in the Pinta-Navajo Springs helium fields in central Apache County. Most wells drilled for water also bottom in the Coconino Sandstone, a good fresh water aquifer. Over 100 exploration holes drilled in central Apache County and adjacent portions of Navajo County for potash salts pass through the Coconino Sandstone into the upper part of the underlying Permian Supai Formation. Whereas the Coconino Sandstone has been penetrated often, progressively deeper stratigraphic horizons have been drilled into less often.

The deeper tests have been drilled in search of oil and gas and their locations have been influenced strongly by surface anticlinal or domal structures, of which 20 or more have been drilled to various depths, but not necessarily to basement (Scurlock, 1967).

To date, with the local exception of helium, the drilling of such structures has not resulted in the commercial production of oil or gas. It seems worthwhile, therefore, to re-examine the region with regard to present

Table 3. — Stratigraphic summary of Paleozoic System in Mogollon slope region. (Approximate thickness ranges given in feet.)

PALEOZOIC SYSTEM (1,000-4,000)*

UPPER PALEOZOIC (1,160-3,600)

PERMIAN (1,160-2,400)

Kaibab - San Andres limestones (0-300)
Interbedded light-colored sandstones and impure carbonates; petroliferous.

Coconino-Glorieta sandstones (160-500)
Clean, light-colored, fine-grained, permeable sandstones; helium bearing.

Supai Formation (1,000-2,000)
Red, brown, orange sandstones, siltstones; grey to brown limestones and dolomites, petroliferous; anhydrite and halite; limestone pebble conglomerates in lower part.

PENNSYLVANIAN (0-1, 200)

Supai Formation, basal (0-400)
Impure thin carbonates; brown to maroon, hard mudstones; sandstones; some limestone pebble conglomerate.

Naco Formation (0-1, 000)
Interbedded fossiliferous grey limestones and shales with darker clastics; frequently a basal conglomerate.

LOWER PALEOZOIC (0-700)

MISSISSIPPIAN (0-150)

Redwall Limestone
Clean, crystalline carbonates, fossiliferous, cherty. Frequent basal rubble zone.

DEVONIAN (0-500)

Martin Formation
Interbedded crystalline and dense dolomites and thin shales; intercrystalline, vuggy, and fracture porosity; petroliferous. Underlying clastics may be, in part, Devonian.

CAMBRIAN ? (0-200)

Tapeats (?) Sandstone
Coarse-grained, conglomeratic, hematite stained sandstone and micaceous shale.

PRECAMBRIAN

Precise descriptions from well cuttings not made but granitic rocks appear to be most common; metamorphic rocks and quartzites not common; all believed older Precambrian in age.

*Approximate thickness ranges given in feet.

concepts about the geologic history to see if ideas might be forthcoming that can lead to new exploration approaches.

The stratigraphic section of the Mogollon slope contains Precambrian crystalline rocks, sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age, and volcanics of Cenozoic age. Petroleum and helium potential appear to be best developed within the Paleozoic rocks, although some helium is known to occur in lower Mesozoic clastic zones near the lower part of the Triassic Chinle Formation. In the discussion to follow it is the Paleozoic sedimentary framework that will receive principal attention.

The thickness of the Paleozoic System varies from 1,000 feet to near 4,000 feet (Table 3). The formational variations that manifest this thickness contrast, coupled with structural difficulties, represent such a complex geologic condition that casual condemnation of the region on the basis of past performance should be discouraged.

Cambrian-Devonian. Cambrian rocks, if present, are limited to a variable, relatively minor thickness of basal Paleozoic coarse-grained siliceous clastics. Fossils have not been recovered from this interval and datable Cambrian rocks wedge out northwest of the Mogollon slope. Basal Paleozoic clastics are of interest because they might serve as reservoir rocks in juxtaposition with overlying sections of marine rocks that are potential sources for petroleum products. They might, in places be as old as Cambrian and, in others, as young as Permian, especially where Permian aged rocks impinge upon the Precambrian basement complex.

Neither Ordovician nor Silurian strata have been recognized.

In the Mogollon slope region the Devonian is represented by the Martin Formation. Although the formation seems to be continuous with parts of the Ouray, Elbert, and Aneth sequence of Upper Devonian rocks to the north, the precise relationships are not well understood. Continuity, if present, would apparently exist on the west in the Oraibi trough (Plate 11B).

The geology of Devonian sedimentary rocks of the Mogollon slope and surrounding region is not well understood. Insufficient data have encouraged various interpretations of the subsurface condition.

The Martin Formation has been discussed by Stoyanow (1936), McKee (1951), Huddle and Dobrovolny (1952), Turner (1958), Teichert (1965), Pine (1968), Beus (1969), and others. The formation ranges in thickness from 0–500 feet and consists largely of dolomites and lesser amounts of shale.

The historical development of ideas concerning paleographic aspects of Devonian stratigraphy are interesting. Early workers tend to emphasize the influence of single directions. Stoyanow (1936) emphasizes a northeasterly trending "Mazatzal Land" in central Arizona that separated the State into northwestern and southeastern basins in Devonian time. On the other hand McKee (1951) suggests that the Devonian is continuous into central Arizona across Mazatzal Land and that pinch out occurs against a northwest-southeast trending face of the Defiance positive that crosses the Mogollon slope just west of Holbrook. Eardley (1949) calls the northwest-southeast depositional belt the "Arizona Sag." Like Stoyanow, Huddle and Dobrovolny (1952) suggest that Mazatzal Land in central Arizona was a northeasterly oriented barrier to Devonian seas that were to the northwest and southeast. However, they compromised its continuity by recognizing Devonian deposition in a "Mogollon Sag" that separated the land barrier to the south, Mazatzal Land, from a land barrier to the north, the Holbrook granitic ridge, that was viewed as an extension of the Defiance positive. The Mogollon Sag is depicted as being between the Rim and Holbrook.

Teichert (1965), working principally in outcrop in central Arizona, reduces Mazatzal Land to a series of isolated, local, Precambrian quartzite islands. He places the Defiance positive in early Martin time in the position of and parallel to the present northwest trending Mogollon Rim, against which the Martin Formation thins to the northeast. By completion of Martin deposition the southwest edge of the Defiance positive is viewed as being near Holbrook in a position similar, at least locally, to that suggested by McKee. Pine's (1968) view is similar to Teichert's except that Pine emphasizes the existence of an elongate northwest plunging trough of Martin occupying the position of Huddle and Dobrovolny's Mogollon Sag.

Turner (1958) postulates the existence of a Devonian "Oraibi trough" that extended from the Four Corners southwestward beneath the then relatively undrilled Black Mesa. Such a trough required a reduction in the areal extent of the Defiance positive of McKee by moving it back to the east. The effect of this was to shorten the northwest trending edge. Subsequent drilling has, in fact, increased by approximately 10,000 square miles the area under which Devonian strata are believed to now exist within the Black Mesa basin.

Regionally, it seems useful to consider Devonian stratigraphic influences as consisting of: (1) a Defiance-Zuni positive to the east on which Devonian strata are absent, (2) a Kaibab positive tending feature to the northwest, and (3) an Oraibi trough between these two features that connects the Four Corners area with the thicker Devonian deposits in the Mormon Mountain-Verde Valley-Jerome area of central Arizona, but with a possible shoaling tendency between Black Mesa and the Verde Valley.

The western edge of the Defiance-Zuni positive is viewed as being concave towards the east so that both northeast and northwest positive trends exist. The southwestern edge is interrupted by northwest trending embayments and promontories that cause local fluctuations in thicknesses over relatively short distances, especially along directions normal to axial trends. Within this framework the much publicized quartzite positives only form local islands. These general features are illustrated in Plate 11B, a Devonian isopach that includes the general Plateau region of northern Arizona.

In the Mogollon slope area the more massive part of the Defiance-Zuni positive is encountered largely in Apache County. Two embayments and promontories extend from the positive to the Navajo County portion of the Mogollon slope, and the southwest part of the Oraibi trough crosses the Mogollon slope in southeastern Coconino County.

Plate 8 is a north-south generalized subsurface section through the Black Mesa basin region. From the Mogollon Rim at well section 1, the Devonian is projected northward to a thinned edge at well section 3 on the Holbrook anticline, the apparent apex of a promontory seemingly aligned in the general direction of the Holbrook anticline. The Devonian thickens into an embayment and then thins onto an edge of the Defiance positive. Continuing northward, Devonian is again encountered in the Oraibi trough. The embayments are plunging to the northwest where the relatively thin southeasterly tapering deposits thicken and coalesce in the Oraibi trough.

The Martin Formation consists largely of dolomites and shales with minor sandstones. Dolomite textures range from dense to coarsely crystalline with porosity types ranging from intercrystalline to vuggy. The darker dolomites usually emit a petroliferous odor on fresh break. The basal fetid dolomite zone of Teichert (see section on Verde Valley) contains oil staining in outcrop near the East Verde River between Payson and Pine. Whether or not this zone is present in the subsurface to the north beneath the Mogollon slope depends upon paleogeographic details. Present data suggest that it may be present beneath at least the southern half of the Mormon Mountain anticline where Devonian strata may approach maximum development on the order of 500 feet.

Only future drilling will provide knowledge of facies trends in and around the numerous features that appear to exist in the subsurface. The possibility of pockets of basal sandstones may offer reservoir opportunities.

Structural history affecting Devonian strata in the Mogollon slope region is not clear. Indications are that several events may have influenced fluid migration. Initially, sedimentation occurred over an irregular surface that probably sloped southward and westward. The distribution of Mississippian strata suggests that pre-Naco erosion may have removed not only some of these strata, but also possibly some Devonian as well. General subsidence occurred in the Pennsylvanian-Permian interval but a more localized sharp downward deflection took place in upper Supai time along the edges of the post-Ft. Apache Member evaporite basin (Plate 8 and Fig. 11).

The northeast tilting that formed the dip on the present Mogollon slope is principally a pre-Upper Cretaceous event. The Precambrian surface between well sections 1 and 6, Plate 8, though not flat, is also not noticeably tilted northward. This suggests that the northward tilting was imposed upon a Precambrian-Paleozoic interface that tended to slope southward. Subsequently, the region has been influenced by Laramide orogenic stresses that may have been responsible for many of the northwestward trending folds in the region. Tertiary history includes minor northward tilting and thousands of feet of vertical uplift as suggested by Cretaceous marine strata above 7,000 feet in elevation.

Mississippian. Mississippian rocks are represented by the Redwall Limestone. In the Mogollon slope region these strata are thin, ranging in thickness from 150 feet on the west to absence towards the east (Plate 12A). A detailed configuration of distribution is difficult to establish with present control but indications are that it is somewhat analogous to the underlying Devonian. However, Mississippian strata appear to have been stripped from positive trends, not only from the larger Defiance positive but also from the smaller promontories that apparently extend from it. It seems doubtful that the involutions along the western edge of the Defiance positive simply are relict characteristics inherited from pre-Devonian time. Renewed activity is indicated throughout the Paleozoic Era, especially between the Rim and Holbrook.

Regionally, the Redwall thickens to the northwest and south away from the Defiance positive. It is characterized by fossiliferous, high purity cherty limestones of varying texture though it is commonly medium- to coarsely-crystalline. Siliceous clastics are scarce, even in proximity to the Defiance positive, a characteristic that might suggest that the present Mississippian wedge out is erosional. Dolomites are not uncommon and petroliferous carbonates have been noted. Intercrystalline porosities might be expected but vugular types do occur. Prior to the deposition of overlying Pennsylvanian strata a solutional, cavernous, or karst surface was developed. Much of the open space, at least near the upper contact, is filled with red mud. The insoluble chert left behind after limestone solution was subsequently reworked into basal strata of the Pennsylvanian. This is the Molas equivalent of some authors.

West of Apache County the Redwall Limestone should be considered a possible reservoir rock for oil, natural gas and helium. The structural complexities applied to the Devonian are also applicable to the Mississippian.

Pennsylvanian. Whereas lower Paleozoic strata range up to 700 feet in thickness, the remainder of the Paleozoic (Pennsylvanian and Permian) is represented by strata ranging up to 3,600 feet in thickness. The change from largely carbonate deposition during the lower Paleozoic to largely siliceous clastic deposition during the upper Paleozoic was initiated after the Mississippian Redwall Limestone was deposited and before the accumulation of the Pennsylvanian Naco Formation. Regionally, highlands and flanking basins were formed. Although it is commonly thought that the Defiance positive was regionally operational during the lower Paleozoic it seems quite likely that it too, along with the Kaibab positive to the west, received its principal uplifting pulse during early Pennsylvanian time. As has already been suggested it also seems likely that the lower Paleozoics were once more extensive in northeastern Arizona and had been stripped away prior to Pennsylvanian deposition.

Although the base of the Pennsylvanian system rests upon an unconformity that is clearly defined, the top of the formation appears to grade into Permian strata assigned to the Supai Formation. Thus far, the designation of a precise Pennsylvanian-Permian boundary has been attempted only by Winters (1963) in outcrop on the Ft. Apache Indian Reservation below the Mogollon Rim. Even here, although the designated contact is sharp and easily mapped, it is lithologically defined, not faunally. In the subsurface to the north it is generally recognized that if the top of the Naco Formation is defined on the basis of the highest occurrence of limestone of Naco character, then the Naco is wholly Pennsylvanian in age. The overlying Supai must then be considered Pennsylvanian-Permian with a poorly defined Pennsylvanian interval. The situation is awkward so an effort is made here to define at least a local working boundary that separates these two periods.

Plate 8, between wells 1 and 6, shows a suggested Pennsylvanian-Permian boundary. It is drawn at a contact zone between overlying orange siltstones and sandstones typical of the Supai Formation, and underlying atypical dark-brown to maroon mudstones. The interval of dark, fine-grained clastics is approximately 200–250 feet thick above a limestone of Pennsylvanian Naco aspect. On Plate 3 this clastic zone is designated, traditionally, as questionable Pennsylvanian Supai. However, it could just as well be included within the Naco Formation with which it might actually be more closely related.

Based on the preceding discussion it is convenient to designate a Permian Supai Formation and a Pennsylvanian Naco Formation in the subsurface of the Mogollon slope region in a manner analogous to the work of Winters (1963) in outcrop below the Rim on the Ft. Apache Reservation to the south (Plate 15). For convenience the Pennsylvanian of the Mogollon slope region is considered to be represented wholly by the Naco Formation.

Kottlowski and Havenor (1962), Fetzner (1960), and Huddle and Dobrovolny (1945) have discussed various aspects of the Pennsylvanian history of the region.

Figure 8 is a diagrammatic representation of the general subsurface geology of the Mogollon slope region along a generally east-west direction. Although not to scale, thickness aspects have been qualitatively indicated.

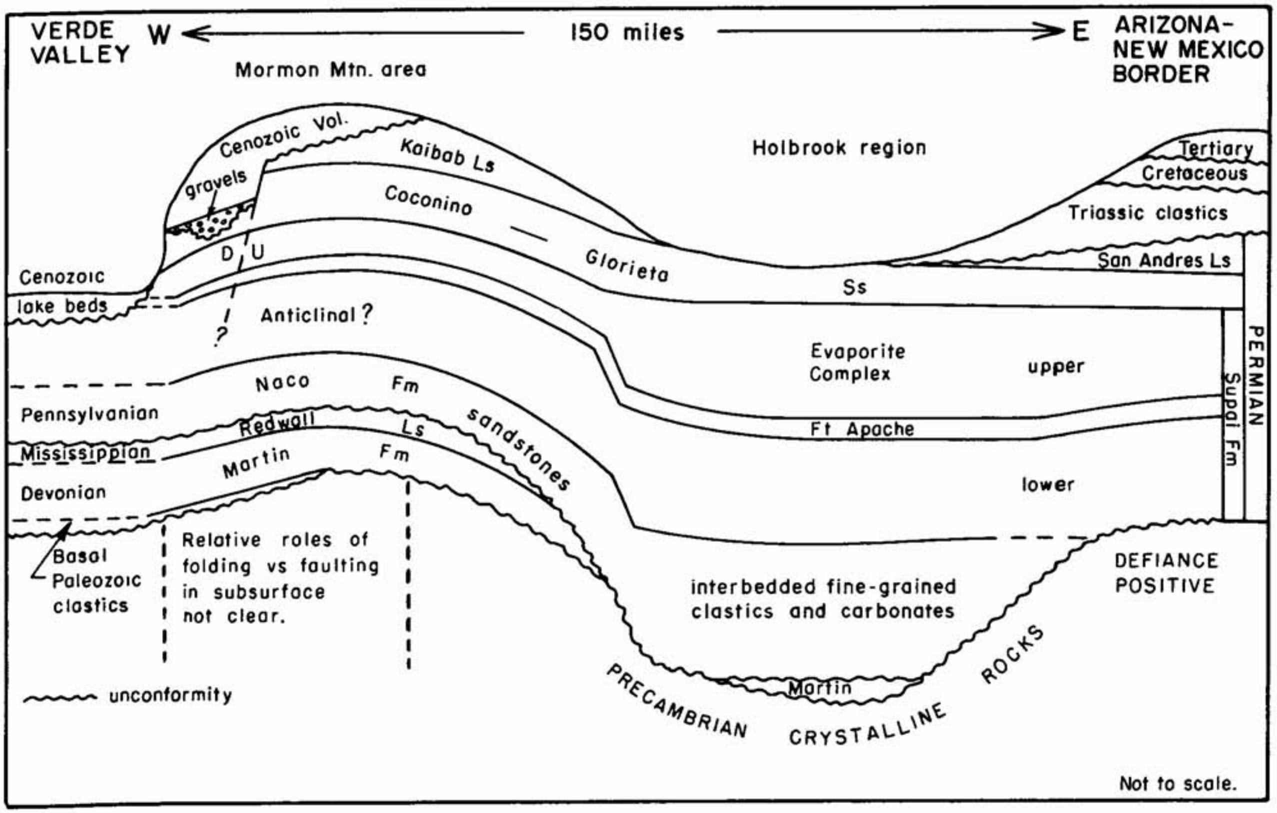


Figure 8. Diagrammatic east-west geologic section across Mogollon slope region — Verde Valley to Arizona-New Mexico boundary.

The Naco Formation thins to the west, pinches out to the east against the Defiance positive, and thickens in the Holbrook region in between. Plate 8, a generally north-south section that crosses this Naco basin suggests that Pennsylvanian strata are consistently between 1,000 and 1,200 feet thick between the Rim and the Little Colorado River. Plate 15 shows how Naco units impinge against the Defiance positive to the northeast in Apache County and also that the Naco rests on progressively older units towards the uplift. This supports an earlier contention that pre-Naco erosion may have stripped away lower Paleozoic strata.

Fetzner (1960) calls this Naco basin the Pedregosa embayment and terminates it about 30 miles north of Holbrook, against a northwest-southeast alliance of the Kaibab-Zuni-Defiance positives, or "uplifts." The thinning in well section 6, Plate 8, is against the Defiance positive picked up by a northeasterly jog in the line of section. Had section 6 been bypassed so that sections 5 and 7 were connected one would be hard pressed to define a positive feature that causes notable overall northward thinning of Pennsylvanian section. Although it seems clear that limestones in the Hermosa to the north and in the Naco to the south disappear towards this central Navajo County area, it also seems likely that they disappear by facies change in a manner that does not result in a total Pennsylvanian pinch out. The top of the dark mudstone zone north of well section 6 may rise in time so as to compromise its use as the top of the Pennsylvanian.

To the west, in outcrop in the area of Oak Creek Canyon south of Flagstaff, the lowermost unit of the Supai has been considered Pennsylvanian in age. This interval is about 400–500 feet thick and rests upon the Mississippian Redwall Limestone. It is composed largely of hard, sometimes calcareous and cherty, cliff forming siliceous clastics that contrast with the remainder of the typically "red bed" Supai. Although this distinct lithologic unit appears to fit naturally into a Naco Formation framework, on Plate 9 it is traditionally shown as Pennsylvanian Supai.

In the subsurface beneath the Mogollon slope where the Naco is thickest, siliceous clastic zones are more abundant than carbonates. Lokke (1962) suggests that sparse fossil data indicate that some of the clastics are of marine origin. The carbonates tend to be dense and often contain a characteristic red chert.

A significant part of the lateral thinning and coarsening of clastics to the west takes place beneath the undrilled portion of the Mormon Mountain region which appears to be anticlinal in nature (Plate 9 and Fig. 8). The anticlinal aspects may be superimposed over an edge of a paleogeographic feature, the Kaibab positive, that influenced thickness and environmental changes in Pennsylvanian time.

Very little is known of the nature of Pennsylvanian stratigraphy beneath the White Mountain volcanic field (Plate 1) south of the eastern portion of the Mogollon slope. Fossiliferous limestones and gray shales increase rapidly to the south in outcrop. These rocks should be expected to be of interest to the east where they probably again abut the Defiance positive. Locally, in outcrop, sills intrude strata of the Naco Formation (Finnell, 1966).

In summary, the Pennsylvanian System in the Mogollon slope region thins and becomes more coarsely clastic to the west above Mississippian Redwall Limestone, pinches out to the east and northeast against Precambrian granitic rocks, and loses carbonates to the north probably, in part, because of replacement by fine-grained red bed clastics to the north. These rocks are not known to be especially petroliferous. Paleogeographic conditions encourage the possibility of such phenomena as reefing, up dip pinch outs, and sand lens development, but sparse drilling has not yet encountered well developed zones of porosity.

In locating future drill sites it will be essential to appraise carefully the total structural setting. The mere existence of a surface anticline may not in itself be sufficient to assure maximum trapping potential in the subsurface.

Permian. Strata assigned a Permian age and belonging to, in ascending order, the Supai Formation, Coconino-Glorieta sandstones and Kaibab-San Andres limestones, represent a relatively complex sequence of rocks that ranges in thickness from 1,000 to 2,400 feet. The Supai is the thickest and the most complex Paleozoic formation in the region. Its maximum thickness is about 2,000 feet where it consists of evaporites, carbonates, and red bed clastics. Some of the carbonates are petroliferous and one, the Ft. Apache Member, has been a principal objective in several exploration tests. The Coconino-Glorieta sandstones range up to 500 feet thick and are noted for their generally light-colored, fine-grained characteristics. The sandstones are variably porous and permeable such that they serve as aquifiers for water and reservoirs for helium. The Kaibab Limestone approaches a maximum thickness of 300 feet and consists of interbeds of impure carbonates and light-colored siltstones and sandstones of varying carbonate content. Outcrop samples frequently display a strong petroliferous odor. Although the formation occurs in the subsurface only in a relatively limited area, its porosity and petroliferous aspects may be of local interest. Its sandstones also could contain helium in limited areas.

Studies involving the stratigraphy of the Supai Formation were presented by Huddle and Dobrovolny (1945) who made a valuable attempt to correlate the surface with the subsurface in the region of the

Mogollon slope. Gerrard (1966) and Frazier (1961) have studied the Ft. Apache Member, while Peirce and Gerrard (1961) have dealt with the upper Supai evaporite sequence. Baars (1962) and McKee and Oriel (1967) have considered regional correlation questions. Winters (1963) established the stratigraphic habit of the outcropping Supai Formation on the Ft. Apache Indian Reservation immediately south of the Mogollon Rim.

An understanding of the geologic history of the Supai Formation should be an advantage to anyone engaged in the search for petroleum and helium in the Mogollon slope region.

In recent years, Baars, McKee and Oriel, and others, have presented stratigraphic concepts and correlations that are demonstrably incorrect. Fundamentally, the issue is the position in the subsurface of the Ft. Apache Member of the Supai Formation. An attempt is made in this study to present data that should assist in developing a better understanding of the problem. Geologic structure cannot be properly perceived if stratigraphic correlations are in error.

Plate 15 is a correlation diagram that ties together surface outcrops of the Mogollon Rim-Ft. Apache Reservation area on the southwest and the Defiance plateau to the northeast, with the subsurface in between. The various terminologies applied in outcrop are shown. Although terms applied at the surface can be extended into the subsurface it is convenient to informally divide the Supai into three parts: lower Supai, Ft. Apache Member, and upper Supai. Plate 8, well sections 1–6, shows this informal subdivision. The 200 feet of "dark mudstone" shown as questionable Pennsylvanian Supai is included in the Naco Formation as discussed earlier and is excluded from the Supai in the present discussion.

The Supai Formation is 2,000 feet thick in the Holbrook anticlinal area and generally thins in all directions but not to absence. In the eastern half of Apache County it rests upon Precambrian rocks over which it maintains thicknesses on the order of 1,600–1,700 feet (Plate 15 and Fig. 9). It is 1,600 feet thick at the Mogollon Rim near Show Low and 1,600 feet thick in Oak Creek Canyon. To the north it is 1,400 feet thick at well section 6 (Plate 8) northeast of Holbrook. These thicknesses define a closed basin that is included in the St. Johns Sag (Kelley, 1955).

In an east-west direction the Naco is thickest where the Supai tends to be thickest (Fig. 8) but to the south the Naco thickens where the Supai thins. Although the Supai thinning may, in part, be due to a minor lateral change to Naco, it is quite clear that most of the thinning takes place in the upper Supai and therefore is not a result of interfingering with the Naco Formation.

In a gross sense the lower Supai contains two rather distinct lithologic subdivisions. The lowest unit is entirely red bed clastics consisting of

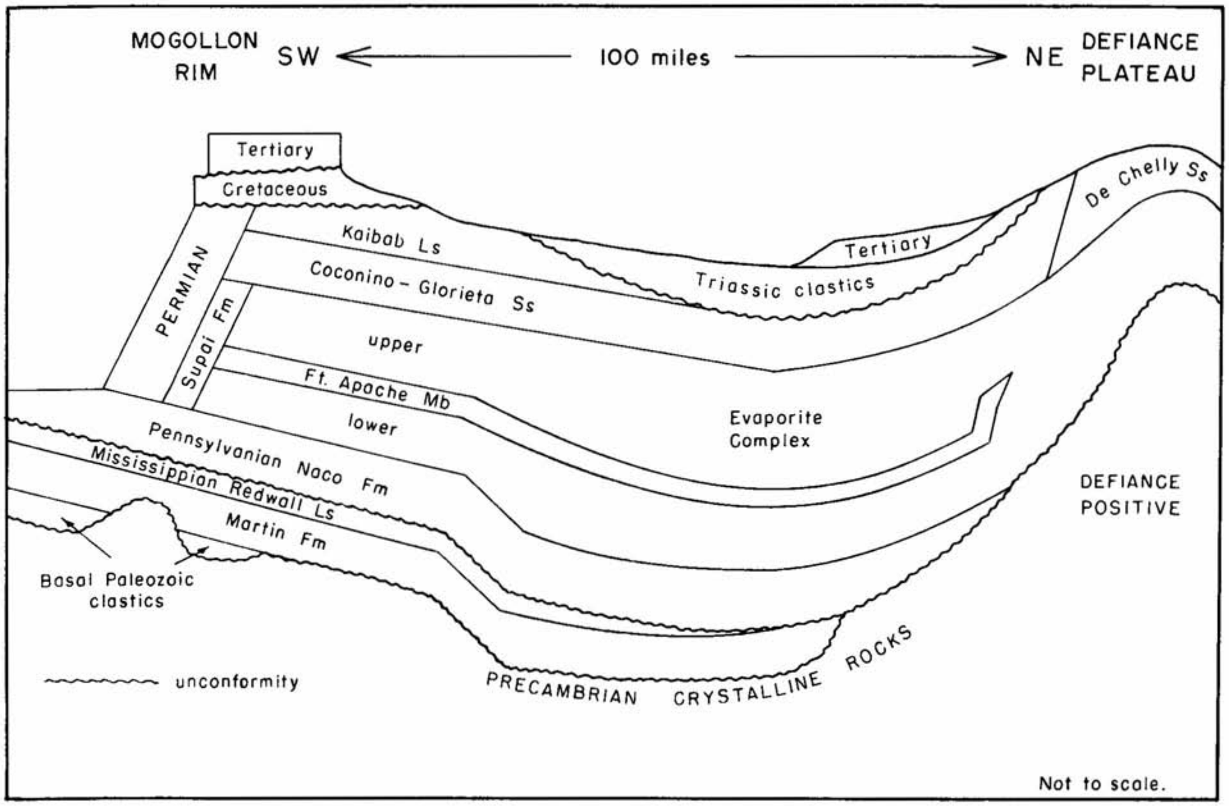


Figure 9. Diagrammatic northeast-southwest geologic section — Mogollon Rim to the Defiance uplift.

orange to red brown siltstones and sandstones. The unit correlates with Winters' outcropping Amos Wash Member (Plate 15). The overlying unit is characterized by red bed clastics interbedded with three to four distinct carbonate and/or sulfate beds. This sequence corresponds to Winters' Big A Butte Member. It is one of these carbonates that contains the lower Supai oil show indicated in well section 1, Plate 8.

The Ft. Apache unit, although originally defined as a limestone, is called a member by Gerrard (1966) because of its lithologic variations, which include shales, dolomites and evaporites. It underlies the entire area of the Mogollon slope therefore is a valuable stratigraphic marker unit when properly identified. Winters (1963) has studied the outcropping faunal content in detail and Gerrard (1964) has studied the Ft. Apache problem in Arizona.

The confusion that has arisen regarding its position in the subsurface stems from the fact that in outcrop on the Mogollon Rim the Ft. Apache is separated from the overlying Coconino Sandstone by a Supai interval as thin as 350 feet whereas, in the subsurface, this upper Supai interval increases to as much as 1,200–1,300 feet. In the subsurface those who attempt to find a Ft. Apache equivalent a short distance beneath the Coconino Sandstone force correlations and obtain poor stratigraphic results. Plate 15 attempts to show the ramifications of this problem regarding interpretations by Baars and by McKee and Oriel.

Because the Ft. Apache Member was defined in outcrop its position there is generally agreed upon by all workers. Baars (1962) thinks that a "DeChelly Sandstone" underlies the Ft. Apache in outcrop beneath the Mogollon Rim. In searching for these units in the subsurface, he examined one well section (Lockhart-No. 1 Aztec Land and Cattle, Sec. 33, T. 14 N., R. 20 E.) and concluded that there was a thin-carbonate just below the Coconino Sandstone that was underlain by a "DeChelly Sandstone." Huddle and Dobrovolny (1945) had previously judged the interval to be largely evaporitic, which is correct. However, Baars declared that they miscorrelated by missing the sandstone unit because of caved evaporites in the well cuttings. Huddle and Dobrovolny were on the right track when they depicted the Ft. Apache as having been displaced downward relative to the Coconino Sandstone. It is clear that major subsidence leading to the development of an important evaporite basin occurred after the deposition of the Ft. Apache, not before. McKee, in McKee and Oriel (1967), subdivides the Permian into intervals A, B and C. He defines the top of interval "A" as being the Ft. Apache Member and then places the principal evaporite deposits in interval "A", below the Ft. Apache. Actually, the evaporite basin is largely an interval "B" event. It would appear that McKee's judgments were influenced by Baars.

The Ft. Apache Member is viewed by Gerrard (1966) as having been formed in a southeasterly to easterly plunging trough. It is approximately 130 feet thick in the subsurface near Springerville and is ten feet thick in Oak Creek Canyon 150 miles to the northwest. The axis of deposition is, interestingly, nearly coincident with the Mogollon Rim. The unit thins northward from 65–75 feet thick near the Holbrook anticline to 25 feet thick northeast of Holbrook. It pinches out to the northeast before reaching the southern end of the Defiance uplift (Plate 15).

The Ft. Apache Member is credited with being a potential petroliferous unit because of its fetidness in outcrop and oil stains in the subsurface. Extensive development of porosity has not yet been encountered but there is reason to expect that it might exist. Some seemingly tight well cuttings and core chips have been found to be spongy, porous, dark, fetid dolomites in which the pores were filled with halite, or common salt. Leaching with warm water removes the salt and reveals the porous framework. Lithologies of this basic type are not known in outcrop, therefore it seems clear that the unit is variable, especially regarding salinity controlled phenomena, such as dolomitization. Exploration directed toward the Ft. Apache should be influenced in large part by its relationship to evaporites and the factors that control facies distribution.

An example of the importance of the subsurface correlation of the Ft. Apache Member to geologic interpretation is shown in Figure 10. Of principal importance is recognition of the fact that subsurface geometry below the Coconino Sandstone changes in response to thickening of the upper Supai, largely because of evaporite deposition. Whereas the Coconino Sandstone and higher units are clearly structurally higher in well section No. 3 than No. 2, the Ft. Apache Member and all lower units, including the lower Paleozoics, are not. Well No. 3 is on the Holbrook anticline, a surface structure that has been drilled more than any other in the region. The attitudes of the Ft. Apache and all other units below it were once steeper between sections No. 2 and No. 3, if vertical movements have raised No. 3 relative to No. 2. However, these movements were not sufficient to overcome the post Ft. Apache-pre-Coconino subsidence, which amounted to approximately 600 feet.

Proper correlation of the Ft. Apache Member makes it possible to correlate the numerous other carbonate units both above and below it that are frequently petroliferous, as indicated in the diagram. Many of these, perhaps up to 10 or more, range in thickness from 10 to 30 feet.

The question of salt solutioning and collapse has been raised by Bahr (1962) and will be discussed in another section. However, in regard to the present discussion, salt solutioning effects are of legitimate concern as the process can markedly affect surface structure and stratigraphic

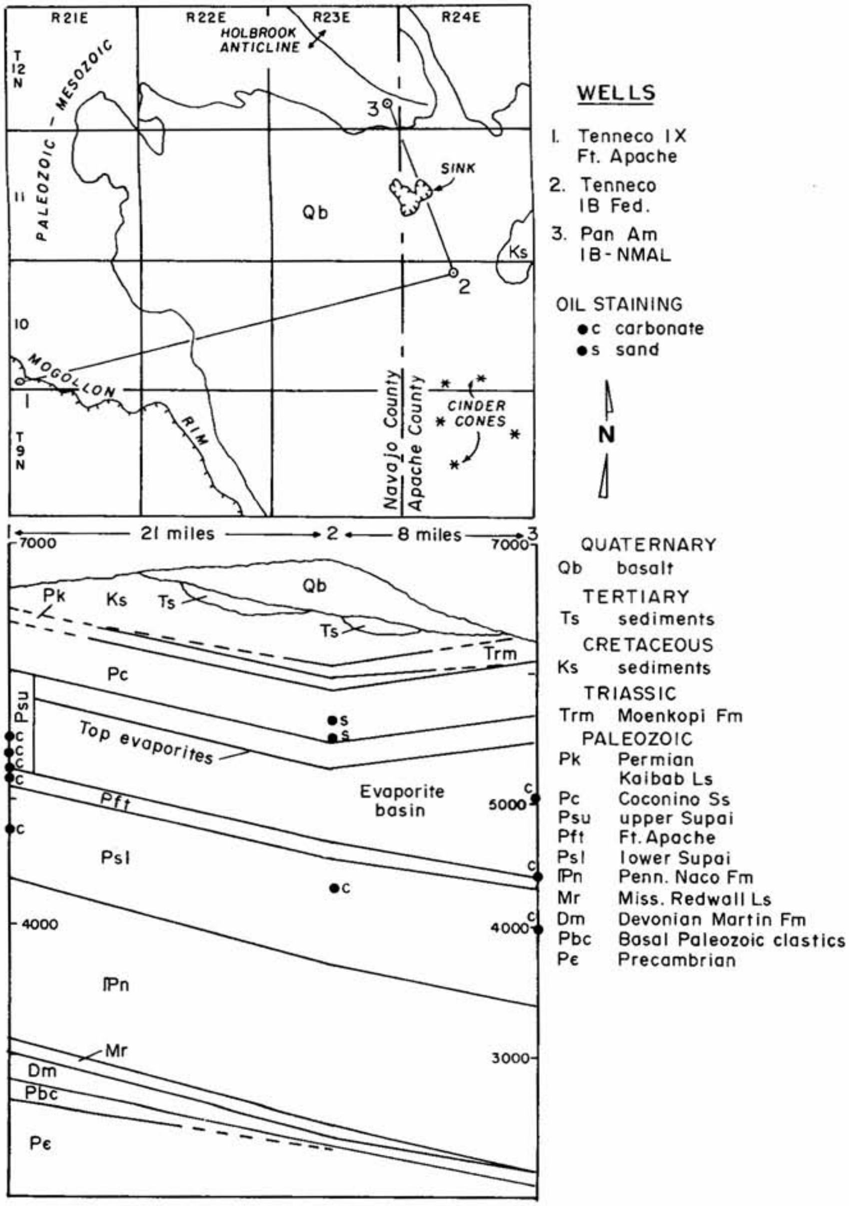


Figure 10. Effects of upper Supai thickening on subsurface structure near the Holbrook "anticline."

thicknesses. Figure 10 shows a sink feature that might readily be attributed to solution beneath the volcanics. However, the absence of evidence of large magnitude collapse, coupled with the observation that well No. 3 contains insufficient salt to account for the necessary section differential, should similar amounts have been dissolved to the south, suggests that the differential thickness in the upper Supai is largely primary.

Because the principal evaporite occurrences are concentrated in a more restricted basin than is the Ft. Apache, there is a belt within the Ft. Apache distribution that is coincident with the edge of the evaporite asin. It is possible that belts of porosity may have been developed in the Ft. Apache Member by dolomitization processes. Such belts would be of unknown width and the regional structural slopes and uplifts would favor accumulation in such trends.

Three structural events are of principal importance: (1) the post Ft. Apache-pre-Coconino subsidence which appears to have been accommodated along relatively narrow zones with steeply sloping edges, (2) the pre-Upper Cretaceous northeast tilting of the Mogollon slope, and (3) post Triassic folding. It is believed that the best possibilities are likely to be stratigraphic in nature, such as up dip porosity pinch outs. If so, random drilling on the most obvious surface structures may not encounter the most favorable subsurface conditions.

Picking the Ft. Apache Member in the subsurface during the course of drilling a well may be challenging because of the usual existence of other carbonates. Once the data are all in, it is easy to pick in hindsight. If one has accumulated the general regional data, its subsurface position may be predictable. Once the tie with the outcropping Ft. Apache is made, the unit is remarkably easy to spot on mechanical logs, especially its base. (See Plate 15.) As a general rule, it is the thickest carbonate in the Supai Formation and occurs at the base of the principal evaporite sequence. Locally, gypsum beds occur below it, both in outcrop and in the subsurface.

Figures 8 and 9, and Plate 15 show the general regional and more detailed geologic setting of the upper Supai. The basin lies between the Mogollon Rim on the southwest and the Defiance uplift on the northeast. The structural configuration in upper Supai time was somewhat analogous to the present configuration of a strucural low between two structural highs.

Figure 11 shows an isopach of the upper Supai. The interval ranges in thickness between 400 and 1,300 feet. As with the Ft. Apache Member, the unit thins to the northwest, southwest, and northeast. Whereas the Ft. Apache thickens to the southeast, the upper Supai tends to thin. It seems logical to conclude that the Ft. Apache resulted from a northwesterly transgression into a relatively narrow embayment that also

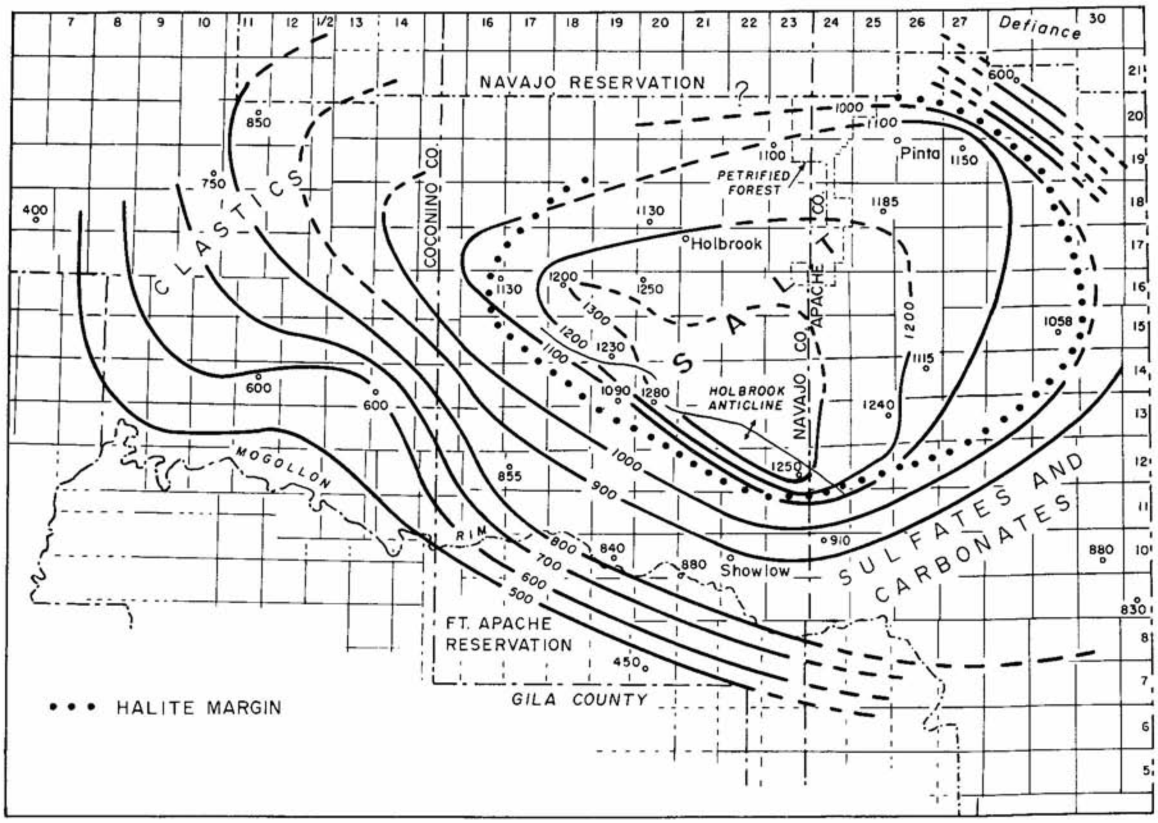


Figure 11. Isopach of the upper Supai evaporite basin.

was elongated towards the northwest. Subsequent structural adjustments and related sedimentation features caused sufficient restriction to initiate evaporite accumulation. There is a gross development of facies trends that suggests that clastics were entering the basin from the northwest, perhaps in deltaic fashion. Halite tends to concentrate in a central zone between the clastics to the northwest and clastics, carbonates and sulfates to the southeast. Halite deposition ends near the Defiance positive on the northeast, as if there was a sharply defined controlling tectonic element along the northeast edge of the basin. Halite disappears suddenly along this trend and the upper Supai thins. Sparsely distributed data suggest that halite distribution may be controlled by sharply defined basin edges with a shelf zone extending towards the southwest, south, and southeast. Carbonate units tend to be widespread and their repeated appearance in vertical section suggests tectonically controlled cyclic deposition.

When subsidence and basin filling were completed the evaporite history was terminated with the widespread, blanket-like deposition of an anhydrite that constitutes a stratigraphic marker throughout the basin wherever evaporites are present. Finally, a waterlaid blanket of clastics encroached upon and covered the filled basin, effectively completing upper Supai depositional history (Plate 15).

The nature of the north edge of the basin in the southern part of the Navajo Reservation is not known because it has not been drilled. Stratigraphic variations may be conducive to the existence of stratigraphic traps, principally for helium. Although many holes were drilled into the upper Supai during the course of exploration for potash, most of these holes penetrated the unit only superficially because, as shown in well sections 7 and 8, Plate 15, the potash is high in the section. However, a hole drilled in SW¼, Sec. 2, T.18N., R.24E., Apache County, as an evaporite test, encountered a strong helium blow at 965 feet in a clastic zone interbedded with salt and anhydrite. The blow continued for 24 hours until it was controlled by a weighted drilling fluid. Gas content, as at Pinta, approximately 12 miles to the northeast, was principally nitrogen with 4 percent helium. It is thought that gas may have entered the system either along fractures, or by lateral migration, and was trapped by an impervious anhydrite cap.

The overlying sandstones of the Coconino-Glorieta type are of interest because this interval in the Pinta area constitutes the principal reservoir rock for Arizona's helium industry.

The Coconino-Glorieta sandstone overlies the Supai Formation in such a way as to cause some difference in opinion as to where the boundary should be drawn, especially in the subsurface. The most reliable criterion seems to be a color change although the change is also manifested in textures. It appears as though most workers tend to pick the contact too low, perhaps failing to realize that the uppermost Supai is sandstone and not just siltstones and shales. The contact is frequently registered on mechanical logs by seemingly minor irregularities.

Over the area of the Mogollon slope there is considerable variation in the thickness and depositional environment of the typically light-colored, clean, silica faceted sandstones that overlie the Supai Formation. From a 700–800 foot section of eolian Coconino Sandstone in the Flagstaff region, toward the east the interval contains more waterlain sand at the base, and thins to 200 feet at the New Mexico border where the unit is referred to the Glorieta Sandstone. In the Show Low section of the Rim the sandstone is approximately 350 feet thick and is largely water deposited as indicated by its small scale wavy bedding and general absence of cross bedding. At the southern end of the Defiance plateau the sandstone interval is about 200 feet thick and consists of interbedded sandstones of waterlain and eolian aspect. Northward from the Holbrook region the Coconino-Glorieta sandstone wedges out above the DeChelly Sandstone and below Triassic strata.

Most of the exploration drilling in the eastern Mogollon slope region of Apache County has been for helium and potash deposits. The potash exploration effort is significant because over 100 of these holes penetrated the Coconino-Glorieta sandstone helium reservoir rock, apparently without encountering commercial quantities of helium. In addition, many water wells produce from this porous aquifier. The Pinta Dome and Navajo Springs helium fields remain the only commercially producing helium fields in Arizona. Dunlap (1969) has treated the geology of these two helium fields and O'Sullivan (1969) has summarized the highlights.

The exploration potential of the Coconino-Glorieta sandstone interval should probably be considered to be related principally to helium. Little is known of the ultimate source of helium, but two principal hypotheses have been mentioned in connection with the Pinta region. One is that the reservoir rock is overlain by the radioactively anomolous Chinle Formation and that helium, a product of radioactive decay, has accumulated downward, perhaps by access along faults that may afford communication between the two zones. The other is that helium has ascended from granitic basement rocks below. Granitic masses are frequently slightly radioactive, and, over a period of time, such large masses might be helium sources. Some workers are concerned with a migration system that would afford a communication link between the basement rocks and the sandstone reservoir rock between 1,400–2,000 feet above. Evaporites occur below the Pinta area and have been considered as possible barriers to vertical migration.

A brief examination of the geologic setting and history of the larger region suggests that basement granitic rocks are the most likely helium sources.

Structurally, the Pinta Dome-Navajo Springs helium fields occupy a saddle formed by a low, northeast-trending ridge that joins the Mogollon slope and Defiance uplift and separates the structurally lower Black Mesa basin to the northwest from a low to the southeast that may be a part of the Gallup sag. Migration need not be conceived as being strictly vertical. The probability of a lateral component from a structurally lower area seems likely. Stratigraphically, the sandstone reservoir represents a thinner, porous and permeable blanket between two relatively thick, impervious, stratigraphic intervals above and below. Whereas the Chinle clays are widespread in distribution the Supai evaporites wedge out rapidly to the northeast. They also disappear to the northwest in an area not yet precisely known. It seems likely that helium gas could rise to the upper limits of permeability where evaporites are not present and follow this barrier until entrapment occurs. The fact that helium does occur between the evaporites indicates that the clastic zones are made accessible by fracturing or by up dip lateral migration from evaporite free areas to the north, or by both. Helium occurrences in Arizona are in a variety of sedimentary host rocks, but, thus far, all are in close proximity to the Defiance uplift and the granites associated with the Defiance positive.

It is generally assumed that the trapping structures in the helium fields are folds and faults of Laramide age. If so, accumulation is no older than Laramide. However, the northeast dipping Mogollon slope is a pre-Laramide structure that could have had some influence on earlier fluid migration. Helium may have moved up dip to the southwest and possibly been trapped, either stratigraphically or structurally. Laramide events may have later caused a readjustment of pressure balances.

If the Chinle Formation is a source of helium then helium prospects are as far flung as an impermeable cap remains above the Coconino-Glorieta sandstone. However, if the source is principally from Pre-cambrian granitic rocks, then prospects may be more limited, especially to the vicinity of the Defiance positive on the southern part of the Navajo Indian Reservation in undrilled territory north and northwest of the present fields.

Petroleum possibilities in the sandstone interval appear to be primarily limited to the areas in the subsurface that are in close proximity to overlying petroliferous carbonates of the Kaibab-San Andres lime-stone interval. For example, dead oil stains have been recorded in Sec. 22, T. 11 N., R. 28 E., in Tenneco's No. 1-C Federal in Apache County from the top of the Coconino-Glorieta sandstone.

The Kaibab-San Andres limestones constitute the highest known

Permian and Paleozoic stratigraphic units, not only on the Mogollon slope, but in northern Arizona. The Kaibab Limestone is at the surface of the Mogollon slope from Show Low northwestward and, therefore, is not an objective in that segment. The eastern half of the slope is covered with Triassic rocks that thicken towards the northeast and therefore constitute more or less potential cover if the Kaibab-San Andres is present in the subsurface.

South and west of Holbrook the Kaibab pinches out to the northeast beneath the Triassic Moenkopi Formation. This edge is the southern exposed part of a subsurface pinch out feature that trends northerly into southern Utah. However, this persistent direction changes on the Mogollon slope by swinging to the northeast such that the carbonates are present farther north in Apache County than they are in southern Navajo County to the west. This eastern limestone occurrence is here attributed to the San Andres Limestone of New Mexico whereas the western phase is referred to the Kaibab Limestone. The term "Limestone" is the official name assigned to the Kaibab, but, as pointed out by McKee (1938) long ago, the unit should be called a "Formation." It has been customary to consider the Kaibab-San Andres limestones as lateral equivalents. In a generalized sense this might be acceptable but in detail the precise relationship is not clear. It might be that both units are separate entities and that, as suggested in sporadic outcrop from the vicinity of Show Low eastward, the San Andres may be transgressive over the Kaibab. The problem is intimately tied in with the underlying Coconino-Glorieta sandstone relationships, which also are not clear. The nature and distribution of this interval in central Apache County has been discussed by Akers (1964), and Brady (1962) comments on some paleontological aspects.

Although the Kaibab-San Andres in the eastern Mogollon slope region is petroliferous there is very little area in which it is buried to any extent. The interval pinches out to the northwest along a strong northeast trend and may be limited in the subsurface on the northeast to areas south of about T. 19 N., R. 31 E. The unit thickens to the southeast to 350 feet. It is buried by approximately 1,650 feet of younger strata near its northernmost edge, is within 300 feet or less of the surface in a large area around St. Johns, and to the south towards the Rim area it is buried by younger strata and volcanics. In T. 10 N., R. 24 E., it is 100 feet thick and 900 feet below the surface, where it is truncated by Cretaceous strata. In T. 9 N., R. 31 E., it is 300 feet thick and is 775 feet below the surface where it again is truncated by Cretaceous strata.

These "limestones" contain fossiliferous limestones, dolomites, and frequently considerable sandstone. The carbonates are dense to vuggy and the sandstones are porous and permeable. These strata are water bearing in the St. Johns region of Apache County.

Petroleum and helium prospects appear to be marginal because of preservation problems created by shallow burial and pre-Upper Cretaceous tilting and erosion. The geologic conditions beneath the largely undrilled White Mountain volcanic field are not known. However, the unit is probably overlain by Upper Cretaceous sandstones and shales, Tertiary sands and gravels, and volcanic rocks of various types ranging from pyroclastics to flows. The effects of volcanic activity on petroliferous units are not known. However, the experience at Dineh-bi-Keyah does not encourage a hasty conclusion in this regard.

The Holbrook "anticline." Of all the structures on the Plateau, the Holbrook anticline is perhaps the most puzzling. The structure is oriented northwest-southeast and can be traced at the surface for at least 45 miles in Navajo County. Its southeastern extent is covered by Tertiary volcanics in Apache County (Plate 1). It attracted drilling attention in the 1920's and was last drilled in 1962. Approximately 20 wells have been spudded in its vicinity. Five tests were drilled to the Precambrian, one to the Devonian, seven to the Permian, and seven did not penetrate Paleozoic rocks. The following discussion is devoted to a reexamination of this structure. Figure 12 summarizes the geologic setting as presently understood from drill data.

Darton (1925) presents the first account of the geologic setting of the Holbrook anticline as well as stratigraphic data of two of the early tests. He describes an "upward doming" and treats the feature as a traditional fold structure with a steeply dipping southwest limb and a shallow dipping northeast limb; and he accurately reported extensive sink development on the steeply dipping southwest limb. In spite of the fact that the presence of subsurface salt was clearly indicated in the drilling records, Darton accounted for the sinks by stating that "Undoubtedly this sandstone (Coconino) is underlain by a limestone member which has been removed in places by solution in underground waters passing into the valley of Dry Lake to the southward."

Holm (1938), in discussing the oil possibilities of Arizona, examined the Holbrook "Dome" of Darton and Hager and stated that "Careful examination by Holm failed to find any consistent signs of true folding, anticlinal structure, or doming." His explanation was that the zone of structure is a fault zone with the north side up. A vertical displacement of approximately 400 feet placed the Supai salt on the north against the Coconino aquifier on the south. Ground waters moving northward down the regional dip dissolved salt and promoted caving which reached the surface as sinks. Thus, Holm minimizes the Holbrook structural trend as a place to drill but emphasizes the "presence of flat, broad, anticlinal folds which cross the trend of the fault scarp at right angles."

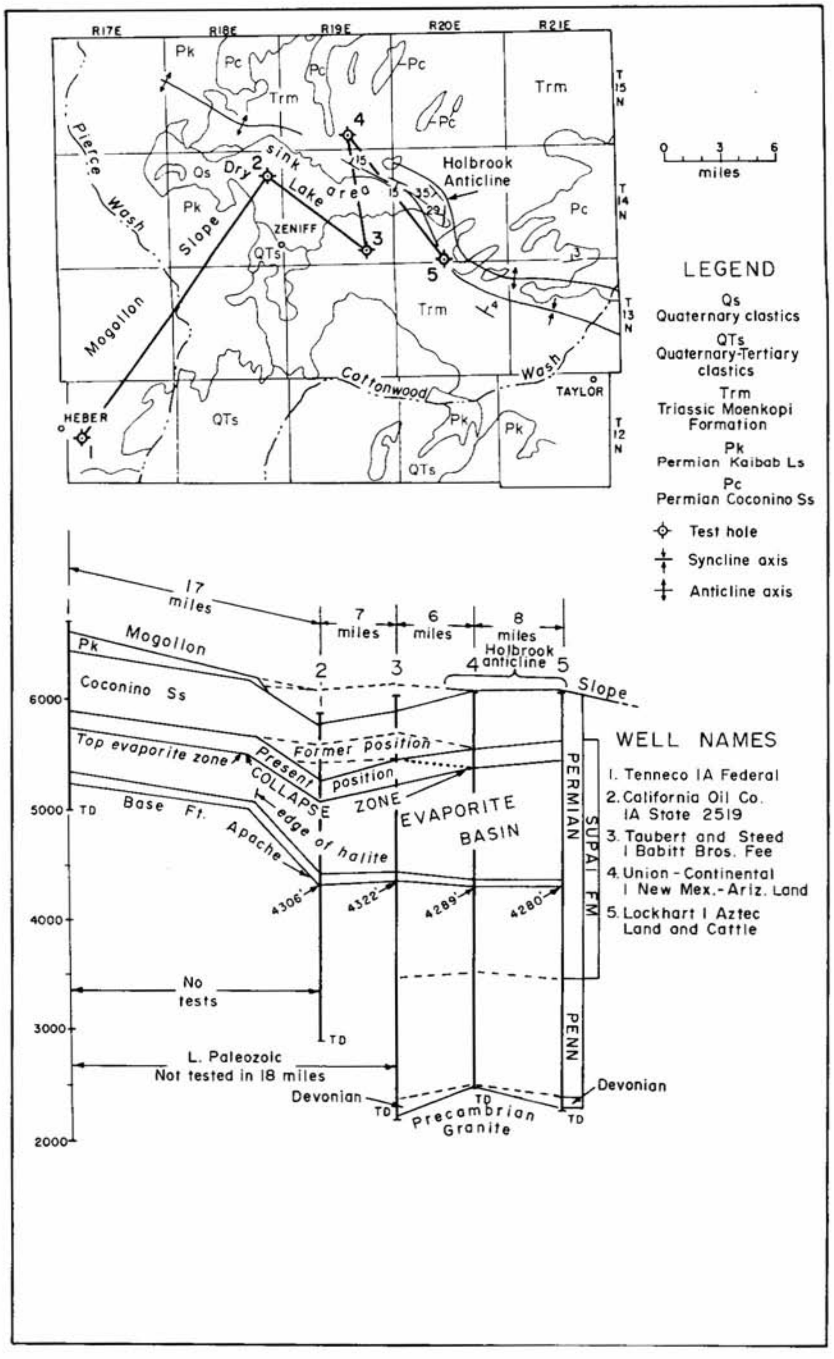


Figure 12. Primary and secondary structural characteristics in the vicinity of the Holbrook "anticline."

Bahr (1962) discusses the Holbrook anticline in detail, developing the concept that the surface feature is the modified expression of a larger subsurface anticline whose axis might lie as much as five miles south of the surface crest. Surface modification is attributed to extensive salt solution and collapse. Bahr suggests that undescribed geophysical data contributed to the idea that the subsurface crest is actually beneath Dry Lake valley, "some miles south of the position of the surface axis."

Figure 12 presents a plan and section view of the area of principal discussion. Dry Lake is an alluvium filled depression that is a local basin of internal drainage. It can be interpreted as being an area of relatively recent collapse because of the paradoxical circumstance of both Pierce and Cottonwood washes appearing to deflect around a topographic low. The northward deflection of the surface axis of the Holbrook anticline could be a roll back in response to collapse, in which case the more southerly segment would tend to more accurately mark the position of any possible subsurface structure. The projection of the southerly segment into Dry Lake valley is geologically sound; however, the primary problem is understanding what it is that is being projected.

The California Oil Company drilled a strat test in 1961 to test structural and stratigraphic conditions beneath Dry Lake. The hole was abandoned in the Naco Formation at 2,862 feet because of difficulties. However, Bahr concludes that "the well appears to have been at least as high, structurally, as the wells drilled on the surface crest of the Holbrook anticline, although some three miles south of these wells." Bahr did not include specific data pertaining to the relative positions of any stratigraphic markers.

Figure 12, in section, shows the elevations of the base of the Ft. Apache Member in four holes, two of which (well sections 2 and 3) are south of the surface anticline and two (well sections 4 and 5) are on the surface anticline. The overall relationships show rather clearly that salt solution has occurred and that the surface expression of an anticline is not reflected in the subsurface beneath the salt. What is reflected is a flattening or an interruption of the persistent northeast regional dip of the Mogollon slope.

The position and trend of the Holbrook "anticline" appears roughly to coincide with a variety of stratigraphic variations which are indicated in Figure 12. The Devonian section is believed to thin by approximately 150 feet between well sections 3 and 4; the Mississippian section is absent in all wells; the Pennsylvanian section thins slightly in well section 4; and the Kaibab Limestone pinches out to the northeast beneath Dry Lake valley. The upper Supai thickens from 550 feet in well section 1 to 1,250 feet in well section 5, which reflects the development of the evaporite basin. Although specific well control is lacking it is thought that the increase in the thickness of the upper Supai evaporitic section takes place over a short lateral distance not far south of well sections 2 and 3. A similar circumstance has been mentioned as occurring at the southeast end of the Holbrook structure and is shown in Figure 10.

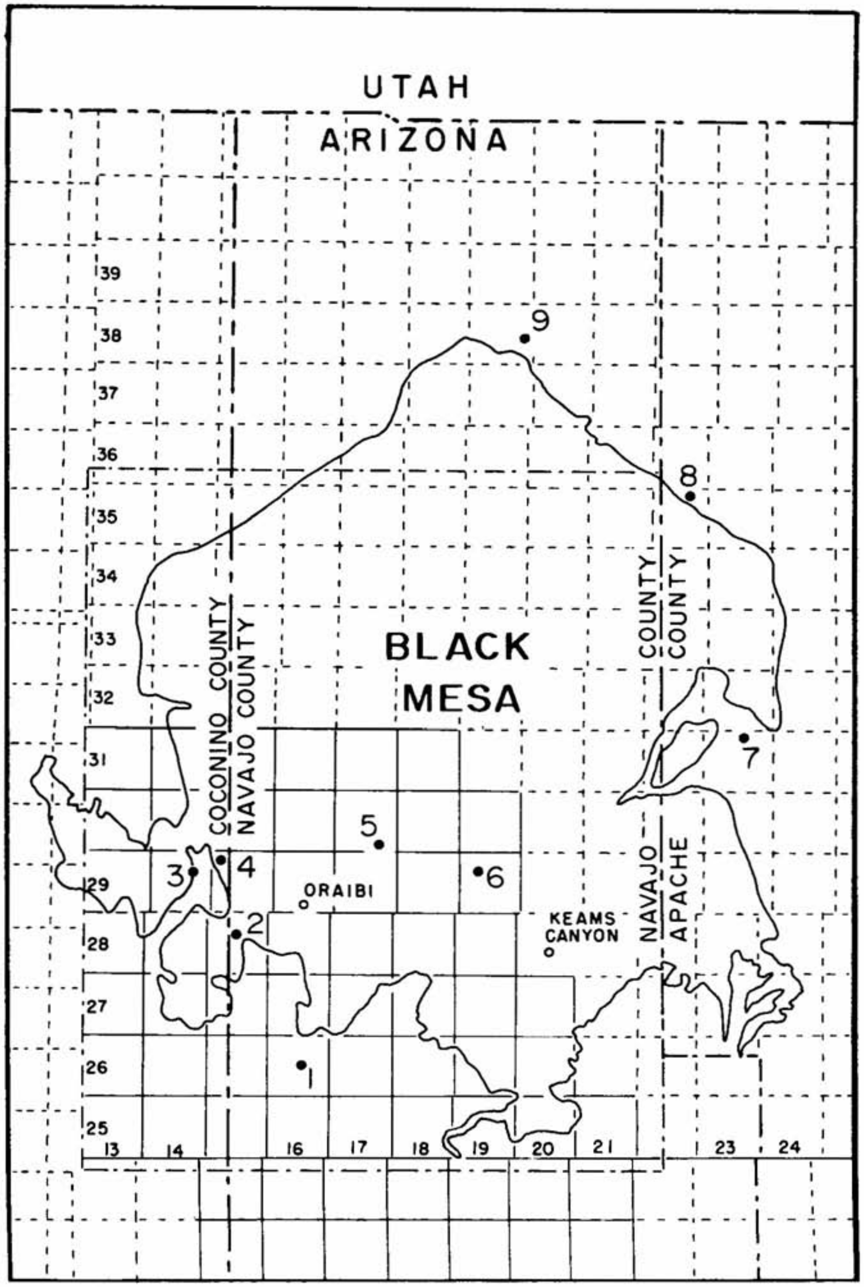
It is believed that the salt solution effects are occurring close to the southwest edge of original salt deposition. Furthermore, it seems likely that basin subsidence occurred along a relatively narrow structural zone in which the Ft. Apache and all older Paleozoic rocks may have been depressed downward approximately 700 feet. This structure, although not tested, is likely to be the most influential on the Mogollon slope as regards the accumulation of oil and gas in the Ft. Apache and all older Paleozoic sedimentary rock units. The region will not have been fairly tested until several basement tests have been drilled along at least a 50 mile belt from 6 to 12 miles southwest of the Holbrook "anticline."

BLACK MESA

Black Mesa, the center of the Black Mesa basin, was first drilled on its eastern edge in 1950. Although the test was of considerable stratigraphic interest because it was far removed from any previous drilling, it did not result in production or, apparently, even a strong show. Subsequently, eight more test holes were drilled between 1964 and 1968, also without production results (Fig. 13). Black Mesa embraces an area of approximately 3,200 square miles; therefore, there has been an average of one test per 355 square miles. Six of these holes were drilled on the

Table 4. — Paleozoic thicknesses in Black Mesa test holes. (See Figure 13 for locations.)

	Well	Penn. & Perm.	Miss. & Dev.	Cambrian	Total Paleozoic
1.	Texaco 1-A Hopi	2777	465	76	3318
2.	Atlantic 9-1 Hopi	2667	597	148	3412
3.	Pennzoil 1 Hopi	2691	650	337	3678
4.	Moore-Miller 1 Hopi	2690	638	249	3577
5.	Skelly 1 Hopi	2756	636	138	3530
6.	Amerada 1 Hopi	2793	699	154	3650
7.	Amerada-Blk. Mtn.-Nav.	2812	381	194	3387
8.	Tenneco 1-8939	2951	742	190+	3883+
9.	Tenneco 1-8531 Nav.	3195	1033	367+	4595+



See Table 4 for data.

Figure 13. Oil, gas, and helium tests on or near Black Mesa.

smaller Hopi Indian Reservation in the southwestern quarter of the Mesa. The other three were along or near the northeast edge of the Mesa on the Navajo Indian Reservation. An approximate area of 1,300 square miles in the northern two-thirds of the Mesa has not been drilled and the only available Paleozoic stratigraphic data are those derived from the few surrounding wells. Lessentine (1969) provides an excellent summary of the sedimentary framework of the Black Mesa area. Plates 8 and 9 are generalized sections that include Black Mesa. Plate 10 is just off the north tip and Plate 1 shows some of the more prominent anticlinal fold structure. Plate 3 is a general areal geologic map presented in connection with the discussion on coal.

The maximum remaining stratigraphic sequence approximates 9,000 feet at the northeast edge of the Mesa, half being Mesozoic and the other half Paleozoic. Table 4 shows Paleozoic thicknesses in the nine wells drilled on or close to the Mesa and Figure 13 shows the geographic locations. These data indicate that the overall Paleozoic section under Black Mesa thins from approximately 4,600 feet at the north end to 3,300 feet at the south end over a distance of 75 miles. The section is approximately 3,600 feet thick on the west edge of the Mesa and 3,400 feet thick on the east side over a distance of 55 miles. The maximum thickness variance in the seven wells in the southern half is only 360 feet whereas the north-south variance is close to 1,300 feet. The overall thickening to the north is a combination of the thickening of each of the three subdivisions shown in Table 4. Of particular interest is the near doubling, to over 1,000 feet, of the Mississippian-Devonian interval towards the north. The Pennsylvanian-Permian interval is relatively constant in the south but thickens 500 feet towards the north, apparently because of addition at the base of strata assigned to the Pennsylvanian Hermosa Group.

Time wise, the Pennsylvanian-Permian separation remains a problem. Although the carbonate zones responsible for Pennsylvanian oil and gas production to the northeast are apparently not recognizable beneath Black Mesa, Pennsylvanian strata at least 600 feet thick are present as interbedded fossiliferous limestones and shales. The limestones are best developed in the northeastern portion of the Mesa. The southward thinning is against the Kaibab-Defiance-Zuni "Uplift" complex of Fetzner (1960). It is doubtful that Pennsylvanian strata are totally absent anywhere in northern Arizona except locally on the Defiance positive to the east and southeast.

Permian stratigraphy is characterized by the regional distribution of light to orange-colored sandstones and darker siltstones, shales, and sandstones. A satisfactory nomenclature has not been worked out to facilitate description and subdivision. Cutler Group terminology is used on the north toward Monument Valley, whereas Supai Formation undifferentiated is extended from all other directions. All of the wells in the southern part of the Mesa have from 1,400–1,600 feet of a dominantly sandstone section below the Triassic and above interbedded darker siltstones, shales, and sandstones, and thin, light-colored carbonates. At the north end of the Mesa a 750 foot sandstone section (DeChelly Sandstone) overlies the distinctive Organ Rock red-brown shales and siltstones (well section 9, Plate 8). This stratigraphic contrast in sandstone proportion is apparently facies in nature as there is no direct indication of overall change in the thickness of the Permian section.

The sandstone problem represents the confluence of the DeChelly Sandstone from the east and north, the Coconino Sandstone from the northwest and west, and Supai sandstones from the west and northwest. Although units are distinguishable in outcrop their separation in the subsurface is difficult. The light-colored Coconino Sandstone is recognizable at the top of the sequence on the west and the orange sandstones of the DeChelly form the top on the east. The two overlap beneath Black Mesa, but, whereas the Coconino is absent on the east, the loss of the underlying DeChelly to the west becomes confused in a general mass of undifferentiated Supai sandstones. Baars (1962) extended the DeChelly into the Supai sandstones of Oak Creek Canyon. However, this was accomplished by placing it beneath the Ft. Apache Member and, as has been shown in Plate 15, the DeChelly of the type area on the Defiance plateau is younger than the Ft. Apache. Well No. 2, Plate 9, appears to contain a thin remnant of the Ft. Apache Member at the base of the 1,400 foot sandstone sequence. In Oak Creek Canyon farther to the west, at least 1,200 feet of sandstones overlie what is believed to be the Ft. Apache Member. It appears as though DeChelly equivalents could occur above the Ft. Apache but not below as Baars suggested. No particular purpose is served by extending the name DeChelly when it cannot easily be defined.

Regional relationships suggest that the Hermit Shale of the Grand Canyon region and the Organ Rock "Shale" of northeastern Arizona thin southward so that the sandstones from above and below them are placed in juxtaposition to form an undifferentiated sandstone belt that extends beneath Black Mesa. An indefinite lower part of the sandstone sequence is probably equivalent to the evaporite section in the Holbrook basin to the south. Whatever remains above is assignable to the Coconino-DeChelly sequence.

The Kaibab Limestone is generally absent beneath Black Mesa but apparently a thin remnant occurs on the west side.

The Devonian-Mississippian interval might offer the best oil, gas, and helium potential beneath Black Mesa. Although shows have been recorded from both sequences, the Devonian has more frequent shows.

The McCracken sandstone and vuggy carbonates, principally dolomites, of the Elbert and Aneth formations, have recorded shows (Table D).

The Cambrian is represented by generally less than 300 feet of combined Bright Angel Shale and Tapeats Sandstone of the Grand Canyon region. Regionally, the Cambrian section thins towards the southeast (Plate 11).

Structurally, the axis of the Black Mesa basin passes under Black Mesa between well sections 4 and 5, Plate 9. The structural relief between these wells is about 1,800 feet. The rise to the east is a function of the Laramide Defiance uplift and the rise to the southwest is apparently almost wholly the function of the older Mogollon slope. It might be that the Mogollon slope was once more extensively developed towards the northeast before being deformed by the Laramide structural cycle. On these larger structures is imposed a system of northwest to north trending elongated folds, also believed to be Laramide in age (Plate 1). Relationships beneath the base of the Cretaceous Dakota Formation between well sections 8 and 9, Plate 8, suggest that it is likely that there are structural irregularities on the Mogollon slope. These are blind structures because the Mesa is capped by Cretaceous strata. Considering the interaction of these diverse structures only geophysical studies can hope to outline the true attitudes of the Paleozoic targets that underlie Black Mesa.

CENTRAL SECTION

The central section includes most of Coconino County or that part of northern Arizona between Flagstaff on the south, the Utah border on the north, the west edge of Black Mesa on the east, and the Mohave County line on the west, an area of approximately 12,000 square miles. The Kaibab uplift and plateau area is north and the Coconino plateau is south of the Grand Canyon. Broadly, the north central section includes the western portion of the larger Black Mesa basin region.

Eleven tests for petroleum have been made in this large region, an average of approximately one per 1,000 square miles. Of these 11 holes, 9 bottomed in either Cambrian or Precambrian rocks. The nature of the show record is summarized in Table D. Shows are of two types, staining in cuttings and cores and those verbally reported. The low drilling rate suggests that in the past, explorationists have not judged the oil potential of the region to be high. However, the eastern portion includes a part of the Navajo Indian Reservation where exploration potential is judged to be relatively high but where drilling is subject to controls not present off of the Reservation.

The geologic framework of the Reservation and adjacent portions to the west warrants attention. Stratigraphic information is limited to the few scattered drill holes and to exposures in the Grand Canyon and Rim country to the south. The general structural framework has been mapped at the surface.

Stratigraphically, Cambrian strata thicken across the region towards the northwest. Devonian strata are thin in the Grand Canyon and the nature and pattern of this thinning from western Black Mesa has a significant bearing on oil, gas, and helium potential. Mississippian strata thicken northwestward and constitute a drilling objective. Pennsylvanian strata, already largely depleted of their fossiliferous marine carbonates in western Black Mesa, continue to be represented by a zone of indefinite thickness consisting of "red beds" with intercalated thin carbonate units. Individual formations within the Permian sequence are more variable in thickness than the Permian as a whole. The Kaibab Limestone and Toroweap Formation thin to absence in the subsurface east of the Echo Cliffs fold structure. The Coconino Sandstone is absent to the north towards the Utah border, the Hermit Shale thins to absence towards the southeast, and the Supai Formation and equivalents thicken to the east and south. The DeChelly Sandstone of the Monument Valley region in northern Navajo County thins to absence towards the west and northwest, but farther south it is lost in undifferentiated Supai Formation sandstones beneath the Coconino Sandstone.

Permian strata, in particular the Kaibab Limestone, are exposed at the surface over much of Coconino County. All older Paleozoic strata are exposed along parts of the Colorado River system (Plate 10) and also along the southwest edge of the Plateau. Breaching of the Paleozoic rocks by erosion, coupled with poorly developed Devonian and Pennsylvanian marine sections, have not been encouraging to exploration over the western half of the region. The Kaibab plateau portion north of the river apparently has a well developed subsurface water-bearing fracture system that supplies springs that issue from Cambrian rocks in the Grand Canyon (Huntoon, personal communication 1970).

In Plate 10 the structural relief caused by monoclinal flexuring between well sections 1 and 3 is approximately one mile and between 2 and 3 it is approximately one-half mile. Southward, sharp flexuring is replaced by a more gentle northeast dip (Mogollon slope?) but the overall structural relief is of similar magnitude. This northwest trending zone of northeast dip is on the west flank of the Black Mesa basin and is approximately 100 miles in length. The lower structural position towards the northeast preserves a wedge of Mesozoic strata that is absent to the southwest.

Beneath the surface expression of the west flank of the Black Mesa basin the Mississippian Redwall Limestone thickens from approximately 100 feet possibly to more than 800 feet and the Devonian thins against the Kaibab positive tending feature (Plates 10, 11B, and 12A).

The important McCracken sandstone unit, as well as dolomites of the Devonian sequence, disappear in the subsurface somewhere west of Black Mesa and their distribution and nature on the west flank of the Black Mesa basin is not known.

