MINERAL RESOURCES, SAN JUAN COUNTY, UTAH, AND ADJACENT AREAS

Part II: Uranium and Other Metals in Sedimentary Host Rocks

Utah Geological and Mineralogical Survey

Special Studies 24 (II)

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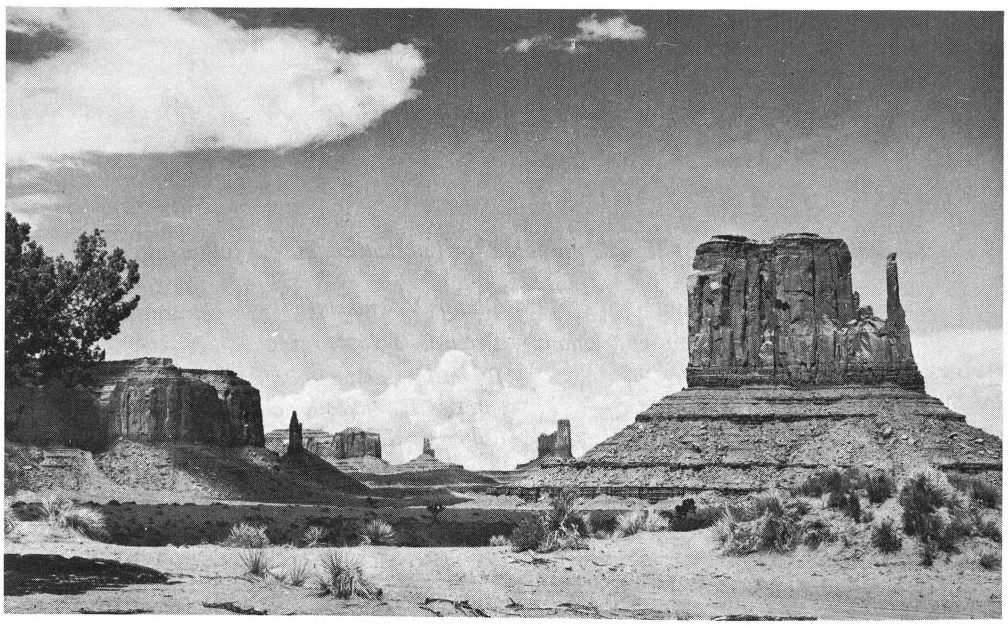
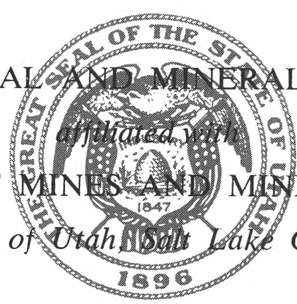
by Hellmut H. Doelling



Monument Valley, Triassic-capped DeChelly sandstone buttes resting on Organ Rock. (Photo by J. H. Rathbone, consulting geologist, Denver, Colo.)



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FOREWORD

This study, proposed by the Water and Power Board of the State of Utah and carried out in cooperation with the U.S. Bureau of Reclamation, covers all of San Juan County and the southern one-third of Grand County, Utah, and the western portions of Mesa, San Miguel, Montrose and Dolores Counties, Colorado.

Essentially a compilation of literature references on the area, the study is augmented by considerable field checking, as well as original data from Utah Geological and Mineralogical Survey files.

Special Studies 24, Mineral Resources, San Juan County, Utah, and Adjacent Areas, is divided into two parts:

Part I Petroleum, Potash, Groundwater and Miscellaneous Minerals
Part II Uranium

Hellmut H. Doelling, economic geologist, Utah Geological and Mineralogical Survey, prepared the groundwater, miscellaneous minerals and uranium sections; Howard R. Ritzma, petroleum geologist, Utah Geological and Mineralogical Survey, authored the petroleum and potash papers.

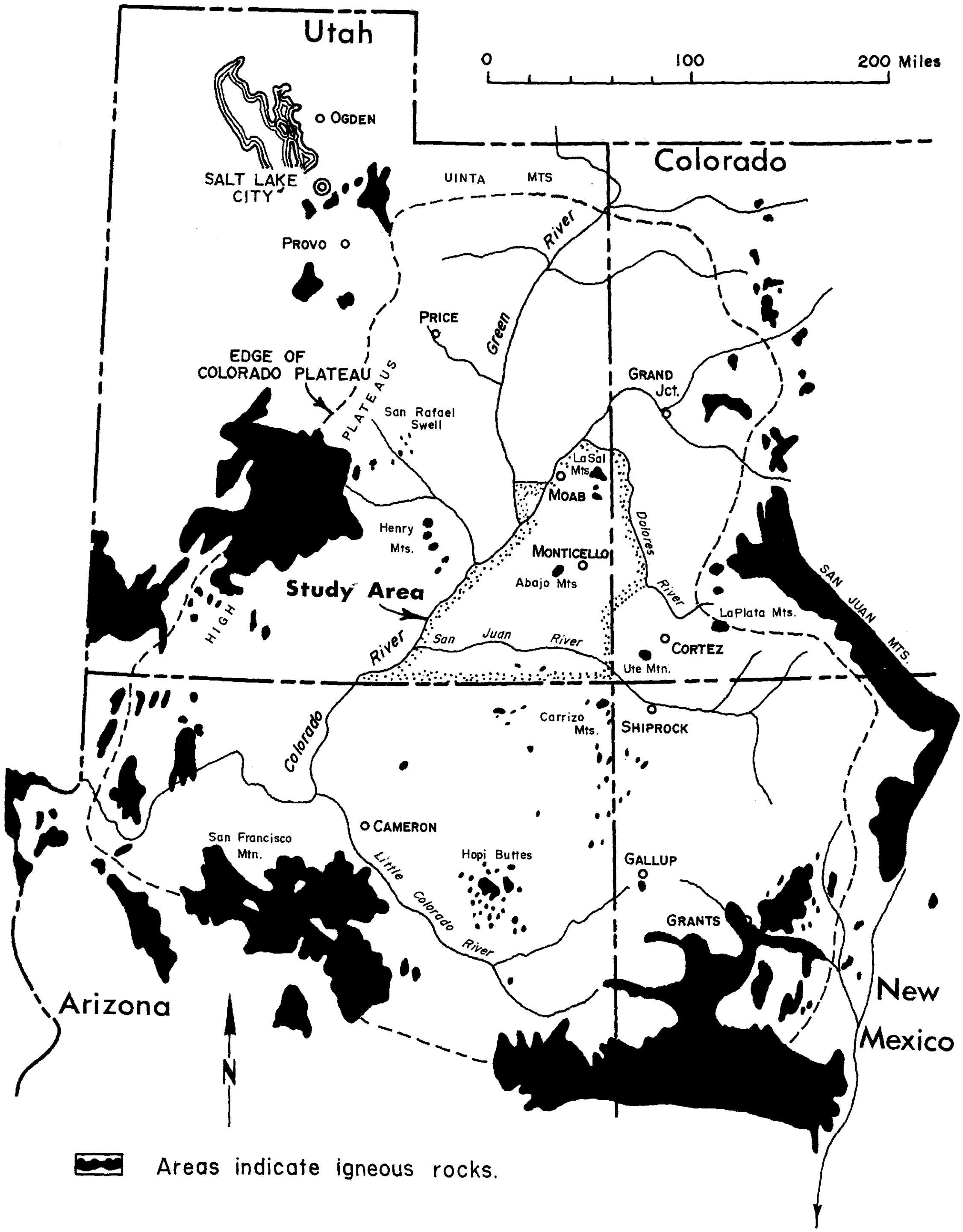

Figure 1. Index map of the San Juan project area with igneous rocks indicated by blackened areas (after Hunt, 1956, modified).

URANIUM AND OTHER METALS IN SEDIMENTARY HOST ROCKS, SAN JUAN PROJECT AREA, UTAH AND COLORADO

by Hellmut H. Doelling[1]

INTRODUCTION

The San Juan project area consists of San Juan County, Utah, a portion of Grand County, Utah, south of the Colorado and Dolores Rivers, and part of western Colorado, west of the Dolores River and north of Dove Creek. It includes a large part of the Colorado Plateau uranium region and its most productive districts, except for the Grants area in New Mexico (fig. 1). Many minerals containing elements of economic value are associated with sedimentary rocks exposed in the project area. These minerals coat fracture surfaces, sand grains, and fossil vegetal material. They impregnate spaces between clastic grains and, in many localities, replace host rock or carbonaceous debris. Metallic constituents of these minerals include vanadium, uranium, radium, copper, lead, zinc, molybdenum, iron, chromium, nickel, cobalt, manganese, arsenic, selenium, yttrium, and silver. Other enriched trace elements have been identified also. Vanadium, uranium, copper, radium, and, perhaps, manganese have been extracted commercially. As price and technology advance, others may be recovered.

The history of mining in the Colorado Plateau reflects fluctuations in the supply of and demand for radioactive elements and vanadium. In 1895, Roentgen discovered and defined X rays emitted from a Crooke's tube. In 1896, Becquerel, a French physicist, observed that certain natural ores gave off a form of energy, which, like X rays, were capable of exposing photographic materials. Three years later, the Curies isolated the radioactive element, radium. Long before these significant achievements, Colorado Plateau Indians used a yellow mineral, now known to be the uranium mineral, carnotite, as a pigment. In 1881, a prospector in the Roc Creek area of Colorado's Paradox district, being unaware of carnotite's properties, sent some to Leadville, Colorado, for gold and silver assay. He was told, of course, that it contained neither metal. Radioactive ore first was produced in 1898, when 10 tons of rich ore (20 percent U_3O_8 and 15 percent V_2O_5) was mined at Roc Creek and shipped to France. At first, production was limited--radium was a curiosity, uranium had few uses, and the potential of vanadium as a ferro-alloy was not yet recognized. The demand for radium jumped once the world realized the role it was to play in medicine and in the production of luminous paints. The production of radium began to expand about 1912, and expansion persisted until 1923. At that time, the plateau's sedimentary ores were mined primarily for radium and secondarily for vanadium. Discovery of the Shinkolobwe, a large deposit of high-grade radium in the Belgian Congo, led to the closing of most mines in the Colorado Plateau. For the next 12 years a recession plagued the industry. Rumors of war in 1935 opened mines long shut, and the ensuing "boom" lasted to the end of World War II in 1945. Throughout this second "boom," vanadium remained the prime product, while uranium was used to produce special alloys of steel, copper, and nickel, to color glass, glaze ceramics, and in scientific studies. Vanadium is used primarily as a steel, brass, and bronze alloy. In steels it frequently is used in combination with other ferro-alloying elements, such as chromium, molybdenum, and tungsten. Vanadium toughens steel by making it more resistant to strain, shock, and fatigue. The element has its place in the electrical, chemical, ceramic, paint, dye, and printing industries, as well.

Birth of the Atomic Age during World War II created critical demand for uranium in weaponry. For this reason, the United States Government created the Atomic Energy Commission in 1946 to stimulate, control and develop uranium mining activities, and to support and guide research in new uses for atomic energy. The Atomic Energy Commission established an ore-buying schedule in 1948, and so set into motion a new period of activity. Uranium became the more important and valuable of the two elements; vanadium assumed the role of by-product. Interest in both uranium and vanadium has continued to the present, despite a modified recession. That recession began in 1958 and ended in 1965, when commercial use of uranium as a power plant fuel supply became economically feasible.

Copper probably was discovered in the plateau as early as 1880, but exploration was not awakened in the White Canyon and Big Indian Wash areas until 1906, when the price of the metal increased. Since that time, several localities have produced intermittently. In past years, some of the ores--notably those at White Canyon--were rejected from time to time, because of an objectionable accompanying substance, uranium. By 1948, when it became profitable to mine uranium, investigators eyed the feasibility of extracting its by-product, copper, which some ores contained in considerable quantity. In the late 1950's, a copper concentrate was shipped to El Paso from the Texas-Zinc uranium mill at Mexican Hat. Today, copper is extracted from uranium ores at the Moab mill, and is leached from sandstone at several localities on the plateau.

1. Economic geologist, Utah Geological and Mineralogical Survey.

Two localities in the San Juan project area, the Wilson Mesa area near Moab and the Muleshoe Wash near La Sal Junction, may have produced some manganese. However, examination of the workings indicates little or no ore has been shipped.

URANIUM ECONOMICS — PAST, PRESENT, AND FUTURE — FOR THE SAN JUAN PROJECT AREA

Portions of the San Juan project area have produced ores intermittently since 1898, but only in the last 20 years has emphasis been on uranium, rather than associated elements such as radium, vanadium, and copper. A need for producing more uranium and developing domestic reserves resulted in the birth of the U. S. Atomic Energy Commission in 1946. Two years later, the AEC put its ore-buying policy into effect, later offering discovery and initial production bonuses, as incentives to stimulate exploration and production. Production increased gradually, and several new finds--notably those in the Big Indian Wash areas--were recorded. Land acquisition and exploration activity peaked in 1954-55, and production reached its zenith four years later. Fed by the discovery of large deposits in New Mexico and Wyoming, the uranium industry, growing more rapidly than expected, soon outstripped the market. By 1957, the Government was obliged to slash ore purchases. On November 24, 1958, the AEC published an announcement delineating limitations on uranium procurement. In essence, the AEC stipulated that those mines operating at the time could produce at their former mining rates, so long as the ore was of an amenable grade. (In this way, the market for this ore was guaranteed to 1963 and, for many mines, through 1966.) In addition, ore from new ore bodies could not be accepted, but could be sold to private enterprise. The AEC's initial production bonus plan ended March 31, 1962, and, as a result, exploration was curtailed and production declined. In 1962, the AEC extended its buying program through 1970. It guaranteed a price of $8 per pound for U_3O_8 up to 1968 and no more than $6.70 thereafter. However, after 1968, the Government would purchase uranium from new properties. To 1962, the market was mainly military. There were indications that uranium would be of ever-increasing importance to the electric power industry--although such expansion was not believed to be imminent.

Electrical utility companies gradually changed their collective mind about the use of nuclear fuels as nuclear power plants proved to be competitive under certain operating conditions. In 1960, there were three nuclear power plants in the United States capable of producing 72,000 kilowatts. Four years later, capacity had risen to 2,000,000 kilowatts, but no new plants were ordered. Capacity jumped to 2,700,000 kilowatts in 1965, and orders were in for plants capable of producing 5 million kilowatts. As a result, a reverse trend in the uranium industry began in late 1965. Land acquisition and exploration activity edged upward, and are still on the way up (1968). More than half of the new power plants ordered by utilities in 1966 were of the nuclear type, and no less than 27, capable of producing 22 million kilowatts, were specified. In addition, producers were allowed to fill contracts with approved foreign countries.

Because of the phenomenal growth of the electrical industry, it is estimated the U.S. will consume 520 million kilowatts by 1980. It is predicted nuclear plants will produce between 80 and 110 million kilowatts of that amount. Of current concern is the question of whether the domestic uranium industry can meet the requirements of nuclear fuel production. If technological advances continue and breeder reactors can be developed by the mid-1970's, the amount of required U_3O_8 would drop 30 percent. Even so, it is estimated that the United States annually will require up to 28,000 tons of new U_3O_8 by 1980. Domestic mines produced approximately 9,700 tons of U_3O_8 in 1966. The market almost certainly will persist for the next 10 to 20 years; so the question of the uranium industry's ability to meet new demands becomes critical.

The San Juan project area up to the present (1968) has produced about 15 percent of the total domestic output of uranium. Prior to 1950, production was small, but, with discovery and development of new deposits, climbed to a peak in 1959. Annual tabulations of uranium and vanadium production, in the project area, for the years 1956 to 1965 follow (p. 12 and 13).

From 1956 to 1965, the San Juan project area produced an average of 1,000,000 tons of ore annually, averaging 0.34 percent U_3O_8 and 0.47 percent V_2O_5. Over this 10-year period, production amounted to 34,000 tons of U_3O_8 and 48,000 tons of V_2O_5, as is shown graphically on Figure 2, p. 9. Most of the production (over 58 percent) has come from the Lisbon-Big Indian Wash area of the Monticello district, Utah. If Lisbon production as shown in Figure 2 is deleted, the result is that depicted in Figure 3, p. 9. Both graphs show maximum production occurring in 1958-59, but annual change is not as great in the second graph. While showing a gradual tapering off, this more uniform graph probably indicates a base production that could be maintained for years, if the demand situation remains favorable. The Lisbon-Big Indian Wash area typifies bonanza-type ore bodies--large, easy-to-mine, but short-lived. Bonanza-type ore bodies are the question marks in any analysis of the supply problem. Normally, they are not found during periods of minimum exploration activity, and this has been the situation since 1958. Discovery of such ore bodies in the San Juan project district could answer the question of whether the area will continue to be the source of 15 percent of the United States' supply of ore in the future. A uranium ore production graph, indicating the 10-year production for individual areas or districts, is shown on Figure 4, p. 14.

Uranium activity in the San Juan project area from 1952 to 1966 is shown in Figure 5, p. 16. Accelerated land acquisition activity, which immediately precedes or parallels maximum exploration, is shown as a bar

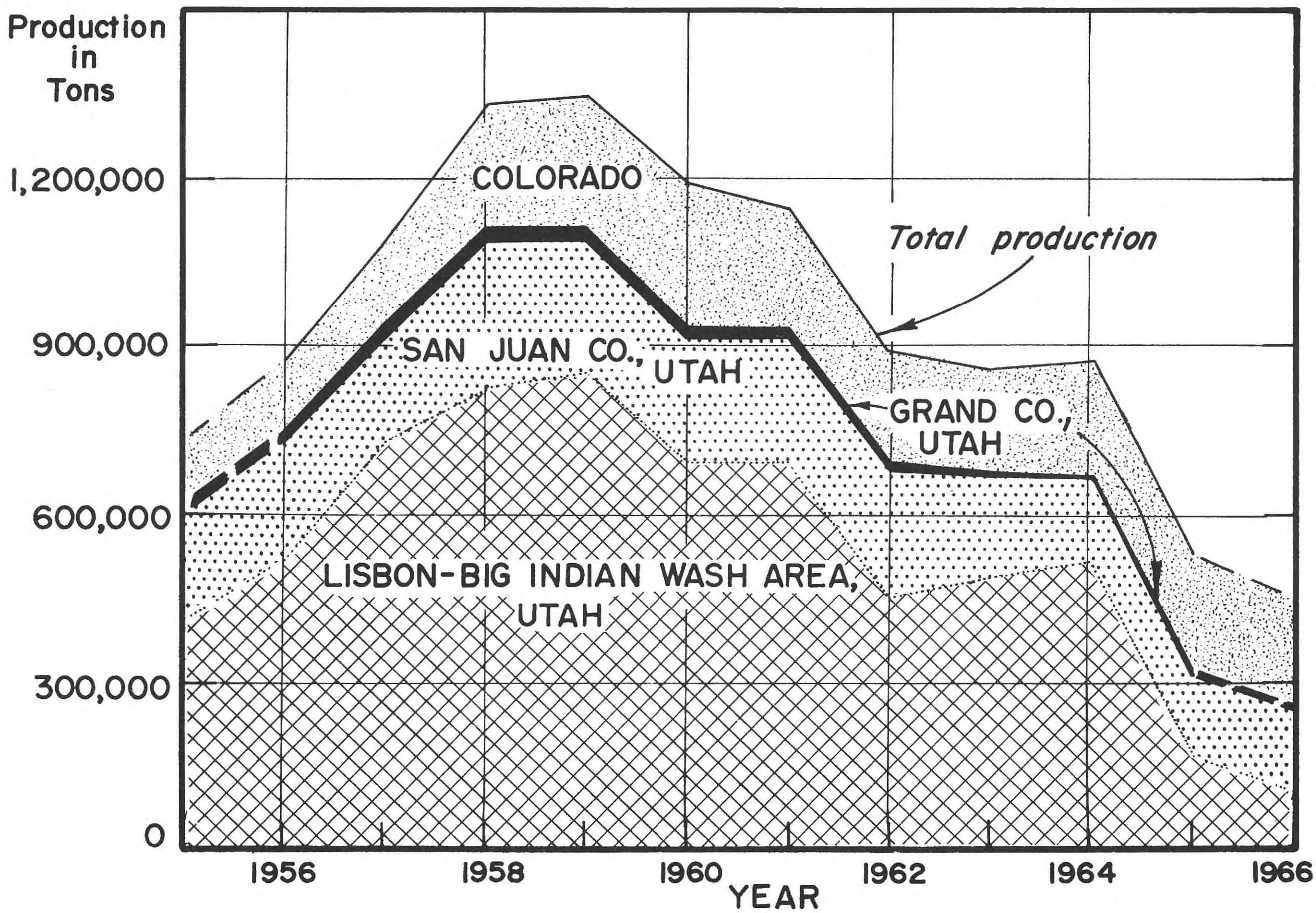

Figure 2. Uranium ore production from 1956 to 1965 (source, U.S. Atomic Energy Commission, Grand Junction, Colo.).

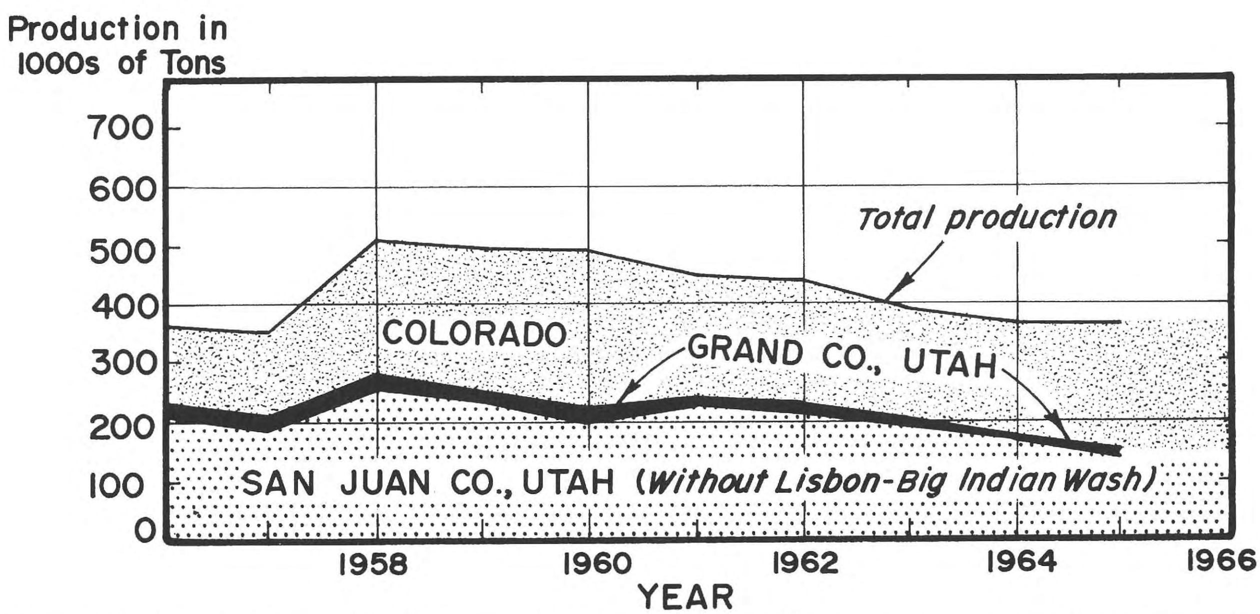

Figure 3. Uranium ore production, San Juan project area, Lisbon area is not included (source, U.S. Atomic Energy Commission, Grand Junction, Colo.).

Table 1. San Juan project area production, 1956 to 1965.

Year	Ore (tons)	U_3O_8 (lbs.)	Percent	V_2O_5 (lbs.)	Percent
1956:					
San Juan County	729,222	4,904,894	0.34	4,784,473	0.33
Grand County	14,021	86,509	0.31	385,579	1.38
Colorado	120,218	763,403	0.32	3,858,758	1.60
Totals:	863,461	5,754,806	0.33	9,028,810	0.52
1957:					
San Juan County	911,217	6,703,410	0.37	5,035,049	0.28
Grand County	20,183	106,252	0.26	484,273	1.20
Colorado	150,751	875,583	0.29	4,312,049	1.43
Totals:	1,082,151	7,685,245	0.36	9,831,371	0.45
1958:					
San Juan County	1,081,741	7,987,378	0.37	4,646,560	0.21
Grand County	25,720	169,179	0.33	652,809	1.27
Colorado	226,100	1,316,850	0.29	6,500,744	1.44
Totals:	1,333,561	9,473,407	0.36	11,800,113	0.44
1959:					
San Juan County	1,088,665	8,072,536	0.37	5,943,934	0.27
Grand County	24,846	130,894	0.26	503,848	1.01
Colorado	253,217	1,409,776	0.28	7,422,114	1.47
Totals:	1,366,728	9,613,206	0.35	13,869,896	0.51
1960:					
San Juan County	903,072	5,694,529	0.32	1,847,931	0.10
Grand County	25,673	132,705	0.26	600,101	1.17
Colorado	266,928	1,416,406	0.27	8,275,393	1.55
Totals:	1,195,673	7,243,640	0.30	10,723,425	0.49

1961:					
San Juan County	916,064	5,347,000	0.29	1,841,460	0.10
Grand County	16,599	96,501	0.29	454,164	1.37
Colorado	213,993	1,127,673	0.26	6,305,177	1.47
Totals:	1,146,656	6,571,174	0.29	8,600,801	0.38
1962:					
San Juan County	679,151	5,001,083	0.37	1,789,617	0.13
Grand County	12,362	79,289	0.32	325,609	1.32
Colorado	200,978	1,038,448	0.26	5,854,498	1.46
Totals:	892,491	6,118,820	0.34	7,969,724	0.45
1963:					
San Juan County	665,730	5,165,784	0.39	1,514,486	0.11
Grand County	5,199	34,069	0.33	129,315	1.24
Colorado	189,589	991,161	0.26	5,766,954	1.52
Totals:	860,518	6,191,014	0.36	7,410,755	0.43
1964:					
San Juan County	665,342	5,485,863	0.41	1,550,877	0.12
Grand County	363	3,387	0.47	5,151	0.71
Colorado	215,797	1,124,686	0.26	6,700,964	1.55
Totals:	881,502	6,613,936	0.38	8,256,992	0.47
1965:					
San Juan County	308,680	1,830,607	0.30	1,461,959	0.24
Grand County	5,148	41,719	0.31	79,283	0.77
Colorado	214,009	1,102,932	0.26	6,980,230	1.63
Totals:	527,837	2,975,258	0.28	8,521,472	0.81
GRAND TOTALS:					
San Juan County	7,948,884	56,193,084	0.36	30,416,346	0.19
Grand County	150,114	880,504	0.29	3,620,132	1.21
Colorado	2,051,580	11,166,918	0.27	61,976,881	1.51
TOTALS, 1956-65:	10,150,578	68,240,506	0.34	96,013,359	0.47

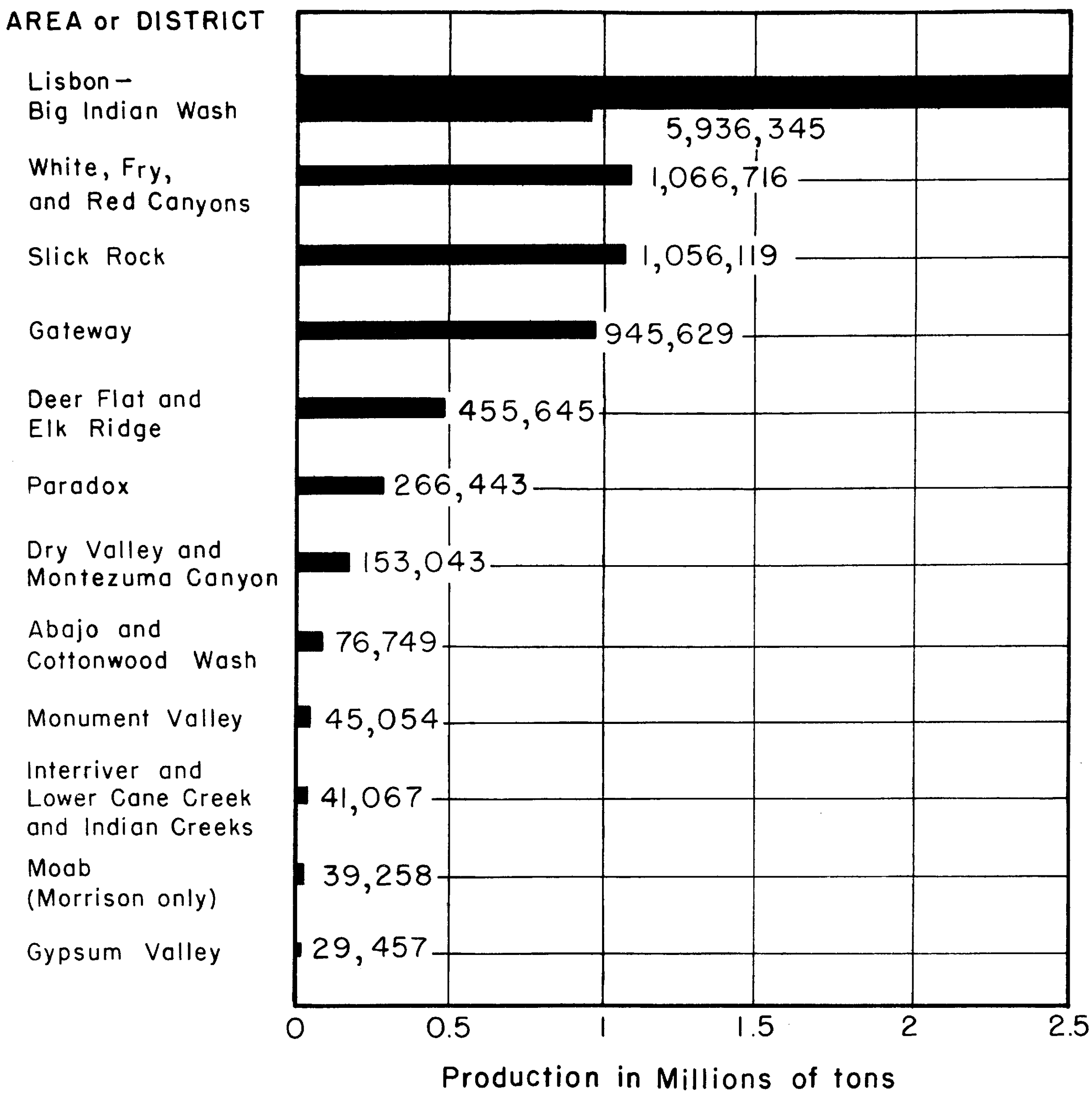

Figure 4. Uranium ore production by area, 1956 to 1965 (source, U.S. Atomic Energy Commission, Grand Junction, Colo.).

graph superimposed on an ore production graph. During the uranium "boom" of the 1950's, maximum activity in land acquisition took place from 1954 to 1955. Over 80,000 claims were filed in 1954, and they probably covered more San Juan County land than actually was available. Grand County recorded 15,305 claims in 1955, surpassing its 1954 mark by a few hundred; top production occurred four to five years later. The present "boom," which began in the latter part of 1965, has not peaked, as yet. County records indicate new claims during the first four months of 1967 surpassed 1966 totals. Since exploration activity tends to respond to land acquisition, it can be assumed that exploration has been stepped up proportionately. The new "boom" is somewhat different than the previous one. Since deeper ore must be located, exploratory activity is both more expensive and more cautious. Oil companies are entering the scene with strong financial backing and exploration experience, and mining companies are having to adapt their practices to the changing conditions.

The U. S. Atomic Energy Commission has estimated the following ore reserves as of January 1, 1966:

Districts	Tons of Ore	Percent U_3O_8
Monticello and Moab	1,220,000	0.243
Uravan Mineral Belt (Bull Canyon, Gateway, Gypsum Valley, Paradox Slick Rock, and Uravan districts)	2,654,000	0.277
White Canyon and Monument Valley Shiprock and Chuska	322,000	0.280
Green River, Thompsons, San Rafael, Henry Mountains	180,000	0.254
	4,376,000	

About 3 million tons of this reserve are in the project area. At the 1965 mining rate, it would take about six years to extract this ore. A strong uranium market has developed, assuring the future of the San Juan project area, if it can produce. Base production from old areas probably will continue well beyond the six years, and, no doubt, will begin to grow in about two years as the current decline levels off. Exploration already has commenced, especially in the Lisbon area and its extensions, in parts of the Sage Plain, and other areas. Four to five years were required to reach maximum production during the last "boom." It is estimated that the current rise will be somewhat slower in ascent, and that its ultimate height will depend on whether or not new bonanza-type ore bodies are found. The following then is an optimistic timetable of what may be expected, provided a few good-sized ore bodies are discovered and developed.

1968: The long decline in production should end. Reserves should increase due to the increased exploration.

1969-70: Certain areas will decline in importance, as others are developed.

1970: Both production and reserves should increase. One or two notable discoveries of ore should have been made.

1972: Production should begin significant expansion. Reserves, while continuing an upward trend, will not increase as rapidly as before.

1975: The rapid growth in production should begin to level off.

1975-80: Production should rise slightly, at first, then fall slowly as the industry settles into a more normal production rate--about one million tons annually. Production will come from deep mines, and mining costs will gradually increase, causing an important rise in the price of the metal.

After 1980: The projection for the years beyond 1980 is highly speculative, of course. The uranium industry's future depends on whether man can continue to find that "less than 1 percent" of area underlain by this valuable mineralized rock, and whether his technology will allow him to remove it economically in the face of competition and substitutes.

Copper

The need for copper continues to grow, and it is expected that copper production will increase slowly. Many uranium ores contain better than 1 percent copper and, as new mines are developed for their uranium and vanadium content, the by-product copper production is certain to rise. At present, the area produces over 300,000 pounds of copper annually.