A reinterpretation of sparse well data influences the Devonian isopach (Plate 11B). Wells drilled in the Verde Valley penetrate approximately 500 feet of Devonian. On the Rim to the north, thinned sections of Devonian rest on Precambrian quartzite. This thinning might be local as has been demonstrated in similar circumstances in the Pine-Payson region to the southeast. The Lockhart-Babbitt well, drilled in 1949 in T. 27 N., R. 9 E., penetrates Devonian strata in an area far removed from other information. The question in this well involves the separation of Devonian from Cambrian rocks. The isopach is drawn on the basis of 400 feet of Martin at this locality in contrast to the 100–200 range of recent workers such as Beus (1969) and Lessentine (1969). If the adjustment is correct, the Devonian section is similar in thickness to that on the west edge of Black Mesa and thinning zones of interest are to be sought to the north and west.

The disappearance of the Kaibab-Toroweap carbonates and sandstones in the subsurface over a 100 mile long stretch of the "up dip" belt is interesting. The geologic setting may be conducive to the existence of stratigraphic traps. The Kaibab is productive in Utah 50 miles north of the Arizona border in the Upper Valley field (Campbell, 1969).

The principal exploration possibilities appear to exist along the east third of the section. However, because of so much undrilled territory, new drilling might produce information that will lead to significant trends that are presently unknown.

NORTHWEST ARIZONA

The Northwest Arizona section is entirely in Mohave County north of the Colorado River and comprises an area of approximately 5,000 square miles in which 18 tests have been drilled. On the west it includes a narrow strip of the Basin and Range province.

None of the tests drilled reach Precambrian rock but 1 bottoms in Cambrian strata, 3 in the Mississippian Redwall Limestone, 6 in Permian strata, 1 in the Triassic, and 7 are drilled to shallow depths in undifferentiated rocks. The first well was drilled in 1909 and the latest in 1966.

Several shows in cuttings and cores are included in Table D. These embrace much of the Paleozoic stratigraphic section from the Cambrian through the Permian, and Triassic shows are also represented. Drilling activity has not resulted in recorded production and all holes are classed as dry and abandoned. However, 15 miles north of the Arizona-Utah border, the small Virgin Field has produced from the Rock Canyon Member (Timpoweap) of the Moenkopi Formation. Apparently, there is some question as to whether the production is from rocks of Permian or Triassic age (Bahr, 1963). The first well in the field was drilled in 1907 and subsequent well depths average 550 feet. A petroleum occurrence so close to Arizona provided an early incentive for exploration interest in northwestern Arizona; Tapp (1963) discusses several shows encountered during drilling near Kanab, a short distance north of the Arizona-Utah border.

The geologic setting of northwestern Arizona contains a mixture of constructive and potentially destructive factors influencing oil, gas and helium potential. The Paleozoic and early Mesozoic sedimentary history is encouraging, but subsequent structural disruption in the form of long fracture systems, uplift, and deep erosion by the Colorado and tributary drainages, are complicating factors that may have had a negative influence on preservation. No wells are closer to the Colorado River than 25 miles and most wells are east of the Hurricane fault system, because faulting is more prevalent to the west in the north trending strip between the Hurricane Fault and the Grand Wash Cliffs on the west (Plate 1).

Swapp (1961) discusses the oil possibilities of northwestern Arizona and concludes that "... positive geologic thinking and a well planned and efficiently executed exploratory program ... will result in the discovery of new oil and gas accumulations of commercial importance." He emphasizes that most of the structural adjustment and consequent fluid migration and entrapment preceded carving of the Grand Canyon.

Potential production exists to whatever extent that commercial accumulations have been preserved from the effects of gravitative movements of fluids, including water, through the plumbing system toward regions of lower pressure as provided by deep canyons, especially Grand Canyon. In the region of principal drilling between the Hurricane and Toroweap faults some objectives are higher in elevation than the bottom of Grand Canyon, and some are lower. To the northeast a gentle northeast regional dip progressively places more of the Paleozoic section at elevations lower than the bottom of Grand Canyon. The elevation at the confluence of Kanab Creek with Grand Canyon (Plate 2) is slightly below 3,000 feet where canyon cutting has exposed the basal Paleozoic Cambrian Tapeats Sandstone. Approximately 36 miles to the north and slightly west of this in the T. W. George No. 1 Federal in T.40N., R. 6W., the elevation of the top of the Kaibab Limestone is only slightly above 3,000 feet. If the Kaibab in the George well is at the same elevation as the bottom of the Grand Canyon at Kanab Creek, then all of the underlying Paleozoic section is even deeper. Because the thickness of the stratigraphic section between the Tapeats and the top of the Kaibab is close to 5,000 feet, the base of the Paleozoic in the George well is 5,000 feet deeper than the river bottom.

The Grand Canyon and other lesser canyons such as Kanab Canyon have a sphere of influence that tends to reduce formation pressures. Closer to the canyons pressure release is greatest for the higher stratigraphic units and least for the lower units. Qualitatively, this feature restricts the amount of area that might be considered as having oil, gas, and helium potential. However, the magnitude of the restriction is a judgment for explorationists to make in accordance with their experience and understanding of the geologic details of a given situation.

The extreme northwestern portion of Arizona is noted for containing a so-called "hinge" line between the Cordilleran geosyncline to the west where Paleozoic marine strata rapidly thicken and a shelf zone to the east on which Paleozoic rocks are comparatively thin. Some thickening takes place within the Plateau before reaching the Basin and Range province. Whereas Paleozoic strata are 7,000 feet thick along the boundary zone between the Basin and Range and Colorado Plateau provinces (McNair, 1951), they are 4,000 feet thick at Bass Trail in the Grand Canyon (Noble, 1922). The 3,000-foot increase in section thickness to the west is made up chiefly by thickening in the pre-Supai Formation marine units.

Changes in geology and in the stratigraphic nomenclature take place in the area of convergence of Nevada, Utah, and Arizona. Molenaar (1969) summarizes the nomenclature in common use in the region and Moore (1958) has summarized the general geologic history of northwestern Arizona. Two guidebooks have direct bearing on this portion of Arizona: (1) Guidebook to the "Geology of Southwestern Utah" (Heylmun, 1963), by the Intermountain Association of Petroleum Geologists, and (2) "Geology and Natural History of the Grand Canyon Region" (Baars, *et al,* 1969), by the Four Corners Geological Society. The "Oil and Gas Possibilities of Utah, Re-Evaluated" (Crawford, 1963), by the Utah Geological and Mineralogical Survey contains comprehensive treatment applicable to adjacent parts of Arizona.

Because of the sparse distribution of well data only generalized statements can be made regarding the subsurface stratigraphic setting. The Grand Canyon and Grand Wash Cliffs areas afford excellent opportunities for surface studies of the bordering regions to the south and west, respectively.

As already mentioned, Paleozoic strata below the Supai Formation thicken to the west and northwest in extreme northwestern Arizona near the edge of the Plateau. The limited well control available in Arizona indicates an east-west consistency in thicknesses of Permian units above the Callville Formation. A combined Callville-Pakoon interval on the west occupies a similar stratigraphic position to the Naco-Hermosa units on the east; both thin against the Kaibab positive but from opposite directions. The Callville-Pakoon interval is absent in the central Grand Canyon region where Supai redbeds rest upon the Mississipian Redwall Limestone. West of the Hurricane fault near the west edge of the Plateau the Tennessee No. 1 USA Schrieber, in T.39N., R.13W., penetrated 1,100 feet of fossiliferous carbonates with interbedded sandstones and shales assigned to the Callville and Pakoon formations. Thirty miles to the east the interval is 700 feet thick and contains more clastics. The thickness of the Callville-Pakoon sequence combined with lateral lithologic changes, porosities, and recorded oil shows, make it an important objective in northwestern Arizona. It has been penetrated by only four test holes.

The Paleozoic section below the Callville-Pakoon sequence has not been completely penetrated. Only one hole, Western No. 1 Federal, T.30N., R.5W., penetrated Mississippian and Devonian strata. In this hole the Redwall Limestone is 700 feet thick and the Devonian Temple Butte Formation is judged to be 500 feet thick. The thickness for the two units combined, 1,200 feet, is as thick as any encountered in the general region of the Black Mesa basin to the east. Both units are legitimate drilling objectives.

The underlying Cambrian sequence, including from top to bottom the Muav Limestone, the Bright Angel Shale, and the basal Tapeats Sandstone, have not been completely penetrated. According to McKee (1951) the total Cambrian ranges in thickness from approximately 1,200 feet at the south end of Kanab Creek to 1,800 feet near the northwest corner of the Plateau in Arizona. The Western No. 1 Federal has a recorded show in the Muav Limestone; no other wells in the northwest section penetrate the Cambrian.

The 2,000-2,500 foot section of principally marine strata between the top of the Cambrian and the base of the Supai clastics constitutes an overall objective that has not been sufficiently tested in northwestern Arizona.

The Permian sequence and history has been reviewed by Bissell (1969). In the central Grand Canyon region the Supai Formation is overlain by the Hermit Formation, and together they aggregate 1,300 feet. The Hermit Formation, consisting of redbed clastics, thickens to the northwest where the Supai Formation becomes, principally, a light-colored sandstone called the Queantoweap Formation. In wells the Queantoweap and Hermit sequence is similar in thickness to the Supai-Hermit sequence in the Grand Canyon to the southeast. The Queantoweap is viewed as representing a depositional environment at a continental-marine interface so that it may be a mixture of marine and non-marine units. Both the Queantoweap and the Hermit have recorded oil shows. Although the Hermit is not usually considered as an environment conducive to the generation of oil it might well have been, at least locally, in the path of migrating hydrocarbon materials. If so, trapping conditions are more important considerations than those concerning where the oil, gas, or helium originally was. Indeed, this problem of preservation, as mentioned earlier, is the principal unsatisfied question regarding northwest Arizona potential.

The Coconino Sandstone overlies the Hermit Formation and thins northward from 300 feet thick in the Grand Canyon to extinction before reaching Utah. Its presence in the subsurface constitutes a relatively thin zone of permeability. Trapping conditions might exist in connection with the overlying units of the Toroweap Formation if some act as impermeable caps.

The overlying Toroweap and Kaibab formations are credited with a number of shows in northwestern Arizona but the question of preservation of oil, gas, and helium in large quantities in these shallower zones is significant. The top of the Kaibab is buried most deeply in the George No. 1 Federal in T.40 N., R.6 W., where it is 2,000 feet below the surface. Eighteen miles to the south it is at the surface and a similar distance to the southeast the entire Kaibab-Toroweap interval is exposed in Kanab Canyon. In the northern part of the region the interval is approximately 1,000 feet thick with about 500 feet being assigned to each formation. Both units contain evaporites in the form of anhydrite beds and thick carbonate sequences containing fossiliferous and cherty dolomites and limestones.

The Permian-Triassic boundary zone is productive in southern Utah in two fields. The Virgin Field is 15 miles north of the Utah border just east of the Hurricane Cliffs and the Upper Valley Field in the Kaiparowits basin, is about 45 miles north of the border above Lees Ferry. Whereas the Permian-Triassic boundary zone is about 500 feet in depth at the Virgin Field, it is nearer 7,000 feet deep at the Upper Valley Field (Campbell, 1969). Dolomites of the Kaibab Formation and the Timpoweap Member of the Moenkopi Formation constitute the reservoir rocks.

West of the Kaibab plateau elongate northwest, north and northeast trending fault systems are more conspicuous than the elongated fold systems so well developed in the Black Mesa basin region to the east. Gentle folding is present and complex movements associated with the fracture systems have also produced folds of various types. The Plateau rocks dip, regionally, 2 to 5 degrees towards the east and northeast (Moore, 1958). Vertical movements on the major faults tend to drop the west sides. Faulting history and pattern is not simple and considerable discussion continues to take place on this subject.

Northwest Arizona does not lack valid drilling objectives. However, as has been emphasized, the structural and erosional history may have resulted in the fragmentation and dispersal of once existent large accumulations of hydrocarbon materials. If this has occurred then the important task is to recognize circumstances that might afford relatively local trapping conditions. In particular, northwest Arizona needs additional effort to test pre-Permian objectives at depths ranging from 3,000 to approximately 6,000 feet along a belt in Arizona within 25 miles of the Utah border.

VERDE VALLEY

Since 1963 a flurry of drilling activity has resulted in the spudding of 18 exploration tests in the Oak Creek-Verde Valley area. Because of this activity a brief geologic discussion is provided.

Although all tests are "dry" holes, claims of oil shows have been made that, to this point, have not been successfully authenticated. One factor in attracting initial drilling attention is that the local geologic setting places lower Paleozoic objectives within 1,500 feet of the surface.

The Verde Valley-Oak Creek region is a triangular shaped area in central Arizona that is largely in Yavapai County but which includes small portions of southern Coconino County to the north and east (Plate 2). The sides of the triangle are formed by topographically higher country: the northwest trending Black Hills to the southwest, the nearly east-west trending Mogollon Rim to the north, and a north-south trending belt of volcanics to the east. The basin thus circumscribed combines geologic aspects of both the Basin and Range and the Colorado Plateau provinces. Cenozoic geologic history is largely responsible for the present topographic and structural setting.

Major contributors to geologic understanding of this interesting region include Twenter and Metzger (1963), Lehner (1958, 1962), Anderson and Creasey (1958), and Teichert (1965).

The central portion of the basin region is occupied by Cenozoic sedimentary deposits of the Verde Formation. To the north these deposits wedge against older rocks including the Paleozoic Supai Formation which spreads out to the south below the steep 1,000 to 2,000 foot high cliffs of the serrate Mogollon Rim. Much of the drilling that has been done was initiated from this Supai surface. Supai strata are gently folded and have been offset by normal faults; the two principal fault systems are the north-south Oak Creek fault and the arcuate, concave towards the southwest, Cathedral Rock fault. Along the Oak Creek fault, strata to the east have been down dropped about 400 to 700 feet (Plate 9). Along the Cathedral Rock fault to the southwest, the strata on the southwest side have been downthrown on the order of 250–800 feet (Twenter and Metzger, 1963, p. 64, 65). Near the faults there are local areas where strata are more steeply dipping. In two areas, one along the Oak Creek fault and one along the Cathedral Rock fault, the top of the underlying Mississippian Redwall Limestone is structurally high enough to be locally truncated along the modern creek beds of Oak Creek and Dry Creek.

Formational nomenclature commonly used in the southern Plateau is included in Table F. Regarding petroleum potential, the remaining section of lower Paleozoic sedimentary rocks, which includes strata representative of the Cambrian, Devonian, and Mississippian periods, is of principal interest. Until the recent exploration activity, the only available knowledge concerning this stratigraphy was that gained from outcrop study in the vicinity of Jerome some 10 to 18 miles to the southwest of the general drilling area. Jerome is in the Black Hills, a block that has been uplifted, relative to the adjacent Verde Valley, along the Verde fault system. Whereas the base of the Paleozoic system in the Black Hills is variable but is generally above 6,000 feet, well data show that the same base is at about 2,800 feet in T. 17 N., R. 5 E., Sec. 34, about three miles south of the Cathedral Rock fault. Much of this structural difference can be accounted for by movement on the Verde fault.

Briefly, the lower Paleozoics in the vicinity of Jerome are characterized by a basal, dark colored, coarse-grained, sometimes conglomeratic sandstone, and overlying carbonates of Devonian and Mississippian age. Even though the basal sandstone remains undated, some workers are willing to accept that it is probably representative of the Tapeats Sandstone of the Grand Canyon region and is, therefore, Cambrian in age. The sandstone is variable in thickness but is generally about 70 feet thick. Between it and a conformable sequence of carbonate rocks of the Martin Formation is a relatively thin zone of undated, light-colored siltstones.

The Martin Formation has been rather extensively studied in outcrop by Teichert (1965). It seems likely that the principal drilling objective of the exploration effort around the Oak Creek-Verde Valley area is contained within the basal portion of this formation. The Martin Formation approximates 500 feet in thickness both in outcrop and in the subsurface to the north.

The widespread occurrence of a vuggy, odorous, dolomite unit at or near the base of the Martin Formation is well known to many geologists. Teichert (1965, p. 29) calls this zone the "fetid dolomite" unit, stating that it varies between 20 and 55 feet thick in outcrop within the general vicinity of Jerome. Teichert (1965, p. 30) states: "In many places, the upper few feet of the unit consists of highly porous dolomite. Rock of this type is generally not well laminated, although some rocks combine distinct lamination with porosity. In some rocks the pores, or vugs, are filled with white crystalline calcite." Also, regarding organic matter that can be observed microscopically, Teichert (1965, p. 32) says: "The marine organisms from which the organic matter in the rock is derived may have been algae or diatoms that lived in the mud or plankton that was killed off periodically through toxic conditions arising in the shallow waters covering the mud," and . . . "The distribution of the unit spans the entire area of investigation; the unit extends over a length of 150 miles and a width of as much as 50 miles." The fetid dolomite unit is overlain by densely crystalline, nonporous dolomites of Teichert's "aphanitic dolomite" unit, which also is widespread in occurrence.

In the Jerome region the Devonian Martin Formation is overlain by about 275 feet of generally coarse crystalline limestones of the Redwall Limestone. Elsewhere in the region, a conglomeratic zone is sometimes present at this contact, a zone that can contribute to circulation problems while drilling. To the northeast, in the area of recent exploration activity, drill data indicate that the Redwall is noticeably thinner and ranges in thickness between 135 and 190 feet. The reason for this apparent thinning is not known. As with the basal contact of the Redwall Limestone, its upper contact is frequently marked by a conglomerate belonging to the overlying Pennsylvanian sediments of either the Naco Formation or the basal Supai Formation. The Redwall Limestone is frequently rubbly in nature near this upper contact, a reflection of solution activity prior to the overlap by Pennsylvanian sediments. This zone, too, is a frequent cause of circulation problems. The thinning of the Redwall Limestone might be due to destruction at the top, but local exposure of the contact along Dry Creek does not support this view. Thinning might also be due to non-deposition, but there is insufficient data to make a final judgment as to the cause of thinning.

Although 18 holes have been spudded since 1963 only 11 are generally known to have reached Precambrian basement rock, which, as in the Jerome region, can consist of either coarsely crystalline granite or more finely crystalline darker rocks of probable metamorphic affinities. Of these 11 only 7 appear to have sufficient records for determination of formational thicknesses. Table 5 is a brief record of the stratigraphic highlights of the 11 holes known to have reached the Precambrian basement.

As already stated, the Martin Formation appears to maintain a subsurface thickness very similar to that in outcrop near Jerome where the fetid dolomite unit is well developed. At the present time the extent of development of this unit in the subsurface is not known. Although examination of well cuttings provides qualitative indication of the presence of some porosity and fetidness in the dolomites of the basal zone of the Martin Formation, quantitative data are lacking. As far as is known, the zone of possible interest has not been cored.

Consideration of the exploration potential of the Oak Creek-Verde Valley region must take into account several known factors that bear

Table 5. — Paleozoic rocks in selected Verde Valley oil tests.

Well	Location	County	Elev.	TD	Status	Tops	Thick-nesses
Hopkins Fed 28-1	SENE 28 18N 5E	Yav.	?	1308	Aband.	Redwall 648 Martin 798 Tapeats 1292 Precamb 1306	150 494
Hopkins Fed 34-2	NENW 34 18N 5E	Yav.	4400	1217	Aband.	Redwall 504 Martin 662 Tapeats 1167 Precamb 1215	158 505
Hopkins Fed 34 1X	SWNW 34 18N 5E	Yav.	4375	1138	Aband.	Redwall 479 Martin 630 Tapeats 1135 Precamb 1137	151 505
Hopkins-Coconino Cattle No. 1	NW 8 17N 5E	Yav.	4400	1195	Aband.	Redwall 512 Martin 696 Tapeats 1120 Precamb 1193	184 424
Harless Fed No. 1	SWNW 4 17N 4E	Yav.	4412	1762?	Aband.	Redwall 503 Martin 655 Tapeats 1160 Precamb 1203	152 505
Yucca Pet. Crary 1 Fee	NESW 5 17N 4E	Yav.	4386KB	1661	Aband.	Redwall 644 Martin ? Precamb ?	
Hopkins No. 1 Hallermund	SESE 31 17N 5E	Yav.	4575KB	1215	Aband.	Redwall 530 Martin 669 Tapeats 1165 Precamb 1212	139 496
Hopkins No. 1 Frye	SWNW 34 17N 5E	Yav.	4000	1405	Aband.	Redwall 582 Martin 753 B. Pal. 1232 Precamb 1273	171 479
Hopkins-Jordan No. 1	SESE 6 17N 6E	Coco.	?	1254	Aband.	Circulation problems Precamb 1220	

upon the existence of possible source and reservoir rocks, and the preservation of economic quantities of oil, gas, or helium at relatively shallow depths.

Regarding source and reservoir rocks, it is suggested that the fetid dolomite unit can, if properly developed, serve as both. Basal Paleozoic sandstones, if porous and permeable, can also serve as reservoirs in juxtaposition with possible overlying source rocks. The aphanitic dolomite unit, if not severely fractured, tends to act as an impermeable barrier above the fetid dolomite zone.

Regarding preservation aspects, the Oak Creek-Verde Valley region has had a complex geologic history that includes the probability of two episodes of gentle regional tilting in a northerly direction, gentle folding of undetermined age but probably prefaulting, and more than one period of Cenozoic disturbance that includes both volcanism and normal faulting, the faulting tending to form blocks that step down toward the axis of the Verde Valley.

Any disturbance that tends to rearrange the geometry of rocks must also tend to adjust the distribution of contained fluids, and these fluid adjustments can result in tendencies to either concentrate or disperse. Any adjustment that tends to allow ground water to circulate freely also tends to expose previously existing accumulations of hydrocarbons or helium to possible dispersement. Pressure balances dictate the prevailing condition, what ever it might be.

The basal portion of the Supai Formation gives up water to wells in the Oak Creek area, and the underlying Redwall Limestone can carry water in solution cavities and channels.

The question to be asked is whether or not any possible accumulations of the commodities in question occurred in response to regional tilting and gentle folding. If so, have any of them been maintained through subsequent disruptive periods of volcanism, faulting, and associated adjustments in ground water movement?

This question will not be similarly evaluated by all. Even though the region may be thought to be marginal in character, careful study with attention to available details could lead to the development of additional shallow drilling prospects that might prove to be better tests of the region than some that have already been drilled.

BASIN AND RANGE

A general summary of the nature and geologic history of the Basin and Range province is given in Figures 1 and 3 and the practical problems to explorationists briefly have been mentioned. The province constitutes over one half of Arizona. However, only limited portions within it are thought to have a reasonable potential for the production of oil, gas, and helium; therefore these areas are given the most attention.

Available records indicate that 121 tests have been made in the province and that 78 bottomed in probable Cenozoic rocks, 10 in possible Cretaceous strata, 7 in Paleozoic rocks, 5 in possible Precambrian rocks, and 21 are not known. The deepest hole is the Arizona Oil and Gas No. 1 State. It was drilled in 1958 to 7,580 feet in T. 14 S., R. 30 E., Sec. 36, Cochise County, bottoming in probable Cenozoic gravelly deposits. The hole was drilled within three miles of outcropping Cretaceous and Paleozoic strata. A local high point on the Paleozoic outcrop is at 6,000 feet, a point 13,580 feet higher than the bottom of the hole. This symbolizes the importance of the structural history within the Basin and Range province. It is to be emphasized that because of a complex geologic history the province is an "exotic" region in which to search for oil, gas, and helium. It is, though more complex, similar to northwestern Arizona in that available data indicate that sufficient marine sedimentary rocks were deposited, at least locally, so that the exploration question is not so much where oil once was as where it might be now.

The regions that attract the attention of serious explorationists are those with a known record of marine sedimentation. Although the geologic record in the province has been shattered, fragmentary data are preserved in mountain ranges and flanking zones. There is evidence for marine deposition in parts of the province during Precambrian, Paleozoic, Mesozoic, and Cenozoic time.

Cenozoic marine to brackish water conditions prevailed in southeastern California and southwestern Arizona. Such deposits have not been productive in Arizona. However, their nature and distribution in the subsurface is largely unknown. McCarthy (1961) has reported on the oil and gas possibilities in southwestern Arizona.

Mesozoic marine deposits are believed to be largely limited to portions of Cretaceous strata preserved in southeastern Arizona. Outcrop studies have been made by several workers but subsurface data are scarce. However, marine Cretaceous rocks do constitute an objective in Cochise County.

The distribution of Paleozoic sedimentary rocks is fragmentary. They crop out extensively in the mountain ranges of Cochise and eastern Pima and Santa Cruz counties (see Arizona Bureau of Mines County geologic map series). Elsewhere, they occur only fleetingly and in such a manner as to offer little encouragement to explore adjacent valleys. Because of the surface indications of a thick sequence of marine Paleozoic and Cretaceous rocks, southeastern Arizona, especially Cochise County, is currently attracting the attention of major oil companies. Much of the San Simon and Sulphur Spring valleys are under lease in response to exploration activity being conducted in adjacent New Mexico and northwest Chihuahua, Mexico.

Geologic studies pertaining to southeastern Arizona are numerous and varied. Because of the structural complexities of the region only stratigraphic studies tend to be regional in scope. The most comprehensive and varied coverage is to be found in three guidebooks of southeastern Arizona published in 1952, 1959, and 1968 (Arizona Geol. Soc., 1952; Heindl, 1959; Titley, 1968), by the Arizona Geological Society, P.O. Box 4489, Tucson, Arizona 85717. Only the 1968 volume remains in print. In addition, the Arizona Geological Society has issued eight volumes of its Digest, which is printed on an irregular basis and contains items pertinent to Arizona geology. Several U.S. Geological Survey publications are basic references including: Gilluly (1956), Gilluly, Cooper, and Williams (1954), Hayes and Landis (1961, 1965), Ransome (1904), and Schrader (1915). Theses of interest include: Bryant (1955), Butler

(1969), Dirks (1966), Havenor (1958), LeMone (1959), McClymonds (1957), Schafroth (1965), Tyrrell (1957), Weber (1950), Wilt (1969), and Wright (1964). Other important contributions include: Darton (1925), Epis and Gilbert (1957), Feth (1948), Hernon (1935), Jones (1963, 1966), Jones and Bacheller (1953), Kottlowski (1960), Lutton (1958), McKee (1951), Sabins (1957 a & b), Stoyanow (1936), Turner (1962), and Wilson (1962). Additional references may be found in Moore and Wilson (1965) and in the references cited in the above items.

A casual examination of the geologic map of Cochise County and adjacent area to the west reveals the following generalities: (1) over half of the surface area is valley, the valleys being elongated in a northwest to just west of north direction; (2) there are three major valleys, from west to east (a) the San Pedro, (b) the Sulphur Spring, and (c) San Simon; (3) the mountainous areas form disconnected chains that tend to parallel the valleys; (4) there are four such chains containing about thirteen mountain links; (5) the valleys pinch and swell; (6) the individual mountains in the chains are elongated in the same sense as the valleys; (7) mountain blocks often contain a parallel fault system that strikes parallel to the elongation of the mountains; (8) the ends of mountain blocks and their contained trends are often truncated by irregular valley margins thus inviting cautious projections into the valleys; (9) outcrops range in age from Precambrian to Cenozoic and include scattered plutons, volcanics, metamorphics, and sedimentary rocks, all of which can occur in one range of mountains; (10) Paleozoic and Cretaceous sedimentary rocks tend to strike parallel to the direction of mountain elongation (northwest); (11) some mountains preserve an orderly, tilted, continuous stratigraphic sequence while others are slivered up; (12) one chain that separates the San Pedro valley from the Sulphur Spring Valley contains the principal exposed granitic plutons and the principal mining camps of Cochise County: (a) Bisbee, (b) Tombstone, (c) Courtland-Gleason, and (d) Johnson Camp; and (13) the edges of mountain blocks in contact with adjacent valleys in the southern three-fourths of Cochise County consist largely of Paleozoic or younger rocks thus holding out hope that Paleozoic and Cretaceous objectives might somewhere be present in the adjacent valleys.

The geology that crops out in the individual mountain links forms the basis for a recapitulation of geologic history. However, the structural history is sufficiently complex as to cause disparity among workers even as to such basic fundamentals as whether compressional or tensional forces have dominated the scene. According to Jones (1966), it is a "forest and trees" problem.

To what extent can the geology of individual mountain ranges be used to speculate as to the all-important geologic setting within the adjacent valleys? Can it logically be assumed that subsurface patterns will be analogous to those expressed on the surface? Assuming objectives occur in the valleys, are they likely to be within economic reach of the drill bit? Considering the limitations of present geologic understanding questions like the foregoing cannot be treated without equivocation. In the end it is likely that deep probes into the valleys of southeastern Arizona will be required just to establish whether or not rocks of interest are preserved beneath valley surfaces.

Surface geologic studies indicate that at least 6,000 feet of largely marine Paleozoic sedimentary rocks was deposited in southeastern Arizona. This sedimentary section is thicker than the Paleozoic section that accumulated in the Plateau province of northern Arizona. Two-thirds or approximately 4,000 feet of the section in southeast Arizona is assigned to the Pennsylvanian-Permian time interval. The remaining one-third, or approximately 2,000 feet, is distributed almost equally between the Cambrian and the combined Devonian-Mississippian periods.

Pye (1959) summarizes marine sedimentation in southern Arizona and Bryant (1968) discusses the highlights of the Paleozoic formations of southeastern Arizona. Table 6 is a brief summary of these formations. Details may be obtained from numerous references, but Wilson (1962) is especially helpful in providing a general summation and also by providing references to papers dealing with specific formations in specific mountain ranges. Also, Bryant briefly describes the locations of accessible localities where various formations can be examined; sketch maps to localities are included.

Mesozoic rocks of southeastern Arizona recently have been reviewed by Hayes and Drewes (1968) and by Hayes (1970). The following brief summary is taken from these reports.

Mesozoic rocks, including volcanic and sedimentary types, aggregate approximately 40,000 feet. Included are rhyolitic to andesitic volcanics, and sedimentary rocks principally of non-marine origin. However, important marine elements are present. Intrusive activity took place in Triassic, Jurassic, and Late Cretaceous time.

Triassic-Jurassic rocks consist largely of volcanics and related sedimentary types that, composited, are on the order of 17,000 feet thick. This group of rocks is concentrated largely in western Cochise County in the Huachuca, Whetstone, and Santa Rita mountains, and the Canelo Hills. A widespread unconformity separates the group from underlying Paleozoic carbonate rocks. The Permian Rainvalley Formation is the highest Paleozoic unit preserved beneath the unconformity. However, Precambrian granitic rocks are represented in conglomerates suggesting that considerable structural activity took place in the time represented by the unconformity.

Jurassic intrusive activity was followed by uplift and erosion which produced the Jurassic-Cretaceous unconformity. Lower Cretaceous rocks rest on Jurassic granite in the Santa Rita, Patagonia, Huachuca, Dragoon,

Table 6. — Paleozoic Formations of Southeast Arizona
(Basic Data from Bryant, 1968)

PERMIAN	
Rainvalley Formation (500) (early Guadalupe)	Gray, brown, red, black limestone and dolomite with some sandstone and siltstone.
Concha Limestone (500) (late Leonard to early Guadalupe?)	Cherty, fossiliferous, medium- to dark-gray limestone; cliff former.
Scherrer Formation (650) (L. to Mid. Leonard)	Brown to white sandstone, red siltstone, some limestone and dolomite. Thins to east.
Epitaph Formation (900) (L. Leonard)	Dolomite, gypsum, red to maroon clastics. Thickens to east.
Colina Limestone (200–600) (Wolfcamp to Leonard)	Dark-gray to black limestone. Top indefinite.
PENNSYLVANIAN–PERMIAN	
Earp Formation (600–1000+) (Virgil & Wolfcamp)	Variable sandstones, siltstone, shales & carbonates. Red chert pebble conglomerate a distinct marker.
PENNSYLVANIAN	
Horquilla Limestone (600–1600) (Derry?–Missourian)	Light- to dark-gray, cherty limestone and mudstones.
Black Prince Limestone (120–280) (L. Pennsylvanian)	Light-gray limestone; basal red shale w/chert fragments.
MISSISSIPPIAN	
Paradise Formation (150) (Meramec–Chester)	Eastern Area only — yellow-brown weathering dark limestone and shale.
Escabrosa Limestone (600–750) (Kinderhook–Meramec)	Light-gray to white, coarse-grained crinoidal limestone.
DEVONIAN	
Martin Formation (300–450)	Yellowish-brown weathering, gray limestone, dolomite, and shale. Dark clastics to east.
CAMBRIAN–ORDOVICIAN	
El Paso Limestone (450–700)	Similar to Abrigo; eastern area only.
CAMBRIAN	
Abrigo Formation (600–800) (Mid. & Late Cambrian)	Heterogeneous thin-bedded limestones, dolomites, & siliceous clastics.
Bolsa Quartzite (400–700) (Mid. to Late Cambrian)	Brown, reddish-brown, white, cross-stratified, conglomeratic, feldspathic, quartzite.

and Mule mountains. That local uplifts and probable faulting occurred during middle Jurassic and earliest Cretaceous time is indicated by the variety of clasts present in the Cretaceous sedimentary rocks. Lower Cretaceous rocks also include volcanics. In the Santa Rita Mountains the volcanic bearing sequence is about 4,000 feet thick.

Elsewhere in southeastern Arizona, Lower Cretaceous rocks, up to 10,000 feet thick, are represented by the Bisbee Group consisting of, from the base upwards, the Glance Conglomerate, Morita Formation, Mural Limestone, and the Cintura Formation. Strata of these formations are largely clastic types believed to have been deposited in a large delta complex on the margin of a sea that existed to the southeast into Mexico. The Mural Limestone is a fossiliferous marine unit. The proportion of marine rocks apparently increases to the southeast.

The Mural Limestone, ranging in thickness between 300–800 feet, is divided into two members. The lower half consists of calcareous mudstones, impure fossiliferous limestone, and calcareous siltstones and sandstones. The upper half consists of thick beds of gray limestone. In the Mule Mountains, adjacent to the Sulphur Spring Valley, the upper member is mostly medium dark gray on fresh fracture and "yields a strongly fetid odor" when freshly broken (Hayes, 1970, p. A19). Thick reefoid lenses are locally present in which rudistids are abundant.

In the Pedregosa and southern Chiricahua mountains the Bisbee Group is about 8,000 feet thick. Apparently, significant marine units are not present in the Dragoon, Little Dragoon, and Dos Cabezas mountains in west central Cochise County.

An unconformity representing uplift and erosion separates the Bisbee Group from Upper Cretaceous sedimentary rocks. Regionally, Upper Cretaceous rocks rest on rocks ranging in age from Lower Cretaceous to Precambrian.

Upper Cretaceous rocks are divided into a lower sedimentary sequence and an upper volcanic sequence. The sedimentary rocks, though thick, are not as widely distributed as are Lower Cretaceous rocks and the Upper Cretaceous volcanics.

The Upper Cretaceous sedimentary rocks have not been formally named in all localities but the best known sequence occurs on the east side of the Santa Rita Mountains where they are included in the Ft. Crittenden Formation, a series of conglomerates, sandstones, siltstones and shales of fresh-water origin in excess of 6,000 feet thick. Similar rocks are present in the Huachuca Mountains, Canelo Hills, and a 4,000 foot sequence of conglomerates in the Pedregosa and Chiricahua mountains is probably equivalent. The Ft. Crittenden and equivalent rocks are viewed as having been deposited in subaerial valleys cut on the Bisbee Formation and older rocks after the initial phases of the Laramide orogeny.

The Upper Cretaceous volcanics, consisting of andesite to dacite breccia, tuff and welded tuff, have a combined thickness of about 4,500 feet. These rocks are extensively recognized and include volcanics formerly considered to be Tertiary in age.

The Mesozoic Era ended with the intrusion of plutonic rocks such as diorite, granodiorite, and some quartz monzonite. Additional plutonism followed in the Tertiary with which important mineralization was associated.

Schafroth (1968) provides recent additional discussion of Cretaceous stratigraphy of southeastern Arizona.

A concise summary of Cenozoic geologic history is provided by Cooley (1967) in text material that accompanies the Arizona Highway Geologic Map published by the Arizona Geological Society. The Cenozoic rock sequence consists largely of igneous rocks in its early part and a complex of sedimentary and volcanic rocks during its later part. The last major adjustment to the positions of mountains and valleys took place during the Basin and Range orogeny in Mid-Tertiary time. Erosion and valley filling by non-marine sediments has continued to the present. However, most valleys are now joined to the Colorado River drainage system but some contain basins of internal drainage and are still accumulating sediments. Valley filling has not necessarily been dominated by the accumulation of coarse-grained sediments. Drilling data suggest the importance of lacustrine conditions in which considerable thicknesses of clays, gypsum, and halite were deposited in basin centers whereas the coarser types accumulated closer to existing highlands.

The geologic history of southeastern Arizona indicates that Paleozoic seas persisted and were sites of deposition for thousands of feet of fossiliferous carbonates and shales. However, subsequent history includes about six episodes of faulting and igneous activity in which differential uplift and erosion have removed, at least locally, all Paleozoic rocks. The reconstruction through time of the positions of uplifts is not possible because over half of the region is beyond view beneath the valleys. The lesson seems to be that a particular outcropping geographic locality reflects repeated large magnitude up and down adjustments, and it may be that the valley areas have undergone similar adjustments. Because outcropping Paleozoic marine sedimentary rocks occur in deformed strips and patches it is possible that they can similarly occur in the valleys. It also seems likely that the complex post-Paleozoic geologic history has tended to minimize the probability that large quantities of Paleozoic oil, gas, or helium remain in Paleozoic rocks. The conditions would appear to favor dispersal and suggest that preservation is to be sought in younger rocks, even igneous types. Thermal and fracturing history could prove to be both creative and destructive depending upon the severity of conditions. If any of these commodities remain in southeastern Arizona it seems probable that they exist in such a wide range of trapping and reservoir conditions that prediction as to type and place would be rendered difficult, if not impossible. One approach would be to consider the possibility of accumulation in Tertiary rocks beneath impermeable caps formed by lacustrine deposits. Most of the "shows" reported in Cochise County are from Tertiary rocks but this is because most of the holes are interpreted as not having penetrated deeper horizons. Unsubstantiated shows such as these are difficult to deal with, so they may or may not be significant.

Of the 41 oil and gas tests on record as having been drilled in Cochise County, 26 are believed to have bottomed in Tertiary rocks, 4 in questionable Cretaceous, 7 in Paleozoic strata, 1 in Precambrian, and 3 are unknown. All of the tests that bottom in Paleozoic rocks were drilled immediately adjacent to or on outcropping Paleozoics. In Sulphur Spring Valley the Waddell-Duncan No. 1 Murray test in T.22S., R.27E., Sec. 5, was drilled to 4,210 feet bottoming in granite after cutting 2,400 feet of Paleozoics. Pennsylvanian rocks were entered beneath 1,600 feet of undifferentiated "valley fill." Mississipian, Devonian and Cambrian rocks were also cut. The test was spudded about 3 miles west of outcropping rhyolitic volcanics and 6 miles southwest of the nearest Paleozoic outcrop in the Swisshelm Mountains. Apparently the nearby volcanics were not encountered. Available logs indicate that red brown arkosic clastics were encountered 500 feet beneath surficial coarse gravels. Perhaps the darker clastics are a part of the Cretaceous sequence, the remnant being about 1,000 feet thick.

About 8 miles farther to the west the Moncrief No. 1 Davis was drilled to a depth of 5,450 feet and bottomed in volcanics of probable Tertiary age. This test is also 7 miles east of outcropping Bisbee Group Cretaceous rocks on the northeast dipping northeast flank of the Mule Mountains. It seems obvious that the Moncrief hole is several thousand feet structurally lower than the Waddell test. There are about 3,600 feet of probable post-mid-Tertiary fine-grained clastics and gypsum above the volcanics.

Even though the Waddell test is in the Sulphur Spring Valley it seems possible to consider that it is actually, structurally speaking, more allied to a mountain block than a basin block whereas the Moncrief test is in a basin block. It is interesting to note that the faulting alignment and general trend of the Dragoon Mountains to the northwest projects to the southeast between these two holes suggesting that structural trends might be usefully projected into valleys where they are truncated or cut off by valleys.

Jones (1966) dissents from the commonly held concept that Laramide orogeny was dominated by severe compression and major overthrusting. He argues "that most of the local compressional effects originated from uplift of granites, high angle faulting, diapiric action, intrusion, and gravity sliding, and not from a major regional compressive stress system developed in the upper crust." Jones thinks that most of the ranges were originally well defiined by vertical movements during either the Nevadan or Laramide orogenies and are not simply a new development of a Basin and Range orogeny.

The implication in this line of reasoning seems to be that the mountain positions as now seen represent trends of repeated activity and, though not so stated, the valleys are something quite alien in that they may not have undergone the disruptions observed in the mountain blocks. Perhaps the rocks in the valleys have not been subjected to the intense plutonism and fragmenting history that is observed in outcrop. However, the Basin and Range structural event did produce differential uplift or subsidence even though the activity may have been superimposed upon previously existing trends and tendencies.

Whatever the geologic history, the valleys of southeastern Arizona will remain a mystery until new drilling brings additional valuable information to light.

SUMMARY AND CONCLUSIONS

Arizona is divided into two unlike parts: the Plateau province to the northeast and the Basin and Range province to the southwest. Past and present oil, gas, and helium production, and known reserves, are confined to the Plateau portion of the State.

Sixty-two wells, all in Apache County, have a production record for either oil, natural gas, or helium. Approximately 9.3 million barrels of oil has been produced since oil was first discovered in northeastern Arizona in 1954; 5.5 billion cubic feet of helium has been produced since 1956; and 8.5 billion cubic feet of natural gas has been produced and utilized since 1954.

The Plateau province, embracing Mohave, Coconino, Navajo, and Apache counties, has hardly been drilled. Initial oil and gas discoveries on the Navajo Indian Reservation in the Four Corners area have encouraged continuous exploration activity in that limited region. Thirteen years after the initial discovery of oil, and 30 miles to the south, the Kerr-McGee Corporation discovered Arizona's most prolific and unique oil field, Dineh-bi-Keyah, in the Chuska Mountains. Since discovery in 1967, through 1969, the field has produced 8.3 million barrels of oil or 89 percent of the total oil production credited to the State. The reservoir is a porous igneous rock of Tertiary age that was intruded into Pennsylvanian marine strata as a sill.

With the exception of the 20 wells that have produced oil in the Dineh-bi-Keyah Field, principally in T. 36 N., there are 20 additional wells with a record of oil or gas production but none is south of T. 40 N. Of the latter 20, fifteen have produced from Pennsylvanian reservoirs, 4 from a Mississippian reservoir, and 1 from Devonian strata (McCracken sandstone). Zones of porous marine carbonates of Pennsylvanian age have been the principal drilling targets in the Four Corners but they are associated with a geologic condition that is limited to only a small portion of northeastern Arizona.

In Arizona there are no recognized geologic trends for explorationists to follow that lead away from the immediate Four Corners producing region. As a consequence, with the exception of the helium producing area, the remainder of the State can be classed as rank wildcat country. The drilling rate in Arizona away from the Four Corners region is low, which suggests that the industry is awaiting some form of encouragement to look further. Because so much of Arizona is untested there are large gaps in knowledge concerning important geologic details. Under these circumstances encouragement to take a closer look can come only from a favorable assessment of one or more of the broader aspects of the geologic framework.

Away from the Four Corners, Paleozoic marine rocks are best developed in Devonian and Mississippian strata that underlie an extensive area of the Black Mesa basin region. The exploration problem is to understand the structural genesis of the basin and the nature, distribution, and influence on sedimentation of paleogeographic features that are hidden in the subsurface.

The Black Mesa basin is manifested by an extensively developed northeast dipping structural slope of pre-Upper Cretaceous age and younger uplifts of probable Laramide age. These structures are superimposed upon paleogeographic features that have had some influence on all Paleozoic strata. The geologic setting encourages the development of lengthy stratigraphic trends as well as lengthy belts of subsequent structural disturbance. The more promising areas for exploration may be those zones where the large subsequent structures are superimposed over subsurface stratigraphic trends.

The zone of wedge out of Devonian and Mississippian strata against the Defiance positive is included in parts of both the west flank of the younger Defiance uplift and the northeast dipping Mogollon slope. The zone outlined by these conditions is untested over thousands of square miles in central Navajo and Apache counties.

In Coconino County, between western Black Mesa and the Colorado River, the thinning of Devonian strata against the Kaibab positive tendency is partially within the structural rise of the west flank of the Black Mesa basin. This setting is also conducive to the existence of a combination of lengthy structural and stratigraphic trends that are untested over a vast region.

Exploration opportunities have not been exhausted in the Mogollon slope region. Although much exploration effort has been expended in the vicinity of the Holbrook "anticline" there is reason to question the subsurface extent of the anticlinal aspect. Of much greater potential significance is the structural condition imposed by subsidence associated with the development of upper Supai evaporites. It is suggested that the Ft. Apache Member and all older Paleozoic strata are deflected downward on the order of 600–700 feet along a narrow zone parallel to but southwest of the Holbrook "anticline." The zone may have stratigraphic importance in that a Ft. Apache Member dolomitization and porosity trend may be associated with the edge of the saline basin. Numerous dark dolomitic zones are interbedded with the evaporites and may constitute some potential in zones of structure. Devonian strata are apparently preserved in northwest trending narrow troughs, one of which partly underlies the subsidence zone mentioned above.

Helium occurs at the north end of the Defiance uplift in Devonian and Mississippian strata, but its principal occurrence is at the south end in the Permian Coconino Sandstone. Helium is believed to have been derived from Precambrian granitic rocks of the Defiance positive mass. These data suggest that the entire west flank of the Defiance uplift is a likely helium exploration province, one that is untested. If the Pinta-Navajo Springs helium has moved laterally from beneath the Black Mesa basin, additional concentrations may occur to the north and northwest, providing trapping conditions, stratigraphic or structural, are present.

The area around the so-called Mormon Mountain anticline in southeastern Coconino County appears to warrant attention. Limited drill data suggest the likely presence of a well developed Devonian section. In addition, Pennsylvanian strata thin into this region from the east. There is little known porosity development to the east but sands in the Oak Creek Canyon section suggest the possible development of sandstone porosities in the Mormon Mountain area.

The lower Paleozoics are targets beneath the relatively untested Coconino plateau south of the Grand Canyon. Devonian strata thin onto the Kaibab positive tendency and Mississippian rocks thicken to the northwest.

Several tests have been drilled in northwestern Arizona, but few have tested the lower Paleozoic section near the Utah border away from the Grand Canyon and the extensive fracture system that is associated with the western edge of the Plateau.

There is some shallow drilling potential beneath the Mogollon Rim in the Verde Valley and the Ft. Apache Indian Reservation. The latter contains an interesting stratigraphic section but more study needs to be made of the structural setting as regards possible trapping mechanisms.

Little is known of the stratigraphic conditions beneath the White Mountain volcanic field. However, projections suggest the presence of significant stratigraphic and structural conditions, especially in regard to lower Paleozoic and Pennsylvanian strata and their relationship to the Defiance positive.

The Basin and Range province has yet to attract much serious drilling. The nature of the preserved stratigraphic record beneath the valley surfaces is largely unknown. Marine Paleozoic rocks are preserved in the mountain blocks of southeastern Arizona, therefore they may be preserved beneath the intervening valleys. Both their actual presence and structural condition will have to be tested by drilling. Paleozoic rocks may have at one time contained oil and gas. However, considering the complex geologic history to which such materials have been subjected, it seems possible that any porous rock, including igneous rocks, could constitute a reservoir for migratory fluids, especially beneath impervious lake deposits. Cretaceous marine strata constitute a relatively local objective.

Arizona has an oil, gas and helium potential that is largely untested. There are extensive regions of favorable country in the Plateau region within which to search for detailed prospects. Much of the potential is likely to be stratigraphic in nature such that random drilling on an isolated anticline may not prove to be a conclusive test. The overall geologic setting is sufficiently complex to require a careful examination of the significance and interrelationships between all forms of available geologic data.

URANIUM

By
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INTRODUCTION

General Statement

The use of uranium as a source of energy, first for military purposes and more recently for supplying sustained power and for fracturing rock, has evolved only within the past thirty years. This energy, called nuclear or atomic energy, can be derived from the fission of uranium in which the atomic nucleus of fissionable uranium is hit by a free neutron and splits violently into two different elements and yields a large amount of energy in the form of heat. In this fission only about 0.1 percent of the mass is converted to energy. Theoretically one gram of fissionable uranium could furnish as much heat as three tons of good coal and one pound could supply ten million kilowatt-hours of electrical energy.

Nuclear fission releases additional neutrons that can bombard other uranium nuclei and thus set up a continuing process called a chain reaction. Uncontrolled, such a chain reaction would proceed rapidly to a tremendous explosion such as occurs from atomic bombs. The use of neutron-absorbing or moderating materials can control the reaction at the desired rate and the regulated energy released used for producing power, heat, propulsion, and useful fissionable or radioactive materials or isotopes.

Uranium was discovered and named one hundred and eighty years ago. Klaproth is credited with its discovery but the metallic element was not derived until 1842 by Peligot. Becquerel, in 1896, first noted the radioactive character of uranium and Rutherford and Soddy proposed the theory of radioactive disintegration in 1902. Soddy also noted in 1911 that atoms of the same element could possess different masses and called these atoms isotopes.

These early experiments with uranium and radioactivity excited little public interest. The Curies, in 1898, extracted radium from uranium ore and this product found application in the treatment of cancer. Uranium salts were used also in limited amounts as coloring agents in ceramics and glass and in specialized photography and luminous paint. The total demand for uranium ore up to the early 1940's never required more than a few hundred tons per year and this had to be high grade material.

It had long been known that the energy released during radioactive disintigration was enormously greater than that released in chemical reactions but the natural process was too slow to be used productively. When Hahn and Strassman successfully split an atom of uranium in 1938, the way was open to develop faster atomic fission and to produce rapidly large amounts of energy. The problem then became one of controlling the rate of fission for productive use.

World War II and the potential use of uranium in atomic weapons diverted nuclear energy research almost exclusively into military channels, but the successful demonstration of a controlled chain reaction by Fermi and his associates in Chicago in December, 1942, opened the door to the eventual use of uranium as a commercial source of energy for civilian purposes.

During World War II tight control over the production, transfer and delivery of uranium was established by the War Department through the Manhattan Engineering District and was passed on to the newly organized U.S. Atomic Energy Commission (AEC) in 1946. One of the early problems for the AEC was to make available a sufficient supply of uranium to fill the military demands. Very limited amounts were available from a few known, relatively low grade deposits in Colorado and from two higher grade deposits in the Belgian Congo and northern Canada. Contracts were made for uranium from other known sources in South Africa, Canada, Portugal, and Australia, but it was most desirable that supplies from domestic sources be increased. To accomplish this the AEC initiated a domestic uranium procurement program in 1948 which over a period of years provided a guaranteed schedule of minimum prices, a bonus for discovery of high-grade ore, development allowances, premiums for higher grade ore and allowances for haulage to uranium mills or buying depots. The results exceeded expectations. From 1946 to 1954, the number of uranium mines in western United States increased from about fifteen to over 900. In order to avoid over-production for government requirements, the purchase program began to be revised in 1958 by allocating the amounts to be purchased only to established mills, stretching out contracts over longer periods, and reducing or eliminating some of the subsidies. The AEC also started to give more consideration to the development of peaceful uses of atomic energy and to the gradual liberalization of tight control on civilian use. The "uranium boom" started to subside in the early 1960's and many mines closed down as soon as their contracts were completed.

Uranium and Its Geochemistry

Uranium is a metallic element having the chemical symbol U, an atomic number 92, and an atomic weight of about 238.07. Thus it is the last and heaviest member of the natural occurring elements in the Periodic Table. Natural uranium is a mixture of three isotopes, i.e., elements having the same atomic number but differing in atomic weights and often to some extent in chemical properties. These isotopes of uranium are U^{238} (99.285 per cent), U^{235} (0.71 percent), and U^{234} (0.0051 percent). These percentages may vary slightly from one geographic source to another. U^{235} is the only naturally fissionable isotope or nuclide of uranium; but under the bombardment by neutrons, the more common isotope, U^{238}, produces plutonium 239 (Pu^{239}) which is another fissionable material. U^{234} is not fissionable and of no importance in atomic energy.

U^{238} and U^{235} are called radioactive because they break down spontaneously at a constant rate into isotopes of other elements by the emission of charged particles from the nuclei of their atoms. In the breakdown through different series of isotopes or daughter products they end up eventually as stable lead isotopes. The rate of decay is measured in half-lives; 4.51×10^9 years for U^{238} and 7.1×10^8 for U^{235}. Careful measurements of the ratios between the amounts of remaining uranium and the daughter isotopes has been used to determine the age of the original uranium and the rock, vein or deposit in which it occurs. However, the equilibrium can be and often is out of balance due to the escape or selective removal of some of the daughter products, which makes the dating unreliable.

Uranium metal is never found in a natural state. It is highly reactive with oxygen and other chemicals. The element has three common valences; i.e., the uranium atom will join with atoms of other elements or chemical radicals in three different combinations. These are expressed as +3, +4 and +6 as in the oxides UO_2, U_3O_8 and UO_3. Most chemical analyses for uranium are expressed in percentages of U or U_3O_8. The radioactivity of uranium makes it possible to determine its presence, and under carefully controlled conditions, the amount can be determined by radiometric instruments such as the Geiger or scintillation counters which measure the emissions from the constant breakdown. Assays based on these readings are expressed as eU or eU_3O_8. They may or may not be the same as chemical assays, often noted as cU or cU_3O_8, due to lack of equilibrium or the presence of other radioactive elements such as thorium or weakly radioactive potassium.

Uranium is present in at least trace amounts in most rocks, and is estimated to make up about two parts per million (2 ppm or 0.002 percent) of the earth's crust. Finch (1967, Table I) has summarized the data on the average uranium content of selected crustal rocks and major rock types. Most kinds of sedimentary rocks contain close to the average uranium content of the earth's crust, basic igneous rocks are usually lower, and granitic rocks higher. The highest mean content of uranium in surface rocks appears to be in the average volcanic glass (5.6 ppm).

The original source of all uranium occurrences on the earth was the molten magma within the earth which crystallized upon intrusion into or extrusion on the earth's crust. In igneous rocks the uranium may occur in minute amounts in such accessory minerals as zircon, apatite and monazite or in a thin miscroscopic film on the crystal interfaces of other minerals. Pegmatites that result from late-stage magmatic deposition may contain uranium-bearing minerals such as complex rare-earth oxides like allanite, euxenite, betafite, pyroclore, samarskite, or rarely as uraninite. Hydrothermal veins may contain trace or sizeable amounts of uraninite in crystalline or powdery form. Detrital heavy mineral deposits, called placers, may contain concentrations of resistant uranium-bearing minerals if the sands are derived from the primary igneous sources. Most uranium minerals in igneous rocks and the uranium films in veins, oxidize in weathering and erosion to produce soluble uranium compounds which can be transported considerable distances by both surface and ground water. The uranium in solution is probably in a high-valence state (+6) but it can be reduced to a lower-valence and precipitated by encountering reducing conditions such as carbonaceous matter or hydrogen sulfide derived from sulfide minerals or bacterial action. Uranium in solution also is absorbed on clay minerals and precipiated by chemical reaction or by evaporation. A large part of the uranium in solution eventually ends up in the ocean where very low concentrations occur in muds and phosphatic sediments. The uranium deposited in terrestrial sediments may be preserved or recycled one or more times by oxidation and re-deposition. These latter forms of occurrences are the standstone-type, found most commonly in the sediments of the Colorado Plateau region and the ones which have supplied the bulk of the United States supply of uranium.

In this report, as in most published reports, a uranium occurrence is a body of rock, vein, or pegmatite containing at least 0.01 percent U_3O_8 or recognizable uranium minerals. In order to be of commercial interest uranium deposits must contain better than 0.1 percent U_3O_8 (two pounds of uranium oxide to a ton of ore) and in most cases at least 0.2 percent. At the present time, some deposits, due to mining, metallurgical and economic factors may require an average grade of 0.4 percent U_3O_8 or more to be considered economically minable. In this report, uranium resources include material averaging at least 0.1 percent U_3O_8 and assumed to be minable now or likely to be minable in the future.

Mineralogy

The common primary uranium minerals are uraninite and coffinite. Both contain +4 valence uranium. The secondary uranium minerals, derived for the most part from uraninite and coffinite by alteration, oxidation, solution and redeposition, are of the +6 valence uranium type. These include a wide variety of colorful arsenates, carbonates, hydrous oxides, phosphates, silicates and vanadates. It is usually difficult if not impossible to identify or distinguish between many of the secondary uranium minerals in the field. Laboratory techniques such as chemical analyses, microscopic examination, or X-ray study usually are required to determine their identity.

Table G lists and briefly describes the uranium minerals identified in occurrences in Arizona. Unidentified uranium has been detected in some occurrences and it may be present in small amounts in such minerals as uraniferous opal or hyalite, pyromorphite, rutile, zircon or iron oxides. Finch (1967, p. 67–79) reviews the chemistry and mineralogy of sandstone-type uranium deposits. U.S. Geological Survey Bulletin 1064 describes the uranium minerals more thoroughly and Bulletin 1250 provides a useful glossary of uranium-bearing minerals.

United States Uranium Requirements

The uranium requirements of the United States have changed rapidly in recent years with the build up of uranium stocks in excess of requirements, with the shifting emphasis from military to civilian use, and with the early lag and now rapidly expanding development and installation of nuclear electric generating capacity. The "Statistical Data of the Uranium Industry" issued yearly by the U.S. Atomic Energy Commission, Grand Junction Office, Grand Junction, Colorado, summarizes the many factors involved in the United States atomic energy picture including purchases, ore production and reserves, distribution of deposits, drilling statistics and projected requirements. The latter item in the statistics of January 1, 1969, is of pertinent interest because it shows that the projected nuclear power growth will increase from an installed capacity of 9,800 net electrical megawatts in 1970 to 145,000 net MWe in 1980. Such an increase would necessitate a jump in annual domestic requirements of short tons of U_3O_8 from 7,500 to 37,400 and in cumulative domestic requirements from 20,900 tons to 244,700 tons. In 1969, 12,850 tons of U_3O_8 in domestic ore was shipped to processing mills and domestic ore reserves at $8 per pound were conservatively estimated at 160,819 tons U_3O_8. Cumulative production was given as 191,095 tons U_3O_8. It is evident that the projected requirements for the future will require increased uranium production from both known and as yet unknown or undeveloped sources. Faulkner (1968) noted that by the year 2000 about 50 percent of all electric generating capacity may be based on nuclear fuel and the cumulative requirements would be between 0.8 and 1.2 million tons of U_3O_8. He noted also that only about 320,000 short tons of reasonably assured domestic reserves of U_3O_8 were available at a price of $10 or less per pound and that an increase in price to $15 per pound U_3O_8 would only add some 140,000 short tons. The estimated additional U.S. uranium resources (potential resources) at up to $15 per pound might add about 540,000 short tons of U_3O_8. Faulkner concludes that although there is no shortage in available domestic uranium it is likely that a price up to $15 per pound will be required to satisfy projected requirements.

In the following discussion and description of uranium occurrences in Arizona, the status of the State's present and future uranium resources is reviewed in the light of these projections.

ARIZONA URANIUM OCCURRENCES

General Statement

Arizona played a minor but important role in the early development of uranium supplies for the atomic energy program. Until the end of 1969 the State had supplied about four percent of the total U.S. production of uranium oxide. Most of the Arizona production was mined prior to 1966. Without the subsidy payments and other benefits from the U.S. Atomic Energy Commission and with the depletion of the more accessible and richer deposits, most Arizona uranium mines could not operate economically. The drop in production also brought about the closing of the uranium mills within reasonable transportation distance. In the 1960's only a few of the larger mining operations could continue production and even these closed down by 1969. At present no uranium is being produced in Arizona. Table H shows the uranium ore production statistics for Arizona from 1942 to 1969.

At present, minable uranium resources in Arizona are insignificant in respect to the total amount estimated for the United States. Potential resources, largely undeveloped or not yet discovered, might add up to a million or more tons of material averaging not more than 0.2 percent U_3O_8. Whether or not these potential resources will become important for atomic energy purposes in the future depends on future demand, price and other economic factors.

The uranium occurrences in Arizona can be classed into five general types in the approximate order of their importance. Sandstone-type occurrences are those found mainly in sandstones, but also in other detrital rocks such as conglomerate, siltstone, tuff, mudstone, limestone and carbonaceous shale. The uranium is introduced by groundwater solutions and precipitated in the sediments after the deposition of the host rock. The source of the uranium may have been distant or nearby and the form of the mineralization is influenced largely by the sedimentary structures.

Pipe-like occurrences are found where the host rocks, mainly flat-lying sedimentary formations, have been brecciated and displaced downward in a circular or oval collapse structure due to probable solution of underlying limestone. Uranium and other minerals were introduced by hypogene or supergene solutions and deposited in the fractures and openings in the brecciated host rocks and, in some cases, disseminated in the host rocks. In general this type incorporates features of both vein and sandstone-type occurrences. Diatreme occurrences are somewhat similar to pipe-like occurrences in structural appearance but have originated where a volcanic explosive vent or pipe has broken through overlying sedimentary rocks. Frequently, subsequent subsidence within the vent has formed a collapse breccia and there is inward slumping and sedimentation in the basin formed by the collapsed vent. Minor uranium mineralization is sometimes found in the slumped and inward dipping sediments but the origin of the mineralization is uncertain.

Vein occurrences are those associated with the filling of distinctive breaks in the host rocks, usually cutting across the layering or bedding of the host rock at a steep angle. The mineralization appears to have had a hydrothermal source. Pegmatite and placer occurrences in Arizona are of very minor importance.

Sandstone-Type

The principal uranium occurrences in Arizona resulted from the precipitation of uranium from solution in sandstones and other related clastic rocks. The shape and attitude of the mineralization in the host rock is usually dependent on the structure of the sediments. The mineralization occurs disseminated in pore spaces or as a replacement of grains, cement or fossil plant matter in the sediments. All known occurrences are late Mesozoic or younger; times when woody plant life was becoming abundant. Also, all are in terrestrial sediments laid down by slow moving, braided and meandering fresh water streams on low lying deltas, alluvial plains or flood plains; or they are in restricted basins or near coastal shorelines. An excellent summary of the geology of epigenetic uranium deposits in sandstone in the United States is given by Finch (1967). The sandstone-type occurrences in Arizona are described below in relation to the specific geologic settings and are presented in the order of apparent relative imporance as a source of uranium.

CHINLE FORMATION

More than 1.6 million tons of uranium ore, over one-half the total Arizona production, has come from the Chinle Formation of Triassic age. About 60 percent of this total was mined from the Shinarump Member in the Monument Valley district of northwestern Apache County and northeastern Navajo County. The largest share came from the Monument No. 2 mine on the eastern side of the Monument Valley district. The Shinarump and Petrified Forest members of the Chinle Formation in the Cameron district of Coconino County provided most of the remaining percentage. Small contributions were made from a few scattered occurrences along the southeastern flank of the Paria Plateau. Unproductive occurrences in the Chinle Formation have been found elsewhere in the Chinle Valley and in northern Mohave County.

The Chinle Formation contains a large share of the potentially minable sandstone-type uranium resources and holds the greatest promise for the discovery of additional potential uranium resources in Arizona. The best and most accessible uranium deposits probably have been mined out and further exploration for and development and mining of uranium from occurrences in the Chinle Formation will be more difficult and at higher costs due to the deposits being at greater depths below the surface.

The colorful uranium-vanadium minerals found in the Shinarump Member in Monument Valley were used as pigments by the Indians long before they were reported by Gregory (1917, p. 50, 148). Butler and Allen (1921) noted that numerous carnotite-type deposits had been found near Kayenta in the Navajo Indian Reservation, the discovery setting off a staking boom. The general isolation and small demand for domestic vanadium did not encourage exploitation and it was not until the need for vanadium for World War II requirements became acute in 1942 that these occurrences received serious attention. Small tonnages of vanadium-uranium ore were mined from the Monument No. 1 and Monument No. 2 mines between 1942 and 1945. Subsequently, the operations became unprofitable due to lower demands and prices.

With the initiation of the AEC incentive program for domestic uranium these Monument Valley areas were reactivated. Production from the Monument No. 2 deposits increased rapidly to become the major source of uranium from Arizona almost until the time it closed down in

1967. The early output came from surface and underground mining of the richer pods and lenses. Later a concentrator was put into operation to upgrade the large amount of low grade mineralization in and around the high grade and thus increase production. By 1956 almost all mining was by open pit operations and the concentrator output accounted for the major share of the production. Mining in the Monument No. 1 area was more sporadic because the mineralization was less consistent. Some extensions of known mineralization and new deposits were found by exploration drilling but by the late 1950's most of the ore had been mined out.

Numerous small to medium deposits were developed in the Shinarump Member outcrops along mesa and canyon rims in Monument Valley during the late 1940's and early 1950's and an intense geologic investigation of the district was undertaken by both the AEC and the U.S. Geologic Survey (USGS) in the early 1950's. All known mineralized exposures were mapped and drilling was contracted to determine the favorable loci and trends of the mineralization, and the character and attitude of the occurrences. The favorability of the Shinarump Member scour and fill paleochannels was recognized as an important factor in uranium occurrence and they became the target for most exploration. As a result several important deposits, including the Moonlight mine, were found by private drilling in buried paleochannels within the central part of the district. Production from Monument Valley district reached its peak in 1955 and then declined.

Prospecting of the Shinarump Member was extended to other areas such as the Vermilion and Echo Cliffs district but the uranium occurrences found were small and low grade. Only two mines shipped small tonnages.

Uranium mineralization was noted in the Cameron district in 1950 but the first discovery of commercial importance was made by a Navajo prospector for the AEC in 1952. Surface and airborne exploration soon located a large number of deposits in the contact zone of the Shinarump and Petrified Forest members of the Chinle. The amount of ore justified the establishment of a purchase depot and uranium mill at Tuba City. By mid-1959 some 270,000 tons of ore had been shipped from about 89 mines (Chenoweth, 1962). Most individual deposits were small and at shallow depths below the surface and thus were mined out within a short period of time. There has been little or no uranium production from the district since 1962.

Surface and airborne prospecting activity followed the outcrops of Chinle southeastward into Apache County in the early 1950's and numerous small scattered occurrences of uranium were found, mainly in the Petrified Forest Member. A few mining operations shipped test lots

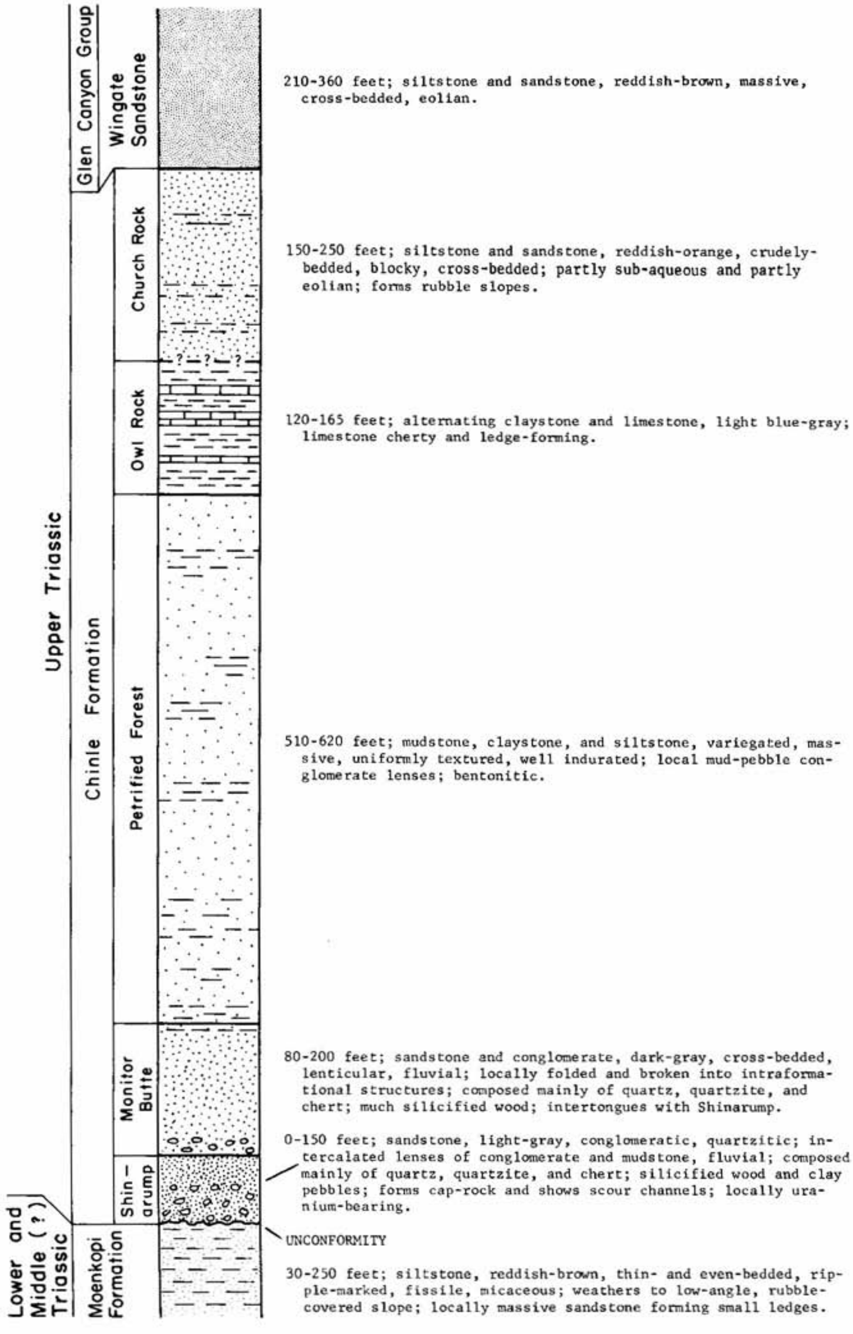

Figure 14. Generalized section of Chinle Formation in Monument Valley district, Arizona. (Modified from Witkind and Thaden, 1963.)

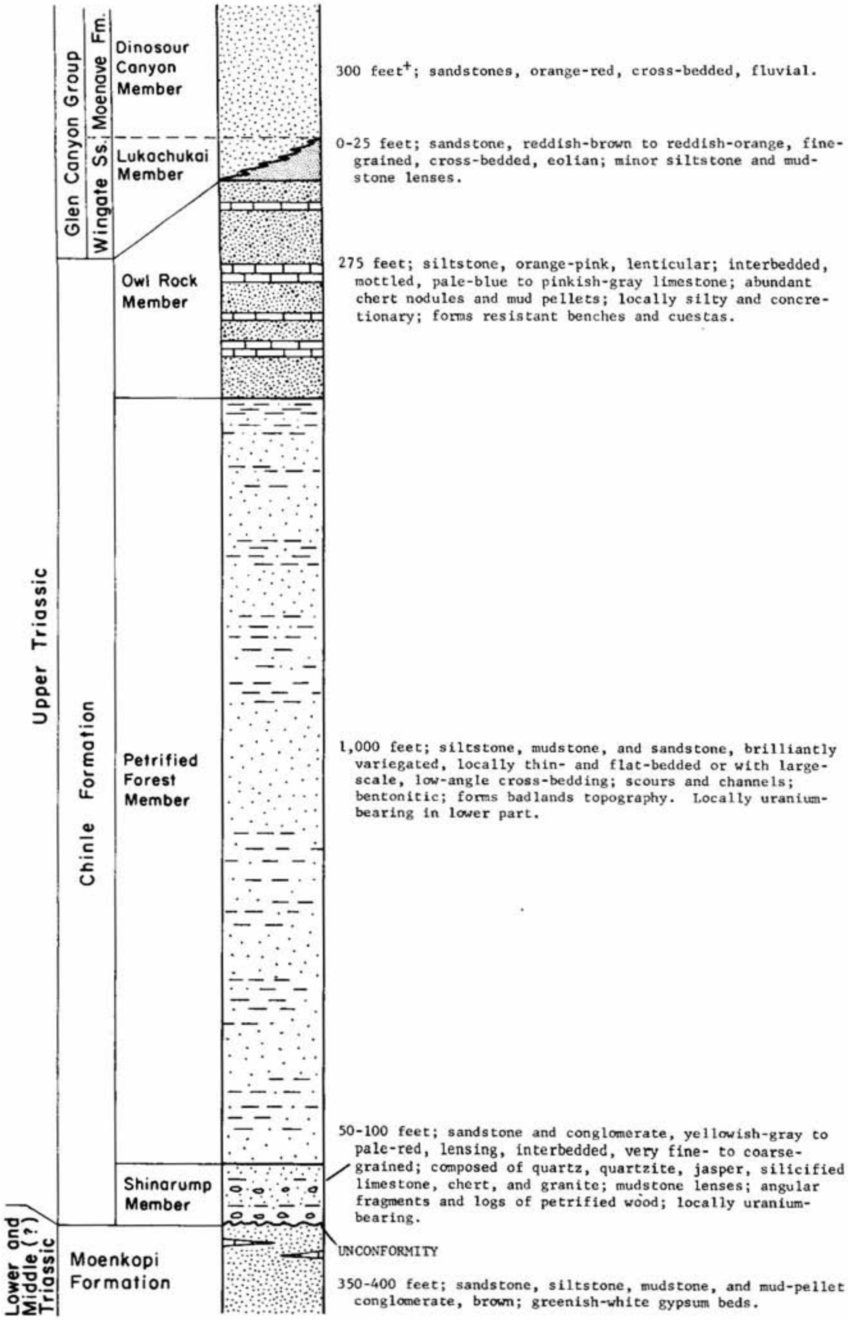

Figure 15. Generalized section of Chinle Formation in Cameron district, Arizona. (Based on Akers and others, 1962.)

of relatively low grade uranium mineralization, but only one area, on the west side of the Petrified Forest National Monument, produced more than one hundred tons. Elsewhere in the Chinle Formation, small occurrences of uranium mineralization were found near Nazlini, Canyon De Chelly, the north end of the Defiance uplift, and in northern Mohave County but none have warranted exploitation.

The Chinle Formation covers a large part of the Colorado Plateau and represents a period when gravel, sand, silt and mud, derived from highlands to the south, were transported by braided, meandering and shifting streams and deposited on an extensive alluvial plain in channels, temporary lake beds and wide-spread mud flats. The Chinle Formation sediments are noted for the spectacular variety of banded colors typical of the Painted Desert and also for the abundance of fossil wood as found in the Petrified Forest. Figures 14 and 15 show generalized sections of the Chinle Formation in the Monument Valley and Cameron districts.

The Chinle Formation rests on the slightly undulating, eroded surface of the Lower and Middle(?) Triassic Moenkopi Formation which consists of non-marine, locally gypsiferous, sandy and silty redbeds interfingering with minor amounts of marine calcareous strata. The erosion after Moenkopi deposition established broad valleys and low divides and locally deeper channels cutting down into pre-Moenkopi strata. On this surface the basal member of the Chinle Formation, the Shinarump, was deposited. This member, dated as Upper Triassic in age, consists of light gray sandstone and conglomerate with rare lenses of mudstone. It is a remarkably extensive and uniform sheet of reworked and consolidated coarse sediments. Its thickness and distribution was largely controlled by the surface relief, averaging between fifty and one hundred feet, but locally attaining as much as several hundred feet. The basal contact is well marked by the change in lithology and color, and by the clearly evident erosional surface. The Moenkopi Formation below the contact often shows a foot or more of bleaching, particularly under the scour and fill paleochannels. Quartzose sandstone predominates but the conglomerate and mudstone lenses are more conspicuous. Carbonized and silicified wood fragments and logs are locally abundant and some channel fillings display fragments and blocks of the bordering strata. The sand, pebbles and cobbles were partly to completely cemented by calcite and silica but locally considerable permeability existed in the strata for a long time subsequent to its deposition. Stream flow was from south and southeast but individual channels have changing orientations.

The Shinarump grades upward and intertongues laterally with younger Chinle members. In Monument Valley the Monitor Butte Member overlies and intertongues with the Shinarump Member but in the Cameron district and in most of the Little Colorado River district the

Shinarump grades upward into the Petrified Forest Member. This latter unit is the thickest and most typical of the Chinle Formation. Predominantly it consists of variegated mudstones and siltstones, but in the eastern part of its outcrop in Arizona it contains a medial sandstone bed. The lower section in particular consists mainly of interbedded red, purple, blue and gray mudstones with locally abundant petrified logs. Local channeling is often distinct. The upper section is redder and contains more sand and silt. A distinctive feature of the Petrified Forest Member is the abundance of impure bentonitic clay derived from volcanic debris. Cadegan (1963) identified the character of the debris as divitrified, silicified and chloritized fragments of volcanic glass; vitric, crystal and lithic tuff; and felsite.

The uppermost members of the Chinle in Arizona are the Owl Rock and Church Rock but neither has any identified relationship to the occurrence of uranium. In the western, southwestern and southeastern areas of Chinle outcrops in Arizona there was an erosional break in sedimentation between the Chinle Formation and the overlying Wingate Sandstone. This hiatus could allow the weathering and breakdown of the volcanic debris to clay which would release traces of uranium and other metals into the ground water.

Intrusive and eruptive basic igneous rocks have broken through or flowed out on the Chinle Formation, but all are considered to be Tertiary or later in age and none appear to have any genetic relationship to the uranium mineralization.

The Chinle Formation in northern Arizona has undergone various downwarps and upwarps and gentle folding (Kelley, 1958). The formation has been exposed due to the Monument upwarp to the north, through a series of uplifts and longitudinal faults to the west, and due to the Defiance uplift to the east. In the center it is bowed downward under thick overlying formations in the Black Mesa basin (Plate 9). In the Cameron area and along much of the Little Colorado River valley the Chinle crops out on an essentially undeformed structural slope that is probably continuous with the Mogollon slope further south. Most of the uplifts and folding took place in late Cretaceous or early Tertiary time apparently after mineralization. Except for the secondary influence that the faulting and jointing, tilting and folding may have had on the oxidation and reworking of the uranium deposits and except for the changes in the flow of groundwater that also might affect the uranium occurrences, there is no recognized finite relationship between the local deformation and the mineralization. However, the Mogollon slope is a pre-Upper Cretaceous feature and when considering the structural picture on a larger scale, the erosion and solution flow prior to Cretaceous sedimentation could have brought metals from source rocks in southern Arizona.

The geology of the Chinle Formation in northern Arizona and the uranium occurrences in it have been described by numerous geologists (Akers and others, 1958; Stewart and others, 1959; Finch, 1959; Akers and others, 1962). Others have dealt in more detail with the separate districts as discussed below. Plate 16 shows the general pattern of outcrops of the Chinle in northern Arizona, the uranium districts and the location of the uranium occurrences numbered to correspond with those listed and briefly described in Table I.

Monument Valley District. This district as a whole covers some 1,500 square miles but only a part lies within Arizona and within the Navajo Indian Reservation. For the most part it is a semi-arid, largely isolated and inaccessible area. All commercial uranium deposits found or suspected occur in the Shinarump Member in or near the bottom of paleochannels cut in the Moenkopi or older formations. The ability to recognize and trace these paleochannels was most important in uranium exploration and was one of the important subjects of the many geological studies as summarized in the more recent reports by Evensen and Gray (1958), Grundy and Oertell (1958), the AEC Guidebook (1959, p. 2–55 to 2–57), Witkind and Thaden (1963), Young (1964), and Malan (1968).

Detailed mapping and study of the channels and their contained sediments revealed scour zones along the bottom and longitudinal bars and torrential cross-bedding along their course. Uranium mineralization appears to favor areas in such sedimentation features where discontinuous cutting and filling took place. The channels tend to be U-shaped and relatively narrow. Normally at any one location they contain only one mineralized scour zone filled with sandstone and conglomerate and capped by siltstone or mudstone. Broad gentle swales in overlying strata or the difference in erosional resistance between channel and bordering sediments may indicate the location of paleochannels.

Not all scour zones in paleochannels contain mineralization. Mineralization appears to be restricted to the more carbonaceous sandstone and conglomerate beds in the lower part of the channel and scour where permeability was sufficient to allow introduction of uranium-bearing solutions and reducing conditions existed to cause precipitation. The belt in Arizona where such favorable conditions occurred appears to have been limited to an area along the Arizona-Utah border from Cane Valley on the east to Nakai Mesa on the west and four to eight miles south (Plate 2).

The length, width, and thickness of the deposits vary greatly although all show linear shapes closely parallel to scour and channel directions and some conformity to sedimentary structures. The mineralization is usually in the form of high-grade lenticular pods or rods, with lengths ranging from a few feet to over 100 feet, widths one-fifth or less the length, and thicknesses of one to ten feet. Pods and rods may be clustered and occasionally separated or surrounded by disseminated low-grade mineralization. Most individual deposits are small. Over one-half (29) of the 54 economic deposits mined contained less than 1,000 tons of ore; 23 contained less than 50,000 tons; one deposit, the Moonlight mine, developed over 100,000 tons; and the Monument No. 2 mine produced more than 500,000 tons (Malan, 1968).

The higher grade, direct shipping ore at the Monument No. 2 mine averaged 0.30 percent U_3O_8 and 1.40 percent V_2O_5. Higher grade ore which was locally encountered in pods was blended with lower than average-grade mineralization to maintain this average grade. Low grade mineralization averaging about 0.04 percent U_3O_8 and 0.40 percent V_2O_5 was concentrated and pelletized to a shipping grade average of 0.24 percent U_3O_8 and 2.60 percent V_2O_5. Copper values are lacking in the Monument Valley No. 2 area but may amount to 0.29 to 2.50 percent in the deposits to the west. Likewise these latter deposits show only 0.22 to 0.81 percent V_2O_5 although they have similar uranium values as in the east. The lime content is variable between deposits and within deposits, 1.4 to 10.3 percent $CaCO_3$ and averaging 4.6 percent. The lime content is usually inversely proportional to the vanadium content and has not caused metallurgical difficulties.

Most of the deposits are oxidized close to the surface with the major ore minerals being the uranium-vanadium tyuyamunite and carnotite and the vanadium hewettite and navajoite in association with iron oxides. Locally torbernite, uranophane, uranopilite, betazippeite and johannite are found and malachite, azurite and hydrous copper sulfates where copper is present in significant amounts. In depth below the zone of oxidation the following are found: the uranium minerals, uraninite and coffinite; the vanadium minerals, montroseite, corvusite, doloresite, and vanadium mica; the iron sulfides, pyrite and marcasite; and when copper is present, chalcopyrite, bornite and native copper.

The Monument Valley district has produced more uranium than any other in Arizona. Malan (1968) noted that as of July 1, 1965, the total production was about 1.5 million tons of ore averaging close to 0.3 percent U_3O_8 or about nine million pounds of U_3O_8. At the same time the ore reserves were estimated by the AEC as only 96,000 tons of ore. The potential resources from undeveloped and presently unknown occurrences, including known marginal occurrences, could amount to several hundred thousand tons. This potential exists within the defined mineralized belt in the lower portions of the Shinarump channels, particularly scour basins filled with sandstone, conglomerate and lenses of carbonaceous mudstone. The more obvious channels have been found but opportunity still exists to discover other channels now buried under later sediments by correlation of known channel segments through exploration drilling and geologic deductions.

Cameron District. This district, covering an area about thirty-three miles north-south by some twelve miles wide, with the settlement of Cameron roughly in the middle, shipped over 100,000 tons of uranium ore having an average grade of about 0.2 percent U_3O_8 from some ninety small-to-medium-sized mines during the 1950's. The mineralization was found at relatively shallow depths in carbonaceous channel sediments of the Shinarump and Petrified Forest members of the Chinle.

The Shinarump crops out in a broad, north-south band and consists of 50 to 100 feet of yellowish-gray to pale red, often banded, fine- to coarse-grained quartzose sandstone and conglomerate with local fragments and logs of petrified wood and pockets of carbonaceous trash. The member rests on the eroded surface of the Moenkopi Formation as marked by large, broad channels and a foot or more of bleaching. Above the Shinarump with a gradational contact are some 1,000 feet of interbedded, varicolored siltstone, mudstone and sandstone lenses typical of the Petrified Forest Member of the Painted Desert region. The bedding is normally thin with some flat but large scale, low angle cross-lamination. The lower part commonly displays lenticular and intraformational channels and scours filled with sandstone and carbonaceous matter. A large part of the finer sediments were derived from volcanic debris now weathered to bentonitic clay.

The Chinle Formation in the Cameron district has been only slightly tilted, faulted and fractured. Igneous activity in the area in the form of basaltic flows and a volcanic cone appear to be later than the mineralization.

The uranium mineralization has been discussed by Austin (1957, 1964), Bollin and Kerr (1958), and Chenoweth (1962). The deposits occur mainly in the upper thirty feet of the Shinarump and the lower sixty feet of the Petrified Forest members where channels and scours occur in a gradational zone. The general stream direction was from the south but the channels are sinuous. The mineralization favored channel bends and steeper scour slopes and is generally aligned with sedimentary features with some deviation along crosscutting fractures. Most ore bodies averaged about 5,000 tons and only a few contained up to 40,000 tons. The productive deposits were within 130 feet of the surface.

The mineralogy in the Cameron district is more complex than in most sandstone-type deposits. Near surface oxidation of the primary uraninite and coffinite, and small amounts of copper, cobalt, manganese and molybdenum mineralization produced a variety of metallic oxides, sulfates, silicates, carbonates, molybdates and rare vanadates. Evidence of considerable remobilization of the minerals by oxidation, solution and redeposition is common.

Most occurrences were found through surface prospecting and surface and airborne radiometric surveys. Development was by drilling and trenching. The economic success of the operations depended largely on the presence of the uranium buying depot and mill at nearby Tuba City and the AEC production and bonus payment schedules. The readily available deposits have been mined out and probably only minor amounts of minable mineralization remain. Potential resources that might be available at a higher price per pound would consist of marginal uranium-bearing material in the known mineralized areas or under deeper cover to the east. This potential probably would not amount to more than 100,000 tons and would be scattered in numerous small deposits.

Vermilion and Echo Cliffs District. This district covers the Chinle outcrops to the west and east of the Colorado River canyon along the southeastern edge of the Paria plateau and the Echo Cliffs flexure. Occurrences in the district have been briefly noted in AEC Preliminary Reconnaissance Reports and the Lee's Ferry area was described by Phoenix (1963).

The general geology is similar in part to the Monument Valley and Cameron districts in that the Shinarump sandstone, conglomerate and occasional interbedded lenses of siltstone and mudstone were deposted on the eroded surface of the Moenkopi Formation. As elsewhere, the Shinarump is most noticeable in sinuous, generally northwest trending channels. Locally, carbonaceous and silicified wood fragments and logs are present. The sequence above the Shinarump, with gradational contacts, is: 175 feet of the equivalent of the Monitor Butte Member, consisting of interbedded sandstone and silty mudstone containing fossil logs; about 625 feet of Petrified Forest Member, consisting of interbedded varicolored shale, siltstone, bentonitic clay and mudstone with local silicified wood; and the Owl Rock Member. The structural history of the district includes broad warping and associated fracturing.

Scattered small and generally low-grade uranium occurrences are found in the Shinarump channel deposits, the Monitor Butte Member, and the Petrified Forest Member. Uraninite, pyrite and chalcopyrite occur in calcite veinlets, fossil wood, or are disseminated in sandstone. Where oxidized the colorful yellow and green secondary uranium and copper minerals coat the sand grains.

Only a few hundred tons were shipped from this district and economic production was marginal even under the AEC bonus price schedule. The geologic conditions do not appear to be as favorable when compared to the more productive districts. Prospecting for additional occurrences back from the cliff outcrops would be difficult and expensive.

Little Colorado River Valley District. The Chinle Formation crops out in an irregular broad band, nine to thirty-six miles wide, along the Little Colorado River from the Cameron district to the New Mexico border with Apache County. The Shinarump Member is identified as a continuous unit only in the western part and is similar to that in the Cameron district. Elsewhere the Shinarump is only locally present and the Petrified Forest Member usually rests directly on the erosional surface cut on the Moenkopi Formation. It is at least 1,500 feet thick near Holbrook. The main section consists of varicolored bentonitic shales interbedded with white, gray or brown bentonitic sandstone and cherty conglomerate locally containing abundant petrified wood. Near the top, interbedded red and brown limestones and calcareous shales may be correlated with the Owl Rock Member. A medial sandstone bed (Sonsela Butte Sandstone) occurs near the middle of the section in the eastern part of the district but grades into siltstone and mudstone to the west (Akers and others, 1958).

Uranium occurs in the lower to middle part of the Petrified Forest Member in the western part of the district and in the middle part associated with the medial sandstone to the east. In general the occurrences are found in the more sandy zones of shallow scours 100 to 200 feet wide, 300 to 1,000 feet long and less than 10 feet deep. The mineralization is surrounded by altered, bleached and iron stained rocks; white, homogenous bentonitic clay often occurs just below most deposits. Carbonaceous debris and fossil wood appear to be closely associated.

The uranium mineralization is mainly oxidized with schroeckingerite, zippeite, autunite, metazeunerite and metatorbernite. Some uraninite and coffinite are found in carbonized logs. Vanadates are minor. Associated minerals are limonite, gypsum, hematite, pyrite, pyrolusite, kaolin and other clay-type minerals.

The production from the numerous, scattered and small uranium occurrences has been small and only from along the west side of the Petrified Forest National Park were commercial shipments made. There are no reserves but potential resources could amount to as much as 1,000 tons of low grade uranium mineralization.

Chinle Valley District. The Chinle Formation is exposed in a broad valley lying between Black Mesa to the west and the Defiance uplift to the east. The stratigraphy is similar to the eastern part of the Little Colorado River valley, including the medial sandstone in the Petrified Forest Member. Several small and usually low-grade uranium occurrences were found by aerial and surface prospecting in scours containing lenses of crossbedded sandstone with associated carbonaceous trash and gray to red mud pellets. The uranium mineralization is of the carnotite-type and occurs as disseminations, fracture fillings and concentrations in small pods within lenses containing carbonized plant debris. The mineralized zones are usually altered and bleached and limonite is abundant. Some minor mineralization also has been found in greenish siltstone associated with abundant carbonized and silicified plant remains.

Ore has not been produced from these small, low-grade deposits and it is doubtful if they could be mined economically under any foreseeable conditions. No resources are estimated but there is a slight possibility for some high cost uranium in the district.

Northern Mohave District. The Chinle Formation crops out around the base of uplifted blocks, such as the Vermilion Cliffs along the Arizona-Utah border and the faulted blocks along the east flank of the Virgin Mountains. Outside of Darton's work (1925), little detailed geology on the Chinle of northern Mohave County has been published.

The Shinarump Member, consisting usually of less than 100 feet of grayish conglomeratic sandstone with minor shale lenses and local carbonaceous trash and petrified logs, rests on the red and brown shales of the Moenkopi Formation without any clear unconformity. Above the Shinarump there is up to 1,000 feet of variegated and interbedded sandstone, shale and claystone containing carbonaceous matter. These strata probably correlate with the Petrified Forest and possibly other Chinle members.

Spotty, yellow uranium mineralization has been prospected in several localities, but the only production has been a few test lot shipments. The occurrences are small and the average grade very low. No potential resources that might be economic at foreseeable prices can be estimated.

MORRISON FORMATION

Carnotite-type mineralization was recognized in the Carrizo Mountains area in northeastern Arizona in 1918 and John Wade, the discoverer, located a large number of claims for vanadium because these deposits were of the high vanadium-low uranium type. Exploration at that time revealed other occurrences along the Arizona-New Mexico border and along the rims of numerous large and small mesas extending southward into the Lukachukai Mountains (Mineral Resources of the United States, 1921, Pt. 1, p. 226). Several companies undertook prospecting campaigns but, except for a few experimental shipments made in the 1920's averaging 4.0 percent V_2O_5 and 0.5 percent U_3O_8, there was little development. The Arizona Bureau of Mines (Butler and Allen, 1921, p. 19) reported some samples running as high as 10 percent V_2O_5 and 5 percent U_3O_8.

Mining of some of these deposits became an important operation in 1941 under the demand for domestic vanadium, and metallurgical tests were run on the ore (U.S. Bureau of Mines, RI 3628, 1942 and RI 3636, 1942). The production was shipped from several mines to processing plants outside the State where the vanadium was recovered but most of the uranium went into the mill tailings. After the demand for vanadium ceased in 1944, production fell off rapidly and only a few small, irregular shipments were made in the next three to four years. From 1941 through 1944 about 10,000 tons of vanadium ore were produced.

In 1948, the AEC guaranteed purchase program for uranium renewed the interest in this area. Detailed studies of the geology and mineralization of the Salt Wash Member of the Morrison Formation in northeastern Arizona had been made by Stokes in 1942 and 1945 but not published until 1951 (Stokes, 1951). Geologists for Union Mines Development Corporation, under a contract from the Manhattan Engineering District, made unpublished reconnaissance surveys in the area between 1943 and 1945. Subsequent reports by both U.S. Geological Survey and AEC geologists are noted elsewhere in this review.

The deposits northwest of the Carrizo Mountains and along the northern Arizona-New Mexico border were first developed and mined; the less accessible occurrences along the precipitous mesa rims were not in production until 1950. Even then Government sponsored drilling and road construction was required. The development of the deposits in the Lukachukai-Cove area and the establishment of an ore buying depot and uranium mill at nearby Shiprock, New Mexico, greatly accelerated production in the district. The total number of active mines, most of which were small, increased rapidly to about sixty by the mid-1950's and by 1967 some fifty mines in the Lukachukai Mountains had produced about four million pounds of U_3O_8 (Chenoweth, 1967). Outside the Carrizo-Lukachukai area at least 500 tons of high grade uranium ore were produced from replacements in carbonized logs in the Salt Wash Member near Chilchinbito. In the late 1950's most of the better grade ore in the older mining areas had been exhausted and, except in the Lukachukai Mountains area, production declined. All production from the Morrison ceased by 1969. It can be estimated that at least 800,000 tons of ore containing upwards of six million pounds of U_3O_8 have been produced from the Morrison Formation in northeastern Arizona.

The Morrison Formation, the major source of uranium in the Colorado Plateau, occurs over a large part of Colorado, Utah and New Mexico, but in Arizona the outcrops are restricted to the northeast corner of the State and the northeast and eastern borders of Black Mesa (Plate 17). It has supplied less than 30 percent of Arizona's uranium output.

Since the early studies by Gregory (1917), the Morrison Formation and its member units have been studied in considerable detail by Baker and others (1936, 1947), Craig and others (1955), Harshbarger (1949), Harshbarger and others (1951, 1957), and Stokes (1944). It is one of a series of clastic sedimentary formations deposited in Jurassic time over

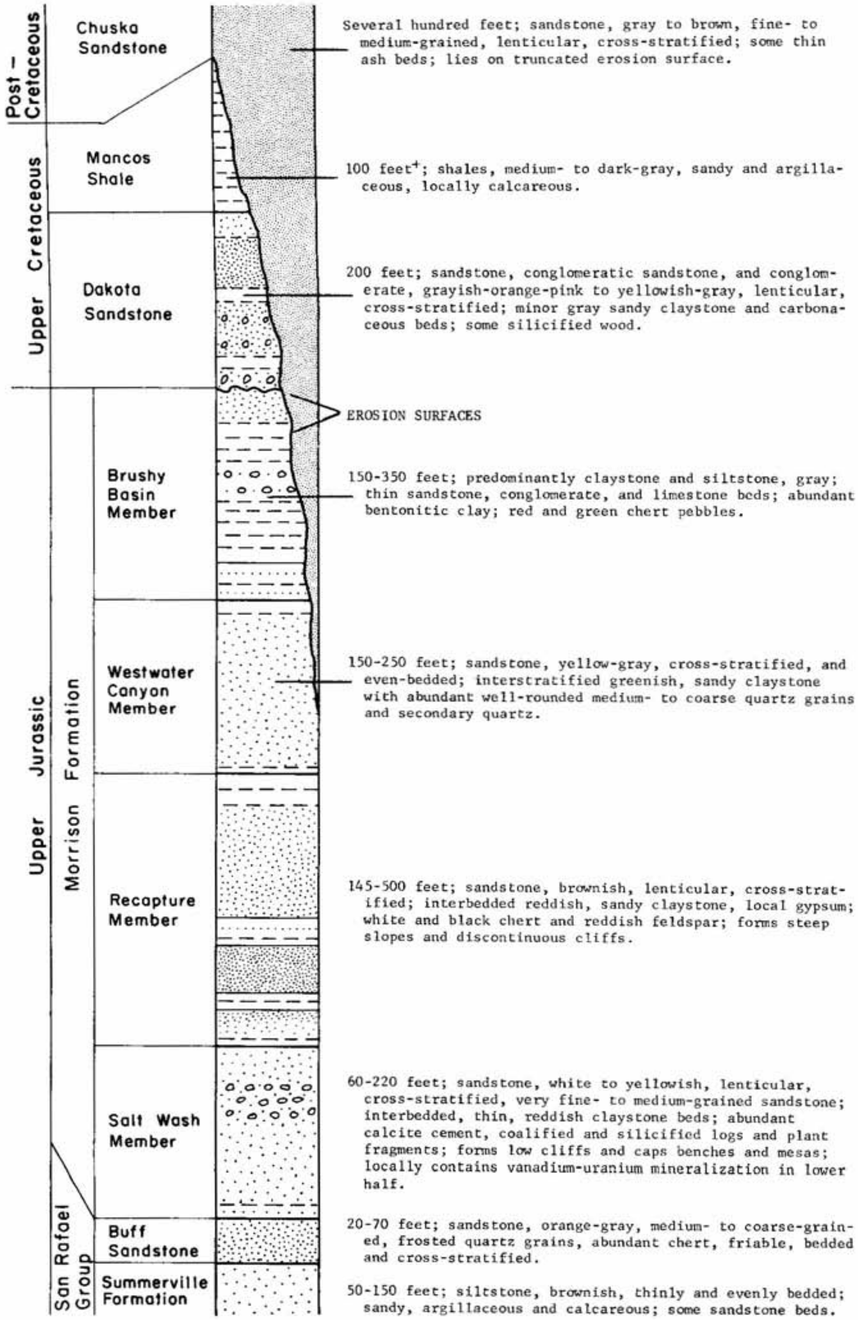

Figure 16. Generalized section of Morrison Formation in northeastern Arizona. (Modified from Strobell, 1956.)

an extensive area on the Colorado Plateau. In northeastern Arizona the Jurassic sediments, which consisted mainly of sand, clay and mud, were deposited by wind or more commonly by meandering stream systems originating to the west and south. Locally they may taper out, intertongue, or may be missing. Figure 16 shows a generalized section of the Morrison and adjoining formations in northeastern Arizona.

The Morrison in Arizona lies on the San Rafael Group of clastic beds with only local disconformity. The basal Salt Wash Member intertongues with the underlying Bluff Sandstone or the Cow Springs Sandstone, both of eolian origin. It consists for the most part of interbedded, lensing, fine- to medium-grained, pale red to gray, quartzose sandstone and poorly bedded, greenish-gray to dark reddish-brown, silty mudstone. To the northwest the member is more sandy and conglomeratic and to the southeast the mudstone facies predominates. In the uranium-bearing area in the northeast corner of the State, the Salt Wash is mainly interbedded sandstone and mudstone with calcium carbonate cement, silicified and carbonized logs, and carbonized plant and wood fragments. The sandstone lenses show cross-stratification, scour-and-fill, ripple marks and other stratification features. The indicated stream-flow direction was from the west and the lithology and structures suggest low-gradient, meandering streams flowing eastward along shifting channels across broad alluvial fans and onto wide flood plains. The Salt Wash thins from about 500 feet to the northwest and 200 feet along the New Mexico border in the northeast, to zero feet to the southwest and south. All the notable uranium occurrences in the Morrison Formation in Arizona occur in the Salt Wash Member.

The other members of the Morrison Formation, the Recapture and Westwater, have somewhat similar lithology to the Salt Wash and in part are contemporaneous. However, their source appears to have been to the south, and in Arizona, they lack vegetal matter. The uppermost Morrison unit, the Brushy Basin Member, is mainly a mudstone with some sandstone lenses that are locally conglomeratic. The mudstone contains impure bentonitic clay derived from the alteration of volcanic debris and some thin siliceous limestone lenses. In Arizona most of the Brushy Basin was stripped away by pre-Upper Cretaceous erosion.

Diorite porphyry laccoliths and sills of Tertiary age have bowed up the sedimentary formations in the Carrizo Mountains. Scattered small plugs and long, thin dikes cut the sediments around the mountains. Near Chilchinbito also, igneous dikes cut the Morrison. All igneous activity was later than the uranium mineralization; therefore the two events have no evident genetic relationship.

The Morrison Formation in Arizona was affected by the major structural features such as the Defiance uplift and the Black Mesa basin

(Plate 17). Kelley (1955, 1956, 1958) and Hunt (1956) describe this deformation. North to northwest aligned folds with a few cross folds occur throughout the area. Northeastward tilting, starting in Morrison time, may have influenced stream courses and may have affected any existing uranium deposits by alterations in ground water movement. Also the Jurassic rocks are truncated by Upper Cretaceous strata along what appears to be a northward continuation of the Mogollon slope. Streams flowing northward over this slope could have moved large quantities of metallic elements into the area where Salt Wash sediments occurred. The source of the metals would be in the Precambrian to pre-Cretaceous rocks exposed in the Mogollon Highlands in southern Arizona.

Uranium occurrences have been found in numerous areas in the Salt Wash Member in northeastern Arizona. These have been grouped arbitrarily and are briefly described in Table J, and their locations are shown with corresponding numbers in Plate 17. An irregular band of uranium occurences extends from northwest of the Carrizo Mountains to the southern Lukachukai Mountains. Another such band occurs along the northern Arizona-New Mexico border. The Chilchinbito occurrence is an isolated example.

Northwest Carrizo District. Starting at Black Rock Point and extending some twelve miles west-northwest through Dry Mesa and Toh-Atin Mesa, numerous uranium occurrences have been found in the lower forty feet of the Salt Wash. The geology and mineralization are described by Hall and Moore (1950), Stokes (1951, 1953), Strobell (1952, 1956), Hatfield and Maise (1953), Reinhart (1953), and Chenoweth (1955).

The Salt Wash in this area consists of about 200 feet of gray to greenish, fine-grained, well-sorted, quartzose sandstone lenses that show cross-stratification and minor interfingering claystone and siltstone layers. The cement is mainly calcite. Fossil logs and carbonized plant material are relatively abundant.

The uranium mineralization is of the carnotite-type, occurring as coatings on sand grains, as interstitial cement, and as replacements of carbonized vegetal matter. The predominant mineralization is a vanadiferous, micaceous, clay-like material. Spotty and irregular occurrences of tyuyamunite, metatyuyamunite and carnotite, and coatings of other uranium minerals are found in the deposits. The mineralization grades from a trace to about 2.0 percent U_3O_8 and up to 5.0 percent V_2O_5. The average ratio of V to U in ore produced has been 10:1 and the $CaCO_3$ to V_2O_5 ratio has been about 4:1. Most of the mineralization is in the form of irregular, elongated, tabular bodies closely associated with carbonaceous matter. Most mineralized bodies are small and thin but they may be clustered. The best mineralization developed along paleochannels, particularly along bends.

This district was one of the first developed and mined in Arizona and has produced over 100,000 tons of ore averaging about 0.2 percent U_3O_8 and 2.0 percent V_2O_5. Only careful and selective mining could produce economic uranium ore and the vanadium by-product was an important contribution. Accessible reserves have been depleted. Some small tonnage of low grade uranium ore may remain around the previously mined area but this potential resource could not be economically mined except at high prices.

North Carrizo District. Scattered, isolated occurrences of Salt Wash occur on the north slope of the Carrizo Mountains and one outcrop contained a small deposit of vanadium-uranium mineralization. The chances for potential resources are very poor.

East Carrizo District. Isolated outcrops of Salt Wash occur on the deeply dissected and intruded eastern slope of the Carrizo Mountains. Farther east the Salt Wash is essentially undisturbed. Vanoxite-type mineralization contains specks and dissemination of carnotite or tuyuamunite and uranium "paint."

The deposits on the mountain slopes have been of minor importance, but those along the New Mexico border were worked originally for vanadium. The uranium values are in small bodies of generally low uranium grade. Few opportunities remain for the development of potential resources.

West Carrizo District. Scattered uranium occurrences, mostly small, have been found along the rims of several mesas down to Segi-ho-cha Mesa. Mineralization has been reported to be of the high-vanadium and low-uranium type in the lower Salt Wash in association with carbonized plant remains. There was small production and any remaining potential resources could only be worked at high uranium prices.

South Carrizo District. Several large and small irregular mesas lie between the main Carrizo Mountains and the Lukachukai Mountains. They are capped by Salt Wash and mineralization occurs in small bodies in lenticular, limey sandstone at several horizons thirty to ninety feet above the base of the Salt Wash. It is often associated with carbonized plant material. Several thousand tons, mainly from Cove Mesa, averaged close to 0.2 percent U_3O_8 and 2.0 percent V_2O_5. Although some potential uranium resources remain, they would not be economic except with a high price for uranium oxide.

Lukachukai Mountains District. These mountains form a steep-walled, deeply serrated, northwest trending ridge at the northwest end of the Chuska Mountains. Morrison Formation members are exposed along the flanks and are partially capped by Tertiary Chuska Sandstone. The strata are flat-lying along the western and central part but are warped by folding on the eastern edge. Vanadium-uranium mineralization is found throughout the middle section of the Salt Wash but appears to be concentrated in a three mile wide zone trending slightly east of north across the southern half of the mountains.

This district was one of the most productive in the Morrison in Arizona and the geology and mineralization has been studied in considerable detail by Masters (1951, 1955), Lowell (1955), Jones (1954), Laverty and Gross (1956) and Dodd (1956). Chenoweth (1967) provides an excellent summary and Dare (1959, 1961) describes the operations of two of the major operating companies.

The Salt Wash thins southward in the mountains due to pre-Upper Cretaceous erosion noted earlier. The mineralized horizons lie thirty to forty feet above the base of the Salt Wash Member. Cross-stratified quartzose sandstone with mud galls and claystones make up about 90 percent of the strata and calcium carbonate cement is abundant. Carbonized plant fragments and carbonized logs are widely distributed and locally abundant.

Tyuyamunite is the main uranium mineral, occurring in irregular disseminations or in concentrations in lenses and bands closely associated with carbonized debris. Minor amounts of uraninite replace carbonized wood. The ratio of vanadium to uranium averages 4:1. The average grade of production was about 0.25 per cent U_3O_8 and 1.10 percent V_2O_5. The mineralized bodies were made up of clusters of numerous small, rich pods separated and surrounded by weak mineralization. Paleostream channels contain the strongest mineralization, but jointing has a secondary effect on the trend of the ore.

Most of the accessible uranium mineralization has been mined out in this district. Some potential resources may occur in the central part of the ridge hidden under deep cover. Exploration for the development of such possible mineralization will be difficult and expensive and economic operations would only be possible at high prices for uranium.

Redrock Valley District. A few small, scattered occurrences of uranium have been found in a narrow fringe of flat-lying Salt Wash along the New Mexico border in Redrock Valley. The small pods and bands in the calcite-cemented sandstone lenses have produced a few hundred tons of vanadum-uranium ore but there is little material that could be considered even as a low grade potential resource.

Chilchinbito-Rough Rock District. These isolated occurrences of uranium in the Salt Wash at the northeastern corner of Black Mesa exist in thin, iron stained sandstone about thirty feet above the base of the member and differ from the usual Salt Wash deposit. The carnotite- type mineralization is confined almost exclusively to replacement of small carbonized logs and there is considerable gypsum in the mineralized strata. Some 500 tons of high-uranium and low-vanadium ore was shipped from carefully selected material and more of this type of mineralization might be present. It could only be developed with a high price for uranium.

OTHER FORMATIONS

The discovery of commercial deposits of uranium in the Morrison and Chinle formations in Arizona led to a search for uranium in other sedimentary formations having similar geologic settings and characteristics. Some 100 occurrences were reported by prospectors and, along with other possible localities, they were checked by reconnaissance or more detailed examination, by personnel of the U.S. Geological Survey and U.S. Atomic Energy Commission in the early and middle 1950's. Uranium was detected in many locations but often only in specimen amounts or in deposits too small, spotty or low grade to be of commercial significance. A few of these occurrences produced a small tonnage of uranium-bearing material, mostly as test lot shipments, but none became sustained mining operations. Some were reexamined and drilled in 1969, but it seems clear that successful economic operations cannot be attained at the present time. Very little, if any, of the uranium-bearing material in these miscellaneous occurrences can be considered as an ore reserve. Their potential as resources of uranium may amount to several thousand tons averaging about 0.2 per cent U_3O_8 and a few tens of thousands if the average grade were dropped to 0.1 percent. Even the best of the occurrences are likely to be relatively small in size and their possible commercial exploitation will depend largely on better prices for uranium oxide and the presence of suitable processing plants within economic transportation distances.

Table K lists many of these miscellaneous occurrences in Arizona and their locations are shown on Plate 18.

Supai Formation. The Supai Formation of Pennsylvanian-Permian age occurs over a large area in northern Arizona, but much of its extent is covered by younger formations. It consists essentially of red, flat-lying, interbedded clastic sediments (sandstone, siltstone, mudstone, and claystone) of deltaic or flood-plain origin, and limestone. The uranium occurrences have only been found along or close to the face of the Mogollon Rim and in the lower part of the formation approximately 800 feet below the Ft. Apache Limestone member. At both Fossil Creek and at Promontory Butte, which are some thirty miles apart, the mineralization appears to be closely associated with a twelve foot thick limestone-pebble conglomerate, and with a gray shaly mudstone above, below or on both sides of the conglomerate. Fragments of coaly material, carbonized wood fragments and carbonaceous trash are scattered in the conglomerate and along some horizontal bedding planes in the mudstone. Uraninite, copper carbonates and copper, iron and other metallic sulfides have been identified in the mineralized zone at Promontory Butte but other uranium minerals have not been observed. The Cibecue occurrence is less well exposed but appears to have a similar geologic setting.

The Promontory Butte occurrence has been prospected by extensive drilling and benching beneath the Mogollon Rim, but the extent and grade of the mineralization has not been disclosed. The uranium mineralization which is so widely distributed in this part of the Supai from Fossil Creek to Cibecue constitutes a relatively new uranium exploration province in Arizona. However, exploration for the most part is made difficult and expensive because the apparently thin mineralized zone occurs along a steep slope of relatively rugged terrain in a moderate to heavy forested area in the Tonto National Forest. Except for a narrow zone near the outcrop, underground mining operations would be required. At present no ore reserves can be estimated, but a potential resource of several hundred thousand tons of low grade uranium mineralization might be present that could only be worked at a high price for uranium.

Kaibab Limestone. This Permian aged formation is mainly a massive, magnesian limestone and dolomite interbedded with chert layers, red beds, gypsum, and thin, sandy or silty limestone. Spotty copper carbonate occurrences have been found in the Kaibab and some of these show weak to very weak radioactivity which is believed to be due to uranium although no uranium mineral has been identified. It seems probable that the mineralization is due to traces of uranium in the solutions from which the copper was precipitated. No potential resources can be estimated. The environment within the Kaibab Limestone is not considered favorable for uranium deposition.

Coconino Sandstone. The Coconino Sandstone of Permian age is composed of medium-grained, well sorted, eolian quartz sand cemented mainly with silica and exhibiting well developed cross-stratification. It does not have favorable geologic characteristics for uranium deposition and the one reported occurrence appears to be anomalous.

Moenkopi Formation. The Moenkopi Formation of Triassic age is essentially non-marine in northern Arizona and consists of interbedded, sandy and silty redbeds. In a few places in northwestern Arizona uranium mineralization has been found associated with carbonaceous trash and copper carbonates, but for the most part throughout northern Arizona, the formation does not appear to be geologically favorable for uranium deposition. No potential resources have been estimated in the Moenkopi.

Navajo Sandstone. This strongly cross-bedded, largely eolian sandstone of Jurassic age does not present a favorable geologic environment for uranium deposition in northern Arizona. In one locality weak uranium mineralization occurs irregularly distributed in association with oxidized copper minerals. No potential resources can be estimated.

Toreva Formation. The Toreva Formation of Cretaceous age, a member of the Mesaverde Group, contains uranium occurrences in a lower sandstone member at the northeastern corner of Black Mesa. This section consists of coarse- to fine-grained clastic sediments with local strata of low grade coal or carbonized plant materials. In the uranium-bearing area, as for the Mesa as a whole, the formation has been folded into broad, gentle anticlines, synclines and monoclines with northwest striking axes (Plate 3.)

The uranium occurrences are generally limited to a thirty to fifty foot zone of light colored quartzose sand lenses close to the top of an arkosic phase. The mineralized lenses and pods are small and usually not more than 30 feet long, 10 feet wide, and 2.5 feet thick. In general they are parallel to the bedding and usually located in shallow paleochannels, particularly at bends or meanders. Carbonaceous to sub-lignite lenses occur above, below or on both sides of the mineralized lenses and pods.

The uranium minerals are carnotite or tyuyamunite accompanied by other vanadates (hewittite and melano-vanadite) and vanadium clays. The mineralization is disseminated in the quartzose lenses, replacing silica and minor carbonate cement. Local spots of high grade have been found but the average U_3O_8 grade is less than 0.2 percent. The U to V ratio is highly variable, from 1:1 to about 1:5. The carbonate content is low.

Several of the deposits have produced ore but in general the grade has been low and sustained commercial mining has not been possible. Recently a considerable amount of exploration drilling has been carried out to determine if a large scale, low grade operation would be feasible. Little or no presently minable ore can be estimated although potential resources could be sizable under more favorable economic conditions, such as a high price for U_3O_8.

Cretaceous (?) Formations in Basin and Range Province. In Santa Cruz County, uranium occurrences have been found in altered, fractured and faulted arkosic sandstone and conglomerate believed to be Cretaceous in age. The classification of the origin of these generally small occurrences is uncertain and the average grade is low. Potential resources are considered to be negligible.

Tertiary and Quaternary Formations. Throughout the Basin and Range physiographic province (Fig. 1), which covers the southwestern half of Arizona, uranium occurrences are known in Tertiary or later sediments. Most of these are associated with lake deposits in which interbedded sandstone, shale, mudstone, bentonitic material, gypsum, and volcanic ash or tuff occur. Carbonaceous trash or plant remains have been identified in some and are suspected in others. Opalitic silica and calcium carbonate are common associates. Most have received little more than superficial reconnaissance examinations and only one has been more thoroughly prospected. Other occurrences of this age group are found on fractures in interbedded volcanics and sandstones. A few occurrences have associated copper and manganese minerals, fluorite and barite, but most contain only uranium and vanadium mineralization which is usually of the carnotite type. Vegetal matter is sometimes present in the sediments.

In general the sedimentary and volcanic material at these occurrences accumulated in intermontane basins which received most of their debris from the local, bordering rocks undergoing erosion and from volcanic outburst. The occurrences of uranium are usually small, spotty, and low grade. The Uranium Aire Group in southwestern Yavapai County, which is the only one that has been prospected in any detail, shows the greatest promise for possible commercial production if economic factors become favorable. It is the only known deposit having potential resources of at least several thousand tons of moderate grade.

Considering the vast amount of Tertiary-Quaternary sediments in the southwestern half of Arizona, the possibilities for additional potential resources in the numerous basin areas cannot be excluded. Lake sediments containing tuff and ash beds, sediments close to areas of volcanic activity and interbedded arkosic sediments and volcanics are particularly interesting for exploration. Because such deposits may be hidden by more recent sedimentation, any drilling or exploration in these basins should be carefully logged and checked for indications of uranium deposition.

ORIGIN OF URANIUM

Many geologists have speculated over the source of the uranium mineralization in the sandstone-type deposits. Finch (1967, p. 35–93) has reviewed and summarized the various theses proposed and has given his own well-founded conclusion on the most probable origin of this type of uranium deposit. He noted that all deposits have certain common characteristics such as host rock types, probable times of deposition, favorable sources of metallic elements, and a logical method and manner of transportation and deposition.

The host rocks for sandstone-type deposits in Arizona are usually continental, fine- to medium-grained sandstones with interbedded mudstone and claystone seams. Often the sandstones tend to be silty and to contain considerable secondary carbonate as cement or as replacement of original constituents. In almost all cases the sedimentary beds were deposited in shifting, meandering and aggrading stream systems over low gradient, broad alluvial fans or in poorly drained basins. The sediments contained a considerable amount of iron oxide. Logs and plant material were rafted along the streams to be deposited along the channels or to be accumulated where stream velocities decreased such as in channel bends or meanders or on the flood plains. Continuous and intermittent aggrading action by the shifting streams buried the lensing sandy, silty and muddy beds containing the logs and carbonaceous debris and compaction began. The amount of carbonate in the rocks suggests that the trapped connate water was essentially alkaline in chemical composition and with compaction, the alkaline water became concentrated in the more porous sandy beds. The beds were flat-lying and subsequently were only moderately deformed by folding. Any ground water movement would have been slow and confined to the more permeable courses in channel sand beds or sandstone strata, particularly where confined by underlying or overlying seams of impermeable mud and clay. The porosity and permeability of such channelways could continue for considerable time, permitting slow ground water movement and access and passage of solutions containing foreign chemical constituents.

The age of the deposits cannot be determined with certainty. The best geologic and isotopic data are somewhat contradictory and suggest only a broad time span. The deposits show no clear genetic relationship to local deformation or igneous intrusion, but structural features on a regional scale could have played an important role. Tilting occurred in the Jurassic-Early Cretaceous interval associated with the uplift in southern Arizona. This movement affected stream flow and movement of ground water charged with dissolved metals through potential sedimentary host rocks. The erosion and liberation of uranium and other metals from volcanic debris in pre-Cretaceous rocks in northern Arizona and the importation of any metals in solution from sources in southern Arizona appears to have occurred mainly prior to the deposition of Upper Cretaceous beds. Isotopic dating has produced widely divergent results which have been given diverse interpretations. The lack of knowledge of the original isotopic composition of the uranium and other elements of the deposits as well as what additions or subtractions of radioactive products or isotopic components may have occurred after deposition confuses the interpretations. It seems certain that many of the deposits result from a succession of transport and deposition stages.

The source of the uranium and other metallic elements has been a matter of speculation. A hydrothermal source has been proposed.

Although it is impossible to rule out the influence of some hydrothermal sources, a direct relationship seems tenuous. Even a telethermal origin, representing the terminal phase of ascending hydrothermal solutions, would require through-going fractures connected with some deep or distant source, extremely widespread migration of hydrothermal solutions to loci of deposition, and relatively high concentrations of mineralizers to overcome the amount of dilution that would occur when mixed with large amounts of barren groundwater. There is no indication of identifiable hydrothermal alteration associated with the occurrences nor have diagnostic hydrothermal gangue minerals been found.

There is considerable evidence that the mineralization could have been derived from trace amounts of uranium and vanadium occurring in near-surface rocks such as the host rocks and associated rocks, or occurring in the connate waters. Volcanic ash averages about 5.6 parts per million uranium (Adams, 1954), the highest average known for major rock types. The formation of bentonitic clay by devitrification and weathering of volcanic ash could release uranium in solution. Bentonitic clay, believed to be derived from volcanic ash has been found in Morrison, Chinle and other rocks associated with uranium deposits. The volcanic material need not be the major constituent in the sediments because relatively small quantities in a large volume of sediments could furnish enough uranium to account for all of the occurrences in the sandstone-type deposits. A source of vanadium similarly can be traced to the destruction, by weathering, of the heavy black sand minerals commonly present in sedimentary sandstone beds or in detritial clays and to the weathering of volcanic flows. Such materials contain a trace or more of vanadium that can be taken up in solution. Another likely source of the uranium and other metals was the Precambrian granitic rocks in the highlands to the south and west.

Experiments indicate that moderate to rich alkaline bicarbonate solutions are capable of dissolving and transporting uranium and vanadium. As previously indicated the water in the continental sediments during and after deposition was alkaline in character, probably an alkaline bicarbonate. A solution of this type could carry the metals in a dissolved state. With continued compaction, solutions could have been squeezed out and caused to flow slowly downward along permeable zones, changing their stratigraphic position only when encountering impermeable zones or channelways provided by crosscutting fractures. The movement of mineralized solutions in the essentially horizontal beds would continue to be slow and uniform except when affected by the influx of fresh ground water, by increased flow gradients due to tectonic movements or igneous intrusions, or when impeded by stratigraphic or structural barriers. Ground water movement is widespread but varies in rate of movement and direction, depending not only on the attitude of the rocks and surface topography but also on the relative permeabilities of rocks. Mineralized solutions percolating through the clastic rocks may have been channeled into some localities and excluded from others.

The alkaline mineralized solutions, although weak in dissolved metal compounds, would precipitate low valent metallic minerals upon encountering reducing conditions such as would occur when carbonized wood or debris, hydrogen sulfide from decay of organic material, or iron sulfides were present. Such deposition would not necessarily be entirely concordant to sedimentary structures because the physical-chemical conditions causing deposition may have been discordant. Thus "rolls," those mineralized bodies having curved surfaces and having a form that may be cylindrical, concentrically banded or other geometric shape, partly conforming to sedimentary structures and partly cutting across the bedding, may be formed. Under such oxidizing conditions, the common hydrous uranium vanadates, carnotite and tyuyamunite, formed. Precipitation would cease when the mineralizing solutions were depleted, the reducing conditions no longer active or when the influx of fresh non-mineralized water flushed out the mineralized solutions. Also, with time and a changing physical and chemical environment, mineralized occurrences could be eroded away or redissolved to move to new loci of deposition or carried away completely. Many sandstone-type deposits represent two or more generations of mineralizing activity and are distant from the original depositional site in both space and time. A combination of all these factors is believed to be responsible for the sometimes scattered and sometimes clustered occurrences of uranium in sandstone-type deposits.

Diatremes and Pipe-Like Bodies

One of the major types of uranium occurrences in Arizona has been the diatreme and pipe-like bodies that occur in the Colorado Plateau province. These occurrences are briefly described in Table L and their locations shown in Plate 18.

Both types of structure consist of nearly vertical, round or oval bodies of deformed rocks that break through essentially flat-lying sedimentary formations. They have characteristics of both vein and sandstone-type deposits and the origin of their mineralization is in doubt.

Diatremes are volcanic vents or pipes explosively blasted through overlying rocks by gas charged magmas. In Arizona about 150 of these structures are clustered in the southeastern corner of the Hopi Indian Reservation and the bordering area on the Navajo Indian Reservation. Others are located in the Monument Valley area and along the northeastern border of Arizona with New Mexico. These diatremes were first studied in detail by Hack (1942) and later were prospected for uranium (Shoemaker, 1956; Shoemaker, Roach, and Byers, 1962).

The Hopi Buttes diatremes range from a few hundred to a few thousand feet in diameter and normally flare out at the surface. Although containing massive tuff, breccia, blocks of country rock, agglomerate and alkaline basalt in depth; near the surface they often have a basin-like form in which a variety of clastic materials have accumulated such as bedded tuff, limestone, clay, silt and evaporites. The uranium occurrences in these structures are associated mainly with the limestone and clastic beds of the Bidahochi Formation of Pliocene age that are interbedded with sandstone and rhyolitic tuffs and ash. The uranium-bearing minerals are mostly unidentified and most occurrences are very low grade. A few deposits have produced a few tens of tons.

The origin of the uranium mineralization in the diatremes is still in dispute; whether from hydrothermal origin or from solution and re-deposition of uranium in the Bidahochi volcanic strata. In any case the deposits are generally small and low grade and not a likely potential source for uranium.

The pipe-like bodies containing uranium occur mainly in the Grand Canyon region and appear to have originated by the solution of Mississippian Redwall Limestone and the collapse of the overlying flat-lying strata as a breccia-filling into the resulting void along fairly sharp vertical walls. Six such structures are known that exhibit various stages of collapse; the best developed, mineralized and explored is the Orphan mine on the south rim of the Grand Canyon. Finch (1967, p. 83, Fig. 11) has indicated a close association of these collapse pipe-like bodies to major fault structures and has shown inferred sections of them in his Figure 12. The mineralogy in some is relatively simple, consisting of copper and iron sulfides and oxides with uraninite and secondary uranium minerals. In others zinc and lead minerals also occur. At the Orphan mine the mineralogy is much more complex. Mineralization generally is localized around the perimeter of collapse structure but at the Orphan mine, ore also occurs in the highly brecciated central interior. Some mineralization is in veins and some occurs as beds in permeable sandstone blocks.

The source of the uranium is unknown but it may be hypogene. There is good evidence, however, that there has been considerable solution and redeposition since its original introduction. This is suggested by the large amount of supergene enrichment.

The Orphan mine has produced about 500,000 tons of good grade uranium ore and is estimated to have reserves and potential resources of several hundred thousand tons. The deposit was located and developed for copper in the early 1900's but the presence of uranium mineralization was not noted until 1951. The lack of a suitable nearby mill is the major deterrent to production from this deposit at the present time. Similar deposits have produced a few hundred tons of ore and probably contain a few thousand tons of potential resources.

It appears probable that undiscovered pipe-like uranium-bearing deposits occur in the Grand Canyon area but because of their relatively small size and concealed outcrops they will be difficult and expensive to find.

Vein-Type

In this report the term "vein-type" is used in a restrictive and arbitrary sense to cover certain mineralized, cross-cutting cracks and fissures. It excludes pegmatites, diatremes and pipe-like bodies, and also those cases where mineralization in a structure appears to have been deposited from either surface or groundwater solutions. In many cases there is no clear-cut evidence of the origin of the uranium, whether from hypogene or supergene solutions. Walker and others (1963) reviewed the geology of uranium-bearing veins in the United States and other geologists have discussed their origin and types. In Arizona the only vein-type occurrences of economic significance are those in the Dripping Spring Quartzite in the Sierra Ancha area of northern Gila County.

DRIPPING SPRING QUARTZITE

Uranium in the Precambrian Dripping Spring Quartzite formation was first noted in 1950 but it attracted little interest because of the rugged topography, inaccessibility, and difficult forest terrain of the Sierra Ancha region. Subsequent discoveries and reports by AEC geologists (Wright, 1950; Kaiser, 1951; Mead and Wells, 1953; and Wells and Rambosek, 1954) and the identification of additional radioactive anomalies by an airborne radiometric survey in 1954 (Magleby and Mead, 1955) led to a claim-staking rush. From 1953 into 1956 some 120 reported occurrences were visited and at least briefly examined by government geologists. For a while a buying depot at Cutter was opened but soon closed because the amount, grade, and type of the uranium shipments did not justify the operational expense. The total recorded production amounted to about 23,000 short tons averaging 0.23 percent U_3O_8, and except for a few cases the mining operations barely met expenses, even under bonus prices for uranium.

Gastil (1953), Sharp (1956), Williams (1957) and Granger and Raup (1959, 1964, 1969a and 1969b) have studied and described the geologic setting of the uranium occurrences. The Dripping Spring Quartzite is a unit of the Apache Group of Younger Precambrian age. The group

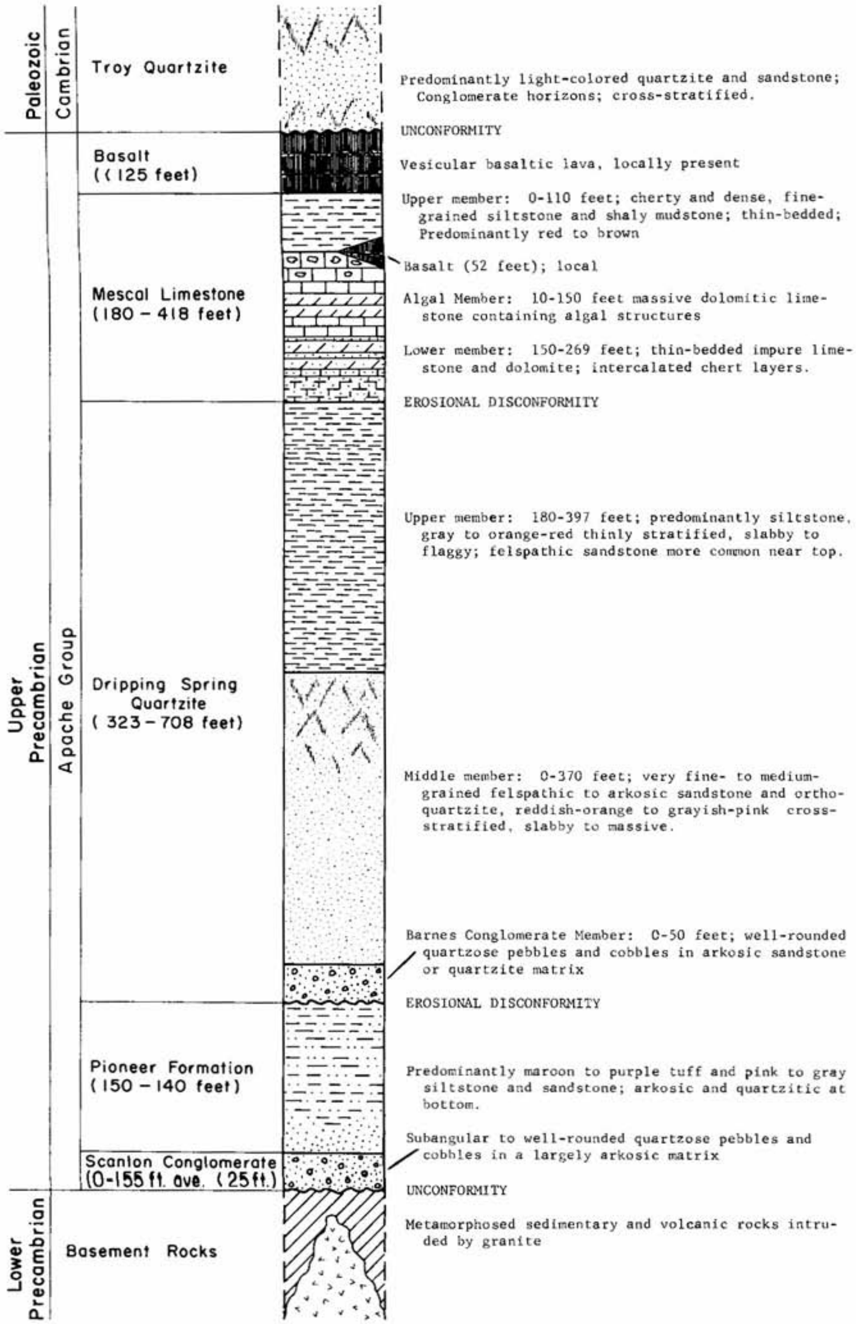

Figure 17. Generalized section of Apache Group, Gila County, Arizona. (After Granger and Raup, 1964.)

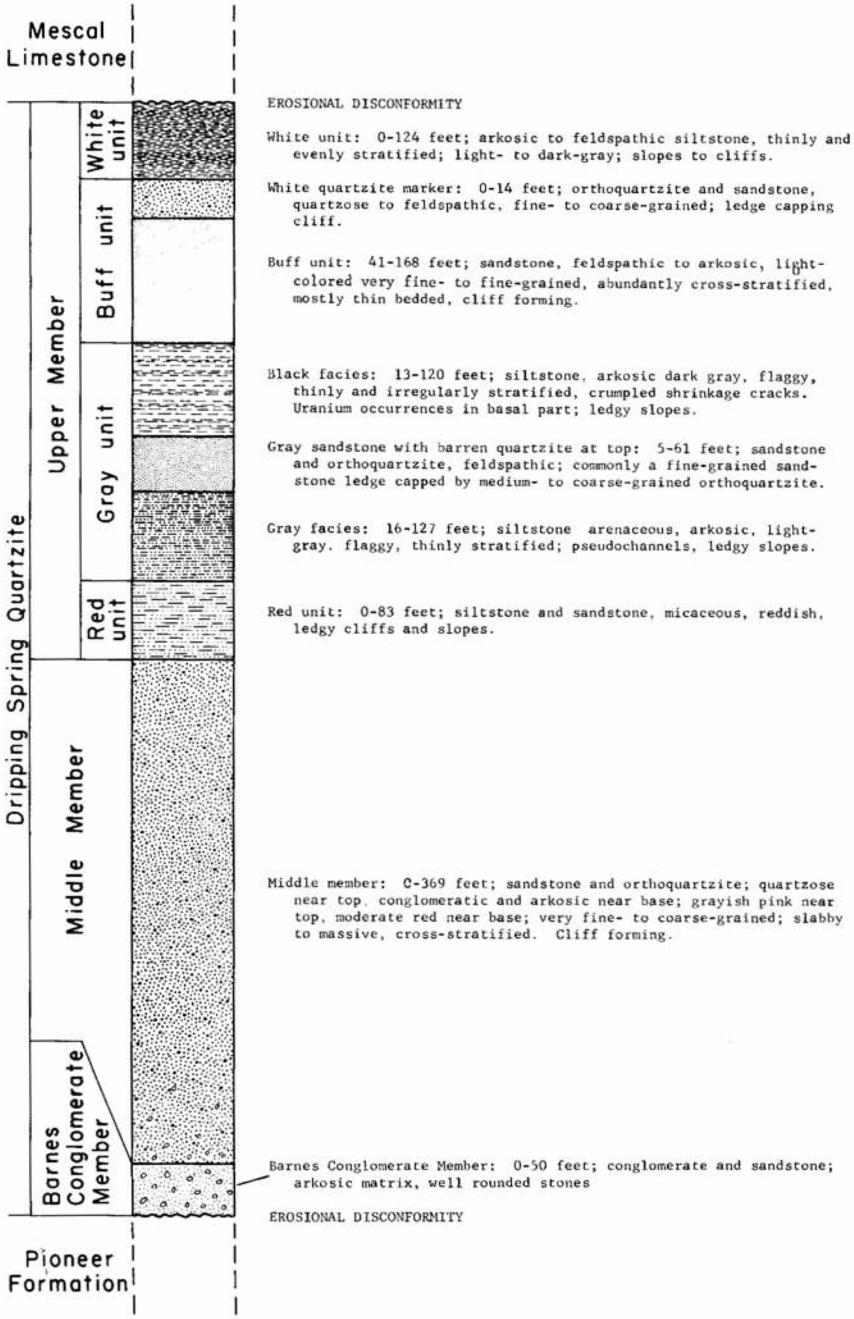

Figure 18. Generalized section of Dripping Springs Quartzite. (After Granger and Raup. 1964.)

consists of conglomerate, sandstone, quartzite, siltstone, dolomitic limestone, and basalt flows (Fig. 17). Its extent is shown in Plate 19. The only notable uranium occurrences are in the upper member of the Dripping Spring Quartzite in the eastern half of Gila County. A generalized columnar section of the Dripping Spring is shown in Figure 18.

Of the four units in the upper member, the gray unit is the principal host for almost all known uranium occurrences and this unit consists of three facies (Granger and Raup, 1964); a bottom sixty-foot gray, thinly- and irregularly-stratified feldspar-rich siltstone; a middle, 15–30 feet, fine- to medium-grained feldspathic sandstone topped by a thin quartzite; and a top 70 to 80 feet of dark gray to black thinly-and-irregularly-stratified feldspar-rich siltstone containing very finely-divided carbon and pyrite.

Older Precambrian granitic rocks showing abnormally high radioactivity underlie the Apache Group. The major intrusive rock affecting the Dripping Spring Quartzite is diabase which invaded the group with multiple intrusions in the form of concordant and discordant, massive sheets with interconnecting large and small dikes. These sheets range from a few feet to 1,000 feet thick and may be limited to small local lenses or extend over several square miles. The dikes also vary greatly in thickness and length. The largest and thickest individual sheet, called the Sierra Ancha sheet by Granger and Raup, lies in the central part of the district and is associated with the strongest and most consistent mineralization. The diabase exhibits differentiation and late-magmatic deuteric alteration close to the contacts and these contact zones show somewhat higher radioactivity than the normal diabase. Hornfels with even higher radioactivity have developed in some of the adjacent siltstones by contact metamorphic action. The apparent association of uranium with differentiation and deuteric alteration, and the favorability of the hornfels for uranium deposition suggests a genetic relationship between the mineralization and diabase.

A series of strong north to northwest trending monoclines were developed in the Apache Group and older rocks before and during diabase intrusion. Some have associated longitudinal faults. Both folds and faults influenced the course of the intrusions. Jointing and fracturing of the Dripping Spring Quartzite is pronounced but these structures normally seem to be tight and well cemented. However, uranium mineralization appears to have been channeled by and deposited in these structures.

The more significant uranium occurrences are listed in Table M and their locations with corresponding numbers are shown in Plate 19. They have characteristics of both vein and bedded deposits but are seldom well defined. The majority are steeply-dipping tabular bodies extending outward with assay walls from a central, more intensely mineralized zone or fracture. The width of the zones vary from less than one foot to no more than about three feet. Vertically they may extend up to eighty feet but are usually much less. Their strike length is normally a few tens of feet but some are several hundred feet long. In places the mineralization flares out horizontally to form small, thin, bed-like replacements in the wall rock. The mineralization is very fine-grained, consisting mainly of uraninite and minor metallic sulfides where unoxidized and a variety of secondary uranium and metallic minerals near the surface. Only a few occurrences have produced tonnages with as high as 0.2 percent U_3O_8.

There are no reserves in the Dripping Spring Quartzite that can be economically mined at the present time. Potential resources averaging 0.1 percent U_3O_8 might amount to several hundred thousand short tons, but this tonnage is scattered in small- to medium-sized occurrences. Because of the nature of the host rock, accessibility, and other economic factors, successful mining would require a high price for uranium.

MISCELLANEOUS VEIN OCCURRENCES

Numerous small vein-type occurrences have been found in Arizona, mainly in close association with intrusive and extrusive rocks in the Basin and Range province. They are listed in Table N and shown with corresponding number in Plate 19. About a dozen of these occurrences have produced, collectively, a few hundred tons of uranium-bearing rock largely as test lots. The host rocks are mainly Precambrian granitic rocks and rhyolitic rocks of various ages. Also some have been found in Mesozoic granitic intrusives and a few in Precambrian schist. Mafic dikes are often present in the intrusives. The associated metalliferous minerals are most commonly base metal sulfides, or their oxidation products, and fluorite is present as a gangue mineral in many occurrences.

The most common uranium mineral in unoxidized occurrences is sooty uraninite, which may possibly represent solution and redeposition of earlier uranium minerals. The secondary uranium minerals are mainly uranophane, autunite, kasolite and torbernite. The uranium minerals are more likely to appear along selvage planes bordering the vein-type structures than in the main vein filling. In some cases the uranium has been judged to be early in the mineralization sequences and in others late. The exact age of the uranium can seldom be determined.

The miscellaneous vein-type occurrences of uranium are very spotty and small. None could be mined for uranium alone and the economic extraction of minute quantities that might be present in base sulfide ore is usually impractical. No potential resources are estimated.

Pegmatites

Numerous reports have been made of uranium-bearing minerals found in pegmatites in Arizona. A few tons and specimen crystal pieces of the complex rare-earth, niobium, tantalum and titanium-bearing minerals (euxenite, fergusonite and samarskite) and the rare-earth silicate (allanite) have been found scattered in the pegmatites of the pegmatite zone in western Arizona, particularly near Kingman and in the Aquarius Range. Such minerals may contain a few hundredths to several percent uranium, but collectively they can add but little to the output of uranium because they cannot be mined economically for the uranium content and also are refractory and require special and expensive metallurgical treatment.

Placer

Some uranium-bearing minerals have been reported in placer-type deposits in Arizona, notably in the black sand accumulations near the Black Mountain Trading Post, Apache County, in Cretaceous beach sands containing ilmenite and niobium-tantalum minerals. Weak radioactivity due to traces of uranium and thorium have been noted in the heavy black mineral concentrates. In a large area southwest of Tucson (T. 16 S., R. 12 E.), weak concentrations of urano-thorite and zircon occur in sands resulting from the decomposition and erosion of granitic rocks (Robison, 1955, AEC PRR A–P–344). Under both present and foreseeable economic conditions these are not considered to be of commercial importance.

SUMMATION AND CONCLUSIONS

Consideration of the uranium resources of Arizona must take into account geographic and geologic aspects and economic factors such as production costs, prices, and markets. An occurrence of uranium cannot be considered a resource unless there is reasonable expectancy that it can be mined, milled, and sold at a profit under foreseeable conditions. As applied in this report, the term "resources" covers all uraniferous material in the ground known to be minable now or likely to be minable in the future. "Reserves" are that part of the resources that have been sufficiently explored to provide quantitative estimates of tonnage and grade and are economically exploitable at the time of the estimate. "Potential resources" are those resources, known or suspected, that are not minable at the present time due to economic conditions and those that have not yet been disclosed but which might be found and become minable in the future. An excellent summary of the geology, production and resources of uranium in Arizona is given by Butler and Byers (1969). This review and summary expands on their report.

The resources of uranium have received more attention and study than any other metal. Both government and private geologists and agencies have supplied a large mass of data on uranium deposits and their characteristics. The intense search for domestic sources of uranium since the 1940's covered almost every section of Arizona. Although many of the examinations were of a reconnaissance nature, no completely new occurrence has been found in recent years. Through 1969, Arizona had supplied only about four percent of the total United States production of uranium and its estimated resources would constitute a similar small percentage of the total resources estimated for the country as a whole. In comparison with the known resources of New Mexico, Wyoming, Utah, Colorado and Texas, the Arizona resources would appear to be insignificant. No uranium is being produced in Arizona at the present time.

From 1942 through 1969, estimates and published figures would indicate that Arizona's production of uranium has amounted to about 2.99 million tons of ore containing about 8.9 thousand tons of U_3O_8 at a value of around $76.1 million (Butler and Byers, 1969; U.S. Bureau of Mines Mineral Yearbooks; and AEC, 1969). Figures on the resources of uranium in Arizona as of January 1, 1970, are not available and can only be roughly estimated. The U.S. Atomic Energy Commission's estimate of some 125,000 tons of ore averaging at least 0.4 percent U_3O_8 as the minable reserves of Arizona on January 1, 1967, cannot be applied to the present. Some of this reserve has been mined, the market price for U_30_8 has been reduced, there are no active uranium mills within economic transportation distances, and only a small amount of new exploration and development work has been carried out in recent years to replenish the reserves. Furthermore, most if not all of the previously existing leases on the Navajo Indian Reservation, where part of the uranium reserves had been estimated, have now expired and it appears likely that the financial obligations under any new negotiated leases will be higher than in the past. In essence therefore, no uranium ore can be strictly classed as "reserve" at the present time.

In the matter of potential resources, Arizona does have possibilities of a considerable tonnage of uraniferous material averaging a possible 0.2 percent U_3O_8. A few hundred thousand tons of such material may still be found in and around the known deposits mined in the past in the Shinarump and Petrified Forest members of the Chinle Formation in the Monument Valley and Cameron districts, in the Salt Wash Member of the Morrison Formation in the northwest Carrizo and Lukachukai Mountains districts, and in the Toreva Formation of northeastern Black Mesa. Based on past experience most of any new deposits found would be relatively small and scattered. A potential also exists for presently unknown deposits in these formations where covered by later formations. Such is the case of the Chinle in the general Black Mesa basin area where it is deeply buried. Again, such deposits are likely to be small and scattered, difficult and expensive to find, and it becomes questionable if such deposits can be considered potential resources at foreseeable uranium prices. Another possible resource could occur in Tertiary sedimentary basins such as in southwestern Yavapai County where a possible 100,000 tons or more of 0.2 percent U_3O_8 may be present. Other such deposits may exist, and as yet not found, in Tertiary sedimentary basins such as the Tonto and Safford basins. At present there is not enough information to determine if geologic conditions were favorable for uranium deposition in these areas. Another possible source yet to be evaluated is the recently prospected uranium occurrence in the Supai Formation along the Mogollon Rim. At present this can only be considered as a marginal possibility but one that deserves close examination.

The collapse-pipe deposit at the Orphan mine still has a reasonable potential of several hundred thousand tons of 0.2 to 0.4 percent U_3O_8 that would be minable if there was a mill within economic distance. Other collapse-pipe deposits may well be present in the Grand Canyon area but hidden by covering formations. They present a small and expensive target for discovery.

The occurrence of uranium in diatreme, vein, pegmatite and placer deposits in Arizona represent marginal mineralization at best. Those in the Dripping Spring Quartzite in the Sierra Ancha area may contain as much as 100,000 tons or more of 0.1 to 0.2 percent U_3O_8, but this mineralization can only be mined at high cost and is metallurgically difficult to treat. Thus it is not likely to be mined under foreseeable uranium prices

In summation, reasonably expected potential resources of uranium mineralization in Arizona that might average 0.2 percent U_3O_8 may amount to about 600,000 tons. Presently undiscovered deposits that might be minable at foreseeable uranium prices up to $15 per pound U_3O_8 could double that figure. At even higher prices a few hundred thousand tons of marginal mineralization might be added. As noted earlier, much depends on the various geographic, geologic and economic factors.

The geographic factors of importance are location of the deposit in respect to transportation facilities, status of land and mineral ownership (Indian, Federal, State, private), accessibility, and distance to the nearest suitable uranium mill. All of these can affect the economic outcome of future uranium production in Arizona.

The geologic factors are most important in assessing the potential resources of the State. Finch (1967) has fully summarized the characteristics of the sandstone-type uranium deposits, noting their geographic and stratigraphic distribution, lithology, depositional history, chemical and mineral character, and the guides to favorable conditions for uranium deposition. The favorable geologic factors appear to be:

1. Continental sedimentation, preferably quartzose and arkosic, consisting of lensing, medium-to-coarse-grained sandstone and

conglomerate containing interbedded seams and lenses of mudstone; such sediments having been laid down on poorly drained deltas and alluvial fans by braided stream systems producing shifting and meandering channels. Thick clean sandstone members and formations and dense argillaceous beds are less favorable.

2. Regional unconformities where channels and scours in the channels have been filled with interbedded conglomerate, sandstone, and mudstone lenses.
3. Areas of pinch-outs of the coarser sediments or where they intertongue with finer grained facies are often favorable loci.
4. The presence of carbonized plant remains is noted in almost all sandstone-type uranium deposits. Where only the carbonized material is replaced or the plant material is silicified rather than carbonized, the conditions for substantial uranium mineralization are less favorable.
5. Tuffaceous volcanic debris, mostly altered to bentonitic clay, is usually closely associated with the host sediments, either in them or in neighboring members or formations. It is strongly suspected that a large amount of the uranium and associated metals were derived from the trace amounts contained in the tuffaceous debris.
6. The sedimentary host rocks should not be strongly deformed. Initial and subsequent dips should have been low to permit slow movement of mineralizing solutions through the rock. Steep uniform dips would likely cause flushing away of the mineralizing solutions. Flat dip would not permit the flow of the solutions to favorable loci for deposition.
7. Most sandstone-type uranium deposits show associated iron, vanadium or copper, and more rarely other metals. The colorful secondary minerals of these metals often mark the location of uranium deposits.
8. Bleaching of the sandstone and mudstone, from red to lighter colors, is a common feature around sandstone-type uranium deposits.

The major host rocks for sandstone-type uranium occurrences in Arizona are the Supai Formation, the Shinarump and Petrified Forest members of the Chinle Formation, the Salt Wash Member of the Morrison Formation, the Toreva Formation and some Tertiary lake beds. All of these exhibit, in part, most of the geologic factors listed above. They contain all of the estimated sandstone-type resources of uranium in the State, and are the most favorable for future prospecting for additional resources wherever favorable conditions exist.

The collapse-pipe deposit at the Orphan mine has been a major source of uranium in Arizona and recognition of the structural and stratigraphic features of these pipes is necessary for finding additional similar deposits. Any evidence of mineralization in the collapse of flat-lying sediments in a chimney-like structure should be checked for the occurrence of uranium.

Diatreme, vein, pegmatite and placer deposits, although so far found to be less favorable for economic deposits of uranium in Arizona, should be checked for uranium mineralization. The chance that a minable concentration of uranium may occur should not be ignored.

The economic factors are many, but in general are no different than those for any mineral deposit. Much depends on the form, size and grade of the deposit and whether it can be mined by open cut or requires underground workings. Most of the uranium produced in Arizona has been mined from depths less than 200 feet from the surface and largely by open cut or from surface adits. Only the Orphan mine required deeper mining. It would appear that much of any future mining of resources in the State would be at greater depths and require underground mining. Most uranium deposits mined in Arizona in the past have been relatively small, less than 1,000 to 20,000 tons of ore per deposit and those over 100,000 tons are rare. It seems likely that most of Arizona's uranium resources would be in similar sized deposits. The average grade of Arizona's production has been close to 0.3 percent U_3O_8 but in the known uranium producing areas the higher grade material has been mined out. Unless substantial high grade material is found, the future average grade will be considerably lower. The potential resources of Arizona are estimated to average no higher than 0.2 percent U_3O_8.

A considerable amount of exploration will be needed to more closely define Arizona's potential resources. A large percentage of such exploration will have to be done by drilling, not only to find buried uranium deposits but also to find and outline favorable loci for uranium mineralization. Drilling depths will have to be greater than in the past. Considering the likelihood of small and scattered deposits, the average cost of exploration per pound of U_3O_8 found could approach or exceed $0.50.

Land acquisition could be an important item depending on ownership and leasing terms. Most of the favorable areas for sandstone-type deposits in Arizona lie within the Navajo Indian Reservation and depending on the lease terms negotiated, royalty payments could amount to a few cents or to several dollars per pound of U_3O_8 produced from deposits within the reservation.