Manganese

Manganese prospects in the project area are small and have not been developed for years. No manganese ore production can be looked for in the near future.

Other Metals in Sedimentary Ores

Other metals and certain rare metals listed on p.9, often are found concentrated in uranium ores. Although none of these metals thus far has been extracted, the picture could change should the demand for a metal or group of metals increase.

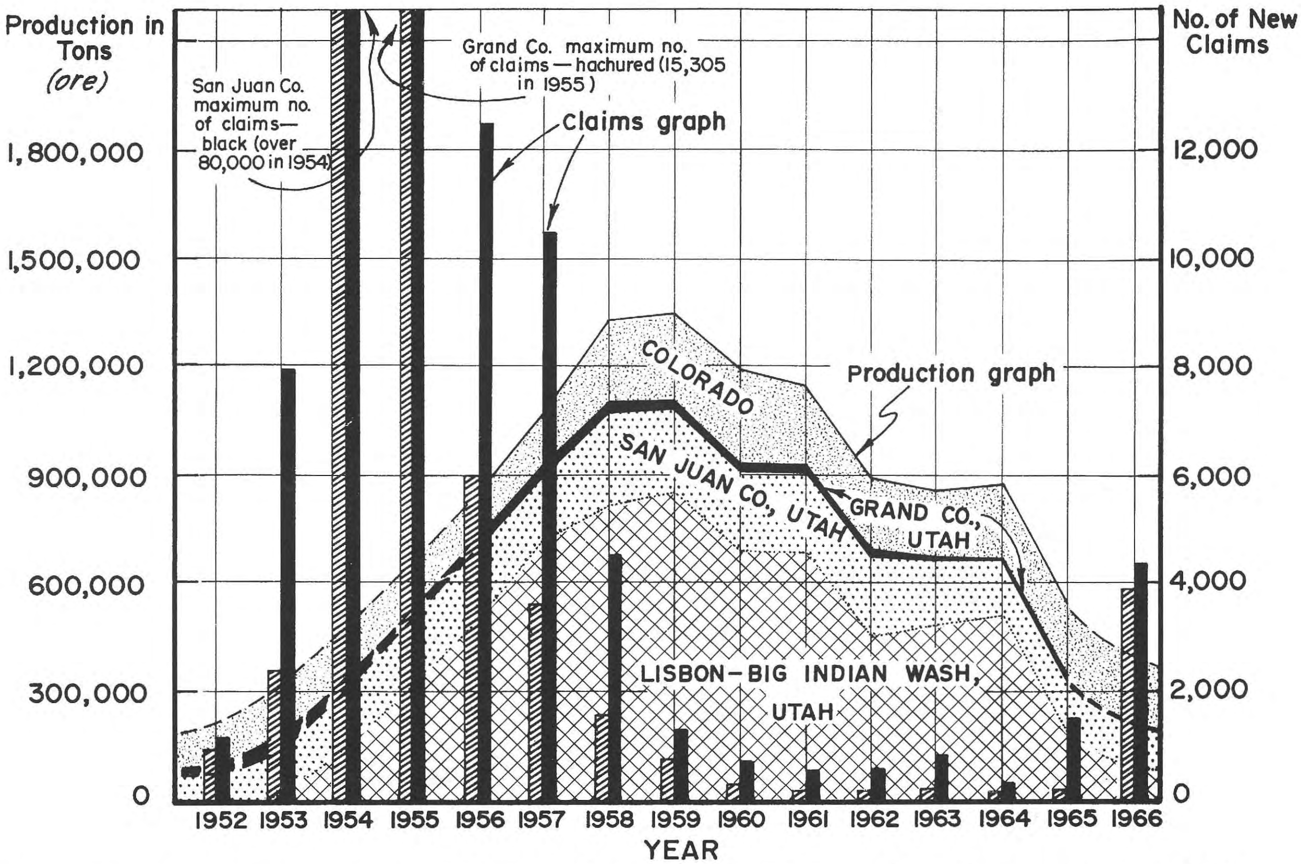

Figure 5. Graph shows uranium activity from 1952 to 1966, claiming and production prior to 1956 have been extrapolated. (Production source, U.S. Atomic Energy Commission, Grand Junction, Colo.; claims source, San Juan and Grand County recorders, Moab and Monticello, Utah.)

WATER USE IN URANIUM MINING, SAN JUAN PROJECT AREA

An analysis of 4,317 uranium mines made by the U. S. Atomic Energy Commission (Jan. 1967 workshop, Grand Junction, Colorado) pointed up the fact that 10 deposits have contributed 35 percent of the ore, while over 3,600 mines have produced about 3 percent. Apparently, over 95 percent of the mines are one- or two-man operations. Larger mines may employ more than 50 men, but most of them probably operate with fewer than 15. Water use at the mines depends to a large degree on the size of the operation and the equipment used, but water use would not exceed several thousand gallons per day, even in large operations. Water in the project area generally is obtained from nearby wells for use in drilling, to allay dust on roads and in mines, as a coolant for some equipment, and for drinking. If some 400 mines were in operation during the peak of production, and approximately 5 percent of these were using 2,500 gallons of water per day, then 50,000 gallons of water would be used per day. In 1965, there were perhaps 160 producing mines, which--using the same method of calculation--probably consumed a maximum of 20,000 gallons per day.

Milling operations, which use more water, commonly accompany mining. At the present time (1968), there are no uranium mills in the San Juan project area. A mill on the north side of the Colorado River near Moab, Utah, handles most of the ore mined in Utah. A sulfuric acid plant at Mexican Hat, Utah, supplies acid to copper leaching operations in and around the project area, and a small copper mill and leaching operation produces concentrates in Fry Canyon, Utah. The amount of water used by these plants is a function of the amount of ore processed and the method used. The mill at Moab consumes 3 to 3.5 tons of water for every ton of ore tested, but some mills have a 1:1 ratio. Currently, the amount of ore treated each year is about 340,000 tons. On this basis, the present rate of water consumption would be about 800,000 gallons per day. Most of the water is derived from the Colorado River; a smaller amount comes from wells. The acid plant at Mexican Hat uses San Juan River water at a rate of 5,000,000 gallons per month, or 167,000 gallons per day. Copper leaching at Fry Canyon initially requires about 10,000 gallons of water and acid per day, but as the liquid is recycled only about 2,000 additional gallons per day are needed. The operation obtains its water from Fry Spring, which normally flows at 4 to 5 gallons per minute. Total water used in the mining and milling of uranium and other sedimentary-type ores amounts to less than 1,000,000 gallons per day. If the uranium activity increases as expected in the San Juan project area, water consumption probably will triple within five years.

FACTORS IN THE FURTHER EXPANSION OF URANIUM IN THE SAN JUAN PROJECT AREA

The search for uranium in the Colorado Plateau during the "boom" of the 1950's was so comprehensive and intensive that most surface and near-surface deposits probably have been discovered. Aside from prospecting extensions of known ore bodies or systems, future search necessarily will be for hidden deposits. In spite of the wide distribution of uranium occurrences and the extent of formations known to be favorable, most of the ground is barren. For example, in the relatively highly mineralized Uravan mineral belt in Colorado, less than 1 percent of the area is underlain by known deposits. For this reason, knowledge acquired to date must be used to select areas of high potential for intensive and expensive drill prospecting. The search for uranium no doubt will be continued, when economic factors favor exploration.

Massive financial support and incentives resulted in the vast amount of geologic work that has been done on all aspects of uranium occurrence. The project area has been mapped topographically and geologically by the U. S. Geological Survey. Maps and numerous publications are available. This writer has synthesized descriptions and interpretations from available data to supplement his own limited investigations.

On the basis of the knowledge and experience gained thus far, several significant generalizations with respect to the project area may be made.

1. The occurrence of uranium and its associated elements is limited to sedimentary strata ranging in age from Permian to Cretaceous.

2. Slightly more than 70 percent of the ore mined in the project area from 1956 to 1965 came from Triassic formations. Of this amount, 99 percent was obtained from basal sandstone lenses in the Chinle Formation.

3. The Jurassic Morrison Formation was credited with 28.6 percent of the area's total production for the years 1956 to 1965. Of this, 70 percent was taken from the Colorado portion of the project area. Only 1.4 percent of production was contributed by all other formations in the project area, and the Permian Cutler Formation probably accounted for most of this.

4. In the Moab, Monticello, White Canyon and Monument Valley districts (Johnson and Thordarson, 1966, p. H48-H49), the Chinle accounts for 91 percent of production and 99 percent of indicated and inferred reserves are attributed to the Chinle. Of the potential reserves in these districts, 50 to 90 percent are believed to lie in the Chinle. The remainder are thought to be in the Morrison.

5. Almost all productive uranium deposits are tabular in form and parallel the bedding of sandstone lenses. Ore boundaries may be described by the limits of the lens, but margins of ore may cut across bedding at any angle. Deposits may be from a few inches to 20 or more feet thick, several hundred feet wide, and approximately 1,000 feet long. Although a majority of deposits are small, most of the production has come from deposits of 10,000 tons and some mines have produced 100,000 tons (Johnson and Thordarson, 1966, p. H24). Some tabular bodies are so clustered that several may be mined in a single operation.

6. Ore bodies usually occupy only a small portion of a sandstone lens. In the Chinle, especially, they tend to inhabit the lowest part of the lens. Although most deposits in the Morrison lie at the base of favorable lenses, they may occur in the center or along the sides.

7. Sandstone lenses are interpreted as fluvial fill of ancient stream channels. Associated mudstone beds that limit lenses are construed to be floodplain deposits. The most distinctive channels are those incised on an ancient erosion surface at the base of the Chinle. These occur mainly on the Moenkopi, but are found in other formations where the Moenkopi is absent. Channel systems have been recognized, particularly in the Elk Ridge-White Canyon area on the west side of the Monument upwarp and in the Monument Valley area. Paleotectonic warping of this surface is believed to have controlled the positioning of channel systems. Channels may occur in any part of the Salt Wash Member along the Morrison.

8. Generally, the positioning or distribution of uranium deposits are not related to faults or fracture systems. However, a few uranium deposits and some occurrences of copper minerals without appreciable associated uranium are found along faults. This is true of the Lisbon Valley fault and other collapsed salt anticlines bordering faults. Some secondary movement of uranium into fractures has occurred, but ordinarily it was not extensive enough to create workable deposits.

9. Most of the ore mined in the project area ranges in grade from 0.2 to 0.5 U_3O_8 (Johnson and Thordarson, 1966, p. H24). Vanadium content of vanadium-uranium deposits usually

is 1 to 2 percent V_2O_5. Copper content of copper-uranium deposits, chiefly on the White Canyon slope of the Monument upwarp, is 1 to 2 percent. Vanadium-uranium ratios are variable, although they may be distinctive for certain areas or formations. Most ore deposits have fairly well-defined limits; ore grade material extends to the edge of mineralization, leaving no marginal low-grade or subgrade material. Some low-grade or subgrade deposits do occur, particularly in the Brushy Basin Member of the Morrison (Johnson and Thordarson, 1966, p. H49).

10. Ore bodies may contain an oxidized zone, a primary zone, or both, but deeply buried deposits should consist entirely of primary minerals. In the primary zone, uranium minerals are uraninite or pitchblende and coffinite; vanadium minerals incorporate the oxide, montroseite, and the silicates, roscoelite, vanadium-bearing hydrous mica, and vanadium-bearing chlorite; the copper minerals are the sulfides, chalcopyrite, bornite, and chalcocite (Johnson and Thordarson, 1966, p. H2-H22). Pyrite and marcasite and other sulfides may be present in all primary deposits. In the oxidized zone of vanadium-uranium deposits, the common minerals are carnotite and tyuyamunite. These minerals are stable oxides, containing both vanadium and uranium. In the oxidized zone of uranium or uranium-copper deposits, a variety of minerals may form, including oxides, carbonates, sulfates, phosphates, arsenates and silicates of both metals. Some of these are soluble, and both uranium and copper are inclined to migrate. The minerals tend to fill spaces between sand grains, and in richer concentrations, they replace carbonaceous material, sand grains, and the clays of included or marginal mudstone.

11. A definitive theory as to the origin of known deposits often serves an important role in mineral exploration. Four factors enter into a study of the distribution of uranium deposits:

    --Source of uranium;
    --Transportation from source to position of deposition;
    --Emplacement of ore body;
    --Preservation of ore body.

Several theories have been formulated as to the source of uranium in the Colorado Plateau province. Early geologists favored a syngenetic origin for plateau deposits; that is, they reasoned the uranium was depossited along with the sands, silts, and muds that now encase it. The earth's crust contains an average of four parts per million uranium, something over 4,200 tons per cubic mile of rock. Igneous rocks contain up up 38 parts per million uranium, equivalent to 40,000 tons of uranium per cubic mile. So, according to this theory, land masses--igneous rocks, and, perhaps, Precambrian basement complexes made up of metamorphosed granites and other igneous rocks--constituted the source. The theory is supported by the fact that the Uncompahgre Highland, which is composed of such rocks, has contributed sediments to the Colorado Plateau province since Pennsylvanian time. Further, detrital grains of the most important host rocks contain small but significant percentages of feldspar, zircon, and other igneous rock-derived grains. Most geologists have discarded the syngenetic theory, because it has serious shortcomings. Uranium has been found associated with most post-Pennsylvanian formations, but only three or four contain significant deposits. Important Salt Wash Member deposits have their source in northern Arizona, and the basal sands of the Chinle pinch out to the north. The sedimentary features of the latter attest to a southeasterly rather than a northeasterly source. No heavy uranium-bearing minerals, such as monazite, samarskite, and brannerite, are associated with the ores, and the plateau's primary ore minerals are almost unknown as placer minerals. Although somewhat uncertain, isotopic age determinations indicate the deposits are younger than the host rocks. In certain areas, uranium deposits are more concentrated in belts and zones, such as the Uravan mineral belt. This fact points to epigenetic rather than syngenetic sources.

Epigenetic theories suggest solutions, charged with uranium, were carried from the source to the deposition point within the host. The two most important host units are overlain by mudstones containing bentonite of volcanic origin, which causes some geologists to infer that leaching of these former igneous materials provided uranium, which then was carried to the host by descending meteoric waters. This hypothesis has its failings also. Many areas beneath these mudstones are unmineralized, although other conditions favorable to uranium precipitation exist within the host. In addition, the impermeability of these overlying beds makes leaching of igneous constituents improbable.

Lateral secretion or widespread distribution by groundwater bearing uranium from igneous terrain also is unlikely. Most ore-bearing strata are discontinuous, lenticular, and enclosed in impermeable mudstones. Lateral migration of charged waters over short distances could have been significant in ore localization, however.

Inasmuch as many deposits are associated with "asphaltites," some workers suggest the petroleum fluids carried the uranium to deposition sites. If this were the case, the uranium could have originated in petroleum source beds. However, away from uranium producing areas, petroleum contains little radioactive material, and crude oils show a jump in radioactivity only in the vicinity of uranium deposits.

In the light of present knowledge, hydrothermal sources best explain the sandstone-type uranium deposits of the Colorado Plateau, although many questions remain unanswered. Facts suggesting hydrothermal origin are:

--The zonal arrangement of favorable areas around laccoliths;

--Primary ore minerals are similar to those in deposits positively identified as hydrothermal;

--Copper and other metal deposits near or associated with uranium ore have a definite association with faults, or are zonally arranged around them;

--While not conclusive, isotopic data relate sandstone deposits to vein deposits in the same region.

If this theory holds, the source of the uranium would be deep-seated and related to the late magmatic activity associated with the emplacement of Colorado Plateau laccoliths. Points that do not seem to support the hydrothermal origin are:

--The fact that most deposits do not appear to be related to structure; faults cutting ore do not influence the grade or the nature of the ore;

--The fact that vanadium, often associated with plateau uranium deposits, is not important as a hydrothermal metal;

--The fact that little alteration of country rock is displayed adjacent to uranium deposits.

Nevertheless, a hydrothermal source seems most credible; so movement of ore-bearing fluids to sites of deposition becomes important. Studies of the uranium content of groundwater in and around uranium deposits indicate it carries less than one part uranium per million (Phoenix, 1959, p. 64); it may be assumed original ore-bearing fluids carried little more. Consequently, large amounts of water would be needed to form deposits, and such features as the porosity and permeability of strata would be important to ore localization. Colorado Plateau strata have been grouped into three categories with respect to transmissivity of water:

1. Non-transmissive strata, including mudstone, claystone, limestone, and other impermeable rocks;

2. Strata of uniform permeability, such as aeolian and marinek sandstones and siltstones;

3. Strata of non-uniform permeability, such as fluvial sands, silts, and muds (Jobin, 1956, p. 208).

Ninety-nine percent of the uranium deposits of the San Juan project area are found in strata of the third type. Theoretically then, ore-bearing fluids were borne into sedimentary strata by internal pressures created by some magmatic disturbance. The fluids apparently rose along highly permeable or transmissive fracture and fault systems. Bentonitic clays adjacent to such fractures probably expanded with wetting and plugged the upward migration of the fluid, shunting it laterally into the formations. Transmissive units just below the plug would be most favored, since internal pressures still would be operative adjacent to fractures. In response to gravity, fluids leaving fractures would flow to the base of the aquifer they had entered, and the first good aquifer below the bentonitic plug would receive most of the ore-bearing fluid. Where internal pressures were less intense, fluids may have moved laterally before being blocked by a major plug. In either case, if chemical and physical conditions favored precipitation of uranium within the aquifer, an ore body would develop. Chemical reactions also require time. Uranium would not have sufficient time to precipitate, if fluids moved rapidly through a uniform aquifer of high transmissivity. A uniform aquifer of low transmissivity or a thin aquifer would not allow enough water to pass favorable areas for ore to localize, and only small and insignificant deposits or shows of mineralization would be formed. Ideally, then, thick, highly transmissive strata should be interbedded and intertongued with impermeable mudstones and claystones. Such a situation would permit large quantities of uranium-bearing liquid to pass, but would cause it to slow along the contacts with the mudstones. Scattered intrachannel mud galls and other trash, changes in the direction of channels, subtle variations in the dip or rocks, or any factor that would slow solutions, have an obvious role in uranium precipitation. Basal sandstones of the Chinle Formation and the Salt Wash Member of the Morrison Formation, which contain most of the uranium deposits in the area, are both overlain by thick bentonitic members. The largest Chinle deposits at Big Indian Wash are underlain by relatively permeable arkosic units rather than the usual impermeable beds of the Moenkopi Formation. Conditions favoring precipitation apparently were met near the point where fluids slowed and perhaps ceased to rise. The deposits' size may be due to the fact that minimal lateral migration prevented fluids from spreading over a large area. All Big Indian Wash deposits are found within a specific contour interval; lateral migration may have been thwarted by a stagnant groundwater situation.

The Uravan mineral belt, a semi-circular belt of concentrated uranium-vanadium deposits in the Salt Wash Member immediately east and extending into the San Juan project area, was delineated first by R. P. Fischer and L. S. Hilpert, 1952. E. V. Reinhardt created a second semicircle around the La Sal Mountains drawing into it areas of productivity not previously included in the old belt. He noted that the old belt is concentric around South Mountain; the new one, around Mt. Waas (North Mountain). In an earlier paper (1954, p. 56), Reinhardt pointed out that each stock provided mineralizing solutions, and that the average distance fluids traveled before giving up most of their uranium content was a function of the size of the stock. Belts farthest from the intrusion indicated a larger stock. However, he observed that strength of mineralization is independent of size. Mines, according to Reinhardt, are found in trends within belts that lie normal to them and radial to the mountains. Better deposits, the approximate direction of roll ore bodies, and a greater amount of bleaching in host rocks are all found along such trends. These trends are the incompetent sedimentary strata reflections of basement structures (complex fractures that lie radial to the laccoliths basement), which allowed the mineralizing solutions to pass.

If precipitation of uranium and the other ore metals is to occur within host units, certain physical and chemical conditions must be met. Certain physical requirements already have been mentioned, such as the mudstone-sandstone interrelationships, presence of clay galls and other channel trash, sudden changes in the direction of channel sandstones, and subtle variations in the dip of strata. All these factors allow time for the precipitation of uranium to occur; in solution, uranium is present in a high valent state and must undergo reduction to be emplaced. Most ore bodies are located in areas in which there is abundant carbonaceous trash, such as dinosaur bone or the twigs, leaves, and logs of fossil vegetal matter. Partial decomposition of this fossil material may have created pockets of hydrogen sulfide gas, which is known to precipitate uranium and copper. M. L. Jensen, 1958, suggested anaerobic bacteria might be responsible for creating hydrogen sulfide wherever fossil organic matter and sulfate solutions are present. Some deposits contain more uranium than can be accounted for by the amount of carbon trash present. Migration of hydrogen sulfide from the point of origin might account for such occurrences. Oil field waters and salt structure waters carry sulfates and, if these solutions were carried along with organic material, the situation would be favorable for the generation of hydrogen sulfide. Stinking Spring, near Fisher Valley in Grand County, Utah, gets its name from the hydrogen sulfide gas it releases. The proximity of favorable formations to salt anticlines or petroleum fields may be beneficial, and, in fact, may explain why deposits are found in what were thought to be unfavorable formations along faults in the Paradox fold and fault belt.

Once the ore has been emplaced, conditions must serve to preserve the deposit; a change in the chemical makeup of groundwater or excessive circulation may redissolve or flush out the uranium. Erosion also has eliminated many ore bodies. To recapitulate, the subsurface uranium geologist should consider:

--Nearness to laccolithic intrusions or other possible sources;

--Structures: synclines, anticlines, monoclines, subtle changes in dip, location of faults and of salt structures;

--Sedimentary characteristics: sandstone-mudstone ratios, position of ore-bearing lenses within a favorable formation, facies changes, the interval over which sandstone alternates with mudstone, channel trends, size of channels, and so forth;

--Nearness to known ore bodies: "one hunts elephants in elephant country" (Jensen, 1955, p. 235);

--Unusual local geologic features associated with ore bodies near the drilling project. In the case of roll ore bodies, for example, it is important to ascertain whether the drilling site is on one side of the ore body or the other (see J.W. King and S. R. Austin, 1965);

--Character of local ore bodies: average size, shape and type; average distance between ore bodies.

By applying the following principles, the subsurface uranium geologist can evaluate specific portions of the project area with respect to uranium mineralization:

1. The basal sandstones of the Chinle Formation or of the Salt Wash Member of the Morrison Formation must be present. Deposits in other units or in members of other formations normally are small and/or of low-grade, and consequently would not justify subsurface prospecting. For this reason, the Monument Upwarp area should be excluded, except where remnants of the basal Chinle can be found (the Elk Ridge and Monument Valley areas). Inasmuch as the Moss Back Member, the uppermost of the basal sandstones, pinches out along a line extending from Gypsum Valley, Colorado, to Moab, Utah, chances of finding ore in the Chinle northeast of that line are poor.

2. Favorable formations consisting of mostly sandstones and conglomerates or of mostly mudstone or siltstone are not favorable. The few Morrison Formation exposures in the southwestern corner of San Juan County, Utah, are in this category, because the Salt Wash Member is close to its source and contains little mudstone.

3. When thick bentonitic shales do not immediately overlie the favorable member, the area does not favor large ore bodies as in the vicinity of Bluff in southeastern San Juan County, Utah (excluding places where erosion has removed the shale).

4. Most favorable areas are near salt anticlines, particularly those structures that have not collapsed. Because of the extensive fracturing and faulting found in collapsed anticlines, it is conceivable that much of the hydrogen sulfide escaped before ore-bearing fluids entered the system. Of course, much would de-

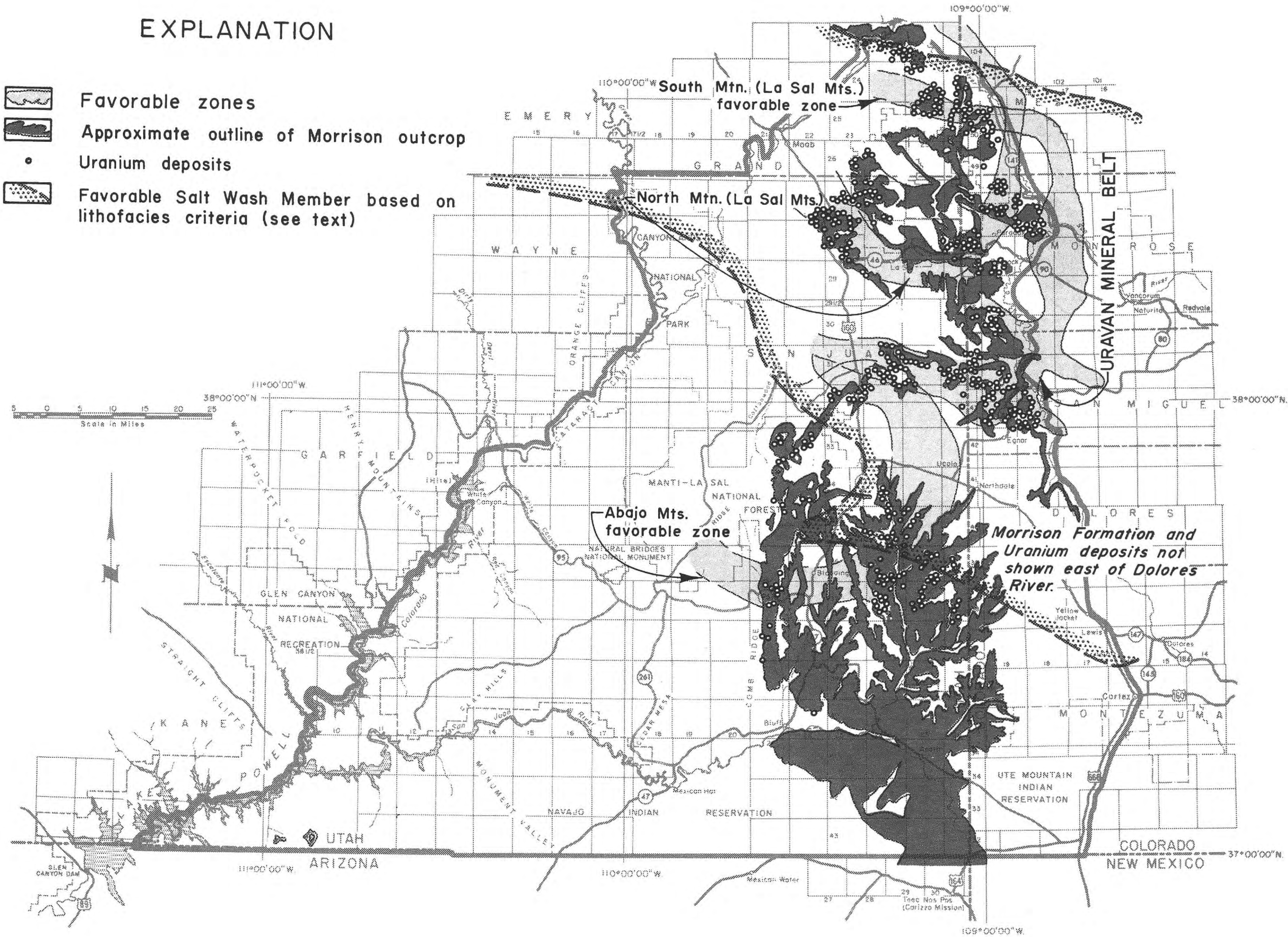

Figure 6. Morrison Formation outcrops, uranium deposits and the favorable Salt Wash Member, San Juan project area.

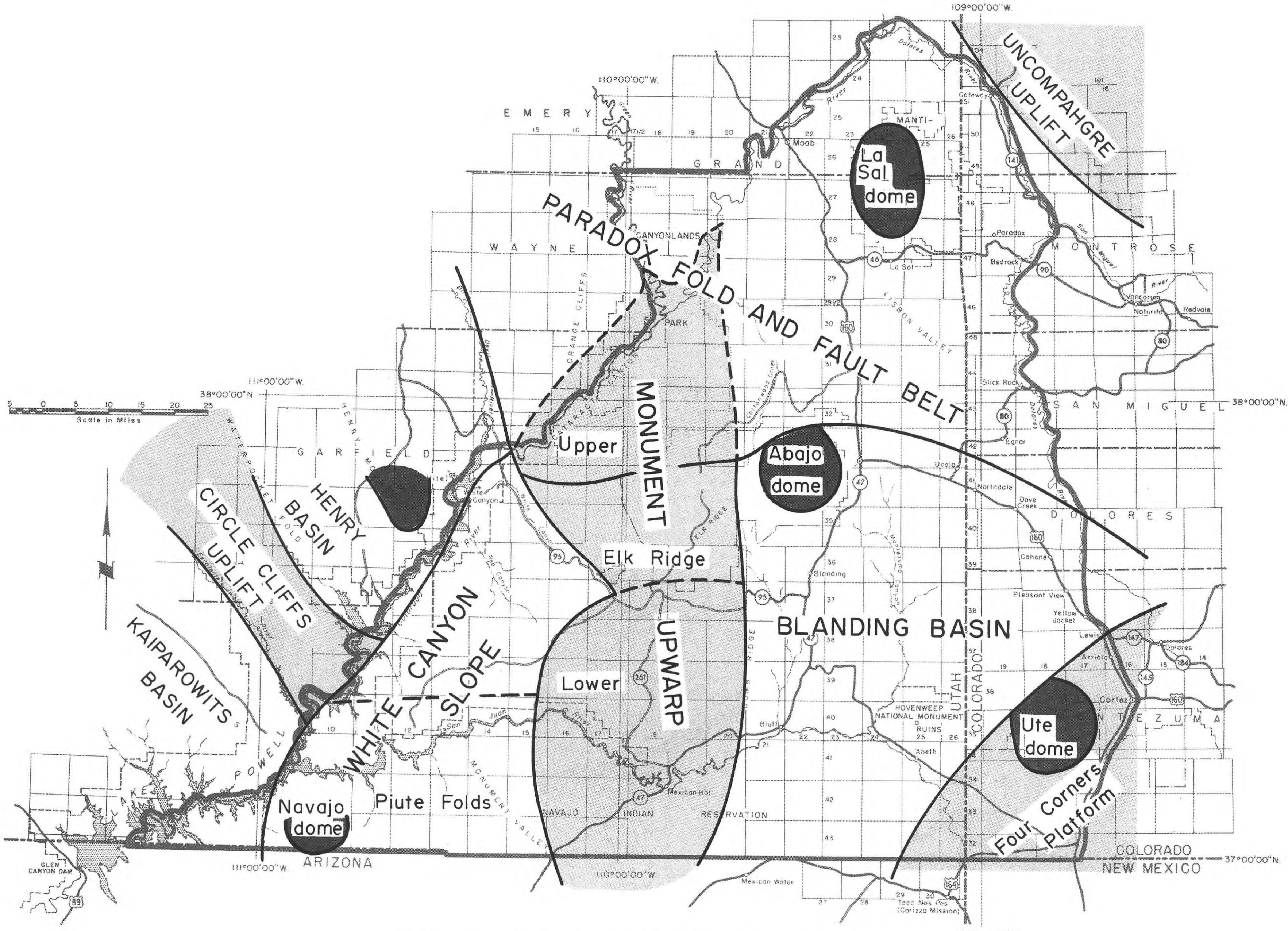

Figure 7. Tectonic divisions of the San Juan project area

pend on whether or not the salt structure had collapsed at the time of mineralization. Some significant ore bodies, however, would be expected to lie along the flanks of such anticlines. Uncollapsed salt structures, especially those associated with a few larger faults, are ideal for sizable ore bodies. Specifically then, the possibility of new ore is good in the vicinity of the Lisbon anticline, the Lisbon Valley fault and its extensions northwest and southeast, the Pine Ridge, the Dolores, and the Boulder Knoll anticlines. While mineralization may not have taken place on the crests of all anticlines, flanks and even the adjoining synclinal areas may have been favored, because, away from faults, liquids flow with gravity and changes of dip occur near synclines. Faults associated with uncollapsed anticlines should be considered extremely favorable. Large ore deposits at Big Indian Wash occur along a specific structural contour interval, perhaps caused by a stagnant groundwater situation.

5. Areas in the Uravan mineral belt (Fischer and Hilpert), the Mount Waas (North Mountain) belt (Reinhardt), and a similar belt around the Abajo Mountains (see fig. 6, p. 21) should be favorable, particularly portions of the Salt Wash Member of the Morrison Formation. Ore in the basal sandstones of the Chinle Formation shows little relationship to laccolithic centers, and it is difficult to pinpoint the source of these deposits. Unprospected tracts between and around known ore deposits in zonal belts of the Salt Wash and in that part of the Sage Plain between Dry Valley and Montezuma Canyon are promising.

6. Unprospected extensions of known channels in the basal member of the Chinle Formation, especially those of proper dimensions, could prove fruitful. Large areas under deep cover in the White Canyon, Red Canyon, and Elk Ridge areas have proved favorable. These channel extensions would be even more attractive if accompanied by subtle changes in dip or sudden changes in channel direction.

Johnson and Thordarson (1966, p. H47) note the occurrence of low-grade deposits in the Brushy Basin Member of the Morrison Formation, and suggest a potential for more low-grade material may exist.

The foregoing is meant to supply some parameters for further uranium exploration within the San Juan project area. Details and illustrations are presented throughout the text, and in the many references cited. Though situations considered favorable are outlined and underscored, none of the aforementioned theories have been proved. For this reason, no hypothesis should be neglected; productive deposits may be found in areas now considered unfavorable.