Mining costs vary with the size of the operation, the degree of mechanization that is possible and feasible, the type of mining required, and above all the size and shape of the deposit. Few uranium mines in Arizona have produced more than 200 tons of ore a day and costs have averaged from about $20 to $40 per ton. Future costs will be higher and probably not less than $50 per ton.

There has been only one uranium mill located in Arizona, at Tuba City, which processed mainly the ore from the Cameron district and from the Orphan mine. All other ore was processed in mills outside the State. At present there is no active uranium mill within reasonable shipping distance of the Arizona potential deposits. Uranium mills require a feed of at least 200 tons a day and an assured ore supply for at least five years to be profitable. Milling costs vary with the type of ore and capacity but probably average about $1 to $1.50 per pound of U_3O_8 produced. The development of new metallurgical processes may make possible the economic treatment of lower grade material if found in substantial quantities.

Adding the average costs of the above items, plus transportation, capital and overhead costs, and a reasonable contingency, the total costs of producing a pound of U_3O_8 from most potential sources in Arizona would fall into the $10 to $15 range when considering current and foreseeable geographic, geologic and economic factors.

The price for uranium is presently depressed. The U.S. Atomic Energy Commission has greatly reduced its purchases and was scheduled to terminate its purchases at the end of 1970. Nuclear power plant construction has not progressed as rapidly as expected and uranium purchases for these plants have been deferred. As a result, the commercial market price for U_3O_8 is presently between $5 and $7 per pound. On the other hand, the projections for future requirements of U_3O_8 still stand although possibly the need will not develop as soon as expected. Reasonably assured reserves in the United States at prices up to $15 per pound of U_3O_8 do not appear to be sufficient to meet this projected future requirement and the potential resources in the same price range will be required to meet the shortage.

Arizona has a share, even if small, of the required potential resources of uranium. To explore for and develop these resources requires time and money. If the economic factors can be maintained at a reasonable level, the financial risks of exploring for uranium in Arizona may be justified by the prospects of a future market for uranium at prices that will make uranium mining in the State profitable. The best prospects still lie in the sandstone-type deposits in favorable sedimentary formations and no drill hole in such sediments should be overlooked for evidence of possible uranium mineralization.

LITERATURE CITED

Adams, J. A. S., 1954, Uranium and thorium contents of volcanic rocks, *in* Faul, Henry, ed., Nuclear geology — a symposium of nuclear phenomena in the earth sciences: New York, John Wiley & Sons, Inc., p. 89–98.

Adams, J. W., and Staatz, M. H., 1969, Rare earths and thorium, *in* Arizona Bur. Mines Bull. 180, p. 245–251.

Agasie, J. M., 1967, Upper Cretaceous palynomorphs from Coal Canyon, Coconino County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 104 p.

Akers, J. P., 1964, Geology and ground water in the central part of Apache County, Arizona: U.S. Geol. Survey Water Supply Paper 1771, 107 p.

Akers, J. P., Cooley, M. E., and Repenning, C. A., 1958, Moenkopi and Chinle formations of Black Mesa and adjacent areas, *in* Guidebook of Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 88–94.

Akers, J. P., Irwin J. H., Stevens, P. R., and McClymonds, N. E., 1962, Geology of the Cameron quadrangle, Arizona, with a section on uranium deposits by W. L. Chenoweth, AEC: U.S. Geol. Survey Map GQ-162.

American Society for Testing and Materials, 1966, Tentative specifications for classification of coals by rank, *in* 1966 Book of ASTM Standards, Part 19, Gaseous fuels; coal and coke: American Society for Testing and Materials, Philadelphia, Pa., p. 73–78.

Anderson, C. A., and Creasey, S. C., 1958, Geology and ore deposits of the Jerome area, Yavapai County, Arizona: U.S. Geol. Survey Prof. Paper 308, 185 p.

Anderson, C. A., Scholz, E. A., and Strobell, J. D., Jr., 1955, Geology and ore deposits of the Bagdad area, Yavapai County, Arizona: U.S. Geol. Survey Prof. Paper 278, 103 p.

Andrews, D. A., Hendricks, T. A., and Huddle, J. W., 1947, The coal fields of Arizona, California, Idaho, Nevada, and Oregon, *in* Analyses of Arizona, California, Idaho, Nevada, and Oregon coals: U.S. Bur. Mines Tech. Paper 696, p. 1–12.

Ankeny, M. J., 1962, A look at coal's future markets: Mining Congress Jour., v. 48, no. 6, p. 51–56.

Arizona Bur. Mines, 1958, 1959, 1960, County geologic map series: Arizona Bur. Mines, Tucson, Arizona.

Arizona Geol. Soc., 1952, Guidebook for field trip excursions in southern Arizona: Arizona Geol. Soc., 150 p.

Arnold, J. M., 1969, Discovery and development of Peabody Coal Company's Black Mesa Mine: Soc. Mining Engineers of AIME, Preprint No. 69-F-349, 18 p.

Austin, S. R., 1957, Recent uranium redistribution in the Cameron, Arizona, deposits, *in* Advances in nuclear engineering: New York, Pergamon Press, v. 2, p. 332–338.

————, 1964, Minerology of the Cameron area, Coconino County, Arizona: U.S. Atomic Energy Comm. RME-99, 99 p., Tech. Inf. Service, Oak Ridge, Tenn.

Averitt, Paul, 1961, Coal reserves of the United States — a progress report, January 1, 1960: U.S. Geol. Survey Bull. 1136, 85 p.

————, 1968, Stripping-coal resources of the United States: U.S. Geol. Survey Bull. 1252-C, 20 p.

————, 1969, Coal resources of the United States, January 1, 1967: U.S. Geol. Survey Bull. 1275, 116 p.

Averitt, P., and O'Sullivan, R. B., 1969, Coal, *in* Mineral and water resources of Arizona: Arizona Bur. Mines Bull. 180, p. 59–69.

Baars, D. L., 1962, Permian System of Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 2, p. 149–218.

————, ed., 1969, Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., Powell Centennial River Expedition, 212 p.

Bahr, C. W., 1962, The Holbrook anticline, Navajo County, Arizona, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 118–122.

————, 1963, Virgin oil field, Washington County, Utah, *in* Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petroleum Geologists, p. 169–171.

Bain, G. W., 1952, The age of the "Lower Cretaceous" from Bisbee, Arizona, uraninite: Econ. Geology, v. 47, p. 305–315.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlation 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.

Beaumont, E. C., and Dixon, G. H., 1965, Geology of the Kayenta and Chilchinbito quadrangles, Navajo County, Arizona: U.S. Geol. Survey Bull. 1202-A, p. A1–A28.

Beus, S. S., 1969, Devonian stratigraphy in northwestern Arizona, *in* Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., p. 127–133.

Bissell, H. J., 1969, Permian and Lower Triassic transition from the shelf to basin (Grand Canyon, Arizona to Spring Mountain, Nevada), *in* Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., p. 135–169.

Blake, W. P., 1898, Anthracite coal in Arizona: Am. Geologist, v. 21, p. 345–346.

Bollin, E. M., and Kerr, P. F., 1958, Uranium mineralization near Cameron, Arizona, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 164–168.

Brady, L. F., 1946, Coal Mine Canyon: Plateau [Flagstaff, Ariz.], v. 19, no. 2, p. 17–20.

————, 1962, Note on the "Alpha" member of the Kaibab Formation, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 42.

Brady, L. F., and Greig, J. W., 1939, Note on a temperature attained in burning coal seams: Am. Jour. Sci., v. 237, p. 116–119.

Brew, J. O., and Hack, J. T., 1939, Prehistoric use of coal by Indians of northern Arizona: Plateau [Flagstaff, Ariz.], v. 12, no. 1, p. 8–14.

Broderick, F. N., 1969, Supply and demand for energy in the United States by states and regions, 1960 and 1965; part 1, coal: U.S. Bur. Mines Inf. Circ. 8401, 21 p.

Bryant, D. L., 1955, Stratigraphy of the Permian System in southern Arizona: Univ. Arizona (Tucson), unpub. PhD thesis, 209 p.

———, 1968, Diagnostic characteristics of the Paleozoic formations of southeastern Arizona, *in* Southern Arizona Guidebook III: Arizona Geol. Soc., p. 33–47.

Butler, A. P., Jr., and Byers, V. P., 1969, Uranium, *in* Mineral and Water Resources of Arizona: Arizona Bur. Mines Bull. 180, p. 282–292.

Butler, A. P., Jr., Finch, W. I., and Twenhofel, W. S., 1962, Epigenetic uranium deposits in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey Mineral Inv. Resource Map MR-21, 42 p. text, incl. loc. index.

Butler, G. M., and Allen, M. A., 1921, Uranium and radium: Arizona Bur. Mines Bull. 117, 26 p.

Butler, G. M., and Tenney, J. B., 1931, Petroleum: Arizona Bur. Mines Bull. 130, 50 p.

Butler, W. C., 1969, The Upper Paleozoic stratigraphy of Total Wreck Ridge, Pima County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 138 p.

Cadigan, R. A., 1963, Tuffaceous sandstones in the Triassic Chinle Formation, Colorado Plateau: U.S. Geol. Survey Prof. Paper 475-B, p. B48–51.

Campbell, J. A., 1969, Upper Valley oil field, Garfield County, Utah, *in* Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., p. 195–200.

Campbell, M. R., 1904, The Deer Creek coal field, Arizona: U.S. Geol. Survey Bull. 225, p. 240–258.

———, 1929, Coal resources of the United States: U.S. Geol. Survey press release, 6 p.

Campbell, M. R., and Gregory, H. E., 1911, The Black Mesa coal field, Arizona: U.S. Geol. Survey Bull. 431-B, p. 229–238.

Chenoweth, W. L., 1955, The geology and the uranium deposits of the northwest Carrizo area, Apache County, Arizona, *in* Guidebook of geology of parts of Paradox, Black Mesa, and San Juan basins: Four Corners Geol. Soc., 1st Field Conf., p. 177–185.

———, 1962, Section on uranium deposits, *in* Akers, J. P., Irwin, J. H., and McClymonds, N. E., 1962, Geology of the Cameron quadrangle, Arizona: U.S. Geol. Survey Map GQ-162.

———, 1967, The uranium deposits of the Lukachukai Mountains, *in* Guidebook of Defiance-Zuni-Mt. Taylor region, Arizona and New Mexico: New Mexico Geol. Soc., 18th Field Conf., p. 78–85.

Chester, J. W., 1951, Geology and mineralization of Hunt's Mesa, Monument Valley, Arizona: U.S. Atomic Energy Comm. RMO-801.

Clinton, N. J., 1956, Uranium reconnaissance of the Black Mountain-Yale Point area, Black Mesa, Navajo Indian Reservation, Arizona: U.S. Atomic Energy Comm. RME-91, 24 p.

Clinton, N. J., and Carithers, L. W., 1956, Uranium deposits in sandstones of marginal marine origin: U.S. Geol. Survey Prof. Paper 300, p. 445–449.

Coal News, 1965, Peabody to mine Indian coal for "WEST" plant: Coal News, no. 3765 (Oct. 1, 1965), p. 2.

Cooley, M. E., 1958, Physiography of the Black Mesa Basin area, Arizona, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 146–149.

———, 1967, Geologic map, explanation, and geologic history of Arizona, *in* Arizona highway geologic map: Arizona Geol. Soc., Tucson, Arizona.

Cooley, M. E., Akers, J. P., and Stevens, P. R., 1964, Selected lithologic logs, drillers' logs, and stratigraphic sections, *in* Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah, Part III: Arizona State Land Dept., Water Resources Report No. 12-C, 157 p.

Cooley, M. E., Harshbarger, J. W., Akers, J. P., and Hardt, W. F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 521-A, 61 p., maps.

Cooper, H. M., Snyder, N. H., Abernathy, R. F., Tarpley, E. C., and Swingle, R. J., 1947, Analyses of mine, tipple, and delivered samples, *in* Analyses of Arizona, California, Idaho, Nevada, and Oregon coals: U.S. Bur. Mines Tech. Paper 696, p. 27–47.

Cooper, J. R., and Silver, L. T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 416, 196 p.

Craig, L. C., and others, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region: U.S. Geol. Survey Bull. 1074-D, p. 125–164.

Crawford, A. L., ed., 1963, Oil and gas possibilities of Utah, re-evaluated: Utah Geol. and Mineralogical Survey, 564 p.

Creasey, S. C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima counties, Arizona: U.S. Geol. Survey Misc. Geol. Investigations Map I-470.

Dare, W. L., 1959, Underground mining methods and costs at three Salt Wash uranium mines of Climax Uranium Co.: U.S. Bur. Mines Inf. Circ. 7908, 36 p.

————, 1961, Uranium mining in the Lukachukai Mountains, Apache County, Arizona, Kerr-McGee Oil Industries, Inc.: U.S. Bur. Mines Inf. Circ. 8011, 30 p.

Darton, N. H., 1925, A résumé of Arizona geology: Arizona Bur. Mines Bull. 119, 298 p.

Davis, G. E., Hardt, W. F., Thompson, L. K., and Cooley, M. E., 1963, Records of ground-water supplies, *in* Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah, Part I: Arizona State Land Dept., Water Resources Report No. 12-A, 159 p.

Devereaux, W. B., 1881, The Deer Creek coal fields, Arizona: Eng. Mining Jour., v. 32, p. 404–405.

Dirks, T. N., 1966, The upper Paleozoic stratigraphy of the Quimby Ranch area, Southern Guadalupe Canyon quadrangle, Cochise County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 79 p.

Dodd, P. H., 1956, Examples of uranium deposits in the upper Jurassic Morrison Formation of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 300, p. 243–262.

Doeringsfeld, Amuedo, and Ivey, 1958, Generalized tectonic map of the Black Mesa Basin, showing major structural features, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 145.

Dumble, E. T., 1902, A carboniferous coal in Arizona: Am. Geologist, v. 30, no. 4, p. 270.

Dunlap, R. E., 1969, The geology of the Pinta Dome-Navajo Springs helium fields, Apache County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 73 p.

Eardley, A. J., 1949, Paleotectonic and paleogeologic maps of central and western North America: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 655–682.

Ellsworth, P. C., and Hatfield, K. G., 1951, Geology and ore deposits of Mesa 6, Lukachukai district, Arizona: U.S. Atomic Energy Comm. RMO-802, 12 p.

Epis, R. C., and Gilbert, C. M., 1957, Early Paleozoic strata in southeastern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, p. 2223–2242.

Epis, R. C., Gilbert, C. M., and Langenheim, R. L., 1957, Upper Devonian Swisshelm Formation of southeastern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, p. 2243–2256.

Evensen, C. G., and Gray, I. B., 1958, Evaluation of uranium ore guides, Monument Valley, Arizona and Utah: Econ. Geology, v. 53, no. 6, p. 639–662.

Faulkner, R. L., 1968, Uranium exploration and production activities in the United States: Remarks given at the Nuclear Energy Symposium, Milan, Italy, Dec. 12-14, 1968: U.S. Atomic Energy Commission, Division of Raw Materials release.

Feth, J. H., 1948, Permian stratigraphy and structure, northern Canelo Hills, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 82–108.

Fetzner, R. W., 1960, Pennsylvanian paleotectonics of Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 8, p. 1371–1413.
Finch, W. I., 1959, Geology of uranium deposits in Triassic rocks of the Colorado Plateau region: U.S. Geol. Survey Bull. 1074-D, p. 125–164.
———, 1967, Geology of epigenetic uranium deposits in sandstone in the United States: U.S. Geol. Survey Prof. Paper 538, 121 p.
Finnell, T. L., 1957, Structural control of uranium ore at the Monument No. 2 mine, Apache Co., Arizona: Econ. Geology, v. 53, p. 25–35.
———, 1966a, Geologic map of the Cibecue quadrangle, Navajo County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ-545.
———, 1966b, Geologic map of the Chediski Peak quadrangle, Navajo County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ-544.
Frazier, R. H., 1961, The Ft. Apache Limestone of east central Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 58 p.
Gastil, R. G., 1953, The geology of the eastern half of the Diamond Butte quadrangle, Gila County, Arizona: Univ. California, unpub. PhD thesis.
Gerrard, T. A., 1964, Environmental studies of the Fort Apache Member, Supai Formation (Permian), east-central Arizona: Univ. Arizona (Tucson), unpub. PhD thesis, 187 p.
———, 1966, Environmental studies of the Fort Apache Member, Supai Formation, east-central Arizona: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 11, p. 2434–2463.
Gilluly, J., 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 49 p.
Gilluly, J., Cooper J. R., and Williams, J. S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 266, 49 p.
Granger, H. C., and Raup, R. B., Jr., 1959, Uranium deposits in the Dripping Spring Quartzite, Gila County, Arizona: U.S. Geol. Survey Bull. 1046-P, p 415–486.
———, 1962, Reconnaissance study of uranium deposits in Arizona: U.S. Geol. Survey Bull. 1147-A, p. 1–54.
———, 1964, Stratigraphy of the Dripping Spring Quartzite, southeastern Arizona: U.S. Geol. Survey Bull. 1168, 119 p.
———, 1969a, Geology of the uranium deposits in the Dripping Spring Quartzite, Gila County, Arizona: U.S. Geol. Survey Prof. Paper 595, 108 p.
———, 1969b, Detailed descriptions of uranium deposits in the Dripping Spring Quartzite, Gila County, Arizona: U.S. Geol. Survey open-file report.
Gregg, C. C., and Moore, E. L., 1955, Reconnaissance of the Chinle Formation in the Cameron-St. Johns area, Coconino, Navajo, and Apache Counties, Arizona: U.S. Atomic Energy Comm. RME-51, 15 p.
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, 161 p.
Grundy, W. D., and Oertell, E. W., 1958, Uranium deposits in the White Canyon and Monument Valley mining districts, San Juan County, Utah, and Navajo and Apache Counties, Arizona, *in* Guidebook to the geology of the Paradox Basin: Intermountain Assoc. Petroleum Geologists, 9th Field Conf., p. 197–207.
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.
Hack, J. T., 1942, Sedimentation and volcanism in the Hopi Buttes, Arizona: Geol. Soc. America Bull., v. 53, p. 335–372.
Hall, R. B., and Moore, F. B., 1950, Results of geologic studies and diamond drilling in the northwest Carrizo area, Apache County, Arizona: U.S. Geol. Survey Trace Elements Memorandum Rept. 108, 13 p.
———, 1969, Map showing locations at holes drilled in 1949 and 1950 by U.S. Geological Survey, Northwest Carrizo area, Apache County, Arizona: U.S. Geol. Survey Open-file Rpt.

Harshbarger, J. W., 1949, Petrology and stratigraphy of upper Jurassic rocks of central Navajo Reservation, Arizona: Univ. Arizona (Tucson), unpub. PhD thesis, 216 p.

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.

Harshbarger, J. W., Repenning, C. A., and Jackson, R. L., 1951, Jurassic stratigraphy of the Navajo County, *in* Guidebook of the San Juan Basin: New Mexico Geol. Soc., 2nd Field Conf., p. 95–99.

Hart, O. M., 1955, Uranium investigations in Mohave County, Arizona: U.S. Atomic Energy Comm. RME-2029.

Hart, O. M., and Hetland, D. L., 1953, Preliminary report on uranium-bearing deposits in Mohave County, Arizona: U.S. Atomic Energy Comm. RME-4026.

Hatfield, K. G., and Maise, C. R., 1953, Reconnaissance of the Northwest Carrizo area, Apache County, Arizona: U.S. Atomic Energy Comm. RME-9, 27 p.

Havenor, K. C., 1958, Pennsylvanian framework of sedimentation in Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 73 p.

Hayes, P. T., 1969, Geology and topography, *in* Mineral and water resources of Arizona: Arizona Bur. Mines Bull. 180, p. 35–58.

————, 1970, Mesozoic stratigraphy of the Mule and Huachuca mountains, Arizona: U.S. Geol. Survey Prof. Paper 658-A, 28 p.

Hayes, P. T., and Drewes, H., 1968, Mesozoic sedimentary and volcanic rocks of southeastern Arizona, *in* Southern Arizona Guidebook III: Arizona Geol. Soc., p. 49–58.

Hayes, P. T., and Landis, E. R., 1961, Lower member of Mural limestone of Early Cretaceous age, Bisbee quadrangle, Arizona, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-B, p. B125–127.

————, 1965, Paleozoic stratigraphy of the southern part of the Mule Mountains, Arizona: U.S. Geol. Survey Bull. 1201-F, 43 p.

Heindl, L. A., ed., 1959, Southern Arizona Guidebook II: Arizona Geol. Soc., 290 p.

Hernon, R. M., 1935, The Paradise Formation and its fauna: Jour. Paleo., v. 9, p. 653–696.

Hewett, D. F., 1925, Carnotite discovered near Aguila, Arizona: Eng. and Mining Jour.-Press., v. 120, no. 1, p. 19.

Heylmun, E. B., ed., 1963, Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petroleum Geologists, 232 p.

Heylmun, E. B., Cohenour, R. E., and Kayser, R. B., 1965, Drilling records for oil and gas in Utah: Utah Geological and Mineralogical Survey Bull. 74, 518 p.

Holm, D. A., 1938, The oil possibilities of Arizona: Arizona State Land Dept., 47 p.

Huddle, J. W., and Dobrovolny, E., 1945, Late Paleozoic stratigraphy of central and northeastern Arizona: U.S. Geol. Survey Oil and Gas Investigation Prelim. Chart 10.

————, 1952, Devonian and Mississippian rocks of central Arizona: U.S. Geol. Survey Prof. Paper 233-D, p. 67–112.

Hunt, C. B., 1956, Cenozoic history of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279, 99 p.

Isachsen, Y. W., and Evensen, C. G., 1956, Geology of uranium deposits of the Shinarump and Chinle formations of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 300, p. 263–280.

Johnson, H. S., Jr., and Thordarson, W., 1956, Regional synthesis studies — Utah and Arizona: U.S. Atomic Energy Comm. TEI-640, p. 188–195.

Jones, D. J., 1954, Sedimentary features and mineralization of the Salt Wash sandstone at Cove Mesa, Carrizo Mountains, Apache County, Arizona — Tech. Rpt. April 1, 1953 to March 31, 1954: U.S. Atomic Energy Comm. RME-3093 (pt. 2).

Jones, R. W., 1963, Structural evolution of part of southeast Arizona, *in* Backbone of the Americas — tectonic history from pole to pole: Am. Assoc. Petroleum Geologists Memoir 2, p. 140–151.

———, 1966, Differential vertical uplift — A major factor in the structural evolution of southeast Arizona: Arizona Geol. Soc. Digest, v. 8, p. 97–124.

Jones, S. M., and Bacheller, W. D., 1953, Measured sections near Dos Cabezas, Arizona, *in* Guidebook of southwestern New Mexico: New Mexico Geol. Soc., 4th Field Conf., p. 149.

Kaiser, E. P., 1951, Uraniferous quartzite, Red Bluff prospect, Gila County, Arizona: U.S. Geol. Survey Circ. 137.

Kelley, V. C., 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: Univ. New Mexico Geol. Pub. 5, 120 p.

———, 1956, Influence of regional structure and tectonic history upon the origin and discovery of uranium on the Colorado Plateau: U.S. Geol. Survey Prof. Paper 300, p. 171–179.

———, 1958, Tectonics of the Black Mesa Basin region of Arizona, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 136–145.

Kerr, P. F., 1958, Uranium emplacement in the Colorado Plateau: Geol. Soc. America Bull., v. 69, no. 9, p. 1075–1111.

Keyes, C. R., 1936, Mesa Verde coal formation in Arizona: Pan-Am. Geologist, v. 65, p. 306–310.

Kiersch, G. A., 1955. Metalliferous minerals and mineral fuels — geology, evaluation, and uses, and a section on general geology, v. 1, *in* Mineral resources, Navajo-Hopi Indian Reservations, Arizona-Utah: The Univ. Arizona Press (Tucson), 75 p.

King, J. W., 1951, Geology and ore deposits of Mesa 5, Lukachukai district, Arizona: U.S. Atomic Energy Comm. RMO-754.

———, 1951, Reconnaissance of Red Rock district, Cove Mesa, and Kinusta (Tree) Mesa, Arizona: U.S. Atomic Energy Comm. RMO-755.

King, J. W., and Ellsworth, P. C., 1951, Geology and ore deposits of Mesa 7, Lukachukai district, Arizona: U.S. Atomic Energy Comm. RMO-803.

Kottlowski, F. E., 1960, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico State Bur. Mines and Mineral Resources Bull 66, 187 p.

Kottlowski, F. E., and Beaumont, E. C., 1965, Coal, *in* Mineral and water resources of New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 87, p. 100–116.

Kottlowski, F. E., and Havenor, K. C., 1962, Pennsylvanian rocks of the Mogollon Rim area, Arizona, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 77–83.

Krumlauf, H. E., and Wollman, C., 1956, (Coal) mines, *in* Kiersch, G. A., Mineral resources, Navajo-Hopi Indian Reservations, Arizona-Utah, v. 1: The Univ. Arizona Press (Tucson), p. 53–63.

Laverty, R. A., and Gross, E. B., 1956, Paragenetic studies of uranium deposits of the Colorado Plateau, *in* 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, p. 195–201.

Lehner, R. E., 1958, Geology of the Clarkdale quadrangle, Arizona: U.S. Geol. Survey Bull. 1021-N, p. 511–592.

———, 1962, Cenozoic history of the Jerome region, Yavapai County, Arizona, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 94–97.

LeMone, D. V., 1959, The Devonian stratigraphy of Cochise, Pima, Santa Cruz counties, Arizona and Hidalgo County, New Mexico: Univ. Arizona (Tucson), unpub. MS thesis, 157 p.

Lessentine, R. H., 1965, Kaiparowits and Black Mesa Basins — stratigraphic synthesis: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1997–2019.

———, 1969, Kaiparowits and Black Mesa basins — stratigraphic synthesis, *in* Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., p. 91–113.

Lokke, D. H., 1962, Paleontological reconnaissance of subsurface Pennsylvanian in southern Apache and Navajo Counties, Arizona, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 84–86.

Lowell, J. D., 1955, Application of cross-stratification studies to problems of uranium exploration, Chuska Mountains, Arizona: Econ. Geology, v. 50, p. 177–185.

Lutton, R. J., 1958, Some structural features in southern Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 138 p.

Lynch, D. W., 1968, The geology of the Esperanza Mine, *in* Southern Arizona Guidebook III: Arizona Geol. Soc., p. 125–136.

Magleby, D. N., and Mead, W. E., 1955, Airborne reconnaissance project, Dripping Spring Quartzite, Arizona: U.S. Atomic Energy Comm. RME-2023.

Malan, R. C., 1968, The uranium mining industry and geology of the Monument Valley and White Canyon districts, Arizona and Utah: Ore deposits in the United States 1933/1967, v. 1, Rocky Mt. Series, AIME, p. 790–804.

Malde, H. E., and Thaden, R. E., 1963, Serpentine at Garnet Ridge: U.S. Geol. Survey Bull. 1103, p. 54–61.

Masters, J. A., 1951, Uranium deposits on southwest rim of Lukachukai Mountains, northeast Arizona: U.S. Atomic Energy Comm. RMO-911.

———, 1955, Geology of the uranium deposits of the Lukachukai Mountains area, northeastern Arizona: Econ. Geology, v. 50, p. 111–126.

McCarthy, D. P., 1961, Geological evaluation of oil and gas possibilities of southwestern Arizona, *in* Oil, gas, and helium in Arizona: Arizona Development Board *for* the Arizona Oil and Gas Conservation Commission, p. 30–34.

McClymonds, N. E., 1957, Stratigraphy and structure of the southern portion of the Waterman Mountains, Pima County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 157 p.

McGavock, E. H., Edmonds, R. J., Gillespie, E. L., and Halpenny, P. C., 1966, Supplemental records of ground-water supplies, *in* Geohydrologic data in the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah, Part I-A: Arizona State Land Dept., Water Resources Report No. 12-E, 55 p.

McGoon, D. O., Jr., 1962, Occurrences of Paleozoic carbonaceous deposits in the Mogollon Rim region, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 89–91.

McKee, E. D., 1938, The environment and history of the Toroweap and Kaibab formations of northern Arizona and southern Utah: Carnegie Inst. Wash. Pub. 492, 268 p.

———, 1950, Opportunities for petroleum development in Arizona: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 2379–2380.

———, 1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., v. 62, p. 481–506.

———, 1958, The Redwall Limestone, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 74–77.

———, 1967, Arizona and western New Mexico, *in* McKee, E. D., and Oriel, S. S., and others, Paleotectonic investigations of the Permian System in the United States: U.S. Geol. Survey Prof. Paper 515, p. 203–223.

McKee, E. D., and Oriel, S. S., and others, 1967, Paleotectonic investigations of the Permian System in the United States: U.S. Geol. Survey Prof. Paper 515, 271 p.

McKenna, J. J., 1966, Buehman Canyon Paleozoic section, Pima County, Arizona: Univ. Arizona (Tucson), MS thesis, 57 p.

McKenny, J. W., and Masters, J. A., 1968, Dineh-bi-Keyah field, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 52, no. 10, p. 2045–2057.

McNair, A. H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: Amer. Assoc. Petroleum Geologists Bull., v. 35, no. 3, p. 503–541.

Mead, W. E., and Wells, R. L., 1953, Preliminary reconnaissance of the Dripping Spring Quartzite formation in Gila and Pinal counties, Arizona: U.S. Atomic Energy Comm. RME-4037.

Merrin, S., 1954, The Cretaceous stratigraphy and mineral deposits of the east face of Black Mesa, Apache County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 93 p.

Miller, H. W., Jr., 1962, Cretaceous rocks of the Mogollon Rim area in Arizona, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 93.

Molenaar, C. M., 1969a, Lexicon of stratigraphic names used in northern Arizona and southern Utah east of the Paleozoic hinge line, *in* Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., p. 69–77.

————, 1969b, Nomenclature chart of the Grand Canyon and adjacent area, *in* Geology and natural history of the Grand Canyon region: Four Corners Geol. Soc., 5th Field Conf., p. 68.

Moore, R. T., 1958, Geology of northwestern Mohave County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 81 p.

————, 1968, Mineral deposits of the Fort Apache Indian Reservation, Arizona: Arizona Bur. Mines Bull. 177, 84 p.

Moore, R. T., and Peirce, H. W., 1967, Geological map of the Fort Apache Indian Reservation, Arizona, *in* Mineral deposits of the Fort Apache Indian Reservation, Arizona: Arizona Bur. Mines Bull. 177, plate 2.

Moore, R. T., and Wilson, E. D., 1965, Bibliography of the geology and mineral resources of Arizona: Arizona Bur. Mines Bull. 173, 321 p.

Morrison, W. E., and Readling, C. L., 1968, An energy model for the United States, featuring energy balances for the years 1947 to 1965 and projections and forecasts to the years 1980 and 2000: U.S. Bur. Mines Inf. Circ. 8384, 127 p.

Noble, L. F., 1922, A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U.S. Geol. Survey Prof. Paper 131, p. 23–73.

Oetking, P., Feray, D. E., and Renfro, H. B., compilers, 1967, Geological highway map of the southern Rocky Mountain region: Am. Assoc. Petroleum Geologists, U.S. Geological Highway Map Series, No. 2.

Oil and Gas Conservation Commission, 1961, Oil, gas and helium in Arizona — its occurrence and potential: Arizona Development Board *for* the Arizona Oil and Gas Conservation Commission, 108 p.

O'Sullivan, R. B., 1958, Summary of coal resources of the Black Mesa coal field, Arizona, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 169–171.

————, 1969a, Crude oil, *in* Mineral and water resources of Arizona: Arizona Bur. Mines Bull. 180, p. 70–77.

————, 1969b, Natural gas, *in* Mineral and water resources of Arizona: Arizona Bur. Mines Bull. 180, p. 77–83.

————, 1969c, Other associated gases, *in* Mineral and water resources of Arizona: Arizona Bur. Mines Bull. 180, p. 83–91.

O'Sullivan, R. B., and Beikman, H., 1963, Geology, structure, and uranium deposits of the Shiprock quadrangle, New Mexico and Arizona: U.S. Geol. Survey Map I-345.

Page, H. G., and Repenning, C. A., 1958, Late Cretaceous stratigraphy of Black Mesa, Navajo and Hopi Indian Reservations, Arizona, *in* Guidebook of the

Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 115–122.

Peirce, H. W., 1967, Permian stratigraphy of the Defiance Plateau, Arizona, *in* Guidebook of Defiance-Zuni-Mt. Taylor region, Arizona and New Mexico: New Mexico Geol. Soc., 18th Field Conf., p. 57–62.

Peirce, H. W., and Gerrard, T. A., 1966, Evaporite deposits of the Permian Holbrook basin, Arizona, *in* Second symposium on salt: Northern Ohio Geol. Soc., v. 1, p. 1–10.

Petersen, R. G., 1957, The Central East Vermillon Cliffs area, *in* Geologic investigations of radioactive deposits — Semi-annual progress report, Dec. 1, 1956-May 31, 1957: U.S. Geol. Survey TEI-690, book 1, p. 152–154, issued by U.S. Atomic Energy Comm.

———, 1960, Detrital-appearing uraninite grains in the Shinarump Member of the Chinle Formation in northern Arizona: Econ. Geology, v. 55, p. 138–149.

Petersen, R. G., Hamilton, J. C., and Myers, A. T., 1959, An occurrence of rhenium associated with uraninite in Coconino County, Arizona: Econ. Geology, v. 54, p. 254–267.

Phoenix, D. A., 1963, Geology of the Lees Ferry area, Coconino County, Arizona: U.S. Geol. Survey Bull. 1137, 86 p.

Pike, W. S., Jr., 1947, Intertonguing marine and non-marine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. America Memoir 24, 103 p.

Pine, G. L., 1968, Devonian stratigraphy and paleogeography in Gila, Graham, Greenlee, and Pinal Counties, Arizona: Univ. Arizona (Tucson), unpub. PhD thesis, 305 p.

Pye, W. D., 1959, Marine sedimentation in southern Arizona, *in* Southern Arizona Guidebook II: Arizona Geol. Soc., p. 5–11.

———, 1960, Preliminary petrographic study of some Cretaceous coals in Arizona: Arizona Geol. Soc. Digest, v. 3, p. 109–110.

———, 1967, Arizona — a new exploration frontier: Oil and Gas Jour., v. 65, no. 19, p. 168–172.

Ransome, F. L., 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.

———, 1916, Some Paleozoic sections in Arizona and their correlation: U.S. Geol. Survey Prof. Paper 98-K, p. 113–166.

Reagan, A. B., 1925, Late Cretaceous formations of Black Mesa, Arizona: Pan-Am. Geologist, v. 44, p. 285–294.

Reeside, J. B., Jr., and Baker, A. A., 1929, The Cretaceous section in Black Mesa, northeastern Arizona: Washington Acad. Sciences Jour., v. 19, no. 2, p. 30–37.

Reinhart, E. V., 1953, Ore controls in the northwest Carrizo area: U.S. Atomic Energy Comm. TM 53, 8 p.

Repenning, C. A., and Page, H. G., 1956, Late Cretaceous stratigraphy of Black Mesa, Navajo and Hopi Indian Reservations, Arizona: Am. Assoc. Petroleum Geologists Bull., vol. 40, no. 2, p. 255–294.

Reyner, M. L., Ashwill, W. R., and Robison, R. L., 1956, Geology of uranium deposits in Tertiary lake sediments of southwestern Yavapai County, Arizona: U.S. Atomic Energy Comm. RME-2057, pt. 1, 43 p.

Ross, C. P., 1925, Geology and ore deposits of the Aravaipa and Stanley mining districts, Graham County, Arizona: U.S. Geol. Survey Bull. 763, 120 p.

Rubel, A. C., 1916, Coal in Arizona: Arizona Bur. Mines Bull. 17, 12 p.

Sabins, F. F., 1957a, Geology of the Cochise Head and western part of the Vanar quadrangles, Arizona: Geol. Soc. America Bull., v. 68, p. 1315–1342.

———, 1957b, Stratigraphic relations in Chiricahua and Dos Cabezas mountains, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 3, p. 466–510.

Schafroth, D. W., 1965, Structure and stratigraphy of the Cretaceous rocks south of the Empire Mountains, Pima and Santa Cruz counties, Arizona: Univ. Arizona (Tucson), unpub. PhD thesis, 135 p.

———, 1968, Stratigraphy of some Cretaceous formations in southeastern Arizona, *in* Southern Arizona Guidebook III: Arizona Geol. Soc., p. 59–67.

Schrader, F. C., 1915, Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona (with contributions by J. M. Hill): U.S. Geol. Survey Bull. 582, 373 p.

Scurlock, J. R., 1967, Geologic structure map of northeastern Arizona: Arizona Oil and Gas Conservation Commission, Phoenix, Arizona.

Sharp, B. J., 1956, Preliminary report on a uranium occurrence and regional geology in the Cherry Creek area, Gila County, Arizona: U.S. Atomic Energy Comm. RME-2036.

Shoemaker, E. M., 1956, Occurrence of uranium in diatremes on the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 300, p. 179–185.

Shoemaker, E. M., Roach, C. H., and Byers, F. M., Jr., 1962, Diatremes and uranium deposits in the Hopi Buttes, Arizona, *in* Petrologic studies — A volume in honor of A. F. Buddington: Geol. Soc. America, p. 327–335.

Simons, F. S., 1964, Geology of the Klondyke quadrangle, Graham and Pinal counties, Arizona: U.S. Geol. Survey Prof. Paper 461, 173 p.

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, with a section on "Sedimentary Petrology" by R. A. Cadigan: U.S. Geol. Survey Bull. 1046 Q.

Stipp, T. F., and Beikman, H. M., 1959, Map of Arizona showing oil, gas, and exploratory wells, pipelines, and areas of igneous and metamorphic rocks: U.S. Geol. Survey Oil and Gas Inv. Map OM-201.

Stokes, W. L., 1944, Morrison formation and related deposits in and adjacent to the Colorado Plateau: Geol. Soc. America Bull., v. 55, no. 8, p. 951–992.

———, 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.

———, 1953, Preliminary sedimentary trend indicators as applied to ore finding in the Carrizo Mountains, Arizona and New Mexico: U.S. Atomic Energy Comm. RME 3043, pt. 1, 47 p.

Stoyanow, A. A., 1936, Correlation of Arizona Paleozoic formations: Geol. Soc. America Bull., v. 37, p. 459–540.

Strobell, J. D., Jr., 1952, Dinne Mesa NE, Preliminary geologic map of part of the Carrizo Mountains area, northeastern Arizona: U.S. Geol. Survey Trace Elements Memorandum Report 423.

———, 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.

Swapp, C. W., 1961, The geology and gas and oil possibilities of northwestern Arizona, *in* Oil, gas, and helium in Arizona: Arizona Development Board, *for* the Arizona Oil and Gas Conservation Commission, p. 35–41.

Tapp, S. C., 1963, Kanab Creek unit area, Kane County, Utah, *in* Guidebook to the geology of southwestern Utah: Intermountain Assoc. Petroleum Geologists, p. 193–198.

Teichert, C., 1965, Devonian rocks and paleogeography of central Arizona: U.S. Geol. Survey Prof. Paper 464, 181 p.

Titley, S. R., ed., 1968, Southern Arizona Guidebook III: Arizona Geol. Soc., 354 p.

Turner, D. S., 1958, Devonian system of the Black Mesa basin, *in* Guidebook of the Black Mesa Basin, northeastern Arizona: New Mexico Geol. Soc., 9th Field Conf., p. 71–73.

Turner, G. L., 1962, The Deming axis, southeastern Arizona, New Mexico, and Trans-Pecos Texas, *in* Guidebook of the Mogollon Rim region, east-central Arizona: New Mexico Geol. Soc., 13th Field Conf., p. 59–72.

Twenter, F. R., and Metzger, D. G., 1963, Geology and ground water in Verde Valley — the Mogollon Rim region, Arizona: U.S. Geol. Survey Bull. 1177, 132 p.

Tyrrell, W. W., Jr., 1957, Geology of the Whetstone Mountains area, Cochise and Pima counties, Arizona: Yale Univ., unpub. PhD thesis, 64 p.

U.S. Atomic Energy Commission, Grand Junction Operations Office, Oct. 1959, Guidebook to uranium deposits of western United States.

———, 1969, Statistical data of the uranium industry, Jan. 1, 1969: U.S. Atomic Energy Comm., Grand Junction Office, Grand Junction, Colo.

———, Preliminary Reconnaissance Reports: Grand Junction Office, Grand Junction, Colo. Open file reports available for inspection on microfiche at Arizona Bur. Mines, Tucson, Ariz.

U.S. Bureau of Mines, 1942, Progress Reports — Metallurgical Division, 52, Ore-testing studies of the ore-dressing section, fiscal year, 1941: U.S. Bur. Mines Rept. Inv. 3638, p. 16–17.

———, 1942, Progress Reports — Metallurgical Division, 55, Dry differential grinding tests of carnotite ores: U.S. Bur. Mines Rept. Inv. 3636.

———, 1942–1967, Minerals Yearbooks 1942–1967.

———, 1965, Bituminous coal, *in* Mineral facts and problems, 1965: U.S. Bur. Mines, p. 119–147.

U.S. Geological Survey, 1921, Mineral Resources of the United States, Part 1, Metals, p. 226.

Veatch, A. C., 1911, Coal deposits near Pinedale, Navajo County, Arizona: U.S. Geol. Survey Bull. 431-B. p. 239–242.

Walcott, C. D., and Bannon, M., 1885, Deer Creek coal field, White Mountain Indian Reservation, Arizona: U.S. 48th Cong., 2d sess., Sen. Ex. Doc. 20, p. 2–7.

Walker, G. W., and others, 1963, Geology of uranium-bearing veins in the conterminous United States: U.S. Geol. Survey Prof. Paper 455-A, B, C, D, E, F.

Weber, R., 1950, The geology of the east-central portion of the Huachuca Mountains, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 191 p.

Wells, R. L., and Rambosek, A. J., 1954, Uranium occurrences in Wilson Creek area, Gila County, Arizona: U.S. Atomic Energy Comm. RME-2005.

Wengerd, S. A., 1958, Pennsylvanian stratigraphy, southwest shelf, Paradox Basin, *in* Guidebook to the geology of the Paradox Basin: Intermountain Assoc. Petroleum Geologists, 9th Field Conf., p. 109–134.

Willden, R., 1964, Geology of the Christmas quadrangle, Gila and Pinal Counties, Arizona: U.S. Geol. Survey Bull. 1161-E, 64 p.

Williams, F. J., 1957, Structural control of uranium deposits, Sierra Ancha region, Gila County, Arizona: U.S. Atomic Energy Comm. RME-3152.

Williams, G. A., 1951, The coal deposits and Cretaceous stratigraphy of the western part of Black Mesa: Univ. Arizona (Tucson), unpub. PhD thesis, 307 p.

Wilson, E. D., 1962, A résumé of the geology of Arizona: Arizona Bur. Mines Bull. 171, 140 p.

Wilson, E. D., Moore, R. T., and Cooper, J. R., 1969, Geologic map of Arizona: Arizona Bur. Mines and U.S. Geol. Survey.

Wilson, E. D., Moore, R. T., and O'Haire, R. T., 1960, Geologic map of Navajo and Apache Counties, Arizona: Arizona Bur. Mines.

Wilson, E. D., and Roseveare, G. H., 1949, Arizona nonmetallics, a summary of past production and present operations: Arizona Bur. Mines Bull. 155, 60 p.

Wilt, J. C., 1969, Petrology and stratigraphy of the Colina Limestone (Permian) in Cochise County, Arizona: Univ. Arizona (Tucson), unpub. MS thesis, 117 p.

Winters, S. S., 1963, Supai Formation (Permian) of eastern Arizona: Geol. Soc. America Memoir 89, 99 p.

Witkind, I. J., 1956, Uranium deposits at base of the Shinarump Conglomerate, Monument Valley, Arizona: U.S. Geol. Survey Bull. 1030-C.

———, 1961, The uranium-vanadium ore deposit at the Monument No. 1-Mitten No. 2 mine, Monument Valley, Navajo County, Arizona: U.S. Geol. Survey Bull. 1107-C.

Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona, *with sections on* Serpentine at Garnet Ridge, by H. E. Malde and R. E. Thaden and Mineralogy and paragenesis of the ore deposit at the Monument No. 2 and Cato Sells mines, by D. H. Johnson: U.S. Geol. Survey Bull. 1103, 171 p.

Wright, J. J., 1964, Petrology of the Devonian rocks in eastern Pima and Cochise counties, Arizona: Univ. Arizona (Tucson), unpub. PhD thesis, 153 p.

Wright, R. J., 1950, Reconnaissance of certain uranium deposits in Arizona: U.S. Atomic Energy Comm. RMO-679.

Young, R. G., 1964, Distribution of uranium deposits in the White Canyon-Monument Valley districts, Utah-Arizona: Econ. Geology, v. 59, p. 850–873.

Young, W. H., and Anderson, R. L., 1947, Thickness of bituminous coal and lignite seams mined in the United States in 1945: U.S. Bur. Mines Inf. Circ. 7442, 17 p.

———, 1952, Thickness of bituminous coal and lignite seams at all mines and thickness of overburden of strip mines in the United States in 1950: U.S. Bur. Mines Inf. Circ. 7642, 18 p.

Young, W. H., and Gallagher, J. J., 1968, Coal — bituminous and lignite: U.S. Bur. Mines, Minerals Yearbook, 1967, v. I–II, p. 331–356.

APPENDIX

Table A. — Chronological list of Arizona wells with a history of production of oil, natural gas, and helium, showing field and producing horizon.

No.	Year	OGCC Per-mit No.	Well Name	Location	Field	Sta-tus	Pro-duc-tion	Production Interval
1	1954	18	Shell 1 Nav	SESE 6 41N 29E	EBB	A	G	Penn
2	1954	22	Consolidated Shell 2 Nav	SENW 3 41N 38E	EBB	P	G,O	Ismay
3	1955	28	Humble 1 Nav	NESE 4 41N 28E	EBB	P	G,O	Desert Cr
4	1956	10	Kerr-McGee 1 Fee	SWSE 33 20N 26E	PD	P	H	Coconino
5	1956	32	Consolidated Shell Franco-Western Nav	SWNW 22 41N 28E	NTA	P	G,O	Paradox
6	1956	35	El Paso 1 Bita Peak	SWNW 19 41N 31E	BP	P	G,O	Ismay
7	1956	-	Kerr-McGee 1 State	SWSW 34 20N 26E	PD	P	H	Coconino
8	1956	37	Kerr-McGee 2 State	NWSE 34 20N 26E	PD	P	H	Coconino
9	1957	37	Kerr-McGee 3 State	NWSE 4 19N 26E	PD	A	H	Coconino
10	1957	38	Kerr-McGee 4 State	SWNE 32 20N 26E	PD	A	H	Coconino
11	1957	39	Kerr-McGee 2 Fee	N NW 35 20N 26E	PD	P	H	Coconino
12	1957	46	Superior H-2 (14-16) Nav	SWSW 16 41N 30E	TFC	A	G,O	Ismay
13	1958	58	Humble E-1 Nav	SWNE 10 41N 28E	EBB	P	O,G	U. Hermosa
14	1959	69	Consolidated Shell 23-11 Nav	NESW 11 41N 28E	EBB	P	G,O	U. Hermosa
15	1959	77	Monsanto (Tex. Pac.) 138-1 Nav	NENE 11 40N 28E	DM	P	O	Miss
16	1959	81	Kerr-McGee (Eastern) 1-2 St	NESW 2 19N 26E	PD	P	H	Coconino
17	1960	80	Eastern 1-10 State	NENE 10 19N 26E	PD	P	H	Coconino
18	1960	88	Kerr-McGee (Eastern) 1-28	SESE 28 20N 26E	PD	P	H	Coconino
19	1960	106	Monsanto (Tex. Pac.) 138-2 Nav	SWNW 12 40N 28E	DM	A	O	Miss
20	1960	113	Texaco Z-1 Nav	NWSW 36 41N 30E	TNP	P	H	Miss
21	1960	77	Monsanto (Tex. Pac.) 138-3 Nav	SWSE 2 40N 28E	DM	P	O	Miss
22	1961	146	Atlantic 7-1 Nav	SESE 7 40N 29E	DM	A	O	Miss
23	1962	194	Eastern 13 Santa Fe	NESW 31 20N 27E	NS	P	H	Coconino
24	1963	226	Texaco AG-1 Nav	NWSE 16 41N 25E	WC	P	O	McCracken
25	1963	232	Pan Am O-1 Nav	SESW 23 41N 30E	-	P	O,G	Ismay
26	1963	234	Eastern Ancon 21 Santa Fe	SENW 31 20N 28E	-	P	H	Shinarump
27	1963	238	Eastern (Kerr-McGee) Barfoot	NESW 32 20N 27E	NS	P	H	Coconino
28	1964	263	Eastern 35 Santa Fe	NESW 27 20N 27E	NS	P	H	Coconino
29	1965	179	Pan Am. F-1 Nav	NWSW 6 40N 28E	DM	A	O	Akah
30	1966	349	Kerr-McGee 3A State	NENE 4 19N 26E	PD	P	H	Coconino
31	1967	377	Kerr-McGee 1 Nav	SESW 32 36N 30E	DK	P	O	sill in Penn
32	1967	378	Kerr-McGee 4A State	NESE 32 20N 26E	PD	A	H	Coconino
33	1967	379	Kerr-McGee 2 Nav	SENW 32 36N 30E	DK	P	O	sill in Penn
34	1967	384	Kerr-McGee 4 Nav	SENE 32 36N 30E	DK	P	O	sill in Penn
35	1967	386	Kerr-McGee 3X Nav	SESE 32 36N 30E	DK	P	O	sill in Penn
36	1967	388	Humble 138-1 Nav	SENE 6 35N 30E	DK	P	O	sill in Penn
37	1967	289	Kerr-McGee 7 Nav	SESW 29 36N 30E	DK	P	O	sill in Penn
38	1967	390	Kerr-McGee 6 Nav	SENE 31 36N 30E	DK	P	O	sill in Penn
39	1967	396	Kerr-McGee 9 Nav	SESE 30 36N 30E	DK	P	O	sill in Penn
40	1967	416	Kerr-McGee 14 Nav	SENW 31 36N 30E	DK	P	O	sill in Penn
41	1967	417	Kerr-McGee 15 Nav	SESW 30 36N 30E	DK	P	O	sill in Penn
42	1967	419	Kerr-McGee 16 Nav	SENW 30 36N 30E	DK	P	O	sill in Penn
43	1967	431	Humble 2-88 Nav	SENE 25 36N 29E	DK	P	O	sill in Penn
44	1968	420	Kerr-McGee 13 Nav	SESW 31 36N 30E	DK	P	O	sill in Penn
45	1968	421	Humble 1-88 Nav	SESE 25 36N 29E	DK	A	O	sill in Penn
46	1968	427	Kerr-McGee F-1 Nav	SESE 24 36N 29E	DK	TA	O	sill in Penn
47	1968	434	Champlin 1-335 Nav	NESE 4 41N 29E	AC	A	O	Akah
48	1968	443	Humble 3-88 Nav	SENE 36 36N 29E	DK	P	O	sill in Penn
49	1968	445	Kerr-McGee B-1X Nav	NWNW 5 35N 30E	DK	P	O	sill in Penn
50	1968	446	Kerr-McGee 10 Nav	SENE 30 36N 30E	DK	P	O	sill in Penn
51	1968	471	Crest 1 Santa Fe	SESE 25 20N 27E	-	P	H	Coconino
52	1969	444	AAA Fishing Tool E-2 Nav	SWNE 9 41N 28E	EBB	A	O	Penn
53	1969	481	Consolidated 1 Nav (2-13)	SWSW 2 41N 28E	EBB	P	O	Akah
54	1969	483	Globe Minerals E-3 (AAA) Nav	NENE 9 41N 28E	EBB	P	O	Des Cr, Akah
55	1969	484	Kerr-McGee C-1 Nav	NWSW 33 36N 30E	DK	P	O	sill in Penn
56	1969	490	Consolidated 3 Nav	NESW 3 41N 28E	EBB	P	O	Desert Cr
57	1969	506	Kerr-McGee 11 Nav	NWSE 32 36N 30E	DK	P	O	sill in Penn
58	1969	509	Globe Minerals E-4 Nav	NENW 9 41N 28E	EBB	P	O	Des Cr, Akah
59	1969	511	AAA Fishing Tool E-1 Nav	NWNE 9 41N 28E	EBB	P	O	Desert Cr
60	1969	514	Consolidated 3-3 Nav	SWSW 3 41N 28E	EBB	P	O	Desert Cr
61	1969	515	Humble 3 Nav	SWSE 4 41N 28E	EBB	P	O	Ismay, Des Cr, Akah
62	1969	518	Consolidated 2-11 Nav	SWNW 11 41N 28E	EBB	P	O	Ismay, Des Cr

Fields
AC = SE Anido Creek Area
BP = Bita Peak
DK = Dineh-bi-Keyah
DM = Dry Mesa
EBB = East Boundary Butte
NS = Navajo Springs
NTA = North Toh Atin
PD = Pinta Dome
TFC = Twin Falls Creek
TNP = Teec Nos Pos
WC = Walker Creek

Status
A = Abandoned
P = Producing
TA = Temporarily abandoned

Production
O = Oil
G = Gas
H = Helium

Other
OGCC = Oil & Gas Conserv. Comm.

Table B. — All time cumulative production of oil, natural gas, and helium in Arizona, by well. (Basic data from Arizona Oil and Gas Conservation Commission.)

Well No.*	Oil (barrels)	Gas (thousands of cubic feet) Natural Gas Used	Natural Gas Lost	Helium
1	0	0	0	0
2	4,580	1,166,141	16,284	0
3	41,905	1,229,157	102,643	0
4	0	0	0	448,885
5	289	544,173	8,320	0
6	7,620	2,292,443	0	0
7	0	0	0	802,306
8	0	0	0	1,162,570
9	0	0	0	6,184
10	0	0	0	48,245
11	0	0	0	492,483
12	622	193,007	8,956	0
13	188,150	329,835	62,635	0
14	31,014	2,128,460	46,153	0
15	148,795	0	991	0
16	0	0	0	547,163
17	0	0	0	43,387
18	0	0	0	683,046
19	19,831	0	0	0
20	490	0	0	385,774
21	270,677	0	3,590	0
22	6,173	0	6,312	0
23	0	0	0	597,399
24	98,431	0	0	0
25	53,880	301,678	40,092	0
26	0	0	0	5,445
27	0	0	0	181,480
28	0	0	0	5,752
29	6,898	0	21,676	0
30	0	0	0	151,663
31	584,206	0	55,282	0
32	0	0	0	277
33	1,390,716	0	100,122	0
34	1,542,603	0	61,080	0
35	1,362,472	0	151,419	0
36	549,777	0	104,560	0
37	538,727	0	42,106	0
38	71,396	0	14,454	0
39	928,944	0	84,283	0
40	94,198	0	43,456	0
41	46,189	0	8,699	0
42	44,409	0	6,954	0
43	367,303	0	34,628	0
44	2,076	0	1,479	0
45	0	0	878	0
46	141	0	1,395	0
47	563	0	2,562	0
48	57,646	0	94,116	0
49	644,855	0	49,268	0
50	64,444	0	7,315	0
51	0	0	0	7,600
52	577	0	4,255	0
53	1,182	0	384	0
54	29,900	0	36,620	0
55	1,114	0	306	0
56	4,072	0	1,692	0
57	83,803	0	19,563	0
58	11,086	0	23,452	0
59	4,426	0	0	0
60	10,792	0	22,717	0
61	4,163	0	8,093	0
62	1,850	0	8,840	0
TOTAL PRODUCTION	9,332,985	8,484,794	1,308,127	5,569,659

*See Table A for well names.

Table C. — All time cumulative production of oil, natural gas, and helium in Arizona, by year. (Basic data from Arizona Oil and Gas Conservation Commission.)

Year	Oil (barrels)	Natural Gas (in thousands of cubic feet) Used	Lost	No. Wells	Year	Helium (thousands cubic feet)	No. Wells
1954	-	-	497	1	1954	-	-
1955	749	-	68,676	1	1955	-	-
1956	-	-	-	-	1956	-	-
1957	-	-	-	-	1957	-	-
1958	11,794	-	15,277	1	1958	-	-
1959	26,433	-	9,974	3	1959	-	-
1960	72,671	-	-	5	1960	-	-
1961	73,631	-	4,884	6	1961	30,358	5
1962	49,925	148,975	12,451	8	1962	371,751	8
1963	67,458	956,435	11,153	8	1963	437,418	8
1964	63,078	1,176,007	9,823	12	1964	543,643	9
1965	100,604	1,476,783	2,873	11	1965	681,316	10
1966	131,251	1,720,739	8,005	11	1966	767,744	11
1967	2,922,595	1,051,102	223,019	25	1967	883,291	11
1968	3,369,430	854,637	433,785	28	1968	979,660	7
1969	2,433,366	1,100,116	507,710	37	1969	874,475	12
TOTALS	9,322,985	8,484,794	1,308,127			5,569,659	

Table D. — Oil, natural gas, and helium shows in Arizona test holes. (Basic data, in part, from Arizona Oil and Gas Conservation Commission.)

This compilation of "shows" results from the past efforts of many workers, companies, and organizations. Logs published by the American Stratigraphic Company, Denver, were especially useful and James Scurlock of the Arizona Oil and Gas Conservation Commission made the initial compilation. However, the final form and content are the responsibility of the Arizona Bureau of Mines. The wells are arranged by townships starting in the northeast corner and proceeding from east to west within each county.

In this report a "show" is any indication of oil, gas, or helium that naturally occurs in rocks. The significance of a show is partially indicated by the class of show. "Production" shows include three subdivisions: underlined depths indicate current production of oil, gas, or helium; asterisked* depths indicate former production; and no symbol on depths indicate non-commercial wells with perforations.

Included in the shows on drill stem test are the lower rank indications such as oil and/or gas cut mud. Shows in cores and cuttings range from free oil, heavy or light oil stain, to dead oil. "X" indicates that an oil show occurs in cores and cuttings somewhere within an interval that also contains a more positive show as indicated by a drill stem or production test.

Reported shows range from reliable company reports to rumors. Some shows from older wells, thought to be unduly optimistic, are not included. However, certain reported shows whose authenticity could not be judged are included, but questioned.

The great range in significance of the various show types should be taken into account when using this compilation. Well records are on file at the Arizona Oil and Gas Conservation Commission by permit number. WW indicates a water well.

The type of show is represented by the first initial of the material: G refers to inflammable gas; O refers to crude oil, oil stain, dead oil, or any direct indication, though perhaps slight, that crude oil is or was present; H refers to helium. Where two materials are present, the most abundant is listed first. A question mark next to the type of show indicates some question about its content; for example, ?G indicates no analysis of the gas has been made to determine if it contains helium or if it is inflammable. The stratigraphic horizons used in this compilation include both formation and member names, as well as time periods; they are summarized in Table F.

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache County				
191	Davis Oil 1 Nav SESE 33 42N 29E	G,O	Barker Cr	-	5340-5417	-	
256	Zoller & Danneberg 161-1 Nav SWSW 7 41N 31E	G	Ismay	-	4560-5517	-	
		G	Desert Cr	-	5568-5576	-	
35	El Paso 1 Bita Peak SWNW 19 41N 31E Bita Peak Field	G	Ismay	<u>5080-5102</u>	5049-5105	X	
		O	Pinkerton Tr	-	5588-5648	X	
44	Superior H-1 Nav NWSW 10 41N 30E	G	Ismay	-	5105-5177	X	
		G	Desert Cr	-	5184-5237	X	
		G	L. Hermosa	-	5550-5620	X	
		O	L. Hermosa	-	-	5690	
		G	Miss	-	6256-6317	X	
299	Duncan 1 El Paso Nav SESE 13 41N 30E	O,G	Ismay	-	5185-5203	X	
		O	Ismay, D.C.	-	-	5230-5290	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
46	Superior H-2 Nav	O	Ismay	-	-	4910	
	SWSW 16 41N 30E	G	Ismay	*4999-5032	-	X	
		G	Ismay	*5035-5040	-	X	
	Twin Falls Creek	G	Ismay, D.C.	*5063-5071	-	X	
	Field	O	L. Hermosa	-	-	5380;5490	
		O	L. Hermosa	-	-	5540	
		O	Miss	-	-	5960	
		O	Miss	-	-	6120-6160	
		G	Aneth	-	6578-6645	X	
128	Superior 23-21	G	Ismay	-	4945-4985	-	
	Nav M	O	Ismay	-	-	5020-5040	
	NESW 21 41N 30E	O	Desert Cr	-	-	5090	
		G	Penn	-	5285-5809	-	
232	Pan Am O-1 Nav	O	Ismay	-	-	5060	
	SESW 23 41N 30E	G	Ismay	5122-5140	5086-5152	X	
		G	Desert Cr	-	5164-5196	X	
		G	Desert Cr, L. Hermosa	-	5457-5536	X	
		O	L. Hermosa	-	-	5570-5690	
		G	Miss	-	6068-6240	X	
		O	Ouray	-	-	6265-6320	
		O	Elbert	-	-	6460-6480	
		O	Aneth	-	-	6630-6730	
425	Miami 1 Nav	G	Desert Cr	-	5010-5035	X	
	NENW 30 41N 30E	G	Penn	-	5157-5185	X	
		O	Ouray	-	-	6100-6140	
		O	McCracken	-	6422-6432	X	
		O,G	Aneth	-	6600-6635	X	
113	Texaco Z-1 Nav	G	Penn	-	5135-5220	-	
	NWSW 36 41N 30E	H	Miss	*6270-6320	-	-	
		G	Miss	-	6180-6299	X	
	Teec Nos Pos	G	Miss	-	6299-6334	X	
	Field	G,O	Elbert	-	6520-6591	-	
		O	McCracken	-	-	6670-6750	
		O	Aneth	6758-6793	-	X	
367	Champlin 1-190	G,O	Ismay	-	5088-5146	-	
	Nav	O	Ismay	-	-	5100-5140	
	SENE 3 41N 29E						
434	Champlin 1-335	G	Ismay	-	4912-4957	X	
	Nav	O	Desert Cr	-	-	4960-5010	
	NESE 4 41N 29E	G,O	Desert Cr	-	5050-5100	X	
		G,O	Akah	5360-5375	5350-5413	-	
		G	Akah	-	5415-5465	-	
18	Shell 1 Nav	G,O	Ismay	-	4619-4670	-	
	SESE 6 41N 29E	G,O	Desert Cr	-	4670-4774	-	
		G	Penn	-	4910-4973	X	
	East Boundary	G,O	Penn	4884-4976	4886-4978	-	
	Butte Field	G,O	Penn	-	5100-5204	X	
		G,O	Penn	-	5200-5304	-	
		G	Miss	-	5738-5820	-	
		G,O	Elbert	-	6014-6080	X	
		G	McCracken	-	6136-6246	-	
		O	McCracken	-	-	6150-6270	
		O	Camb	-	-	6430-6450	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet)			
				Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
168	LaRue 1 Toh Atin	G,O	Desert Cr	-	5198-5229	-	
	NENE 22 41N 29E	G,O	Desert Cr	-	5240-5427	-	
		O	Penn	-	-	5210-5440	
		O	Penn	-	-	5630-5820	
		O	Penn	-	-	5880	
		O	Miss	-	-	6140-6150	
		O	Miss	-	-	6170-6200	
139	Davis C-1 Nav	O	Ismay	-	-	5060	
	SESE 29 41N 29E	G,O	Desert Cr	-	5216-5231	-	
481	Consolidated 1 Nav	G,O	Ismay	-	4649-4717	-	
	SWSW 2 41N 28E	G	Ismay	-	4650-4782	X	
		G	Desert Cr	-	4887-4929	-	
	East Boundary	O	Akah	4897-4909	-	4940	
	Butte Field	G,O	Penn	-	5208-5255	5270	
22	Shell 2 Nav	G	Ismay	4540-4585	4535-4601	X	
	SENW 3 41N 28E	G	Ismay	4650-4690	4620-4707	-	
		G,O	Desert Cr	-	4740-4950	-	
	East Boundary	G	Penn	-	4973-5121	-	
	Butte Field	G	L. Hermosa	-	5190-5225	-	
		G,O	Miss	-	5669-5693	X	
		O	Miss	-	-	5755	
		G,O	Dev	-	5768-5873	-	
		G,O	Dev	-	5945-6032	X	
		G	Dev	-	6250-6310	-	
490	Consolidated	O	Ismay	-	4612-4638	4645;4655	
	3 Nav	O	Ismay	-	-	4700-4740	
	NESW 3 41N 28E	O	Desert Cr	4778-4782	4760-4793	X	
		G	Desert Cr	-	4840-4895	X	
	East Boundary	G,O	L. Hermosa	-	5228-5253	-	
	Butte Field	G,O	Miss	-	5675-5706	X	
514	Consolidated	G	Desert Cr	-	4681-4696	-	
	3-3 Nav	O	Desert Cr	4698-4706	-	-	
	SWSW 3 41N 28E	O	Desert Cr	4746-4756	-	-	
		O,G	Desert Cr	-	4725-4772	-	
	East Boundary	G,O	Akah	-	4800-4851	-	
	Butte Field						
28	Humble 1 Nav	G	Ismay	-	4600-4629	-	
	NESE 4 41N 28E	G	Ismay	-	4629-4689	X	
		G	Ismay	-	4683-4728	-	
	East Boundary	G,O	Desert Cr	-	4778-4798	X	
	Butte Field	G,O	Desert Cr	*4806-4816	4799-4831	X	
		G,O	Penn	-	4856-4902	X	
		G,O	Miss	-	5560-5595	-	
		G	Miss	-	5595-5616	-	
		G	Miss	-	5651-5672	-	
		G,O	Miss	-	5689-5720	X	
		O	Elbert	-	-	5974	
		G	McCracken	-	6119-6139	X	
		O	Aneth	-	-	6322-6338	
515	Humble 3 Nav	O	Ismay	4717-4723	-	-	
	SWSE 4 41N 28E	O	Desert Cr	4763-4768	-	-	
		O	Akah	4848-4852	-	-	
	East Boundary	O	Akah	4862-4866	-	-	
	Butte Field						

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
508	Globe Minerals 1	G,O	Desert Cr	-	5315-5380	-	
	SESE 5 41N 28E	G	Desert Cr & Akah	-	5465-5525	-	
483	Globe Minerals	O,G	Desert Cr	-	4730-4776	-	
	Nav E-3 (AAA)	O,G	Desert Cr & Akah	-	4800-4923	-	
	NENE 9 41N 28E	O	Desert Cr & Akah	4756-5046	-	-	
	East Boundary Butte Field	O	L. Penn	-	5120-5173	-	
511	AAA Fishing Tool Nav E-1 NWNE 9 41N 28E East Boundary Butte Field	O	Desert Cr	4732-4798	-	-	
444 (65)	Humble E-2 Nav	O	Penn	*4286-4900	-	-	
	(AAA)	G	Penn	-	4264-4330	-	
	SWNE 9 41N 28E	O	Penn	-	4574-4629	-	
		G,O	Penn	-	4800-4855	-	
	East Boundary Butte Field	O	Penn & Ismay	-	4799-4905	-	
		G	Desert Cr	-	4990-5025	-	
		G	Penn	-	5222-5240	-	
		G	Penn	-	5400-5425	-	
		G	Miss	-	6068-6120	-	
509	Globe Minerals E-4 Nav	G,O	Ismay & Desert Cr	-	4890-4987	-	
	NENW 9 41N 28E	O	Desert Cr	4958-4962	-	-	
		G,O	Desert Cr	-	4990-5040	-	
	East Boundary	O	Akah	5131-5135	-	-	
	Butte Field	G	Akah	-	5120-5225	-	
58	Humble E-1 Nav	G	U. Hermosa	-	4204-4269	-	
	SWNE 10 41N 28E	G,O	U. Hermosa	-	4494-4556	X	
		G,O	U. Hermosa	-	4600-4675	X	
	East Boundary	O,G	U. Hermosa	4518-4644	-	-	
	Butte Field	G	Ismay	-	4732-4776	X	
		G	Desert Cr	-	4865-4893	X	
		G,O	Penn	-	4940-4986	-	
		O	Penn	-	-	5070	
		G,O	Penn	-	5339-5359	-	
518	Consolidated	O	U. Hermosa	-	4548-4562	-	
	2-11 Nav	G,O	U. Hermosa	-	4659-4767	-	
	SWNW 11 41N 28E	O	Ismay & Desert Cr	4674-4905	-	-	
	East Boundary	G,O	Desert Cr	-	4947-4963	-	
	Butte Field	G,O	Akah	-	5035-5057	-	
69	Shell 23-11 Nav	G,O	U. Hermosa	4460-4608	-	X	
	NESW 11 41N 28E	O	Desert Cr	-	-	4980	
	East Boundary Butte Field	O	Desert Cr	-	-	5020-5090	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet)			
				Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
32	Franco Western	O,G	Paradox	-	5129-5179	-	
	1 Nav	G	Paradox	-	5201-5285	X	
	SWNW 22 41N 28E	G	Paradox	5359-5392	5356-5415	X	
	North Toh Atin						
205	Franco Western	O	Miss	-	6010-6150	X	
	2 Nav						
	SENW 27 41N 28E						
166	LaRue 2 Dinne	G	Desert Cr?	-	5680-5830	-	
	NENE 22 41N 27E						
165	LaRue 1 Dinne	G	L. Hermosa?	-	5730-5800	-	
	NWNW 23 41N 26E						
50	Gulf-British-Am	O	Ismay	-	-	4725	
	Walker Cr 1 Nav	O	Desert Cr	-	-	4855;4885	
	SWSE 28 41N 26E	O	L. Hermosa	-	-	5235	
260	MacDonald 1 Nav	O	L. Hermosa	-	-	5060-5090	
	SWSW 31 41N 26E	O	L. Hermosa	-	-	5125;5240	
		O	L. Hermosa	-	-	5300-5380	
		O	Miss	-	-	5760-5720	
		O	Ouray?	-	-	6090	
		O	McCracken	-	-	6265	
304	Tenneco 1 Nav	G,O	Ismay	-	4722-4741	X	
	SWSW 33 41N 26E	G,O	Akah?	-	4883-5070	-	
226	Texaco AG-1 Nav	O	McCracken	6370-6384	6338-6398	X	
	NWSE 16 41N 25E	O,G	Aneth	-	6392-6490	X	
		O,G	Aneth	-	6397-6444	X	
	Walker Creek Field						
295	Great Western	O	Akah	-	-	5010-5040	
	2 El Paso Nav						
	NENE 17 41N 25E						
266	Texaco AG-2 Nav	O	L. Hermosa	-	-	5420	
	NWNE 21 41N 25E	O	Miss	-	-	5990	
		O	Aneth	-	-	6525-6545	
248	Gulf-Garnet Ridge	O	Aneth	-	-	6610-6655	
	1 Nav	O	Aneth	-	-	6735	
	NENE 16 41N 24E						
290	Occidental 1 Mon	O	Hermosa	-	-	955-1030	
	Valley	G	McCracken	-	2216-2246	-	
	NWSW 12 41N 22E	O	Elbert	-	-	2275;2320	
		O	Aneth	-	-	2550	
		O	Aneth	-	-	2610-2630	
		O	Aneth	-	-	2655	
		O	Tapeats	-	-	2772;2965	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
105	British-American	G	Penn	-	4900-5067	X	
	C-1 Nav	G	Penn	-	5101-5338	-	
	SWSW 5 40N 30E	O	Penn	-	-	5390	
		G	Miss	-	5984-6055	-	
		G	Miss	-	6059-6120	-	
		O	Elbert	-	-	6210	
		O	McCracken	-	-	6375	
146	Atlantic 7-1 Nav	G	L. Hermosa	-	5088-5107	-	
	SESE 7 40N 29E	G	L. Hermosa	-	5250-5267	-	
		G,O	Miss	-	5575-5605	X	
	Dry Mesa Field	O,G	Miss	*5604-5618	5606-5639	X	
		O	Ouray	-	-	5705	
176	Pan American 1	G	Ismay	-	4760-4880	X	
	Moko Nav	G	Desert Cr	-	4881-5042	X	
	NESW 15 40N 29E	G	L. Hermosa	-	5340-5445	-	
		G	Miss	-	5665-5739	-	
274	Marathon 1 Nav	O	Desert Cr	-	-	5630	
	NESE 18 40N 29E	O	L. Hermosa	-	-	5740;5990	
		O	Miss	-	-	6200-6213	
		O	Miss	-	6226-6262	X	
213	Pure 138-5 Nav	O	Ismay	-	-	4690	
	SWSW 1 40N 28E	O	Desert Cr	-	-	4790-4810	
		G	L. Hermosa	-	5019-5064	X	
		G	Miss	-	5473-5550	X	
		G	Miss	-	5550-5620	X	
		O,G	Miss	-	5592-5640	X	
115	Monsanto (Texas	G	Desert Cr	-	4577-4607	X	
	Pacific) 138-3 Nav	G	L. Hermosa	-	4780-4891	-	
	SWSE 2 40N 28E	G	L. Hermosa	-	4850-4878	-	
		O	Miss	5306-5329	-	-	
	Dry Mesa Field	O	Miss	-	-	5332-5352	
179	Pan Am F-1 Nav	O	Desert Cr	-	-	6250-6270	
	NWSW 6 40N 28E	G	Desert Cr	-	6320-6411	X	
		G	Akah	*6422-6437	6409-6510	X	
	Dry Mesa Field	G,O	Akah	-	6579-6640	X	
		G,O	L. Hermosa	-	6649-6773	X	
		G	L. Hermosa	-	6777-6880	X	
		G	Miss	-	7004-7080	-	
		G	Miss	-	7110-7142	-	
		O	Miss	-	-	7150-7240	
513	Curtis Little	G,O	Akah	-	5110-5163		
	1 Nav 2193						
	NWNW 9 40N 28E						
77	Monsanto (Texas	O	Ismay	-	-	4720	
	Pacific) 138-1 Nav	O	Desert Cr	-	-	4790;4930	
	NENE 11 40N 28E	O	L. Hermosa	-	-	4960-4990	
		G	L. Hermosa	-	5037-5080	X	
	Dry Mesa Field	O	L. Hermosa	-	-	5070-5190	
		O	L. Hermosa	-	-	5290;5330	
		O,G	Miss	5566-5589	5550-5592	X	
		O,G	Miss	-	5592-5618	5590-5640	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
116	Texas Pacific	O	Desert Cr	-	-	4865;4910	
	138-4 Nav	G	L. Hermosa	-	5050-5103	X	
	NENW 11 40N 28E	O	Miss	-	-	5570-5610	
106	Monsanto (Texas	O	Desert Cr	-	-	4918-4935	
	Pacific) 138-2 Nav	G	L. Hermosa	-	5049-5079	X	
	SWNW 12 40N 28E	G	L. Hermosa	-	5225-5253	-	
		G	L. Hermosa	-	5249-5314	-	
	Dry Mesa Field	O	Miss	*5576-5590	5529-5618	5551-5592	
		O,G	Miss	*5632-5647	5620-5661	5620-5686	
138	Western States	O	Miss	-	-	5900	
	2 Nav	O	McCracken	-	-	6110;6300	
	NWNE 17 40N 28E						
94	LaRue 1 Nav	G,O	Desert Cr	-	5484-5610	-	
	NWNW 18 40N 28E	G,O	Desert Cr	-	5610-5750	-	
		G,O	L. Hermosa	-	5882-5901	-	
		O	Miss	-	-	6390	
261	Occidental 1	O	Akah	-	-	5380-5520	
	Texaco-Nav	G	Miss	-	5925-5945	-	
	NWNW 6 40N 27E	O	Miss	-	-	5955-5970	
		O	Miss	-	-	6000-6065	
		O	Ouray	-	-	6220-6250	
		O	Elbert	-	-	6485-6495	
		O	McCracken	-	-	6540-6550	
		O	McCracken	-	-	6570-6595	
95	Texas Pacific	O	Penn	-	-	4690-4745	
	190-1 Nav	O	Ismay	-	-	4930	
	SESE 20 40N 26E	O	Akah	-	-	5380-5470	
		G	Miss	-	5925-5945	X	
		O	Ouray	-	-	6220-6250	
145	Bonanza 1 Nav	O	Desert Cr	-	-	4970-4990	
	NWNW 30 40N 26E	O	Miss	-	-	5556-5564	
		O	Dev	-	-	6300-6315	
271	Texaco AK-1 Nav	O	Penn	-	-	5120-5220	
	NENE 6 40N 25E	G,O	Dev	-	6423-6491	-	
60	Pan American 1	G,O	Cutler	-	3025-3123	-	
	Tohlacon Nav	O,G	Desert Cr	-	4795-4946	X	
	NESE 11 40N 25E	O,G	L. Hermosa	-	4946-4962	X	
		G,O	L. Hermosa	-	4964-5102	-	
		G	L. Hermosa	-	5105-5197	X	
		G,O	Miss	-	5460-5541	X	
		O	Miss	-	-	5763-5800	
		G,O	Elbert & McCracken	-	5901-6010	-	
		O	McCracken	-	-	6040-6120	
		G,O	Aneth	-	6230-6286	6230-6350	
247	Pan Am Q-1 Nav	O	McCracken	-	6428-6525	X	
	NESW 8 40N 24E						
382	JCM 1 Nav Mobil	O	DeChelly	-	-	1750-1790	
	NWNW 16 39N 25E	O	Miss	-	-	5180-5200	
		O	Miss	-	-	5275	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
272	Socony Mobil 155-1 Nav SENW 28 39N 25E	H	Penn	-	4407-4474	-	
292	Superior 22-12 Nav SENW 12 39N 23E	O	Aneth	-	6097-6119	X	
		O	Aneth	-	6100-6216	X	
265	Superior V-33-12 Nav NWSE 12 39N 23E	O,G	McCracken	-	5992-6009	-	
		O,G	Aneth	-	6071-6091	-	
468	Pan Am 1-AF Nav SENW 12 38N 30E	O	Penn	-	-	3470-3530	
		O	Tert sill	-	-	3830-3910	
		O	Tert sill	-	4000-4049	4010-4170	
		O	Tert sill	-	-	4510-4560	
415	Pan Am V-1 Nav NESE 16 38N 29E	O	Tert sill	-	-	3400-4450	
280	Pan Am T-1 Nav SESE 20 38N 27E	O	Penn	-	-	4850	
		O	Penn	-	-	4910-5000	
		G	Miss	-	5251-5425	X	
		G	Dev	-	5590-5690	X	
		O	Aneth	-	-	5680-5796	
424	Amer Mining 1 Nav SENW 28 38N 24E	O	Penn	-	-	5140-5320	
507	Gulf 1 Nav 2290 NENE 34 37N 30E	G	Hermosa	-	3650-3710	-	
491	Gulf 1-BS Nav NWNE 12 37N 29E	G	Barker Cr	-	3200-3325	-	
298	Blackburn 35-1 Nav NWNW 35 37N 29E	O	Aneth	-	-	3580-3600	
311	Blackburn 8-1 Nav SESE 8 37N 27E	O	Penn	-	-	4140-4160	
		O	Miss	-	-	4480	
476	Buttes 1-23 Nav SESE 23 37N 27E	O	Penn	-	-	3440-3520	
389	Kerr McGee 7 Nav SESW 29 36N 30E Dineh-bi-Keyah	O	Tert sill in Penn	3072-3112	-	X	
446	Kerr McGee 10 Nav SENE 30 36N 30E Dineh-bi-Keyah	O	Tert sill in Penn	3028-3048	-	-	
419	Kerr McGee 16 Nav SENW 30 36N 30E Dineh-bi-Keyah	O	Tert sill in Penn	3163-3212	-	-	
417	Kerr McGee 15 Nav SESW 30 36N 30E Dineh-bi-Keyah	O	Tert sill in Penn	3159-3246	-	-	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
396	Kerr McGee 9 Nav	O	DeChelly	-	-	1210-1300	
	SESE 30 36N 30E	O	Tert sill	3420-3460	-	3410-3480	
		O	Penn	-	-	3530	
	Dineh-bi-Keyah						
390	Kerr McGee 6 Nav	O	DeChelly	-	-	1530-1600	
	SENE 31 36N 30E	O	Tert sill	-	-	3655	
		O	Tert sill				
	Dineh-bi-Keyah		in Penn	3672-3726	-	-	
416	Kerr McGee 14 Nav	O	Tert sill				
	SENW 31 36N 30E		in Penn	3829-3920	-	-	
	Dineh-bi-Keyah						
420	Kerr McGee 13 Nav	O	Tert sill				
	SESW 31 36N 30E		in Penn	4182-4208	-	-	
	Dineh-bi-Keyah						
384	Kerr McGee 4 Nav	O	Tert sill				
	SENE 32 36N 30E		in Penn	2898-2960	-	X	
	Dineh-bi-Keyah						
379	Kerr McGee 2 Nav	O	Tert sill				
	SENW 32 36N 30E		in Penn	3060-3114	-	X	
	Dineh-bi-Keyah						
377	Kerr McGee 1 Nav	O	Tert sill				
	SESW 32 36N 30E		in Penn	2885-2942	-	X	
	Dineh-bi-Keyah						
506	Kerr McGee 11 Nav	O	Tert sill				
	NWSE 32 36N 30E		in Penn	2831-2893	-	-	
	Dineh-bi-Keyah						
386	Kerr McGee 3X Nav	O	Tert sill				
	SESE 32 36N 30E		in Penn	3427-3457	-	-	
	Dineh-bi-Keyah						
422	Kerr McGee C-2 Nav	O	Basal Trias	-	-	1280-1430	
	SENW 33 36N 30E	O	DeChelly	-	-	1440-1600	
		O	Penn	-	-	3510	
	Dineh-bi-Keyah	O	Penn	-	-	3610-3640	
		H	McCracken	4134-4220	-	X	
		H	McCracken	-	4109-4196	X	
		O	Camb	-	-	4320-4370	
484	Kerr McGee C-1 Nav	O	Basal Trias	-	-	1154-1300	
	NWSW 33 36N 30E	O	Tert sill				
			in Penn	3459-3496	-	X	
	Dineh-bi-Keyah						

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
401	Humble 87-1 Nav	O	Penn	-	-	4680-4710	
	SENE 23 36N 29E	H	Dev-Camb	-	5231-5505	X	
		O	McCracken	-	-	5230-5280	
		O	Aneth-Camb	-	-	5430-5450	
427	Kerr McGee F-1 Nav	O	Tert sill				
	SESE 24 36N 29E		in Penn	*4239-4251	-	-	
	Dineh-bi-Keyah						
431	Humble 2-88 Nav	O	Tert sill				
	SENE 25 36N 29E		in Penn	4045-4111	-	X	
		GHO	Tert sill	-	4045-4075	X	
	Dineh-bi-Keyah	G,O	Tert sill	-	4045-4095	X	
		O	Elbert	-	-	4470-4525	
		G	Elbert &				
			McCracken	-	4543-4659	-	
		G	Aneth, Camb	-	4692-4821	X	
421	Humble 1-88 Nav	H	Tert sill	3407-3463	-	X	
	SESE 25 36N 29E	O	Tert sill	-	-	3590-3660	
		O	Penn	3734-3754	-	X	
	Dineh-bi-Keyah						
443	Humble 3-88 Nav	O	Penn	-	-	3575	
	SENE 36 36N 29E	O	Tert sill	3725-3778	-	3690-3770	
		G	Tert sill	-	3687-3712	X	
	Dineh-bi-Keyah						
494	Riddle 1	O	Barker Cr	-	-	-	3246-3255
	Gottlieb Nav						
	SWNW 30 36N 27E						
435	Simmons 1 Nav	O	Penn	2402-2428	-	X	
	SESW 30 36N 27E						
345	Cactus 1 Nav 8816	G	McCracken	-	5540-5595	-	
	SWNE 23 36N 24E						
395	Anadarko 1-135 Nav	O	McCracken	-	-	3930-3980	
	NWNW 3 35N 30E	H	Aneth	-	4014-4242	-	
385	Kerr McGee B-2 Nav	H	L. Hermosa	3904-3907	-	-	
	SENE 5 35N 30E	H	L. Hermosa	3924-3935	-	-	
		H	McCracken				
	Dineh-bi-Keyah		& Aneth	-	4417-4480	-	
		H	Aneth	-	4514-4565	-	
445	Kerr McGee B-1X	O	Tert sill	2953-2983	-	X	
	Nav	O	Tert sill				
	NWNW 5 35N 30E		in Penn	3062-3084	-	X	
	Dineh-bi-Keyah						
381	Kerr McGee B-1 Nav	O	Tert sill				
	SENW 5 35N 30E		in Penn	-	-	3660-3760	
		O	Penn	-	-	3850-3880	

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Production	Drill Stem Test	Cores & Cuttings	Reported
				Show point or interval (depth in feet)			
			Apache Co. (cont'd)				
388	Humble 138-1 Nav	O	Tert sill	-	-	3410-3570	
	SENE 6 35N 30E	O	Tert sill in Penn	3342-3559	-	X	
	Dineh-bi-Keyah	O	McCracken	-	-	4090	
400	Humble 138-2 Nav	O	Penn	-	-	4460	
	SESE 6 35N 30E	O	Miss	-	-	4570	
393	Humble 140-1 Nav	H	McCracken	-	4532-4633	-	
	SENE 8 35N 30E	H	Aneth	-	4663-4806	-	
426	Kerr McGee 1-H Nav	O	Basal Trias	-	-	2219-2270	
	NENE 14 35N 30E	O	Penn	-	-	4550-4570	
		O	Camb	-	-	5270-5290	
452	Humble 1-146 Nav	H	McCracken	-	3825-3936	-	
	SESW 15 35N 30E	H	Aneth	-	3944-4075	-	
454	Humble 1-151 Nav	O	Penn	-	3293-3325	-	
	SENE 35 35N 30E	O	Penn	-	-	3510	
		G	McCracken	-	3671-3773	X	
WW	Lukachukai School (USGS water well)	O	DeChelly or Shinarump	-	-	-	?
461	Buttes 1-25 Nav SESE 25 35N 28E	H	McCracken	-	2748-2810	X	
526	Buttes 1-31 NENE 31 35N 27E	?G	McCracken	-	2224-2280	-	
308	Tenneco 1 Nav 8939	O	McCracken	-	-	6340-6375	
	NENW 2 35N 22E	O	Aneth	-	-	6500-6560	
428	Pan Am 1-AB Nav NWSE 32 7N 7W Nav	?H	Miss	-	2380-2570	-	
477	Union 1-166 Nav	O	Miss	-	-	2390	
	NWNW 20 6N 6W Nav	O	Dev	-	-	2410-2420	
74	Brown & Assoc 2 Fee	H	Coconino	-	-	-	565
	SWNE 27 21N 28E	O	Supai	-	-	1310-1330	
107	Eastern 1 Santa Fe	?H	Coconino	-	1494-1535	-	
	SENW 35 21N 26E	?H	Coconino	-	1541-1576	-	
234	Eastern Ancon 21 Santa Fe SENW 31 20N 28E	H	Shinarump	1172-1196	-	-	
237	Eastern 18 Santa Fe NESW 13 20N 27E	H	Shinarump	-	-	-	1150
134	Crest 8 Santa Fe SENW 25 20N 27E	H	Coconino	1351-1355	-	-	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
473	Crest-Ariz Helium 8X Santa Fe SENW 25 20N 27E	H	Coconino	1346-1358	-	-	
471	Crest-Ariz Helium 1 Santa Fe SESE 25 20N 27E	H	Coconino	*1215-1225	-	-	
129	Crest 5 Santa Fe NESW 26 20N 27E	H	Coconino	1138-1158	-	-	
263	Eastern 35 Santa Fe NESW 27 20N 27E Navajo Springs	H	Coconino	1052-1062	-	-	
258	Eastern 32 Santa Fe NESW 28 20N 27E Navajo Springs	H	Coconino	*1090-1100	-	-	
255	Eastern 31 Santa Fe SE 29 20N 27E Navajo Springs	H	Coconino	* 992-1018	-	-	
194	Eastern 13 Santa Fe NESW 31 20N 27E Navajo Springs	H	Coconino	964- 980	968- 978	-	
238	Kerr McGee Barfoot State NESW 32 20N 27E Navajo Springs	H	Coconino	986-1008	-	-	
110	Crest 2 Santa Fe NESW 33 20N 27E Navajo Springs	H	Coconino	*1062-1072	-	-	
88	Eastern 1-28 State SESE 28 20N 26E Pinta Dome	H	Coconino	937-1000	940- 956	X	
38	Kerr McGee 4 State SWNE 32 20N 26E Pinta Dome	H	Coconino	* 828- 832	-	-	
378	Kerr McGee 4A State NESE 32 20N 26E Pinta Dome	H	Coconino	* 793- 796	-	-	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
10	Kerr McGee 1 Fee SWSE 33 20N 26E Pinta Dome	H O	Coconino Ft Apache?	950-1150 -	- -	- 2310	
-	Kerr McGee 1 State SWSW 34 20N 26E Pinta Dome	H	Coconino	1098-1100	-	-	
36	Kerr McGee 2 State NWSE 34 20N 26E Pinta Dome	H	Coconino	1000-1020	-	-	
39	Kerr McGee 2 Fee N½NW 35 20N 26E Pinta Dome	H	Coconino	* 952	-	-	
195	Desert 1 State NWNW 32 19N 29E	?H	Triassic	-	-	-	1280-1300
124	Crest 3 Santa Fe NESW 3 19N 27E	?H ?H	Shinarump Coconino	- -	- -	- -	1161-1165 1245-1264½
236	Eastern 17 Santa Fe SWNW 4 19N 27E Navajo Springs	H	Coconino	1038-1057	-	-	
206	Eastern 14 Santa Fe SENW 5 19N 27E Navajo Springs	H	Coconino	1026-1056	-	-	
204	Crest 7 Santa Fe SWNE 6 19N 27E Navajo Springs	H	Coconino	1048	-	-	
348	Eastern 2 Reese SWNE 1 19N 26E Navajo Springs	H	Coconino	1012-1016	-	-	
81	Eastern 1-2 State NESW 2 19N 26E Pinta Dome	H	Coconino	974-1000	970- 991	987-1017	
349	Kerr McGee 3A State NENE 4 19N 26E Pinta Dome	H	Coconino	965- 980	-	-	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
37	Kerr McGee 3 State NWSE 4 19N 26E	H	Coconino	*1010-1145	-	-	
	Pinta Dome						
80	Eastern 1-10 State NENE 10 19N 26E	H	Coconino	* 975- 979	-	-	
	Pinta Dome						
167	Ram 1-14 State SW 14 19N 26E	H	Shinarump	795- 805	-	-	
320	Walker Bros 1 Lansdale Fee SWNE 17 19N 26E	?H	Coconino	-	854- 865	-	
262	McCaughey 1 Sunland State SWNE 20 19N 26E	?H	Coconino	-	856- 859	-	
214	Fletcher 1-21 Spurlock NWSE 21 19N 26E	H	Shinarump?	672- 683	-	-	
143	Teil 1 Kruglich-Fletcher NESE 22 19N 26E	?H	Shinarump	744- 748	-	-	
346	Apache 1-22 State NWSE 22 19N 26E	?H	Chinle	-	tested-no depth info	-	
318	Apache 1 Spurlock Wetzler Fee SWNE 23 19N 26E	H	Shinarump	878- 893	-	-	
451	Hallett 1 State SENE 28 19N 26E	H	Shinarump	-	820- 830	-	
120	Sierra 1 State SWNE 2 19N 25E	O G	Chinle Coconino	- -	- -	610; 680 -	 973- 976
-	Zuni 1 Arizona SESE 6 19N 24E	O	Chinle?	-	-	-	635- 700
-	Kern Co Land 1 SW 2 18N 24E	H	Supai	-	-	957- 965	blew out
322	Apache 2 Spurlock-Wetzler NESE 27 18N 26E	H	Shinarump	-	905- 935	-	
373	Eastern 3 NMA C 9 16N 25E	?H	Coconino	-	-	-	566- 614
98	Pan Am 1-A NMA SESE 12 13N 25E	O O O O O	Coconino Supai Supai Supai Supai	- - - - -	- - - - -	300 1150;1450 1620;1800 1950;2100 2250;2350	

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet): Production	Drill Stem Test	Cores & Cuttings	Reported
			Apache Co. (cont'd)				
WW	BLM Concho Spr NWSE 18 12N 26E	O	Kaibab	-	-	810	
375	Tenneco 1-C Fed SENW 22 11N 28E	O	Kaibab	-	-	180; 210	
		O	Kaibab	-	-	260- 440	
		O	Coconino	-	-	520- 550	
		O	Supai	-	-	1000-1040	
		O	Supai	-	-	1230-1250	
		O	Supai	-	-	1370-1420	
		O	Ft Apache	-	-	1490-1550	
371	Tenneco 1 Merrill Fee SWSW 26 10N 30E	CO_2	Kaibab	-	-	-	184- 518
		O	Supai	-	-	1040-1060	
		O	Ft Apache	-	-	1490-1540	
370	Tenneco 1-B Fed SWNE 4 10N 24E	O	Coconino	-	-	1240-1260	
		O	Coconino	-	-	1420-1450	
		O	L. Penn	-	-	2550-2610	
66	Mae Belcher 1 State SENW 20 9N 31E	H	Dakota	-	-	-	698- 743
		O	San Andres	-	-	790; 830	
		O	Glorieta	-	-	-	1295-1302
		O	Supai	-	-	1570-1600	
		O	Supai	-	-	1940	
		G	Penn	-	-	-	2810
			Cochise County				
-	Funk Dev 1 Fee SENE 27 13S 30E	?O	sand, shale	-	-	-	1250;1650
		?O	sand, shale	-	-	-	1730;2030
		?O	sandy lime	-	-	-	2060-3580?
		?O?G	lime, shale	-	-	-	4170-6651?
-	Bowie Oil Syndicate 1 SENW 16 13S 28E (may be swamp gas)	O	brown sand	-	-	-	719-1619
		G	lime shale	-	-	-	1600-1750
		O	sand, shale	-	-	-	1925-1935
		O	lime shale	-	-	-	2100-2300
		O,G	sand	-	-	-	2650-2775
		O,G	sandy shale	-	-	-	2958-3276
		G	sandy shale	-	-	-	3354-3460
		O,G	shale	-	-	-	3560-3600
		O,G	sand	-	-	-	3812-4110
-	Waddell-Duncan 1 McComb SWSE 23 13S 24E	O	?	-	-	-	3920-3930
		O	volcanics	-	-	-	4570-4575
73	Duncan 3 State 33 13S 22E	?G	?	-	-	-	1111
-	San Simon 1 State SWSE 16 14S 31E	O	?	-	-	-	373- 400
		O	brown sand	-	-	-	374- 584
		O	?	-	-	-	796- 816
-	Ryan 1 Ryan SENW 34 14S 30E	O,G	?	-	-	-	360- 520

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Production	Drill Stem Test	Cores & Cuttings	Reported
				Show point or interval (depth in feet)			
			Cochise Co. (cont'd)				
-	Chicken yard "wells" 6 14S 25E	O	? "pumped" & sold 10,000 gals. before 1928				14- 18
WW	So Pacific RR 6 14S 25E	O	? "pumped" & sold 2,800 gals.				T.D. 650
-	Geronimo 1	?O	blue shale	-	-	-	176- 221
	Brunning	?O	shale	-	-	-	548- 586
	NENE 6 14S 25E	?O	shale	-	-	-	645- 650
-	Geronimo 1	?O	blue shale	-	-	-	11- 18
	Clark-Holliday	?O	blue shale	-	-	-	51- 78
	NENE 6 14S 25E	?O	shale, sand	-	-	-	392; 425
-	Wilcox 1 Ariz	O	?	-	-	-	576- 580
	Sulphur Springs	O	?	-	-	-	1125-1130
	SESE 9 14S 25E	O	sand	-	-	-	1390-1410
		O	sand	-	-	-	2340-2360
-	Century 1	?G	blue shale	-	-	-	885- 905
	Colglazier	?G	lime	-	-	-	1040-1070
	NWNW 17 17S 19E	?G,O	sandy shale	-	-	-	1225-1255
		?G	blue shale	-	-	-	1255-1300
224	Moncrief (Allen)	?G	?	-	-	-	2640-2675
	1 Davis	?O	?	-	-	-	2856-2899
	SENE 25 21S 25E	?O	oil odor	-	-	-	3120;3300
		?O	congl, sand	-	-	-	3804;3944
		?O	congl, sand	-	-	-	5230;5280
34	Southwest (Basin)	O	?	-	-	-	2195-2655
	1 Davis Clark	?G	top Miss	-	-	-	2400
	NENE 5 21S 24E	O	Miss DST	-	-	-	2570-2590
		O,G	Dev	-	-	-	3405-3415
212	Moncrief 1	O	Penn-Perm	-	-	1170	
	Davis Clark	O	Penn-Perm	-	-	1950-1965	
	NWSE 5 21S 23E	O	Miss	-	-	2825	
		O	Dev	-	-	3020-3040	
		O	Dev	-	-	3360-3400	
93	Fraser 1 State NESE 19 21S 23E	?G,O	sand	-	-	-	1409-1459
			Coconino County				
275	Underwood 1-32 Jacob Lake NENE 32 39N 2E	O	Miss	-	-	2750-2770	
-	Burrel Collins 1X SWSE 22 34N 8E	O	Kaibab	-	-	-	180- 200
321	Moore, Moore & Miller 1 Hopi NWNW 6 29N 15E	O	Naco	-	-	6010-6025	

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Coconino Co. (cont'd)				
474	Pennzoil 1-11 Hopi NWNW 11 29N 14E	O	Miss	-	-	5970-6000	
6	Sinclair 1 Santa Fe SWNE 35 28N 1W	O	Supai	-	-	1950	
-	Lockhart Babbitt NENE 21 27N 9E	O	Dev	-	-	3290;3330	
		O	Dev	-	-	3325-3328	
-	Arizona 1 Sunshine SW 13 20N 12½E	O	Supai?	-	-	-	1440
240	Pickett 1 Padre Canyon State NWSE 26 20N 10E	O	Martin	-	-	3405-3420	
		O	Martin	-	-	-	3570-3575
72	Western 1 Walters SENW 24 19N 10E	?G	Toroweap	-	-	-	300- 340
		?G	Coconino	-	-	-	645- 705
		G	Supai	-	-	-	1860-2135
376	Steinberg 1A Flowalt Babbitt SESW 24 19N 10E	O?	Redwall	-	-	3180-3210	
71	Monsanto 1 Cabin Wash SWNE 30 14N 14E	O	Supai	-	-	1300-1335	
		O	Supai	-	-	1490	
464	Eastern 1 Fed Moqui Bardo NWSW 10 14N 11E	O	u. Supai	-	-	1630-1640	
		O	Ft Apache	-	-	1735	
		O	Miss	-	-	3540-3561	
			Graham County				
-	Underwriters 1 Mack NWNE 13 6S 24E	O	sand	-	-	-	1460-1463
-	Bear Springs Oil 1 Allen SESE 25 10S 28E	O	sand	-	-	-	360; 500
		O	shale, sand	-	-	-	1030;1070
		O	brown sand	-	-	-	1532?
249	Ram 1 Sierra Bonita Fee SESE 2 11S 22E	O	?	-	-	-	1300-1310
		O	?	-	-	-	1560-1562
			Maricopa County				
-	Tannehill 1 Beardsley SENE 25 4N 2W	?O	black shale	-	-	-	2540;3280
-	Camelback Totweiller 1 NENW 30 2N 4E	?O	seepage	-	-	-	surface
		?O	oil colors in various intervals	-	-	-	?618-2742

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Maricopa Co. (cont'd)				
171	Montezuma 1-A Fed NWSW 30 2S 9W	?O	odor in cuttings	-	-	-	181- 248
			Mohave County				
-	Virgin Oil 6 State 32 42N 15W	O	"oil sand"?	-	-	-	545
-	Cane Bed Well SE 16 41N 6W	O	sand?	-	-	-	246
		O	sand?	-	-	-	461
33	Falcon-Seaboard 1 Fed	O	Hermit	-	-	1330-1360	
	NWNE 28 40N 8W	O	Hermit	-	-	1675;1705	
		O	Hermit	-	-	1780-1800	
		O	Hermit	-	-	1860-1920	
		O	Queantoweap	-	-	1970;2115	
		O	Queantoweap	-	-	2515	
		O	Pakoon	-	-	2580	
		O	Callville	-	-	3180	
56	Lyons 1 Fed NESW 35 39N 6W	O	Moenkopi	-	-	-	65- 180
		O	Kaibab	-	-	1340-1380	
		O	Toroweap	-	-	1390	
		O	Toroweap	-	-	1540-1580	
		O	Toroweap	-	-	1735	
347	Skelly 1 Ariz Fed A	O	Moenkopi	-	-	80- 220	
	NESE 2 39N 7W	O	Kaibab	-	-	855- 900	
		O	Kaibab	-	-	1170-1190	
		O	Toroweap	-	-	1530-1760	
		O	Miss	-	-	3930	
114	Tenneco 1 Schreiber SESW 35 39N 13W	O	Callville	-	-	3140	
		O	Callville	-	-	3575,3600	
43	Western 1 Fed NWSE 31 38N 5W	O	Toroweap	-	-	-	240; 410
		O	Toroweap	-	-	550	
		O	Toroweap	-	-	900- 940	
		O	Hermit	-	-	1270	
		O	Miss	-	-	3455	
		O	Dev	-	-	-	4300
		O	Muav	-	-	4370	
		O	Muav	-	-	4440-4535	
53	Fields 1X Fed SWSW 17 38N 7W	O	Kaibab	-	-	-	160- 460
		O	Toroweap	-	-	-	600- 612
		O	Coconino	-	-	-	1111-1150
			Navajo County				
13	Texas 1-A Nav SWSE 34 42N 18E	O	Hermosa	-	-	2775;2815	

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Navajo Co. (cont'd)				
281	Superior W-21-29 Nav NENW 29 38N 21E	O O O	McCracken McCracken Aneth	- - -	- - -	6577 6611 6653	
283	Tenneco 1 Nav 8351 SESW 24 38N 19E	O	Aneth	-	6960-7054	X	
WW	Peabody water well Black Mesa 36N 18E	G	Dakota	-	-	-	flam. gas
310	Amerada 1 Hopi SENE 8 29N 19E	O O O	Chinle Moenkopi McCracken	- - -	- - -	3400;3750 3930 7330-7350	
312	Atlantic 9-1 Hopi SWSE 9 28N 15E	O O	Elbert Aneth	- -	- -	6050 6430-6450	
-	General Pet 14-6 Creager State SWNW 6 19N 23E	O H?G	Supai Supai	- -	- -	- -	1520-1525 1530-1550
301	Ferrin 1 State NESW 10 19N 17E	O	Permian	-	-	-	1350
344	Ferrin 1 NMA NWNW 22 19N 17E	O	Supai	-	-	-	910
235	Franklin, Aston & Fair C-1 NMA SWNE 27 18N 23E	H	Shinarump	-	-	-	204- 214
89	Tucson 1X Woodman Fed SWSE 30 18N 20E	?H ?H	Coconino Ft Apache?	- -	- -	- -	600 1600
54	Besoil 1 Hunt SESE 31 18N 20E	O G O	Coconino Supai Supai	- - -	- - -	- - -	95; 385 610; 840 1370-1680
460	Cree 1 Scorse Fee SWSW 33 18N 20E	O O	Supai Ft Apache?	- -	- -	1380-1415 1550	
217	Franklin-Aston-Fair A-1 NMA SWNE 1 17N 23E	H	Shinarump	-	-	-	670
359	Ark La 10 NMA SWSE 27 16N 23E	H	Supai	-	-	1059	
85	Pan Am A-1 Aztec SENE 5 16N 20E	H,G G,H O O O H ?G	Coconino Coconino Supai Ft Apache Ft Apache Naco Elbert	- - - - - - -	- - - - - - -	- - 1340 1700-1720 - - -	280; 370 510- 690 1721-1771 3250;3310 3686-3697

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Navajo Co. (cont'd)				
86	Pan Am B-1 Aztec	O	Supai	-	-	1360-1430	
	SWNE 9 16N 18E	O	Supai	-	-	1610-1640	
		O	Ft Apache	-	-	1800-1835	
		O	l. Supai	-	-	1880;1910	
		O	Naco	-	-	3495	
		O	Martin	-	-	3626	
-	Black Canyon	G,O	Coconino	-	-	-	200; 234
	NENE 20 16N 17E	O	Coconino	-	-	-	241- 244
20	Eisele 1 McCauley	O	Penn	-	1600	-	
	SWSW 1 16N 16E						
-	Hopi 1	?G	Supai	-	-	-	679- 710
	NWNE 21 15N 19E						
-	Union Cont 1 NMA	O	Supai	-	-	1570	
	SWNE 34 15N 19E	O	Ft Apache	-	-	1702-1734	
		O	Ft Apache	-	-	1745-1775	
		O	Naco	-	-	3165;3256	
-	Union Cont 1	O	Supai	-	-	1700-1713	
	Aztec	O	Ft Apache	-	-	1880-1898	
	NENE 19 15N 18E	O	Naco	-	-	3289-3328	
		O	Naco	-	-	3386-3405	
		O	Naco	-	-	3408-3426	
		O	Naco	-	-	3610-3630	
		G,O	Naco	-	-	3665-3685	
		O	Naco	-	-	3763-3767	
		O	Martin	-	-	3795-3812	
-	Holbrook 1	G	Supai	-	-	-	2695;2700
	NE 23 15N 18E	G	Supai	-	-	-	2705;2736
		G	Supai	-	-	-	2760-2765
		G	Supai	-	-	-	2815
		O	Supai	-	-	-	2920;2925
		O	Supai	-	-	-	2967-2975
		G	Supai	-	-	-	2985
		O	Supai	-	-	-	2992;3004
		O	Supai	-	-	-	3010;3012
-	Adamana Oil Co	O	Ft Apache	-	-	-	1740-1750
	SWSE 4 14N 20E	O	Supai	-	-	-	1940-1950
		G	Supai	-	-	-	2260-2300
		O	?oil sand	-	-	-	3387
61	L Johnson 1 Aztec	O	Supai	-	-	1190-1210	
	NE 33 14N 20E	O	Supai	-	-	1500-1530	
97	L Johnson 2 Aztec	O	Supai	-	-	-	1510
	SWNE 33 14N 20E	?G	Supai	-	-	-	1517-1523
-	Lockhart 1 Aztec	G	?	-	-	-	in pipe
	NESE 33 14N 20E	O	Supai	-	-	1500	
		O	Ft Apache	-	-	-	1678-1741
		O	Ft Apache	-	-	1710-1740	
		O	l. Supai	-	-	-	2873-3129
		O	l. Supai	-	-	-	3175-3449
		O	l. Supai	-	-	-	3452-3515
		O	l. Supai	-	-	-	3657-3708

Table D. — *Continued*

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Production	Drill Stem Test	Cores & Cuttings	Reported
				Show point or interval (depth in feet)			
			Navajo Co. (cont'd)				
291	Taubert Steed 1	O	Supai	-	-	1080-1090	
	Babbitt Bros Fee	O	Supai	-	-	1240-1265	
	NENE 35 14N 19E	O	Supai	-	-	1325	
76	Pan Am 1-B NMA	O	u. Supai	-	-	1240	
	SWNE 25 12N 23E	O	u. Supai	-	-	1400-1425	
		O	Ft Apache	-	-	1850	
		O	l. Supai	-	-	2220-2270	
		O	l. Supai	-	-	2405-2420	
		?H	l. Supai	-	-	-	2723-2726
		?H	Naco	-	-	-	3867
		G	Miss?	-	-	-	4090
		G	Miss?	-	-	-	4140
374	Tenneco 1-A Fed	O	Kaibab				
	SESE 18 12N 17E		cavings	-	-	X	
		O	Coconino	-	-	300- 330	
		O	Coconino	-	-	570- 600	
		O	Supai	-	-	760- 780	
		O	Ft Apache	-	-	1390-1520	
368	Tenneco 1X	O	Supai	-	-	1140-1190	
	Ft Apache	O	Supai	-	-	1260-1300	
	NESE 31 10N 21E	O	Supai	-	-	1380-1420	
		O	Ft Apache	-	-	1445-1540	
		O	l. Supai	-	-	1880-1900	
		G	Martin	-	3620-3700	-	
369	Tenneco 1 Fed	O	Supai	-	-	1250	
	NWNW 15 10N 19E	O	Ft Apache	-	-	1660-1690	
			Pima County				
-	Eloy Dev Assoc SWNE 6 12S 11E	?G	?	-	-	-	4632-4638
192	Mountain States 1 State NENE 29 19S 18E	?G	?	-	-	-	1007
219	Mountain States	O	Cret	-	-	1250-1270	1300;1500
	1A State	O	Cret	-	-	1610-1640	1600-1700
	NENE 29 19S 18E	O	Cret	-	-	2140-2200	1900
		O	Cret	-	-	2340-2370	
		O	Cret	-	-	2505-2570	
		O	Cret	-	-	3140-3160	
			Pinal County				
-	Casa Grande Valley 1 Dev SESE 25 6S 7E	?O	light shows in many? intervals	-	-	-	716-4729
-	Hatchett et al 1	O	shale, sand	-	-	-	500; 720
	McFarland NENW 22 7S 8E	O,G	?	-	-	-	1040-1060

OGCC Permit Number	Well Name Location & Field	Show Type	Strat. Horizon	Show point or interval (depth in feet) Production	Drill Stem Test	Cores & Cuttings	Reported
			Santa Cruz County				
-	Jones 1 Larrimore NWSE 9 20S 16E	O,G	?	-	-	-	3216
			Yavapai County				
141	Sierra 2 Campbell SWNW 23 20N 3W	H	Miss	-	-	-	430
133	Sierra 1 Campbell SWSW 23 20N 3W	H	Dev	-	-	-	?
479	Hopkins 34-1X Fed SWNW 34 18N 5E	O	Miss	-	-	-	1080-1095
485	Riddle 3-A Fed NENE 3 17N 4E	O	Dev	-	-	-	in water bailed
-	Harless 27B Fed NWNW 4 17N 4E	O	Dev?	-	-	-	no info.
			Yuma County				
-	Mitchell 1 Dunford 18 7S 12W	?O ?O	shale blue shale	- -	- -	- -	1235-1250 1695-1720
-	Loftus 1 NENW 4 8S 13W	?G	?	-	-	-	2545-2550
45	Gila 1 Kamrath NESE 15 8S 22W	?G O O	Miocene? Miocene? Miocene?	- - -	- - -	- - -	800;1200 1200;1500 1800;1900
-	Yuma Valley 1 Musgrove NENE 11 11S 25W	O O O	shale, sand sand sand	- - -	- - -	- - -	1254-1270 2263-2304 2664-2675

Table E. — Drill holes in Arizona through 1969: Oil, gas, and helium, with selected mineral exploration tests.

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Apache Co.			
42N	29E	SESE	33	191	Davis Oil 1 Nav	62	5784	Molas
41N	31E	SWSW	7	256	Z & Danneberg 161-1 Nav	63	5690	Akah
41N	31E	SWNW	19	35	El Paso 1 Bita Peak	56	5648	Pinkerton Tr
41N	30E	NWSW	10	44	Superior H-1 Nav	57	6317	Miss
41N	30E	SESE	13	299	Duncan 1 El Paso Nav	64	5400	Desert Cr
41N	30E	SWSW	16	46	Superior H-2 Nav	57	6787	Precamb
41N	30E	NESW	21	128	Superior 23-21 Nav M	60	5991	Miss
41N	30E	SESW	23	232	Pan Am O-1 Nav	63	6805	Precamb
41N	30E	NENW	30	425	Miami 1 Nav	67	6637	Aneth
41N	30E	NWSW	36	113	Texaco Z-1 Nav	60	6998	Precamb
41N	29E	SENE	3	367	Champlin 1-190 Nav	66	5287	Desert Cr
41N	29E	NESE	4	434	Champlin 1-335 Nav	68	6173	Miss
41N	29E	SESE	6	18	Shell 1 Nav	54	6490	Camb
41N	29E	NENE	22	168	La Rue 1 Toh Atin	61	6301	Miss
41N	29E	SESE	29	139	Davis C-1 Nav	61	6749	Aneth
41N	28E	SWSW	2	481	Consolidated 1 Nav	69	5900	Dev?
41N	28E	SENW	3	22	Shell 2 Nav	54	6339	Aneth
41N	28E	NESW	3	490	Consolidated 3 Nav	69	5708	Dev
41N	28E	SWSW	3	514	Consolidated 3-3 Nav	69	4855	Akah
41N	28E	NESE	4	28	Humble 1 Nav	55	6382	Aneth
41N	28E	SWSE	4	515	Humble 3 Nav	69	5010	Akah
41N	28E	NWNE	5	118	Humble 2 Nav	60	6260	Ouray?
41N	28E	SESE	5	508	Globe Minerals 1	69	5700	Akah
41N	28E	NENE	9	483	AAA Fishing E-3 Nav	69	5173	Akah
41N	28E	NWNE	9	511	AAA Fishing Tool E-1 Nav	69	5000	Akah
41N	28E	SWNE	9	444	Humble (AAA) E-2 Nav (65)	58	6520	Ouray
41N	28E	NENW	9	509	Globe Minerals E-4 Nav	69	5225	Akah
41N	28E	SWNE	10	58	Humble E-1 Nav	58	5410	Pinkerton Tr
41N	28E	SWNW	11	518	Consolidated 2-11 Nav	69	5057	Akah
41N	28E	NESW	11	69	Shell 23-11 Nav	59	5513	Paradox
41N	28E	SWNW	22	32	Franco Western 1 Nav	56	5902	Miss
41N	28E	SENW	27	205	Franco Western 2 Nav	62	6259	Ouray
41N	27E	NENE	22	166	La Rue 2 Dinne	61	6260	Molas
41N	27E	NENW	29	31	Hancock 29-1 Dinne Nav	56	6500	Ouray
41N	26E	NWNW	23	165	La Rue 1 Dinne	61	6332	Molas
41N	26E	SWSE	28	50	Gulf-Bri Am 1 Walker Crk	58	6421	Aneth
41N	26E	SWSW	31	260	MacDonald 1 Nav	63	6501	Aneth
41N	26E	SWSW	33	304	Tenneco 1 Nav	65	6606	Precamb
41N	25E	NWSE	16	226	Texaco AG-1 Nav	63	6615	Precamb
41N	25E	NENE	17	295	Gr Western 2 Nav	64	6457	McCracken
41N	25E	NENE	20	245	Gr Western 1 Nav	63	7099	Precamb
41N	25E	NWNE	21	266	Texaco AG-2 Nav	64	6781	Precamb
41N	24E	NENE	16	248	Gulf 1 Garnet Ridge Nav	63	6769	Camb
41N	23E	NWSW	7	-	San Juan (Midwest) Nav	24	2083	Dev-Miss
41N	22E	NWSW	12	290	Occidental 1 Monument-Nav	64	3029	Camb
40N	30E	SWSW	5	105	Bri Am C-1 Nav	60	6419	Precamb
40N	29E	SESE	7	146	Atlantic 7-1 Nav	61	5785	Precamb
40N	29E	NESW	15	176	Pan Am Moko-Nav	62	5868	Precamb
40N	29E	NESE	18	274	Marathon 1 Nav	64	6262	Miss
40N	28E	SWSW	1	213	Pure 138-5 Nav	62	5640	Miss
40N	28E	SWSE	2	115	Monsanto (Tex Pac) 138-3 Nav	60	5411	Miss
40N	28E	NWSW	6	179	Pan Am F-1 Nav	65	7359	Precamb
40N	28E	NWNW	9	513	Curtis Little 1 Nav 2193	69	6002	Precamb
40N	28E	NENE	11	77	Monsanto (Tex Pac) 138-1	59	6080	Precamb
40N	28E	NENW	11	116	Tex Pacific 4 Nav	60	5799	Precamb
40N	28E	SWNW	12	106	Monsanto (Tex Pac) 138-2 Nav	60	5771	Precamb
40N	28E	NWNE	17	138	Western States 2 Nav	60	6341	Precamb

Table E. — *Continued*

Apache Co. (cont'd)

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
40N	28E	NWNW	18	94	La Rue 1 Nav	59	6916	Precamb
40N	27E	NWNW	6	261	Occidental 1 Tex-Nav	64	6795	Camb
40N	26E	SESE	20	95	Tex Pacific 190-1 Nav	59	6424	Camb
40N	26E	NWNW	30	145	Bonanza 1 Nav	61	6515	Camb
40N	25E	NENE	6	271	Texaco AK-1 Nav	64	6750	Tapeats
40N	25E	NESE	11	60	Pan Am Tohlacon-Nav	58	6598	Precamb
40N	24E	NESW	8	247	Pan Am Q-1 Nav	63	6617	Camb
39N	30E	SESE	1	467	Odessa 1 Nav	68	2317	Moenkopi
39N	29E	SESE	1	503	Monsanto 1 Nav 717	69	8461	Precamb
39N	26E	NWSW	19	305	Cactus 1 Nav	65	6197	Precamb
39N	25E	NWNW	16	382	JCM 1 Nav-Mobil	67	6031	Precamb
39N	25E	SENW	28	272	Socony Mobil 155-1 Nav	64	5644	Precamb
39N	24E	SESE	7	297	Amerada 91-1 Nav	64	6573	Tapeats
39N	23E	SENW	12	292	Superior 22-12 Nav	64	6468	Precamb
39N	23E	NWSE	12	265	Superior V-33-12 Nav	64	6325	Precamb
39N	23E	NWSW	24	412	Horizon 1-24 Nav-Mobil	67	6452	Precamb
38N	30E	NWNW	2	497	Depco 1 Nav 1546	69	5012	sill in Dev
38N	30E	SENW	12	468	Pan Am 1-AF Nav	68	4809	Miss
38N	30E	NWNW	18	423	Skelly 1-Q Nav	67	5373	sill-McCracken
38N	30E	NESE	32	316	Pure-Sun Tidewater 1 Nav	65	4404	sill in Dev
38N	29E	NESE	16	415	Pan Am V-1 Nav	67	4445	sill in Penn
38N	27E	SESE	20	280	Pan Am T-1 Nav	64	5870	Precamb
38N	24E	SENW	28	424	American Mining 1 Nav	67	5807	Molas
38N	22E	NWNW	1	433	McCulloch 1-1X Nav	67	765	Navajo
37N	30E	NENE	34	507	Gulf 1 Nav 2290	69	4600	Precamb
37N	29E	NWNE	12	491	Gulf 1-BS Nav	69	4145	sill in Dev
37N	29E	SESE	33	489	Odessa 2 Nav	69	3605	Precamb
37N	29E	NWNW	35	298	Blackburn 35-1 Nav	64	3657	Precamb
37N	28E	NENE	24	520	Buttes 1-24	69	3920	Miss
37N	27E	SESE	8	311	Blackburn 8-1 Nav	65	4986	Camb
37N	27E	SESE	23	476	Buttes 1-23 Nav	68	3800	Miss
37N	25E	NWSE	4	455	Champlin 1-171 Nav	68	5268	Precamb
36N	30E	SESW	19	517	Continental Energy E-2X Nav	69	2170	Coconino?
36N	30E	SESE	20	398	Kerr McGee E-1 Nav	67	3868	Precamb
36N	30E	SESW	29	389	Kerr McGee 7 Nav	67	3270	Hermosa
36N	30E	SESE	29	391	Kerr McGee 8 Nav	67	3660	Precamb
36N	30E	SENE	30	446	Kerr McGee 10 Nav	68	3868	Precamb
36N	30E	SENW	30	419	Kerr McGee 16 Nav	67	3221	Hermosa
36N	30E	SESW	30	417	Kerr McGee 15 Nav	67	3246	Hermosa
36N	30E	SESE	30	396	Kerr McGee 9 Nav	67	3720	Miss
36N	30E	SENE	31	390	Kerr McGee 6 Nav	67	3835	sill in Penn
36N	30E	SENW	31	416	Kerr McGee 14 Nav	67	3920	Hermosa
36N	30E	SESW	31	420	Kerr McGee 13 Nav	68	4444	Miss
36N	30E	SESE	31	392	Kerr McGee 5 Nav	67	4620	?
36N	30E	SENE	32	384	Kerr McGee 4 Nav	67	2960	sill in Penn
36N	30E	SENW	32	379	Kerr McGee 2 Nav	67	3275	Hermosa
36N	30E	SESW	32	377	Kerr McGee 1 Nav	67	3864	Precamb
36N	30E	NWSE	32	506	Kerr McGee 11 Nav 8832	69	2893	sill in Penn
36N	30E	SESE	32	380	Kerr McGee 3 Nav	67	1853	DeChelly
36N	30E	SESE	32	386	Kerr McGee 3X Nav	67	3600	Penn
36N	30E	SENW	33	422	Kerr McGee C-2 Nav	67	4371	Camb
36N	30E	NWSW	33	484	Kerr McGee C-1 Nav	69	3590	Hermosa
36N	29E	SESW	11	519	Union Calif 1-N11	69	3896	Precamb
36N	29E	SWSW	17	522	Union Calif 1-M17	69	5057	Miss
36N	29E	SENE	23	401	Humble 87-1 Nav	67	5505	Precamb
36N	29E	SESE	24	427	Kerr McGee 1-F Nav	68	4465	Miss
36N	29E	SENE	25	431	Humble 2-88 Nav	67	4821	Precamb
36N	29E	SENW	25	447	Humble 4-88 Nav	68	4500	Miss
36N	29E	SESE	25	421	Humble 1-88 Nav	68	3850	Miss
36N	29E	SENE	36	443	Humble 3-88	68	3875	Miss

Table E. — *Continued*

Apache Co. (cont'd)

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
36N	28E	NWNW	6	300	Blackburn 6-1 Nav	64	4347	Precamb
36N	27E	SWNW	30	494	Riddle 1 Gottlieb Nav	69	3460	Miss
36N	27E	SESW	30	435	Simmons 1 Nav	68	3313	Aneth
36N	24E	SWNE	23	345	Cactus 1 Nav 8816	66	5720	Camb
36N	22E	NWNW	14	325	Cactus 1 Nav 8515	65	6689	Precamb?
35N	30E	NWNW	3	395	Anadarko 1-135 Nav	67	4242	Precamb
35N	30E	NWNW	4	525	Mesa 1B Nav	69	3972	sill in Penn
35N	30E	SENE	5	385	Kerr McGee B-2 Nav	67	4565	Precamb
35N	30E	NWNW	5	445	Kerr McGee B-1X Nav	68	3165	Penn
35N	30E	SENW	5	381	Kerr McGee B-1 Nav	67	4130	Miss
35N	30E	SENE	6	388	Humble 138-1 Nav	67	4280	Precamb
35N	30E	SESE	6	400	Humble 138-2 Nav	67	4607	Miss
35N	30E	SENE	8	393	Humble 140-1 Nav	67	4854	Precamb
35N	30E	SWNW	10	501	Odessa 1 Nav 1797	69	4978	McCracken
35N	30E	NENE	14	426	Kerr McGee 1-H Nav	67	5345	Precamb
35N	30E	SESW	15	452	Humble 1-146 Nav	68	4213	Precamb
35N	30E	SENE	35	454	Humble 1-151 Nav	68	3963	Precamb
35N	29E	SENE	1	463	Pan Am 1-AE Nav	68	5742	Molas
35N	29E	SWSW	25	478	Little 1 Nav Tohotso	68	3867	Precamb
35N	28E	SWNW	5	354	Buttes 1 Nav 8850	66	3030	Precamb
35N	28E	SESE	25	461	Buttes 1-25 Nav	68	3000	Precamb
35N	27E	NENE	31	526	Buttes 1-31 Nav	69	2482	Precamb
35N	22E	NENW	2	308	Tenneco 1 Nav 8939	65	6754	Tapeats
34N	28E	SESW	4	438	Gulf 1-4 Nav	67	2681	Precamb
31N	23E	SWNE	3	-	Amerada Black Mtn Nav	50	5766	Precamb
* 7N	7W	SWSE	7	432	Depco 1 Nav	67	2797	Precamb
* 7N	7W	SESE	15	480	Doherty 1-15 Nav	68	3001	Precamb
* 7N	7W	NWNE	26	430	Texaco 1-BC Nav	67	2937	Precamb
* 7N	7W	NWSE	32	428	Pan Am 1-AB Nav	67	3020	Precamb
* 7N	8W	NESE	4	437	Gulf 1 Nav Agua Sal	67	2656	Camb?
* 7N	8W	NWSW	11	439	Gulf 1-11 Nav	67	2687	Precamb
* 7N	8W	SENE	22	440	Gulf 1-22 Nav	67	2836	Precamb
* 7N	9W	SESE	14	466	Buttes 1-14 Nav	68	2701	Precamb
* 6N	6W	NWNW	20	477	Union 1-166 Nav	68	2800	Precamb
* 6N	7W	NESW	12	429	Gulf 1 Nav Defiance	67	2594	Precamb
* 6N	7W	NENE	26	448	Texaco 1-BF Nav	68	2825	Precamb?
* 6N	7W	NENE	32	496	Gulf 1 Nav 1219 (Anadarko)	69	2778	Precamb
* 6N	8W	SESE	26	453	Little 1 Nav	68	2315	Precamb
* 4N	7W	SWSW	11	499	Gulf 1 Nav 1481	69	2375	Precamb
* 4N	7W	SWSW	36	500	Gulf 1 Nav 1797	69	2032	Precamb
* 2N	6W		21	-	Wilson Cranmer 1	?	249	Precamb
* 2N	9W		15	-	Wilson Cranmer 2	?	826	Precamb
29N	24E	SENW	21	510	Gulf 1 Nav 2310	69	4552	Precamb
23N	30E	NWNW	24	-	Hogback 1	27	1510	Precamb
21N	29E	SWNE	31	218	Eastern 16 Santa Fe	62	828	Coconino
21N	28E	SWNE	22	90	Kerr McGee 1 Natoni	59	460	Coconino
21N	28E	NESW	25	227	Eastern 23 Santa Fe	63	590	Coconino
21N	28E	NWNW	26	84	Brown & Assoc 3 Fee	59	580	Coconino
21N	28E	SWNE	27	74	Brown & Assoc 2 Fee	59	2135	Precamb
21N	28E	NENE	28	70	Brown & Assoc 1 Fee	59	1322	up Supai
21N	26E	NESW	27	504	Thoureen 1 Santa Fe			
21N	26E	SENW	35	107	Eastern 1 Santa Fe	60	1616	Coconino
21N	25E	NESW	25	505	Thoureen 1 Nav 1767	69	1272	Coconino
20N	29E	SWSW	29	406	Kerr McGee 4 Santa Fe	67	1113	Coconino
20N	29E	NWNW	31	-	Duval 17A Strat	64	1909	up Supai
20N	28E	NESW	19	152	Eastern 4 Santa Fe	61	1479	Coconino
20N	28E	NWNE	23	407	Kerr McGee 5 Santa Fe	67	1205	Coconino
20N	28E	C	25	155	Eastern 6 Santa Fe	61	1286	Coconino

*Navajo Base Line

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Apache Co. (cont'd)			
20N	28E	NESW	29	282	Eastern 3 Santa Fe	64	1352	Coconino
20N	28E	SENW	31	234	Eastern 21 Santa Fe-Ancon	63	1361	Coconino
20N	28E	SESE	33	-	Duval 23 Strat	64	2068	up Supai
20N	27E	SENW	3	276	Eastern 28 Santa Fe	64	1037	Coconino
20N	27E	SENE	5	268	Eastern 22 Santa Fe	64	1022	Coconino
20N	27E	SENW	7	108	Eastern 2 Santa Fe	60	1240	Coconino
20N	27E	NESW	11	188	Eastern 12 Santa Fe	62	1305	Coconino
20N	27E	NESW	13	237	Eastern 18 Santa Fe	63	1353	Coconino
20N	27E	SWNE	15	209	Eastern 15 Santa Fe	62	1244	Coconino
20N	27E	NESW	19	112	Crest 1 Santa Fe	60	1226	Coconino
20N	27E	NESW	21	264	Eastern 36 Santa Fe	64	1285	Coconino
20N	27E	NWSE	22	414	Kerr McGee 12 Santa Fe	67	1283	Coconino
20N	27E	NWSW	23	405	Kerr McGee 10 Santa Fe	67	1330	Coconino
20N	27E	N/2	24	284	Eastern 24 Santa Fe	64	1340	Coconino
20N	27E	NESW	24	203	Crest 9 Santa Fe	62		Coconino
20N	27E	SENW	25	134	Crest 8 Santa Fe	61	1372	Coconino
20N	27E	SENW	25	353	Apache 1 Santa Fe Crest	66	1286	Moenkopi
20N	27E	SENW	25	473	Crest-Ariz Helium 8X Santa Fe	68	1363	Coconino
20N	27E	C SW	25	472	Crest-Ariz Helium 2 Santa Fe	68	1445	Coconino
20N	27E	SESE	25	471	Crest-Ariz Helium 1 Santa Fe	68	1225	Coconino
20N	27E	SWNE	26	182	Crest 11 Santa Fe	62	1391	Coconino
20N	27E	NWNW	26	-	Duval 21 Strat	64	1978	up Supai
20N	27E	NESW	26	129	Crest 5 Santa Fe	60	1180	Coconino
20N	27E	NESW	26	151	Crest 5-A Strat	61	1135	Coconino
20N	27E	NESW	26	289	Eastern 25 Santa Fe	64	1223	Coconino
20N	27E	NESW	27	263	Eastern 35 Santa Fe	64	1072	Coconino
20N	27E	NESW	28	258	Eastern 32 Santa Fe	63	1133	Coconino
20N	27E	SE	29	255	Eastern 31 Santa Fe	63	1049	Coconino
20N	27E	NWSE	30	259	Eastern 33 Santa Fe	63	1265	Coconino
20N	27E	NESW	31	194	Eastern 13 Santa Fe	62	980	Coconino
20N	27E	NESW	32	238	Kerr McGee Barfoot-State	63	1087	Coconino
20N	27E	NESW	33	110	Crest 2 Santa Fe	60	1140	Coconino
20N	27E	SWNE	34	140	Brown 1 Santa Fe	61	1214	Coconino
20N	27E	SENW	34	269	Eastern 37 Santa Fe	64	1202	Coconino
20N	27E	NENE	35	130	Crest 6 Santa Fe	61	1231	Coconino
20N	26E	NWNW	9	147	Linehan 1-9 Spurlock	61	1230	Coconino
20N	26E	SWSW	13	119	Wilson 1 Harris	61	1127	Coconino
20N	26E	SWSE	21	136	Linehan 1-21 Spurlock	61	1082	Coconino
20N	26E	SESW	23	296	Eastern 1 Reese	64	1098	Coconino
20N	26E	NESE	27	64	Kerr McGee 1 Reese	58	1052	Coconino
20N	26E	SESE	28	88	Eastern 1-28 State	60	1091	Coconino
20N	26E	NWSE	30	122	Sierra 3 State	60	1036	Coconino
20N	26E	SENE	31	137	Linehan 1-31 Spurlock	61	860	Coconino
20N	26E	SWNE	32	38	Kerr McGee 4 State	57	836	Coconino
20N	26E	NESE	32	378	Kerr McGee 4A State	67	834	Coconino
20N	26E	SWSE	33	10	Kerr McGee 1 Fee	56	2517	low Supai
20N	26E	SWSW	34	-	Kerr McGee 1 State	56	1520	up Supai
20N	26E	NWSE	34	36	Kerr McGee 2 State	56	2502	low Supai
20N	26E	NWNE	35	142	Kerr McGee 3 Fee	61	1086	Coconino
20N	26E	NW	35	39	Kerr McGee 2 Fee	57	1006	Coconino
20N	26E	SWNE	36	91	Kerr McGee 5 State	59	1200	Coconino
20N	25E	SESE	22	75	Tex Am 1 Fitzgerald	59	471	Chinle
20N	25E	SESE	22	99	Tex Am 2 Fitzgerald	59	1327	Coconino
19N	29E	NWNW	9	408	Kerr McGee 6 Santa Fe	67	1388	Coconino
19N	29E	NWNW	32	195	Desert 1 State	65	2660	?
19N	28E	SENW	9	150	Eastern 5 Santa Fe	61	1784	Coconino
19N	28E	NWSE	19	403	Kerr McGee 2 Santa Fe	67	1518	Coconino
19N	28E	NESW	21	-	Duval 19 Strat	64	2127	up Supai
19N	28E	SENW	34	404	Kerr McGee 3 Santa Fe	67	1760	Coconino
19N	27E	SENW	1	273	Eastern 34 Santa Fe	64	1440	Coconino

Table E. — *Continued*

Apache Co. (cont'd)

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
19N	27E	SWNE	3	124	Crest 3 Santa Fe	60	1280	Coconino
19N	27E	SWNW	4	236	Eastern 17 Santa Fe	63	1057	Coconino
19N	27E	SENW	5	206	Eastern 14 Santa Fe	62	1100	Coconino
19N	27E	SWNE	6	204	Crest 7 Santa Fe	62	1060	Coconino
19N	27E	NENE	8	250	Eastern 29 Santa Fe	63	1101	Coconino
19N	27E	SENW	8	216	Eli 2 Santa Fe	62	1138	Coconino
19N	27E	NENE	9	185	Eli 1 Santa Fe	62	1208	Coconino
19N	27E	NESW	9	109	Eastern 3 Santa Fe	60	2932	low Supai
19N	27E	NWNW	10	-	Duval 28A Strat	64	1894	up Supai
19N	27E	SWNE	12	229	Eastern 19 Santa Fe	63	1422	Coconino
19N	27E	SWNW	14	402	Kerr McGee 1 Santa Fe	67	1417	Coconino
19N	27E	SWSW	19	-	Duval 30 Strat	64	1890	up Supai
19N	27E	SWNE	22	-	Duval 15 Strat	64	1981	up Supai
19N	27E	CE/2	23	230	Eastern 20 Santa Fe	63	1557	Coconino
19N	27E	NENE	24	413	Kerr McGee 11 Santa Fe	67	1455	Coconino
19N	27E	SWSW	28	-	Duval 39 Strat	64	2001	up Supai
19N	26E	SWNE	1	348	Eastern 2 Reese	66	1067	Coconino?
19N	26E	SWNW	1	157	Eastern 1 Reese	61	1077	Coconino
19N	26E	NESW	2	81	Eastern 1-2 State	59	1054	Coconino
19N	26E	NENE	4	349	Kerr McGee 3A State	66	1005	Coconino
19N	26E	NWSE	4	37	Kerr McGee 3 State	57	1198	Coconino?
19N	26E	SWNE	5	196	Ram 1-5 Hortenstine	63	948	Coconino
19N	26E	SENE	6	78	Eastern 1-6 State	60	1013	Coconino
19N	26E	SWNE	9	178	Ram 1-9 Hortenstine	63	993	Coconino
19N	26E	NENE	10	80	Eastern 1-10 State	60	1035	Coconino
19N	26E	NESW	12	123	Sierra 2 State	60	1100	Coconino
19N	26E	NESE	12	-	Duval 2 Strat	63	1594	up Supai
19N	26E	SENW	13	135	Linehan 1-13 Spurlock	61	1083	Coconino?
19N	26E	SW	14	167	Ram 1-14 State	62	1004	Coconino
19N	26E	SWSW	14	177	Ram 1A-14 State	62	812	Coconino?
19N	26E	SESE	15	352	Eli 1 Hortenstine	66	986	Coconino
19N	26E	SWNE	16	121	Sierra 4 State	60	1016	Coconino?
19N	26E	SWNE	17	320	Walker 1 Lansdale	65	865	Coconino
19N	26E	SWNE	20	262	McCaughey 1 Sunland St	64	862	Coconino
19N	26E	NWSE	21	214	Fletcher 1-21 Spurlock	63	926	Coconino
19N	26E	SWSW	22	-	Duval 12 Strat	64	1583	up Supai
19N	26E	NESE	22	143	Teil 1 Kruglich-Fletcher	61	760	Moenkopi?
19N	26E	NWSE	22	346	Apache 1-22 State	66	1701	Supai
19N	26E	SWNE	23	318	Apache 1 Spurlock	65	1098	Coconino?
19N	26E	NWSW	23	148	Linehan 1-23 Spurlock	61	990	Coconino
19N	26E	SENW	26	465	Hallett 2 State 10603	68	1279	Coconino
19N	26E	NENW	27	149	Linehan 2-27 Spurlock	61	957	Coconino
19N	26E	SENE	28	451	Hallett 1 State 10602	68	997	Coconino
19N	26E	NESW	28	68	Wilkinson 1 Sunland St	60	1040	Coconino
19N	26E	NESW	28	87	Wilkinson 2 Sunland St	61	960	Coconino
19N	26E	NENE	36	-	Duval 1A Strat	63	2005	up Supai
19N	26E	NWNE	36	449	Hallett 1 State 10603	68	1376	Coconino?
19N	25E	SWNE	2	120	Sierra 1 State	60	1047	Coconino
19N	25E	NENW	11	210	Martin 1 Fitzgerald	62	847	Coconino?
19N	25E	C	13	153	Armour 1 Paulsell	61	812	Coconino
19N	25E	NE	23	-	Armour 4 Paulsell		776	Coconino?
19N	25E	C	25	184	Busby 1 Paulsell	62	930	Coconino?
19N	25E	SENW	26	189	Busby 1 State	62	879	Coconino
19N	25E	NENE	36	-	Duval 6 Strat	63	1342	up Supai
19N	25E	NESW	36	190	Busby 2 State	62	758	Coconino
19N	24E	SESE	6	-	Zuni 1 Arizona		950	Chinle
18N	29E	NESW	16	180	Martin 1 State	62	2068	Moenkopi
18N	28E	SESE	15	-	Duval 25 Strat	64	2789	up Supai
18N	28E	SWSE	19	-	Duval 44 Strat	65	2675	up Supai
18N	27E	NWNW	7	-	Duval 34 Strat	64	1865	up Supai

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Apache Co. (cont'd)			
18N	27E	NWSE	10	-	Duval 9 Strat	64	2512	up Supai
18N	27E	SESE	35	-	Duval 43A Strat	65	2445	up Supai
18N	26E	SENE	4	-	Duval 37 Strat	64	1564	up Supai
18N	26E	SWSW	6	-	Duval 33 Strat	64	1206	up Supai
18N	26E	NESW	7	287	Walker 1 Paulsell	64	660	Coconino
18N	26E	W/2	10	-	Duval 16 Strat	64	1414	up Supai
18N	26E	SWNE	13	355	Apache 13 Spurlock-Wetzler	66	1245	up Supai
18N	26E	SENE	16	-	Duval 20 Strat	64	1440	up Supai
18N	26E	NW	18	-	Duval 24 Strat	64	1224	up Supai
18N	26E	NWNW	19	-	Duvel 3 Strat	63	1321	up Supai
18N	26E	W/2	22	-	Duval 32 Strat	64	1845	up Supai
18N	26E	NENE	24	-	Duval 11 Strat	64	1739	up Supai
18N	26E	SWNW	25	341	Apache 3 Spurlock-Wetzler	66	1244	Coconino
18N	26E	NESE	27	322	Apache 2 Spurlock-Wetzler	65	1137	Coconino
18N	26E	NWSW	30	-	Duval 26 Strat	64	1496	up Supai
18N	26E	NENW	34	-	Duval 13A Strat	64	1548	up Supai
18N	25E	SWNE	10	288	Walker 1 State	64	608	Coconino
18N	25E	NWNW	10	-	Duval 18 Strat	64	1433	up Supai
18N	25E	C	14	-	Duval 35 Strat	64	1147	up Supai
18N	25E	SWNW	16	387	Henderson 1 State 8665	67	510	Coconino
18N	25E	NENE	18	-	Duval 8 Strat	63	923	up Supai
18N	25E	W/2	20	-	Kern 6 Strat	64	1021	up Supai
18N	25E	NESE	21	63	Kerr McGee 2 Hortenstine	58	540	Coconino
18N	25E	NENW	23	57	Kerr McGee 1 Hortenstine	58	3456	Precamb
18N	25E	SESE	24	-	Kern Co 8 Strat	64	1421	up Supai
18N	25E	NWNW	28	-	Duval 22 Strat	64	1268	up Supai
18N	24E	SW	2	-	Kern 1 Strat	64	1134	up Supai
18N	24E	SE	12	-	Kern 5 Strat	64	1012	up Supai
18N	24E	NWNW	17	-	Duval 31 Strat	64	955	up Supai
18N	24E	SESW	20	-	Duval 36 Strat	64	955	up Supai
18N	24E	SWSW	31	-	Duval 27 Strat	64	1064	up Supai
17N	29E	NENE	27	-	Duval 38 Strat	64	2529	up Supai
17N	28E	NENE	34	-	Duval 42 Strat	64	2107	up Supai
17N	27E	SWSE	15	-	Duval 14 Strat	64	2347	up Supai
17N	26E	NWSE	1	-	Duval 5 Strat	63	1905	up Supai
17N	26E	SWNE	3	442	Crest 1 Spurlock	68	3784	Precamb
17N	26E	SESE	16	-	Nat'l Potash 1 Nav	64	1507	up Supai
17N	26E	NENE	18	-	Duval 10 Strat	64	1528	up Supai
17N	26E	NWNW	36	-	Nat'l Potash 2 Nav	64	1572	up Supai
17N	25E	NENE	2	-	Kern Co 7 Strat	64	1600	up Supai
17N	25E	NE	6	-	Kern Co 3 Strat	64	1385	up Supai
17N	25E	C	22	-	Kern Co (U S Borax) 2 Strat	64	1430	up Supai
17N	25E	NWNW	29	-	Phillips 1-P Strat	64	1305	up Supai
17N	25E	SESE	36	-	U S Borax B-1 Strat	64	1308	up Supai
17N	24E	NENW	13	-	Ark La 11 NMA	65	1500	up Supai
16N	29E	NENE	34	-	Duval 7 Strat	64	1302	up Supai
16N	26E	NWNE	2	-	Duval 4 Strat	63	1641	up Supai
16N	26E	NENE	20	-	Phillips 2-P Strat	65	1449	up Supai
16N	25E	NESW	5	365	Eastern 1 NMA	66	683	Coconino
16N	25E	NWNW	6	-	Ark La 27 NMA	65	1560	up Supai
16N	25E	NWNW	6	-	Ark La 27X NMA	65	781	Coconino?
16N	25E	C	9	373	Eastern 3 NMA	66	614	Coconino
16N	25E	SENE	27	-	Ark La 18 NMA	65	1747	up Supai
16N	24E	NWNE	19	-	Ark La 1 NMA	64	2800	low Supai?
16N	24E	SWNE	30	-	Ark La 56 NMA	65	1420	up Supai
16N	24E	SWNE	32	324	Ark La 1 State	65	1450	up Supai
16N	24E	SWNW	34	-	U S Borax 1 Strat	63	1813	up Supai?
15N	30E	SESE	32	-	Hinkson 3		1300	Coconino
15N	29E	NWSE	21	49	Harrison 1 Townsend	58	750	Coconino?
15N	29E	NENE	22	-	Argo 1 State	43	2637	Precamb

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Apache Co. (cont'd)			
15N	29E	NWNE	22	-	Phillips 3-P Strat	65	1024	up Supai
15N	28E	NESE	4	-	Duval 40 Strat	64	1839	up Supai
15N	27E	SESE	18	-	Duval 41 Strat	64	1514	up Supai
15N	26E	SWNW	31	339	Grimm 1 Platt	66	1817	Ft Apache
15N	24E	NWSW	23	-	Ark La 2 NMA	64	2570	low Supai
15N	24E	NWNE	29	-	Ark La 42 NMA	65	1410	up Supai
14N	26E	SENE	14	-	Franco-Ariz 1 Gov	39	2595	Precamb
14N	25E	NENW	18	-	Ark La 3 NMA	64	2610	low Supai?
14N	25E	SWSW	28	-	Ark La 4C NMA	65	2488	low Supai?
13N	27E	NWNE	28	-	Greer 1 Rincon	49	498	Kaibab?
13N	25E	SESE	12	98	Pan Am 1 NMA	59	3680	Precamb
12N	31E	NENW	9	100	Townsend 1 Fed	59	585	Coconino
11N	31E	SESE	29	159	Ram 1 State	63	850	Coconino
11N	28E	SENW	22	375	Tenneco 1-C Fed	67	1687	low Supai
10N	30E	SWSW	26	371	Tenneco 1 Merrill	67	1577	low Supai
10N	30E	SWNE	27	187	Eastern 1 Coyote Crk	62	476	Coconino
10N	30E	SWNE	27	207	Eastern 1-A Coyote Crk	62	2351	Precamb
10N	25E	SWNW	2	200	Cities Service 204A Strat	62	637	Glorieta?
10N	25E	SWSE	2	-	Cities Service 204 Strat	62	287	Cen volc
10N	24E	SWNE	4	370	Tenneco 1 Fed B	67	4657	Precamb
9N	31E	SENW	20	66	Mae Belcher 1 State	59	2921	low Supai
9N	27E	SWSW	22	197	Cities Service 201 Colter	62	1353	Cret
9N	27E	SESE	26	-	Cities Service 203 Strat	62	1193	Cret
9N	27E	NENE	34	198	Cities Service 13 Strat	62	1230	Cret
9N	27E	SWSW	35	201	Cities Service 10 Strat	62	428	Cen volc
8N	28E	NWNE	6	199	Cities Service 4 Strat	62	976	Cret
8N	28E	SWNW	15	199	Cities Service 202 Strat	62	1186	Cret
					Cochise Co.			
13S	31E	NW	31	-	State 1 Winslow		1190	?
13S	31E	SESE	31	-	Fitzwater-Thayer 1	51	4137	Tert? volc?
13S	30E	SENE	27	-	Funk 1 Fee	38	6668	Cret?
13S	28E	SENW	16	-	Bowie Oil Syndicate 1	25	4110	Tert?
13S	25E	NESW	31	-	Hill 10 Wilcox	65	1892	?
13S	24E	SWSE	23	-	Waddell-Duncan 1 McComb	50	6865	Tert volc?
13S	22E	SENE	29	-	Duncan 2 Clayton	45	1180	Cenozoic
13S	22E	NESE	29	-	Duncan 1 Clayton	45	1000	Cenozoic
13S	22E	NWNW	33	23	Duncan 1 State	55	1435	Cenozoic
13S	22E	NWNW	33	23	Duncan 2 State	57	5310	?
13S	22E		33	73	Duncan 3 State	60	2185	Cenozoic
14S	31E	SWSE	16	-	San Simon 1 State	23	2000	Cenozoic
14S	30E	SENW	34	-	Ryan 1 Ryan	31	990	Cenozoic?
14S	30E	NENE	36	21	Ariz Oil & Gas 1 State	58	7580	Cenozoic?
14S	25E	NWSW	4	-	Waddell & Duncan 1 Lawson	50	2702	Cenozoic
14S	25E	NENE	6	-	Geronimo 1 Holliday	30	428	Cenozoic
14S	25E	NENE	6	-	Geronimo 1 Brunning	31	770	Cenozoic
14S	25E	SESE	9	-	Wilcox 1 Ariz Sul Springs	25	2360	Cenozoic
14S	24E	SESW	30	-	Francis 1 Proctor	50	4605	Tert? volc?
14S	21E	SENW	22	82	Bomack Oil 1 State	60	440	Escabrosa
15S	26E	NWSE	19	-	Benedum Trees 1 Arzberger	31	3298	Cenozoic?
15S	23E	NWNW	1	103	Hatchett 1 State	61	670	Cenozoic
16S	31E	SWNE	9	-	Portal Drlg C-9 State	53	5353	Tert volc?
16S	31E	NENE	10	48	Thomson 1 State	58	5434	Tert? volc?
16S	24E	NWNW	36	-	McCall 1 State	28	1510	Tert? Cret?
16S	20E	NWSE	34	-	Pomerene	50	1000	Cenozoic?
17S	19E	NWNE	17	-	Century 1 Colglazier	31	1550	Cret?
18S	24E	SESE	24	104	Donnelly 1 State	60	523	Cret?
18S	24E	SESE	24	111	Donnelly 1-A State	60	1193	Cret?