GENERAL GEOLOGY OF THE URANIUM DEPOSITS, SAN JUAN PROJECT AREA

Slightly less than 70 percent of the uranium deposits of the United States are located in the Colorado Plateau, in Utah, Colorado, Arizona, and New Mexico (fig. 1). The plateau, a crudely circular to oval physiographic province, is underlain by sedimentary rocks and surrounded by large areas of extrusive rocks. Rock layers within its confines are warped, in various degrees, by numerous upwarps, basins, anticlines, synclines, monoclines, and domal intrusions. The San Juan project area, near the center of the plateau, includes all of San Juan County and portions of Grand County, Utah, and Mesa, Montrose, San Miguel, and Dolores Counties, Colorado. The project area not only includes uranium districts and areas that account for 75 percent (or more) of Utah's total production, but extensive portions of Colorado's uranium producing districts and areas, as well.

Stratigraphy

Uranium deposits generally are localized in sedimentary rocks. Almost all exposed formations contain at least traces of uranium mineralization, but only three have been significantly productive, the Jurassic Morrison, the Triassic Chinle, and the Permian Cutler Formation. A fourth, the Triassic Moenkopi Formation, has produced uranium, but only from strata adjacent to its contact with the overlying Chinle.

Sedimentary strata of the San Juan project area range in age from Pennsylvanian to Quaternary, but post-Cretaceous unconsolidated or partly consolidated sediments are not known to be mineralized. A brief description and account of mineralization in each formation follows; discussion of the three most productive formations has been expanded appropriately.

Hermosa Formation

The Pennsylvanian Hermosa Formation, the oldest stratigraphic unit in the project area, is exposed in the cores of several salt anticlines, both in the Paradox Fold and Fault Belt (fig. 7) and in the southern portion of the Monument upwarp. The exposed Hermosa can be subdivided into two members. The older of these consists of salt, gypsum and anhydrite, interbedded with black and brown shale, minor dense gray limestone, and rare sandstone beds. Thickness varies considerably from place to place, reportedly ranging from 0 to 11,000 feet. Thickness in the project area, however, varies from 436 to 1,800 feet, averaging 1,000 feet in most places. Variances are attributed, in part, to salt flowage. The upper Hermosa is a gray to gray-blue cherty, fossiliferous limestone with interbeds of gray, black, and red sandy shales and greenish-gray sandstones. In canyon walls, the unit weathers into steep staircase-like topography. Only one mine in the Hermosa, an operation in the Gypsum Valley district of Colorado, has been productive. Thin lenticular limestone beds with shale partings constitute the host rock. Ore is localized in closely spaced fractures within the limestone, an indication that groundwater may have carried uranium downward from the overlying Salt Wash Member of the Morrison Formation. Some copper mineralization in the Hermosa has been found adjacent to faults in the Lisbon-Big Indian Wash area, and abundant radon gas has been detected from a well drilled into its lower Paradox Member, south of Elk Ridge.

Rico Formation

The Rico Formation, transitional between the Marine Hermosa below and the continental Cutler Formation members above, is mainly of Pennsylvanian age in the Four Corners platform area. The unit straddles the Pennsylvanian-Permian time line in the Elk Ridge-White Canyon areas. The Rico consists of alternating gray, marine fossiliferous limestone, and reddish and purplish mudstone, siltstone, and sandstone, which make it appear to have red and gray stripes with a weathered step-like topography. In areas closest to the Uncompahgre uplift, clastics predominate and sands are arkosic. In those areas most distant from the uplift, limestones predominate and sandstone of extremely fine-grain grades into siltstone. The Rico, which ranges in thickness from 300 to 700 feet, thins to the southwest, and is absent locally in the vicinity of salt anticlines. Exposures occur in the upper and lower Monument upwarp areas, and, perhaps, are scattered as small outcrops near the La Sal dome and salt anticlines in the Paradox fold and fault belt.

The upper part of the Rico Formation is mineralized along faults and fractures of the upper Monument upwarp area and in the immediately adjacent Paradox fold and fault belt areas. Uranium may have been transferred to the Rico by groundwater from overlying formations.

Cutler Formation

Except in the area east of the Monument upwarp's eastern boundary, where the Cutler Formation consists of brown, red, or purple arkose, arkosic sandstone, siltstone, and mudstone, with sporadic thin beds of cherty unfossiliferous limestone, the Permian Cutler Formation can be subdivided into several members and facies. The facies, comprising highly lenticular sandstone and arkose beds suggestive of a fluvial origin, have been called "the Bogus Tongue Member." The Bogus Tongue ranges in thickness from 1,000 to 3,000 or more feet; its thickest portion is near the Uncompahgre uplift. It thins and is missing locally in the vicinity of the piercement type salt anticlines. Members are easily definable west of the Bogus Tongue.

In the western part of the San Juan project area, the Halgaito Tongue--not everywhere present--reaches a maximum thickness of 465 feet. Lowest of the Cutler members, the Halgaito Tongue pinches out south of the White Canyon mining area, but is exposed only south of the pinchout zone. It consists of red to brown silty and shaly sandstone, shale, and thin, dense, gray, unfossiliferous limestone beds. Vertebrate remains have been found in irregular beds of clay-pellet conglomerate. The Halgaito Tongue weathers to a steep-benched slope.

The Cedar Mesa Sandstone Member lies above the Halgaito Tongue. The unit, which ranges in thickness from 275 to 1,250 feet, thins gradually to the west and more abruptly to the east and north from its thickest section south of Elk Ridge in the lower Monument upwarp area. It is a thick-bedded to massive, cross-bedded, light-colored, fine-grained, calcareous sandstone, with sporadic interbeds of dense, blue-gray limestone and red and brown shale. Usually, it is a cliff-former and, as it weathers, produces platforms, arches, natural bridges, and "biscuits." It is best exposed in the cliffs of Cedar Mesa and along White Canyon.

Another red bed unit, the Organ Rock Tongue, consists of red-brown mudstone and micaceous siltstone and sandstone. The sandier lower portion of the unit contains plant fossils, and weathers into spheroidal, nodular, and fluted forms. Ranging in thickness from 130 to 870 feet, the unit thickens to the northeast and southeast, and thins to the northwest.

The DeChelly Sandstone Member overlies the Organ Rock Tongue in the southern part of the area. The White Rim Sandstone Member is located in the White Canyon mining area. Both units consist of massive, cross-bedded, tan or gray sandstone. The DeChelly, which is exposed only in the southern part of the Monument upwarp, ranges up to 400 feet in thickness. It is comprised of conglomeratic lenses of clay galls, lime pellets, and shale fragments. The White Rim, exposed only in the vicinity of the White Canyon mining area, appears as a thin, white stripe up to 20 feet thick.

The Cutler Formation contains impressive uranium and copper deposits, which have been productive in a number of areas. In the Bogus Tongue Member, arkosic lenses and adjoining rocks contain copper-uranium and some vanadium minerals. Such lenses occur in a north-south trending belt, extending northward from Indian Creek mining area to the lower Cane Creek and Interriver areas. Some ore parallels the faults that cut this formation. The Bogus Tongue has been productive, in a small way, in the Big Indian Wash area, where it lies directly beneath the Triassic Chinle Formation. Most of the ore occurs in arkosic lenses in the upper part of the Cutler. Weak mineralization is present in some places where the Cutler is cut by faults adjacent to the salt anticlines of the Paradox fold and fault belt.

Western members of the Cutler Formation generally are barren in the San Juan project area, although immediately south of the Utah-Arizona state line significant

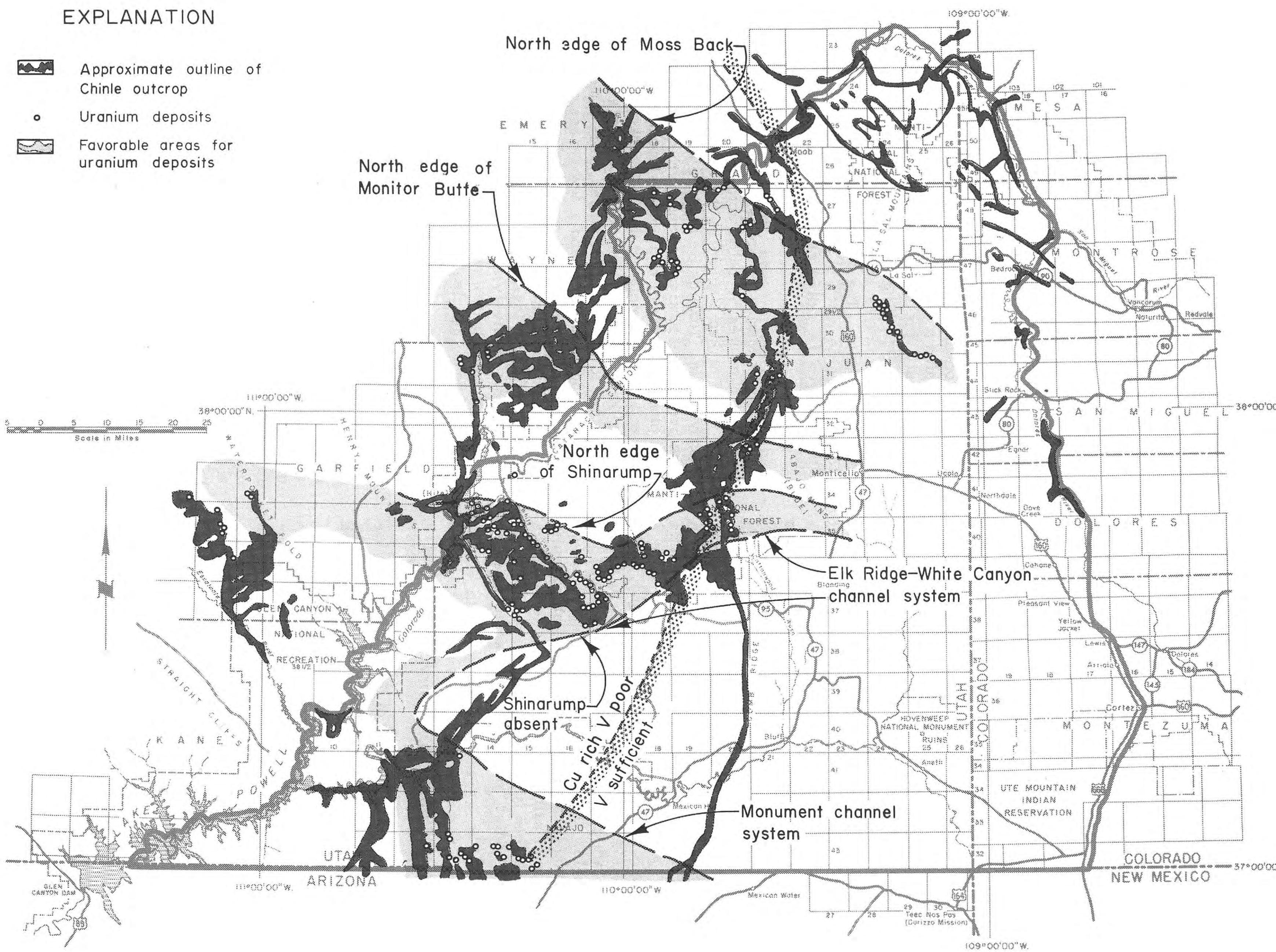

Figure 8. Chinle Formation outcrops, uranium deposits, and favorable areas for uranium, San Juan project area.

uranium-vanadium mineralization occurs in the DeChelly Sandstone Member at the Monument No. 2 mine. This mine is one of the best producers of the Colorado Plateau area. Here, the Triassic Moenkopi Formation is missing (as it is at Big Indian Wash), and the lower Chinle Formation channel sandstones rest directly on the DeChelly. The DeChelly is mineralized along this contact to a depth of eight feet.

Moenkopi Formation

The Triassic Moenkopi Formation is exposed around the periphery of the Monument upwarp, and in parts of the Paradox fold and fault belt. In most places, the Moenkopi can be subdivided into the lower Hoskinnini Member (not always present) and an upper member. Some older reports refer to the Hoskinnini as a member of the Cutler Formation. The Hoskinnini Member is a red-brown, nodular-weathering, sandy mudstone that ranges up to 120 feet in thickness. The upper Moenkopi ranges from 60 to 940 feet in thickness. It locally is absent near the salt anticlines, and thinnest in the southern part of the San Juan project area. It consists of evenly bedded brown to red-brown mudstone and siltstone, interbedded with ripple-marked brown to gray sandstone, sporadic limestone lenses, and clay gall conglomerate. Mineralization in the Moenkopi always is found near the top of the formation in those sandstone or conglomerate lenses in contact with basal sandstones of the overlying Chinle Formation. One mine in the Elk Ridge area is in a sandstone lens 40 feet below this contact, and, at the Rainy Day mine west of the project area in Circle Cliffs, the larger part of the ore body was found immediately below the contact. Other isolated occurrences of mineralization have been found along faults near the pierced salt anticlines. Production from the Moenkopi has been minor and mainly associated with Chinle ore bodies, except for the two occurrences mentioned above.

Chinle Formation

Slightly more than 70 percent of the ore mined in the San Juan project area from 1956 to 1965 came from Triassic formations. It is estimated that at least 99 percent of this amount was obtained from basal sandstone units in the Chinle Formation. In a useful classification of the Chinle Formation, with respect to uranium, Stewart (1957) designated the members in ascending order as (1) Shinarump, (2) Monitor Butte, (3) Moss Back, (4) Petrified Forest, (5) Owl Rock, and (6) Church Rock. The lower three members each contain notable uranium deposits, but as the upper three do not, they are treated as the upper Chinle in this report.

The Shinarump Member is a gray to yellow, medium- to coarse-grained to conglomeratic, cross-bedded and lenticular sandstone, interbedded with greenish-gray mudstone and siltstone. Silicified and carbonaceous wood and channel slump debris are particularly striking features. Individual beds and lenses vary greatly in thickness, and the entire member, discontinuous over much of the area, ranges up to 210 feet thick. Characteristically, the Shinarump fills channels cut into the underlying Moenkopi Formation. The two channel systems in the San Juan project area, the northern Elk Ridge-White Canyon system and the southern Monument system, coalesce near Red Canyon in the western part of the area. The Shinarump is absent in the area between the two systems and north of the White Canyon district (fig. 8). It thickens and becomes continuous further west.

The Monitor Butte Member generally overlies the Shinarump Member. Where the Shinarump is absent, however, it fills channels and, in places, blankets the Moenkopi Formation. The north edge of the Monitor Butte is located a short distance north of the Shinarump pinchout. The Monitor Butte, which may be as much as 250 feet thick, is a gray to greenish-gray claystone and clayey sandstone containing sporadic sandstone lenses. The Monitor Butte is part of the "lower mudstone unit" in the Elk Ridge area and at White Canyon is called the "mudstone-sandstone" unit.

The Moss Back Member occurs as a northwest-trending lens that measures 50 miles across from the Clay Hills south of Red Canyon to the north side of the Interriver area. Towards its northern edge, the Moss Back becomes discontinuous, and north of the Monitor Butte pinchout, rests directly on the Moenkopi Formation, and fills channels cut in the Moenkopi or other underlying units. The Moss Back is a pale-orange, light-brown to gray, cross-stratified, fine- to medium-grained sandstone containing a few lenses and thin beds of siltstone, mudstone, and conglomerate. The sandstones contain in many places abundant carbonaceous or siliceous fossil wood and channel debris. It weathers to a relatively resistant ledge, and forms the caprock of many buttes and mesas. It attains its maximum thickness, 200 feet, in the southern part of the area.

Except in a few small areas near the salt anticlines, the upper Chinle, which consists of the Petrified Forest, Owl Rock, and Church Rock Members, is continuous throughout the area. The total thickness, ranging from 200 to 1,133 feet, is greatest to the south. The upper Chinle, composed mainly of variegated mudstone and thin sandstone beds, also contains limestone beds, limestone conglomerate, lenses of quartz grit, and siltstone. Many of the mudstone beds are calcareous and many are bentonitic. Fossil remains of fresh water invertebrates, silicified and carbonaceous wood, and reptilian bones and teeth are fairly common. In most places, the upper Chinle weathers to a concave slope, which may be benched, where more resistant, thin sandstone beds and lenses occur.

With reference to the Chinle as a whole, nearly all the uranium deposits, except Big Indian Wash, are in the bottom of sandstone lenses, occurring in whatever member is in contact with the underlying Moenkopi

Formation. The richest ore is found at the bottom of the channels in the deepest scours. As a consequence, the Shinarump is ore-bearing in the southern part of the area, and the Moss Back Member, ore-bearing in the northern part. Most of the ore deposits in the Monument Valley and White Canyon districts are in the Shinarump. The Monitor Butte Member's few deposits are in the Elk Ridge and White Canyon areas, while a few are known to lie in the Orange Cliffs area across the Colorado River in Garfield County. The Moss Back is the productive member in the Big Indian Wash, Indian Creek, lower Cane Canyon, and Inter-river areas. The upper Chinle is mineralized in a few places, but essentially is unproductive. Deposits at Big Indian Wash (which account for 79 percent of Chinle production) are in the Moss Back Member, where it lies directly on the Cutler Formation. Production from the Shinarump Member accounts for 20 percent of the Chinle total. The remaining 1 percent includes production from other parts of the Moss Back, and a bit from the upper Chinle and the Wingate Formations.

Additional deposits in the Chinle Formation may lie in the areas shown in Figure 8. In these places, basal sandstone units become discontinuous and are confined to channels. The unusually large deposits at Big Indian Wash appear, wherever the basal Chinle sandstones rest directly on the Cutler. East of a dividing line, extending from Monument Valley northward to Moab, the Chinle Formation's uranium deposits contain vanadium minerals; west of this line, they hold mainly copper minerals.

In the White Canyon district, the uranium ore embodies up to 1 percent copper; data on the total copper recovered are not available. The vanadium content of the Chinle Formation's ores is about 0.47 percent at Big Indian Wash, 0.39 percent at Monument Valley, 0.14 percent in mining areas west of Moab, 0.06 percent at Elk Ridge and Deer Flat, and 0.27 percent at White Canyon.

Wingate Sandstone

The uppermost Triassic formation in the San Juan project area is probably the cliff-forming Wingate Formation. Its normal thickness of 225 to 375 feet is reasonably constant over the area, except where it was involved in steep folding, or in the vicinity of the salt anticlines. Its exposures parallel those of the Chinle everywhere, as a sort of monument set upon it. The formation is a pale, reddish-brown, buff, or orange, fine- to medium-grained eolian sandstone, characterized by vertical joints and plentiful dark-staining by desert varnish. Owing to uneven cementation in some places, the weathered surface of the cliff is pock-marked, giving it a Swiss cheese appearance. Uranium mineralization in the Wingate has been noted in the salt anticline area, but it is seldom considered a potential host. Isolated instances of mineralization exist in the Paradox district and in the Gypsum Valley district of Colorado along faults related to salt anticline deformation. Nevertheless, total production has been insignificant.

Kayenta Formation

The middle unit of the Glen Canyon Group is the Kayenta Formation, assigned either to the Triassic or the Jurassic. It represents a fluvial interval, in contrast to the eolian lithology of the Wingate below, or the Navajo above. The Kayenta consists of irregularly bedded, lenticular sandstone, with subordinate shale and conglomerate. The common color grades from red to maroon, but white, light-gray, buff, or lavender sandstone beds do occur. Fresh water mollusks have been discovered in limy sandstone beds near the top. The Kayenta Formation ranges from 40 to 320 feet in thickness, and is absent in Paradox and Gypsum Valleys. Thinnest sections occur in the southeast part of the area. Uranium mineralization is present in the Kayenta in Lisbon Valley and at Roc Creek in the Paradox district. As with the Wingate Formation, these occurrences are related to faults associated with salt anticlines. The potential for deposits of importance in the Kayenta is small.

Navajo Sandstone

The eolian Navajo Sandstone of Jurassic age is best known from its exposures in the great cliffs of Zion National Park, Utah. In the San Juan project area, it has a similar appearance, but is much thinner. It thins and then disappears to the east. Its thickness ranges from 0 feet northeast of the San Miguel River in Colorado to 1,100 feet in the western part of the White Canyon slope near Navajo Mountain. Exposures are abundant everywhere, except in the Monument upwarp area and in the salt anticline area in Colorado, where it was not deposited. The Navajo is a massive, cross-bedded, yellowish-gray to pale-orange sandstone, containing sporadic lenses of gray, fresh-water limestone. It weathers into steep cliffs, modified by alcoves, niches, and narrow fracture-inspired canyons. Near the top, weathering creates rounded domes, mounds, and other irregular shapes. It is an excellent aquifer and many springs issue from it, but it has no potential for uranium ore. One occurrence of copper-uranium mineralization has been reported along fractures paralleling basic dikes near the Red Mesa Trading Post. The Post, close to the Arizona border, is approximately 15 miles east of Comb Ridge, Utah.

Carmel Formation

The Jurassic Carmel Formation overlies the Navajo Sandstone as a thin, reddish scab. It is considered to be a nearshore littoral deposit, consisting of red and white, earthy, lumpy, unevenly bedded sandstone, red mudstone, and lenses of gray limestone. In places, the bedding is contorted, and shows local unconformities. The formation thins eastward, and was not deposited in parts of Gypsum and Paradox Valley. In the project area, it is absent near the Utah-Colorado border. It is as much as 230 feet thick near Cataract Canyon on the Colorado River. The only example of mineralization of the Carmel in the San Juan project area is in Gypsum Valley, where the Carmel and Entrada are not separated. It is not considered to be important as a host rock. Small, low-grade deposits have been reported from near the top of the Carmel, northwest of the project area (near Saucer Basin, 30 miles south of Green River, Utah).

Entrada Sandstone

Except for an area near Navajo Mountain, outcrops of the Entrada Sandstone are restricted to that part of the area east of the Monument upwarp. Thickness ranges between 66 and 400 feet. The formation thins to the east, and was not deposited on parts of Gypsum and Paradox Valleys. In Colorado, it forms the "Slick Rim" cliffs, which consist of orange-red to tan, fine- to medium-grained sandstone. In southern Grand County and northern San Juan County, an upper white, cross-bedded, fine-grained sandstone member is known as "the Moab Tongue." To the west, the Entrada becomes more silty and earthy, and orange-red colors tend to predominate. Most uranium minerals are associated with faults in the Paradox and Gypsum Valley areas. Copper minerals may be found at the Tuffy copper mine in the Abajo area of the Monticello district. Uranium production from the Entrada Formation has been, and is expected to be, unexceptional.

Summerville Formation

The Summerville Formation of Jurassic age is partly a red to brown-colored siltstone and partly a calcareous claystone unit that has sporadic layers of reddish-brown sandstone. Thin veinlets of gypsum are common. It either weathers to red, clay-covered slopes or ribbed, vertical cliffs. Thickness of the formation varies from 25 to 208 feet. The Summerville remains thin near Moab and southern Grand County, thickens in the central and southern part of San Juan County, and is absent in parts of the Paradox and Gypsum Valleys. Uranium minerals have not been reported from this section of the San Juan project area.

Bluff Sandstone

The Bluff Sandstone, Jurassic in age, is restricted to the southeastern part of San Juan County. It extends only as far north as the Blanding and Cottonwood mining areas. An eolian sandstone that forms cliffs and platforms, it may be white to gray-brown, massive, thick-bedded, or cross-bedded. The best exposures lie on either side of the San Juan River, near the town of Bluff, Utah. The thickness fluctuates from a feather edge to 350 feet, as the Salt Wash Member of the Morrison that lies above it thins. Despite the interfingering of these two, the stratigraphic level that normally contains uranium deposits is only slightly mineralized in the Salt Wash of the Bluff-Butler Wash area. As a consequence, significant production cannot be expected from the Bluff.

Junction Creek Sandstone

The Junction Creek Sandstone, Jurassic in age, occurs only in the southern part of the Slick Rock district of Colorado. Probably, it can be correlated with parts of the Summerville and Bluff Sandstone Formations. The 20- to 150-foot thick unit is a light-buff, fine-grained sandstone, with eolian type cross-bedding. It is not known to be mineralized.

Morrison Formation

With a record of 28.6 percent of the total production of the San Juan project area, the Morrison Formation of Jurassic age is second to the Chinle Formation in economic importance. Over 70 percent of the Morrison production has come from the Colorado portion of the project area. Outcrops of the Morrison Formation lie almost entirely in the eastern portion of the area (fig. 6). Several favorable zones or belts, discussed earlier (p. 17-23), superimposed on parts of these outcrops, are shown in Figure 6.

Over most of the project area, the Morrison Formation is composed of the lower Salt Wash Sandstone Member and the Brushy Basin Shale Member. In the southeastern part of San Juan County, however, these two members are separated by the Recapture Creek and the Westwater Canyon Members. Of these four, the Salt Wash has been the most productive. The Morrison is a grayish-orange, light-brown to white lenticular sandstone, locally conglomeratic, interbedded with greenish-gray and grayish-red shale and siltstone. Sandstone lenses, alternating with shale, produce a step-like topography on the weathered surface. Sandstone lenses, thicker than 40 feet, are more apt to contain uranium deposits of commercial size than smaller lenses. Lenses 120 feet thick are known in the area. Total thickness of the Salt Wash may differ from 250 to 550 feet. Although several horizons of the Salt Wash contain commercial ore, the most productive ore bodies occur near the top of the member in the Colorado portion and the immediately adjoining Utah portions. In other areas, the productive lens appears near the base or middle of the member. Thickness may vary as much within a short distance as it does regionally. The source area for the Salt Wash is in Arizona, close to the place the Colorado River leaves Utah. Northeast of this point, the member thins to the north.

Like the Salt Wash, the Recapture Shale Member, which immediately overlies it, consists of interstratified sandstone and mudstone. The pinkish-gray to light-brown sandstone is fine- to medium-grained, cross-stratified, and notably friable. The mudstone beds display variable shades of red coloration. Locally, they are calcareous, gypsiferous, or both. Since the source area is near the site of Gallup, New Mexico, the member thins northward. Thickness in the project area ranges from 0 to 300 feet. Although the Recapture pinches out and intertongues with the Salt Wash in the vicinity of Blanding, it is not known further north. The Recapture is non-productive.

The Westwater Sandstone Member is yellowish-gray to light-brown, fine- to medium-grained, dominantly a cross-stratified sandstone. In many places, silty, greenish-gray or reddish interbedded claystone appears. The sandstone of the Westwater is resistant and cliff-forming. This contrasts sharply with the softer, more friable Recapture below. The source area, as is the Recapture's, is to the south. It intertongues with the overlying Brushy Basin Member. The maximum thickness is 300 feet. The Westwater is not productive in the San Juan project area.

Shale beds of the Brushy Basin Shale Member are mostly bentonitic. They are variegated, but red and purplish colors dominate. Thin limestone, conglomerate, or sandstone lenses are interbedded. The Brushy Basin weathers to rounded slopes. Thickness ranges from 220 to over 700 feet; the thickest sections are in the Slick Rock district of Colorado and the thinnest are in the southwest corner of the project area. In many places, sandstone and conglomerate lenses near the base of the Brushy Basin are mineralized, and some lenses at other levels contain ore.

The Salt Wash is the productive ore horizon of the Gateway, Paradox, Slick Rock, Gypsum Valley, and Moab districts, and of the Montezuma Canyon, Cottonwood, Abajo, and Dry Valley areas of the Monticello district. The Brushy Basin is mineralized in the Paradox and Slick Rock districts, and Montezuma Canyon and Dry Valley areas. A broad area, occupying the north half of the project area in the Salt Wash, has been established as favorable by Craig and others (1951, p. 58) on the basis of lithofacies (fig. 6). The Salt Wash is more favorable for uranium occurrence where:

- --The total member exceeds 240 feet in thickness;
- --The stream channel deposits comprise 40 to 55 percent of the thickness of the member;
- --The total thickness of the stream channel deposits is 90 to 200 feet;
- --The stream channel deposits are reasonably continuous.

Ore deposits in the Morrison Formation are of the vanadium-uranium type. The ratio between these two elements changes from mine to mine and from district to district. The vanadium-uranium ratios for each producing area in the Morrison are tabulated below (based on 1956 to 1965 production figures):

Abajo area, Monticello district	10:1
Cottonwood area, Monticello district	10:1
Gypsum Valley district, Colorado	8:1
Dry Valley area, Monticello district	7.5:1
Slick Rock district, Colorado	7:1
Paradox district, Colorado and Utah	5.6:1
Moab district	4:1
Gateway district, Colorado and Utah	2.3:1
Big Indian Wash-Lisbon, Monticello	2.3:1
Montezuma Canyon, Monticello district	1.3:1

Unlike the Chinle Formation, the Morrison contains very little copper, except in the Slick Rock district. Even there, the ores have averaged only 0.07 percent copper.

Burro Canyon Formation

The Burro Canyon Formation of Cretaceous age forms the rim of the Sage Plain area east of the Abajo Mountains, and its area of outcrop extends into Colorado. It is a sequence of conglomerate sandstone, shale, and thin lenses of limestone. The light-gray to light-brown sandstone beds are poorly sorted, lenticular, irregular in thickness and form, and cross-stratified. In some areas, the lower contact interfingers with the Brushy Basin, elsewhere it is unconformable with it. Uranium minerals are known to occur in the Burro Canyon Formation in a claim northwest of Naturita, Colorado, east of the project area. Some uranium-vanadium-copper mineralization has been found adjacent to faults in the Lisbon Valley area. The Dakota-Burro Canyon Formation in the Abajo Mountains is the host rock for copper mineralization at the Copper Queen mine. Nevertheless, the mineral potential for the Burro Canyon Formation is anything but considerable.

Dakota Sandstone

The Dakota Sandstone of Cretaceous age is an irregularly bedded, coarse-grained, gray to yellowish-brown conglomeratic sandstone, with interbedded light-gray sandy shale. Locally, it contains carbonaceous shale and coal. The thickness ranges to a maximum of 200 feet; the formation is thinner in the northern and western parts of the area. No important Dakota deposits of uranium have been found in the project area, although ore has been mined from at least two localities in New Mexico. Copper minerals occur in the Dakota, in Lisbon Valley, and on the flanks of the Abajo Mountains. Annual production of copper from the Dakota is slightly more than 10,000 pounds annually.

Mancos Shale

The Cretaceous Mancos Shale, the youngest widespread sedimentary consolidated unit in the San Juan project area, consists of dark-gray marine shales, interrupted at intervals by yellowish-gray sandstone layers. No uranium mineralization in this formation has been reported in the project area.

Relationship of Stratigraphy to Uranium Deposits

Although there are occurrences of uranium minerals in most of the formations of the San Juan project area, only the Chinle and Morrison are widely and significantly mineralized. Typically, the host rocks are sandstone lenses formed in channels of fluviatile origin, associated with mudstones that were floodplain deposits. Both Chinle and Morrison deposits are overlain by impermeable, bentonitic mudstone layers.

Geologic Structure and Its Relation to Uranium Deposits

As tectonic or deformation structures have profound effects in controlling the deposition and distribution of mineral deposits, many geologists have attempted to relate uranium deposits in the Colorado Plateau to structural features--faults, folds and igneous intrusions. The concensus is that all but a tiny fraction are related directly to the configuration of favorable sedimentary units. Only a few, notably the copper-bearing deposits, have a direct and obvious relation to faults and folds, or to igneous intrusions. The relations to structures, therefore, are subtle, intimately related to the timing of tectonic activity that influenced formation and location of favorable host rocks, and the conditions that existed, when mineralization took place. The structure of the Colorado Plateau has been considered in numerous publications. A brief summary of structure in the project area is included in this paper with the aid of Figures 7 and 9.

Major tectonic features are the northward-trending Monument upwarp, or uplift, with the Blanding Basin to the east and the White Canyon slope to the west, and the northwestward-trending Paradox fold and fault belt in the northern part of the area between the Uncompahgre uplift to the northeast and the Monument upwarp. The La Sal and Abajo domes, which are pierced by igneous intrusions, are formed in the Paradox fold and fault belt and the northwest corner of the Blanding Basin, respectively. However, while there are many open folds there are relatively few faults. Folds, faults and complex fracture systems mark the Paradox belt in the southern part of the area. Because the Paradox belt is underlain by salt beds that slope away from the Uncompahgre uplift, it is believed movement within the salt has been a major factor in folding and faulting of overlying formations. As some Mesozoic formations in the Paradox belt were not deposited over salt anticlines, these movements apparently have been taking place throughout post-Pennsylvanian time, and have influenced the configuration of sedimentary deposition, which in turn affected the location of uranium deposits. Other movements, continuing to the present time, have exposed parts of uranium-bearing formations to erosion, and so have controlled the pattern of outcrops in which uranium deposits have been found.

With respect to the deposition of uranium, the matter of timing in the development of tectonic features is particularly significant. If the evidence of lead-uranium ratios (Stieff, Stern and Milkey, 1953, p. 15) is correct--and the time of uranium deposition or redistribution is latest Cretaceous or early Tertiary (Johnson and Thordarson, 1966, p. H36)--then the sedimentary structures and the tectonics that influenced their configuration antedate the deposition of uranium, and most of the folds, faults and fracture systems post-date them. This would account for the general lack of association with faults. As some of the copper deposits have a distributive relation to faults (Johnson and Thordarson, 1966, p. H36-H37), they may have been deposited later than the uranium. Groundwater may have redeposited uranium and other elements, and could be responsible for minor occurrences of such minerals in faults and fractures.

The Monument upwarp and the White Canyon slope areas reflect the influence of tectonic activity prior to deposition of the Chinle Formation. The Moenkopi and even older formations were variably disturbed and eroded and channels were cut in these formations. A topographic high was centered in what is now the middle portion of the lower Monument upwarp. Streams were forced to flow around the margins of this high or through its structural sags. Streams on the southwest margin of this high formed the Monument channel system, and joined the northern channel system near Red Canyon. Distribution of other channels may have been influenced by the warping of the pre-Chinle erosion surface.