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Cochise Co. (cont'd)			
21S	25E	SENE	25	224	Moncrief (Allen) 1 Davis	63	5450	Tert volc
21S	24E	NENE	5	34	Southwest (Basin) 1 Davis-Clark	58	3570	Martin
21S	24E	NWSE	5	212	Moncrief 1 Davis-Clark	63	3525	Camb?
21S	23E	SESE	17	222	Moncrief 1 State	63	2446	Paleoz carb
21S	23E	NESE	19	93	Fraser 1 State	61	1899	Penn? carb
22S	27E	SENW	5	-	Waddell-Duncan 1 Murray	50	4210	Precamb
22S	27E	NWNW	24	-	Douglas 1 Evans	48	702	Cenozoic
23S	27E	SWSW	27	-	Owens 1 Bruno	47	680	Cenozoic
23S	27E	NWNW	34	-	Owens 1 Fourr	48	475	Cenozoic
23S	27E	NWNW	34	30	Cochise Oil 1 Goldman	58	1000	Cenozoic
24S	31E	NENE	2	52	Thomson 2 State	58	802	Naco Gp?
24S	23E	NWNW	4	-	Ari-Tex 1 Goins	45	1005	Naco Gp?
					Coconino Co.			
39E	2E	NENE	32	275	Underwood 1-32 Jacob Lake	64	3868	Brt Angel
37N	14E	NE	28	-	Sinclair 1 Nav	52	7210	Tapeats
34N	8E	SWSE	22	-	Burrell Collins 1-X (Cob)	47	3244	Camb
34N	8E	SESE	22	-	Collins 1 Nav	47	3432	Tapeats
29N	15E	NWNW	6	321	Moore & Miller 1 Hopi	65	6998	Precamb
29N	14E	NWNW	11	474	Pennzoil 1-11 Hopi	68	6940	Precamb
28N	1W	SWNE	35	6	Sinclair 1 Santa Fe	52	3544	Tapeats
27N	9E	SWSW	15	-	Barron-Steele 1 Babbitt	48	2165	Supai
27N	9E	NENE	21	-	Lockhart 1 Babbitt	49	3624	Tapeats
25N	8W	NENE	34	47	Ray Terry 1 State	58	1943	Tapeats
22N	10E	SENW	3	-	Flagstaff 1 Kellum	49	2420	Supai?
21N	6E	SWSW	11	-	Nav Ordinance 1 Depot	50	1654	Supai
20N	12½E	SW	13	-	Arizona 1 Sunshine		1470	Coconino
20N	11E	NENW	12	186	Owens 1 Diablo Amarillo	62	3628	Precamb
20N	10E	NWSE	26	240	Pickett 1 Padre Canyon St	64	3596	Precamb
20N	5E	SWNW	24	351	Potter (Willett) 1 State	65	4000	Precamb
19N	13E		28	-	Bar V Bar	38	603	Coconino
19N	10E	NWSE	5	239	Shoshone 1 Hildyard	63	1125	Supai?
19N	10E	SENW	24	72	Western 1 Fed	61	3020	Naco
19N	10E	SESW	24	372	Steinberg 1 Flowalt Babbitt	66	888	Supai?
19N	10E	SESW	24	376	Steinberg 1A Flowalt Babbitt	67	6500	Precamb
19N	6E	NESE	17	436	Oil Discovery 1 Fed	67	3253	Precamb
17N	6E	SESE	6	498	Hopkins 1 Jordan Strat	69	1254	Precamb
17N	6E	SENW	8	486	Hopkins 1 Stevenson	69	215	Supai?
16N	14E	NESW	29	202	Allen 1 O'Haco	62	510	Coconino?
15N	10E	SWNW	21	475	Pease 1 Fed	69	3610	Precamb
14N	14E	SWNE	30	71	Monsanto 1 Cabin Wash	59	3805	Precamb
14N	11E	NWSW	10	464	Eastern 1 Fed Moqui Bardo	69	3691	Martin
					Graham Co.			
4S	23E	NWNW	19	-	Knowles 1	19	810	Cenozoic
5S	24E	NESE	17	-	Alexander 1 Graham	06	1400	?
5S	24E	NENE	30	-	Ashurst 1	28	1247	Cenozoic
5S	24E	SWNE	30	-	Gila 1 Oil Syndicate	31	2645	Cenozoic?
6S	24E	NWNE	13	-	Underwriters 1 Mack	28	3767	Cenozoic?
7S	26E		17	-	Southern Pac	07	1820	Cenozoic
8S	26E	SENW	6	-	Idle 1 Healy	13	1800	?
9S	21E		14	-	Waggoner 3 Eureka	48	1501	?
10S	30E		20	-	U S Oil	20	700	?
10S	29E	NENE	20	-	Whitlock 1 Penrod	30	521	Cenozoic

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Graham Co. (cont'd)			
10S	28E	SESE	25	-	Bear Sp Oil 1 Allen	29	1532	Cenozoic
10S	28E	SESE	32	-	Clark 1	26	1000	?
10S	28E	NWNE	35	-	U S Oil	17	900	?
10S	28E	NENE	36	-	Whitlock 1 State	27	1925	Cenozoic
11S	28E		28	-	Howle 1	12	1100	?
11S	28E	SWNE	28	-	Bear Sp Oil 1 Reed	28	670	Cenozoic
11S	23E	NENW	6	-	Hooker 1	30	1985	Cenozoic
11S	22E	SESE	2	249	Ram 1 Sierra Bonita	65	1823	Cenozoic
					Maricopa Co.			
5N	4E	SWNE	7	16	Landrum 1 Salzer	53	1030	Cenozoic
5N	3E	NENW	14	14	Landrum 1 State	53	1146	Cenozoic
5N	2W	NWSW	19	-	Wucherer et al		500	?
5N	2W	NWNE	33	-	Wucherer et al	48	5000	?
5N	3W	NENE	33	-	Robertson Oil 1 Whittman	46	4365	Tert? volc
5N	3W	NENW	33	-	Robertson Oil 2 Whittman	48	5000	Tert? volc
4N	4E	SWSW	8	-	Glenn Oil 2 State	49	4520	Cenozoic
4N	4E	SESW	8	-	Biery 1 State	51	5396	Cenozoic
4N	4E	NWSW	13	-	Campbell 1 Pierce	50	1585	Cenozoic
4N	2W	SENE	25	-	Tannehill 1 Beardsley	38	3350	Cenozoic?
3N	4E	NENW	2	-	Glenn 1 State	48	4159	Precamb schist
2N	4E	NENW	30	-	Camelback-Totweiler 1	07	2818	Cenozoic
2N	4E	SESW	30	-	Newcom-Langley 1	38	1050	Cenozoic
1N	4E	NWSW	5	-	American Union Pet Co	31	600	Cenozoic
1N	3E	SESE	2	-	Peoples Oil 1 Gardner	45	3550	Cenozoic
1N	2W		11	-	Belluzi	48	1004	Cenozoic
1N	4W	NW	34	-	Reaves Oil 1 Fugua	39	4117	Cenozoic
1N	4W	W/2	34	-	Dixie 1 State	47	3505	Cenozoic
1N	6W		34	-	Wilson	48	1413	Cenozoic
2S	9W	NWSW	30	171	Montezuma A-1	62	248	Cenozoic
2S	9W	NWSW	30	208	Montezuma A-1X	64	441	Cenozoic
					Mohave Co.			
42N	8W	SWSW	31	-	Arizona 1 State	09	936	?
42N	15W		32	-	Virgin Oil	31	1405	?
42N	15W		32	-	Virgin Oil 6 State	31	545	?
41N	6W	SE	16	-	Cane Bed Well		542	?
41N	8W	NENW	18	-	Antelope 1 Morris	32	1522	Kaibab?
41N	15W	SWSE	29	-	Virgin Oil 4	18	2600	?
40N	6W	NWSW	12	40	George 1 Fed	57	2202	Kaibab
40N	8W	NWNE	28	33	Falcon-Seaboard 1 Fed	56	3753	Redwall
40N	8W	SESW	28	25	Valen 1 Fed	54	120	?
39N	6W	NWSW	14	42	Poteet & Lyons 1 Fed	57	2303	Coconino
39N	6W	NESW	35	56	Lyons 1 Fed	58	1820	Toroweap
39N	7W	NESE	2	347	Skelly 1A Fed	66	4031	Redwall
39N	13W	SESW	35	114	Tenneco 1 Schreiber	60	4015	Redwall
38N	5W	NWSE	31	43	Western 1 Fed	58	4666	Brt Angel
38N	7W	NWSW	17	117	Fields 2 Fed	60	32	Moenkopi
38N	7W	SWSW	17	41	Fields 1 Fed	57	460	Kaibab
38N	7W	SWSW	17	53	Fields 1X Fed	58	1159	Hermit
38N	7W	NWNE	29	502	Harris 1 Fed 3758A			
26N	16W	NENE	28	-	Kerr McGee 2 Red Lake	58	2135	Tert? salt
26N	16W	SESE	30	-	Kerr McGee 1 Red Lake	58	2608	Tert? salt

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Navajo Co.			
42N	18E	SWSE	34	13	Texas "A" Nav	53	4523	Camb
39N	21E	NENW	36	270	Texas AM-1 Nav	64	7182	Precamb
38N	21E	NENW	29	281	Superior "W" 21-29 Nav	64	7207	Precamb
38N	19E	SESW	24	283	Tenneco 1 Nav 8351	64	7400	Precamb
30N	17E	SWNE	35	309	Skelly 1 Hopi	65	7780	Precamb
29N	19E	SENE	8	310	Amerada 1 Hopi	65	7750	Precamb
28N	15E	SWSE	9	312	Atlantic 9-1 Hopi	65	6640	Precamb
26N	16E	NWNW	15	307	Texaco 1-A Hopi	65	5915	Precamb
21N	18E	SWNW	35	231	Peak 1 NMA	63	1350	Coconino
20N	21E	NWSE	4	211	Linehan 1 Mathews	62	965	Coconino
20N	21E	SESW	11	158	Linehan 1 Jeffers	61	1714	Coconino?
20N	17E	SENW	27	233	Peak 2 NMA	63	910	Moenkopi
19N	23E	SWNW	6	-	Gen Pet 14-6 Creager St	49	3432	Precamb
19N	23E	SWNW	9	160	Fohs 1-9 Santa Fe	61	1073	Coconino
19N	23E	NESW	16	173	Fohs 2-16 State	61	997	Coconino
19N	23E	NWSW	16	164	Fohs 1-16 State	61	845	Moenkopi
19N	23E	SENE	21	161	Fohs 1-21 Santa Fe	61	710	Coconino
19N	23E	NWSW	26	174	Fohs 1-26 Finley	61	727	Coconino
19N	23E	SENE	29	-	Fohs 1-29 Santa Fe	61	723	Coconino
19N	23E	NWNW	34	162	Fohs 1-34 Santa Fe	62	678	Coconino
19N	23E	SWSW	36	-	Duval 29 Strat	64	1454	up Supai
19N	22E	SWSW	1	26	Hager Mills 1 Santa Fe	55	1182	Coconino
19N	22E	SESE	13	181	Fohs 1-13 Santa Fe	62	1838	up Supai?
19N	17E	NESW	10	301	Ferrin 1 State	66	1417	up Supai?
19N	17E	NWNW	22	344	Ferrin 1 NMA	66	1250	up Supai?
18N	23E	NESW	18	340	Ark La 24 NMA	66	1560	up Supai
18N	23E	NENE	21	360	Ark La 23 NMA	66	1919	up Supai
18N	23E	SWNE	27	235	Franklin et al C-1 NMA	63	310	Coconino
18N	23E	SWNE	27	254	Franklin et al C-2 NMA	63	380	Coconino
18N	23E	SWNE	35	221	Franklin et al A-2 NMA	62	390	Coconino
18N	23E	NWSE	36	253	Franklin et al 1 Bernstein	63	215	Moenkopi
18N	20E	SWNE	28	83	Arrowhead 1 Besoyan	59	1987	low Supai
18N	20E	SWSE	30	67	Tucson 1 Woodman Fed	59	310	Coconino?
18N	20E	SWSE	30	89	Tucson 1-X Woodman Fed	60	1783	low Supai?
18N	20E	SESE	31	54	Besoil 1 Hunt	58	1683	low Supai
18N	20E	SESE	31	470	Cree 1 Hunt	68	1605	low Supai
18N	20E	SESW	32	-	Oil Holdings 1	51	180	?
18N	20E	SWSE	32	356	Kalil 1 Zelia St	67	1400	up Supai
18N	20E	SWSW	33	460	Cree 1 Scorse	68	3585	Precamb
18N	20E	SESW	33	55	Besoil 1 Perkins	58	485	Coconino?
17N	23E	SWNE	1	217	Franklin et al NMA	62	1285	up Supai
17N	23E	SESW	5	337	Ark La 6 NMA	66	1635	up Supai
17N	23E	SWSW	8	-	Ark La 38 NMA	65	1600	up Supai
17N	23E	SWSE	8	361	Ark La 44 NMA	66	1331	up Supai
17N	23E	NENE	19	335	Ark La 36 NMA	65	1473	up Supai
17N	23E	SESE	23	-	Ark La 22 NMA	65	1718	up Supai
17N	23E	SENE	29	333	Ark La 39 NMA	65	1340	up Supai
17N	23E	SWSW	31	364	Ark La 20 NMA	66	1029	up Supai
17N	22E	NWSW	21	331	Ark La 33 NMA	66	1142	up Supai
17N	22E	SWNW	22	220	Franklin et al B-1 NMA	62	375	Coconino
17N	22E	NWSW	24	334	Ark La 7 NMA	65	1275	Coconino?
17N	22E	SE	28	244	NMA 3 Fee	63	1418	up Supai
17N	22E	NWSW	36	326	Ark La 3 State	65	1170	up Supai
17N	20E	NWNW	21	-	Gr Basin 1 Taylor-Fuller	27	4675	Precamb
17N	16E	SWNW	4	350	Ferrin 1 AJA-Babbitt	66	80	Coconino
16N	23E		1	-	Petrified Forest Natl Mon	34	1023	Coconino?
16N	23E	SWNW	5	357	Ark La 15 NMA	66	1157	up Supai
16N	23E	NE	6	-	Ark La 83 State	65	1320	up Supai
16N	23E	SENE	7	-	Ark La 88 NMA	65	1325	up Supai
16N	23E	SWNE	9	-	Ark La 17 NMA	65	1420	up Supai
16N	23E	NWNW	13	342	Ark La 16 NMA	66	1430	up Supai

Table E. — *Continued*

Navajo Co. (cont'd)

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
16N	23E	NE	18	-	Ark La 32 State	65	1255	up Supai
16N	23E	SENW	18	358	Ark La 25 State	66	1100	up Supai
16N	23E	SWNE	19	-	Ark La 68 NMA	65	985	up Supai
16N	23E	SWNE	21	-	Ark La 12 NMA	65	1295	up Supai
16N	23E	NENE	26	-	Ark La 14 State	65	1300	up Supai
16N	23E	SWSE	27	359	Ark La 10 NMA	66	1007	up Supai
16N	23E	SWSE	28	336	Occidental 1 State	65	1035	up Supai
16N	23E	SWSW	29	-	Ark La 51 NMA	65	1260	up Supai
16N	23E	SENW	30	338	Occidental 2 State	65	960	up Supai
16N	23E	SWNE	34	-	Ark La 89 NMA	65	942	up Supai
16N	23E	SWSW	34	363	Ark La 31 State	66	926	up Supai
16N	23E	SWNE	36	-	Ark La 59 State	65	1315	up Supai
16N	22E	SWNE	12	-	Ark La 46 NMA	65	1247	up Supai
16N	22E	SWNE	14	-	Ark La 26 NMA	65	1176	up Supai
16N	22E	SENE	16	329	Ark La 64 State	65	3380	up Supai?
16N	22E	NESE	23	362	Ark La 19 NMA	66	945	up Supai
16N	22E	SENE	25	-	Ark La 37 NMA	65	1075	up Supai
16N	22E	NESE	27	328	Ark La 77 NMA	65	1000	up Supai
16N	20E	SENE	5	85	Pan Am A1 Aztec Land & Cattle	59	4003	Precamb
16N	18E	SWNE	9	86	Pan Am B1 Aztec Land & Cattle	59	3936	Precamb
16N	17E	NENE	20	-	Black Canyon	27	476	Coconino
16N	16E	SWSW	1	20	Eisele 1 McCauley	55	4231	Precamb
15N	23E	SWNE	10	323	Ark La 7 State	65	1060	up Supai
15N	22E	NENE	3	343	Ark La 55 NMA	66	975	up Supai
15N	22E	CE/2	24	243	NMA 2 Fee	63	1844	up Supai
15N	19E	NWNE	21	-	Hopi 1	27	2420	low Supai
15N	19E	SWNE	34	-	Union Continental 1 NMA	44	3609	Precamb
15N	18E	SWSE	14	-	Winslow Oil 2	?	3000	low Supai
15N	18E	NENE	19	-	Union Continental 1 Aztec	43	3850	Martin
15N	18E	NE	23	-	Holbrook 1	24	3023	low Supai
14N	23E	NE	12	-	Ark La 5 NMA	65	1350	up Supai
14N	22E	NE	5	242	NMA 1 Fee	63	1500	up Supai
14N	20E	SWSE	4	-	Adamana Oil Co	24	3387	Naco
14N	20E	NE	33	61	L Johnson 1 Aztec	59	3746	Precamb
14N	20E	SWNE	33	97	L Johnson 2 Aztec	63	1540	Ft. Apache
14N	20E	NESW	33	126	L Johnson 3 Aztec	60	610	up Supai
14N	20E	NESE	33	-	Lockhart 1 Aztec	49	3734	Precamb
14N	19E	NENE	35	291	Taubert & Steed 1 Babbitt	65	3822	Precamb
14N	18E	NW	12	154	Calif 1 State	61	1947	low Supai
14N	18E	NW	12	175	Calif 1A State	62	2947	Naco
13N	20E	SESE	3	-	Lynch 1 Aztec	51	1990	low Supai
12N	23E	SWNE	25	76	Pan Am 1B NMA	59	4497	Precamb
12N	17E	SESE	18	374	Tenneco 1 A Fed	67	1700	low Supai
10N	21E	NESE	31	368	Tenneco 1X Ft. Apache	66	4059	Precamb
10N	19E	NWNW	15	369	Tenneco 1 Fed	67	1840	low Supai

Pima Co.

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
11S	10E	NESE	27	11	Berry Min Dev 1 Fed	53	3212	Tert? Cret? volc
12S	11E	SWNE	6	-	Eloy Dev 1 State	49	4950	Tert?
17S	10E		11	-	Ridge Mining Co 2 Sierrita	58	1465	?
18S	18E	NESW	33	3	Cienega 1 State	52	2760	Cret
18S	18E	NWNW	34	19	Ted Jones State	54	2656	Cret
19S	18E	NENE	29	192	Mountain States 1 State	62	1050	Cret
19S	18E	NENE	29	219	Mountain States 1A State	64	4410	Cret
19S	17E	SE	22	-	Ariz 1 Boyce	42	2991	Tert
19S	17E	SWSE	22	-	Anderson 2 Empire	51	1350	?

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Pinal Co.			
1S	8E	SESE	17	5	Robinson et al 1	56	2836	Precamb? granite
2S	10E	SW	32	-	East Lantron 1 State	49	1007	Cenozoic
4S	9E	SW	25	-	Schoenheit 1 Moorehouse	45	415	Cenozoic
4S	3E	NENW	36	-	Robinson 1 Harbor	51	3642	Cenozoic?
5S	14E		8	-	Hackberry	05	700	?
5S	10E	SWSW	31	15	Western 1 Fed	53	5132	Tert?
6S	8E		18	-	Crouch Drl 1 Holland	64	3243	?
6S	7E	SESE	25	-	Casa Grande Dev 1	44	4742	Tert
7S	8E	NENW	22	-	Hatchett 1 McFarland	45	1260	Cenozoic
8S	17E	NWNW	33	-	San Pedro 1 Smith	30	1485	Cenozoic
8S	16E	SWSE	25	-	Santa Maria Expl 1	48	2144	Cenozoic
8S	10E	SENW	8	317	Ari Mass 1 State	67	832	Cenozoic
8S	7E		12	-	Creed Cherry	48	2247	Cenozoic
					Santa Cruz Co.			
20S	16E	NWSE	9	-	Jones 1 Larimore	43	3394	Cret?
21S	18E	SW	6	-	Nogales Oil & Gas	21	1115	Tert
					Yavapai Co.			
25N	9W	NESE	27	-	Chedester	58	96	?
20N	3W	SWNW	23	141	Sierra Campbell 2	61	1155	Tapeats?
20N	3W	SWSW	23	133	Sierra Campbell 1	61	1182	Tapeats
18N	5E	SENE	28	458	Hopkins 28-1 Fed	68	1308	Precamb
18N	5E	SESE	31	487	Hopkins 1 Hallermund Strat	69	1215	Precamb
18N	5E	NENW	34	495	Hopkins 34-2 Fed	69	1217	Precamb
18N	5E	SWNW	34	469	Hopkins 34-1 Fed	69	500	Redwall
18N	5E	SWNW	34	479	Hopkins 34-1X Fed	68	1138	Precamb
18N	5E	SWNW	34	482	Hopkins 34-1Y Fed			
18N	4E	NESW	32	257	Yavapai 18 Alsbury	64	306	?
18N	2W	SE	20	-	Chino Valley 1 State	38	2060	Precamb
18N	2W	NWNW	26	332	O'Donnell Ewing 1 Fed	65	1205	Tapeats
18N	2W		27	-	Chino Valley 1	13	1800	?
18N	2W	SESE	27	-	Anthony 1 Discoverer	03	2003	Precamb
18N	2W	NENE	34	-	Aricopa 1 Lyons	40	3010	?
17N	5E	NW	8	493	Hopkins 1 Coconino Strat	69	1195	Precamb
17N	5E	SWNW	34	492	Hopkins 1 Frye Strat	69	1405	Precamb
17N	4E	NENE	3	285	Harless 36C Fed	65	340	Supai?
17N	4E	NENE	3	485	Riddle 3-A Fed	69	1242	Tapeats
17N	4E	NWNW	4	267	Harless 27 Fed	64	1294	Precamb
17N	4E	NWNW	4	278	Harless 27B Fed	64	1958	Precamb
17N	4E	SWNW	4	169	Harless 1 Fed	64	1762	Precamb
17N	4E	NESW	5	293	Yucca 1 Crary	64	1661	Precamb
16N	4E	NWNW	20	96	Cottonwood 1 State	59	1485	Tert
13N	5E	NWNW	9	-	Ariz-Verde Oil Co 2	13	1225	Tert volc
13N	5E	NWNW	14	-	Ariz-Verde Oil Co 1	13	1625	Tert volc
11N	10W		16	-	Klaner & Doolin	58	1096	?
9N	6W	SENE	5	330	C & J Drig 1 State	66	2327	?

Table E. — *Continued*

TOWNSHIP	RANGE	QUARTER LOCATION	SECTION	OGCC PERMIT NO.	WELL NAME	YEAR COMPLETED	TOTAL DEPTH (FEET)	BOTTOM UNIT
					Yuma Co.			
10N	14W	SE	6	-	Sutton 1 Johnson	46	400	?
8N	13W	SWSW	20	457	El Paso 1 Fed Butler Strat	68	1359	Precamb
7N	19W	SESE	10	462	El Paso 1-B Fed La Posa	68	1400	Tert
7N	19W	NENW	24	459	El Paso 1-A Fed La Posa Strat	68	2815	metamorph
7S	12W		18	-	Mitchell 1 Dunford	43	2000	?
7S	13W	NENE	16	156	Des Drig (Keoughan) 1 State	63	6710	Cenozoic?
8S	13W	NENW	4	-	Loftus 1	28	2630	?
8S	22W	NESE	15	45	Gila 1 Kamrath	59	2140	Cenozoic?
8S	22W	SESE	15	62	Gila Valley Oil 1 Corinth	59	380	Cenozoic
8S	23W	SESE	32	-	Yuma 1 Sinclair	26	1815	?
9S	23W	SWSW	19	24	Colorado 1 Elliott	54	3255	Cenozoic?
10S	23W	NENE	31	17	Stewart 1 Fed	54	3660	Cenozoic
10S	24W	NWSW	24	27	Colo 1 Fed	55	6015	Cenozoic
10S	24W	NWNW	35	9	Hickey 1 Fed	52	920	Cenozoic
11S	25W	NWNE	11	-	Yuma 1 Musgrove	40	4868	Cenozoic

Table F. — Stratigraphic names and general formational characteristics of the Northeastern, Northwestern, and Southern parts of the Colorado Plateau, in Arizona.

NORTHEASTERN ARIZONA

CENOZOIC		
Quaternary	lava flows & alluvium	
Tertiary	lake sediments & alluvium	
MESOZOIC		
Cretaceous		
Mesa Verde Gp		500-1000
Yale Point Ss	ss, yel gy, cs-bd	250- 400
Wepo Fm	mdst & slst, ol gy; ss, yel gy; coal	300- 750
Toreva Fm	ss, yel gy; sh & slst, dk; coal	150- 300
Mancos Sh	sh & slst, dk gy, calc, foss	400- 700
Dakota Ss	ss, pl or, cs-bd; slst, carbonaceous	30- 130
Jurassic		
Morrison Fm	ss & sh, var, alluvial deposits	600-1000
San Rafael Gp		100-1000
Cow Springs Ss	ss, gn gy, calc, eol, cs-bd	110- 450
Entrada Ss	ss, rd, thick bd, cs-bd; slty ss, rd	40- 450
Carmel Fm	ss, wh, yel bn; slst, pl rd bn	35- 650
Triassic		
Glen Canyon Gp		100-1500
Navajo Ss	ss, pl or, pl rd bn, thick bd, eol, cs-bd	0-1400
Kayenta Fm	ss, rd purp, cs-bd; slst & sh, var	55- 700
Moenave Fm	ss, pl rd, rd bn; slty ss	200- 350
Wingate Fm	ss & slst, rd or, thin bd; ss, eol, cs-bd	100- 600
Chinle Fm	ss & slst, rd; mdst & slst, var	400-1000
Shinarump Mb	congl; ss, cs-bd	30- 250
PALEOZOIC		
Permian		
Cutler Gp	ss, sdy sh, ls & congl; redbeds	1000-1500
DeChelly Ss	ss, pl rd bn; up=eol, low=aqueous; cs-bd	0- 820
Organ Rock Sh	sh, slst, ss, rd & rd or	200- 900
Cedar Mesa Ss	ss, lt, cs-bd; calc	0- 500
Halgaito Fm	ss, slst, mdst, rd & rd bn, thin bd	0- 430
Pennsylvanian		
Hermosa Gp		800-1600
Honaker Trail Fm (Upper Hermosa)	ls & ss, gy & rd gy; sh & slst, gy gn	0- 750
Paradox Fm		0- 600
Ismay zone	ls, gy, foss; blk sh at top & base	
Desert Cr. zone	ls, lt gy, tan, foss; blk sh	
Akah zone	ls & dol, gy, foss; slst & anhy, gy	
Barker Cr. zone	slst, gyp, dol, gy; ls, cty, gy; sh, blk	
Pinkerton Trail Fm (Lower Hermosa)	ls & dol, gy, foss; slty sh, slst, ss	0- 300
Molas Fm	slst, rd bn; sh, lav; ss, calc, ct peb	0- 200
Mississippian		
Redwall Ls		0- 500
Horseshoe Mesa Mb	ls, wh, bf, thin bd, aph, cty	30- 50
Mooney Falls Mb	ls, gy, thick bd, aph, crin	50- 235
Thunder Springs Mb	ls, gy, crin; with ct interbeds	25- 175
Whitmore Wash Mb	dol, gy, thick bd, ool	50- 200

Abbreviations: blk-black, bl-blue, bf-buff, bn-brown, dk-dark colored, gn-green, gy-gray, lav-lavender, lt-light colored, ol-olive, or-orange, pl-pale, pk-pink, purp-purple, rd-red, var-variegated, yel-yellow, wh-white; anhy-anhydrite, cong-conglomerate, dol-dolomite, evap-evaporites such as salt and anhydrite, gyp-gypsum, ls-limestone, mdst-mudstone, redbeds include orange, red-orange, red and brown siltstone, sandstone and shale; ss-sandstone, sh-shale, slst-siltstone; alt-alternating, aph-aphanitic, bd-bedded, calc-calcareous, ct-chert, cty-cherty, cs-bd-cross bedded, crin-crinoidal, eol-eolian, foss-fossiliferous, glau-glauconitic, mic-micaceous, ool-oolitic, peb-pebbles, sdy-sandy, slty-silty; mott-mottled, Cr-Creek, Fm-Formation, Gp-Group, Mb-Member.

Table F. — *Continued*

NORTHEASTERN ARIZONA (cont'd)

Devonian		
Ouray Ls	ls & dol, lt, ool; sh, gn	0- 300
Elbert Fm	dol, sdy, thin bd; sh, gn & rd	0- 300
McCracken Ss	ss, wh, gy, rd, glau; dol, sdy	0- 150
Aneth Fm	ls, dol & sh, dk bn, blk, resinous	0- 130
Ord & Sil not recognized		
Cambrian?		
Tapeats? Ss	ss, rd, gn; basal Paleozoic clastics	0- 200
PRECAMBRIAN	quartzite, granite, schist-greenstone	

SOUTHERN PLATEAU

CENOZOIC AND MESOZOIC	generally same as in NE Arizona	
PALEOZOIC		
Permian		
Kaibab Ls	ls, cty, sdy, foss; ss & dol, lt col	0- 350
Kaibab-San Andres	S. of Defiance uplift	
Coconino Ss	ss, buff, wh, cs-bd, eol	50- 900
Coconino-Glorieta	ss, lt, alt flat & cs-bd; S. of Defiance	0- 300
Supai Fm	redbeds (ss & slst)	600-2000
upper Supai	redbeds, evap, dolo	350-1300
Ft. Apache Mb	dol & ls, bn; gy sh & evap	0- 130
lower Supai	redbeds, ls, gyp	700- 900
Pennsylvanian		
lowermost "Supai"	mdst & sh, rd bn, mar	200- 500
Naco Fm	ls, gy, dense, crin, cty; rd sh	0-1000
Molas zone	redbeds, ct congl	0- 75
Mississippian		
Redwall Ls	ls & dol, lt, cty	0- 450
Devonian		
Martin Fm	ls & dolo, gy bn; sh, gn; some ss	0- 500
Ord & Sil not recognized		
Cambrian		
Tapeats?	ss, arkosic, cs-bd, congl lenses	0- 150
PRECAMBRIAN	quartzite, granite, schist-greenstone	

NORTHWESTERN ARIZONA

CENOZOIC AND MESOZOIC	generally same as in NE Arizona	
PALEOZOIC		
Permian		
Kaibab Ls	ls, cty, sdy, foss; ss & dol, lt	0- 820
Toroweap Fm	redbeds, gyp, ls	0- 300
Coconino Ss	ss, buff wh, cs-bd, eol	0- 900
Hermit Sh	redbeds, mostly sh	0- 900
Supai Fm	ss, or, calc, cs-bd; slst & sh, rd bn	0-1600
Queantoweap Ss	ss, pk, gy, cs-bd, calc	0- 900
NW equiv of Supai		
Pakoon Ls	ls & dol, gy; extreme NW Arizona	0- 700
Pennsylvanian		
Callville Ls	ls, extreme NW Ariz; Supai to E.	0- 700
Mississippian		
Redwall Ls	ls & dol, lt, cty	150-1300
Devonian		
Martin Fm	ls & dol, gy bn; sh, gn; some ss	75-1300
Temple Butte Ls	dol & ss, purp; only G. Canyon & W.	
Ord & Sil	undif. carbonates; extreme NW Arizona	
Cambrian		
Muav Ls	ls, bl gy, thin bd; sh & ls, mott	0- 475
Bright Angel Sh	sh, gn, mic, foss; some ss & ls	25- 375
Tapeats Ss	ss, arkosic, gn, bn, rd, cs-bd, congl	0- 300
PRECAMBRIAN	sediments, quartzite, granite, greenstones	

Table G. — Uranium ore minerals identified or found in Arizona.

Mineral	Composition	Description	Occurrence
Oxides			
Uraninite (Pitchblende)	Ideally UO_2 but usually a mixture of +4 and +6 valence uranium due to oxidation. May contain some thorium and other metal impurities.	Sometimes well crystallized but usually microcrystalline, botryoidal, or powdery. Brittle. Color velvet brownish or greenish black. Heavy. Submetallic luster. Strong radioactivity. U=46.5 to 88.2 percent depending on purity.	Trace amounts occur in granitic rocks and rhyolitic lavas in accessory minerals such as sphene and zircon or as dust along intercrystal faces. Occasionally occurs in granitic pegmatites. Small amounts found in some hydrothermal base-metal sulfide veins. Minor amounts have been found also associated with fluorite-bearing veins and in veinlets in the Dripping Spring Quartzite deposits of Gila Co. The pipe-like deposits such as in the Orphan mine, Coconino Co., contain considerable amounts of uraninite. Uraninite is commonly found as replacement of carbonized wood or vegetal matter or as disseminations and interstitial cement in sandstone-type deposits.
Becquerelite	$7UO_3 \cdot 11H_2O$	Tabular crystals but usually in fine-grained aggregates or coatings. Soft. Brittle. Color amber yellow to brownish yellow. Adamantine luster. Transparent. U=75.7 percent. Difficult to identify.	Rare but sometimes found associated with uraninite as secondary alteration product in sandstone-type deposits.
Gummite	Mixture of hydrated oxides of uranium including silicates, phosphates and oxides.	Fine-grained, dense and gumlike masses or coatings. Color orange, red, brown, greenish-black or yellow.	As secondary alteration band or coating around or close to uraninite.
Schoepite	$UO_3 \cdot 2H_2O$	Tabular crystals and as dense microcrystalline aggregates. Brittle. Soft. Color sulfur-yellow to lemon-yellow. Adamantine luster. Transparent. Pale green fluorescence with ultraviolet radiation. U=71.9 percent. Difficult to identify.	A secondary alteration product from uraninite.

Table G. — *Continued*

Mineral	Composition	Description	Occurrence
Fourmarierite	$PbO \cdot 4UO_3 \cdot 5H_2O$	Usually in dense aggregates. Relatively hard. Color orange-red to golden-red. Subadamantine luster. U=64.6 to 65.3 percent. Usually mixed with other secondary uranium minerals.	Secondary alteration product of uraninite and usually a constituent of gummite.
Arsenates			
Zeunerite	$Cu(UO_2)_2(AsO_4)_2 \cdot 10\text{-}12H_2O$	Probably fine platy crystals of good cleavage. Color green to emerald-green. Weak vitreous luster. U=47.7 to 49.5 percent. In field cannot be distinguished from torbernite and metatorbernite.	The fully hydrated zeunerite is probably very rare and metazeunerite is the more common secondary alteration product where copper, arsenic and uranium minerals occur.
Metazeunerite	$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$	Rectangular plates or foliated and micaceous aggregates of platy crystals. Good cleavage. Soft. Color grass-green to emerald-green. Weak yellow-green fluorescence with ultraviolet radiation. U=46.4 percent. In field cannot be distinguished from torbernite and metatorbernite.	Metazeunerite is a common secondary alteration product where copper, arsenic and uranium minerals occur.
Carbonates			
Schroeckingerite	$NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$	Usually as crusts, clusters, rosettes or globular aggregates of scales. Micaceous cleavage. Soft. Color greenish-yellow. Weak vitreous luster. Transparent. Bright yellowish-green fluorescence in ultraviolet light. U=26.8 percent.	Relatively common secondary mineral in sandstone-type deposits and in some vein-type deposits.
Andersonite	$Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$	Clusters of minute pseudo-cubic crystals. Color bright yellow-green. Bright yellow-green fluorescence in ultraviolet light. U=39.2 percent. Usually mixed with other minerals in efflorescence; and difficult to distinguish in field.	Rare secondary mineral in some sandstone- and vein-type deposits.

Table G. — *Continued*

Mineral	Composition	Description	Occurrence
Bayleyite	$Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$	In crusts. Color yellow. Dehydrates to pale yellow or yellowish-white. Weak yellow-green fluorescence in ultraviolet light. U=28.9 percent. Difficult to distinguish in field.	A rare secondary mineral reported in efflorescence on mine walls.
Swartzite	$CaMg(UO_2)(CO_3)_3 \cdot 12H_2O$	Intergrowth crusts with andersonite and schroeckingerite. Color green. Bright yellowish-green fluorescence with short-wave ultraviolet light. Dehydrates readily to dull yellowish-white. U=32.6 percent. Difficult to distinguish in field.	A rare secondary mineral found in efflorescence on mine walls.
Phosphates			
Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$	Thin to thick tabular plates, usually small but distinctive. Good cleavage. Soft. Color lemon-yellow to sulfur-yellow, sometimes slightly greenish. Transparent to translucent. Strong yellowish-green fluorescence in ultraviolet light. U=48.3 to 50.1 percent. Hard to distinguish from meta-autunite and some other yellow uranium minerals of similar characteristics.	A very common and widespread secondary alteration product of uraninite in vein-type deposits and found locally in sandstone-type deposits.
Meta-autunite I Meta-autunite II	$Ca(UO_2)_2(PO_4)_2 \cdot 2\text{-}6H_2O$ $Ca(UO_2)_2(PO_4)_2 \cdot 0\text{-}6H_2O$	Crystals similar to autunite but formed by dehydration of autunite. Color may be slightly more greenish and fluorescence weaker. Usually not distinguishable from autunite and some other yellow uranium minerals in field. U=53 to 59 and 53 to 61.8 percent respectively.	Almost always associated with autunite, particularly in warm, arid areas or near-surface exposures.
Torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$	Thin to thick, tabular, rectangular or octagonal plates, often grouped together. Good cleavage. Soft. Color emerald-green to grass-green. Vitreous to subadamantine luster. Transparent to translucent. May be weakly fluorescent under ultraviolet light. Indistinguishable in field from metatorbernite, zeunerite and metazeunerite. U=47.1 percent.	Very common in small amounts in oxidized zone of copper sulfide veins when uraninite present in vein or wall rock. Found also in some oxidized porphyry copper deposits. Common in copper-uranium sandstone-type deposits.

Table G. — *Continued*

Mineral	Composition	Description	Occurrence
Metatorbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 4(?)\text{-}8H_2O$	Usually in thin, irregularly curved tablets commonly grouped in aggregates or rosettes. Color pale to dark green. Dull luster. Transparent to translucent. No fluorescence. Difficult to distinguish in field from torbernite and metazeunerite. U=50.8 to 55.0 percent.	A very common secondary mineral found with torbernite.
Meta-uranocircite	$Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Thin tablets or plates in composite or fan-like groups. Good cleavage. Soft. Color yellow-green. Pearly luster. Transparent. Green fluorescence in ultraviolet light. Cannot be distinguished from other similar appearing uranium minerals in the field. U=47.1 percent.	Relatively rare secondary mineral but identified in some vein- and sandstone-type deposits.
Phosphuranylite	$Ca(UO_2)_4(PO_4)_2 \cdot (OH)_4 \cdot 7H_2O$	Thin dense, scaly or earthy coatings or aggregates. Soft. Color deep golden to deep yellow. Not fluorescent. U=63.3 percent. Hard to recognize in the field.	Occurrence may be widespread but in very small quantities in sandstone-type deposits as secondary mineral after uraninite.
Sabugalite	$HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$	Dense aggregated crusts of very thin square or rectangular plates. Good cleavage. Soft. Color bright yellow to lemon-yellow. Weak vitreous luster. Transparent to translucent. Lemon-yellow fluorescence, bright in long-wave and less so in short-wave ultraviolet light. U=53.6 percent. Cannot be distinguished in field from other similar uranium minerals.	A rare secondary mineral. Small amounts identified in some sandstone-type deposits.
Bassetite	$Fe(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Platy crystals. Good cleavage. Soft. Color olive-green and olive-brown to yellowish-brown and yellow. Transparent. Not fluorescent. U=51.0 percent.	A rare secondary mineral. May be found in oxidized veins containing pyrite and uraninite.

Table G. — *Continued*

Mineral	Composition	Description	Occurrence
Saléeite	$Mg(UO_2)_2(PO_4)_2 \cdot 8\text{-}10H_2O$	Usually in thin crusts or interlocking aggregates of rectangular plates or scales. Good cleavage. Soft. Color pale yellow. Weak to waxy luster. Transparent to weakly translucent. Fluoresces lemon-yellow in ultraviolet light, brightly under long-wave and less so under short-wave. Hard to distinguish in field. U=50.9 to 53.0 percent.	A rare secondary mineral in oxidized zones of vein-type deposits.
Dewindtite (probably some as renardite)	$Pb_3(UO_2)_5(PO_4)_4(OH)_4 \cdot 10H_2O$(?)	Microscopic rectangular tablets. Brittle. Color canary-yellow. Translucent. Fluoresces green in ultraviolet light. U=49.5 percent.	A rare secondary mineral reported in a few sandstone-type deposits.
Silicates			
Coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$ with variable amounts of (OH) substituting for (SiO_4)	Aggregates or disseminations of extremely small particles. Color black. Luster dull to adamantine. Powdery to brittle. Hard to distinguish from uraninite. U=40.9 to 60.2 percent.	Known to occur in hydrothermal vein-type deposits but more commonly found in unoxidized black vanadium ore of sandstone-type deposits.
Uranophane (Beta-uranophane)	$Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	Minute needles, usually in aggregates or crusts of fibrous or velvety appearance. Brittle. Soft. Color lemon-yellow, pale straw-yellow or honey-brown. Pearly to waxy luster. Weak green fluorescence. Uranophane and beta-uranophane are dimorphous and indistinguishable in the field. U=55.6 percent.	Uranophane is a common secondary mineral while beta-uranophane is rare. Identified in many vein- and sandstone-type deposits in Arizona.
Boltwoodite	$K_2(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	Relatively hard, nearly spherical pellets or in tuffs and felted masses of very delicate, slender needles. Color greenish-yellow to pale yellow or nearly white. Difficult to distinguish in the field. No fluorescence. U=58.2 percent.	Relatively common secondary mineral in sandstone deposits but not often recognized.

Table G. — *Continued*

Mineral	Composition	Description	Occurrence
Sklodowskite	$Mg(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	Tiny acicular crystals in velvety coatings, in radially fibrous spherules and in small compact, granular masses. Brittle. Color pale citron-yellow. Silky to subvitreous luster. Indistinguishable from uranophane in the field. U=56.6 percent.	A rare secondary mineral identified in some sandstone-type deposits.
Kasolite	$Pb(UO_2)(SiO_3)(OH)_2$	Small lathlike crystals in rosettes, fibrous aggregates or granular masses and crusts. Relatively hard. Color ocher-yellow to brownish-yellow. Dull luster. U=40.5 percent.	A secondary mineral, often a constituent of gummite. Reported from a sandstone-type occurrence and some vein-type deposits.
Weeksite	$K(UO_2)_2(Si_2O_5)_3 \cdot 4H_2O$	Radiating fibrous clusters. Soft. Color yellow. Waxy to silky luster. Indistinguishable from uranophane in the field. U=43.4 percent.	A secondary mineral reported from opalized mudstone.
Sulfates			
Zippeite (and related species having Na, Co, Ni, Mg, Fe, or Zn)	$K_4(UO_2)_6(SO_4)_3(OH)_{10} \cdot H_2O$	Thin coatings or warty aggregates. Color orange-yellow to golden-yellow. Dull luster. Faint fluorescence if any. U=63.4 percent.	Usually a late secondary mineral occurring as an efflorescence in sandstone-type deposits.
Johannite	$Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$	Small aggregates or scaly and fibrous coatings. Color dark to light green. Vitreous luster. Transparent to translucent. Not fluorescent. U=50.8 percent.	A secondary mineral in oxidized vein- and sandstone-type deposits.
Uranopilite	$(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$	Thin crusts and films or small felty aggregates. Soft. Color lemon- to straw-yellow. Strong bright lemon-yellow fluorescence. Resembles zippeite.	A secondary mineral where sulfides may be present.

Table G. — *Continued*

Mineral	Composition	Description	Occurrence
<u>Vanadates</u>			
Carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$	Microcrystalline masses, disseminations, coatings, interstitial cement and powder. Micaceous cleavage. Soft. Color bright yellow to greenish-yellow. U=52.8 to 55.0 percent. Closely resembles tyuyamunite and metatyuyamunite and term "carnotite-type" often applied to group.	Found in almost all sandstone-type deposits, disseminated or concentrated in bodies usually closely associated with carbonized logs or vegetable matter and with other uranium and vanadium minerals. Also found more sparingly in some oxidized veins and pipes as alteration of primary uranium minerals. A major ore mineral in Arizona.
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 5\text{-}8H_2O$	Most commonly microcrystalline to powdery in thin films, coatings or impregnations. Micaceous. Soft. Color usually canary-yellow to lemon-yellow. Difficult to distinguish from carnotite and metatyuyamunite in the field but sometimes more coarsely crystalline and slightly more greenish than carnotite. U=49.4 to 54.1 percent.	Similar occurrence to carnotite but more usual in the more limy sandstone-type deposits.
Metatyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 3\text{-}5H_2O$	Mostly microcrystalline to powdery in thin coatings, films, and impregnations. Soft. Color canary-yellow to greenish-yellow. Adamantine to waxy luster. Hard to distinguish from carnotite and tyuyamunite in the field. U=52.9 to 55.1 percent.	Associated with carnotite and tyuyamunite in limy sedimentary-type deposits.
Rauvite	$CaO \cdot 2UO_3 \cdot 5V_2O_5 \cdot 16H_2O$(?)	Very fine-grained, dense, slickensided masses, botryoidal crusts or filmy coatings. Sometimes interstitial. Color purplish, bluish-black or reddish-brown. Adamantine to waxy luster. U=26.1 percent.	Small amounts found in many vanadium-uranium deposits of sandstone-type. May be intermediate secondary mineral in alteration of uraninite to carnotite or tyuyamunite.
Sengierite	$Cu(UO_2)_2(VO_4)_2 \cdot 8\text{-}10H_2O$	Thin plates and flaky coatings. Good cleavage. Brittle. Soft. Color yellowish-green. Vitreous to adamantine luster. U=47.0 to 48.7 percent.	A very rare secondary mineral. Reported from vein-type deposits.

Table H. — Uranium production statistics for Arizona.

County	No. of Operations	Ore Sh.T.	U_3O_8 Contained		$ Value		Notes
			%	Lbs.	Per Sh.T.	Total	
							1942-1944
Apache Navajo	10	11,600	0.15	34,800	5.00	58,000	Scattered small mines in Carrizo Mountains and Monument Valley areas produced vanadium ore. Amount of contained uranium later extracted from tailings estimated.
							1945-1947
Apache Navajo	4	100	0.15	300	5.00	500	Small leasing operations produced vanadium ore. Estimated uranium content extracted later.
							1948-1952
Apache Coconino Navajo	30	210,900	0.36	1,522,000	33.98	7,167,000	Production mainly from Carrizo Mountains and Monument No. 2 mine areas in Apache Co. and Monument No. 1 mine in Navajo Co. Intense exploration in Lukachukai Mountains, Apache Co. and Cameron district, Coconino Co. but little production.
							1953
Apache Coconino Gila Navajo	45	146,800	0.32	939,500	27.35	4,015,000	Production mainly from Monument No. 2 mine area, and from Lukachukai Mountains district after ore buying depot established at Shiprock, New Mexico. Development of ore in Cameron district but little production. Minor production from Red Bluff mine, Gila Co., western Monument Valley district and from deposits near Petrified Forest National Monument, east of Holbrook.
							1954
Apache Coconino Gila Navajo	60	174,100	0.33	1,149,100	28.28	4,923,000	Production mainly from Monument No. 2 mine area and Lukachukai Mountains district. New mill established at Shiprock, New Mexico, for ore from Carrizo Mountains and Lukachukai Mountains areas. Mostly exploration and development with minor production in Cameron district, Coconino Co., Dripping Spring Quartzite deposits, Gila Co., and in western Monument Valley district, Navajo Co.

Table H. — *Continued*

County	No. of Operations	Ore Sh.T.	U_3O_8 Contained %	U_3O_8 Contained Lbs.	$ Value Per Sh.T.	$ Value Total	Notes
							1955
Apache Coconino Gila Others	59 3 88 14 12	210,900	0.26	1,096,700	21.35	4,503,000	Apache Co. produced almost 90 percent of State output with Monument No. 2 mine area supplying about 50 percent and the Lukachukai Mountains area nearly 40 percent. Cameron district production held up waiting construction of Tuba City ore buying depot and mill. About 4,000 tons of 0.15 percent U_3O_8 shipped to new ore buying depot at Cutter, Gila Co. Operations in Graham (1), Maricopa (3), Mohave (1), Navajo (3), Pima (1), Santa Cruz (1), and Yavapai (2) Counties made small shipments, mostly test lots.
							1956
Apache	60	166,500	0.24	796,000			Apache Co. production mainly from Monument No. 2 mine and Luckachukai Mountains district. In Navajo Co. new ore found in Monument No. 1 mine area and at Moonlight mine in western Monument Valley district. Mines in Cameron district, Coconino Co. started shipping to Tuba City and shipments continued to Cutter ore buying depot, Gila Co. Mostly small lot shipments made from operations in Cochise (1), Maricopa (1), Mohave (1), Pima (2), Santa Cruz (1), and Yavapai (2) Counties. AEC estimated Arizona reserves as 2.6 million tons of 0.30 percent U_3O_8.
Coconino	64	88,300	0.22	438,000			
Gila	17	6,800	0.19	25,600			
Navajo	12	17,700	0.23	81,100			
Others	8	200	0.22	900			
Total	161	279,500	0.24	1,341,600	20.02	5,596,000	
							1957
Apache	39	149,500	0.23	690,000			Apache Co. production largely from Monument No. 2 mine and Lukachukai Mountains district. Cameron district, Coconino Co. reached peak production. Cutter ore buying depot closed at mid-year. Moonlight and other mines in western Monument Valley district increased Navajo Co. production. Small lots shipped from operations in Maricopa (1), Pima (1), Santa Cruz (1), and Yavapai (2) Counties. AEC estimated Arizona reserves as 1.4 million tons at 0.32 percent U_3O_8.
Coconino	58	92,000	0.28	512,000			
Gila	10	10,300	0.25	52,000			
Navajo	9	51,000	0.31	319,900			
Others	5	500	0.33	3,300			
Total	121	303,300	0.26	1,577,200	22.75	6,900,000	

Table H. — *Continued*

County	No. of Operations	Ore Sh.T.	U_3O_8 Contained		$ Value		Notes
			%	Lbs.	Per Sh.T.	Total	
							1958
Apache	30	110,200	0.29	641,000			Apache Co. production mostly from Monument No. 2 mine and Lukachukai Mountains district. In Coconino Co. production of high grade from Orphan mine offset drop in Cameron district. Moonlight and other mines in western Monument Valley district boosted Navajo Co. production. Small lots shipped from operations in Cochise(1) and Mohave (1) Counties and several hundred tons from Yavapai (2) County. AEC estimated Arizona reserves as 1.4 million tons at 0.34 percent U_3O_8.
Coconino	46	65,000	0.37	480,000			
Navajo	6	73,400	0.32	470,500			
Others	4	700	0.29	4,000			
Total	86	249,300	0.32	1,595,500	26.84	6,692,000	
							1959
Apache	16	85,400	0.26	445,800			Apache Co. production almost entirely from Monument No. 2 mine and Lukachukai Mountains district. Orphan mine production overshadowed Cameron district in Coconino Co. Moonlight and other mines in western Monument Valley district boost Navajo Co. into production lead. Uranium Aire deposit in Yavapai Co. shipped almost a thousand tons and one operation in Cochise shipped a small lot. AEC estimated Arizona reserves as 1.2 million tons of 0.35 percent U_3O_8.
Coconino	37	54,000	0.38	406,300			
Navajo	11	113,000	0.29	656,300			
Others	2	1,000	0.27	5,000			
Total	66	253,400	0.30	1,513,400	24.90	6,309,000	
							1960
Apache	19	108,800	0.25	544,300			Monument Valley No. 2 mine and Lukachukai Mountains district furnished most of Apache Co. production; the Orphan mine and Cameron district, most of that from Coconino Co.; and the Moonlight and other mines in western Monument Valley district, that from Navajo Co. The Hope and Little Joe mines in Gila Co. shipped to Tuba City as did the Star No. 1 mine in Cochise Co.
Coconino	30	91,000	0.28	522,600			
Gila	4	2,100	0.36	15,000			
Navajo	10	81,800	0.25	405,500			
Other	1	100		100			
Total	64	283,700	0.26	1,487,400	21.92	6,219,000	

Table H. — *Continued*

County	No. of Operations	Ore Sh.T.	U_3O_8 Contained		$ Value		Notes
			%	Lbs.	Per Sh.T.	Total	
							1961
Apache	16	89,400	0.25	448,000			Ore ranging from 0.13 to 0.43 percent U_3O_8 mined mainly from Monument No. 2 mine and the Lukachukai Mountains district. Orphan mine continued output but Cameron district production decreased in Coconino County. Navajo Co. production from Moonlight and neighboring mines.
Coconino	17	76,700	0.26	319,400			
Navajo	9	62,100	0.28	422,900			
Total	42	228,200	0.26	1,190,300	21.75	4,965,000	
							1962
Apache	20	88,200	0.23	407,200			Apache Co. production maintained mainly by Monument No. 2 mine and the Lukachukai district. The Orphan mine, Coconino Co. was closed down for much of the year and the Cameron district ore was nearly mined out. The Moonlight mine and others in western Monument Valley district, Navajo Co., shipped ore ranging from 0.15 to 0.34 percent U_3O_8.
Coconino	4	400	0.21	1,700			
Navajo	7	54,600	0.30	326,700			
Total	31	143,200	0.26	735,600	21.28	3,047,000	
							1963
Apache	29	51,600	0.23	238,900			Apache Co. production continued, mainly from Monument No. 2 mine and the Lukachukai district with values ranging from 0.07 to 0.34 percent U_3O_8. The Orphan mine accounted for most of the Coconino Co. production and the Moonlight and nearby mines for Navajo Co. production.
Coconino	3	62,100	0.53	660,300			
Navajo	6	36,900	0.30	223,300			
Total	38	150,600	0.37	1,122,500	32.17	4,844,000	
							1964
Apache	21						The Orphan mine in Coconino Co. was the largest producer, followed by the Monument No. 2 mine in Apache Co. and the Moonlight mine group in Navajo Co. Other small producers, including Hack's No. 1 mine in Mohave Co. contributed. Shipment grades ranged from 0.11 to 0.48 percent U_3O_8.
Coconino	1						
Mohave	1						
Navajo	7						
	30	102,300	0.37	756,700	31.81	3,253,000	

Table H. — *Continued*

County	No. of Operations		Ore Sh.T.	U_3O_8 Contained %	U_3O_8 Contained Lbs.	$ Value Per Sh.T.	$ Value Total	Notes
								1965
Apache Coconino Navajo	18 1 7	26	117,900	0.38	896,000	33.24	3,918,000	The principal producer was the Orphan mine. Apache Co. production came from the Monument No. 2 mine and the Lukachukai Mountains district. The Moonlight mine area, Monument No. 1 mine and Mitchell Mesa accounted for the Navajo Co. production. Grades ranged from 0.07 to 1.51 percent U_3O_8.
								1966
Apache Coconino Navajo Yavapai	22 1 5 2	30	64,200	0.36	462,200	30.82	1,978,000	Apache Co. resumed first place production position from output of Monument No. 2 mine and the Lukachukai Mountains district. The Orphan mine only produced first half of year. Moonlight group and others in Monument Valley district and ore from southwestern Yavapai Co. contributed. Grades ranged from 0.08 to 1.37 percent U_3O_8.
								1967
Apache Coconino	13 1	14	15,700	0.28	88,000	22.29	351,000	Monument No. 2 mine closed down except for clean-up and production from Lukachukai Mountains district diminishing. Orphan mine reopened in September. Grades ranged from 0.08 to 2.09 percent U_3O_8. Tuba City mill contract terminated and mill closed down.
								1968
Apache Coconino	6 1	7	44,200	0.37	326,900	31.60	1,396,000	Orphan mine was major producer. Balance of production mainly from Lukachukai Mountains district. Grade averaged 0.11 to 0.47 percent U_3O_8.
								1969
Coconino	1		W	W	W	W	W	Orphan mine only producer and data not available.
Grand Totals (excluding 1969)			2,989,900	0.30	17,835,700	25.47	76,138,000	

Note: Data for tables derived, adjusted and rounded from U.S. Bureau of Mines Minerals Yearbooks, Butler and Byers (1969, p. 283) and "Statistical Data of the Uranium Industry" by U.S. AEC, Grand Junction Office, Colorado.

Table I. — Uranium occurrences in the Chinle Formation.

Numbers correspond with the occurrence numbers on Plate 16.

No.	Name	Location	Geology and Mineralization	Notes	References
	East Monument Valley				
1.	Blackwater and Harvey Black claims	Approx. E. central Sec. 3, NW. 1/4 Sec. 10 and E. 1/2 Sec. 9, T. 41 N., R. 23 E. (Protracted) Apache Co.	No detail information available. Appears to be medium-to coarse-grained sandstone and conglomerate with abundant carbonized and silicified plant material in Shinarump Member. Mineralization mainly of carnotite-type with $V_2O_5:U_3O_8$ ratio of 3.8:1.	Several relatively small workings produced a few hundred tons of ore and one may have produced over 1000 tons. Reportedly ore grade mineralization remains.	Johnson and Thordarson, 1966. Finch, 1967.
2.	Monument No. 2 mine area (Monument No. 2, South Extension, Cato Sells Tract 1 & 2, Chee Nez 1, John M. Yazzie 1, Black and Blackwater mines)	Approx. W. 1/2 Sec. 29, N. central Sec. 32, T. 41 N., R. 23 E. (Protracted) Apache Co.	Unusually thick, basal, "trashy," cross-bedded, Shinarump conglomeratic sandstone with relatively abundant clay and silicified, carbonized and mineralized wood occurs in deep scour and paleochannel eroded into underlying Moenkopi Formation and even Permian DeChelly Sandstone. Scour is at least two miles long by three miles wide by fifty feet deep with inner paleochannel about 700 feet wide and some thirty feet deeper, aligned to N 18° W. Mineralization occurs at numerous horizons in Shinarump and for seven feet into DeChelly under paleochannel, in bands filling interstices in sandstone, coating pebbles and fractures and concentrated in elongated, horizontal, flattened cylindrical "rods" up to eight feet in diameter and over 100 feet long. "Rods" show concentric banding of mineralized sandstone and limonitic cement around structureless sandstone core, aligned with paleochannel trend. Mineralization has U:V ratio of 1:5 and is low lime. Tyuyamunite and carnotite are principal ore minerals; uraninite is found in logs. Montroseite, navahoite, becquerelite, fourmarierite, rauvite, volborthite, steigerite, hewettite, corvusite, uranophane, torbernite and metazeunerite recognized. Considerable low grade mineralization surrounds high grade zone.	Most productive mine area in Arizona. Has produced over 500,000 tons of ore and concentrates averaging about 0.30 and 0.24% U_3O_8 respectively. Mined originally for vanadium and later by underground and open pit for uranium. Concentrator operated to upgrade low grade mineralization. Operations closed down in 1967 and equipment removed. Deposits reportedly essentially mined out and very limited resources remain along edges of mineralized zone.	Witkind, 1956. Witkind and Thaden, 1963. Johnson and Thordarson, 1966. Finnell, 1957.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	Central Monument Valley				
3.	Mitchell Mesa	Approx. NE. 1/4 Sec. 13, T. 41 N., R. 20 E. and central Sec. 18, T. 41 N., R. 21 E. (Protracted) Navajo Co.	Shinarump caps mesa and lies in WNW trending paleochannel cut into Moenkopi, up to 350 feet wide and 75 feet deep. Massive coarse-grained sandstone grades downward into conglomeratic sandstone with clay pebbles. Tyuyamunite-type mineralization with minor tobernite occurs in thin seam surrounded by vanadium mineralization and carbonaceous debris at east end, possibly secondary deposition.	No production and average grade low. No resources estimated.	Witkind, 1956, p. 107. Witkind and Thaden, 1963. Finch, 1967.
4.	Hunts Mesa (Koley No. 2 and Sam Charlie No. 1)	Approx. N. central Sec. 10 and NW. 1/4 Sec. 11, T. 40 N., R. 21 E. (Protracted) Navajo Co.	Shinarump, mostly concealed under sand dunes, caps mesa and lies in at least two or more paleochannels trending E-W cut into Moenkopi; one wide and relatively shallow, the other narrow and deeper. Moenkopi deeply cracked with Shinarump filling cracks. Paleochannels show conglomeratic sandstone with clay and siltstone pebbles at bottom grading upward into coarse-to medium-grained sandstone. Minute specks of azurite, malachite and tyuyamunite impregnates paleochannel fill and mineralization partially replaces clay pebbles. Sediments are cross-bedded and contain silicified and carbonized wood.	A few hundred tons produced but grade erratic.	Chester, 1951. Witkind and Thaden, 1963.
5.	Brodie No. 5	Approx. S. central Sec. 21, T. 40 N., R. 21 E. (Protracted) Navajo Co.	Medium-grained lenticular Shinarump sandstone in 150 foot long by 20 foot deep paleochannel trending E-W in Moenkopi. Carnotite-type and secondary copper minerals. Silicified wood.	Little if any production. Mineralization generally low grade. Resources doubtful.	Witkind and Thaden, 1963.
6.	Koley Black No. 1 (Ben No. 2)	Approx. N. central Sec. 11, T. 39 N., R. 20 E. (Protracted) Navajo Co.	Maze of paleochannels, 35-250 feet wide form NW striking system. Coarse conglomeratic beds grade upward into coarse-grained sandstone. Abundant silicified wood and black coaly material. Copper mineralization in paleochannel fill. Airborne radioactivity noted but drilling by USAEC failed to find uranium mineralization.	No production or resources but radioactivity may denote potential in area.	Witkind and Thaden, 1963.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	West Monument Valley				
7.	Harvey Black	Approx. SW. 1/4 Sec. 1, T. 41 N., R. 19 E. (Protracted) Navajo Co.	No detail information available. Massive medium-grained Shinarump sandstone in paleochannel some 200 feet wide and 50 feet deep cut in Moenkopi. Silicified wood and carbonized debris. Secondary copper minerals. Character of uranium mineralization not reported.	Unknown production or resources.	Witkind and Thaden, 1963. AEC Guidebook, 1959.
8.	Monument No. 1 Annex and Mitton No. 2	Approx. NE. 1/4 Sec. 24 to S. central Sec. 13, T. 41 N., R. 19 E. and W. central Sec. 19, T. 41 N., R. 20 E. (Protracted) Navajo Co.	"Trashy" conglomerate, silica-cemented sandstone and calcite-cemented sandstone with silicified wood, carbonaceous matter and clay pebbles occur in basal remnant of paleochannel of Shinarump cut into Moenkopi. Two 2,000 foot long segments trend N to NW. Ore zone varies from ten to 95 feet wide and 1-18 feet thick, consisting of uranium-vanadium and copper minerals impregnating "trashy" conglomerate and silica-cemented sandstone. Calcite-cemented sandstone lenses unmineralized. Unoxidized core surrounded by oxidized mineralization. Roughly concentric mineralization with tyuyamunite, metatyuyamunite, metatorbernite, corvusite, hewettite, volborthite, pyrite, azurite, chrysocolla, malachite and limonite. V:U ratio averaged 2.5:1 but varied greatly throughout.	Produced a few hundred tons of vanadium ore in 1942-1944 period. Reopened in 1952 and until 1956 produced several thousand tons. Resources now depleted.	Witkind, 1961. Witkind and Thaden, 1963.
9.	Moonlight	Approx. NW. 1/4 Sec. 16, T. 41 N., R. 19 E. (Protracted) Navajo Co.	Little detail information available. Buried paleochannel of Shinarump cut in Moenkopi discovered by drilling. Character and mineralogy probably similar to other Monument Valley deposits. Ratio of V:U reportedly nearly equal. Ore extends down into underlying Moenkopi.	Large open pit mine produced some 200,000 tons of ore. Resources depleted. Pit about 145 feet deep with some underground adits from bottom.	AEC Guidebook, 1959. Malan, 1968.
10.	Starlight, East Starlight	Approx. W. central Sec. 17, T. 41 N., R. 19 E. (Protracted) Navajo Co.	No detail information available. Buried paleochannel of Shinarump cut in Moenkopi discovered by drilling. Similar but smaller than Moonlight.	Underground mines produced a few thousand tons. Resources probably depleted.	AEC Guidebook, 1959. Johnson and Thordarson, 1966

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
11.	Fern No. 4	Approx. NW. corner Sec. 4, T. 41 N., R. 19 E. (Protracted) Navajo Co.	No detail information available. Paleochannel with Shinarump cut into Moenkopi. Character and mineralization similar to other Monument Valley deposits.	A few thousand tons produced from surface and underground operations. Resources probably depleted.	Ditto
12.	Sunlight (Big Four), South Sunlight	Approx. S. central Sec. 21, T. 41 N., R. 19 E. (Protracted) Navajo Co.	No detail information available. Buried paleochannel of Shinarump cut into Moenkopi. Character and mineralization similar to other Monument Valley deposits.	Underground mine which produced up to 100,000 tons of ore.	Ditto
13.	Boot Jack	Approx. W. central Sec. 4, T. 40 N., R. 19 E. (Protracted) Navajo Co.	Ditto	Underground mine probably produced up to 50,000 tons of ore.	Ditto
14.	Noschoy	Approx. central Sec. 2, T. 40 N., R. 19 E. (Protracted) Navajo Co.	Ditto	Underground mine probably produced a few hundred tons of ore.	AEC Guidebook, 1959.
15.	Tract No. 11	Approx. W. central Sec. 16, T. 41 N., R. 18 E. (Protracted) Navajo Co.	No detail information available. Paleochannel of coarse-grained massive sandstone with silicified wood. Character and mineralization similar to other Monument Valley deposits.	Probably produced a few hundred tons.	AEC Guidebook, 1959. Witkind and Thaden, 1963.
16.	Todechene (Azansoso)	Approx. SE. corner Sec. 8, T. 40 N., R. 18 E. (Protracted) Navajo Co.	Little detail information available. Paleochannel of coarse-grained massive sandstone with carbonized and silicified wood showing carnotite, vanadium minerals, malachite and limonite.	Little if any production. Mineralization generally low grade.	Witkind and Thaden, 1963. Finch, 1967.
	<u>Vermilion Cliffs</u>				
17.	Lehneer Prospect	NW. 1/4 Sec. 34, T. 41 N., R. 7 E. In Paria Canyon on N. side of Paria River. Coconino Co.	Small, tabular occurrence of metatorbernite, torbernite, zippeite and secondary copper minerals associated with sparse black carbonaceous material in thicker sandstone in upper and lower sandstone strata of Chinle above Shinarump.	Short drift on mineralization but no production. Mineralization limited and low grade.	Phoenix, 1963.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
18.	Redwing Prospect	South central Sec. 34, T. 41 N., R. 7 E. In Paria Canyon on S. side of Paria River. Coconino Co.	Ditto	Ditto	Ditto
19.	Sandy No. 1, 2 and 3 claims	West central Sec. 12, T. 40 N., R. 7 E. In Paria Canyon on E. side of Paria River. Coconino Co.	Metahewettite and possibly other uranium minerals at and near base of nearly flat-lying Shinarump.	No production and resources questionable.	Barrett and Collins, 1953, AEC PRR R-R 101.
20.	El Pequito mine	NW. corner Sec. 14, T. 40 N., R. 7 E. About 2 mi. WNW of Lees Ferry. Coconino Co.	Small spoon-shaped channel of Shinarump containing conglomeratic sandstone and carbonized wood. Uraninite with pyrite and chalcopyrite occurs in calcite veinlets and oxidized uranium and copper minerals coat pebbles and sand grains as well as impregnating carbonized wood.	Some production reported but resources limited and low grade.	Phoenix, 1963.
21.	Sam claims	SE. 1/4 Sec. 2, T. 39 N., R. 6 E. On upper Badger Canyon about 2 mi. NW. of Vermilion Cliffs Lodge. Coconino Co.	Betazippeite and metatorbernite impregnate pore space in siltstone and occur in 1 1/2 x 3 foot lenticular pods paralleling bedding in lower part of 30 foot thick lens of grayish-red siltstone near top of Petrified Forest Member.	No production of ore grade reported. Resources limited and low grade.	Phoenix, 1963.
22.	Sun Valley mine	West central Sec. 32, T. 39 N., R. 6 E. In canyon about 2 mi. WSW. of Cliff Dwellers Lodge. Coconino Co.	Scour channel with chert-and quartzite-pebble conglomerate in U-shaped bend, 1,000 feet long by 400 feet wide, contains 130 feet of Shinarump. Uraninite grains with pyrite, sphalerite, hematite, rare galena, and secondary zippeite, betazippeite, uranyl phosphate and ilsemanite (rhenium noted) as interstitial materials. Some carbonized plant remains.	Several hundred tons of ore produced from some 400 feet of underground workings. Some limited resources. Average grade may be around 0.20% U_3O_8.	Peterson and others, 1959. Peterson, 1960.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
23.	Jasper group claims	SW. 1/4 Sec. 27, T. 39 N., R. 6 E. About 1/2 mi. NE. of Cliff Dwellers Lodge. Coconino Co.	Yellow uranium mineralization with copper carbonates and some carbonaceous material in 20 foot plus Shinarump conglomerate in channel.	No production recorded and mineralization is low grade.	Holen and Twitchell, 1955, AEC PRR R-R 275.
24.	Vermilion No. 1 mine	NE. 1/4 Sec. 20, T. 38 N., R. 5 E. On Emmett Hill S. of U.S. 89. Coconino Co.	Metatorbernite and possibly other uranium and copper minerals occur in a small 300 foot long, 30-50 foot wide, 10-20 foot deep channel filled with poorly sorted clay, sand and gravel of Shinarump. Mineralization in Shinarump and Moenkopi at or near contact.	Produced a few tons of low grade mineralization. Resources of low grade very limited. Open pit.	Peterson, 1957.
	<u>Echo Cliffs</u>				
25.	F & B claim	Probably about E. 1/2 Sec. 22, T. 38 N., R. 7 E. (Protracted) Coconino Co.	Becquerelite with natroalunite reported in Chinle sandstone. No detail information available.	Production unknown and resources possibly limited.	Gruner and Knox, 1957.
	<u>Cameron District</u>				
26.	Huskon No. 5	East central Sec. 36, (Unsurveyed), T. 31 N., R. 9 E. Coconino Co.	Uraninite and various secondary uranium minerals associated with petrified logs and halos around logs. Some fracturing of beds. In cross-bedded sandstone and mudstone channel(?) of Petrified Forest Member.	A few thousand tons produced.	Rambosek and Williams, 1952, AEC PRR RA-16. Bollin and Kerr, 1958. AEC Guidebook, 1959.
27.	Shadow Mountain Collapse	Secs. 20, 29, (Unsurveyed), T. 31 N., R. 9 E. Coconino Co.	Uranium mineralization in inward dipping Petrified Forest Member. Drilling did not indicate volcanic origin but appears as collapse structure into Shinarump.	Mineralization reported as too deep for economic exploitation.	Bollin and Kerr, 1958. Kerr, 1958. AEC Guidebook, 1959.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
28.	Huskon No. 6	NE. 1/4 Sec. 27, T. 30 N., R. 9 E. (Protracted) Coconino Co.	Relatively small semi-circular body of uranium mineralization in channel sandstone and mudstone in Shinarump.	Several thousand tons ore shipped.	Bollin and Kerr, 1958.
29.	Lemuel Littleman Nos. 1 & 7	SE. 1/4 Sec. 27, T. 30 N., R. 9 E. (Protracted) Coconino Co.	Small channel deposit near bottom of Petrified Forest Member. No detail information.	Relatively small production.	AEC Guidebook, 1959.
30.	Jeepster No. 1	North central Sec. 35, T. 30 N., R. 9 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
31.	Montezuma group	SW. corner Sec. 33, T. 30 N., R. 9 E. (Protracted) Coconino Co.	Channel deposits in upper Shinarump Member. No detail information.	Ditto	Ditto
32.	Casey No. 3	North central Sec. 3, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
33.	Kachina No. 6	NW. 1/4 Sec. 11, T. 29 N., R. 9 E. Coconino Co.	Channel deposit near base of Petrified Forest Member. No details available.	Ditto	Ditto
34.	Jack Daniels No. 1	South central Sec. 11, T. 29 N., R. 9 E. Coconino Co.	Somewhat irregular lens, about 225 by 500 feet in plan and up to ten feet thick, occurs in NNW trending sandstone-siltstone channel near base of Petrified Forest Member. Both oxidized and unoxidized minerals present. Carbonized fossil logs containing uraninite common but most mineralization consists of disseminated uraninite in sandstone.	Largest open pit operation in area. Up to 40,000 tons produced. Mined out.	AEC Guidebook, 1959. Bollin and Kerr, 1958.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
35.	Charles Huskon No. 19	Central Sec. 11, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Relatively small mineralized lens in lower part of Petrified Forest Member.	Small production.	AEC Guidebook, 1959.
36.	Huskon No. 12	NW. 1/4 Sec. 15, T. 29 N., T. 9 E. (Protracted) Coconino Co.	Two relatively small elongated lenses of mineralization in channels in upper part of Shinarump Member.	A few thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
37.	Max Johnson No. 1	West central Sec. 24, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Mineralized body, about 400 feet long by 120 feet wide in SW trending channel in lower part of Petrified Forest Member.	Some 7,000 tons probably produced.	Ditto
38.	Lemuel Littleman No. 2	North central Sec. 24, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Relatively small mineralized body in lower part of Petrified Forest Member.	Small production.	AEC Guidebook, 1959.
39.	Huskon No. 1	East central Sec. 23, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Uniformly mineralized, 310 foot long by 200 foot wide, somewhat irregular lens-like body filling lower part of SW trending scour channel in lower part of Petrified Forest Member. Some fracture control of mineralization at angle to channel direction. Mineralization occurs in sandy facies containing carbonized fossil plant material and is highest grade at base of scour where bottomed in blue to red mudstone.	Several thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958. Isachsen and Evensen, 1956.
40.	Max Johnson No. 10	SE. 1/4 Sec. 23, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Relatively small mineralized lens in lower part of Petrified Forest Member.	Small production.	AEC Guidebook, 1959.
41.	Max Johnson No. 9 (Alice Tolino No. 1)	East central Sec. 24, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Lens-like mineralized body, 200 foot long by 100 foot wide, in N trending channel in lower part of Petrified Forest Member.	A few thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
42.	Elwood Canyon shaft	West central Sec. 19, T. 29 N., R. 10 E. (Protracted) Coconino Co.	No information available.	Production unknown.	AEC Guidebook, 1959.
43.	Yazzie No. 101	SW. 1/4 Sec. 18, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Moderately large, 430 foot long by 150 foot wide, lens-like mineralized body in NW trending scour channel in lower part of Petrified Forest Member.	Several thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
44.	Huskon No. 2	SW. corner Sec. 18, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Somewhat irregular podlike mineralized body, about 110 feet in NW trending channel direction and 300 feet across, apparently controlled by concentration of carbonaceous plant material and variation of permeability in scour and fill sediments in channel.	A few thousand tons.	AEC Guidebook, 1959. Bollin and Kerr, 1958. Isachsen and Evensen, 1956.
45.	Yazzie No. 312	NE. corner Sec. 25, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Relatively large, about 500 feet by 200 feet, lens-like mineralized body in NNW trending channel in lower part of Petrified Forest Member.	Probably several thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
46.	Boyd Tisi No. 2	SW. 1/4 Sec. 30, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Probably small mineralized pod in lower part of Petrified Forest Member.	Small production.	AEC Guidebook, 1959.
47.	Juan Horse No. 3	SW. 1/4 Sec. 30, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
48.	Lemuel Littleman No. 3	West central Sec. 35, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Probably small channel deposit in upper Shinarump Member.	Ditto	Ditto