CHARACTERISTICS OF PRINCIPLE HOST ROCKS AND ASSOCIATED URANIUM DEPOSITS

Significant characteristics of the Cutler, Chinle and Morrison Formations, which have a bearing on the occurrence of uranium are summarized below. The three formations contain more than 99 percent of the ore so far discovered in the San Juan project area. These units appear to offer the best hope for the future of the uranium mining industry in this area.

Deposition Environment of Host

Cutler Formation
Fluvial

Chinle Formation
Fluvial

Morrison Formation
Fluvial

Location of Deposits within the Host

Cutler Formation
Mostly in discontinuous arkosic lenses, interbedded with mudstone, at any stratigraphic level, but commonly the upper part of the formation is favored.

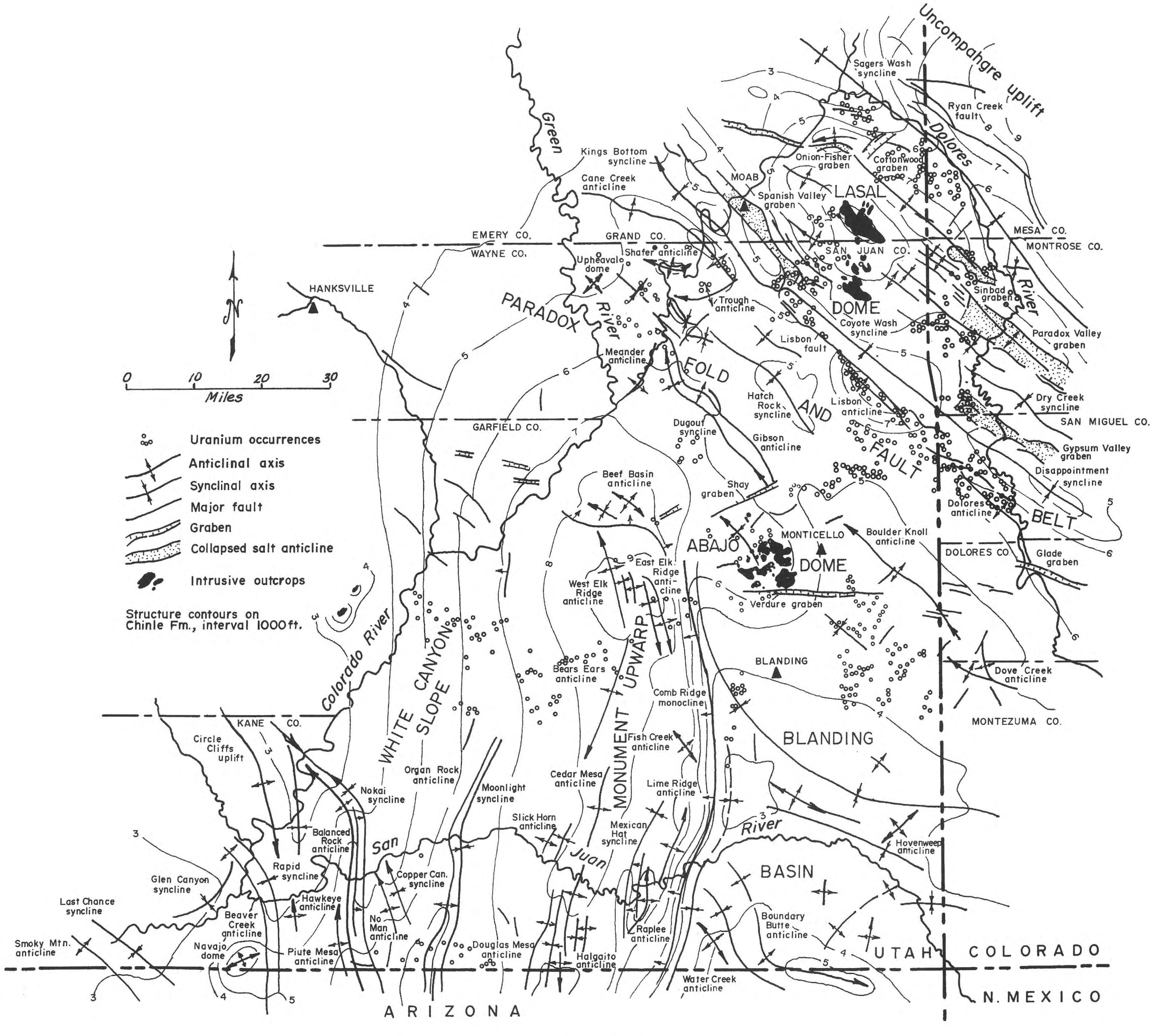

Figure 9. Map showing generalized structure in the San Juan project area (after Kelley, 1955).

Chinle Formation

In the basal sandstone of whichever member (Shinarump, Monitor Butte, or Moss Back) immediately overlies the Moenkopi Formation.

Morrison Formation

Largely in the Salt Wash Sandstone Member, in sandstone lenses at any stratigraphic level, but mostly in the upper part of the member.

Nature of the Overlying Unit

Cutler Formation

Dominantly siltstone and mudstone of the generally impermeable Moenkopi Formation.

Chinle Formation

The host sandstone lenses or beds are overlain by the upper Chinle, dominantly a variegated, impermeable mudstone, containing much bentonite.

Morrison Formation

The Salt Wash is overlain by the Brushy Basin Shale Member in areas of exploitable deposits. The Brushy Basin is dominantly a variegated mudstone, containing abundant bentonite.

Nature of the Underlying Units

Cutler Formation

Alternating limestone, sandstone, and mudstone beds of the Rico Formation.

Chinle Formation

Mudstone and siltstone beds of the Moenkopi Formation.

Morrison Formation

Mudstone and siltstone beds of the Summerville Formation.

Thickness of Host Lenses

Cutler Formation

Ore bodies occur in thin, as well as thick (up to 28 feet), arkose lenses. Most of the thin, mineralized lenses are topped by thick, mineralized lenses.

Chinle Formation

Except in Big Indian Wash area, ore deposits are confined to channel sandstone lenses, especially those 300 to 1,000 feet wide and over 40 feet thick.

Morrison Formation

The largest ore deposits are in thick sandstone lenses (over 40 feet). When several lenses are clustered, most of the ore will be found in a single lens.

Textural Characteristics of the Host Lens

Cutler Formation

Coarse-grained, porous, cross-stratified, lenticular.

Chinle Formation

Fine- to coarse-grained, but medium- to coarse-grained lenses predominate. Some lenses with poor to fair sorting of conglomerate, cross-stratification and varying porosity also are present.

Morrison Formation

Fine- to medium-grained, cross-stratified and lenticular, with varying porosity.

Composition of Host

Cutler Formation

Arkose, with pebbles of granite, orthoclase, quartzite, gneiss, and greenstone.

Chinle Formation

Sandstone, consisting dominantly of quartz grains, with mica, feldspar, zircon, and other minerals. In some places, sandstone beds are arkosic.

Morrison Formation

Sandstone, predominately quartz grains (86 percent). Feldspar (7 percent), chert (7 percent) and minor amounts of other minerals also are present.

Cementation and Interstitial Material of Host

Cutler Formation

Calcite content generally is high (7 - 12 percent). Almost no carbonaceous material is associated with the arkose.

Chinle Formation

Cement is mainly secondary quartz, with some calcite. The ores commonly contain abundant interstitial clay and locally abundant carbonaceous material.

Morrison Formation

Cement consists of calcite and secondary silica. Interstitial clay and some interstitial carbonaceous material also are present locally in association with ore minerals.

Mudstone-Sandstone Relationships

Cutler Formation

In some deposits, pebbles of red mudstone within the arkose are replaced, in part, by uranium minerals. Some mineralization has penetrated adjoining mudstone beds adjacent to the arkose lenses.

Chinle Formation

Many sandstone beds contain channel trash, thin mudstone lenses and mudstone. Loci of facies change from sandstone to mudstone within short distances, are considered favorable for uranium deposits. The optimum sandstone-mudstone ratio should be 1:1. Usually, at least one side of an ore body is terminated by mudstone.

Morrison Formation

Thick, ore-bearing, sandstone lenses are bordered by mudstone units, and contain thin lenses of mudstone and clay gall trash along their margins. Ore generally is located where closely spaced sandstone and mudstone alternate. Areas favorable for ore contain 40-55 percent sandstone with respect to mudstone.

Color Alteration

Cutler Formation
Although arkosic lenses in the Cutler are both reddish and light-colored, ore exists only in the light-colored variety.

Chinle Formation
Mudstone in the underlying Moenkopi and within the basal sandstones usually is bleached in the vicinity of large ore deposits. Red colors are replaced by shades of yellow, green, cream, or light-gray.

Morrison Formation
Sandstone in favorable areas generally is white to brown, but never exhibits strong reddish colors. Mudstone, normally purplish or reddish, is greenish-gray to light-gray in the vicinity of ore.

Relationship of Ore to Host Unit

Cutler Formation
Ore minerals occur as concretions and disseminations in arkose and along bedding planes in the adjoining mudstone. Most of the minerals are concentrated in the upper parts of the arkose lenses, and are spottily distributed.

Chinle Formation
Ore minerals fill pore spaces, replace interstitial clay, cementing materials, organic matter, and, more rarely, sand grains. Most ore bodies lie along the lower margins of channels, especially in the deepest scours. The abnormally large Big Indian Wash deposits lie in the lowest part of the Moss Back Member, regardless of lows and highs at the base of the Member.

Morrison Formation
Ore minerals fill pore spaces, and replace interstitial clay, cementing materials, and organic matter. Ore deposits occur along the margins, the bottom or the middle of thick sandstone lenses; most are along the bottom.

Structural Relationships

Cutler Formation
Some deposits in arkosic lenses are adjacent to faults, but most exhibit no relation to obvious deformation structures. At Big Indian Wash, ore lies beneath an unconformity, separating the Cutler from the Chinle. Some bodies appear to be related to minor structural noses or terraces.

Chinle Formation
Channel positions cut in the Moenkopi appear to have been decided by the tectonic warping of the erosion surface beneath the Chinle. Large deposits at Big Indian Wash trend parallel to the Lisbon anticline.

Morrison Formation
The positions of ore bodies are not related to faults or other deformation structures. There may be a spatial relationship to intrusive igneous centers.

Size and Shape of Ore Bodies

Cutler Formation
Most deposits are small, occurring as blebs, pods, and irregularly shaped bodies. The ore is spotty and of low-grade. Larger bodies are crudely tabular, several feet thick, a few hundred feet wide, and hundreds of feet long.

Chinle Formation
Maximum size of ore bodies is over 20 feet thick, by several hundred feet wide, by over 1,000 feet long. These are aligned parallel to sedimentary trends, and most are roughly tabular and oval in plan. Where the channel configuration is irregular, ore body shapes also are irregular and larger.

Morrison Formation
Ore bodies are aligned parallel to sedimentary trends; most are roughly tabular and oval in plan. Where contact between sandstone and mudstone is irregular, ore bodies tend to have irregular shapes. In some, mineralization cuts across sedimentary features. Ore bodies commonly are up to 9 feet in thickness, up to 50 feet in width, and up to 200 feet in length. Long, sinuous bodies may be 5 feet thick, 15 feet wide, and up to 300 feet in length. Large ore bodies are exceptional.

Mineralogy

Cutler Formation
Mainly copper-uranium mineralization, but vanadium also is present. Minerals include carnotite, becquerelite and copper sulfides.

Chinle Formation
Copper-uranium mineralization occurs in the western part of the San Juan project area, and uranium-vanadium mineralization in the eastern part. Primary ore minerals are found in deeper mines, and oxidized ore minerals in shallow mines. Primary minerals include uraninite and copper sulfides in copper-uranium type. Abundant secondary uranium minerals are metatorbernite, metaautunite, metazeunerite, and uranophane. In oxidized deposits, vanadiferous primary minerals include uraninite, coffinite, and montroseite. Tyuyamunite and corvusite are prominent.

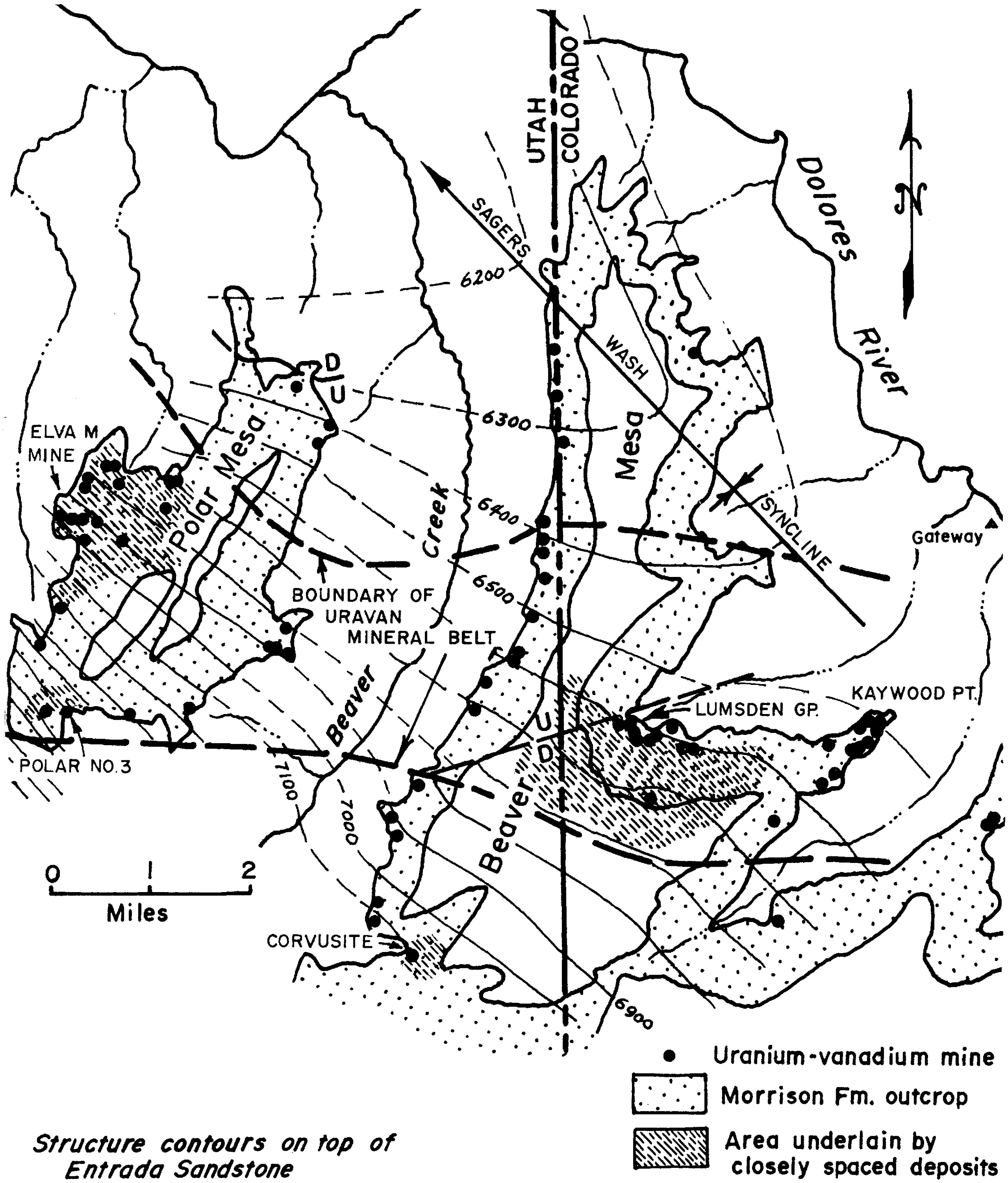

Figure 10. Map showing uranium-vanadium mines and structural contours on top of Entrada Sandstone in the West Gateway district (after Eicher and Miller, 1964).

Morrison Formation

Morrison ores are primarily the uranium-vanadium type, consisting of uraninite and montroseite in primary deposits, and carnotite, tyuyamunite, vanadium clays or mica, and corvusite in the oxidized zone.

In addition, channels containing ore bodies in the Chinle Formation also embrace weakly mineralized jasperoid or other varieties of silica. Localities where abrupt changes are noted in the sedimentary trends of the Morrison or Chinle are favorable for the occurrence of valuable uranium deposits. Exceptionally large deposits have been located in those places where the Chinle rests directly on rock that is more permeable than the Moenkopi Formation (the Cutler Formation at Big Indian Wash and the DeChelly Sandstone in the Monument No. 2 mine in Arizona).

URANIUM DISTRICTS AND AREAS, SAN JUAN PROJECT AREA

Gateway District

One part of the Gateway district is in Grand County, Utah, the other in Mesa County, Colorado, in the northern portion of the San Juan project area (fig. 10). The United States Atomic Energy Commission includes in the Gateway district some areas east of the Dolores River, which are outside of the area under discussion. Polar Mesa and Beaver Mesa are economically important areas in the western part of the district. Although the Dewey Bridge area belongs to the Thompsons district of central Grand County, Utah, the author includes it, because its deposits are similar to those of the Gateway (see plate 1 for data relative to uranium districts and areas, San Juan project area).

The Chinle Formation is present, but contains no important ore bodies; the Salt Wash Member of the Morrison Formation provides host rock for most of the ore in the Gateway district. The Salt Wash is approximately 300 feet thick, and ore occurs in the upper portion of the unit, particularly in a horizon known locally as the "Payoff" sand about 270 feet above the Entrada-Summerville contact.

The "Payoff" sand horizon is from 10 to 80 feet thick, and contains all of the largest ore bodies in the district. Although unimportant mineralization occurs 50 feet above and below it, the thickest portion of the "Payoff" sand lens (that part over 25 feet) is most favorable. The lens consists of a light-gray or light-brown, fine- to medium-grained sandstone, with thin splits, seams and pebbles of green mudstone as well as lenses and matte-like bodies of fossil logs and carbonized vegetal matter normally associated with the ore.

Structurally, most of the Gateway is part of the southwest limb of the Sagers Wash syncline (fig. 10). Dips generally range from 2° to 4° northeast, although dips of 7° occur. The northwest-trending synclinal axis cuts across the northern third of Beaver Mesa. A structural low, superimposed on this southwest limb of the syncline, includes the major uranium-vanadium producing area known in the Gateway. This 1- to 1.5-mile wide low is bounded on the southeast by a gentle monocline and on the northwest by a fault.

Ore bodies range in size from 100 to 5,700 tons, but closely spaced deposits may merge, and, as a consequence, 10,000 tons may be extracted from one mine. Deposits are generally tabular; otherwise, they are irregularly shaped. Some bodies, locally referred to as "rolls," are present where tabular bodies merge or thicken. Ore bodies have long axes that trend generally north to northeast. Both oxidized and unoxidized ores are present, but the unoxidized or partly oxidized bodies are most significant. Oxidized deposits usually are found where overburden is minimal. Unoxidized minerals from the western Gateway district include uraninite, coffinite, montroseite, lumsdenite and doloresite. Oxidized ores contain carnotite, tyuyamunite, and corvusite. Pyrite is also abundant in ores and in carbon trash.

Less than 1 percent of the district's surface is underlain by uranium deposits and less than 10 percent is considered favorable ground. The Uravan mineral belt cuts across Polar Mesa and Beaver Mesa and coincides with most of the better deposits. Guides to ore in the Salt Wash Sandstone are as follows:

1. Sandstone lenses 25 feet thick or more are favorable.
2. Mudstone in contact with ore-bearing sandstone is gray-green.
3. Ore-bearing sandstone contains thin, discontinuous green mudstone lenses and abundant masses of fragmentary carbonaceous material.
4. Light-gray or light-brown sandstone is more favorable than that of red or brownish color.

Minor mineralization has been found in the basal Chinle and in the basal sandstones of the Brushy Basin Member of the Morrison Formation. Not enough work has been done to permit proper evaluation.

In mined ore, vanadium-uranium ratios range from 3:1 to 7:1, an average ratio of 4:1. Ore averages from 0.25 percent to 0.35 percent U_3O_8 and from 0.85 percent to 1.85 percent V_2O_5. From 1956 to 1965, the average was 0.30 percent U_3O_8 and 1.04 percent V_2O_5. During that 10-year period, the district produced more than 900,000 tons of ore, containing over 2,800 tons of U_3O_8, and over 1,000 tons of V_2O_5. Production figures are listed on the following page.

PRODUCTION 1956 to 1965:

	Tons (ore)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	51,403	348,865	1,395,365
1957	95,208	540,982	2,156,578
1958	119,902	726,896	2,805,431
1959	116,980	700,449	2,622,860
1960	118,639	698,584	2,869,125
1961	95,822	573,744	2,221,333
1962	91,569	522,428	1,928,415
1963	84,092	494,706	1,842,954
1964	80,736	490,760	1,741,033
1965	91,278	547,556	2,144,507
Total	945,629	5,664,970	21,727,601

Moab District

Although there has been production from mines in the Permian Cutler Formation and the Triassic Chinle, most of the ore of the Moab district (figs. 11 and 12) has come from the Salt Wash Member of the Jurassic Morrison Formation. The Salt Wash is the host rock for uranium-vanadium deposits at Wilson Mesa, Brumley Ridge, upper Cane Canyon and Browns Hole southeast of Moab and west of the La Sal Mountains (fig. 12). In many places, the Salt Wash sandstone outcrops are broken by faults into irregularly shaped, discontinuous areas. The northernmost deposits at Wilson Mesa are in Grand County; deposits farthest south are in San Juan County, and adjoin the northern part of the Lisbon (Big Indian Wash) area of the Monticello district near La Sal Junction.

The ore occurs 100 to 180 feet above the base of the Salt Wash Member, which is from 250 to 300 feet thick. Most deposits are in the upper part of the member in one or two horizons. As in other areas, thickest sandstone lenses contain the largest deposits. At upper Cane Canyon, the most productive of the four Salt Wash areas, ore occurs in two sandstone lenses, which are separated by 25 feet of shale to the south, but merge to the north. Maximum thickness of the upper lens is 30 feet, of the lower lens, 45 feet. Host units consist of light-gray to light-brown, fine- to medium-grained sandstone, with interbedded green mudstone lenses. The sandstone is cross-bedded and contains clay galls, mudstone partings, carbonized vegetal matter, and aggregates of granule conglomerate. The ore is associated mainly with thick masses of carbonized vegetal matter.

Beds in the productive areas are faulted and folded, dip as much as 35°, and are excessively fractured locally. The Spanish Valley salt anticline separates the Brumley Ridge area from the upper Cane Canyon area, and gentle synclines occur near Browns Hole and Wilson Mesa. Brumley Ridge and upper Cane Canyon areas are highly faulted. Although the area is disturbed, ore deposits do not appear to be related to structure. The deposits are 3 to 12 miles from the laccolithic centers. Several theories of ore emplacement mention the La Sal Mountain igneous activity as a possible source of uranium-bearing fluids.

The relatively small and sparsely distributed ore bodies are lenticular in shape and normally have much greater length than width; they are as much as 5 feet thick and 200 feet long. Some are coalesced or have merged to form larger bodies. Trends of ore bodies at upper Cane Canyon are northeast.

Ore metals are uranium and vanadium and principal minerals are carnotite and vanoxite. More recently, unoxidized ore probably has been mined from increasing depth. Leaching of primary ores has veneered many fractures with tyuyamunite and some of the rarer uranium minerals. The complex iron mineral, celadonite, often is found close to the ore.

Little has been published on the Moab district because production has been small, but ore guides attributed to other Salt Wash areas probably would fit here, i. e. thick sandstone lenses, brown and gray, instead of reddish sandstones, green mudstone, carbonized vegetal matter, and so forth. Extension of known deposits suggests others of significance may be found in the Browns Hole-West Coyote Creek area.

The vanadium-uranium ratio generally runs from 4:1 to 7:1; the average for the 1956 to 1965 producing period was 5.3:1. Ore has averaged 0.28 percent U_3O_8 and 1.51 percent V_2O_5 for the same period. The most productive area has been upper Cane Creek. Wilson Mesa and Brumley Ridge were operated only intermittently from 1956 to 1965. During this 10-year period, a little less than 40,000 tons of ore was produced, yielding more than over 100 tons of U_3O_8 and a little less than 600 tons of V_2O_5. There has been a steady decline since 1956.

PRODUCTION 1956 to 1965:

	Tons (ore)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	9,467	54,419	277,650
1957	9,454	50,700	281,553
1958	5,574	31,572	175,482
1959	2,445	16,955	87,408
1960	1,932	13,218	59,798
1961	3,202	17,186	89,746
1962	2,576	14,438	82,297
1963	1,880	10,587	63,884
1964	1,309	6,745	36,791
1965	1,419	7,224	31,464
Total	39,258	223,044	1,186,073

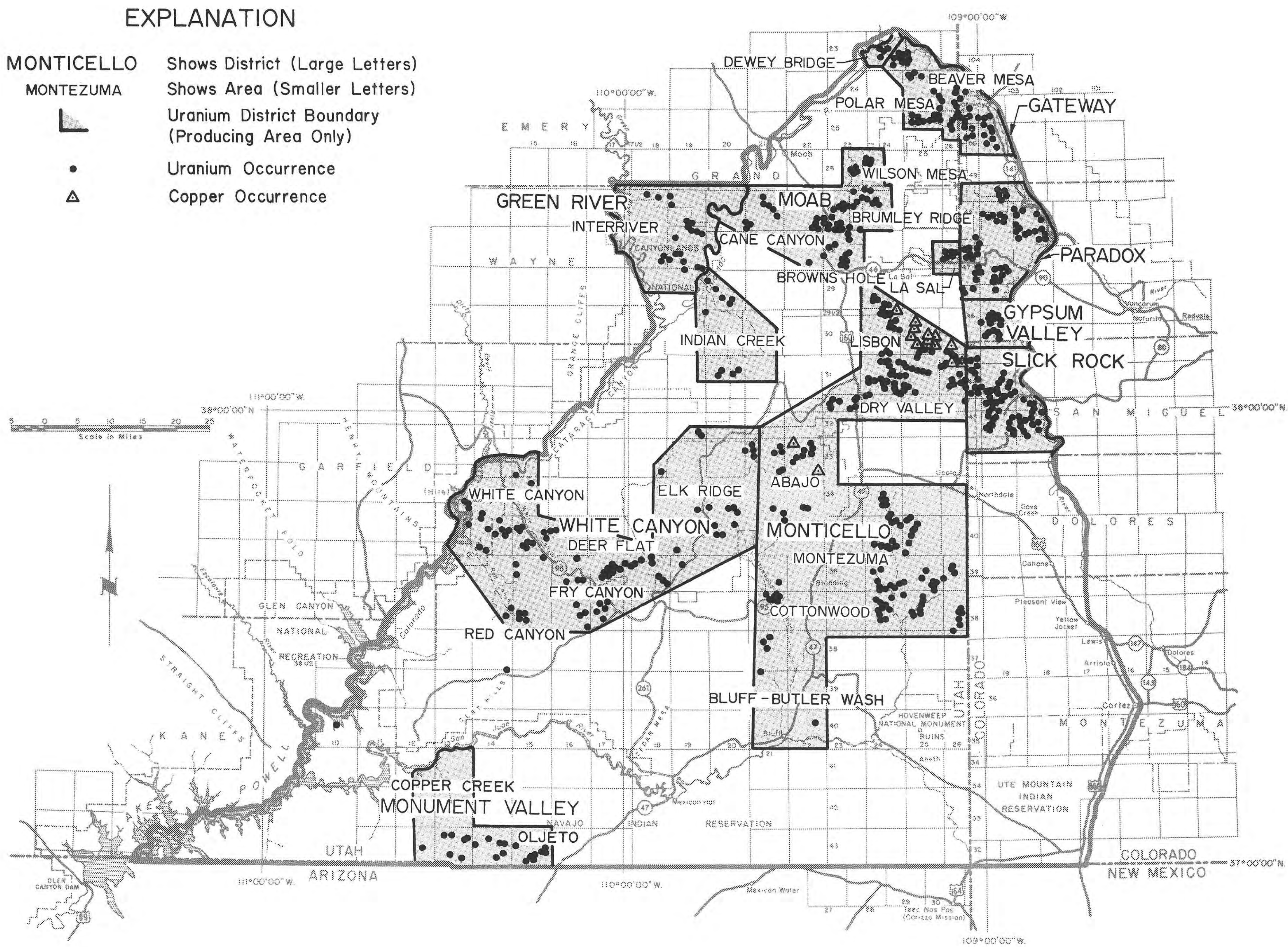

Figure 11. Uranium districts and areas in the San Juan project area.

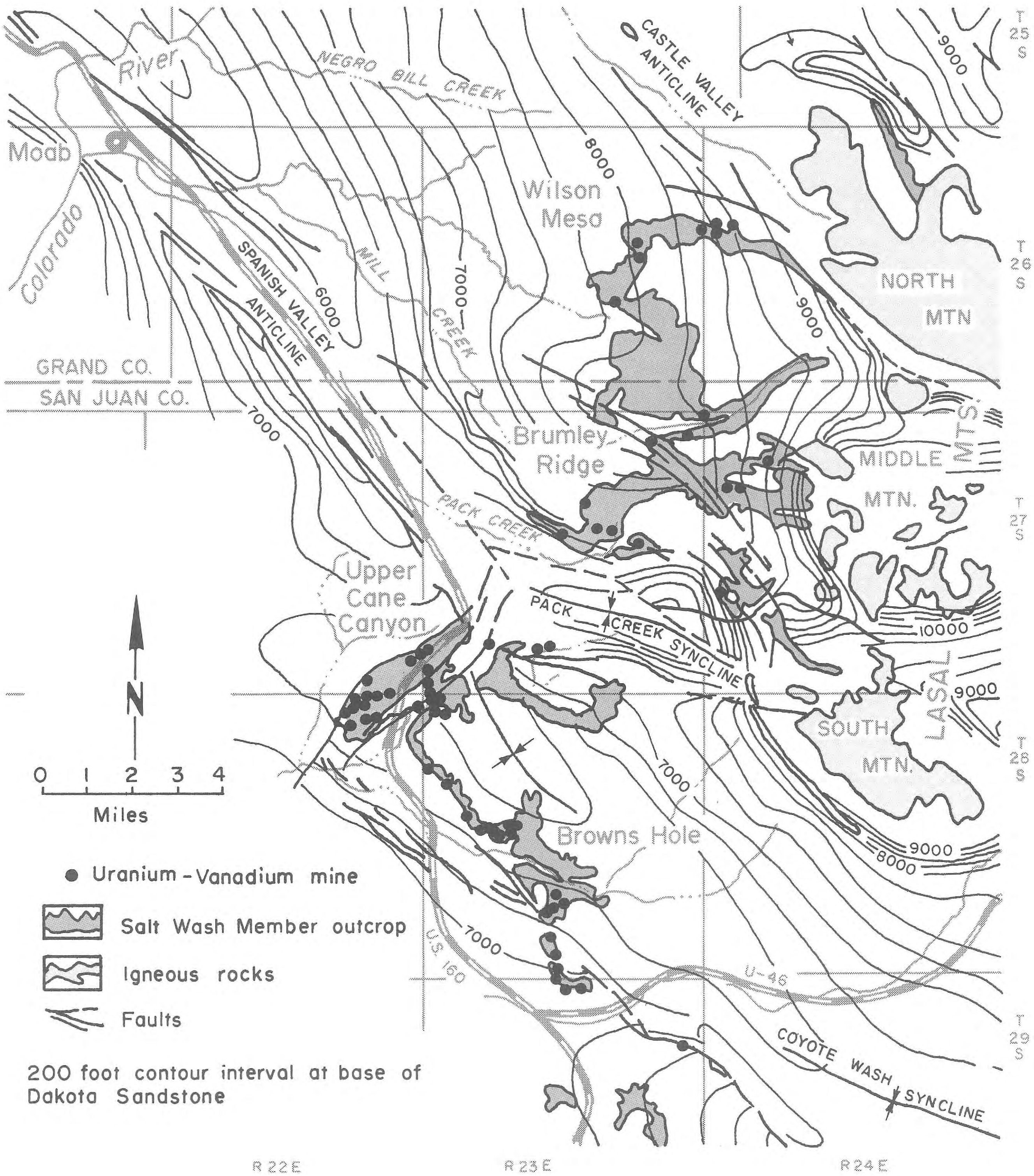

Figure 12. Map showing uranium-vanadium production sites in the Morrison Formation, Moab district (after Williams, 1964).

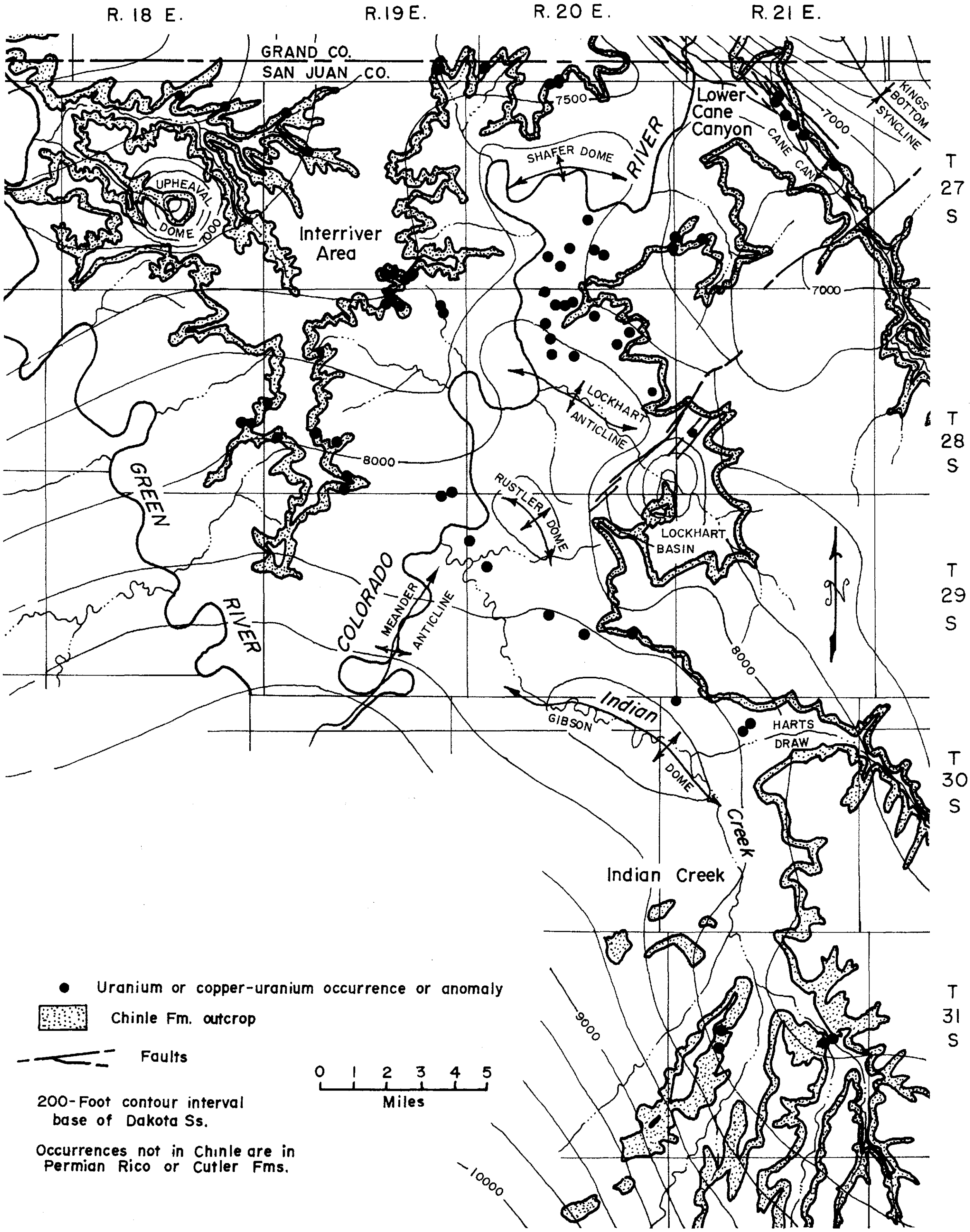

Figure 13. Uranium, copper-uranium, or anomalous occurrences in the Interriver area, Green River districts; lower Cane Canyon, Moab district; Indian Creek, Monticello district (after Williams, 1964).

Interriver, Lower Cane Canyon, Indian Creek Areas — Green River, Moab, Monticello Districts, Utah

Interriver, lower Cane Canyon, and Indian Creek areas are immediately south of the Grand and San Juan County line southwest of Moab (figs. 11 and 13). The three areas are in adjoining parts of three districts: the Interriver area is a part of the Green River district west of the Colorado River, and lower Cane Canyon lies in the Moab district. Except for Indian Creek, much of the area is now in Canyonlands National Park or adjoins it.

Of the three producing horizons, the first two contribute only about $6\frac{1}{2}$ percent to the total production. The Permian Rico Formation is mineralized near its upper portion, along faults in the lower Cane Canyon area, and along the closely jointed crest of the Gibson anticline. In the latter occurrence, tyuyamunite is disseminated in a host bed of petroliferous, sandy limestone. Only a minor amount of ore has been produced from the Rico, which is about 500 to 575 feet thick.

Lying above the Rico is the Bogus Tongue Member of the Cutler Formation. The Bogus Tongue is also of Permian age, and makes up the entire Cutler section in this area. The member is approximately 675 feet thick, and consists of red, purple, and white, arkosic sandstone and red mudstone and siltstone. The arkose lenses, thought to be fluvial in origin, contain most of the mineralization. Both purplish and light-gray or white arkose lenses occur, but only the light-colored, non-red variety is mineralized. Dix (1953) has outlined five types of mineralization:

1. Copper-uranium concretions within the arkose.
2. Copper and uranium minerals disseminated within the arkose.
3. Mineralization at the contact between the arkose and the underlying red mudstone or siltstone.
4. Copper and uranium minerals on the bedding planes of mudstone or siltstone, which underlie the arkose.
5. Copper and uranium minerals in thin lenses of arkose, contained within mudstone or siltstone beneath the main arkose (similar to no. 1).

Types 1, 2, and 5 are the most favorable for ore production. Type 3 is widespread, but in the past, has been uneconomical because of the thinness of the ore horizon. Type 4 has a spotty mineralization in thick zones, and in one area, was estimated to yield an average 0.09 percent U_3O_8 content within a 30-foot zone. Concretions in type 1 contain sooty chalcocite, cuprite, and secondary uranium minerals, as well as sparse native copper. Several concretions collected near Harts Draw assayed 1.42 percent U_3O_8 and 31.96 percent copper (Dix, 1953). Other minerals associated with the deposits include troegerite, uranophane, zeunerite, brochantite, and cyanotrichite. Silver (1.52 oz./ton) is fairly high in type 2. Most of the ore is high in lime, averaging approximately 12 percent. In Dix's report, analyses of many channel and grab samples from the Indian Creek, Lockhart Canyon, and lower Cane Creek areas indicate an average of 0.36 percent U_3O_8, 0.16 percent V_2O_5, 12.2 percent $CaCO_3$, and 0.8 percent Cu (this figure excludes one grab sample containing 32 percent copper).

Little is known about the size of the deposits, but judging from production records they are small. Ore occurs in many stratigraphic horizons within the Bogus Tongue; some deposits are 10 feet above the Rico contact, and others, 172 feet below the top of the unit. Some of the deposits are on minor structural noses or terraces.

Deposits in the Cutler also occur along faults, notably in the lower Cane Creek area, where the host rock is bleached and shows weak argillic alteration. The minerals are carbonates, clay minerals, vanadium-bearing clays, copper sulfides, uraninite, galena, pyrite, and secondary minerals such as andersonite. liebigite, and sharpite.

The last group of deposits is in the Moss Back Member of the Chinle Formation, and is the most important economically. The deposits normally are associated with carbonaceous vegetal matter at the bottoms and sides of channels cut into the underlying Moenkopi Formation. The channels are filled with massive or thick-bedded sandstones, which contain intercalations of mudstone, siltstone, conglomerate, and other channel debris. The deposits seem to be localized where the thickness of the channel fluctuates over a short horizontal distance. The Moss Back ranges in thickness from 0 to 115 feet, although 25 feet is the most common thickness outside of the channels. In this unit, fossil debris generally is silicified away from channels, but is carbonized in the channels. The Moss Back pinches out to the north, which places the areas in a zone of inferred favorable ground (Johnson, 1959). A few Moss Back deposits are associated with faulting along salt anticlines.

Ore minerals include uraninite, bornite, pyrite, chalcopyrite, chalcocite, covellite, malachite, azurite, limonite, schroeckingerite, and zipeite. Galena and sphalerite have been found in a few places. In the Indian Creek area, the vanadium and copper content are low, but barium and cobalt high. The ore also contains 2 to 3 percent iron, and some of it has up to 1 ounce of silver per ton.

Hinrichs (1956) noted some features common to all deposits in both Permian or Triassic hosts:

--Copper mineralization and high lime content characterize the ores;

--With respect to vanadium-uranium ratios, the deposits can be subdivided into two categories: deposits with a 1:4 ratio, the bedded type in the Cutler and Chinle Formations, not associated with faulting in areas of low dip; deposits with a 2:1 ratio in the Rico, Cutler, and Chinle, which occur along faults, notably on the Cane Creek anticline;

--The increase in vanadium along the faulted deposits is ascribed to a Paradox Formation source, since ash from oils produced from the Cane Creek anticline contain up to 5 percent vanadium.

Production figures for the three areas indicate a vanadium-uranium ratio of 1:2, a U_3O_8 content of 0.29 percent, and a V_2O_5 content of 0.15 percent. During the 1956 to 1965 production period, a little over 51,000 tons of ore was produced, for a yield of 119 tons of uranium concentrate and 60 tons of vanadium concentrate. Of the 41,000 tons of ore, 36,000 tons or 84 percent has come from the Indian Creek area, 9 percent from lower Cane Canyon, and 7 percent from the Interriver area. Permian formations contributed only 7 percent of the ore. Production from the Salt Wash Member of the Morrison Formation near Indian Creek added 2.5 percent. The remainder has come from the Moss Back Member of the Chinle Formation. Production has been intermittent and has declined steadily in all three areas since 1955.

PRODUCTION 1956 to 1965:

	Tons (ore)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	22,223	144,630	52,113.72
1957	6,690	37,799	18,421
1958	2,228	11,781	6,873
1959	3,938	19,830	3,765
1960	963	4,402	16,068
1961	631	3,102	5,295
1962	949	2,927	18,317
1963	1,381	4,336	--
1964	1,757	8,261	--
1965	302	1,147	--
Total	41,062	238,216	120,852.72

Big Indian Wash or Lisbon Valley Area — Monticello District, Utah

With a production of 5,936,345 tons of ore (fig. 4), or 58 percent of the total for the project area, the Lisbon-Big Indian Wash area of the Monticello district has been, and continues to be, the outstanding area in the Colorado Plateau. It is located near the Utah-Colorado state line about 10 to 15 miles south of the La Sal Mountains in San Juan County (figs. 11 and 14). Although most formations exposed in the area (Pennsylvanian-Cretaceous) have been mineralized to some degree, four formations account for almost all ore production, and of these, the Chinle Formation is responsible for 95 percent. The Chinle's major deposits occur along the southwest flank of the Lisbon Valley salt anticline.

The formation is 340 to 480 feet thick, and most of the ore has been found in the lowermost fluvial sandstone member, the Moss Back, an arkosic sandstone, fairly to poorly sorted, in which grain size ranges from silt to small pebbles. Interbedded and intercalated with the sandstone beds are lenses of mudstone, siltstone, limestone pebble conglomerate, and mudstone pebble conglomerate. Cement is calcareous. Although carbonized vegetal matter is widespread, it is too meager to have localized the large ore bodies. In many places, concretions and stringers of reddish, slightly radioactive chert have replaced sandstone, but there appears to be no relationship between the presence of chert and rock of ore grade. The Moss Back rests unconformably upon the Permian Cutler Formation because the Triassic Moenkopi Formation, normally in that position, was eroded before the Moss Back was deposited. Rather than being in channels cut into the Cutler, ore is associated with paleo-highs as well as paleo-lows.

Faulting has not influenced the grade of uranium ore, but the ore bodies are elongated parallel to the south limb of the Lisbon Valley anticline, and lie between the 6,200 and 6,700-foot contour line at the base of the Chinle Formation. All deposits are on the southwest flank of the anticline, which dips 6^o to 8^o to the southwest as do the ore bodies. Scattered downdip drilling has not located significantly mineralized ground, but has picked up remnants of the Moenkopi Formation.

Ore bodies in the Moss Back usually have a maximum thickness of over 20 feet (some reports indicate as much as 60 feet). Average thickness probably is about 8 feet. The bodies are several hundreds of feet wide, well over 1,000 feet long and some have yielded more than 1,000,000 tons of high-grade ore. Several mines have been developed on a single large ore body. Ores are richest where the sandstones are most heterogeneous, where mudstone pebbles or carbon trash are concentrated. The bodies are generally tabular, although somewhat irregular in detail. Host rocks are slightly altered; red rocks have bleached to gray or green. In places, mineralization has spread as much as 2 feet into the underlying Cutler. Boundaries are sharp between ore and barren rock. The gray-green Moss Back Member is up to 100 feet thick, but most of the ore is found in the bottom 20 feet, and is thickest where the enclosing sandstone unit is the thickest.

For the most part, ore minerals are unoxidized and consist of uraninite, coffinite, and montroseite. Locally, fine-grained galena, pyrite, molybdenite, and jordesite accompany the uranium minerals. Copper minerals such as chalcopyrite, copper carbonates, and native copper occur sparsely in a few deposits. The

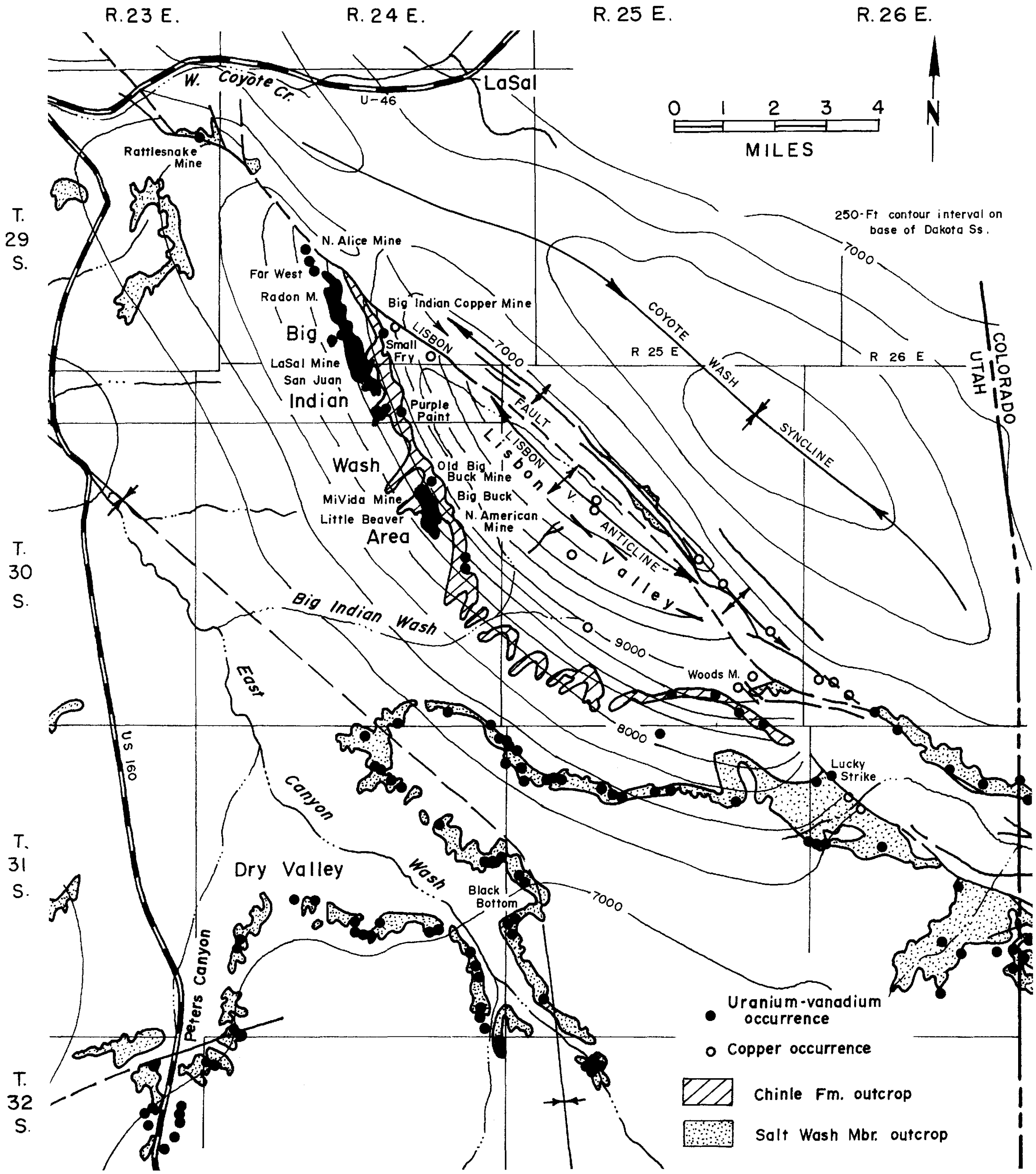

Figure 14. Uranium-vanadium and copper occurrences in the Big Indian Wash (Lisbon) and the Dry Valley areas, Monticello district (after Williams, 1964).

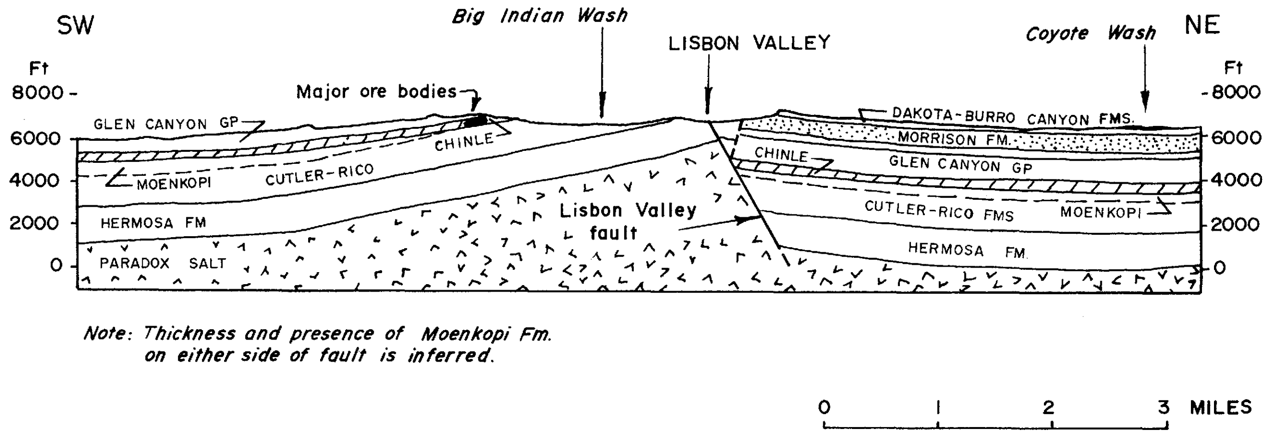

Figure 15. Section across Lisbon Valley anticline (after Lekas and Dahl, 1956).

vanadium content of the ore varies from mine to mine, but, like molybdenum, decreases regionally in a northwest direction. However, in the northwestern part of the area, workers have noted an increase in strontium as celestite mineralization in the Radon mine. In places, ores are enriched with lead, zinc, molybdenum, and cadmium.

Economically, the second most important unit is the Morrison Formation of Jurassic age. Two producing horizons in the Morrison account for a little over 5 percent of the total production of the district. The largest mine in the Morrison Formation, the Rattlesnake, is in this area. Many of the formation's smaller mines and prospects are located in the southeastern part of the Lisbon Valley area.

The Morrison consists of two members, the lower 325-foot thick Salt Wash and the upper 450-foot thick Brushy Basin Member. Sparsely scattered ore bodies in the Salt Wash are confined to the uppermost, thick, continuous sandstone lens, which is commonly over 45 feet thick. The lens is interbedded with those of mudstone, siltstone, fine conglomerate, and carbonized vegetal debris. Brushy Basin ore occurs in dark brownish-gray pebble conglomerate and coarse-grained sandstone lenses 50 feet above the Salt Wash contact. Carbonaceous debris is widespread in the Brushy Basin Member.

Most deposits in both members are small, yielding only a little more than 1,000 tons, although the Rattlesnake mine has produced over 100,000 tons. The majority of ore bodies are thinly tabular, up to a few feet thick, tens of feet wide, and as much as 200 feet long. On the average, deposits in the Brushy Basin Member may be somewhat larger than those in the Salt Wash. Carnotite, tyuyamunite, and vanadium mica are the major minerals. The vanadium-uranium ratios range up to 15:1, but average 2.3:1. Trace amounts of copper also are present, but are not in sufficient quantities to permit recovery.

The Permian Cutler Formation has accounted for the remaining uranium production of the Lisbon Valley district. The unit's deposits have been developed to a small extent, although several investigators have estimated a considerable reserve. The ore is in the upper portion of the unit, less than 100 feet below the Moss Back contact, and is localized in fluvial sandstones or arkoses that are medium- to coarse-grained and generally light-brown in color. Red or purple sandstones are mostly barren. Larger bodies are crudely tabular, several feet thick, a few hundred feet wide and hundreds of feet long. Most occurrences are blebs, pods, and irregularly shaped bodies, spotty in distribution and of low-grade. Minerals are usually oxides, mainly carnotite, becquerelite, and vanadium hydromica. Some copper carbonates also are present. Carbonaceous trash usually is absent.

Copper, with or without significant associated vanadium or uranium, has been recovered from the Big Indian and Pioneer mines in the Dakota and Burro Canyon Formations. The units, both of Cretaceous age, are adjacent to the Lisbon Valley fault. Though the copper minerals are not in the fault zone, their distribution along the fault trace suggests fault control for initial deposition. The host rock is chiefly a poorly sorted medium- to coarse-grained sandstone containing carbonaceous material and, more rarely, pyrobitumens. At the Big Indian copper mine, two 10- to 15-foot host horizons are separated by 30 feet of barren green and gray shales. The copper minerals are malachite, brochantite, chalcocite, digenite, covellite, chalcopyrite and locally tenorite, cuprite, and native copper. Ore minerals coat sand grains, fill microscopic fractures and interstices of sand grains, and replace organic matter. In rich concentrations, ore minerals may corrode sand grains. Barite and pyrite are locally abundant.

Mineralized bodies are roughly tabular to lenticular, but vary in respect to both plan shape and copper content. Larger deposits exceed 1,000 feet in length, may be 100 feet wide, and up to 10 feet thick. As in the uranium-vanadium deposits, the host rocks are virtually unaltered.

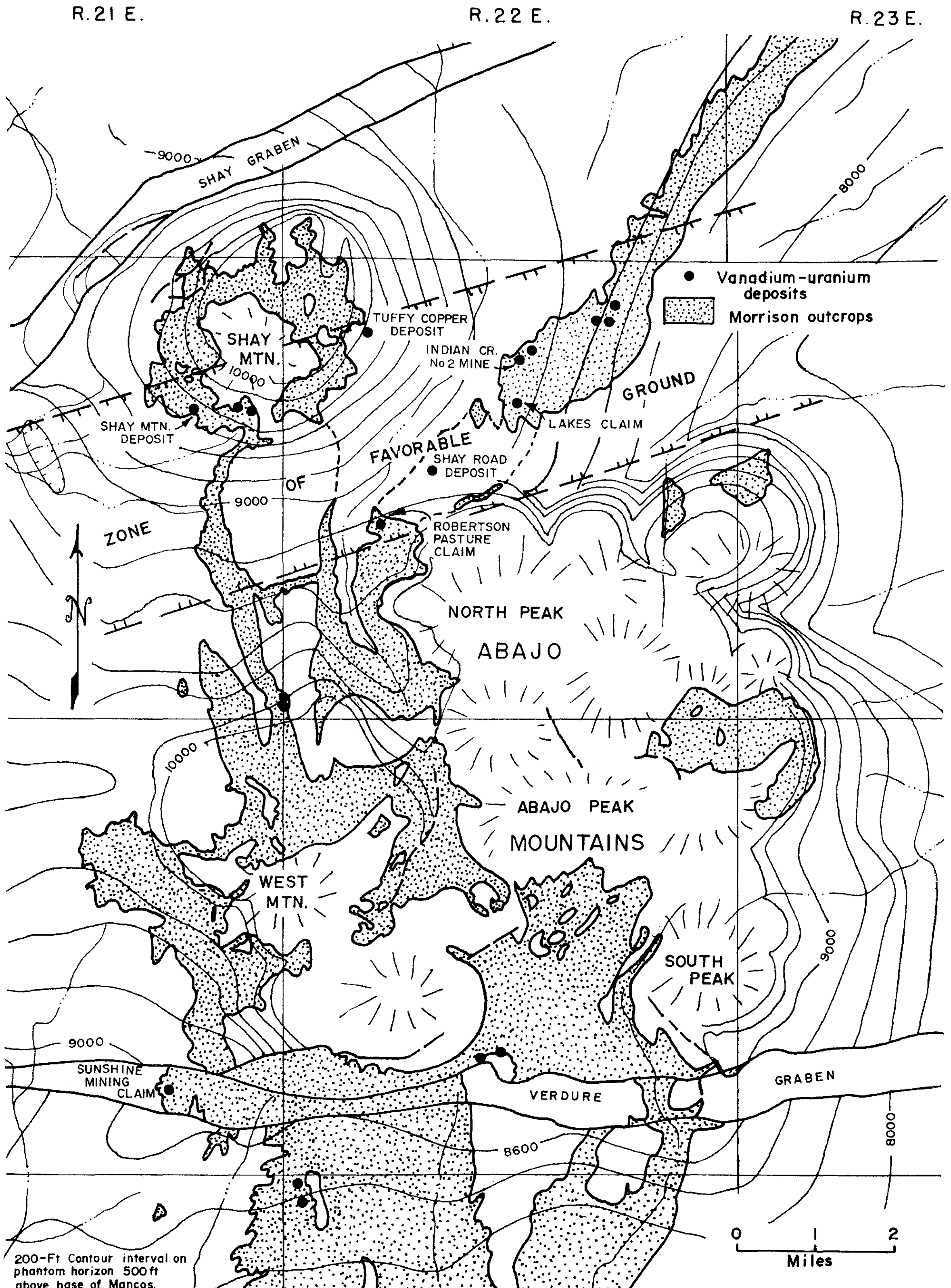

Figure 16. Vanadium-uranium occurrences in the Abajo area, Monticello district (after Witkind, 1964).

Other units containing minor amounts of copper minerals include the Pennsylvanian Hermosa Formation, the Jurassic Kayenta Formation, and the Cretaceous Burro Canyon Formation. The Burro Canyon occurrence also has associated uranium and vanadium, but malachite, azurite, and volborthite are the common minerals.

Some manganese mineralization is present along the northward extension of the Lisbon Valley fault, especially in the Jurassic Carmel Formation and Navajo Sandstone. Most deposits are small and undeveloped.

From 1956 to 1965, a little less than 6,000,000 tons of ore was mined from the Big Indian Wash-Lisbon Valley area. This tonnage yielded over 23,000 tons of U_3O_8 and over 9,000 tons of V_2O_5. Ore grade averages 0.39 percent for uranium and 0.15 percent for vanadium. Of the total production over 5,600,000 tons, or almost 22,000 tons of U_3O_8 and about 6,500 tons of V_2O_5, have been obtained from deposits in the Chinle Formation. The Chinle was discovered by Charles Steen in July 1952. Uranium ore grade has been consistent and averages 0.39 percent, with variable vanadium content averaging 0.12 percent.

The Morrison Formation produced a little more than 300,000 tons of ore, containing over 1,100 tons U_3O_8 and 2,600 V_2O_5. Average ore grade for uranium is 0.36 percent and 1.66 percent for vanadium. During the same 10-year period, only 780 tons of ore, which yielded 3,682 pounds of U_3O_8, or a 0.24 percent ore grade, was attributed to the Permian Cutler Formation. Vanadium content was not recorded.

PRODUCTION 1956 to 1965:

	Tons (ore)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	515,441	3,734,746	3,378,259
1957	726,287	5,720,654	3,610,849
1958	827,960	6,713,117	3,427,670
1959	854,635	6,923,410	4,927,308
1960	698,284	4,631,957	1,138,637
1961	690,264	4,233,081	660,272
1962	465,084	4,027,187	532,204
1963	484,608	4,397,138	249,349
1964	501,453	4,700,020	179,410
1965	172,329	1,187,512	134,615
Total	5,936,345	46,268,822	18,283,573

To 1960, a few dozen copper deposits in the Lisbon Valley area had a combined production of more than 150,000 tons of ore, most of which came from the two largest mines (Big Indian and Blackbird). These mines have been operated intermittently since before 1913, especially during World Wars I and II. Average ore grade is 1.4 percent.

Abajo and Cottonwood Areas — Monticello District, Utah

Most of the mines of the Abajo area are on the north side and somewhat to the west of the major peaks of the Abajo Mountains, but the Cottonwood area is 13 to 15 miles to the south (figs. 11, 16 and 17). To the west is the Elk Ridge area of the White Canyon district, which produces uranium from the basal sandstone members of the Chinle Formation. Only Jurassic host units are considered, even though some of the eastern Chinle mines of the Elk Ridge area are included with the Abajo area in the collection of production statistics in this discussion. There are scattered mines and prospects comprising the Bluff-Butler Wash area of the Monticello district south of the Cottonwood area.

Jurassic and Cretaceous rocks flank the Abajo Mountains, although Triassic units are exposed in some of the deeper canyons and west of the Comb Ridge Monocline. The Salt Wash Member of the Morrison Formation contains economically important vanadium-uranium mineralization in the Abajo and Cottonwood areas. In the Abajo area, the Jurassic Entrada Sandstone and the Cretaceous Dakota-Burro Canyon Formations (undivided) contain copper occurrences.

There are two members of the Morrison Formation in the Abajo area and at least four members in the Cottonwood area--Salt Wash Sandstone, Recapture Creek, Westwater Canyon, and Brushy Basin. Only two of the last named, the Salt Wash and Brushy Basin, are present in the Abajo area. The Bluff Sandstone (considered by some workers a basal Morrison member, but by most, an individual formation) underlies the Salt Wash in the Cottonwood area, instead of the usual Jurassic Summerville Formation. The Bluff pinches out just north of the Cottonwood area and thickens to the south. As it thickens, the Salt Wash thins. These units interfinger south of the Cottonwood area. In places, the Bluff is mineralized at the stratigraphic level of uranium deposits in the Salt Wash of the Bluff-Butler Wash area to the south.

The Salt Wash Member is 210 feet to 245 feet thick in the Cottonwood area and 250 to 550 feet thick in the Abajo area. It is a buff, light-gray, light-red, or white, fine- to medium-grained sandstone, intercalated with mudstone, siltstone, limy sandstone lenses and stringers of pebbles. The mudstones were red, brown, gray, gray-green, or variegated, but ordinarily they are altered to grays or greens in the vicinity of the deposits. Sandstone lenses are as much as 25 feet thick, and when two or three of these thick beds are superimposed, they form a major sandstone unit. In most places, uranium ore is found 100 to 200 feet above the base of the Salt Wash, but in the Cottonwood it occurs in the third major sandstone bed above the base.

The Recapture Creek Member is partly in continuity with and partly above the Salt Wash stratigraphically. The lithologic description is similar to that of the Salt Wash, which makes it difficult for workers to differ-

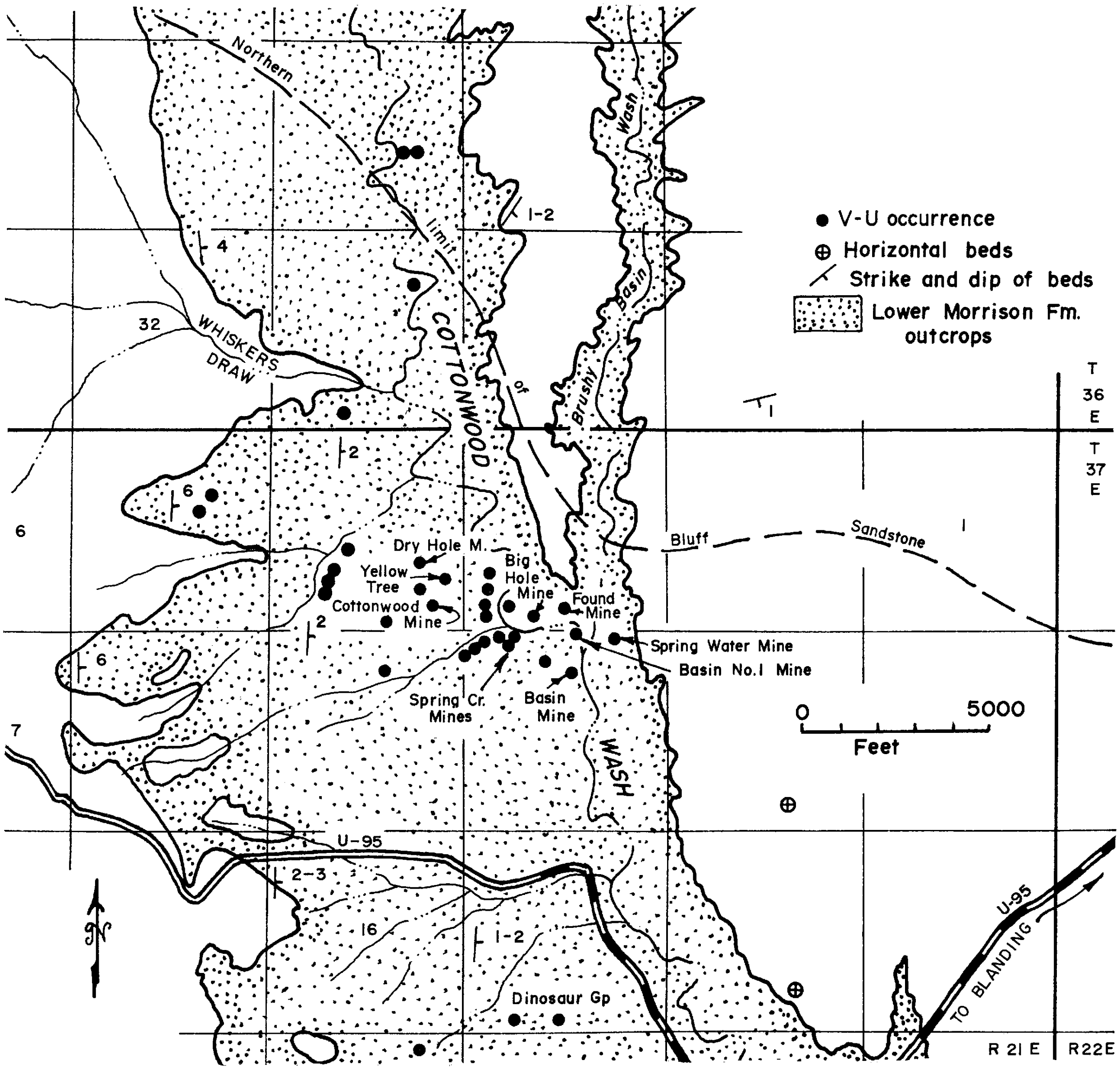

Figure 17. Vanadium-uranium occurrences in the Cottonwood area, Monticello district (after Pitman, 1958).

entiate between the two units in the field. The mudstone's more brownish coloration and the pinkish-gray tints in the more friable sandstone help distinguish them. The northern edge of the Recapture reaches the Cottonwood area.