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
49.	Huskon No. 14	SW. 1/4 Sec. 36, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
50.	Montezuma No. 1	South central Sec. 36, T. 29 N., R. 9 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
51.	Juan Horse No. 4	East central Sec. 31, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Probably small pod in scour channel in lower part of Petrified Forest Member.	Ditto	Ditto
52.	Evans Huskon No. 34	West central Sec. 9, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Relatively small mineralized occurrence in upper part of Petrified Forest Member.	Ditto	Ditto
53.	Charles Huskon No. 20	Ditto	Ditto	Ditto	Ditto
54.	Charles Huskon	East central Sec. 17, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Prospect only.	Ditto
55.	A & B No. 3	South border Secs. 21, 22, T. 29 N., R. 9 E. Coconino Co.	Mineralized deposit in channel in upper part of Shinarump Member.	Probably small production.	Ditto
56.	A & B No. 2	Central Sec. 5, T. 28 N., R. 9 E. Coconino Co.	Ditto	Ditto	Ditto

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
57.	Charles Huskon No. 3	West central Sec. 7, T. 28 N., R. 10 E. Coconino Co.	Uniformly mineralized, narrow, elongated lenslike bodies in lower part of scour and fill channel, trending NE to E, in lower part of Petrified Forest Member and into Shinarump Member. Much carbonaceous material. Ore zone extends for over 1,000 feet but averaged only about 100 feet wide.	Probably several thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958. Isachsen and Evensen, 1956.
58.	Manuel Denetsone No. 2 (shaft)	North central Sec. 5, T. 28 N., R. 10 E. (Protracted) Coconino Co.	No information. Probably small mineralized body in lower part of Petrified Forest Member.	Probably small production.	AEC Guidebook, 1959.
59.	Jefferson Canyon	West central Sec. 4, T. 29 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
60.	Jack Huskon No. 3	SE. corner Sec. 4, T. 28 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
61.	Jack Huskon No. 1	SW. 1/4 Sec. 10, T. 28 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
62.	Paul Huskie 1 & 2	NE. 1/4 Sec. 22, T. 28 N., R. 9 E. Coconino Co.	No information. Probably small channel deposit in upper Shinarump Member.	Ditto	Ditto
63.	Huskon No. 7	NE. 1/4 Sec. 19, T. 28 N., R. 10 E. Coconino Co.	Small lenslike to podlike mineralized body in N. trending channel at base of Petrified Forest Member. Abundant carbonized plant remains.	A few hundred tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958. Isachsen and Evensen, 1956.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
64.	Yazzie No. 102	East central edge Sec. 19, T. 28 N., R. 10 E. Coconino Co.	Ditto	Ditto	AEC Guidebook, 1959. Bollin and Kerr, 1958.
65.	Huskon No. 10	North 1/2 Sec. 29, T. 28 N., R. 10 E. Coconino Co.	Long (1,450 foot), narrow (ave. 100 foot) irregularly mineralized body in SW-NE trending channel cut into Petrified Forest Member and down into Shinarump Member. Mineralization controlled by concentrations of carbonized plant remains and permeability of scour and fill sediments in channel.	Several thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958. Isachsen and Evensen, 1956.
66.	Yazzie No. 105	North central Sec. 29, T. 28 N., R. 10 E. Coconino Co.	Probably part of Huskon No. 10 mineralized zone.	Part of Huskon No. 10 production.	AEC Guidebook, 1959.
67.	Huskon No. 8	South central Sec. 30, T. 28 N., R. 10 E. Coconino Co.	No information. Probably small mineralized body in Petrified Forest Member.	Probably small production.	Ditto
68.	Taylor Reid No. 2	SE. 1/4 Sec. 36, T. 28 N., R. 9 E. Coconino Co.	No information. Probably small mineralized body in Shinarump Member.	Ditto	Ditto
69.	Boyd Tisi No. 1	East central Sec. 31, T. 28 N., R. 9 E. Coconino Co.	No information. Probably small mineralized channel deposit in lower Petrified Forest Member.	Ditto	Ditto
70.	Huskon No. 11	East southern edge Sec. 33, T. 28 N., R. 10 E. Coconino Co.	Mineralized lens up to 500 feet long and 100 feet wide in channel cut in Shinarump Member, trending NE. Abundant carbonized plant remains.	Probably several hundred tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
71.	Mel Gardner prospect	SW. 1/4 Sec. 34, T. 28 N., R. 10 E. (Protracted) Coconino Co.	No information available. Mineralization would be in lower part of Petrified Forest Member.	Production not known.	AEC Guidebook, 1959.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
72.	Ryan No. 1	SE. 1/4 Sec. 34, T. 28 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Possibly some small production.	Ditto
73.	Evans Huskon No. 35	North central Sec. 36, T. 28 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
74.	Section 1	NE. 1/4 Sec. 1, T. 27 N., R. 9 E. Coconino Co.	No information available. Mineralization probably in upper part of Shinarump Member.	Ditto	Ditto
75.	Ada and Nordell	Central Sec. 6, T. 27 N., R. 10 E. Coconino Co.	Ditto	Ditto	Ditto
76.	Liba Group (Pretty Girl)	NE. 1/4 Sec. 4, T. 27 N., R. 10 E. Coconino Co.	Ditto	Ditto	Ditto
77.	Howard No. 1	NE. 1/4 Sec. 7, T. 27 N., R. 10 E. Coconino Co.	Ditto	Ditto	Ditto
78.	Section 9	North central Sec. 9, T. 27 N., R. 10 E. Coconino Co.	Ditto	Ditto	Ditto
79.	Ramco No. 21	NW. 1/4 Sec. 11, T. 27 N., R. 10 E. Coconino Co.	Three mineralized bodies, largest up to 600 feet long and 100 feet wide, in scour and fill sediments in channels trending NW. and NE. Abundant carbonized plant remains. Channels are in lower part of Petrified Forest Member.	A few thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
80.	Ramco Nos. 20 & 22	Central to E. central edge of Sec. 11, T. 27 N., R. 10 E. Coconino Co.	Long (up to 1,800 feet), narrow (ave. 100 feet) mineralized zone in irregular scour and fill sediments, trending NE. Some control possible by fracturing at slight angle to channel.	Several thousand tons produced.	Ditto

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
81.	Ryan No. 2	NE. 1/4 Sec. 11, T. 27 N., R. 10 E. Coconino Co.	Mineralization similar to Ramco Nos. 20 & 22 but smaller body.	A few hundred tons.	Ditto
82.	Navajo 26	South central Sec. 18, T. 27 N., R. 10 E. Coconino Co.	No information available. Deposit would be in upper part of Shinarump Member.	Possibly a small production.	AEC Guidebook, 1959.
83.	Luster No. 1	SW. 1/4 Sec. 17, T. 27 N., R. 10 E. Coconino Co.	Ditto	Ditto	Ditto
84.	Grub No. 14	NE. 1/4 Sec. 16, T. 27 N., R. 10 E. Coconino Co.	Ditto	Ditto	Ditto
85.	Murphy group (Black Point)	SW. 1/4 Sec. 15, T. 27 N., R. 10 E. Coconino Co.	Scattered channel deposits associated with abundant carbonized logs and plant remains in fine- to medium-grained sandstone and mudstone at bottom of Petrified Forest Member or upper part of Shinarump Member. Some migrated uranium mineralization found in Pleistocene gravels also.	Probably minor production.	AEC Guidebook, 1959. Austin, 1957.
86.	Yazzie No. 1	NW. 1/4 Sec. 14, T. 27 N., R. 10 E. (Protracted) Coconino Co.	No information available. Deposit would be in lower part of Petrified Forest Member.	Ditto	AEC Guidebook, 1959.
87.	Yazzie No. 2	Ditto	Ditto	Ditto	Ditto
88.	Jackpot No. 40	East central Sec. 15, T. 27 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
89.	Huskon No. 17	West central Sec. 14, T. 27 N., R. 10 E. (Protracted) Coconino Co.	Long (1,200 feet), irregular (ave. 100 foot wide) mineralized body associated with abundant carbonized plant remains in scour and fill sandstone and mudstone in N. trending channel in lower part of Petrified Forest Member.	A few thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
90.	Jackpot Nos. 1 & 5	Central Sec. 14, T. 27 N., R. 10 E. (Protracted) Coconino Co.	No information available. Deposit would be in lower part of Petrified Forest Member.	Probably minor production.	AEC Guidebook, 1959.
91.	Amos No. 8	NE. corner Sec. 34, T. 27 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
92.	Max Johnson No. 7	SW. 1/4 Sec. 34, T. 27 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
93.	Charles Huskon No. 9	South center Sec. 34, T. 27 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
94.	Riverview group	North central Sec. 8, T. 26 N., R. 10 E. Coconino Co.	Uranium mineralization along vein-like channels in a collapse area where Chinle sediments have been dropped down into Moenkopi Formation.	Some production.	AEC Guidebook, 1959. Bollin and Kerr, 1958. Kerr, 1958.
95.	E. Lee No. 1	SW. 1/4 Sec. 2, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Irregular branching mineralized lenses up to 130 feet long and 100 feet wide oriented mainly to NE. in braided scour and fill channel and modified by fracturing and permeability characteristics of sandstone and mudstone of lower part of Petrified Forest Member. Channel N. trending.	At least a few thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
96.	Julius Chee No. 4	South center Sec. 2, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Somewhat smaller deposit similar to E. Lee No. 1.	Ditto	Ditto

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
97.	Julius Chee No. 3	NW. 1/4 Sec. 11, T. 26 N., R. 10 E. (Protracted) Coconino Co.	No information available. Deposit probably similar to Julius Chee No. 4 but probably smaller.	Probably a few hundred tons produced.	AEC Guidebook, 1959.
98.	Julius Chee No. 2	North central Sec. 11, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
99.	Elwood Thompson No. 1 (Ramco No. 23)	South central edge Sec. 1, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Probable several hundred tons produced.	Ditto
100.	Ramco No. 24	North central Sec. 12, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
101.	Charles Huskon No. 18	SW. 1/4 Sec. 12, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Ditto	Ditto	Ditto
102.	Charles Huskon No. 4 and Paul Huskie No. 3	South center Sec. 11, T. 26 N., R. 10 E. (Protracted) Coconino Co.	Very irregular mineralized lenses and pods in scour and fill sediment in channels generally N. to NE. trending. Abundant carbonized logs and plant remains. In the sandstone-mudstone sediments of lower part of Petrified Forest Member.	Probably several thousand tons produced.	AEC Guidebook, 1959. Bollin and Kerr, 1958.
103.	E. Lee No. 3 and J. Semallie	NE. 1/4 Sec. 13, T. 26 N., R. 10 E. Coconino Co.	No information available. Probably mineralization is similar to that of area in lower part of Petrified Forest Member.	Possibly several hundred tons produced.	AEC Guidebook, 1959.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	Miscellaneous Occurrences Along Little Colorado River				
104.	Hosten Nez and Yellow Jeep	Sec. 32, T. 28 N., R. 12 E. (Protracted) Coconino Co.	Uraninite, becquerelite(?), and tyuyamunite associated with Mn oxide and carbonized fossil wood occur in lenticular bodies up to 70 feet long and 12 feet thick. Host rock is lens of varicolored shaly sandstone and sandstone with clay pebbles, possibly of upper Chinle or lower Kayenta Formation. Mineralization replaces clay pebbles, coats fractures and bedding surfaces and impregnates manganese concretions and carbonized fossil wood.	Some production but amount indefinite.	Granger, 1951, USGS, AEC PRR. Granger and Raup, 1962.
105.	Calvin Chee	Approx. NW. 1/4 T. 22 N., R. 13 E. Coconino Co.	Schroeckingerite(?) in sandstone lens containing very abundant carbonized plant remains, probably Petrified Forest Member.	No production known.	Finch, 1967.
106.	O'Harco-Robinson Prospect	Approx. SW. 1/4 Sec. 31, T. 20 N., R. 16 E. Navajo Co.	Reportedly autunite and tyuyamunite or metatyuyamunite found in Shinarump Member conglomerate. No detail information available.	Ditto	Ditto
107.	O'Harco Ranch	Approx. N. central Sec. 25, T. 19 N., R. 16 E. Navajo Co.	Reportedly unidentified uranium mineralization in siltstone(?) of Petrified Forest Member.	Probably small amount of low grade mineralization.	Ditto
108.	Unnamed	Approx. Sec. 23, T. 20 N., R. 17 E. Navajo Co.	Reportedly unidentified uranium mineral in Chinle Formation sandstone and mudstone with abundant carbonized plant remains.	Ditto	Ditto
109.	Hanson No. 1	Approx. Sec. 11, T. 18 N., R. 19 E. Navajo Co.	Reportedly unidentified uranium minerals associated with abundant carbonized wood and coaly material in light-brown, coarse-grained bentonitic sandstone of Petrified Forest Member.	Ditto	Ditto
110.	Anna Bernice Claims	West central Sec. 20, T. 19 N., R. 19 E. Navajo Co.	Unidentified uranium minerals in thin jasper lenses in flat-lying bentonitic shale of Chinle Formation.	Very low-grade mineralization.	Granger and Raup, 1962.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
111.	P. Costen	NE. 1/4 and S. central Sec. 1, T. 18 N., R. 19 E. Navajo Co.	Reportedly carnotite-like mineralization in two areas in irregularly thick beds, 4-5 feet thick. Sandy orange and black shale with abundant petrified wood, close to base of Chinle. Associated carbonized and silicified wood, gypsum and iron oxides.	Low-grade mineralization.	Gregg, 1952, AEC PRR ED:R-204.
112.	Gerwitz Prospect (Spurlock-Westler Ranch)	Approx. W. center Sec. 26, T. 19 N., R. 20 E. Navajo Co.	Becquerelite and unidentified primary uranium mineral in layer of light-brown, coarse-grained bentonitic sandstone containing abundant carbonized plant remains. Believed to be Petrified Forest Member.	Probably low grade and no production reported.	Moore, 1953, AEC PRR ED:R-228. Finch, 1967.
113.	Curry Jones Prospect	Approx. N. central Sec. 22, T. 18 N., R. 23 E. Navajo Co.	Zippeite associated with carbonized trash in bentonitic sandstone of Petrified Forest Member.	Ditto	Gregg, 1953, AEC PRR ED:R-226.
114.	Little John and Ruth Claims	NW. 1/4 Sec. 2, T. 17 N., R. 23 E. Navajo Co.	Uranium mineralization (uraninite, coffinite, zeunerite, schroeckingerite, and torbernite) occurs in gray medium- to coarse-grained sandstone and gray bentonitic mudstone in Petrified Forest Member. Abundant petrified logs and carbonaceous trash.	Several hundred tons produced.	Gregg and Moore, 1955. Finch, 1967. Gregg, 1953, AEC PRR ED:R-225.
115.	Tract No. 2	SE. 1/4 Sec. 33, T. 16 N., R. 23 E. Navajo Co.	Yellow uranium mineral associated with dull-brown petrified logs, probably in sandy bentonitic clay and sand of Petrified Forest Member.	Low grade and no production reported.	Granger and Raup, 1962. Finch, 1967.
116.	Tract No. 1	SE. 1/4 Sec. 1, T. 17 N., R. 23 E. Navajo Co.	Unrecognized uranium mineralization in lens in flat-lying buff-colored sandstone, bentonitic clay and conglomerate containing abundant carbonized and silicified fossil logs and plant material.	Ditto	Ditto
117.	M. Young and others	NE. 1/4 Sec. 12, T. 17 N., R. 23 E. Navajo Co.	Unidentified uranium mineralization associated with sand lenses and carbonaceous trash in lower Petrified Forest Member(?).	Low grade and probably no production.	Gregg, 1953, AEC PRR ED:R-224.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
118.	Unnamed	Approx. Sec. 30, T. 16 N., R. 23 E. Navajo Co.	Unidentified uranium mineralization noted associated with carbonaceous material. Probably in lower Chinle Formation.	Generally low grade but one pick-up load sent to Grants, New Mexico.	Standard, 1953, AEC PRR ED:R-222.
119.	Grant Prospect	Approx. Sec. 1, T. 15 N., R. 25 E. Apache Co.	Reportedly carnotite-like mineralization associated with carbonized plant remains in sandy clay and shale of lower Chinle Formation.	Low grade and no production reported.	Finch, 1967.
120.	Hinkson Cattle Co.	SW. 1/4 Sec. 30, T. 15 N., R. 25 E. Apache Co.	Carnotite-like mineralization associated with petrified and carbonized logs left as erosional remnants of lower Chinle Formation.	Low grade and no production.	Moore, 1953, AEC PRR ED:R-221.
121.	Unnamed	NW. 1/4 Sec. 3, T. 14 N., R. 26 E. Apache Co.	Unidentified uranium mineralization associated with carbonized plant remains in conglomeratic sandstone and siltstone in scour and fill channel in Chinle Formation.	No production reported.	Gregg, 1953, AEC PRR ED:R-223. Finch, 1967.
122.	Tom Cat 1-8, Lookout and Maybe claims	SE. 1/4 Sec. 1, T. 11 N., R. 27 E. Apache Co.	Carnotite-like mineralization associated with abundant carbonized wood in yellow to greenish shale containing sandy layers and lenses. Probably about middle of Chinle Formation.	Generally low-grade but some select higher grade samples. No production.	Moore, 1954, AEC PRR ED:R-261. Ashwill, 1955, AEC PRR A-19.
	Nazlini-Canyon de Chelly Area				
123.	Zealy-Tso drilling block	Approx. SE. 1/4 Sec. 6, (Unsurveyed), T. 5 N., R. 9 W. (Navajo Base) Apache Co.	Carnotite-like minerals and malachite associated with carbonaceous trash in light-brown and grey sandstone, probably Shinarump Member.	Moderate grade mineralization but no production recorded.	Evensen, 1955, AEC PRR ED:R-521.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
124.	Unnamed	Reportedly from various places in T. 5 N., R. 10 W. (Navajo Base) Apache Co.	Samples containing unidentified uranium minerals submitted. All appeared associated with carbonaceous trash in lower to middle part of Chinle Formation.	Mostly low-grade and relatively small occurrences.	Ariz. Bur. Mines records.
125.	Anomaly 15-30.1	SW. 1/4 T. 2 N., R. 9 W. Apache Co.	Several occurrences reported of unidentified uranium minerals associated with abundant carbonized and silicified plant remains in greenish siltstone of Chinle Formation.	Ditto	Finch, 1967.
	Northern Mohave County				
126.	Kaibab Indian Reservation lease	Approx. SE. 1/4 Sec. 6, T. 41 N., R. 3 W. (Protracted) Mohave Co.	Yellow U-bearing mineral in small nodules and seams in pink and white gypsum and petrified logs. Some sooty black, highly radioactive mineral in gypsum. Believed to be Petrified Forest Member.	One prospect pit, grab sample assayed 0.53, 0.518 percent eU_3O_8.	Holen and Tagg, 1955, AEC PRR SL-124.
127.	Rainbow (Last Chance)	NW. 1/4 Sec. 25, T. 40 N., R. 6 W. Mohave Co.	Copper-uranium mineralization occurs in coarse-grained, poorly sorted sandstone with pebble conglomerate lenses. Iron oxides, manganese oxides and carbonaceous trash. Probably sandy strata of Petrified Forest Member. Shallow mineralization.	Old copper prospect. Uranium assays 0.012 to 0.024 percent U_3O_8. Copper assays 0.025 percent.	Holen and Twitchell, 1955, AEC PRR R-Rs-106.
128.	Radon claims	SE. 1/4 Sec. 23, T. 40 N., R. 6 W. Mohave Co.	Probably continuation of occurrence at Rainbow (No. 127).	Few loads reported shipped.	Scott and Twitchell, 1954, AEC PRR R-R-204.
129.	Unnamed	North center Sec. 10, T. 38 N., R. 15 W. Mohave Co.	Carnotite-type mineralization apparently in Shinarump Member.		R. T. Moore, 1968, oral communication.

Table I. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
130.	Iris claim	North center Sec. 4, T. 38 N., R. 6 W. Mohave Co.	Radioactivity associated with carbonaceous trash in pebble conglomerate, probably Shinarump Member, at contact with Moenkopi Formation. Flat, irregular stringer of galena occurs in Moenkopi near contact.		Malan and Twitchell, 1954, AEC PRR R-R-255.
131.	Cedar Wash occurrence	Approx. S. Center Sec. 28, (unsurveyed), T. 37 N., R. 16 W. Mohave Co.	Carnotite-type mineralization apparently in Shinarump Member.		R. T. Moore, 1968, oral communication.
132.	Jacobs Ranch	South central Sec. 4, T. 36 N., R. 16 W. Mohave Co.	Ditto		Ditto

Table J. — Uranium occurrences in the Morrison Formation.

Numbers correspond with the occurrence numbers on Plate 17.

No.	Name	Location	Geology and Mineralization	Notes	References
			Apache County		
	Northwest Carrizo Area				
1.	Barton No. 3 area	Approx. NE. 1/4 Sec. 28, (Unsurveyed), T. 41 N., R. 27 E. At NW. end of Toh-Atin Mesa.	No detail information available. Reported to be carnotite-type mineralization in fine-grained Salt Wash sandstone. Several small deposits.	Production restricted to a few hundred tons. Resources limited.	Butler and others, 1962. Finch, 1967. O'Sullivan and Beikman, 1963.
2.	Unnamed occurrence	Approx. NW. 1/4 Sec. 15, (Jnsurveyed), T. 41 N., R. 28 E. In wash to N. of Toh-Atin Mesa.	No detail information available. Probably carnotite-type mineralization in Salt Wash sandstone under alluvial cover. Found in seismic shot holes.	Probably little or no production. Indefinite resources.	O'Sullivan and Beikman, 1963. Chenoweth, 1955.
3.	Unnamed occurrence	Approx. NW. 1/4 Sec. 30, (Unsurveyed), T. 41 N., R. 29 E. In wash to N. of Black Rock Mesa.	Ditto	Ditto	Ditto
4.	Unnamed occurrences	Approx. E. 1/2 Sec. 4, T. 40 N., R. 28 E. (Protracted) and SE. corner Sec. 33 (Unsurveyed) T. 41 N., R. 28 E. On N. trending prong at W. end of Dry Mesa.	Spotty carnotite-type mineralization of rattlesnake-type and in carbonized logs in lower Salt Wash sandstone with interfingering mudstone and prominent iron staining. Appears to be in scour channels in underlying Bluff Sandstone.	Some minor production from small deposits. Limited resources.	Maise and Million, 1952, AEC PRR ED:R-202. O'Sullivan and Beikman, 1963.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
5.	Unnamed occurrences	Approx. N. central Sec. 10 and S. central Sec. 3, T. 40 N., R. 28 E. (Protracted) Along rim of deep embayment on N. side of Dry Mesa.	Spotty carnotite-type mineralization in cross-stratified sandstone lenses and in carbonized logs. Probably lower Salt Wash in scour channel in Bluff Sandstone.	Minor production or resources.	Chenoweth and Fergusson, 1954, AEC PRR ED:R-263.
6.	Unnamed occurrences	Approx. N. 1/2 Sec. 2, T. 40 N., R. 28 E. (Protracted) On prong and little mesa on N. side of Dry Mesa.	No detail information available.	Possibly minor production and resources.	Stokes, 1951. O'Sullivan and Beikman, 1963. Chenoweth, 1955.
7.	Unnamed occurrences	Approx. N. center Sec. 11, T. 40 N., R. 28 E. (Protracted) At head of embayment on N. side of Dry Mesa.	Ditto	Ditto	Ditto
8.	Hogan mine area	Approx. SW. 1/2 Sec. 1, T. 40 N., R. 28 E. (Protracted) On N. prong of Dry Mesa.	No detail information available. Reportedly schroeckingerite, carnotite, tyuyamunite and metatyuyamunite in scattered, relatively small bodies in fine-grained shaly and limy sandstone of lower Salt Wash. Carbonized logs and "trash" abundant.	One of the early vanadium mines of area. A possible 20,000 tons may have been produced but remaining resources probably limited and low grade.	Stokes, 1951. Chenoweth, 1955. O'Sullivan and Beikman, 1963. Finch, 1967.
9.	Gila mine area	Approx. SE. 1/4 Sec. 1 and N. central Sec. 12, T. 40 N., R. 28 E. (Protracted) On N. prong of Dry Mesa.	Ditto	Developed later than Hogan area. May have produced a few thousand tons. Remaining resources limited.	Ditto

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
10.	Rattlesnake Group mine area	Approx. S. center Sec. 6, T. 40 N., R. 29 E. (Protracted) On prong N. of Black Rock Point.	No detail information available. Geology and mineralization typical of Northwest Carrizo area but mineralized bodies up to 300 by 200 feet horizontally and eight feet thick. Group lies in a major meander of paleostream channel in Salt Wash.	Most productive mines of area, having produced up to 100,000 tons of vanadium-uranium ore. Could be additional resources in surrounding area to N.	Ditto
11.	Black Rock Point mine area	Approx. NW. 1/4 Sec. 8, T. 40 N., R. 29 E. (Protracted) On N. prong of Black Rock Point.	No detail information available. Geology and mineralization believed typical of Northwest Carrizo area.	Developed for uranium and probably produced a few thousand tons of vanadium-uranium ore. Resources probably limited.	Ditto
12.	No. 5 mine area	Approx. NE. 1/4 Sec. 7, T. 40 N., R. 29 E. (Protracted) On N. prong of Black Rock Point.	Ditto	Early production of a few thousand tons of vanadium-uranium ore. Resources probably limited.	Ditto
13.	Two Level and Horse Portal mines area	Approx. SW. 1/4 Sec. 8, T. 40 N., R. 29 E. (Protracted) At head of Rattlesnake Canyon cutting into Black Rock Point.	Ditto	Early vanadium mines. Production limited to a few thousand tons of ore. Resources probably limited.	Ditto
14.	Unnamed occurrences	Approx. NE. 1/4 Sec. 8, T. 40 N., R. 29 E. (Protracted) On prong on W. side of Rattlesnake Canyon.	Ditto	Probably only a few thousand tons produced. Resources limited.	Ditto

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
15.	North Martin mine area	Approx. S. center Sec. 12, T. 40 N., R. 28 E. (Protracted) On E. rim of Dry Mesa.	Ditto	Early mining for vanadium. Probably produced a few thousand tons. Spotty and limited resources.	Ditto
16.	Martin mine area	Approx. N. central Sec. 13, T. 40 N., R. 28 E. (Protracted) On E. rim of Dry Mesa.	Ditto	One of larger mines of area. Early producer of vanadium ore and later of uranium. Production estimated at up to 40,000 tons. May be some resources.	Ditto
17.	No. 8 mine area	Approx. NE. 1/4 Sec. 13, T. 40 N., R. 28 E. (Protracted) On rim on E. side of Tsitah Wash.	Ditto	Early vanadium mining and a few thousand tons produced. Resources limited.	Ditto
18.	Sah Tah mine area	Approx. S. central Sec. 13, T. 40 N., R. 28 E. (Protracted) At head of Tsitah Wash Canyon.	Ditto	Ditto	Ditto
19.	John McCoy No. 1 area	Approx. S. central Sec. 22, T. 40 N., R. 27 E. (Protracted) On nose of divide one mile NW. of Sweetwater Trading Post.	Carnotite-type mineralized body (10 by 5 feet by 20 inches) in large, limy, fine-grained, light gray sandstone lens underlain by green and red mudstone galls and partings. Abundant carbonized "trash" with intense limonitic staining. In Salt Wash Member 20 feet above base.	No production reported. No resources estimated.	Chenoweth, 1955, AEC PRR ED:R-428.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	North Carrizo Area				
20.	North Mesa mine area	Approx. N. center Sec. 16, T. 40 N., R. 30 E. (Protracted) On W. tributary of Teec Nos Pas Wash.	No detail information available. Reportedly carnotite-type mineralization in fine-grained, quartzose Salt Wash sandstone with carbonized debris.	A few thousand tons probably produced but resources very limited.	Stokes, 1951. O'Sullivan and Beikman, 1963. Finch, 1967.
	East Carrizo Area				
21.	Zona I area	Approx. NW. 1/4 Sec. 28, T. 40 N., R. 30 E. (Protracted) On E. flank of Carrizo Mountains.	Vanoxite-type mineralization with carnotite-type specks and paint in three, one-foot thick horizons separated by barren zones with gray mudstone. Red mudstone above and below mineralized, fine-grained, quartzose sandstone containing carbonized debris. Occurrence is in lower 50 feet of Salt Wash and is underlain, deformed, and altered by later igneous intrusive sill.	A few thousand tons of picked ore averaging about 0.2 percent U_3O_8 and 4.0 percent V_2O_5 produced. Resources believed to be very limited.	Chenoweth and Fergusson, 1954, AEC PRR ED:R-262. O'Sullivan and Beikman, 1963. Finch, 1967.
22.	Harvey Begay #3 area	Approx. NW. 1/4 Sec. 12, T. 39 N., R. 30 E. (Protracted) On E. flank of Carrizo Mountains.	Vanoxite-type mineralization with disseminated carnotite-type specks in one-foot black sandstone containing black mudstone galls. Light-gray, fine-grained, quartzose sandstone above and below. Strongly fractured, mineralized zone exposed in 15 by 20 foot bench. Abundant carbonized debris and calcite cement. Probably Salt Wash. Diorite sill above and dike to south.	Small amount of picked ore produced but no resources.	Archer and Labrecque, 1956, AEC PRR ED:R-532. O'Sullivan and Beikman, 1963.
23.	Barton No. 4 area	Approx. S. central Sec. 12, T. 39 N., R. 30 E. (Protracted) On N. side of Cottonwood Canyon, E. flank of Carrizo Mountains.	Black vanoxite-type mineralization with disseminated carnotite-type specks and paint in lenses of fine-grained, quartzose sandstone containing carbonized debris. Three exposures in lower 20 feet of Salt Wash and one 50 feet above. No mudstone but diorite intrusive nearby.	Small production. Grade reported to be 0.02 to 0.4 percent U_3O_8 and 0.8 to 6.0 percent V_2O_5. Resources very limited.	Chenoweth, 1954, AEC PRR ED:R-265. O'Sullivan and Beikman, 1963.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
24.	Syracuse mine area	Approx. NE. 1/4 Sec. 25, (Unsurveyed), T. 39 N., R. 31 E. On S. side of south tributary of Cottonwood Wash close to New Mexico border.	No detail information available but probably similar to Canyon and Oak Spring mine areas (Nos. 25 & 26).	Old vanadium mine with low grade uranium content. Few thousand tons produced. Limited resources.	Stokes, 1951. O'Sullivan and Beikman, 1963. Finch, 1967.
25.	Oak Spring mine area	Approx. N. central Sec. 36, (Unsurveyed), T. 39 N., R. 31 E. Near head of Oak Spring Wash.	Vanoxite-type mineralization with disseminated carnotite-tyuyamunite in finely and unevenly bedded, light-gray, fine-grained Salt Wash sandstone with blue-green clay seams and lenses above and below and abundant carbonized debris. Mineralization mostly conformable to bedding but discontinuous along 400 feet of outcrop and up to 6 feet thick. Ore zone about 54 feet above Bluff contact. Channeling and cross-lamination noted but only one log found. High lime content.	Several thousand tons shipped with grades of 0.1-0.3 percent U_3O_8 and 2.1-3.2 percent V_2O_5. Mined originally for vanadium. May be additional scattered resources.	Hatfield, 1951, AEC PRR CEB:R-54.
26.	Canyon mine area	Approx. E. central border Sec. 25, (Unsurveyed), T. 39 N., R. 31 E. To N. of Oak Spring.	Similar to Oak Spring Mine area. Mineralization fairly continuous for some 300 feet and up to 9 feet thick, mostly bedded with few rolls.	Several thousand tons produced with grade ranging from 0.13 to 0.34 percent U_3O_8 and 2.3 to 2.79 percent V_2O_5. Limited resources.	Hatfield, 1951, AEC PRR CEB:R-55.
27.	Unnamed occurrences	Approx. NE. 1/4 Sec. 27 and SW. 1/4 Sec. 23, T. 40 N., R. 30 E. (Protracted) On N. side of Shoe Game Wash Canyon.	No information available. May be similar to Zona I (No. 21).	Very limited production if any, or resources.	O'Sullivan and Beikman, 1963.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	West Carrizo Area				
28.	Unnamed occurrences	Approx. S. central Sec. 32, T. 40 N., R. 29 E. (Protracted) North rim of Toh-Chin-Lini Mesa.	No detail information available. Reportedly of carnotite-type mineralization in fine-grained Salt Wash sandstone.	Very limited production and resources.	Stokes, 1951. O'Sullivan and Beikman, 1963.
29.	Eurida mine area	Approx. SE. 1/4 Sec. 11, SW. 1/4 Sec. 12, NE. 1/4 Sec. 13, N. border Sec. 14 and NE. 1/4 Sec. 15, T. 39 N., R. 28 E. (Protracted) Mesa to S. of Toh-Chin-Lini Canyon.	Ditto	Reported to have produced several thousand tons but generally with relatively low uranium values.	Ditto
30.	Sunnyside mine area	Approx. W. side Sec. 36, T. 39 N., R. 28 E. (Protracted) On Sunnyside Mesa.	No detail information available. Reportedly carnotite-type mineralization in medium-grained, shaly sandstone with carbonized debris of Salt Wash Member.	Not more than a few hundred tons produced and scattered resources limited.	Ditto
31.	Miscellaneous occurrences	Approx. central Sec. 29, SW. 1/4 Sec. 28, NW. 1/4 Sec. 22 and S. central Sec. 27, T. 39 N., R. 28 E. (Protracted) Broad mesa between Seklagaidesa and Alcove Canyons.	No detail information available. Reportedly carnotite-type mineralization in fine-grained Salt Wash sandstone with carbonized debris.	Ditto	Ditto

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
32.	Unnamed occurrences	Approx. NE. 1/4 Sec. 3, T. 38 N., R. 28 E. (Protracted) On narrow mesa between tributaries of Alcove Canyon.	Ditto	Ditto	Ditto
33.	Friday Mesa area	Approx. W. central Sec. 1, T. 38 N., R. 28 E. (Protracted) On Friday Mesa.	No detail information available. Reportedly carnotite-type mineralization in medium-grained Salt Wash sandstone with carbonized debris.	Ditto	Ditto
34.	Segi-ho-cha Mesa area	Approx. SE. 1/4 Sec. 2, NE. 1/4 Sec. 10, NW. 1/4 and SW. 1/4 Sec. 13, NW. 1/4 Sec. 14, T. 38 N., R. 28 E. (Protracted)	Ditto	Ditto	Ditto
	South Carrizo Area				
35.	Alcove-Tah Acon Mesa area	Approx. central and SE. 1/4 Sec. 10, NW. 1/4 and SE. 1/4 Sec. 13, NE. 1/4 Sec. 23, NW. 1/4 Sec. 24, N. 1/2 Sec. 25, T. 38 N., R. 27 E. (Protracted)	No detail information available. Reportedly carnotite-type mineralization in fine- to medium-grained sandstone with carbonized plant remains.	Ditto	Ditto

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
36.	Kinusta (Tree) Mesa area	Approx. S. center Sec. 21, SW. 1/4 Sec. 28, N. 1/2 and SE. 1/4 Sec. 34, S. 1/2 Sec. 33, T. 38 N., R. 28 E. (Protracted)	Vanadium mineralization with weak and irregular carnotite-type specks and paint in several horizons 40-90 feet above Bluff Sandstone in fine- to medium-grained Salt Wash sandstone containing carbonized debris. Best mineralization in 70-90 foot horizon.	Up to 1,000 tons produced averaging 0.06 percent U_3O_8 and 1.72 percent V_2O_5. May be some additional resources.	King, 1951.
37.	Cove Mesa area	Approx. S. central Sec. 36, T. 38 N., R. 28 E. and N. to S. central Sec. 1, N. central Sec. 12, T. 37 N., R. 28 E. (Protracted)	Scattered and relatively small 1-3 foot thick mineralized bodies of tyuyamunite, metatyuyamunite and carnotite along flanks of meandering paleochannels. Salt Wash host is a massive, friable, thick-bedded, fine- to medium-grained, limy, lenticular sandstone with minor interfingering claystone and siltstone. Local carbonized logs and debris. Mineralization occurs 30-95 feet above base of Salt Wash.	Some 5,000 tons produced, averaging 0.16 percent U_3O_8 and 1.8 percent V_2O_5. Resources believed to be depleted.	King, 1951. Jones, 1954. Lowell, 1955.
38.	East Mesa area	Approx. NE. 1/4 Sec. 24, T. 37 N., R. 28 E. (Protracted)	No detail information available. Reportedly similar to Cove Mesa deposits (No. 37).	A few hundred tons mined. No resources estimated.	Dodd, 1956.
39.	West Mesa area	Approx. central Sec. 24, T. 37 N., R. 28 E. (Protracted)	Ditto	Ditto	Ditto
40.	Blackhorse Creek area	Approx. SW. 1/4 Sec. 13, T. 39 N., R. 29 E. (Protracted) On E. side of Whirling Mountain.	No detail information available. Probably carnotite-type mineralization occurs in band of Salt Wash sandstone intruded by diorite porphyry sills.	Probably very minor production.	Strobell, 1956. O'Sullivan and Beikman, 1963.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	Lukachukai Mountains Area				
41.	Northeastern Mexican Cry Mesa area	SW. part of central Sec. 25, T. 37 N., R. 28 E. (Protracted)	No detail information available. Reportedly carnotite-type mineralization in fine-grained sandstone with carbonized logs and debris.	Minor production.	Dodd, 1956. O'Sullivan and Beikman, 1963.
42.	Southwestern Mexican Cry Mesa area	N. central and SW. 1/4 Sec. 2, T. 36 N., R. 28 E. (Protracted)	Ditto	Ditto	Ditto
43.	Mesa No. 7 area	Approx. SE. 1/4 Sec. 36, T. 37 N., R. 28 E. (Protracted) At NE. corner of Lukachukai Mountains.	Vanoxite-type mineralization, with spotty uranium, impregnates a light tan, fine- to medium-grained quartzose sandstone about 50-70 feet above base of Salt Wash. Mineralization is discontinuous and only up to one foot thick for 75 feet along rim. Two foot long by 10 inch thick exposure, underlain by green mudstone assayed 0.23 percent U_3O_8.	Little or no production or resources.	King and Ellsworth, 1951.
44.	Mesa No. 6 area	Approx. S. center Sec. 5 and NE. 1/4 Sec. 7, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	Vanoxite-type mineralization with local carnotite, pintadoite, and pascoite occurs in fine- to medium-grained, light tan, limy, quartzose sandstone associated with clay galls and seams. Lower 60-100 feet of pink Salt Wash barren. On S. side, 5-10 foot long, 4 inch thick zone with tan sandstone above and blue-gray mudstone below ran 0.31 percent U_3O_8. Farther to the east, a 200 foot long vanadium exposure contained 8 foot long roll with 2.5 foot thick uranium band assaying 0.35 percent U_3O_8. Other occurrences small, spotty and irregular.	Produced a few hundred pounds at most and resources limited.	Ellsworth and Hatfield, 1951.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
45.	Mesa No. 5 area	Approx. SE. 1/2 Sec. 8, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	Vanoxite-type mineralization with disseminated carnotite scattered throughout bottom of 1-5 feet of light-tan, fine-grained, limonite stained, friable, limy Salt Wash sandstone 65-95 feet above its base. Thin mudstone seams and clay galls locally abundant. Pinkish sandstone below is barren. Gypsum and calcite fairly abundant. Deposits consist of clusters of small mineralized bodies in several horizons, 1-5 feet thick and up to 40 feet long. Grade varies from 0.37-0.50 percent U_3O_8 and 1.0-2.0 percent V_2O_5. V:U ratio 7:1.	Several thousand tons produced having better than average grade. A small resource may remain but probably of lower grade.	King, 1951.
46.	Mesa No. 4 1/2 area (4 B, Frank Nos. 182 and 709 mines)	Approx. in common corner of Secs. 7, 8, 17 and 18. (Protracted) On E. side of ridge.	Widely scattered clusters of small bodies of metatyuyamunite, pascoite, melanovanadite, hummerite, rossite, and metarossite in lenticular, light-gray to light-tan Salt Wash sandstone interbedded with thin bands of bluish mudstone and surrounded by barren reddish sandstone and mudstone. Bodies often connected by thin mineralized bands and occur in several horizons about 40 feet above Bluff Sandstone. Most mineralization associated with paleostream channels and carbonized debris. Traces of uraninite found in carbonized wood. Fine-grained iron oxides occur as pseudomorphs after pyrite or as earthy coatings on clay galls. Thickness of mineralization varies from a few inches to 6 feet, average 2.5-3.0 feet. Bodies are irregularly tabular, elongated along sedimentary structures. Overall vanadium:uranium ratio 5.2:1 but best uranium ore had ratio of 2:1.	Up to 100,000 tons produced averaging 0.25-0.30 percent U_3O_8 and 1.14-1.20 percent V_2O_5. Readily available resources depleted but some low grade mineralization may remain. One of major mines in area.	Dodd, 1956. Dare, 1959.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
47.	Mesa No. 4 area	Approx. NE. 1/4 and central Sec. 17, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	No detail information available but small mineralized bodies probably had geology and minerali-tion similar to general area.	A few hundred tons may have been produced. No resources estimated.	O'Sullivan and Beikman, 1963.
48.	Mesa No. 3 area	Approx. N. central Sec. 20, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	N-S zone, 1,500 foot long and up to 200 feet wide, of high vanadium-low uranium, tyuyamunite-carnotite mineralization occurs in sandstone with minor mudstone lenses about 20-30 feet thick along paleostream channel. Lime content is low to medium. Blue mudstone underlies most mineralization.	Several thousand tons produced and resources largely depleted except for some low grade in pillars and surrounding rock.	Dare, 1961.
49.	Mesa No. 2 1/2 area	Approx. NE. 1/4 Sec. 20, NW. 1/4 Sec. 21, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	Scattered bodies of high-vanadium, tyuyamunite-carnotite mineralization in clusters up to 13 feet thick along a paleostream channel. Ore was low to medium lime type.	Over 10,000 tons produced and better grade mineralization largely depleted.	Dare, 1961.
50.	Mesa No. 2 area	Approx. NW. 1/4 Sec. 16 and NW. 1/4 Sec. 21, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	Relatively large clusters of high vanadium, low to medium lime, carnotite-tyuyamunite mineralization, 8 to 9 feet thick on an average, in lenticular masses of various shapes and sizes in two horizons where paleostream channels cross. Host Salt Wash sandstone lenses 20 to 30 feet thick with bluish mudstone below and occasionally above. Mineralized zone about 40-60 feet above base of Salt Wash. In thicker sandstone lenses, mineralization up to 20 feet thick but lower grade than where thinner on flanks of channels.	Up to 100,000 tons mined averaging about 0.25 percent U_3O_8 and 1.2 percent V_2O_5. Available resources of ore grade largely depleted. One of major mines.	Dare, 1961.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
51.	Mesa No. 1 3/4 area	Approx. SW. 1/4 Sec. 21, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	Little detail information available. Northeasterly dipping mineralization up to 4 feet thick. Irregular in outline along continuation of one of curving paleochannels of Mesa No. 2 mine with which it is connected.	Over 10,000 tons produced at an average grade for general area. Resources probably depleted.	Dare, 1961.
52.	Mesa No. 1 1/2 area	Approx. E. central Sec. 21, T. 36 N., R. 29 E. (Protracted) On E. side of ridge.	No detail information available. Relatively small bodies.	Possibly a few thousand tons mined. No resources estimated.	Dare, 1961.
53.	Mesa No. 1 area	Approx. SE. 1/4 Sec. 16, SW. 1/4 Sec. 15, and NW. 1/4 Sec. 22, T. 36 N., R. 29 E. (Protracted) At SE. end of ridge.	Spotty high vanadium, moderately high lime, carnotite-tyuyamunite in scattered clusters of generally small and irregular mineralized bodies.	Some 50,000 thousand tons produced. May be limited resources.	Dare, 1961.
54.	Thirsty Mesa area (Hall mine)	Approx. NE. 1/4 Sec. 11, T. 36 N., R. 28 E. (Protracted) At NW. end of ridge.	No detail information available. Mineralized bodies reportedly controlled by sedimentary trends and jointing in Salt Wash.	Up to a few thousand tons may have been produced. Some resources may be present.	O'Sullivan and Beikman, 1963. Chenoweth, 1967.
55.	Fall Down Mesa area	Approx. SW. 1/4 Sec. 19, T. 36 N., R. 29 E. (Protracted) On W. side of ridge.	No detail information available.	Ditto	Ditto
56.	Step Mesa area	Approx. N. central Sec. 30, T. 36 N., R. 29 E. (Protracted) On W. side of ridge.	Ditto	Ditto	Ditto

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
57.	Flag Mesa area	Approx. NW. 1/4 Sec. 29, T. 36 N., R. 29 E. (Protracted) On W. side of ridge.	Ditto	Some 30,000 tons may have been mined and additional resources may be present.	Ditto
58.	Knife Edge Mesa area	Approx. SE. 1/4 Sec. 29, T. 36 N., R. 29 E. (Protracted) On W. side of ridge.	Ditto	A few thousand tons mined and some resources may be left.	Ditto
59.	Three Point Mesa area	Approx. SW. 1/4 Sec. 28, T. 36 N., R. 29 E. (Protracted) On W. side of ridge.	Ditto	Up to 40,000 tons probably mined and some resources may still be present.	Ditto
60.	Cisco Mesa area	Approx. S. center Sec. 28, T. 36 N., R. 29 E. (Protracted) At SW. end of ridge.	Ditto	Ditto	Ditto
61.	Camp Mesa area	Approx. SE. corner Sec. 28, T. 36 N., R. 29 E. (Protracted) At SW. end of ridge.	Ditto	Ditto	Ditto
	Red Rock Valley Area				
62.	Upper Red Rock mine area (Nakai Chee Begay)	Approx. SE. 1/4 Sec. 36, (Unsurveyed), T. 38 N., R. 31 E. On State boundary about 3 mi. N. of Red Rock Trading Post.	Two horizons of vanadium mineralization containing spotty carnotite-type minerals in rolls and pods containing carbonized debris. Host Salt Wash sandstone is fine-grained and quartzose.	Several hundred tons may have been shipped containing about 0.3 percent U_3O_8 and up to 2 percent V_2O_5. Resources probably very limited.	Comstock, 1950, AEC PRR CEB:R-23. King, 1951.

Table J. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
63.	Red Rock Bridge occurrence	Approx. NE. 1/4 Sec. 24, (Unsurveyed), T. 37 N., R. 31 E. At Red Rock Trading Post.	One foot thick band of vanadium mineralization with minor carnotite near base of Salt Wash. Sandstone is fine-grained and quartzose with interbedded mudstone and carbonized debris.	Minor production if any and low uranium grade. No resources estimated.	King, 1951.
64.	Jerome Chee occurrence	Location indefinite. Reportedly some 6-7 miles S. of Red Rock Trading Post.	Discontinuous exposures of fair vanadium mineralization with flecks of carnotite in 6 inch thick horizon about 2 feet above base of Salt Wash. One 100 x 12 foot horizontal bench showed vanoxite, pintadoite and hewettite in fine-grained, weakly cross-laminated, quartzose sandstone with interbedded mudstone and claystone. Carbonized debris relatively abundant.	Possibly 50 tons mined but U_3O_8 grade very low. No resources estimated.	King and Droullard, 1950, AEC PRR CEB:R-24. King, 1951.
	Chilchinbito--Rough Rock Area				
65.	Tom Wilson and Tom Klee mine area	Approx. SE. 1/4 Sec. 2, T. 35 N., R. 22 E. to SW. 1/4 Sec. 6, T. 35 N., R. 23 E. (Protracted) About 4.5 mi. NW of Rough Rock.	Scattered secondary high uranium-low vanadium, high lime mineralization, mainly in high grade log replacements, in Salt Wash sandstone rim.	Several hundred tons of selected ore averaging better than 3 percent and only about 0.1 percent vanadium. Resources probably limited.	Chester, 1951, AEC PRR GJEB:R-76.
			Navajo County		
66.	Blue Lake mine area	Approx. center Sec. 34, T. 39 N., R. 21 E. (Protracted) On rim of bluff about 3 mi. SW. of Baby Rock Point.	Bedded selective replacement of carnotite-type mineralization associated with hematite and abundant dark minerals in Salt Wash sandstone. Weak to moderate radioactivity.	Very little production. No resources.	Chester, Pursley and Leonard, 1951, AEC PRR GJEB:R-103.

Table K. — Uranium occurrences in miscellaneous sedimentary formations.

Numbers correspond with the occurrence numbers on Plate 18.

No.	Name	Location	Geology and Mineralization	Notes	References
	Supai Formation--Permian-Pennsylvanian				
S1.	Promontory Butte area	Approx. central Sec. 24, T. 11 N., R. 12 E. Gila Co.	Uraninite-type and possibly other uranium minerals in limestone-pebble conglomerate and overlying carbonaceous shale. Minor sulfides of iron, copper and lead. Bedded type of deposit essentially horizontal and 1-4 feet thick. Abundant carbonized wood and plant remains.	Prospected by an adit in 1950's and recently drilled and benched. Extent and grade unknown.	Finch, 1967. ABM reconnaissance, 1969.
S2.	Fossil Canyon area	Approx. S. central Sec. 24, T. 12 N., R. 7 E. (Protracted) Gila Co.	Weak radioactivity associated with limestone-pebble conglomerate close to carbonaceous shale and thin coaly seams.	Prospected for coal beds in the 1960's.	McGoon, 1962. ABM reconnaissance, 1969.
S3.	Cibecue area	Approx. NW. 1/4 Sec. 11, T. 8 N., R. 17 E. (Protracted) Navajo Co.	Unidentified uranium mineral and copper oxides in gray limy mudstone overlain by six feet of resistant thin-bedded calcareous silty sandstone.	Field reconnaissance indicated limestone-pebble conglomerate and carbonized plant material.	Weathers, 1954, AEC PRR A-P-175. ABM reconnaissance, 1969.

NOTE: Other occurrences in the Supai Formation are listed under "Uranium Occurrences in Diatremes and Pipes, Table L."

No.	Name	Location	Geology and Mineralization	Notes	References
	Kaibab Limestone--Permian				
S4.	Anita Copper deposit	Approx. SE. 1/4, T. 29 N., R. 1 E. Coconino Co.	Very weak radioactivity noted with copper carbonate mineralization disseminated in sandstone and limestone and concentrated on joints in Kaibab Limestone.	Old copper workings.	Gibson, 1951, AEC PRR RG-34.
S5.	Copper #1 and Willaha group	Secs. 34, 35, T. 28 N., R. 1 E. Coconino Co.	Radioactivity up to 10X background in two foot zone in and below copper oxide mineralization in bedded Kaibab Limestone.	Old copper workings.	Rambosek and Weathers, 1953, AEC PRR A-P-41.

NOTE: Other old copper oxide and carbonate prospects and mines in Kaibab Limestone show very weak radioactivity but no uranium minerals have been identified.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	Coconino Sandstone--Permian				
S6.	Saucer No. 1	Reportedly in T. 34 N., R. 4 E. (Protracted) Indefinite. Coconino Co.	Radioactivity 10-100X background, possibly uraninite, found with malachite impregnating sandstone bedding in Coconino Sandstone at contact with Hermit Shale.	No workings.	Petersen, 1955, USGS-AEC PRR-1378.
	Moenkopi Formation--Triassic				
S7.	Katy J. claims	Approx. SW. 1/4 Sec. 14, T. 39 N., R. 4 W. Mohave Co.	Uranium mineralization (0.016 to 0.224 eU percent), possibly torbernite, occurs with copper carbonate and carbonaceous trash in eight inch friable, white to tan, medium-grained sandstone between red sandy shale.	Prospected.	Holen and Twitchell, 1955, AEC PRR R-R-286.
S8.	Little Three #1	Reportedly Sec. 6, T. 39 N., R. 3 W. Mohave Co.	Radioactivity 50-100X background found associated with stringers and pockets of carbonaceous trash and fair copper showing in brown medium- to fine-grained sandstone and shale in lower part of Moenkopi.	Prospected.	Scott and Twitchell, 1954, AEC PRR R-R-205.
	Navajo Sandstone--Jurassic and Jurassic(?)				
S9.	White Mesa Copper (Arizona claim)	Approx. S. center Sec. 5, T. 37 N., R. 9 E. (Protracted). Coconino Co.	Generally weak uranium mineralization (torbernite) associated with oxidized copper mineralization in white to gray, crossbedded sandstone.	Old copper mines.	Gibson, 1951, AEC PRR RG-35-51.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
	Toreva Formation--Cretaceous				
S10.	Yale Point claims (Hillside No. 1, Rough Rock group, Dan Taylor No. 1)	Approx. Sec. 11, T. 34 N., R. 23 E. (Protracted) Apache Co.	Light gray, quartzose, fine-grained, well sorted and sometimes cross-bedded sandstone above carbonaceous seam just below middle member. Disseminated or small pods of carnotite or tyuyamunite, one to two feet thick and 30-35 feet long along rim. Grab samples showed 0.01 to 0.38 percent U_3O_8, and 0.08 to 0.84 percent V_2O_5 as coating on sand grains.	Prospected and possibly some minor production.	Gray, 1955, AEC PRR ED:R-551. Clinton, 1956.
S11.	La Gloria Oil & Gas claims	Approx. N. 1/2 Sec. 2, T. 33 N., R. 23 E. (Protracted) Apache Co.	Carnotite coating grains in fine- to coarse-grained quartzose sandstone interbedded between carbonaceous siltstone just below middle member.	Prospected and probably some minor production.	Clinton, 1956.
S12.	Etsitty No. 1 (M. O. 5)	Approx. Sec. 10, T. 33 N., R. 23 E. (Protracted) Apache Co.	Carnotite or tyuyamunite and rauvite coating grains of tan and light-gray, highly carbonaceous, quartzose sandstone interbedded between carbonaceous siltstones just below middle member. Possible ore zone about 125 feet long by 25 feet wide, elongated to N, and about one foot thick in channels. Average grade below 0.2 percent with some high grade spots. V_2O_5 grade variable but generally less than for U_3O_8.	Some minor production.	Clinton, 1954, AEC PRR ED:R-264. Clinton, 1956. Clinton and Carithers, 1956.
S13.	North Tah Chee Wash	Approx. SW. 1/4 Sec. 18, T. 33 N., R. 23 E. (Protracted) Apache Co.	Unidentified radioactive mineral (carnotite?) in very fine-grained, poorly sorted, lensing and somewhat cross-bedded light-tan to light-gray quartzose sandstone containing ferruginous concretions, rutile, ilmenite and carbonaceous trash, just below middle member.	No production known.	Clinton and Wolfers, 1954, AEC PRR ED:R-1296 and ED:R-1293. Clinton, 1956.
S14.	West Burnt Corn Wash	Approx. W. central Sec. 21, T. 33 N., R. 23 E. (Protracted) Apache Co.	Carnotite or tyuyamunite and minor vanadium minerals coating grains in light-tan to light-gray, fine-grained, well sorted, quartzose sandstone above carbonaceous seam just below middle member.	No production known.	Clinton, 1956.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S15.	M. O. 2	Approx. SW. 1/4 Sec. 20, T. 33 N., R. 23 E. (Protracted) Apache Co.	Carnotite or tyuyamunite coating grains in bands following cross-bedding in light-gray, quartzose fine- to coarse-grained sandstone interbedded between carbonaceous siltstones. Ore zone about 450 feet long by 1.5 feet wide, oriented along bend in paleochannel direction. Grade very variable. Just below middle member.	No production known.	Clinton, 1956. Clinton and Carithers, 1956.
S16.	Ruin Mesa (Charlie James No. 1 and Salina No. 4)	Approx. Sec. 30, T. 33 N., R. 23 E. (Protracted) Apache Co.	Carnotite and tyuyamunite coating quartz grains of light gray, fine- to coarse-carbonaceous quartzose sandstone. Mineralized zone 200 feet long by five feet thick but some parts discontinuous. Four-foot channel sample gave 0.32 percent U_3O_8 and 0.25 percent V_2O_5, 0.8 percent $CaCO_3$ but average grade much lower. Just below middle member.	Some minor production.	Clinton and Wolfers, 1954, AEC PRR ED:R-1289. Clinton, 1956.
S17.	M. O. 28	Approx. central Sec. 25, T. 33 N., R. 22 E. (Protracted) Apache Co.	Carnotite or tyuyamunite coating quartz grains in somewhat discontinuous bands along bedding in light-gray fine- to coarse-grained carbonaceous sandstone. Ore zone about 500 feet long by three feet thick. Just below middle member.	Possibly some minor production.	Clinton, 1956.
S18.	Dry Run Canyon	Approx. E. central Sec. 4 and NW. 1/4 Sec. 3, T. 32 N., R. 23 E. (Protracted) Apache Co.	Carnotite coating grains in spotty bands in light-gray, fine- to coarse-grained, quartzose and carbonaceous sandstone. Ore zones 15 to 50 feet long and 1 to 2 feet thick. Just below middle member.	No production known.	Clinton and Wolfers, 1954, AEC PRR ED:R-1291, 1292, and 1297. Clinton, 1956.
S19.	Alkali Water Gap	Approx. NW. 1/4 Sec. 35, T. 33 N., R. 23 E. and E. center edge Sec. 9, T. 32 N., R. 23 E. (Protracted) Apache Co.	Carnotite replacing cement and coating grains along cross-bedding in light-gray, quartzose fine- to coarse-grained carbonaceous sandstone interbedded between carbonaceous strata. Possibly some vanadium mineralization also. Mineralized bodies 10-100 feet long and 1-2 feet thick. Just below middle member.	No production known.	Clinton, 1956.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S20.	Polacca Wash	Approx. W. central edge and SE. corner Sec. 20, T. 33 N., R. 22 E. (Protracted) Apache and Navajo Cos.	Relatively weak carnotite paint on fractures, disseminated in thin bands, and replacement of cement in light-gray, quartzose, fine- to coarse-grained carbonaceous sandstone. Spotty values. Low tonnage and grade. Mineralized bodies 30 to 50 feet long and 2-3 feet thick. Just below middle member.	No production known.	Clinton, 1956.
	Tertiary Formations				
S21.	Dreamer group	Probably in SE. 1/4 Sec. 21, T. 40 N., R. 16 W. Mohave Co.	Yellow uranium mineral, carnotite-type, on fractures in Tertiary sandstone. Radioactivity as high as 5X background.	Prospected.	King, 1955, AEC PRR R-R-285.
S22.	Wharton property	Probably central Sec. 22, T. 40 N., R. 16 E. Mohave Co.	Yellow uranium mineral, carnotite-type(?), with gypsum and manganese oxide coating fractures in Tertiary clay, silt, and sandstone (Muddy Creek Formation?). Sediments flat-lying and well sorted. Radioactivity up to 10X background. Sample ran 0.02 percent eU_3O_8.	Prospected.	Olsen and Papulak, 1955, AEC PRR SL-200.
S23.	Kissee-Mitchell lease	Probably SE. 1/4 Sec. 23, T. 30 N., R. 18 W. (Protracted) Mohave Co.	Minor amounts of carnotite-type mineral and uranium-bearing fluorescent silica associated with iron staining in softer marly zone between resistant limestone beds. Sediments are Tertiary in age overlying granitic schist. One foot vertical chip sample ran 0.02 percent eU_3O_8 and select sample, 0.22 percent eU_3O_8.	Prospected.	Ashwill, 1957, AEC PRR A-116.
S24.	Lucky 44	Approx. NE. 1/4 Sec. 18, T. 30 N., R. 20 W. (Protracted) Mohave Co.	Carnotite-type mineral or uranophane as surface coatings on bedding planes or in sandy pockets in Tertiary lucustrine interbedded bentonitic clay, bentonitic siltstone, opalitic silica, and fluviatile sandy conglomerate. Abundant gypsum and calcium carbonate. Up to 10X background radioactivity over mineralized coatings on altered volcanics.	Prospected.	Henderson, 1955, AEC PRR C-23.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S25.	Cisco	Approx. SW. 1/4 Sec. 23, T. 30 N., R. 20 W. (Protracted) Mohave Co.	Carnotite-like mineral in small scattered pockets in opalized zones of white, friable tuffaceous limestone of Tertiary age. Select sample ran 0.348 percent eU_3O_8.	Prospected.	Richards, 1956, AEC PRR C-96.
S26.	Dab No. 1 and Dreamer	Approx. E. center Sec. 21, and SW. 1/4 Sec. 22, T. 30 N., R. 20 W. (Protracted) Mohave Co.	Thin smears of carnotite-type and autunite(?) mineralization in Tertiary mudstone interbedded with tuff and clay. Dab No. 1 samples ran 0.383 and 0.878 percent U_3O_8; at Dreamer, 0.024 percent but mineralization generally weak and spotty.	Adit and dozer cuts.	Barrett, 1955; Richards, 1956, AEC PRR N-SL-275.
S27.	Catherine and Michaels	Probably NE. 1/4 Sec. 21, T. 16 1/2 N., R. 12 W. Mohave Co.	Uraniferous milky-white to greenish uraniferous opal with irregular patchy manganese oxide in local replacement layer in thinly laminated, poorly consolidated limestone unit of tilted Tertiary sedimentary series overlying Precambrian granite. Channel samples ran 0.005 to 0.013 percent U. Specimen ran 0.2 percent U.	Prospected.	Granger, 1951, AEC PRR USGS. Granger and Raup, 1962.
S28.	Candy Bar group	Probably N. 1/2, T. 12 N., R. 13 W. Location indefinite. Mohave Co.	Unidentified uranium mineralization in Tertiary (Artillery Formation, Eocene) in 3 to 5 foot beds of mudstone and sandstone overlain by red volcanic flows and underlain by red conglomerate. Chip samples ran 0.05 and 0.07 percent eU_3O_8.	Prospected.	Robison, 1956, AEC PRR A-81.
S29.	Lucky Four	Probably NE. 1/4 Sec. 36, T. 12 N., R. 13 W. Mohave Co.	Coatings of tyuyamunite or carnotite on fractures in siliceous material and limestone in five foot carbonaceous bed in Tertiary (Artillery Formation, Eocene) mudstone-limestone series beneath thrust sheet of gneiss.	Prospected.	Robison, 1956, AEC PRR A-82.
S30.	Masterson group	Central Sec. 22, T. 12 N., R. 13 W. Mohave Co.	Unidentified uranium mineral associated with carbonaceous trash and palm-like vegetal matter in Eocene Artillery Formation limestone and mudstone about 100 feet above Precambrian granite.	Prospected.	Reyner and Robison, 1956, AEC PRR A-88.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S31.	Red Hills (Tate)	West central Sec. 7, T. 11 N., R. 13 W. Mohave Co.	Secondary yellow and orange uranium minerals associated with some copper oxides coating fractures in shattered and brecciated chalcedonic quartz, barite, fluorite and copper oxide vein in fault or sedimentary breccia at base of Artillery Formation (Eocene). Breccia consists of fragments of schist, felsite, conglomerate and limestone cemented by silica, carbonate and manganese oxide; part of thrust sheet. Radioactivity strongest at intersections of crosscutting shear zones and vein. Channel samples in shaft averaged 0.06 percent U_3O_8 over 10 foot wide. Select samples ran up to 0.314 percent U_3O_8. Origin believed to be due to groundwater deposition.	Shallow shaft and surface cuts.	Hart, 1955. Granger and Raup, 1962.
S32.	Pretty Folly (Smokie #1, Hudson)	Approx. Sec. 35, T. 17 N., R. 3 E. (Unsurveyed) Yavapai Co.	Very thin coating of carnotite-type mineralization on fractures in white tuffaceous strata of Verde Formation (Pleistocene or Pliocene?) lake beds. Radioactivity 7X background. Select sample from stockpile ran 0.02 percent eU_3O_8.	Prospected.	Robison, 1955, AEC PRR A-56.
S33.	Uranium Aire group (Anderson mine et alia)	Secs. 9, 10 and 11, T. 11 N., R. 10 W. Yavapai Co.	Carnotite in two carbonaceous layers, 85 feet apart and about 2 1/2 feet thick in mudstone-limestone unit in Tertiary lake bed sediments interbedded with minor conglomerate and ash beds. Considerable faulting and minor folding. Palm-type wood fragments opalized, carbonized and replaced by chalcedony. Abundant limonite and hematite. Some secondary enrichment. V to U ratios vary from 1:1 to 1:2.4 for 0.11 and 0.64 percent U_3O_8 respectively.	Few small shipments. Considerable exploration.	Reyner and others, 1956.
S34.	Dizzy Lizy	Approx. Sec. 28, T. 7 S., R. 18 W. (Unsurveyed) Yuma Co.	Unidentified uranium mineralization in 4 foot tuffaceous bed in Tertiary sedimentary-volcanic series. Radioactivity up to 25X background. Select sample ran 0.08 percent eU_3O_8.	Prospected.	Robison, 1955, AEC PRR A-46.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S35.	Wooley group	Approx. Sec. 32, T. 7 S., R. 18 W. (Unsurveyed) Yuma Co.	Uranophane and autunite as fracture coatings in quartz veins cutting brown sandstone and in basic flow rocks of series of Tertiary sandstones and mudstones with intercalated sills and flows. Radioactivity about 100X background. Select sample ran 0.455 percent U_3O_8. Average grade much lower.	Prospected.	Reyner and Ashwill, 1955, AEC PRR A-P-300.
S36.	Lake Bed claim	Approx. Sec. 2, T. 8 S., R. 19 W. (Unsurveyed) Yuma Co.	Uranophane, pyromorphite(?) and chalcedony in Tertiary volcanic tuffs covered by sandstone. Radioactivity about 30X background.	Prospected.	Rambosek and King, 1952, AEC PRR A-R-34.
S37.	Red Knob claims	Approx. Sec. 10, T. 8 S., R. 19 W. (Unsurveyed) Yuma Co.	Carnotite or tyuyamunite, weeksite, uranophane(?) vanadinite(?), calcite and gypsum in weakly mineralized zone of high grade pockets about 1-3 feet thick and at least 100 feet long by 10 feet wide in Tertiary opalized mudstone in lake bed sequence of volcanics, mudstones and sandstones with minor layers of chalcedony and opal. Strong silicification. Radioactivity averages 5-10X background with maximum of 100X background.	Prospected and some uranium mineralization stockpiled.	Reyner and Ashwill, 1955, AEC PRR A-P-302.
S38.	Isley-Lillard claims	Approx. common corner area of Secs. 6, 7, T. 8 S., R. 18 W. and Secs. 1, 12, T. 8 S., R. 19 W. Yuma Co.	Unidentified uranium, mainly in opalitic and chalcedonic white ash layers in shaly beds in Tertiary lake bed shales, sandstones and volcanics. Radioactivity about 6X background.	Prospected.	Reyner and Sayre, 1955, AEC PRR A-P-389.
S39.	St. Louis group	Approx. Sec. 35, T. 7 S., R. 19 W. (Unsurveyed) Yuma Co.	Uranophane(?) in shale strata of Tertiary lake beds consisting of sandstone, mudstone, shale and ash beds. Select samples up to 1.79 percent eU_3O_8.	Prospected.	Ashwill and Sayre, 1955, AEC PRR A-P-390.
S40.	Misc. Muggins Mts. Prospects (Bonnie, Marvin, Jap, William, HWWR, "B" # 1, 2, and 3)	Approx. Sec. 2, 12, T. 8 S., R. 19 W. Yuma Co.	Uranophane(?) in shaly mudstone strata of Tertiary series of lake bed sediments. Radioactivity 6-7X background. Select samples ran 0.05 and 0.24 percent eU_3O_8.	Prospected.	Ashwill and Sayre, 1955, AEC PRR A-P-390.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S41.	Golden Duck group	East center Sec. 19, T. 7 N., R. 2 W. Maricopa Co.	Torbernite and schroekingerite in rhyolite tuff member of Tertiary volcanic series of pyroclastics and flows with basal arkose conglomerate covering Precambrian complex. Some mineralization on shear fractures. Sooty material and chrysocolla, iron oxides and secondary quartz noted. 1 1/2 foot vertical chip sample ran 0.10 percent U_3O_8, select sample 0.57 percent U_3O_8.	Shafts and adits (200 feet plus development on eight claims).	Ashwill and Miller, 1955-1956, AEC PRR A-77. Finch, 1967.
S42.	Vulture Mts.-Black Butte (Milton Ray group, Jar, Black Butte Uranium, Aguila)	SE. 1/4 Sec. 14, SW. 1/4 Sec. 13 and NE. 1/4 Sec. 24, T. 6 N., R. 8 W.; NW. 1/4 Sec. 19 and NW. 1/4 Sec. 20, T. 6 N., R. 7 W. Maricopa Co.	Carnotite occurs along bedding planes and on fractures in shaly beds of buff to white limy bentonitic tuff, 100 to 200 foot thick, capped by lava flows. Tuffs are part of shales, marls, and limestone Tertiary lake beds. Gypsum and chalcedony seams and stringers. Very low grade, seldom more than 0.01 percent U_3O_8.	Prospect pits and trenches.	Hewett, 1925. Granger and Raup, 1962. Putluck and Wells, 1953, AEC PRR A-P-83. Ashwill, 1955, AEC PRR A-P-342, 343.
S43.	Los Cuatros group	Approx. SE. 1/4 T. 6 N., R. 3 E. Maricopa Co.	Unidentified uranium mineral in two foot, thin crenulated volcanic ash bed below silicified volcanic ash of Tertiary age. Reported average grade of 0.03 percent U_3O_8 with select material up to 0.06 percent U_3O_8.	Prospected by drilling.	Miller, 1956, AEC PRR A-76.
S44.	Duke, White and Hyder claims	Approx. Sec. 36, T. 2 S., R. 10 W. (Unsurveyed) Maricopa Co.	Unidentified uranium mineralization in Tertiary shale or mudstone in lake bed type sediments capped by tuff and volcanics and intruded by dikes. Abundant iron oxides and silicification. Radioactivity about 4X background and samples indicate about 0.01 percent eU_3O_8.	Discovery shaft and drill holes.	Ashwill, 1955, AEC PRR A-P-382.
S45.	White Bluffs Uranium area	Secs. 21, 22, 27 and 28, T. 8 S., R. 28 E. Graham Co.	Uranophane as coatings along bedding planes and on fractures of light-gray siliceous lake beds associated with interbedded diatomaceous earth, bentonitic clay and evaporites of Tertiary-Quaternary Gila Group. Some bleaching. Select samples ran 0.08 percent eU_3O_8.	Prospected.	Mace, 1955, AEC PRR A-P-330.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S46.	Flat Tire group	SE. 1/4 Sec. 9, T. 8 S., R. 28 E. Graham Co.	Carnotite-type mineral coating fractures in 12-15 foot bed of hard greenish-brown clay of Tertiary-Quaternary Gila Group. Select samples ran as high as 1.38 percent eU_3O_8.	Shallow shaft.	Robison, 1955, AEC PRR A-P-381.
S47.	Last Chance group	SE. 1/4 Sec. 21, T. 8 S., R. 28 E. Graham Co.	Carnotite-type mineral as thin coatings in opalized seam in bedded clay and tuff of Gila Group. Low grade values, 0.01-0.02 percent eU_3O_8.	Location work.	Robison, 1955, AEC PRR A-P-379.
S48.	Pluto group	SW. 1/4 Sec. 22, T. 8 S., R. 28 E. Graham Co.	Unidentified uranium mineral in lake bed, interbedded clays and tuff of Gila Group. Select sample ran 0.01 percent eU_3O_8.	Dozer cut.	Robison, 1955, AEC PRR A-P-378.
S49.	Royal John	South central Sec. 22, T. 8 S., R. 28 E. Graham Co.	Carnotite-type mineral in bedded tuffs and clays of lake bed sediments of Gila Group. Select sample ran 0.01 percent eU_3O_8.	Dozer cuts and pit.	Robison, 1955, AEC PRR A-P-376.
S50.	Canuk group	Probably SE. 1/4 Sec. 23, T. 8 S., R. 28 E. Graham Co.	Carnotite-type mineral as coating on fractures in opalized beds in lake bed sediments, tuffs, and gravels of Gila Group. Samples ran from 0.01 to 0.07 percent eU_3O_8.	Prospect pits.	Robison, 1955, AEC PRR A-P-375.
S51.	Christmas claims	NE. 1/4 Sec. 28, T. 11 S., R. 18 E. Pima Co.	Unidentified uranium mineral associated with chalcedony and calcite coatings in vugs in volcanic glass in recent lake beds of loosely consolidated sand and gravel and thin beds of tuff and volcanic flow rocks. Horizontal chip sample ran 0.015 percent eU_3O_8.	Prospect pit.	Robison, 1955, AEC PRR A-P-282.
S52.	Half Moon No. 3	West center Sec. 22, T. 11 S., R. 13 E. Pima Co.	Uraniferous opal in 8 feet of reddish brown opalite covered by horizontal, loosely consolidated lake bed muds and clays, gravels and cobbles. Chip sample ran 0.051 percent eU_3O_8 and select sample 0.074 percent eU_3O_8.	Dozer cut.	Robison, 1955, AEC PRR A-P-315.
S53.	Dutchess claim	Approx. NE. 1/4 Sec. 17, T. 15 S., R. 13 E. Pima Co.	Uranophane and gypsum in 1-2 foot zone in silty limestone beds. Cut samples ran 0.05-0.06 percent eU_3O_8.	Pit and wagon drill holes.	Miller, 1955, AEC PRR A-65.

Table K. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
S54.	Red Hills claim	NW. 1/4 Sec. 5, NE. 1/4 Sec. 6, T. 16 S., R. 17 E. Pima Co.	Uranophane in highly silicified, brecciated, quartz pebble conglomerate, probably Tertiary sediments. Chip sample from pit ran 0.136 percent eU_3O_8; grab sample from bottom ran 0.060 percent eU_3O_8 and select sample 0.381 percent eU_3O_8.	Prospect pits.	Robison, 1955, AEC PRR A-P-314.
S55.	Duranium claims	SW. corner Sec. 20, T. 20 S., R. 14 E. Santa Cruz Co.	Kasolite, uranophane and autunite in an altered arkosic sandstone within a conglomerate, probably Cretaceous. Ore zone 100 feet long by 12 feet wide by 4 feet thick. Grab samples ran from 0.054 to 0.792 percent eU_3O_8 and select sample 2.378 percent eU_3O_8.	Prospect pit.	Robison, 1954, AEC PRR A-P-285.
S56.	Santa Clara claim	NE. corner Sec. 6, T. 23 S., R. 11 E. Santa Cruz Co.	Sooty uraninite in highly fractured and faulted, steeply dipping sandstones and conglomerates, probably Cretaceous. Chip samples ran 0.026 and 0.078 eU_3O_8, grab samples ran 0.028 and 0.153 percent eU_3O_8.	Prospect pit and trench.	Robison, 1955, AEC PRR A-P-293.
S57.	Inez Ellen claims	Approx. Sec. 8, T. 14 S., R. 21 E. Cochise Co.	Radioactivity in 2 to 20 foot beds of friable sandstone, mudstone and quartzite, possibly Quaternary-Tertiary sediments of Gila Group. No visible uranium minerals. Samples ran 0.19 and 0.26 percent U_3O_8.	Shaft and drift.	Miller, 1957, AEC PRR A-114.