The Westwater Canyon Member is a coarse-grained, light- to greenish-gray, medium-bedded to massive sandstone, interbedded with red and green mudstone layers. The unit is less resistant than either the Salt Wash or the Recapture Creek and is more strongly jointed than either. The northern edge of the Westwater Canyon falls between the Abajo Mountains and the Cottonwood mining area. The Brushy Basin Shale Member at the top of the Morrison sequence is present in both areas. Only the Salt Wash Member is mineralized, but pinchout zones are considered favorable for uranium emplacement.

Copper minerals without significant association of uranium and vanadium occur in the Jurassic Entrada Sandstone and in the Dakota-Burro Canyon Formation (undivided) of the Abajo area. The Entrada Sandstone is a pale-orange, massive, cross-bedded, very fine- to medium-grained sandstone, 165 to 170 feet thick. Copper minerals occur 30 feet above the Entrada's base east of Shay Mountain. The Dakota-Burro Canyon Formation (undivided) is 80 to 125 feet thick, and consists of brown, massive, cross-bedded conglomerates and sandstones. Copper minerals are in sediments high on the side of a laccolithic peak. Mineralization in the Entrada deposit follows joints or is disseminated along crossbeds, and in the Dakota-Burro Canyon is concentrated in a fracture zone in beds that dip 53°.

Vanadium-uranium deposits in the Salt Wash show little, if any, relation to structure. Beds dip gently (less than 7°), and minor faults near such depositions have not been mineralized. The Cottonwood deposits are on the east flank of the Monument Upwarp and are concentrated where dips change from an average 3° to 7°, to an average of 0° to 2°.

In the Abajo area, there are two types of ore bodies, oval bodies averaging 3 feet by 10 feet by 15 feet and tabular bodies averaging 3 feet by 40 feet by 200 feet. In places, oval bodies are clustered and tabular bodies are rare. Richest ore is found in the center of the ore body; grade gradually diminishes outward. The zone between unmineralized rock and ore grade material ranges in thickness from 1 inch to 3 feet. Vertical contacts generally are sharp rather than gradational. Most ore bodies are near the bases of the major sandstones, others may lie anywhere within them. The Cottonwood deposits are roughly tabular, averaging 2 feet by 50 feet by 100 feet, although ore bodies up to 5 feet by 140 feet by 280 feet have been found. These bodies are scattered within the major ore-bearing sandstone and may occur on two levels. The axial trend of ore bodies is northeast to east, paralleling sedimentary trends of the Salt Wash.

In both areas, ore is concentrated where permeable sandstone beds are interbedded with intrachannel trash, especially carbonaceous matter and mudstone lenses. Ore minerals replace macerated vegetal matter and cement and fill the interstices between sand grains. Almost all Abajo deposits are oxidized, and contain minerals of the carnotite-vanadium hydromica type. Tyuyamunite and limonite coat fractures near the deposits. Similar oxidized deposits occur in the Cottonwood area, but they are unoxidized below the water table, and consist chiefly of uraninite and montroseite with corvusite, pascoite, metarossite, and pyrite. Average lime content is 6 percent.

In the Tuffy copper deposit, an ore zone up to 2 feet in thickness contains nodules of a black, fine-grained copper mineral coated with azurite and malachite. At the Copper Queen, azurite and malachite are the chief minerals associated with small quantities of pyrite, chalcopyrite, chalcocite, bornite, covellite, and chrysocolla. The minerals coat bedded and crossbedded planes in sandstone and fill fractures.

Vanadium-uranium ratios in both areas average 10:1, but ratios recorded by individual mines range from 4:1 to 20:1. Uranium concentrations are relatively low, averaging 0.14 percent in the Abajo area and 0.16 percent at Cottonwood. Vanadium content averages near 1.5 percent in both. Production from 1956 to 1965 totalled more than 75,000 tons of ore, a yield of over 120 tons of U_3O_8 and nearly 1,200 tons of V_2O_5. Ninety percent of the ore was taken from the Cottonwood mining area. Copper production has been insignificant and spasmodic.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	9,605	32,893	283,316
1957	7,659	28,021	286,731
1958	3,829	14,116	138,931
1959	530	2,295	19,782
1960	1,081	3,489	33,420
1961	4,624	16,620	160,831
1962	12,314	37,246	387,992
1963	10,758	31,573	302,362
1964	11,967	34,127	328,184
1965	14,382	42,653	415,568
Total	76,749	243,033	2,357,117

Dry Valley and Montezuma Canyon Areas — Monticello District, Utah

The Dry Valley area of the Monticello district lies north of Monticello and adjacent to the Big Indian Wash-Lisbon Valley area (figs. 11 and 14). Montezuma Canyon is a deeply incised drainage system south of Monticello (fig. 18). Uranium-vanadium mineralization in both areas is confined almost entirely to the Salt Wash Member of the Morrison Formation.

The Salt Wash is a light-colored, massive, cross-bedded, lenticular sandstone, interbedded with reddish siltstone and mudstone lenses. It is 200 to 450 feet thick in Montezuma Canyon and 350 to 520 feet thick along the cliffs of Dry Valley. The largest and richest deposits are in thick sandstone lenses, the uppermost lens at Dry Valley and lenses associated with abundant carbonaceous vegetal trash near the middle of the unit in Montezuma Canyon. The Salt Wash thins toward the south, until it disappears in the southern part of the Montezuma Canyon area. Strata are almost horizontal, dipping less than 2° in a southerly direction. A series of east-west trending faults, with displacements up to 180 feet, cross the northern part of Montezuma Canyon, but distribution of mineralization bears no genetic relation to them.

At Dry Valley, ore bodies average 3 feet by 30 feet by 200 feet and are clustered in producing areas. In two, perhaps three, such areas, the ore trends in a northerly direction. Ore bodies, both tabular and roll type, occur at any stratigraphic level within the host lens, but generally hug the bottom or sides.

At Montezuma Canyon, ore bodies may be at any position within the thick host lenses; small ore bodies also inhabit thin sandstone beds. Of the deposits that

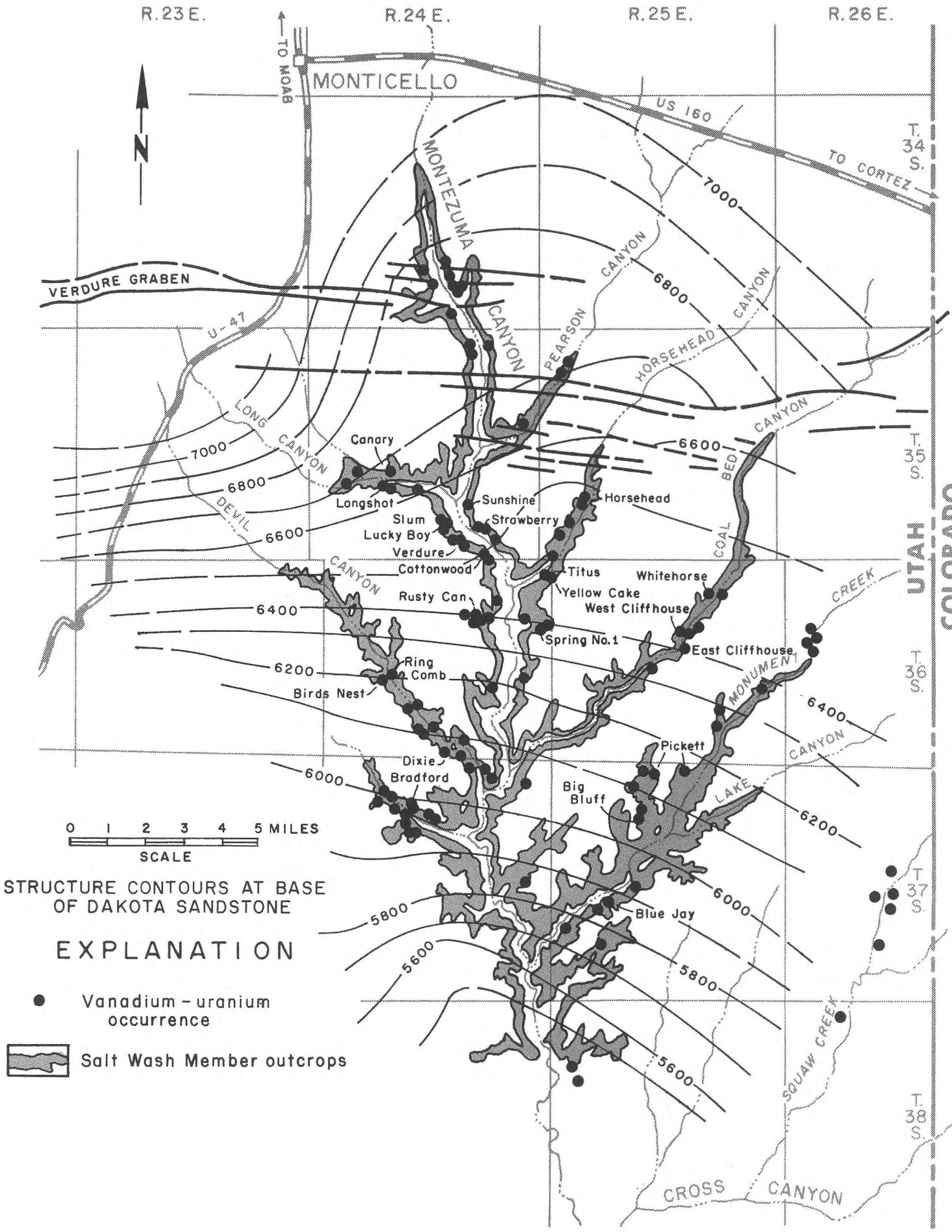

Figure 18. Map showing vanadium-uranium occurrences, Salt Wash Member outcrops and structural contours at the base of the Dakota Sandstone in the Montezuma Canyon area, Monticello district (after Huff and others, 1958).

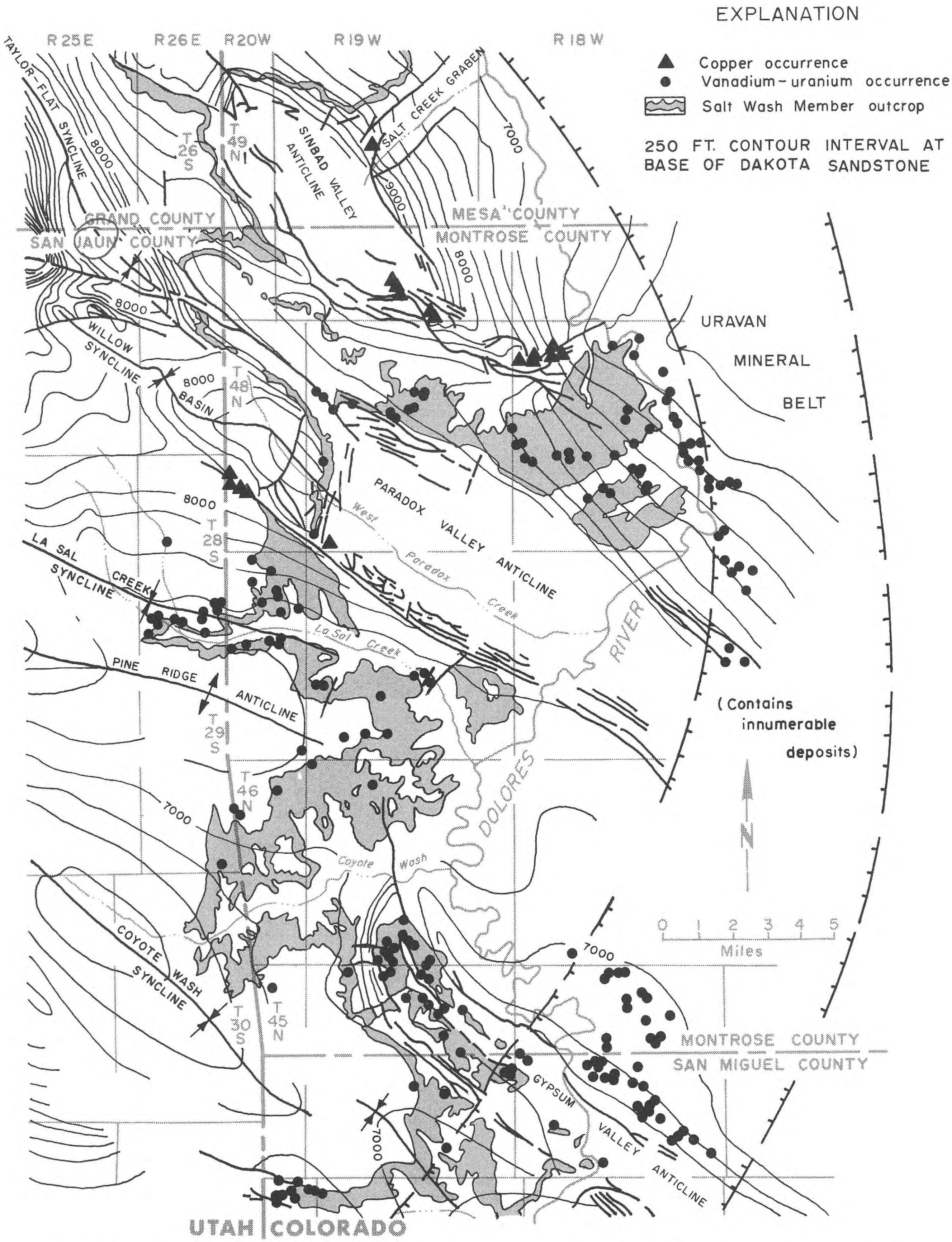

Figure 19. Map showing Salt Wash Member outcrops, copper and vanadium-uranium occurrences in the Paradox and West Gypsum Valley district (after Williams, 1964).

have produced 70 percent of the ore and retain 75 percent of the reserves, 35 percent are in a sandstone lens 150 feet thick and 13,000 feet long in the central part of the area.

The zonal arrangement of the Montezuma Canyon deposits is a striking feature described by Huff and Lesure (1962, p. 226-237) and ascribed by them to diffusion. The ore zone, about 2 feet thick, an irregularly shaped ellipsoidal shell that encases a brown core of porous sandstone and carbonaceous material, is surrounded by gray sandstone tightly cemented by calcite. The zone tends to parallel bedding, but crosses it at the margins of the ellipses. The ore zone's ellipsoid shell is 20 to 40 feet in length, 10 to 20 feet in width and 4 to 10 feet in thickness. Minerals of the ore zone are roscoelite, carnotite, metatyuyamunite, simplotite, metarossite and other uranium-vanadium minerals, all of which point to oxidation of earlier ore minerals. The core and the gray zone are barren.

The Brushy Basin Member, a varicolored mudstone with intercalated sandstone and conglomerate lenses, is mineralized in the southeastern part of the Montezuma Canyon area. It is the uppermost member of the Morrison in Montezuma Canyon, and ranges in thickness from 250 to 430 feet. A thin wedge of Westwater Canyon Member, 180 feet at its thickest point, separates the Brushy Basin from the Salt Wash. Ore minerals occur in claystone and concretionary mudstone 150 feet from the top of the member and 20 feet below a conglomerate lens.

Ore minerals in all deposits are characteristic of the oxide zone. Carnotite, tyuyamunite, and vanadium clays occur at Dry Valley, and simplotite, metarossite, carnotite, metatyuyamunite and some roscoelite occur in Montezuma Canyon. The ratio of vanadium to uranium in Montezuma Canyon is usually low, 1.3:1. Geochemists have suggested that vanadium content decreases westward in the Colorado Plateau, except in vanadium "islands," such as the one surrounding the Henry Mountains in Garfield County. However, vanadium-uranium ratios from neighboring deposits are much higher, 10:1 at Abajo and Cottonwood and 7.5:1 at Dry Valley. In most areas, vanadium mineral concentrations do not coincide exactly with those of uranium; conditions favoring vanadium precipitation perhaps were not as pronounced at Montezuma Canyon, which is characterized by its peculiar ellipsoidal ore zones.

Production at Dry Valley from 1956 to 1965 totalled slightly more than 105,000 tons of ore, an average of 0.18 percent U_3O_8 and 1.35 percent V_2O_5, or 70 percent of the total given in the table below. This ore yielded 185 tons of uranium concentrate and over 1,400 tons of vanadium concentrate. Montezuma Canyon produced over 37,000 tons of ore that gave a yield of over 91 tons of U_3O_8 and almost 117 tons of V_2O_5; ore grade averaged 0.24 percent for uranium and 0.31 percent for vanadium. Ore tonnage totals fluctuated greatly from year to year during the 10-year period, but have not fallen sharply in recent years.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	10,674	46,636	214,828
1957	7,223	26,416	183,775
1958	20,053	82,340	404,461
1959	21,743	89,966	476,246
1960	8,532	35,739	230,978
1961	18,041	56,403	407,650
1962	20,968	76,338	453,020
1963	16,648	51,807	317,298
1964	16,504	61,869	416,559
1965	12,657	43,916	301,014
Total	153,043	571,430	3,405,829

Paradox District — Montrose and Mesa Counties, Colorado and San Juan County, Utah

The Paradox mining district encompasses much of Montrose County, Colorado, the south end of Mesa County, Colorado, west of the Dolores River and an adjacent part of San Juan County, Utah, in the vicinity of La Sal Creek, where some of the more productive deposits occur (figs. 11 and 19). This district was the site of the earliest uranium mining, and, in fact, produced the ore sent to the Curies in France in 1898.

Although several formations in the Paradox district are mineralized, at least 98 percent of the ore has come from the Morrison Formation. This unit consists of two members, the 250- to 400-foot thick Salt Wash and the 250- to 500-foot thick Brushy Basin. The Salt Wash is composed of white to gray, light-buff and rusty-red, fine- to medium-grained, cross-bedded, massive, lenticular sandstone interbedded with red, green, or light-gray shale and mudstone and sporadically distributed lenses of dense-gray limestone. The Salt Wash contains three to eight major sandstone ledges, each ranging from 20 to 150 feet in thickness, and separated by clay and shale layers. The result is a cliff and slope topography. The uppermost thick, continuous sandstone lens is commonly the most highly mineralized of the sequence.

The Brushy Basin Member is a variegated claystone containing scattered lenses and beds of conglomeratic sandstone, sandstone, and sandy limestone. Much of the claystone is bentonitic, possibly indicating volcanic ash falls during deposition. The ore occurs in two horizons, the first in lenses of conglomerate near the base of the member and the second in sandstone lenses near the top. These Brushy Basin deposits are abundant near Wray Mesa south of the La Sal Creek area.

Occurrences of copper minerals are associated with faults related to anticlinal structure in some Paleozoic units, the Triassic Moenkopi and Wingate Formations, and in the Jurassic Kayenta and Entrada Formations. Only rarely are uranium and vanadium ores associated with the copper minerals.

The distribution of deposits in the Morrison shows no direct relation to tectonic structure, in spite of the fact the Paradox district is marked by collapsed salt anticlines, attendant fault systems, and gentle intervening synclines and anticlines. The Morrison's most productive deposits are near La Sal Creek where the axis of a syncline passes through the area, but ore bodies are parallel to the sedimentary features rather than to tectonic structures.

The largest Salt Wash ore deposits are near the edges of the thick ore-bearing sandstone where a transition to sandy mudstone takes place, or in the lowermost scours and on the flanks or noses of ridges that project into paleostream channels. The situation is even more favorable where slump features, such as mudstone galls and fragments, breccia, carbonaceous vegetal trash, and thin mudstone lenses occur in sandstone channels. Ore bodies also have been found in thin sandstone layers above and below the ore-bearing lens, but generally these are small.

Most ore is found in small pods containing from 10 to 500 tons, although as much as 100,000 tons of ore have been taken from a single cluster of deposits. Very few clustered areas, however, contain that much ore, and an average of 3,000 tons is a more realistic figure. Individual pods commonly are joined by weakly mineralized sandstone. Locally, deposits attain a thickness up to 30 feet, but 2- to 9-foot thicknesses are far more common. Ore occurs as tabular bedded deposits or as rolls. Bedded deposits are like pancakes in plan and roll bodies are up to 600 feet long and almost equidimensional in their hourglass or crescent-shaped cross sections. Hard, barren sandstone pods, tightly cemented with calcite, may surround or border portions of deposits or form irregular halos 5 to 15 feet away.

In mines that do not penetrate far behind the outcrop, ores are oxidized, appear gray or yellowish-gray, and are dry. Minerals are carnotite, tyuyamunite, corvusite, brightly colored vanadates, and vanadium hydromica or clay. In deeper and larger mines, unoxidized ore is reached that commonly is black and wet. It consists of uraninite, coffinite, montroseite, and vanadium hydromica or clay. The minerals impregnate sandstone and mudstone, replacing carbon, calcite, silica, and clay in rich deposits. Some places, the mudstone is enriched sufficiently to be mined as ore. Locally, deposits are enhanced by copper, lead, zinc, and selenium.

In several rock formations, copper minerals occur as disseminations in sandstone adjacent to faults associated with salt anticlines. The largest deposits are found near faults that are perpendicular to the axes of anticlinal structures. Most deposits are near Sinbad Valley and Roc Creek salt structures. A few also boast an acceptable uranium and vanadium content.

During the 1956 to 1965 production period, uranium ore averaged 0.28 percent U_3O_8 and 1.56 percent V_2O_5. Vanadium-uranium ratios for individual mines range from 4:1 to 14:1, but the average for the district is 5.6:1. More than 45 percent of the 266,000 tons of ore produced during the 10-year period came from the Utah portion of the La Sal Creek area. The entire La Sal Creek area produced over 70 percent of the Paradox district ore. Ores from Utah's La Sal Creek area also are richer in vanadium, averaging 1.82 percent against 1.36 percent for the rest of the district. However, uranium content is about the same in both portions. Ores mined from 1956 to 1965 yielded 746 tons of uranium concentrate and 4,168 tons of vanadium concentrate.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	24,194	159,119	954,946
1957	22,980	147,001	866,981
1958	25,262	163,667	779,786
1959	21,494	131,471	744,425
1960	21,789	124,864	776,064
1961	32,693	173,934	981,547
1962	23,508	136,774	663,668
1963	25,947	139,823	819,118
1964	39,086	182,158	1,010,562
1965	29,490	133,953	769,692
Total	266,443	1,492,764	8,366,789

Western Gypsum Valley District — Montrose and San Miguel Counties, Colorado

The Gypsum Valley district lies in Montrose and San Miguel Counties, Colorado (figs. 11 and 19), and includes ground on both sides of the Dolores River. This summary deals only with the portion west of the river.

Uranium-vanadium deposits occur in the Hermosa Formation of Pennsylvanian age, the Wingate Formation of Triassic age, and the Carmel-Entrada Formations (undivided), and the Salt Wash and Brushy Basin Members of the Morrison Formation of Jurassic age. However, the Salt Wash deposits are most important economically. The member consists of a sequence of light-colored, lenticular, cross-bedded sandstone beds that alternate with green, gray, red, or purple mudstone and claystone. In Gypsum Valley, where it many times rests directly on the Pennsylvanian salt, it is about 350 feet thick.

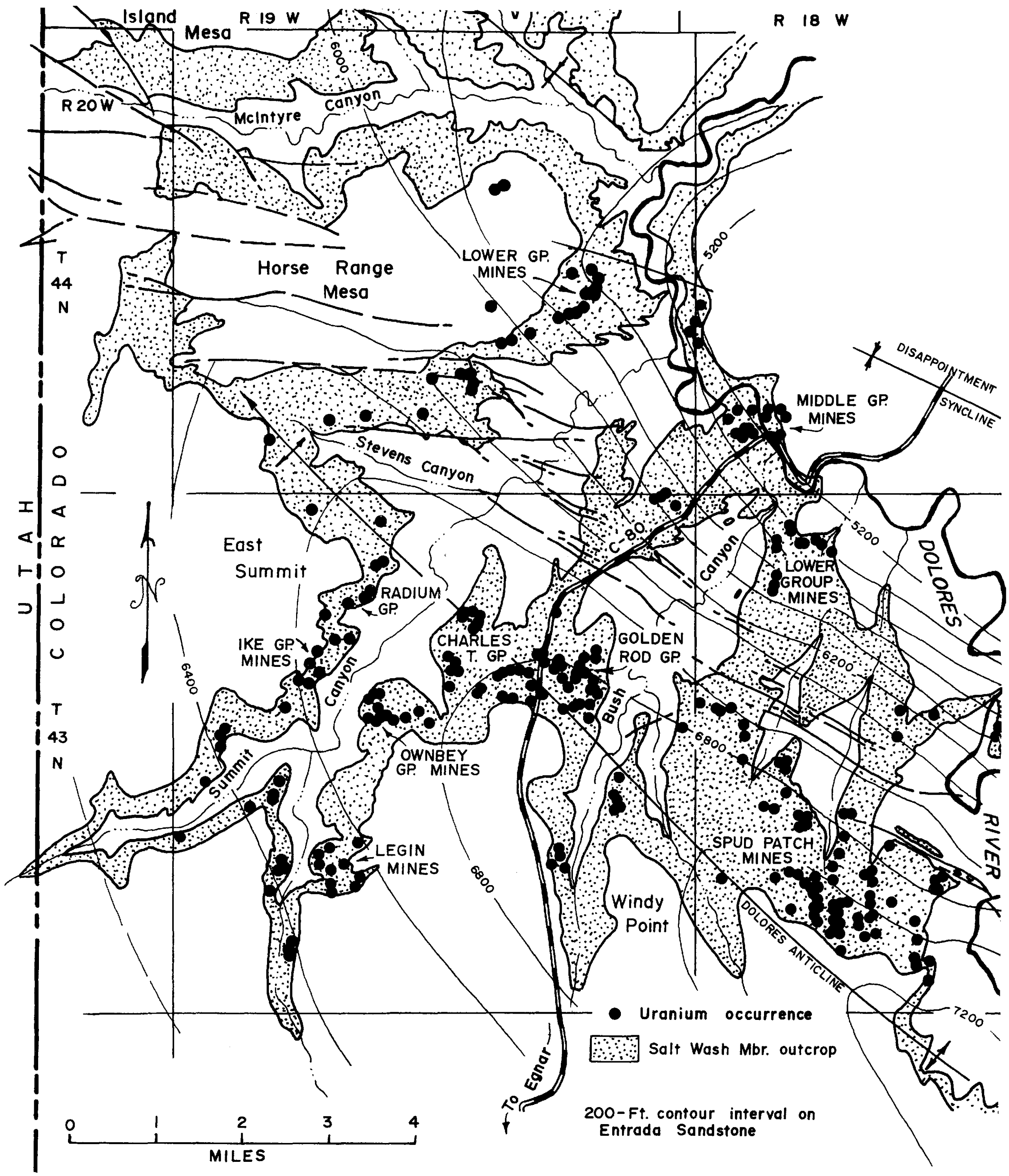

Figure 20. Uranium occurrences and Salt Wash Member outcrops in San Miguel County, Colo., Slick Rock district (after Cater, 1955).

The structure is dominated by the collapsed northwest-trending salt anticline, and is bordered by a host of peripheral faults. Strata have collapsed inward in some areas, assuming a variety of attitudes; at some mines, strata dip as steeply as 40°.

Most deposits lie in the uppermost continuous, thick sandstone lens of the Salt Wash Member. The lens ranges in thickness from 30 to 90 feet, but averages about 60 feet. Three to seven ore layers or rolls are distributed vertically throughout. For the most part, upper ore layers are too thin or too low-grade to mine; the richest ore bodies are confined to the lens' lower 20 feet. Roll ore bodies are as much as 12 feet thick; blanket-like bodies average 2.5 feet. Pebbles, thin seams and stringers of claystone, and abundant carbonaceous trash are associated with ore bodies. Moreover ore is localized where the Salt Wash thins over the salt anticline and where it contacts the underlying salt.

Ore minerals are carnotite and vanadium micas and some occurrences of copper minerals have been noted. Ore minerals along with limonite, calcite, and silica form overgrowths on sand grains. Little ore has been taken from the western part of Gypsum Valley, and, probably because of the small size of ore bodies, this small production waned toward the end of the 1956 to 1965 period. Vanadium-uranium ratios have averaged 8:1 and ore content, 0.24 percent U_3O_8 and 1.91 percent V_2O_5. From 1956 to 1965, not quite 30,000 tons of ore were mined, from which 72 tons of uranium concentrate and 563 tons of vanadium concentrate were recovered.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	9,468	44,336	331,012
1957	5,638	29,798	239,540
1958	3,694	19,465	136,754
1959	2,094	12,281	96,835
1960	1,506	7,738	60,255
1961	1,258	5,542	44,106
1962	1,009	5,491	37,596
1963	1,536	5,554	54,733
1964	1,678	6,260	61,995
1965	1,576	7,747	64,921
Total	29,457	144,212	1,127,747

Slick Rock District — San Miguel County, Colorado

The Slick Rock uranium and vanadium district is mostly in San Miguel County, Colorado, but includes a few mines in adjoining Dolores County (figs. 11 and 20). About 75 percent of the district lies west of the Dolores River and the statistical information that follows refers to that portion only.

As in other Colorado districts (Gateway, Paradox, and Gypsum Valley), the Salt Wash Member of the Morrison Formation is the most valuable ore-producing horizon. The basal part of the overlying Brushy Basin Member of the Morrison is mineralized as is the basal portion of the Chinle Formation in a few places. The Salt Wash Member's thickness varies noticeably over short distances, ranging from 28 to 450 feet. The Salt Wash weathers to a ledge and slope topography; ledges are formed by sandstone lenses, which are white to gray, light-buff, and rusty-red, fine- to medium-grained, cross-bedded, lenticular, and massive. Individual lenses may be as much as 125 feet thick and may be continuous for a mile or two. Thin lenses and pebbles of reddish mudstone and pockets of carbonaceous material are abundant in local sandstone lenses. Slopes, carved on thin sandstone lenses, have almost the same characteristics as thicker lenses--reddish shale and mudstone and locally a few thin lenses of dense-gray limestone. Contact with the overlying Brushy Basin Member is gradational and generally is located at the base of the lowermost conglomerate lens of the sequence.

The Brushy Basin Member also varies appreciably in thickness, ranging from 300 to 700 feet. It is a varicolored bentonitic mudstone and shale interbedded with a few conglomeratic sandstone, conglomerate, sandstone, and limestone lenses. A few lowermost conglomeratic lenses near the contact with the Salt Wash Member are mineralized.

The Slick Rock district contains parts of three major structural elements, the Disappointment syncline, the Dolores fault zone, and the Dolores anticline. The axes of all three trend northwest, and all are believed to have been formed as the result of subterranean salt flowage on the southwest flank of the Uncompahgre uplift. Principal producing areas are concentrated southwest and northeast of the Dolores fault zone, which lies between the synclinal and anticlinal axes. Deposits seem to occur where a slight change in dominant fault direction takes place. In the northwestern part of the district, faults trend about N. 80° W., whereas in the southeastern part they trend N. 50° W. Displacements rarely exceed 100 feet. These faults appear to be related to concentrations of copper and lead in the ore, but there seems to be no direct relationship between the faults and the concentrations of uranium and vanadium. The favorable Uravan mineral belt includes the Slick Rock district at its southern end.

Most uranium-vanadium ore bodies in the Salt Wash Member are in the uppermost thick, continuous lens of sandstone. However, in some parts of the southern and eastern portions of the district, middle sandstone lenses contain important ore bodies. Moreover, workers have located ore bodies above and below the main producing horizon. Ore normally is associated with abundant carbonaceous debris, pebbles and slump features along the bottom and sides of sandstone lenses,

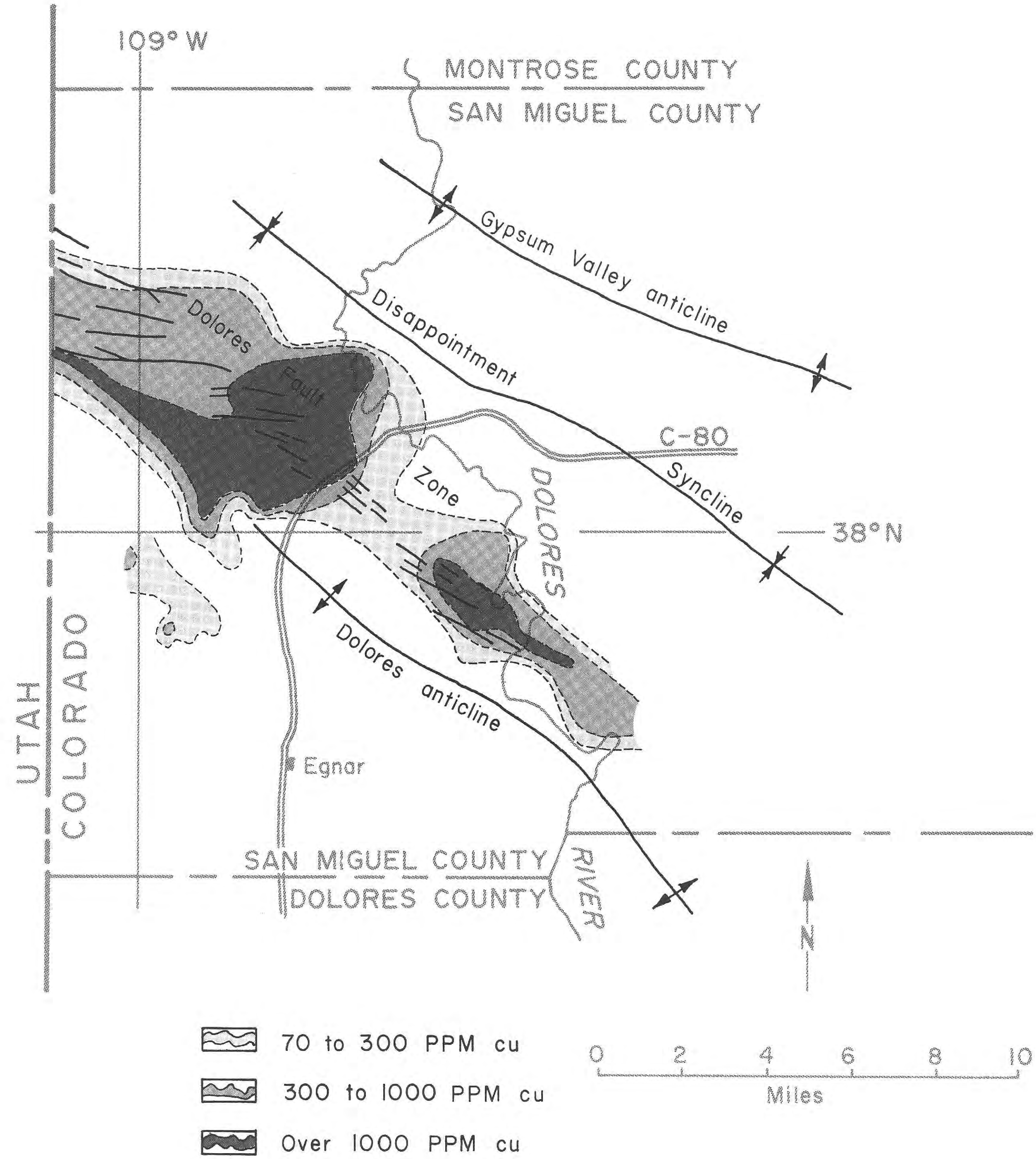

Figure 21. Copper in uranium deposits of the Slick Rock district, Colo. (after Shawe, 1957).

but may occur in association with the central parts of a lens. Tabular ore bodies roughly parallel sedimentary structures, especially bedding. In places, where sandstones contain considerable debris and other irregularities, they tend to have an uneven outline. Where rock is homogeneous, ore bodies tend to be oval in plan and somewhat lenticular in cross section. These tabular bodies average 3 feet in thickness, but may be as much as 20 feet thick and more than 200 feet in length. Roll ore bodies are elongate, sinuous, and vary considerably in thickness and width along their lengths. Maximum dimensions are 5 feet by 15 feet by 300 feet. Most roll-type bodies are near the impermeable boundaries at the edges of elongate permeable sandstone lenses. Whereas tabular bodies contain from a few to several tens of thousands of tons of ore, roll ore bodies are limited to a few thousand tons.

Large deposits are found most often in the thick parts (40 feet or more) of sandstone lenses; few deposits occur in sandstone lenses less than 20 feet thick. Relatively coarse-grained sandstone that is yellowish-brown and speckled with limonite stain is more favorable than reddish-brown, fine-grained sandstone. Mudstone in the vicinity of ore bodies has been altered from reddish colors to gray. Consequently, if gray-altered mudstone lies beneath a thick sandstone lens, chances are good that ore will be found in the lens.

Ore minerals impregnate and, more rarely, replace sandstone. Most near-surface deposits lie within the zone of oxidation, but some deeper mines reach unoxidized ore. Chief minerals are carnotite, a micaceous vanadium mineral, tyuyamunite, montroseite, corvusite, and uraninite. Minute grains of the sulfides of iron, copper, and lead are preserved in the unoxidized ore. The uranium-vanadium deposits in the Morrison Formation of the Slick Rock district are unusual in that they contain an appreciable amount of copper and lead. Some ore holds as much as 0.3 percent copper, 0.018 percent lead, 0.0014 percent cobalt, 0.0008 percent nickel, 0.022 percent zinc, 0.021 percent arsenic, 0.0044 percent molybdenum, and 0.0001 percent antimony. As shown in Figure 21, copper and lead centered on the Dolores fault zone are arranged in crude zones.

All the same, the mines are operated solely for their uranium and vanadium content, even though they have produced radium and many claims are patented. Prior to 1955, ore averaged 0.22 percent U_3O_8, 1.7 percent V_2O_5, and 0.07 percent copper, but from 1956 to 1965 average content was 0.25 percent U_3O_8 and 1.8 percent V_2O_5. The vanadium-uranium ratio ranges from 1:1 to 20:1, with differences being noted from mine to mine. The vanadium-uranium ratio for the district averages 7:1. Over 1,000,000 tons of ore were produced from 1956 to 1965, netting over 2,600 tons of uranium concentrate and almost 19,000 tons of vanadium concentrate.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	57,712	360,753	2,031,739
1957	58,881	331,562	2,063,609
1958	106,733	601,438	3,748,933
1959	138,122	708,281	4,788,664
1960	155,385	749,218	5,521,439
1961	113,450	540,109	4,007,614
1962	103,962	488,741	3,829,147
1963	95,843	456,631	3,683,642
1964	111,913	534,403	4,437,061
1965	114,118	520,153	4,596,669
Total	1,056,119	5,291,289	37,708,517

Deer Flat and Elk Ridge Areas — White Canyon District, Utah

The Deer Flat and Elk Ridge areas of the White Canyon district of central San Juan County, Utah, lie some 20 miles west of Blanding (figs. 11 and 22). Elk Ridge, an erosion remnant of Triassic rocks, towers above the broad surface of the Monument Uplift. Its mines are at altitudes ranging from 6,500 to 8,500 feet. The Deer Flat area is at the west end of Elk Ridge.

Ore has been produced from three stratigraphic horizons, the Moss Back Member of the Chinle Formation, and the lower mudstone units of the Chinle and the Moenkopi Formations. Indications of mineralization have been noted near the contact of the Rico and Cutler Formations and abundant radon has been observed in samples of mud from an oil well drilled south of Elk Ridge that penetrated the Paradox Member of the Hermosa Formation of Pennsylvanian age. The most productive horizons are those in the Chinle Formation, particularly those of the lower mudstone unit. That lower unit, which is up to 160 feet thick, thins and pinches out in the northern part of the Elk Ridge area. It rests unconformably upon the Moenkopi Formation, fills shallow channels, and is unconformably overlain by the Moss Back Member. The lower mudstone can be subdivided into two units--a lower unit up to 60 feet thick of discontinuous, cross-bedded, medium- to coarse-grained and conglomeratic sandstone lenses, and an upper unit of blue and gray, predominantly massive mudstone. Some writers have referred to the basal sandstone lenses as the Shinarump Member and the mudstone part as the Monitor Butte Member. However, the lenses often are found to be at slightly different stratigraphic levels within the mudstone.

The Moss Back Member of the Chinle Formation is a massive sandstone 55 to 150 feet thick, which in hand specimen is indistinguishable from the sandstone of the lower mudstone unit. In the northern part of the Elk Ridge area, it blankets the Moenkopi and the lower mudstone and fills channels cut in both. The only ore-bearing portion of the Moss Back lies in the northern part of the Elk Ridge area.

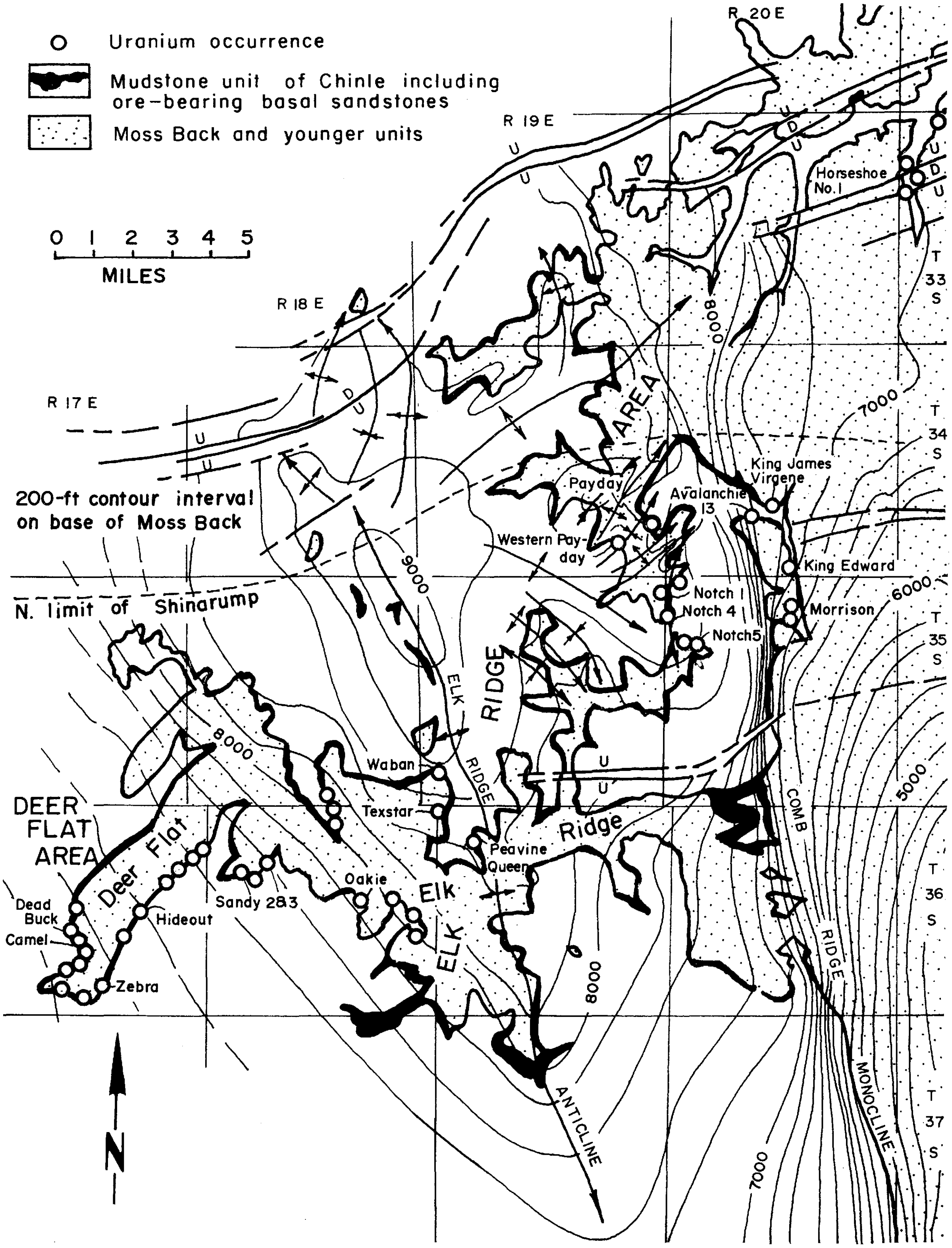

Figure 22. Uranium occurrences, mudstone unit of the Chinle, Moss Back and younger units, in the Elk Ridge and Deer Flat areas, White Canyon district (after Lewis and Campbell, 1965).

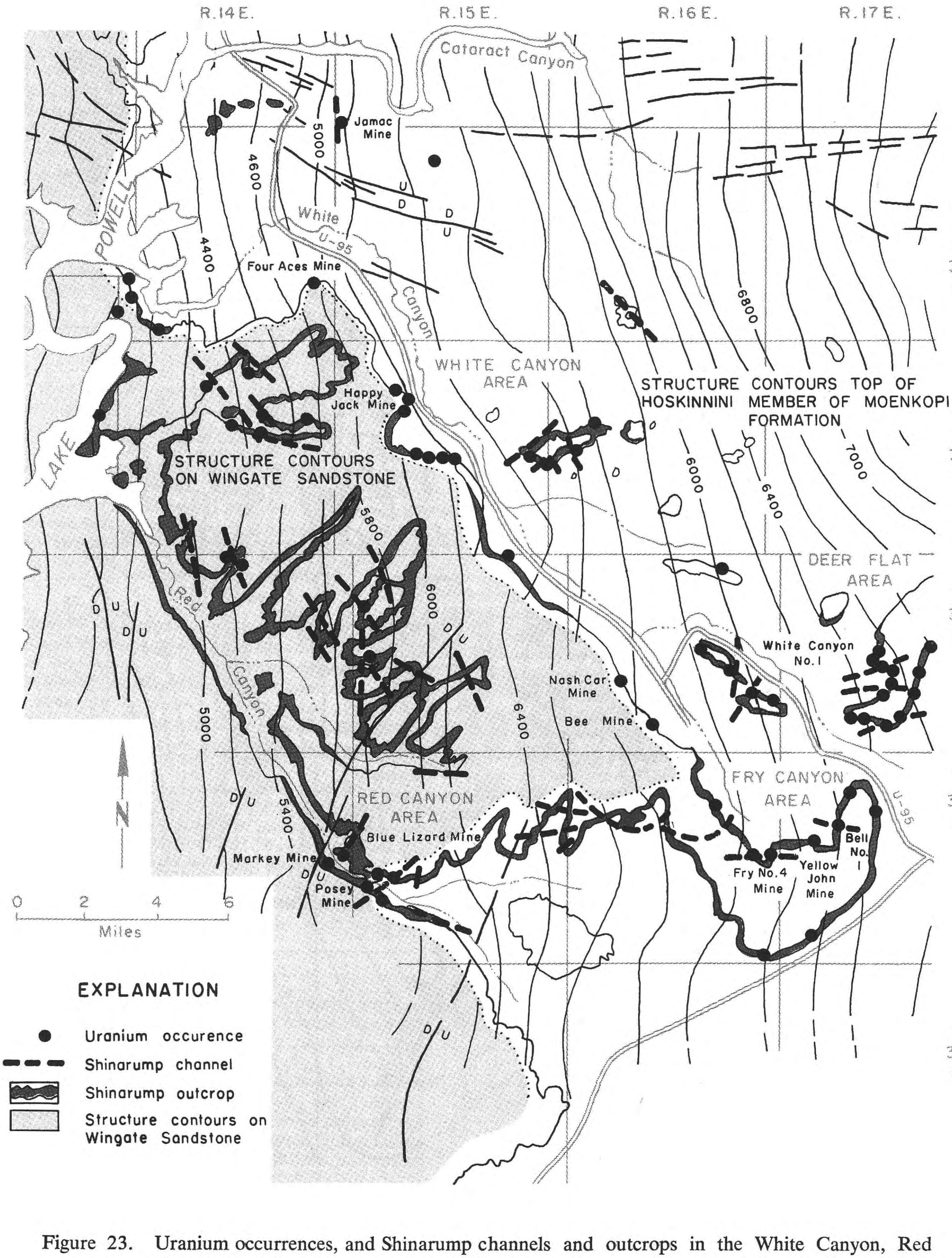

Figure 23. Uranium occurrences, and Shinarump channels and outcrops in the White Canyon, Red Canyon, and Fry Canyon areas, White Canyon district (after Thaden and others, 1964).

The Monument uplift and its associated structural features have had an obvious effect on the Deer Flat and Elk Ridge areas. The upwarp is somewhat asymmetrical with the steeper limb on the east side of the Elk Ridge anticlinal axis. Dips are gentle on both sides of the axis, rarely exceeding 5°, except at the Comb Ridge monocline where dips up to 30° have been recorded. Shallow anticlinal, synclinal, and monoclinal flexures superimposed on the upwarp bow the strata by a few degrees. Some of the flexures are parallel; others transverse to main structural trends. Several faults and grabens cut through strata in the Elk Ridge area, and while displacements of over 100 feet are rare, some are several times that amount. Although ore bodies are scattered over large areas on either flank and near the axis of the Monument upwarp, their distribution does not appear to be associated directly with the faults or the uplift. However, Deer Flat deposits seem to be related to shallow monoclinal flexures. The only structural element that has had any effect on ore localization is the sag in the Moenkopi Formation, formed prior to Chinle deposition, that confined the basal sandstone lenses of the lower mudstone unit. The westward flowing stream that occupied the sag cut a series of channels[1/] across the central portions of the Elk Ridge and Deer Flat areas. This channel system is 3 to 6 miles wide, but individual channels measure 15 to 25 feet in depth and a few feet to 1,000 feet in width. Ore has been found only where a sandstone lens is in contact with the underlying Moenkopi Formation. This holds true even when a sandstone lens is a short distance above the mudstone.

The Moss Back Member contains ore only in the northern part of the area, where it is in direct contact with the Moenkopi. Deposits are roughly tabular or lenticular bodies containing from a few tons to more than 15,000 tons of ore. The bodies often are capped by an impermeable mudstone or shale layer in the sandstone. Most productive ore bodies--300 to 500 feet long, 50 to 150 feet wide and 2 to 10 feet thick--are in the center. Commonly, the deposit thins from its center outward in all directions. In every instance, ore is associated with abundant carbonaceous matter, such as logs (rare), twigs, leaves, and tiny fragments. Mineralization generally is confined to the basal sandstone lens, although in places it extends from a few inches to a few feet into the Moenkopi. In one mine, ore is found 40 feet below the contact in a sandstone and conglomeratic sandstone lens in the Moenkopi. Radioactivity increases slightly near this contact, regardless of whether mudstone or sandstone impinges on the Moenkopi Formation.

Ore deposits are made up of fine-grained minerals, difficult to identify in the field. Sandstones may be darkened by asphaltite-like material, carbonaceous matter, or primary uranium minerals; so a counter is the best aid in determining the presence of ore in the field. Most deposits are unoxidized, are of the uranium-copper type, and contain uraninite as the chief mineral. Much of the asphaltite-like material is uraniferous and makes up a considerable percentage of the ore in some mines. Locally, chalcopyrite, bornite, domeykite, tennantite, and pyrite are abundant and galena and sphalerite are present in trace quantities. Contrary to the characteristics of most deposits in the Morrison Formation and many in the Moss Back, vanadium only occurs in trace amounts and is represented by a few secondary minerals. Secondary minerals occur in fractures, along outcrops, and along the walls of mines. These include andersonite, zippeite, coffinite, uranophane, metaautunite, schroeckingerite, uranothollite, tyuyamunite, malachite, azurite, chalcanthite, chalcocite, cuprosklodowskite, metazeunerite, ilsemannite, jarosite, erythrite, limonite, hematite, and bieberite. Ore minerals occupy the interstices between sand grains and, in places, replace carbonaceous matter, calcite and silica cement, and sand grains. Insofar as mineralogic changes are concerned, alteration of rock adjacent to ore bodies is insignificant. However, the Moenkopi Formation is often bleached under ore bodies and along fractures.

1. The so-called Elk Ridge-White Canyon channel system.

Ore grade varies considerably within an ore body. In mining most high-grade ore is mixed with low-grade and sub-ore grade material, in order to provide a uniform, or nearly uniform, acceptable grade. Ore grade for both Deer Flat and Elk Ridge is approximately 0.26 percent U_3O_8 and 0.06 percent V_2O_5. From 1956 to 1965, the mines produced 455,000 tons of ore, which yielded 1,200 tons of uranium concentrate and almost 27 tons of V_2O_5. The Deer Flat area produced 45 per- of the total ore.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	50,070	262,452.69	450.00
1957	27,461	141,152.80	1,696.48
1958	58,259	284,139.49	12,493.12
1959	36,577	180,012.12	1,497.00
1960	56,842	308,967.91	---
1961	47,966	248,403.91	---
1962	34,745	171,611.71	439.16
1963	35,243	168,943.67	13,422.65
1964	59,214	342,028.00	11,984.51
1965	49,268	290,685.36	11,198.87
Total	455,645	2,398,397.66	53,181.79

White Canyon, Red Canyon, and Fry Canyon Areas — White Canyon District, Utah

The White Canyon, Red Canyon and Fry Canyon areas, which form the western portion of the White Canyon district, are in the remote west-central part of San Juan County near the Colorado River (figs. 11 and 23). Drainage of Fry Canyon and White Canyon, to which Fry Canyon is tributary, flows northwestward to the

Colorado River. Red Canyon is about 9 or 10 miles south of White Canyon and parallels it. The Shinarump Member, the ore-bearing unit of the Chinle Formation, forms cliffs at the edges of mesas and buttes bordering all three canyons.

Although some of the adjacent units are mineralized, essentially all the ore of the western White Canyon district has come from the Shinarump Member. The Shinarump, the basal unit of the Chinle, rests unconformably upon the Moenkopi Formation. Channels and other irregularities on the Moenkopi paleosurface are filled by Shinarump sediments--fluvial interbedded sandstone, conglomerate, and mudstone. At the Happy Jack mine, the district's largest, the Shinarump is divided into three subunits. The lower subunit consists of sandstone lenses interbedded with roughly 10 to 30 percent mudstone or siltstone in the form of thin lenses, partings, clay galls, and reworked Moenkopi sediments. This lower subunit occurs only as channel fill and so is discontinuous in the area. The middle subunit, essentially a structureless gray or red mudstone, also is confined to the channels. The upper subunit, a massive sandstone, extends beyond the channel systems. Although not present everywhere, the entire Shinarump ranges up to 80 feet in thickness and is thickest in the most favorable uranium areas. The thickness of the three subunits varies greatly throughout the area, but at the Happy Jack mine they are 5 feet, 12 feet, and 28 feet thick in ascending order. The lower subunit is the most productive; the middle and upper parts of the Shinarump contain sporadic occurrences of ore. The sandstone lenses of the Shinarump are primarily light in color--pale-orange, grayish-yellow, white, or gray. They are poorly sorted with extremely fine-grained to very coarse-grained and conglomeratic textures. The sandstone is feldspathic, but dominantly quartzose, and portions of it contain interstitial clay and abundant carbonaceous matter.

Overlying the Shinarump is a gray or gray-blue mudstone-sandstone unit, 120 to 250 feet thick, that consists of impure mudstone and interbedded sandstone lenses. This unit has been correlated in part with the Monitor Butte Member of the Chinle Formation. The Moss Back Member of the Chinle Formation, a massive, resistant, sandstone ledge, lies above the mudstone-sandstone unit. Not everywhere present, the Moss Back ranges up to 200 feet in thickness. While these units in the western part of the White Canyon district contain little ore, they have been productive elsewhere.

The Shinarump and succeeding units were deposited by westward and northwestward flowing Triassic rivers and streams. These cut and filled channels on the Moenkopi's surface and laid down floodplain debris on interchannel areas. The Elk Ridge-White Canyon channel system, which provided the most important host rocks, enters the western White Canyon area at Deer Flat. There, the channel system is 3 to 6 miles wide, but it diverges into an alluvial fan to the west where the system widens to 18 miles. In the western White Canyon district, individual channels were not cut as deeply as other Shinarump channeled areas, because widely-spaced streams spread over a broader area. That swamp conditions prevailed between streams at the wide western end of the channel system is evidenced by the presence of several coal beds. The Monument channel system stretches northwesterly from the Monument Valley district and probably joins the Elk Ridge-White Canyon system at the southwest corner of the fan. Deposits of the Monument channel system are blanket-like and hold little uranium in the White Canyon area. The channels of the western White Canyon district range in width from 30 to 1,000 feet and in depth from 2 to 50 feet. Some large ore bodies occur where channels intersect or change direction.

The western White Canyon district lies on the western flank of the Monument upwarp (Elk Ridge anticline), where the strike is northwesterly, and dips gently to the southwest. Only a few faults and grabens (possibly attributable to subterranean salt deformation) trend east-west at the north end of the district. Another group of faults at the south and west end of the area are related to the Henry Mountains uplift. Strong vertical fracturing is common in all formations, and some faults and fracture surfaces are bleached and coated with silica, limonite, and calcite. None of these structures, however, seems to have influenced the localization of ore, but some ore occurrences are associated with gentle changes in dip. Such structural terraces have been associated with the Happy Jack mine and a few other large ore bodies. Young (1964, p. 851) noted a broad structural high east (and perhaps south) of the White Canyon district that confined the channel systems to paleotopographic or paleostructural lows at its edges. Johnson and Thordarson (1959, p. 123) suggest a Triassic structural sag held the Elk Ridge-White Canyon channel system in its present position. These streams terminated in a fan near Deer Flat and debouched sediments over a large part of the western White Canyon district. These paleostructural elements appear to have had a direct bearing on uranium emplacement.

Ore bodies are of the copper-uranium, low-lime type; vanadium is present in small quantities only. Most deposits are on the bottom, sides, or the scours of channels, especially those of irregular configuration that change direction or intersect other channels. Most of the ore occurs where individual sandstone lenses pinch out against mudstone and where sandstone rests upon mudstone of the lower Shinarump. Ore grade is related directly to the amount of carbonaceous material present. Such matter generally is a composition of twigs, leaves, fragments, and, more rarely, thin coal seams, and carbonized logs.

While ore bodies up to 10 feet thick have been found in the western White Canyon district, most average

3.5 feet. Deposits range from 50 to 1,000 feet in length and from 10 to 500 feet in width. Gradation between ore and subgrade or barren rock generally is sharp and little low-grade, sub-ore exists. Ore grade, as well as the ratio between copper and uranium varies markedly within an ore body and from one ore body to another. Ore minerals in the interstices between detrital sandstone grains replace carbonaceous matter, calcite and silica cement. In rich ore bodies, they replace quartz and feldspar grains. For the most part, ores are unoxidized, except where the overburden is shallow. Uraninite is the primary ore mineral and uranophane, metatorbernite, phosphuranylite, metazeunerite, and a zippeite-like mineral are common. Less common are uranopilite, johannite, metaautunite, cuprosklodowskite, and becquerelite. Primary sulfides such as pyrite, chalcopyrite, sphalerite, galena, and bornite are plentiful locally. These primary minerals are the source of a host of secondary minerals, a few of which include native copper, malachite, antlerite, ilsemannite, jordesite, erythrite, native sulfur, and barite. Ore bodies are roughly tabular and elliptical in plan. In general, the greater the heterogeneity of rock and channel configuration, the more irregular the shape of the ore body.

The western White Canyon district, comprising the White Canyon, Red Canyon and Fry Canyon areas, is second only to the Lisbon Valley district in uranium production in Utah. Over 1,000,000 tons of ore produced from 1956 to 1965 yielded 2,629 tons of U_3O_8, but only 29 tons of V_2O_5. The White Canyon area produced 55 percent, Red Canyon 40 percent, and Fry Canyon 5 percent of the total amount. Copper, which constitutes 1 percent of White Canyon uranium ores, has been recovered, but production figures are not available. Ore grade has averaged 0.25 percent uranium.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	95,220	519,373.51	10.93
1957	97,862	522,001.93	7,766.42
1958	148,701	759,777.89	44,446.84
1959	154,181	758,553.62	54.00
1960	123,627	626,110.98	2,019.00
1961	131,423	662,995.23	---
1962	127,985	595,187.01	4,242.00
1963	97,729	410,711.58	---
1964	53,637	237,261.51	---
1965	36,351	163,922.76	112.55
Total	1,066,716	5,255,896.02	58,651.74

Monument Valley District, Utah

Part of the Monument Valley uranium district in Utah is in the Navajo Indian Reservation adjacent to the Arizona line (figs. 11 and 24). This discussion is limited to the Utah portion of the district, although references will be made to the Monument No. 2 mine, which is in Arizona. The Monument Valley district is divided into three areas--the Comb Ridge area to the east, the Oljeto Mesa area in the center, and the Copper Creek area to the west. Ore-bearing formations crop out at the margins of steep-sided mesas and buttes.

The principal ore-producing unit is the Shinarump Member of the Chinle Formation, which lies unconformably upon the Moenkopi Formation in the Utah part of the district. At the Monument No. 2 mine, however, the pre-Shinarump erosion surface has cut into the De-Chelly Sandstone Member of the Cutler Formation. In most places, uranium mineralization has penetrated rocks beneath the Shinarump only a few inches, but in some instances it has intruded as much as 7 feet. The Moenkopi Formation consists mainly of reddish-brown and chocolate-brown, thin, sandy shale beds, and some fine-grained sandstone lenses, bleached a drab greenish-gray adjacent to the contact. Many investigators believe the thickness of this bleached zone indicates the presence of uranium mineralization in the Shinarump Member, or at least makes the possibility more favorable.

Shinarump sediments fill channels cut into the Moenkopi Formation and cover the sediments of this subjacent unit in most places. However, in a few places, upper Chinle beds rest directly upon the Moenkopi. The Shinarump is absent north of Monument Valley in the Clay Hills area and along Comb Ridge. It consists mainly of light-colored, cross-bedded, medium- to coarse-grained sandstone with sporadic lenses of conglomerate and mudstone. Channels are 40 to 2,000 feet wide, from 20 to 200 feet deep, and trend N. 60° W. Although uranium may be localized in any channel, those 300 to 1,000 feet wide are most favorable. Ore bodies generally are found in the deepest parts and scours of such channels.

Most of the Utah portion of the district is on the west flank of the Monument upwarp, but a few deposits have been found along Comb Ridge to the east. The asymmetrical Monument upwarp plunges south in the vicinity of Monument Valley. Strata dip gently, except in the vicinity of Comb Ridge. Three sets of north-south trending fold axes, a few faults, and a few igneous dikes occur in the Oljeto Mesa and Copper Creek areas. Vertical fracturing is widespread, but no structures appear to have affected the localization of ore.

Ore bodies either are partly or wholly oxidized. Western deposits, notably from the Copper Creek area, are of the copper-uranium type and eastern deposits of Comb Ridge and parts of Oljeto Mesa of the uranium-vanadium type. Vanadium content tends to drop as copper content increases. Except for that at the Mon-

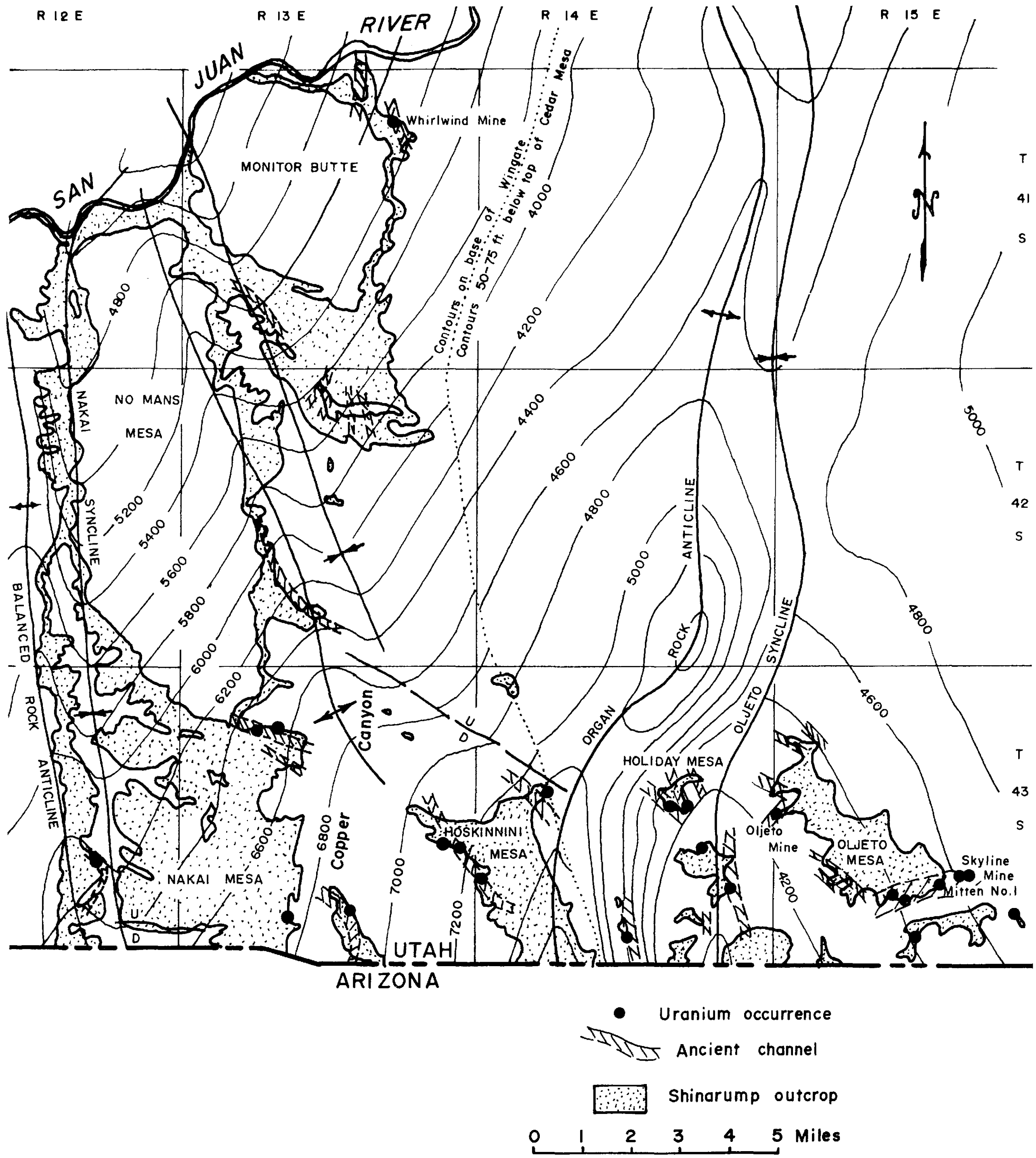

Figure 24. Uranium occurrences, ancient channels and Shinarump outcrops in the Monument Valley district, San Juan County, Utah (after Baker, 1935, and Lewis and Trimble, 1959).

ument No. 2 mine, ore bodies are small and generally up to 10 feet thick, 20 feet wide and 200 feet long. Long axes of the deposits parallel sedimentary channels. Where vanadium is an important ore constituent, ore bodies are zoned; rich vanadium lies below and down-dip from rich uranium ore. Most ore bodies pinch out sharply against channel walls. Some minerals, redistributed by groundwater, occur in the first few inches of the Moenkopi. At the Monument No. 2 mine, where the relatively porous and permeable DeChelly Sandstone lies directly under the Shinarump Member, an unusually large ore body was formed. Presumably the porous unit below allowed groundwater to carry uranium as much as 8 feet into the DeChelly Sandstone. Weakly mineralized ground connects clusters of ore bodies. Ore grade varies considerably from one ore body to another and even within the same body. In some areas, ore grade declines gradually, but in most the boundary between ore grade material and barren rock is sharp. The most abundant mineral is tyuyamunite, but uranophane, autunite, torbernite, and in the deeper portions of mines, uraninite are present. Copper minerals include malachite, azurite, chalcanthite, chalcocite, chalcopyrite, and bornite. Vanadium minerals include corvusite, navajoite, and calciovolborthite. Ore minerals are disseminated along bedding planes in sandstone and replace carbonaceous material to form tabular to lenticular bodies. Interesting ore guides relative to Monument Valley channels have been developed. Jasperoid pebbles occur in all uraniferous channels, but fluoresce only when uranium is present. Silica, in the form of opal or chalcedony, is fluorescent near uranium deposits, and does not fluoresce when uranium is absent.