Table L. — Uranium occurrences in diatremes and pipes.

Numbers correspond with the occurrence numbers on Plate 18.

No.	Name	Location	Geology and Mineralization	Notes	References
P1.	Garnet Ridge (Keith Francis claim)	East center Sec. 29, T. 41 N., R. 24 E. (Protracted) Apache Co.	Relatively weak and sparsely disseminated tyuyamunite and possibly other uranium minerals in friable and bleached Navajo sandstone along walls of serpentine rubble pipes. Diatreme type. Selected samples ran up to over two percent U_3O_8 but occurrence small and average is low grade.	Drilled but no commercial production known.	Malde and Thaden, 1963. Shoemaker, 1956.
P2.	Hopi Buttes area	Scattered over an area of approximately 875 square miles at SE. corner of Hopi Indian Reservation and within adjoining Navajo Reservation.	Uranium mineralization localized in and adjacent to diatremes of Pliocene age in Bidahochi Formation. Sediments in diatremes consist of bedded tuff, limestone, clay, silt, evaporites and chert. Disseminated, extremely fine uranium widespread in limestone and often concentrated in laminated siltstone and shale. Grade of uranium usually below 0.01 percent but some local occurrences may approach 0.2 percent.	Most occurrences tested but only one, Morales claim, produced a few tens of tons averaging about 0.17 percent U.	Shoemaker, 1956.
	(a) Sun No. 14 claim	Approx. Sec. 32, T. 23 N., R. 21 E. (Unsurveyed) Navajo Co.			
	(b) Bidahochi Butte	Approx. SE. corner Sec. 12, T. 23 N., R. 21 E. (Protracted) Navajo Co.			
	(c) Morales claim	Approx. SW. 1/4 Sec. 30, T. 25 N., R. 23 E. (Protracted) Navajo Co.			
P3.	Grandview mine	NE. 1/4 Sec. 5, T. 30 N., R. 4 E. (Protracted) Coconino Co.	Undetermined uranium mineral associated with limonite; copper carbonates, silicates and sulfides; and pyrite in brecciated, bleached and partially marmorized Redwall Limestone in pipe-like body. Weak to moderate radioactivity.	Last worked in early 1900's.	Marvin, 1951, AEC PRR RG-33.
P4.	Copper House Colition Nos. 1 and 2	Approx. Secs. 1 and 2, T. 32 N., R. 11 W. Mohave Co.	Unidentified uranium mineralization associated with copper mineralization in curving or circular brecciated zones in bleached and fractured, coarse sediments of the Supai Formation. Assay results showed 0.006 to 0.165 percent U_3O_8.	Prospected for copper and uranium but no production noted.	Meehan, 1953, AEC PRR R-R-135, 136. Finch, 1967.

Table L. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
P5.	Orphan mine	SW. 1/4 Sec. 14, T. 31 N., R. 2 E. Coconino Co.	Uraninite and secondary uranium minerals in a nearly vertical, circular, pipe-like body of collapse breccia. The breccia consists mostly of highly fractured Coconino Sandstone and Hermit Shale dropped into the collapse structure. Strong bleaching and alteration. Mineralization, strongest around the periphery, consisting of disseminations and vein-like stringers of uraninite in association with sulfides of iron, copper, lead, zinc, cobalt and molybdenite. Pipe increases somewhat in size downward from 175 to 450 feet in diameter. Ore is high grade, average samples running up to over 1.0 percent U_3O_8.	A major producer in Arizona, supplying close to 500,000 tons of ore averaging 0.30 to 0.60 percent U_3O_8. Probably contains at least 100,000 tons of additional ore of about 0.30 percent U_3O_8.	Granger and Raup, 1962. AEC Guidebook, 1959. Finch, 1967.
P6.	Ridenour mine	NE. 1/4 Sec. 6, T. 31 N., R. 8 W. Coconino Co.	Carnotite-type mineralization associated with copper carbonates, silicates and sulfides along with pyrite and iron oxides in an inferred pipe-like body of fractured and bleached, collapsed Supai Formation sediments. Mineralization is both disseminated and in vein-like structures, strongest along the periphery. Samples ran from trace to almost 0.5 percent U_3O_8. Vanadium to uranium ratio greater than 10:1 and vanadium minerals widely distributed. Traces of cobalt also detected.	Originally mined for copper. Some production shipped and a small resource may remain.	Miller, 1954, AEC RME-2014. Finch, 1967.
P7.	Hack Canyon mine	NE. 1/4 Sec. 26, T. 31 N., R. 5 W. Mohave Co.	Uraninite and secondary uranium minerals associated with primary and secondary copper minerals in brecciated Hermit Shale in throat of apparent pipe-like body of collapse breccia. Uranium values probably average 0.1 to 0.2 percent U.	Originally mined for copper and some minor uranium ore production. There are possibilities of some additional ore.	Granger and Raup, 1962. Finch, 1967.
P8.	Copper Mountain mine	SW. 1/4 Sec. 14, T. 32 N., R. 10 W. Mohave Co.	Probably uraninite and secondary uranium minerals associated with copper, zinc and lead minerals in brecciated fine-grained sandstone of Supai Formation on periphyry of pipe-like body of collapse structure. Samples ran from 0.013 to 0.75 percent eU_3O_8.	Worked originally for copper. No uranium production reported.	King and Henderson, 1953, AEC PRR A-P-99. Finch, 1967.

Table M. — Uranium occurrences in the Dripping Spring Quartzite.

Numbers correspond with the occurrence numbers on Plate 19.

No.	Name	Location	Geology and Mineralization	Notes	References
1.	Able occurrence	Approx. Sec. 1, T. 8 N., R. 12 E. Gila Co. In upper Spring Creek.	Probably in upper member. No diabase noted close-by and no uranium minerals recognized. Maximum radioactivity 22X background. High grade chip sample ran 0.35 percent eU_3O_8. Chip sample of two foot bed ran 0.03 percent eU_3O_8. Probably only secondary uranium mineralization.	No production. No resources estimated.	Schwartz, 1955, AEC PRR A-P-351.
2.	Alta Vista group (Little Sis No. 1 et alia, Irish Barco)	Secs. 4, 5, 8 and 9, T. 4 N., R. 14 E. (Protracted) In short, deep, SW. trending canyons draining mesas to N. and E.	Probably in flat-lying black facies overlying barren quartzite. No apparent nearby diabase but faulting to E. Anomalous radioactivity related to limonite-stained fractures with copper carbonates. No uranium minerals recognized. Radioactivity moderately high and selected Cu-stained sample ran 0.056 percent eU_3O_8.	Ditto	Schwartz, 1954, AEC PRR A-P-250. Granger and Raup, 1969b, p. 6.
3.	Andy Gump deposit	NE. 1/4 Sec. 34, T. 7 N., R. 14 E. (Protracted) On E. wall of Cherry Creek Canyon about 0.7 miles S. of China Spring Creek.	In fine-grained black facies about 12 feet above barren quartzite. Diabase dike along fault to S. Moderately strong radioactivity in two foot thick strata along vein-like zone cut by limonite-filled joints. Minor metatorbernite, sparse disseminated pyrite and efflorescent white sulfate. Selected samples ran 0.17, 0.13, and 0.72 percent U_3O_8.	No production and resources doubtful.	Ashwill and Schwartz, 1954, AEC PRR A-P-239. Granger and Raup, 1969b, p. 6.
4.	Big Buck group (Cyprus, Snow White, Bear Track)	South central Sec. 25, T. 6 N., R. 14 E. On rugged W. wall of Cherry Creek about 1/2 mile S. of Gold Spring Canyon. Elev. 4,400 feet.	In very fine-grained black facies about 20 feet above barren quartzite. Strong diabase dikes to SE. and W. along edge of Sierra Ancha diabase sheet and close to Cherry Creek monocline. Vein-like along limonite-filled fractures. No visible uranium minerals. Pyrite and minor calcite and fluorite. Relatively high radioactivity in vein zone.	Two shipments: -22.5 tons of 0.19 percent U_3O_8 (Late 1956) -179.03 tons of 0.14 percent U_3O_8 (4/57) Limited resources.	Schwartz, 1955, AEC PRR A-61. Granger and Raup, 1969a, Fig. 21. Granger and Raup, 1969b, p. 8.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
5.	Big Six group (Citation Nos. 1 thru 5, Sorrel Horse Nos. 1 and 2)	West 1/2 Sec. 4, T. 6 N., R. 14 E. On W. wall of Cherry Creek Canyon at about 5,500 foot elevation.	In gray facies about 35-70 feet below barren quartzite and 10-35 feet above Sierra Ancha diabase sheet. Partly altered to hornfels with aplite stringers. Spotty radioactivity and uranium mineralization associated with minor limonite. Weak fine-grained sulfides. Selected high grade sample ran 2.36 percent U_3O_8 but average samples ran no higher than 0.16 percent U_3O_8.	No production noted. May be a few hundred tons of low grade material present.	Granger and Raup, 1969b, p. 10.
6.	Black Brush group (10 claims)	SE. 1/4 Sec. 4, T. 6 N., R. 14 E. On S. slope of ridge between NE. trending canyons tributary to Cherry Creek, at about 5,600 foot elevation.	At intersection of fracture zone with black facies immediately overlying barren quartzite. Sierra Ancha diabase sheet 80 feet below. Close to Cherry Creek monocline. Irregular radioactivity. Primary uraninite associated with minor pyrrhotite, chalcopyrite, marcasite, galena and pyrite. More sulfides in barren quartzite. Torbernite near surface. Select samples ran greater than 1.5 percent U_3O_8 but average over one foot width was less than 0.1 percent U_3O_8.	Two shipments: -7.94 tons of 0.11 percent U_3O_8 (Late 1955) -11.23 tons of 0.07 percent U_3O_8 (mid 1956) May be a few hundred tons of very low grade material.	Schwartz, 1955, AEC PRR A-P-310. Granger and Raup, 1969a, Fig. 40. Granger and Raup, 1969b, p. 12.
7.	Black Diamond group	NE. 1/4 Sec. 32, T. 5 N., R. 14 E. In Red Bluff area at head of box canyon.	In black facies in two foot stratum about 60 feet above barren quartzite where cut by vertical fractures. Large diabase body to SW. Abnormal radioactivity. Sparse metatorbernite and bassetite, minor pyrite, abundant limonite, and white fluorescent sulfate.	No production known. No resources estimated.	Schwartz and Robison, 1955, AEC PRR A-P-337. Granger and Raup, 1969b, p. 15.
8.	Blevins Canyon deposit (36+ claims)	NE. 1/4 Sec. 1, T. 6 N., R. 12 E. (Protracted) On N. wall of Dupont (Blevins) Canyon at about 5,500 foot elevation.	Bedded deposit in fine-grained arkosic sandstone of upper member in paleochannel cut in middle member. Probably discordant diabase body eroded away above. Copper-bearing quartz veins to N. Abnormal radioactivity over 15 foot of strata for 200 feet along canyon wall but only metatorbernite recognized. Abundant copper and limonite staining. Selected sample ran 0.351 percent eU_3O_8. Three foot vertical cut sample ran 0.032 percent eU_3O_8.	Ditto	Schwartz, 1954, AEC PRR A-P-257. Granger and Raup, 1969b, p. 16.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
9.	Blue Eagle deposit	NE. 1/4 Sec. 10, T. 6 N., R. 14 E. On steep wall of canyon on W. side of Cherry Creek.	Probably in black facies in silty strata well above any known diabase. Radioactive zone inches to one foot thick and up to 60 feet long. No uranium minerals recognized but sulfides present. Select sample ran 0.92 percent eU_3O_8. One foot channel sample ran 0.28 percent eU_3O_8.	No production known. May be a few tons of low grade material.	Schwartz, 1956, AEC PRR A-105.
10.	Blue Rock deposit (Devil's Chasm claim group)	NE. 1/4 Sec. 36, T. 6 N., R. 14 E. On E. face of Cherry Creek Canyon at about 4,500 foot elevation.	Vein-type on fractures, joints and bedding planes in slightly metamorphosed black facies 25-68 feet above barren quartzite. Diabase bodies to W. and possibly formerly to E. Bassetite, metatorbernite, gypsum and white fluorescent sulfate. Moderate to strong radioactivity.	No production known. No resources estimated.	Granger and Raup, 1969b, p. 19.
11.	Brushy Basin Trap deposits (Bobcat et alia)	NW. 1/4 Sec. 27, T. 7 N., R. 14 E. (Protracted) At bottom of PB Creek about 600 feet upstream from Cherry Creek.	Probably in upper 50 feet of black facies with alternating dark and light gray siltstone and laminae of pink sandstone. Nearest diabase to ESE. Weak and irregular uranium mineralization with irregular fracturing. Disseminated pyrite, metatorbernite, kaolin, limonite and sulfates. Minor bassetite, saleeite and nontronite. Irregular moderate radioactivity. Samples ran 0.01-0.17 percent eU_3O_8.	Ditto	Kinneson and Fink, 1955, AEC PRR A-P-366. Granger and Raup, 1969b, p. 22.
12.	Cataract deposit (7 claims)	SW. 1/4 Sec. 19, T. 7 N., R. 13 E. (Protracted) On southward projecting nose of Middle Mountain on N. slope of Cataract Canyon at about 5,600 foot elevation.	Apparently a bedded deposit in lower part of upper member in shallow channel cut in middle member. No diabase close-by. Weakly disseminated pyrite and chalcopyrite with fracture coatings of limonite, clay, metatorbernite, malachite and chrysocolla. Irregular radioactivity. Selected samples ran 0.18 to 0.21 percent eU_3O_8.	Ditto	Schwartz, 1955, AEC PRR A-P-353. Granger and Raup, 1969b, p. 24.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
13.	Conway deposit	South central Sec. 34, T. 7 N., R. 12 E. (Protracted) On bench between Malicious Gap and Mud Spring Canyon on SW. slope of Copper Mountain.	In upper member. Diabase may underlie deposit. Cut by copper-bearing quartz vein. Autunite, metatorbernite, and disseminated sulfides. Radioactivity about 26X background. Chip samples ran 0.30 and 0.66 percent eU_3O_8.	Ditto	Schwartz and Kinneson, 1956, AEC PRR A-92.
14.	Devil's Charm deposits (May be same as Blue Rock deposit)	South central Sec. 36, T. 6 N., R. 14 E. (Protracted) In Devil's Chasm and on steep walls W. of Cherry Creek.	Along fracturing in upper member. Diabase below and in nearby dikes. Some disseminated pyrite and other sulfides. Sparse metatorbernite. Radioactivity up to over 100X background. Samples ran 0.06-0.22 percent eU_3O_8.	Ditto	Schwartz, 1956, AEC PRR A-106.
15.	Donna Lee deposits (15 claims)	SE. 1/4 Sec. 13, T. 5 N., R. 14 E. On W. wall of Deep Creek Canyon at about 4,800 foot elevation.	In strongly weathered and oxidized black facies 10-15 feet above barren quartzite. Major fault to W. Diabase sills in Pioneer Formation below and dike in fault. Irregular vein-type mineralization--pyrite, limonite, secondary copper minerals, gypsum and sulfate. Metatorbernite only uranium mineral noted. Relatively strong radioactivity. Chip and grab samples ran 0.24-0.29 percent eU_3O_8.	No production reported. Possibly about 100 tons of low to moderate grade material.	Schwartz, 1954, AEC PRR A-P-262. Schwartz, 1955, AEC PRR A-6. Granger and Raup, 1969b, p. 27, Fig. 2.
16.	Easy deposit (12 claims)	SE. 1/4 Sec. 35, T. 7 N., R. 13 E. (Protracted) On SW. slope of McFadden Peak about 1 1/4 miles WSW. of Lookout Tower at 6,100 foot elevation.	Bedded-type deposit in lower part of upper member immediately above contact with middle member. No nearby diabase known. Sparse and irregular abnormal radioactivity. Finely disseminated pyrite and chalcopyrite. Metatorbernite, uraniferous opal, saleeite, bassetite, metazeunerite, covellite and limonite. Select samples ran 0.42 percent eU_3O_8. Cut and grab samples ran 0.02-0.08 percent eU_3O_8.	No production reported. No resources estimated.	Granger and Raup, 1969b, p. 30.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
17.	Fairview deposit (16 claims)	South central Sec. 12, T. 6 N., R. 12 E. (Protracted) On SW. slope near top of SSE. trending ridge extending from Greenback Peak (Lookout Mt.) at about 5,600 foot elevation.	Three bedded-type deposits, one to two foot thick, in upper member some 60-70 feet above contact with middle member. Diabase above and to NE. Strong fracturing and jointing. Abundant limonite. Metatorbernite, bassetite, uraniferous hyalite, and uranophane. Irregular radioactivity. Grab samples ran 0.56 percent and 0.08 percent eU_3O_8. Chip samples ran 0.18 percent eU_3O_8.	Ditto	Schwartz, 1955, AEC PRR A-P-336. Granger and Raup, 1969b, p. 32.
18.	First Chance deposits (11 claims)	SE. 1/4 Sec. 1, T. 5 N., R. 13 E. About 0.4 miles N. of Parker Creek Experimental Station at about 5,600 foot elevation.	Vein-type deposits along fractures in black facies about 10-13 feet above barren quartzite. Complex structure. Sierra Ancha diabase sheet originally close-by. Disseminated pyrite, chalcopyrite and chalcocite. Metatorbernite, malachite, azurite, bassetite, uraniferous hyalite on fractures. Abundant limonite, chalcanthite and sulfate. Radioactivity weak to moderate. Channel samples ran 0.02 to 0.12 percent U_3O_8.	One shipment: 35.53 tons of 0.08 percent U_3O_8 (2nd Quat. 1957). Possibly 100 tons of low grade material.	Granger and Raup, 1969a, Fig. 26. Granger and Raup, 1969b, p. 35.
19.	Grand Chance, Fringe, Late Comer deposits	SE. 1/4 Sec. 25, T. 7 N., R. 12 E. (Protracted) On E. flowing tributary below Buckaroo Tank.	In upper member. Metatorbernite noted. Radioactivity up to 3X background.	No production reported. No resources estimated.	Ashwill and Schwartz, 1954, AEC PRR A-P-237.
20.	Grand View claims	East center Sec. 18, T. 5 N., R. 14 E. At bottom of NW. trending Pocket Creek about 200 feet downstream from BM 5266.	Associated with fracturing in metamorphosed gray facies below barren quartzite and above Sierra Ancha diabase sheet. Cut by aplitic and pegmatitic dikelets. Moderate radioactivity.	Ditto	Schwartz, 1954, AEC PRR A-P-249. Granger and Raup, 1969b, p. 39.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
21.	Great Gain deposit (Grand Gain, Spring Creek)	South central Sec. 30, T. 7 N., R. 13 E. (Protracted) On nose of irregular ridge projecting E. between tributary stream canyons.	Bedded-type in three foot strata at bottom of middle member. Irregular fracturing. Diabase to S. Metatorbernite, uraniferous hyalite, limonite, meta-autunite on fractures and disseminated. Weak to moderate radioactivity. Samples ran 0.03 to 0.04 percent eU_3O_8. Sample of stockpile ran 0.06 percent eU_3O_8.	Ditto	Granger and Raup, 1969b, p. 40.
22.	Grindstone deposit	North central Sec. 25, T. 6 N., R. 14 E. On W. wall of Cherry Creek Canyon on small bench on N. side of Cold Spring Canyon at about 4,250 foot elevation.	Probably vein-type along fractures in moderately metamorphosed black facies 10 feet above barren quartzite and 10 feet below diabase sill. Diabase dike to NW. Disseminated and fracture filling of pyrite, pyrrhotite and limonitic gouge. Uraniferous hyalite. Moderate radioactivity. Chip sample ran 0.26 percent eU_3O_8.	Ditto	Granger and Raup, 1969b, p. 43.
23.	Hillside deposit	SW. 1/4 Sec. 32, T. 5 N., R. 17 E. Below mesa above Ash Creek.	In upper member, underlain by diabase. Disseminated pyrite, gypsum, calcite and unidentified uranium mineral. Radioactivity about 20X background. Samples ran 0.17-0.268 percent eU_3O_8.	Ditto	Ashwill and Schwartz, 1954, AEC PRR A-P-233.
24.	Hope deposits (16 claims)	NE. 1/4 Sec. 30, T. 6 N., R. 14 E. On steep NE. wall of Workman Creek about 1.5 miles upstream from Globe-Young road.	Vein-type in hornfels of black facies 10-25 feet above barren quartzite. Sierra Ancha diabase sheet cuts host rocks discordantly with associated irregular aplite dikes and sill-like syenite. Contains black deuteric veinlets. Abundant disseminated and veinlets of pyrite and marcasite, pyrrhotite, molybdenite, galena, sphalerite, chalcopyrite, calcite, chlorite, nontronite and disseminated and stringers of uraninite. Oxidized portion shows B-uranophane, metatorbernite, limonite and gypsum. Some fluorite noted.	Most productive deposit. Shipments: 1,380 tons-0.18 percent U_3O_8; 188 tons-0.13 percent U_3O_8; 4,743 tons-0.28 percent U_3O_8; 2,000 tons-0.38 percent U_3O_8. Probably a few thousand tons of low to moderate grade still present.	Schwartz, 1954, AEC PRR A-P-289. Granger and Raup, 1969a, Pl. 3. Granger and Raup, 1969b, p. 44.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
25.	Horse Shoe deposit (Crying Jew et alia)	SW. corner Sec. 11, T. 6 N., R. 14 E. On N. side of Gold Creek about 0.7 miles from Cherry Creek at about 4,300 foot elevation.	Bedded-type in shattered gray facies. Two to eight feet thick. Sierra Ancha diabase sheet above and to W. About 30 feet above contact with middle member. Ample sulfides but no uranium minerals recognized; pyrite, marcasite, chalcopyrite, sphalerite and galena disseminated or in veinlets. Radioactivity about 100X background. Probably disseminated uraninite.	Two shipments: 6.55 tons-0.17 percent U_3O_8; 7.34 tons-0.02 percent U_3O_8. No resources estimated.	Schwartz, 1956, AEC PRR A-102. Granger and Raup, 1969a, Fig. 48. Granger and Raup, 1969b, p. 54.
26.	Hot Spot deposits	West side Sec. 4, 9, T. 6 N., R. 14 E. On steep E. wall of McFadden Horse Mountain.	In upper member. Strong iron oxide and unknown uranium mineral. Maximum radioactivity about 50X background.	No production reported. No resources estimated.	Weathers, 1954, AEC PRR A-P-219.
27.	Iris deposit	NE. 1/4 Sec. 3, T. 4 N., R. 14 E. (Protracted) In bottom of tributary canyon W. of Oak Creek.	Vein-type on irregular fracture in gray facies about 40 feet below barren quartzite. No nearby diabase noted. Disseminated pyrite, metatorbernite, uranophane. Moderate radioactivity. Grab samples of select material ran 0.24 and 0.29 percent eU_3O_8.	Ditto	Schwartz, 1955, AEC PRR A-P-290. Granger and Raup, 1969b, p. 57.
28.	Izzy deposit (5 claims)	Approximately in north central Sec. 28, T. 7 N., R. 13 E. On rim of canyon at SE. corner of Redman Mesa.	In upper member. No diabase noted. Metatorbernite, iron oxides, pyrite. Maximum radioactivity about 10X background. Samples ran 0.1 to 0.2 percent eU_3O_8.	Ditto	Schwartz and Fink, 1955, AEC PRR A-P-369.
29.	Jackie deposits (Lucky Chance, Uranium)	Approx. east center Sec. 9, T. 4 N., R. 14 E. On steep upper slopes to SE. of Alta Vista (No. 2) group.	In upper member. No nearby diabase noted. Disseminated copper oxides along fractures but no uranium minerals noted. Maximum radioactivity about 15X background. Samples ran 0.10 to 0.21 percent eU_3O_8 and 8.48 percent Cu.	Ditto	Wells, 1954, AEC PRR A-P-180. Schwartz, 1956, AEC PRR A-109.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
30.	Jim claim	SW. 1/4 Sec. 30 and NW. 1/4 Sec. 31, T. 5 N., R. 14 E. In First Water Canyon about 300 feet SE. of Globe-Young Road.	Irregular vein-like mineralization in lower 20 feet of gray facies about 50 feet above base of lower member. Some pyrite, abundant limonite and sulfate efflorescence. Spotty radioactivity but no uranium minerals noted. Chip sample ran 0.045 percent eU_3O_8.	Ditto	Ashwill and Schwartz, 1954, AEC PRR A-P-238. Granger and Raup, 1969b, p. 59.
31.	Jon deposit (Several claims)	SW. 1/4 Sec. 29, T. 6 N., R. 14 E. On NE. side of Workman Creek about 1.7 miles upstream from the Globe-Young road.	Vein-type in hornfels of grey facies about 65 feet below Buff unit and 12 feet above discordant Sierra Ancha diabase sheet. Strong faulting and irregular aplite. Calcite-pyrite in fractures. Abundant pyrite and galena, pyrrhotite and sphalerite common. Nontronite and chlorite. No uranium minerals recognized but irregular radioactivity moderate to strong.	Few truck loads shipped running 0.11 to 0.066 percent U or 0.084 to 0.058 percent eU_3O_8. Possibly a few hundred tons of low grade remain.	Weathers, 1954, AEC PRR A-P-225. Granger and Raup, 1969a, Fig. 27. Granger and Raup, 1969b, p. 60.
32.	Lamanite deposit	Approx. Sec. 19, T. 5 N., R. 15 E. (Protracted).	In Apache Group (probably Dripping Spring Quartzite). Underlain by diabase. No uranium minerals noted but maximum radioactivity almost 100X background.	No production. No resources estimated.	Schwartz, 1955, AEC PRR A-P-274.
33.	Little Joe deposits (11 claims)	West central Sec. 19, T. 6 N., R. 14 E. On N. side of Workman Creek at about 0.5 miles E. of Globe-Young road and 6,000 foot elevation.	In vertical tabular breccia zones in hornfels in fault block of black facies, 30 feet above barren quartzite and just above discordant Sierra Ancha diabase sheet. Irregular aplite dikes. Uraninite in thin streaks and small blebs. Uranophane, metatorbernite. Locally disseminated pyrite, marcasite, jarosite, gypsum, chalcanthite. Abundant limonite. Moderate to strong radioactivity. Samples ran 0.14 to 0.86 percent eU_3O_8, averaged 0.30 percent eU_3O_8.	Several shipments, approx. 1,753 tons-0.19-0.20 percent U_3O_8.	Schwartz, 1955, AEC PRR A-P-311. Granger and Raup, 1969a, Pl. 1. Granger and Raup, 1969b, p. 65.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
34.	Lost Dog deposits	North central Sec. 30, T. 6 N., R. 14 E. On S. side of Workman Creek about 1 mile upstream from the Globe-Young road and 5,900-6,000 feet elevation.	Vein-type with some bedded mineralization in fractured and partly recrystallized black facies just above barren quartzite and overlying Sierra Ancha diabase sheet. Disseminated pyrite and sparse chalcopyrite and graphite. Abundant metatorbernite on fractures and bedding planes. Uraniferous hyalite, rare galena. Radioactivity irregular but locally strong.	About 1,400 tons shipped ranging from less than 0.01 to 0.20 percent U_3O_8.	Barrett, 1954, AEC PRR A-P-232. Granger and Raup, 1969a, Pl. 2, Figs. 18, 28. Granger and Raup, 1969b, p. 74.
35.	Lucky Boy deposit (50 claims)	North central border Secs. 31-32, T. 2 S., R. 15 E. 1/4 mile W. of old Pioneer Stage Station road.	In shear zone in dipping bedding planes of black facies about 40-45 feet above barren quartzite and 170 feet below Mescal Limestone. Diabase sheet 70 feet below. Abundant fracturing. Probably very finely disseminated uraninite, especially in association with mica and chloite mafic alteration. Pyrite, pyrrhotite, chalcopyrite, metatorbernite, bassetite, fluorescent opal, uranophane, limonite, jarosite, gypsum.	Some 2,430 tons shipped ranging from 0.1-0.2 percent U_3O_8 and averaging 0.18 percent U_3O_8. Some resources remain.	Granger and Raup, 1969a, Fig. 38. Granger and Raup, 1969b, p. 78.
36.	Lucky King deposit (17 claims)	Approx. SE. 1/4 Sec. 36, T. 2 S., R. 15 E. On N. slope of El Capitan Mountain.	Probably in upper member. Local diabase. Iron and manganese oxides, pyrite, metatorbernite. Maximum radioactivity about 20X background. Select sample ran 0.08 percent eU_3O_8 and chip sample 0.04 percent eU_3O_8.	No production. No resources estimated.	Schwartz and Kinneson, 1955, AEC PRR A-P-355.
37.	Lucky Stop deposits (17 claims)	NW. 1/4 Sec. 30, T. 6 N., R. 14 E. On SW. side of Workman Creek about 0.6 miles upstream from Globe-Young road at 5,800 foot elevation.	Vein-type with some disseminated mineralization in lower 20 feet of black facies just above barren quartzite and diabase intrusion. Minor recrystallization. Uraninite, pyrite, galena, pyrrhotite, chalcopyrite, sphalerite, marcasite, sphene, diopside, chlorite, albite, calcite.	2,383 tons shipped ran 0.15-0.20 percent U_3O_8, averaged 0.16 percent U_3O_8. 95 tons ran 0.22 percent U_3O_8. Some resources remain.	Weathers, 1954, AEC PRR A-P-222. Granger and Raup, 1969a, Figs. 18, 20. Granger and Raup, 1969b, p. 82.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
38.	Mack deposit	NE. 1/4 Sec. 2, T. 6 N., R. 13 E. (Protracted) In head-water drainage basin of Parker Creek on SW. side of McFadden Peak.	In upper member at about contact with middle member. No diabase noted. Metatorbernite with iron oxides. Maximum radioactivity about 100X background. Select sample ran 0.18 percent eU_3O_8. Chip sample ran 0.04 percent eU_3O_8.	No production. No resources estimated.	Kinneson, 1956, AEC PRR A-101.
39.	Major Hoople deposit (10 claims)	South center Sec. 26, T. 7 N., R. 14 E. On tributary of China Spring Creek about 1 mile E. of Cherry Creek.	In upper member, particularly in black facies. Discordant diabase to E. Major faulting. Sparsely disseminated pyrite. Metatorbernite, gypsum and sulfate on fracture and bedding planes. Irregular radioactivity in various horizons.	Ditto	Schwartz, 1955, AEC PRR A-P-354. Granger and Raup, 1969b, p. 87.
40.	May deposit (3 claims)	NW. 1/4 Sec. 31, T. 7 N., R. 13 E. (Protracted) About 1/2 mile NE. of Buck Peak (Lauffer Mountain).	Spotty mineralization in metamorphosed red unit about one foot above bottom of upper member. Spots of hornblende, feldspar, quartz, mica and chlorite, cut by aplitic-type dikes. Discordant diabase along fault to E. Uraniferous hyalite, sparse metatorbernite, disseminated pyrite, abundant limonite. Moderate radioactivity. Sample ran 0.08 percent eU_3O_8.	Ditto	Schwartz and Kinneson, 1955, AEC PRR A-P-349. Granger and Raup, 1969b, p. 90.
41.	Navajo deposit	North central Sec. 27, T. 7 N., R. 14 E. (Protracted) On E. side near the bottom of Cherry Creek about 0.5 miles N. of junction with China Spring Creek.	Weak, leached vein-type mineralization in black facies about 55-60 feet below top of gray unit. Sparse metatorbernite with abundant limonite. Gypsum and sulfate common. Spotty radioactivity.	Ditto	Ashwill and Schwartz, 1954, AEC PRR A-P-240. Granger and Raup, 1969b, p. 92.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
42.	North Star deposit	NW. 1/4 Sec. 6, T. 7 N., R. 12 E. (Protracted) In shallow valley at headwaters of Gun Creek about 5 miles NW. of Copper Mountain.	Secondary mineralization along fractures in gray facies 55 feet below barren quartzite. Abundant fracturing. No diabase close-by. Metatorbernite, saleeite and bassetite. Sparse pyrite and gypsum. Abundant limonite. Low and irregular radioactivity.	Ditto	Schwartz, 1954, AEC PRR A-P-265. Granger and Raup, 1969b, p. 94.
43.	Peacock deposit (10 claims)	South central Sec. 16, T. 5 N., R. 17 E. (Protracted) On steep south side of Salt River Canyon, 400 feet S. of river.	In black facies about 15-20 feet above barren quartzite. Diabase sill below. Uraniferous opal, local pyrite, abundant limonite. Moderate radioactivity. Samples ran 0.042 to 0.082 percent eU_3O_8. Specimen ran 0.237 percent eU_3O_8.	Ditto	Schwartz, 1954, AEC PRR A-P-258. Granger and Raup, 1969b, p. 95.
44.	Quartzite deposit	NW. 1/4 Sec. 12, T. 6 N., R. 14 E. In steep re-entrant on E. wall of Cherry Creek Canyon about 1 mile N. of junction with Horse Camp Creek. Elevation 4,600 feet.	Weathered mineralization on bedding planes and jointing in black facies two to three feet above barren quartzite. No diabase noted. Iron oxides, malachite staining, kaolinite, sulfate, minor pyrite, metatorbernite. Weak radioactivity. Chip samples ran 0.06-0.11 percent eU_3O_8.	Ditto	Schwartz, 1956, AEC PRR A-87. Granger and Raup, 1969b, p. 97.
45.	Rainbow deposit (2 claims)	SE. 1/4 Sec. 32, T. 5 N., R. 14 E. On small nose just S. of road to Oak Creek.	Vein-type in partly recrystallized black facies about five feet above barren quartzite. Strong fracturing and large discordant diabase sill to SW. Uranium mineralization apparently associated with graphite, hydrocarbon, clay and chlorite. Disseminated pyrite, sparse metatorbernite on fractures. Moderate to high radioactivity. Samples ran 0.11 to 0.50 percent eU_3O_8.	Ditto	Wells, 1954, AEC PRR A-P-179. Granger and Raup, 1969a, Fig. 29. Granger and Raup, 1969b, p. 98.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
46.	Red Bluff deposits	SE. 1/4 Sec. 31, T. 5 N., R. 14 E. About 750 feet E. of Globe-Young road on E. and W. walls of Warm Creek Canyon.	Vein-type and some bedded-type in gray unit from lower black facies and upper 35 feet of gray sandstone facies, divided by barren quartzite. Partly recrystallized to hornfels. Thick diabase dike divides the deposit; aplite dikes, and deuteric veinlets in diabase. Disseminated uraninite, pyrite, chalcopyrite, galena, metatorbernite, bassetite, meta-autunite, beta-uranophane, saleeite, kasolite, uraniferous opal, gypsum, limonite, malachite, chlorite, kaolinite, illite. Spotty ore and radioactivity. Samples ran 0.04-0.70 percent eU_3O_8.	Over 2,000 tons of greater than 0.1 percent U_3O_8 shipped and several hundred tons stockpiled. Could be potential low-grade resources.	Granger and Raup, 1969a, Pl. 4, Figs. 16, 17. Granger and Raup, 1969b, p. 102.
47.	Red Cliffs deposit	West central Sec. 11, T. 5 N., R. 13 E. In Connor Canyon.	In Dripping Spring Quartzite along Sierra Ancha monocline but no definite information on geology and mineralization.		Granger and Raup, 1969a, Fig. 1.
48.	Rick-Tick & Lady Esther deposit	Approx. north center Sec. 22, T. 7 N., R. 14 E. On W. wall of Cherry Creek about 1 1/4 miles N. of PB Creek.	In upper member. Diabase intrudes overlying Mescal Limestone. Metatorbernite, autunite, iron oxides. Maximum radioactivity about 40X background. Sample ran 0.11 percent eU_3O_8.	No production. No resources estimated.	Schwartz, 1955, AEC PRR A-P-352.
49.	Rock Canyon deposit	NW. 1/4 Sec. 14, T. 5 N., R. 16 E. (Protracted) In bottom of Rock Creek Canyon about 0.4 miles N. of Salt River.	Vein-type in black facies about 15-25 feet above barren quartzite. Partly recrystallized. Diabase sill below. Ankerite-filled fracture with pyrite, uraninite, limonite and sulfates. Irregular moderate radioactivity. Selected sample ran 0.45 percent eU_3O_8. Grab sample ran 0.28 percent eU_3O_8.	Five tons stockpiled but none shipped. May be minor resources.	Wells, 1953, AEC PRR A-P-144. Schwartz, 1956, AEC PRR A-79. Granger and Raup, 1969b, p. 110.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
50.	Roxy deposit (14 claims)	East central Sec. 21, T. 9 N., R. 15 E. On E. side of Gentry Creek.	Spotty mineralization in black facies a short distance above barren quartzite. No diabase noted. Metatorbernite, uraniferous opal, saleeite, limonite, gypsum. Weak to moderate radioactivity.	No production. No resources estimated.	Schwartz and Mace, 1955, AEC PRR A-P-323. Granger and Raup, 1969b, p. 114.
51.	Shepp No. 2 (5 claims)	Central border Sec. 31, T. 8 N., R. 15 E. and Sec. 36, T. 8 N., R. 14 E. In Wilson Creek about 1.4 miles ENE. of junction with Cherry Creek.	Both vein-and bedded-type. Irregular mineralization in black facies about 40 feet above barren quartzite. Diabase above and to N. Disseminated pyrite and chalcopyrite. Calcite and clay in fractures. Metatorbernite, limonite, gypsum, malachite, azurite. Weak to moderate radioactivity. 1.7 foot wide chip sample ran 0.11, 0.17 percent eU_3O_8. Composite sample ran 0.12 percent eU_3O_8.	Few tons stockpiled but none shipped. Minor resources probably low-grade.	Raup, Shride and Haines, 1953, AEC PRR D-718. Wells and Mead, 1953, AEC PRR A-P-43. Granger and Raup, 1969a, Fig. 24. Granger and Raup, 1969b, p. 115.
52.	Sky deposit (20 claims--Fran et alia)	East central Sec. 3, T. 3 S., R. 15 E. On nose between creeks feeding into El Capitan Canyon, about 0.6 miles E. of State Highway 77.	Bedded-type, probably lowest strata in upper member in paleochannel in quartzite. Discordant diabase to S. Appears to be limited secondary enrichment with metatorbernite coating and fracture filling. Pyrite, malachite, limonite, gypsum, and barite. Spotty radioactivity.	No production. No resources estimated.	Mead, 1954, AEC PRR A-P-229. Schwartz, 1955, AEC PRR A-P-229. Granger and Raup, 1969b, p. 118.
53.	Snakebit deposit (9 claims--Sunset, Mono, et alia)	SE. 1/4 Sec. 32, T. 5 N., R. 17 E. (Protracted) On N. wall of deep tributary canyon to Ash Creek at 4,450 foot elevation.	Bedded-type along fracture in black facies about two feet above barren quartzite. Thick diabase sill below to W. Limonite with metatorbernite, disseminated pyrite, chalcopyrite, galena, and sparse sphalerite. Irregular radioactivity. Samples ran 0.05 to 0.16 percent U_3O_8.	Ditto	Ashwill and Schwartz, 1954, AEC PRR A-P-234. Granger and Raup, 1969b, p. 120.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
54.	Sorrel Horse deposits (Citation, Lobo, T-Bone, and Maybe)	South central Sec. 4, T. 6 N., R. 14 E. On walls of NE.-trending tributary to Cherry Creek at 5,440 foot elevation.	Weak vein-type and disseminations at various stratigraphic horizons in grey facies below barren quartzite. Sierra Ancha diabase sheet intrudes beds 60 to 70 feet below barren quartzite; irregular syenite type segregations, black deuteric veinlets, local aplite dikes. Mica, pyrite, sparse chalcopyrite, limonite, quartz, siderite, fluorite, sphalerite, galena, clay. Moderate radioactivity but no uranium minerals noted. Sample ran 0.57 percent eU_3O_8.	Ditto	Schwartz, 1955, AEC PRR A-62. Schwartz, 1956, AEC PRR A-100. Granger and Raup, 1969b, p. 122.
55.	S. T. deposits	Central Sec. 31, T. 7 N., R. 13 E. (Protracted) On E. slope of Buck Peak (Lauffer Mountain).	In upper member. No diabase evident. Pyrite, metatorbernite, meta-autunite. Weak radioactivity. Chip samples only ran 0.02 percent eU_3O_8.	Ditto	Schwartz, 1955, AEC PRR A-P-338.
56.	Suckerite deposit (16 claims--Definitely et alia)	South center Sec. 24, T. 6 N., R. 13 E. (Protracted) 300 feet S. of Workman Creek and 0.3 miles W. of Globe-Young road on W. flank of ridge.	In narrow, mineralized, bedding-plane fracture zone in xenolith enclosed in diabase along Sierra Ancha monocline. Mineralized zone about 10-15 feet above diabase and 45 feet below Buff unit. Rock mildly recrystallized, abundant limonite and sulfides. Uraninite, pyrite, pyrrhotite, molybdenite, chalcopyrite, and galena in short veinlets and disseminated grains.	Some 2,453 tons shipped averaging 0.234 percent U_3O_8. Probably additional resources present.	Schwartz, 1954, AEC PRR A-P-252. Granger and Raup, 1969a, Pl. 2, Fig. 37. Granger and Raup, 1969b, p. 125.
57.	Sue deposit (57 claims)	SE. border Sec. 24, T. 5 N., R. 14 E. and SW. border Sec. 19, T. 5 N., R. 15 E. (Protracted) On S. slope of Bull Canyon about 2.7 miles WSW. of Cherry Creek at 4,700 foot elevation.	Discontinuous secondary mineralization in fractured, oxidized, weakly recrystallized black facies above, in and below barren quartzite. Diabase along fault to E. Metatorbernite, bassetite, meta-autunite, gypsum, pyrite, illite, sulfate. Limonite, calcite and kaolin in fractures. Radioactivity weak to moderate but not in equilibrium. 65 channel samples ranged from 0.01-3.47 percent eU_3O_8.	Less than 500 tons of low-grade shipped and possibly a few hundred tons remain.	Schwartz, 1955, AEC PRR A-P-273. Granger and Raup, 1969b, p. 129, Fig. 8.

Table M. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
58.	Tomato Juice deposit (24 claims--Grandview, King Snake et alia)	SE. 1/4 Sec. 14, T. 5 N., R. 16 E. (Protracted) In Regal Canyon about 900 feet SE. of Salt River at 3,200 foot elevation.	Vein-type associated with ankerite-filled fissure in black facies. Partly recrystallized. Strong faulting with nearby diabase intrusion. Spotty pyrite, chalcopyrite and fluorite. Disseminated uraninite and minor uranophane. Gypsum. Strong radioactivity in fracture.	140 tons of 0.16 percent U_3O_8 shipped and a few hundred tons remain.	Schwartz and Fink, 1955, AEC PRR A-P-364. Granger and Raup, 1969a, Fig. 19. Granger and Raup, 1969b, p. 136.
59.	Uranium 1-17 deposit	NW. 1/4 Sec. 2, T. 6 N., R. 12 E. (Protracted) On W. rim of Sierra Ancha Mountains.	In upper member under diabase sill. Metatorbernite. Maximum radioactivity about 6X background.	No production. No resources estimated.	Rambosek and Schwartz, 1954, AEC PRR A-P-242.
60.	Walnut Creek deposit	NE. 1/4 Sec. 25, T. 8 N., R. 14 E.	Probably in upper member. Uranophane and torbernite with limonite. Radioactivity about 10X background. Samples ran 0.1-0.2 percent eU_3O_8.	Ditto	Raup, Shride and Haines, 1953, AEC PRR D-717.
61.	Workman deposits	Central Sec. 19, T. 6 N., R. 14 E. On N. side of Workman Creek about 0.65 miles E. of Globe-Young road at 6,000 foot elevation.	Vein-type in black facies, hornfels above and below barren quartzite. Sierra Ancha diabase sheet below. Much fracturing. Pyrite, pyrrhotite, uraninite, coffinite, marcasite, uranophane, metatorbernite, limonite, gypsum, uraniferous hyalite. Mineralization relatively weak.	Less than 200 tons shipped. Probably small amount of low-grade mineralization remains.	Weathers, 1954, AEC PRR A-P-221. Granger and Raup, 1969a, Pl. 2, Fig. 13. Granger and Raup, 1969b, p. 140.

Table N. — Uranium occurrences in veins. (Excluding those in Dripping Spring Quartzite.)

Numbers correspond with the occurrence numbers on Plate 18.

No.	Name	Location	Geology and Mineralization	Notes	References
V1.	Chapel claim	NE. 1/4 Sec. 25, T. 33 N., R. 10 W. Mohave Co.	Uranophane(?) and possibly other uranium minerals in leached zone in sandy facie of Hermit Shale with copper oxides. May be indication of pipe-like breccia body. Indicated grade probably below 0.02 percent U_3O_8.	Prospected and possibly a few tons shipped out.	Nelson and Rambosek, 1952, AEC PRR RA-11.
V2.	Corley, Lind, and Ellington mine	Approx. Sec. 6, T. 29 N., R. 17 W. Mohave Co.	Unidentified greenish-black, resinous radioactive mineral associated with base metal and iron sulfides and oxides in quartz veins cutting metamorphic rocks and gneissic granite. Sample of stockpiled ore ran 0.25 percent U_3O_8.	Small shafts and adit.	Miller, 1953, AEC PRR A-P-122.
V3.	De la Fontaine mine	SE. 1/4 Sec. 5, T. 22 N., R. 17 W. Mohave Co.	Uranium mineralization, probably uraninite, finely disseminated locally in quartz-base metal sulfide filled fracture zones and shear breccias in granite and schist. Local high radioactivity.	An old base-metal mine.	King and Rambosek, 1952, AEC PRR-35. Hart, 1955. Hart and Hetland, 1953.
V4.	Misc. Cerbat Range mines		Finely disseminated uranium mineralization associated with base metal sulfides and quartz gangue in fault fissures and shear zones in granite. Samples range from less than 0.01 to about 0.50 percent U_3O_8 but overall average is too low to recover economically.	Old base-metal and precious metal mines.	Misc. AEC PRR reports. Hart, 1955. Hart and Hetland, 1953.
	Detroit group	W. central Sec. 31, T. 23 N., R. 17 W.			
	Summit mine	Central Sec. 32, T. 23 N., R. 17 W.			
	Bobtail mine	SW. 1/4 Sec. 31, T. 23 N., R. 17 W.			
	Jim Kane (Monitor group)	NE. 1/4 Sec. 8, T. 22 N., R. 17 W.			
	Prosperity et alia	N. central Sec. 6, T. 22 N., R. 17 W.			
	J. C. and Fort Lee, and others in area	SE. 1/4 Sec. 12, T. 22 N., R. 18 W. Mohave Co.			

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V5.	Big Lodge mine	Sec. 33, T. 28 N., R. 20 W. Mohave Co.	Slight radioactivity in red, brecciated and recemented jasper along hanging wall of base sulfide and carbonate structure in granitic rocks.	Old mining property.	Nelson and Rambosek, 1955, AEC PRR R-A-9.
V6.	Democrat mine	Sec. 12, T. 19 N., R. 15 W. Mohave Co.	Uranium mineralization, probably finely disseminated uraninite, occurs with arsenopyrite-pyrite, gold-silver fissure vein cutting Precambrian rocks.	Old mining property.	Hart and Hetland, 1953, AEC PRR A-P-25. Hart and Hetland, 1953.
V7.	Uranium Basin	Approx. S. central T. 20 N., R. 13 W. (Unsurveyed) Mohave Co.	Uranothorite occurs scattered in replacement of granite between a shear zone and a pegmatite.	Prospected.	Adams and Staatz, 1969.
V8.	White Owl group	Sec. 5, T. 12 N., R. 14 W. Mohave Co.	Radioactivity associated with pegmatites and fault zones containing fluorite, chalcedonic quartz and calcite. Samples indicated that radioactivity due to thorium as well as uranium.	Prospected.	Ashwill and Reyner, 1954-1955, AEC PRR A-P-307.
V9.	State mine	SE. 1/4 Sec. 4, T. 13 N., R. 12 W. Mohave Co.	Autunite abundantly disseminated in fault gouge and adjacent wall rock of post-mineral fault cutting quartz vein carrying gold-silver mineralization. Samples show trace to over 0.3 percent eU_3O_8.	An old gold-silver mine.	Hart and Hetland, 1953.
V10.	Hillside mine, Seven Star claim	NW. 1/4 Sec. 21, T. 15 N., R. 9 W. Yavapai Co.	Pitchblende and secondary uranium carbonates (andersonite, bayleyite, swartzite) locally present in gold-silver-base sulfide-fluorite fissure vein cutting Precambrian Yavapai Schist. Samples showed trace to 0.11 percent U_3O_8.	Mined extensively for gold, silver and base sulfides. A few tons of uranium ore shipped.	Wright, 1950. Anderson, Scholz and Strobell, 1955.
V11.	Kitten No. 1 claim	SW. 1/4 Sec. 27, T. 15 N., R. 9 W. Yavapai Co.	Metatorbernite, pyrite and fluorite disseminated in and along fracture zone cutting porphyritic granite. Samples showed 0.094 and 0.013 percent U.	Prospected.	Granger and Raup, 1962.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V12.	Cardinal claim	Sec. 27, T. 14 N., R. 8 W. Yavapai Co.	Radioactivity in two-foot vein cutting Precambrian granite. Two-foot chip sample ran 0.05 percent eU_3O_8; select samples ran 0.08 and 0.13 percent eU_3O_8.	Prospect cut.	Robison, 1955, AEC PRR A-41.
V13.	Ethiopia claims	Sec. 22, T. 15 N., R. 9 W. Yavapai Co.	Kasolite in small galena, iron oxide, and quartz veins along joints in granite. Cut samples ran 0.02 to 0.07 percent eU_3O_8; select dump samples up to 0.13 percent eU_3O_8.	Underground workings.	Wells and Putluck, Rambosek and Putluck, 1953, AEC PRR A-P-99, 99 Suppl.
V14.	Uranus group (Uranus 1-3, Mizpah, Terminal, Nest Egg, Planet Saturn, Total Wreck)	Approx. SE. corner T. 10 N., R. 5 W. and SW. corner T. 10 N., R. 4 W. Yavapai Co.	Radioactivity associated with iron oxide and fluorite in quartz-pyrite-calcite gold-bearing fault structures cutting Precambrian metamorphics and granite. Select samples ran up to 0.14 percent U_3O_8.	Extensive old gold workings.	Ashwill, 1955, AEC PRR A-15.
V15.	Buckhorn, Cuba, Lucky Day, Independence mines	SE. 1/4 Sec. 8, SW. 1/4 Sec. 9, T. 11 N., R. 5 W. (Unsurveyed) Yavapai Co.	Sparse torbernite along a quartz vein and thin coating of uranophane(?) on surface of granite. Average sample less than 0.01 percent U but radioactivity of granite is locally abnormal. Tungsten and beryllium mineralization present.	Old copper, tungsten and gold mines.	Granger and Raup, 1962.
V16.	Little Surprise	SE. 1/4 Sec. 33, T. 11 N., R. 1 E. Yavapai Co.	Torbernite(?) in small quartz-barite vein with copper staining cutting Precambrian rocks. Grab sample ran 0.701 percent eU_3O_8.	Old silver prospect.	Barrett and Robison, 1954, AEC PRR A-P-245.
V17.	Ford claim (Gazelle mine)	NE. 1/4 Sec. 33, T. 10 N., R. 1 W. Yavapai Co.	Torbernite and uranophane in small quartz stringers in fault carrying base metal sulfides and gold and silver values. Select sample assayed 0.18 percent eU_3O_8.	Old gold mine.	Robison, 1955, AEC PRR A-16.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V18.	Abe Lincoln mine	SE. 1/4 Sec. 11, T. 8 N., R. 3 W. Yavapai Co.	Uraninite(?) and schoepite associated with copper and iron minerals and quartz, calcite and fluorite gangue in gouge veins cutting Precambrian complex of gneiss and schist intruded by granite and dikes. Select samples from dumps ran up to 0.46 percent U.	Old copper mine.	Granger and Raup, 1962.
V19.	Denver group	Approx. NW. 1/4 T. 8 N., R. 3 W. Yavapai Co.	Radioactivity associated with copper mineralization, fluorite, quartz, calcite, pyrite and siderite along fault-fissure vein cutting Precambrian complex. Select sample ran up to 0.61 percent U_3O_8.	Old copper workings.	Ashwill, 1955, AEC PRR A-54.
V20.	Willbank group	Approx. Sec. 4, T. 8 N., R. 1 W. Yavapai Co.	Unidentified uranium mineralization with some thorium in dikes and shear zones in Precambrian complex. Iron staining and barite. Chip sample assayed 0.28 percent eU_3O_8.	Prospect pits.	Miller, 1956, AEC PRR A-78.
V21.	Black Donkey group	Approx. Sec. 4, T. 8 N., R. 1 W. Yavapai Co.	Radioactivity associated with limonite and some autunite along quartz-calcite vein in shear zone in Precambrian complex. Select assays ran as high as 0.55 percent U_3O_8 but grade usually below 0.1 percent.	Small prospect workings.	Miller, 1956, AEC PRR A-91.
V22.	Golden Duck, Shamrock Mining & Development Co.	NW. 1/4 T. 7 N., R. 2 W. Yavapai Co.	Yellow uranium minerals coating fractures in pegmatite cutting Precambrian Complex. Samples assayed up to 0.207 percent U_3O_8.	Prospected for pegmatite minerals.	Ashwill, 1955, AEC PRR A-P-347.
V23.	Lucky Find group	Sec. 6, T. 7 N., R. 6 E. Maricopa Co.	Autunite in fault zone and radioactivity associated with iron oxide where altered basic dike is brecciated and faulted in Precambrian granite. Assays show 0.06-0.49 percent eU_3O_8.	Prospect pits.	Robison, 1956, AEC PRR A-96.
V24.	Manley-Bickle group	Sec. 12, T. 6 N., R. 5 E. Maricopa Co.	Yellow uranium mineral associated with fluorite and calcite at intersection of mineralized shear zones in Precambrian granite. Some thorium present. Select samples ran 0.05 to 1.05 percent U_3O_8.	Prospected and trial production.	Ashwill, 1955, AEC PRR A-P-340.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V25.	Copper Kid group	Sec. 10, T. 6 N., R. 4 E. Maricopa Co.	Uraninite, copper carbonates, galena and barite in red jasper zone in Precambrian schist intruded by dikes. Select sample ran 0.77 percent U_3O_8.	Old lead-silver prospect.	Reyner and Ashwill, 1954, AEC PRR A-P-280.
V26.	Cottonwood claims	SW. 1/4 Sec. 33, T. 7 N., R. 6 E. (Protracted) Maricopa Co.	Unidentified uranium mineralization associated with iron oxides and gouge along fault fissure in granite. Select sample ran 0.52 percent eU_3O_8.	Small adit.	Robison, 1955, AEC PRR A-P-341.
V27.	Golondrina claims	Approx. SE. 1/4 Sec. 13, T. 11 S., R. 25 E. (Unsurveyed) Graham Co.	Radioactive pyromorphite, quartz and limonite in cavities and fractures in layer of agglomerate or flow breccia and porphyritic volcanics. Trace of copper minerals. Generally low grade but some samples ran as high as 0.26 percent eU_3O_8.	Prospect pits and adit.	Granger and Raup, 1962.
V28.	Stony Peak claims	Sec. 20, T. 10 S., R. 25 E. Graham Co.	Autunite and uranophane with fluorite stringers on fracture planes in granite. Samples ran 0.14 and 0.27 percent U_3O_8.	Surface prospecting.	Miller, 1957, AEC PRR A-110.
V29.	Morenci area	S. 1/2 T. 3 S., R. 29 E.; N. 1/2 T. 4 S., R. 29 E. Greenlee Co.	Traces of scattered uranium mineralization (torbernite?) found associated with copper mineralization.	Large open pit mine.	ABM files.
V30.	Waterfall claims	Sec. 30, T. 5 S., R. 15 E. Pinal Co.	Unidentified uranium mineral associated with limonite in vein in granite. Assay showed 0.090 to 0.172 percent eU_3O_8.	Prospect pits and adit.	Robison, 1955, AEC PRR A-P-298.
V31.	Honey Bee No. 4	Sec. 16, T. 4 S., R. 13 E. Pinal Co.	Unidentified uranium mineral with iron oxides in shattered fine-grained mafic dike and porphyry dike cutting granite. Average grade very low but select sample ran 0.021 percent U.	Surface pits and adit.	Granger and Raup, 1962.
V32.	Shorty claims	Sec. 15, T. 4 S., R. 13 E. Pinal Co.	Unidentified uranium mineral associated with iron and manganese oxides in shear zones in porphyritic granite. Grade probably less than 0.01 percent U.	Prospect pits and adit.	Ditto

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V33.	Wooley No. 1	Sec. 33, T. 4 S., R. 13 E. Pinal Co.	Unidentified uranium mineral associated with iron and weak copper oxides or staining in veins cutting granite. Selected sample ran 0.017 percent U.	Prospected.	Ditto
V34.	Name Unknown	Secs. 26 and 35, T. 4 S., R. 11 E. Pinal Co.	Radioactivity associated with zones of small stringers of iron and copper oxides and carbonates in granite. Select assay ran 0.012 to 0.124 percent eU_3O_8.	Old adits and shaft.	Ashwill, 1954, AEC PRR A-P-291.
V35.	Hillside group	Sec. 35, T. 4 S., R. 12 E. Pinal Co.	Torbernite(?) associated with copper carbonate in faulted dike in granite. Cut samples ran from 0.01 to 0.11 percent eU_3O_8.	Prospected.	Robison, 1955, AEC PRR A-P-345.
V36.	M & M group	Sec. 10, T. 9 S., R. 5 E. Pinal Co.	Carnotite in fractures along shear zone in altered perlite. Cut sample ran 0.017 and select sample 0.065 percent eU_3O_8.	Surface cuts.	Robison, 1955, AEC PRR A-P-346.
V37.	Van Hill No. 5 (Vanover)	Secs. 9 and 15, T. 13 S., R. 18 E. Pima Co.	Autunite associated with purple fluorite in fracture zone cutting altered quartzite bed (Cambrian). Strong leaching. Sample ran 0.008 percent U but radioactivity relatively strong.	Prospect pit.	Granger and Raup, 1962.
V38.	Sure Fire No. 1	Sec. 15, T. 13 S., R. 18 E. Pima Co.	Radioactive minerals (uranophane and autunite) associated with quartz-fluorite and minor copper in leached, crushed and altered Precambrian schist. Samples indicate 0.002 to 0.008 percent U.	Prospect pits.	Granger and Raup, 1962.
V39.	Van Hill Nos. 7 and 8	NW. 1/4 Sec. 24, T. 13 S., R. 18 E. Pima Co.	Unidentified uranium mineralization in petroliferous limestone bed (Naco?). Samples assayed 0.011 to 0.021 percent U.	Surface prospecting.	Granger and Raup, 1962.
V40.	Copper Squaw	Sec. 19, T. 14 S., R. 2 E. Pima Co.	Unidentified uranium mineralization associated with oxidized copper and iron in vein in altered andesite. Selected samples ran 0.76 and 1.4 percent eU_3O_8 but may have other radioactive elements besides uranium.	Old copper property.	Wells and Putluck, 1953, AEC PRR A-P-102.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V41.	Linda Lee	Approx. Secs. 2 and 11, T. 15 S., R. 2 E. Pima Co.	Torbernite and gummite(?) in iron oxide vein in arkose near granite contact. Samples ran 0.053 to 0.155 percent eU_3O_8.	Pits.	Robison, 1955, AEC PRR A-331.
V42.	Black Dike	Secs. 23, 24, 25 and 26, T. 17 S., R. 10 E. Pima Co.	Pitchblende and manganese oxide along fractures and in contact metamorphized granite along basaltic dike. Associated copper mineralization and fluorite. Assays showed 0.011 to 0.16 percent U.	Shaft.	Granger and Raup, 1962.
V43.	Hopeful No. 1	Sec. 36, T. 17 S., R. 11 E. Pima Co.	Yellow and green secondary uranium minerals in zone cutting fractured and silicified quartzite near contact zone with granite. Select samples ran slightly over one percent eU_3O_8.	Pit.	Miller, 1956, AEC PRR A-84.
V44.	Diamond Head group	Sec. 34, T. 17 S., R. 11 E. Pima Co.	Uraninite associated with iron and copper sulfides and hematite, in fault vein structure cutting intrusive. Assays of 0.22 and 0.74 percent U_3O_8 reported but average much lower.	Adit and pits.	Miller and Miller, 1956, AEC PRR A-94.
V45.	Escondida	Sec. 34, T. 17 S., R. 11 E. Pima Co.	Uraninite with iron and copper sulfides in contact zone along basic dike intruding granitic rock. Select samples ran 0.03 to 0.06 percent eU_3O_8.	Pits.	Miller, 1955, AEC PRR A-35.
V46.	Glen claims	NW. 1/4 Sec. 30, T. 17 S., R. 11 E. Pima Co.	Unidentified uranium mineralization in and along breccia zone cutting granite and altered wall rock. Assay ran 0.015 percent U and some 200 feet SE, 0.027 percent U.	Open cut.	Granger and Raup, 1962.
V47.	Lena No. 1 and Genie No. 1	Secs. 8 and 5, T. 18 S., R. 11 E. Pima Co.	Sooty pitchblende and kasolite(?) coating fractures along base sulfide-quartz fissure vein cutting granite. Channel samples assayed 0.004 and 0.012 percent U but probably some higher grade spots. Genie similar to Lena but shows abundant tourmaline.	Shaft and pits.	Granger and Raup, 1962.
V48.	Abe Lincoln	Secs. 34 and 35, T. 17 S., R. 11 E. Pima Co.	Metatorbernite, secondary copper minerals, molybdenite, quartz and chlorite in fault fissure in granite.	Old drift.	Miller, 1956, AEC PRR A-90.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V49.	Esperanza mine	Secs. 8, 9, 16 and 17, T. 18 S., R. 12 E. Pima Co.	Uraninite and secondary uranium minerals associated with molybdenite and copper minerals in New Year's Eve mine and in veinlets in porphyry copper deposit. Assays of old ore stockpile ran 0.111 to 0.182 percent eU_3O_8.	Shaft and open pit.	Robison, 1954, AEC PRR A-P-255. Lynch, 1968.
V50.	King mine	E. central Sec. 24, T. 18 S., R. 15 E. Pima Co.	Pitchblende with iron and copper sulfides and quartz-calcite gangue in pockets along limestone-quartz monzonite contact. Samples assayed 0.14 to 0.93 percent eU_3O_8.	Old silver-copper mine.	Miller, 1955, AEC PRR A-37.
V51.	Gismo group	Sec. 5, T. 21 S., R. 10 E. Pima Co.	Sooty uraninite, kasolite and schroeckingerite identified with copper and iron mineralization in fault-fissure vein in granite. Samples assayed 0.12 to 0.30 percent eU_3O_8.	Old gold-silver mining area.	Magleby, 1957, AEC PRR A-114.
V52.	Iris and Natalie claims	SW. 1/4 Sec. 26, T. 21 S., R. 11 E. Pima Co.	Kasolite(?) reportedly found in specimen from copper-bearing shear zones in rhyolite cut by iron stained quartz veins. Probably spotty, local occurrences.	Old property.	Granger and Raup, 1962.
V53.	Four Queens	Sec. 33, T. 20 S., R. 15 E. Santa Cruz Co.	Autunite and torbernite with some vanadium-bearing mineral mainly along fractures in rhyolite-tuff agglomerate. Select sample assayed 0.12 percent U_3O_8.	Pit and drill holes.	Miller, 1957, AEC PRR A-112.
V54.	Alto group (Gold Tree, El Plomo)	SE. 1/4 Sec. 12, N. 1/2 Sec. 13, T. 21 S., R. 14 E. Santa Cruz Co.	Very fine uraninite crystals on cross-fractures in quartz-latite agglomerate. Assay showed 0.07 percent eU_3O_8.	Old silver-base metal mine.	Miller and Robison, 1955, AEC PRR A-P-360.
V55.	Bowling Green and Lucky Spur groups	Secs. 17 and 20, T. 21 S., R. 15 E. Santa Cruz Co.	Uraninite associated with galena and metatorbernite on fracture planes in veins cutting granite. Samples assayed 0.02 to 0.16 percent eU_3O_8.	Old lead-silver workings.	Miller and Robison, 1955, AEC PRR A-P-359.
V56.	Cracker Jack group	Sec. 29, T. 21 S., R. 15 E. Santa Cruz Co.	Pitchblende(?) associated with base sulfide mineralization in fissure veins cutting quartz latite. Assays up to 0.07 percent eU_3O_8.	Prospect pits.	Miller, 1955, AEC PRR A-39.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V57.	Grandview group	N. center Sec. 20, T. 22 S., R. 10 E. Santa Cruz Co.	Kasolite with iron and copper oxides in vein cutting silicified volcanics. Samples assayed up to 0.076 percent eU_3O_8.	Shaft and open cut.	Reyner and Robison, 1955, AEC PRR A-P-319.
V58.	Little Doe	Sec. 20, T. 22 S., R. 10 E. Santa Cruz Co.	Gummite(?) and kasolite(?) with iron and copper oxides in fracture zones in volcanics. Samples assayed 0.036 to 0.125 percent U_3O_8.	Old workings.	Webb and Coryell, 1952, AEC PRR A-SL-3. Miller and Weathers, 1953, AEC PRR A-SL-3 (Suppl.).
V59.	Lone Star #1	Sec. 23, T. 22 S., R. 10 E. Santa Cruz Co.	Sooty uraninite on fractures in rhyolite dike. Assay ran 0.012 percent eU_3O_8.	Prospect pit.	Robison, 1955, AEC PRR A-P-294.
V60.	Purple Cow claims	Sec. 36, T. 22 S., R. 10 E. Santa Cruz Co.	Torbernite crystals on fractures in dacite dike. Select assay ran 0.026 percent eU_3O_8.	Prospect pit.	Robison, 1954, AEC PRR A-P-286.
V61.	Annie Laurie	SE. 1/4 Sec. 1, T. 23 S., R. 11 E. Santa Cruz Co.	Pitchblende and secondary uranium minerals associated with base sulfide and oxides in shear fractures in altered granite and porphyry. Selected samples may be relatively high but average is close to 0.01 percent U.	Prospect pits.	Granger and Raup, 1962.
V62.	White Oaks mine (Clark mine)	NE. 1/4 Sec. 2, T. 24 S., R. 12 E. Santa Cruz Co.	Kasolite, uranophane, dumontite, autunite, and uranium-bearing pyromorphite with oxidized lead and copper minerals in fissures and gouge of shear zone in rhyolite volcanics. Selected samples assayed up to 0.82 percent U but average much lower.	Adits and pits.	Ditto
V63.	Silver Mine claim	Sec. 5, T. 24 S., R. 12 E. Santa Cruz Co.	Autunite, uranophane and uraninite in highly fractured rhyolite porphyry. Assays up to over one percent U_3O_8 but average much lower.	Drifts and surface prospects.	Robison, 1954, AEC PRR A-P-292.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V64.	Happy Day claims	Sec. 5, T. 24 S., R. 12 E. Santa Cruz Co.	Kasolite and autunite in highly fractured rhyolite porphyry. Selected assays ran 0.025 to 0.353 percent eU_3O_8 but average much lower.	Drifts and pits.	Robison, 1954, AEC PRR A-P-284.
V65.	Reactor and Opaline groups	Secs. 5 and 8, T. 24 S., R. 12 E. Santa Cruz Co.	Autunite, uranophane and some uraninite in shear zone in faulted and sheared rhyolite porphyry.	Pits and cuts.	Miller, 1956, AEC PRR A-108.
V66.	Redfield (Robles Spring) deposit	SW. 1/4 Sec. 30, T. 13 S., R. 19 E. Cochise Co.	Radioactivity (small blebs of uraninite) along fault contact and in fault blocks between carbonaceous schist, limestone and intrusive. Strong leaching and oxidation. Sample ran only 0.004 percent U.	Adit and pit.	Miller, 1955, AEC PRR A-50. Granger and Raup, 1962.
V67.	Valley View claims	Approx. SE. 1/4 Sec. 22, T. 13 S., R. 26 E. Cochise Co.	Radioactivity associated with altered dense gray rock and in quartz vein in granite. Some disseminated sulfides. Samples ran 0.04, 0.06 and 0.19 percent U_3O_8.	Pits.	Wright, 1950, AEC PRR.
V68.	Uranium Hill claims	Sec. 32, T. 14 S., R. 28 E. Cochise Co.	Radioactivity associated with quartz-fluorite-iron oxide veins in porphyritic granite. Core samples assayed 0.30 and 1.09 percent U_3O_8.	Diamond drill holes.	Miller, 1955, AEC PRR A-59.
V69.	Fluorine Hill	Secs. 33 and 34, T. 17 S., R. 25 E. Cochise Co.	Uranophane or autunite(?) associated with fluorite in narrow carbonate vein in iron stained, fractured and silicified rhyolite. Grab sample contained 0.11 percent U.	Prospect pits.	Granger and Raup, 1962.
V70.	First Chance	N. center Sec. 9, T. 18 S., R. 19 E. Cochise Co.	Radioactivity associated with fluorite, calcite and iron oxide in shear zone in porphyritic granite. Assays showed 0.13 and 0.16 percent eU_3O_8.	Pit.	Miller, 1955, AEC PRR A-57.
V71.	Lost Apache	Approx. Secs. 9 and 10, T. 18 S., R. 19 E. Cochise Co.	Unidentified uranium mineral associated with wulfenite, fluorite and iron oxides in lead and vanadium mineralization in vein in granite. Select sample assayed 0.04 percent eU_3O_8.	Pits.	Miller, 1955, AEC PRR A-24.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V72.	Windmill group	Sec. 10, T. 18 S., R. 19 E. Cochise Co.	Uranophane, autunite and uraninite(?) in fault gouge zone in sheared granite. Select sample ran 0.72 percent U_3O_8.	Shaft, trenches and drill hole.	Miller and Robison, 1955, AEC PRR A-1.
V73.	Bluestone mine (Star No. 1?)	SE. 1/4 Sec. 26, T. 18 S., R. 19 E. Cochise Co.	Autunite, tyuyamunite and other uranium minerals associated with andesite dike cutting granite. Select sample ran 0.07 percent eU_3O_8.	Pits.	Miller, 1955, AEC PRR A-25. Butler and Byers, 1969.
V74.	Walnut mine	Sec. 17, T. 23 S., R. 20 E. Cochise Co.	Uraninite with copper and iron sulfides in irregular lenses and quartz veins along faults and fractures in granite.	Old lead-scheelite property.	Miller, 1956, AEC PRR A-95.
V75.	Last Chance	Sec. 4, T. 24 S., R. 29 E. Cochise Co.	Uranophane along fracture planes in altered rhyolite.	Drift and prospect pits.	Robison, 1955, AEC PRR A-P-269.
V76.	Elanna	Sec. 35, T. 17 S., R. 25 E. Cochise Co.	Radioactivity associated with shear zone in silicified limy shale near contact with volcanic agglomerate. Selected sample assayed 0.20 percent U_3O_8.	Old prospect pits.	Robison, 1955, AEC PRR A-P-335.
V77.	Bisbee area	Sec. 16, T. 23 S., R. 24 E. Cochise Co.	Very fine-grained uraninite occurs in slip planes or as crusts in zones through base-metal sulfide ore-bodies. Average grade would be low.	Major base-metal mine.	Bain, 1952.
V78.	Mickey Dolan mine	SE. 1/4 Sec. 5, T. 6 N., R. 13 W. Yuma Co.	Unidentified uranium mineral associated with secondary copper and iron minerals in fault cutting granite and schist. Samples assayed 0.018 to 0.185 percent U_3O_8.	Pits, shaft and drifts.	Williams and Walthier, 1953, AEC PRR A-SL-4.
V79.	Bonanza mine	NW. 1/4 Sec. 26, T. 7 N., R. 13 W. Yuma Co.	Unidentified uranium mineral associated with iron and copper secondary minerals in fissure cutting granite and schist. Sample assayed 0.07 percent U_3O_8.	Incline shaft and drifts.	Ashwill, 1954-1955, AEC PRR A-P-301.
V80.	Rayvern group	NW. 1/4 Sec. 13, T. 6 N., R. 18 W. Yuma Co.	Uranophane and meta-autunite associated with iron and copper staining in fissures and limestone beds overlying granite. Select samples ran 0.03 to 0.08 percent eU_3O_8.	Small pits and shaft.	Ashwill, 1955, AEC PRR A-P-348.

Table N. — *Continued*

No.	Name	Location	Geology and Mineralization	Notes	References
V81.	State lease	Sec. 36, T. 4 N., R. 20 W. Yuma Co.	Unidentified uranium mineral with iron oxides and galena(?) in quartz-hematite-magnetite veins cutting intrusive diorite(?). Some thorium associated. Samples ran 0.224 to 1.25 percent U_3O_8.	Prospected.	Ashwill, 1954, AEC PRR A-P-303.
V82.	Topaz claims	Sec. 22, T. 4 N., R. 20 W. Yuma Co.	Radioactivity in quartz-iron oxide veinlets reportedly showing some molybdenite and scheelite along schist-diorite contact. Select sample assayed 0.14 percent U_3O_8.	Discovery pits.	Ashwill, 1955, AEC PRR A-P-308.
V83.	Unnamed claims	Sec. 25, T. 4 N., R. 20 W. Yuma Co.	Unidentified uranium mineral associated with biotite in schist intruded by diorite and quartz veins. Select samples ran 0.027 and 0.034 percent U_3O_8.	Old adit and shaft.	Ashwill, 1954, AEC PRR A-P-304.
V84.	McMillan prospect	NE. corner Sec. 16, T. 12 S., R. 16 W. (Unsurveyed) Yuma Co.	Unidentified uranium mineral associated with secondary iron and copper minerals in fracture zone in granite. Sample of stockpiled copper ore ran 0.034 percent U_3O_8.	Adits and open cut.	Granger and Raup, 1962.