From 1956 to 1965, the Utah portion of the Monument Valley district produced 45,000 tons of uranium ore. About 120 tons of uranium concentrate and 175 tons of vanadium concentrate were obtained. Ore grade of 0.27 percent U_3O_8 and 0.39 percent V_2O_5. The east to west vanadium diminution negates any meaningful vanadium-uranium ratio on a mine-to-mine basis, but the district's ratio is 1.5:1. Copper is extracted from mines in the western part of the district, but production figures are not available.

PRODUCTION 1956 to 1965:

	Ore (tons)	U_3O_8 (lbs.)	V_2O_5 (lbs.)
1956	6,086	38,452.36	64,749.14
1957	12,193	83,857.42	96,244.30
1958	5,728	25,945.87	107,424.91
1959	6,969	31,335.99	37,628.00
1960	2,508	11,011.47	---
1961	3,606	16,571.46	12,690.00
1962	5,529	25,552.26	22,739.13
1963	760	3,967.66	282.98
1964	545	1,473.15	2,981.00
1965	1,130	3,522.33	6,943.00
Total	45,054	241,689.97	351,682.46

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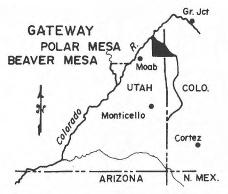
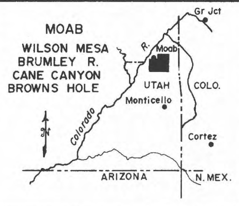
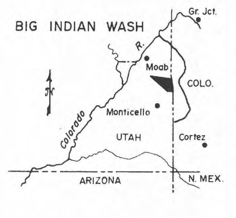
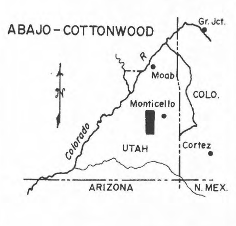
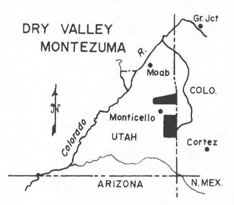
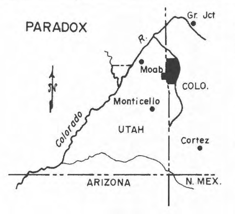
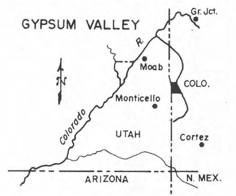
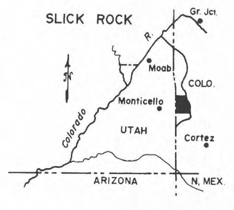
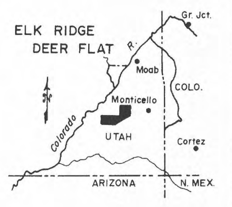
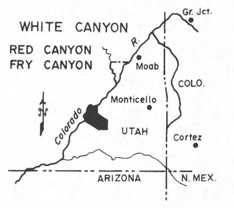
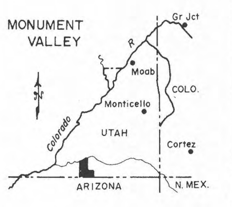
DISTRICT OR AREA	FORMATION, AGE, THICKNESS OF HOST ROCK	LOCATION WITHIN HOST SEDIMENTARY ORE CONTROLS	LOCAL STRUCTURE	SIZE, SHAPE OF DEPOSITS	ORE METALS AND MINERALOGY	V:U RATIOS ZONAL ARRANGEMENTS TRACE ELEMENTS	PRODUCTION 1956-1965	ORE GUIDES GIVEN BY AUTHORS	MISCELLANEOUS INFORMATION	REFERENCES
GATEWAY POLAR MESA BEAVER MESA 	Salt Wash Sandstone Member (Morrison Formation), Jurassic, approximately 300 feet thick. Ore 50 feet thick, most favorable ore zone, 270 feet above Entrada-Summerville contact.	"Payoff" sand horizon, 10-80 feet thick, has largest ore bodies; deposits above and below always small; most favorable sandstone lenses, at least 25 feet thick. Sandstone, light gray or light brown, fine- to medium-grained, contains carbonaceous material and thin splits, and/or pebbles of green mudstone. Ore usually associated with fossil carbonized vegetal trash.	Strike on Polar Mesa and southern two-thirds of Beaver Mesa N. 55°-60°W., dip 2°-4° NE. Axis of Sagers Wash syncline crosses north end of Beaver Mesa. Major ore-producing area, a structural low superimposed on northwest-dipping beds, and bounded by 90-foot displacement fault on the northeast and by gentle monoclinal fold on the southeast.	Ore bodies, tabular, irregularly shaped, of varying size. Ore bodies referred to locally as "rolls." Deposits range from 100-5,700 tons, but if ore bodies or rolls, merge, production can hit 10,000 tons. Ore bodies have long axes that trend north to northeast.	Ore contains vanadium and uranium. Significant deposits are of the unoxidized or partially oxidized vanadium-uranium type: Uraninite, Coffinite, Montroseite, Lumsdenite, Carnotite, Tyuyamunite, Corvusite, Pyrite, Dolomite	Vanadium-uranium ratio, 3:1-7:1. Average, 4:1.	1956 51,403 tons 1957 95,208 tons 1958 119,902 tons 1959 116,980 tons 1960 118,630 tons 1961 95,822 tons 1962 91,569 tons 1963 84,092 tons 1964 80,736 tons 1965 91,278 tons (Areas west of Dolores River only)	1. Mudstone, in contact with ore-bearing sandstone, gray green. 2. Ore-bearing sandstone contains thin, discontinuous green mudstone lenses and abundant masses and fragments of carbonaceous material. 3. Ore-bearing sandstone, light gray or light brown.	Less than 1 percent underlain by uranium deposits; less than 10 percent of ground favorable. Basal Brushy Basin Sandstone slightly mineralized in places. Lowest mineralized bed 80 feet above base of Salt Wash Sandstone.	U.S. Geol. Survey TEI 540, p. 27-29. U.S. Geol. Survey TEI 620, p. 53-55. U.S. Atomic Energy Comm. RME 22. U.S. Bureau of Mines RI 3930, p. 11-13.
MOAB WILSON MESA BRUMLEY R. CANE CANYON BROWNS HOLE 	Salt Wash Sandstone Member (Morrison Formation), Jurassic, 250-300 feet thick. Ore 100-180 feet above base of Salt Wash, generally in upper part of unit.	Ore in one or two horizons, generally in thick sandstones. At upper Cane Canyon, ore in two sandstone lenses, which are separated by 25 feet of shale to the south, but which merge to the north. Thickest portion of upper lens, 30 feet; that of lower lens, 45 feet. Sandstone, light gray to light brown, fine- to medium-grained, interbedded with green mudstone lenses, cross-bedded, clay galls, mudstone partings, and aggregates of granule conglomerate. Ore usually associated with carbonized vegetal matter.	No apparent relationship between structure and ore. Beds faulted and folded in many places. Units (dip up to 35°) are fractured excessively locally. Regional area one of salt anticlines with accompanying synclines on east flank of laccolithic La Sal Mountins. Distance from mountain peaks to ore, 3-12 miles.	Ore bodies, relatively small, sparsely distributed, occasionally clustered, lenticular. Lengths range from 5-200 feet, greatly exceed widths. Thickness ranges from feather edge to 5 feet. Ore bodies at upper Cane Canyon trend northeast.	Ore metals: uranium, vanadium. Mineralogy typical of Salt Wash deposits in other areas – carnotite, vanoxite (vanadium oxide) principal minerals. Many fractures surrounding deposits veneered with tyuyamunite and some rare uranium minerals. Celadonite (a complex iron mineral) often near ore.	Vanadium-uranium ratio, 4:1-7:1. Average, 5.3:1	1956 9,467 tons 1957 9,454 tons 1958 5,574 tons 1959 2,445 tons 1960 1,932 tons 1961 3,202 tons 1962 2,576 tons 1963 1,880 tons 1964 1,309 tons 1965 1,419 tons (Morrison production only)	Specific ore guides not given, but believed to be the same generally as for other Salt Wash Sandstone areas.	Extension of known deposits suggests other significant deposits may be discovered in Browns Hole-West Coyote Creek area.	U.S. Atomic Energy Comm. RME 58 (pt. I). U.S. Bureau of Mines RI 3930, p. 27.
INTERRIVER LOWER CANE CAN. INDIAN CREEK 	Rico Formation, Permian, 500-575 feet thick. Mineralization along faults and fractures near top of unit. Cutler Formation, Permian: Bogus Tongue Member, 675 feet thick. Ore in bleached arkosic lenses at any stratigraphic level. Chinle Formation, Triassic: Moss Back Member, 0-115 feet (average 25 feet) thick. Ore at sides, bottoms of channels.	Deposits in Bogus Tongue Member, mainly in Moss Back Member. No apparent structural controls. Bogus Tongue ore: concretions or disseminations in white or gray, bleached arkose lenses in red mudstones and siltstones. Surrounding rock slightly mineralized. Ore on sides, bottoms of scours in Moenkopi Formation. Scours filled with massive (Moss Back) sandstones, interbedded with lenses of conglomerate, siltstone and green-gray mudstone, and carbonized organic debris. Bogus Tongue ore probably localized by hydrogen sulfide, Moss Back ore by organic matter.	Tyuyamunite mineralization along closely spaced fractures near crest of Gibson anticline in sandy, petroliferous limestone beds. Rico and Cutler Formations mineralized along Cane Creek anticlinal faults. Host rocks bleached, exhibiting weak argillic alteration where telethermal origin postulated. Beds dip gently, plunging north at north end of Elk Ridge upwarp. Gentle, anticlinal and synclinal, salt-influenced folds are superimposed. Numerous attendant faults.	In the Rico Formation and part of the Cutler, deposits follow fault trends. Other bodies stratiform, irregularly shaped. Deposits in channels elongate with channel trend. Largest deposits in Moss Back near Indian Creek, but these are small compared to those of White Canyon or Uravan areas.	Ore metals: uranium, vanadium, copper. Ore, mostly copper-uranium type, high in lime. Copper locally abundant; extraction potential questionable. Vanadium more concentrated at fault-controlled deposits. Cutler concretions – sooty chalcocite, cuprite, native copper, brochantite, secondary uranium minerals. Other minerals in deposits – trögerite, uranophane, zeunerite, uraninite, carnotite, becquerelite, metatyuyamunite, schroeckingerite, bayleyite, andersonite, liebigite, sharpite, erythrite, cobaltite, ilsemannite, bieberite, covellite, bornite, malachite, azurite, cyanotrichite, pyrite, galena, sphalerite.	Bedded-type deposits, vanadium-uranium ratio, 1:4. Fault-type deposits, vanadium-uranium ratio, 2:1. Trace elements, somewhat concentrated with deposits – silver, lead, zinc, cobalt, and molybdenum. Some ore in the interriver area has been assayed at 1 ounce silver/ton and 0.10 percent cobalt. Assays also have tabulated traces of gold. Up to 1.52 ounces of silver have been assayed in the Cutler.	1956 22,223 tons 1957 6,690 tons 1958 2,228 tons 1959 3,938 tons 1960 963 tons 1961 631 tons 1962 949 tons 1963 1,381 tons 1964 1,757 tons 1965 302 tons Less than 7 percent from Rico - Cutler, about 2.5 percent from Salt Wash included.	Moss Back guides: ore, normally on bottom, sides of channels containing abundant carbonaceous trash and other debris, and where unit exhibits abrupt changes in thickness over a short, lateral distance. Bogus Tongue guides: favorable arkosic lenses bleached white or light gray. Purple and red lenses considered unfavorable. Mineralization often localized on minor structural noses or terraces. In faulted or fractured deposits, slight alteration or copper-uranium or limonite mineralization noted near large deposits.	Paradox Formation possible source of copper and vanadium in deposits. Ash from oil from Cane Creek anticline contains up to 5 percent vanadium. Five types of mineralization listed for Cutler Formation in RME 4038. Ore-bearing channels near Indian Creek associated with broad structural low. Moss Back minerals have replaced organic matter, are disseminated in surrounding rock. Recent groundwater action has produced halos of limonite with slight radioactivity around many fractures.	U.S. Atomic Energy Comm. RME 4011. U.S. Atomic Energy Comm. RME 4038. U.S. Geol. Survey TEI 490, p. 35-36. U.S. Geol. Survey TEI 590, p. 42-43. U.S. Geol. Survey TEI 620, p. 62-64. U.S. Geol. Survey TEI 690, p. 104-107. Trans. Soc. Min. Eng., v. 235, p. 127-132.
BIG INDIAN WASH 	Hermosa Formation, Pennsylvanian, 1,160 feet thick (copper). Cutler Formation, Permian, 882 feet thick (copper*, uranium, vanadium, manganese). Chinle Formation, Triassic, 340-480 feet thick (uranium, vanadium, copper). Kayenta Formation, Jurassic, 250 feet thick (copper). Carmel Formation, Jurassic, 60 feet thick (manganese). Morrison Formation, Jurassic: Salt Wash Member, 325 feet thick, Brushy Basin Member, 450 feet thick (uranium, vanadium, copper). Burro Canyon Formation, Cretaceous, 200 feet thick (copper, uranium, vanadium). Dakota Sandstone, Cretaceous, 100 feet thick (copper). *Underlined minerals have been produced.	Chinle, Morrison, and Cutler deposits most important. Chinle: deposits in lower 20 feet of Moss Back Member, in grayish, fluvial sandstone, interbedded with lenses of mudstone, siltstone, and fine conglomerate. Carbonaceous material widespread. Morrison: Salt Wash deposits in thick, uppermost sandstone lenses, intercalated with mudstone and vegetal trash; Brushy Basin deposits in dark, brownish-gray pebble conglomerate and coarse-grained sandstone lenses 50 feet above Salt Wash contact. Vegetal trash also present. Cutler: ore in light-brown, arkosic, channel-type lenses in upper 100 feet. Little or no carbonaceous trash associated with ore.	Important uranium-vanadium deposits show little relation to structure, but Chinle deposits parallel trend of Lisbon anticline and are between 6,200-6,700-foot structure contours on base of Chinle. Ore bodies dip 6°-8° SW and are not related to channel structures; they are as thick on paleohighs as on lows. Uranium deposits just above, on angular unconformity that separates Moss Back Member from Cutler Formation. Most important copper and manganese deposits along Lisbon Valley fault or branch faults.	Chinle: deposits, roughly tabular, irregular in outline. Maximum thickness, over 20 feet. Large deposits, several hundred feet wide, over 1,000 feet long, yield over 1,000,000 tons of ore. Morrison: ore masses occur as thin tabular bodies and rolls a few feet thick, tens of feet wide, and a few hundred feet long. Ore body clusters in important areas. Most mines produce less than 10,000 tons, although one operation produced over 100,000 tons Cutler: deposits, generally tabular. Largest bodies a few feet thick, a few hundred feet wide, and several hundred feet long. Production small, but reserves high. Copper deposits, small, nearly tabular; average yield low, 1,000 tons except Dakota (100,000 tons). Manganese deposits, blanket veins no more than 6 inches thick. Veins extend only 50 feet along outcrop, but distributed over 1,000 feet.	Ore metals: uranium, vanadium, copper, possibly manganese. Chinle deposits: mostly unoxidized minerals – uraninite, coffinite, montroseite, locally galena, pyrite, molybdenite, jordisite; copper minerals sparse, malachite, azurite, native copper, also greenockite (CdS). Morrison deposits: mostly oxidized minerals – carnotite, tyuyamunite, vanadium hydromica. Cutler deposits: mostly oxidized minerals – carnotite, becquerelite, vanadium hydromica, and copper carbonates. Copper deposits: malachite, brochantite, chalcocite, digenite, covellite, chalcopyrite. Locally, tenorite, cuprite, native copper, vanadium hydromica, volborthite, oxidized uranium and vanadium minerals. Manganese deposits contain pyrolusite.	Vanadium content of ores increases from 0-1 percent southeastward as strontium decreases in Chinle. Average vanadium-uranium ratio, 1:3. Morrison Formation vanadium-uranium ratios vary up to 15:1, average 2.3:1. Vanadium-uranium ratios deduced from production records. Ores generally enriched with lead, zinc, molybdenum, and cadmium.	1956 515,441 tons 1957 726,287 tons 1958 827,960 tons 1959 854,635 tons 1960 698,284 tons 1961 690,264 tons 1962 465,084 tons 1963 484,608 tons 1964 501,453 tons 1965 172,329 tons Chinle production is 94.7 percent of total and Morrison production is 5.28 percent of total.	Specific ore guides not given, but green mudstones, light-gray or brown sandstones, and arkoses near Chinle-Cutler unconformity associated with ore. Morrison ore, usually in thick, sandstone lenses in upper Salt Wash and in coarse, clastic lenses in lower Brushy Basin. Morrison guides from other areas generally hold. Important copper mineralization along faults.	Big Indian-Lisbon area, largest uranium producer in San Juan County. Chinle Formation at Big Indian Wash rests unconformably on the Cutler. Missing Moenkopi has been picked up by scattered drilling on the down-dip side of important Chinle deposits, but no significant ore cores have been obtained. Rattlesnake mine in the Morrison, only large uranium ore body operated on downthrown (northeast) side of Lisbon Valley fault. Orange and reddish chert occurs as small nodules and stringers in Chinle, but exhibits no relation to ore grade. Host rocks, little altered adjacent to most uranium-vanadium ore bodies. Contacts, generally sharp between ore and barren rock.	U.S. Geol. Survey Bull. 979-B, p. 128-131, 1952. U.S. Atomic Energy Comm. RME 4022 (rev), 1954. Utah Geol Soc. GB 9, p. 95-105, 1954. U.S. Geol. Survey TEI 490, p. 33-34, 1954. U.S. Geol. Survey TEI 590, p. 39-42, 1955. U.S. Geol. Survey TEI 640, p. 51-58, 1956. IAPG GB 7th Ann., p. 161-168, 1956. U.S. Geol. Survey TEI 690, p. 95-103, 1957. U.S. Geol. Survey TEI 700, p. 36-46, 1957. U.S. Bureau Mines IC 7801, 1957. U.S. Bureau Mines IC 7803, 1957. U.S. Geol. Survey TEI 750, p. 14-25, 1958. Internat. Geol. Cong. 21st, pt. 15, p. 133-148, 1960.
ABAJO-COTTONWOOD 	Entrada Sandstone, Jurassic: 165-170 feet thick near Abajo Mountains (copper mineralization in Abajo area). Morrison Formation, Jurassic: Salt Wash Member, 250-550 feet thick in Abajo area, 210-245 feet thick in Cottonwood area (uranium, vanadium). Dakota-Burro Canyon Formations (undivided), Cretaceous, 80-125 feet thick in Abajo area (copper).	Salt Wash Member, most important mineralized unit, consists of light-brown, massive, cross-bedded, fine- to coarse-grained sandstone, interbedded with light-gray or brown mudstone beds. Plant remains, clay galls, mudstone partings, and granule conglomerate lenses locally plentiful in sandstone. Mineralization 150 feet above base in Abajo area and in third major sandstone lens above base at Cottonwood. The Entrada is a pale-orange, massive, cross-bedded, very fine- to medium-grained sandstone, mineralized (copper) 30 feet above its base in one mine (Abajo area). Dakota-Burro Canyon is a brown, massive, cross-bedded conglomerate and sandstone with intercalated green mudstone lenses, mineralized (copper) in one mine (Abajo area).	Vanadium - uranium mineralization shows little relation to structure. Cottonwood deposits 15 miles from Abajo intrusions in sag on east limb of Monument upwarp. Abajo deposits, 2-3 miles from mountains. Average dip of strata, under 7° in both areas. Dakota-Burro Canyon copper deposit beds dip 53°; ore concentrated in fracture zones. Entrada mineralization (copper) joint-controlled, slightly radioactive. Minerals disseminated in cross-bedded planes.	Two types of ore bodies in Abajo area: (1) oval, average dimensions, 3 feet by 10 feet by 15 feet; (2) tabular, average dimensions, 3 feet by 40 feet by 200 feet. Richest ore in center; ore grade gradually diminishes outward. Gradation between ore and barren rock, 1 inch to 3 feet. Oval bodies sometimes clustered. Cottonwood ore bodies average 2 feet by 50 feet by 100 feet; largest ore body, 5 feet by 140 feet by 280 feet. Ore zone in Entrada copper deposit, up to 2 feet thick. Other dimensions of this deposit and of deposits in the Dakota-Burro Canyon area unreported.	Cottonwood ore oxidized and unoxidized. Unoxidized minerals – uraninite, montroseite; oxidized minerals – tyuyamunite, corvusite, and pascoite. Other minerals – vanadium hydromica, metarossite, pyrite, limonite. Minerals replace organic matter and cement, fill interstices between grains. Abajo vanadium-uranium deposits generally oxidized; tyuyamunite and vanadium hydromica most abundant minerals. Copper deposits include azurite, malachite, pyrite, chalcopyrite and lesser amounts of chalcocite, bornite, covellite, chrysocolla.	Vanadium-uranium ratio in both areas, approximately 10:1. At Cottonwood, individual mine ratios vary, range from 5:1-14:1.	1956 9,605 tons 1957 7,659 tons 1958 3,829 tons 1959 530 tons 1960 1,081 tons 1961 4,624 tons 1962 12,314 tons 1963 10,758 tons 1964 11,967 tons 1965 14,382 tons 90 percent of production from Cottonwood.	1. Thickness of ore-bearing sandstone: thickest sandstones most favorable, since larger amounts of ore bearing solutions can be transmitted through thick, porous, permeable units. 2. Color: little change below water table. Above water table, yellow changes to orange limonite because of iron concentration in deposits. 3. Abundance of carbonaceous material within ore-bearing sandstone. Carbon trash generally associated with uranium deposits. 4. Altered mudstone associated with ore-bearing sandstone beds. Changes slight, but gray and green mudstone more favorable than red and purple.	Abajo area: Salt Wash uranium deposits localized in 4-mile-wide zone trending N. 80° E. Ore in crude 200-foot-wide channels scoured 5-10 feet into underlying mudstone. Calcium carbonate content high. Cottonwood area: northern edges of Bluff Sandstone and Recapture Creek and Westwater Creek Members (Morrison Formation) pinch out near area. Ore deposition, consistently thickest in lowest portion of channels. Ore bodies, in area of transition between sandstone and mudstone.	U.S. Bureau Mines RI 3930, p. 24-26, 1946. U.S. Atomic Energy Comm. RME 3093, 1954. U.S. Geol. Survey TEI 490, p. 38-39, 1954. U.S. Geol. Survey TEI 590, p. 55-56, 1955. U.S. Geol. Survey TEI 620, p. 72-73, 1956. U.S. Geol. Survey TEI 640, p. 61-63, 1956. U.S. Geol. Survey TEI 700, p. 48-58, 1957. U.S. Atomic Energy Comm. RME 109 (rev), 1958. U.S. Geol. Survey Prof. Paper 453, 1964.
DRY VALLEY MONTEZUMA 	Morrison Formation, Jurassic: Salt Wash Sandstone Member, 200-520 feet thick; Brushy Basin Member, 200-440 feet thick; members separated by 0-180 feet of Westwater Canyon Member in Montezuma Canyon area.	Salt Wash Member, most important host, consists of a massive, cross-bedded, light-colored sandstone, fer thick). Ore in thick, uppermost sandstone lens. Montezuma Canyon ore in thick sandstone lens near center of Salt Wash. Vegetal trash helps to localize ore within lens. Deposits in claystones and concretionary mudstones, 150 feet below top of Brushy Basin Member and about 200 feet beneath lens of conglomerate in southeastern part of Montezuma Canyon area.	No apparent structural relationship to ore. Beds almost flat, dip up to 2° southward. Several faults cross the north end of Montezuma Canyon area (up to 180 feet of displacement), but have not influenced ore deposition.	Average ore body, 20-40 feet long, 10-20 feet wide, up to 2 feet thick. Ore masses scattered anywhere within thick host lenses. Large bodies, up to 70 feet wide by 120 feet long, only in thick continuous parts of host lens. Ore bodies, roughly tabular, parallel to bedding, or as rolls where ore zones cross sedimentary features.	Deposits generally oxidized; minerals – simplotite, metarossite, carnotite, metatyuyamunite, roscoelite.	Vanadium-uranium ratios: Dry Valley, 7.5:1. Montezuma Canyon, 1.3:1. Ore in Montezuma Canyon zoned: middle ore zone, shaped like irregular, flattened ellipsoid, enveloped by an outer gray, mostly barren zone; encases inner brown, mostly barren zone.	1956 10,674 tons 1957 7,223 tons 1958 20,053 tons 1959 21,743 tons 1960 8,532 tons 1961 18,041 tons 1962 20,968 tons 1963 16,648 tons 1964 16,504 tons 1965 12,657 tons Dry Valley production a little under 70 percent of total.	1. Ore bodies associated with thick sandstone lenses that are the fill of ancient, meandering stream channels. 2. Ore bodies generally associated with accumulations of logs and organic trash. 3. Mudstones, gray in vicinity of deposits.	One centrally located area in Montezuma Canyon has 35 percent of known deposits; has produced over 70 percent of the ore; contains 75 percent of estimated ore reserves; may constitute an extension of Uravan mineral belt. Most mines and prospects in one large sandstone lens, 13,000 feet long and up to 150 feet thick. Best deposits at Dry Valley in two, possibly three northward-trending ore zones.	U.S. Geol. Survey TEI 490, p. 33, 39-40, 1954. U.S. Geol. Survey TEI 540, p. 52-56, 1955. U.S. Geol. Survey TEI 590, p. 34-36, 1955. U.S. Geol. Survey TEI 620, p. 55-57, 1956. U.S. Geol. Survey TEI 640, p. 63-69, 1956. U.S. Geol. Survey TEI 690, p. 76-84, 1957. U.S. Geol. Survey TEI 750, p. 14-25, 1958. U.S. Geol. Survey maps MF 162-168, 1958. Econ. Geol., v. 57, p. 226-237, 1962.
PARADOX 	Morrison Formation, Jurassic, chief mineralized unit: Salt Wash Member, 250-400 feet thick; Brushy Basin Member, 250-500 feet thick. Some copper, uranium, vanadium mineralization also along fault planes in Wingate, Kayenta, and Entrada (Mesozoic) Formations and in Paleozoic units.	Salt Wash Member, which contains most of the important uranium deposits, is a light-colored, fine- to medium-grained, cross-bedded, massive, lenticular sandstone, interbedded with red, green, or light-gray shale and mudstone. Ore in thick, uppermost sandstone lens. Brushy Basin Member is a variegated claystone with a few lenticular, conglomeratic sandstone lenses. Deposits in uppermost part of member and in cherty conglomeratic sandstone near base.	Important ore deposits apparently unrelated to structure. Collapsed salt anticlines, intervening synclines, attendant faults in area, which is located between the La Sal Mountains and Uravan mineral belt. In a few places, copper and some uranium and vanadium mineralization impregnate Paleozoic and Mesozoic formations adjacent to faults.	Ore bodies occur as pods, tabular pancake-like bodies, and rolls. Individual ore bodies produce up to 500 tons. Clustering creates important areas capable of yielding over 100,000 tons, but averaging about 3,000 tons. Ore may be 30 feet thick, 2-9 feet average. Roll bodies elongate, up to 600 feet long, have hourglass or crescent-shaped cross sections. Thickest ore deposits in bases of thick sand lenses. Deposits elongate with sedimentary trends.	Ore not bodies, oxidized; some, beneath water table under thick cover, unoxidized. Unoxidized ore, black, normally wet, bears uraninite, coffinite, montroseite, and vanadium hydromica or clay. Oxidized ores, gray to yellowish gray, dry, have carnotite, tyuyamunite, corvusite, brightly colored vanadates, vanadium hydromica, and clay. Copper minerals – chalcopyrite, azurite, malachite, bornite, pyrite. Ore minerals fill pore spaces in sandstone, replace cement, sand grains, carbonized vegetal trash.	Vanadium-uranium ratio, 5.6:1; Utah portion of La Sal Creek area, 6.4:1; remainder of area, 4.9:1. Individual mine ratios vary. Hard, barren sandstone pods cemented with calcite often border part of a deposit or surround it as a halo 5-15 feet away. Selenium, copper, lead, and zinc highly concentrated locally. Silver content high in some copper deposits.	1956 24,194 tons 1957 22,980 tons 1958 25,262 tons 1959 21,494 tons 1960 21,789 tons 1961 32,693 tons 1962 23,508 tons 1963 25,947 tons 1964 39,086 tons 1965 29,490 tons LaSal Creek area, Utah, portion produced over 45 percent of total.	1. Sandstone beds of ore-bearing horizon, lenticular, 30 feet or more thick. 2. Sandstone should be light brown, white or light gray. 3. Green or gray mudstone should be present above or below sandstone, within the sandstone as seams, pellets, or in the interstices between sand grains. 4. Carbonaceous material should be present as scattered flakes and/or trash pockets.	In this district, particularly La Sal Creek, largest deposits near edges of thickest sandstone units where transition to sandy mudstone exists; in shallow scours at base of sandstone; and in flanks or noses of ridges that project into paleostream courses. Best copper deposits adjacent to faults normal to salt anticlines. Occasionally, mudstone units highly uraniferous and mined as ore.	U.S. Atomic Energy Comm. RME 69 (pt. 1), 1954. U.S. Atomic Energy Comm. RME 3093, 1954. U.S. Geol. Survey TEI 540, p. 36-38, 1955. U.S. Geol. Survey TEI 590, p. 36-39, 1955. U.S. Geol. Survey TEI 620, p. 57-60, 1956. U.S. Geol. Survey Prof. Paper 300, p. 165-167, 1956. U.S. Geol. Survey TEI 690, p. 84-95, 1957. U.S. Geol. Survey Prof. Paper 508, 1965.
GYPSUM VALLEY 	Morrison Formation, Jurassic, chief mineralized unit: Salt Wash Member, approximately 350 feet thick. Other mineralized units include: Brushy Basin Member, Morrison Formation; Hermosa Formation, Pennsylvanian; Wingate Formation, Triassic; Carmel-Entrada Formations (undivided), Jurassic.	Salt Wash Member consists of equal amounts of gray, light-colored lenticular sandstone and reddish, gray, or green shale. Ore in uppermost continuous sandstone lens, localized where Salt Wash thins over salt anticline and near contact of salt with overlying Salt Wash.	Gypsum Valley, a structurally complex collapsed salt anticline. Numerous faults at edge of collapse feature; rocks have collapsed inward in variable degrees. Deposits in axial zone and on northeast flank	Ore in 60-foot thick sandstone bed with two to seven ore layers, 0.5-4 feet thick. Some layers subgrade, lower layers better. Some ore in rolls.	Ore oxidized minerals – carnotite, vanadium mica. These, limonite, calcite, and silica form overgrowths on sand grains. Secondary copper minerals locally present.	Vanadium-uranium ratio, 8:1.	1956 9,468 tons 1957 5,638 tons 1958 3,694 tons 1959 2,094 tons 1960 1,506 tons 1961 1,288 tons 1962 1,009 tons 1963 1,536 tons 1964 1,678 tons 1965 1,576 tons (West portion of district only)	Specific ore guides not given by authors, but guides for other Salt Wash producing areas would apply.	Ore-bearing sandstone beds in lower member of Morrison Formation normally light yellow or tan; contain gray or green seams, galls, and pebbles of mudstone or claystone; underlain by mudstone. Carbonaceous organic remains also associated with ore.	U.S. Bureau Mines RI 3930, p. 15-18, 1946. Utah Geol. Soc. GB 3, 1948. U.S. Geol. Survey Oil and Gas Prelim. Map 93, 1948. U.S. Geol. Survey TEI 540, p. 35, 1955.
SLICK ROCK 	Morrison Formation, Jurassic: Salt Wash Member, 28-450 feet thick. Thickness varies greatly from place to place. Some mineralization in Brushy Basin Member (Morrison Formation) and in lowermost sandstone lenses of Chinle Formation, Triassic.	Salt Wash Member, most important (uranium-vanadium) producer; white to gray, light-buff, and rusty-red sandstone, interbedded with red shale and mudstone, and, locally, with a few thin lenses of gray limestone. Ore localized in thick, fine- to medium-grained, cross-bedded sandstone lenses, up to 120 feet thick, normally near top of Member. Brushy Basin Member is a varicolored mudstone containing sand and conglomerate lenses that are mineralized occasionally.	Structural elements: Disappointment syncline, Dolores anticline, and Dolores fault zone. Most ore, left and right of northwest-trending fault zone between northwest-trending synclinal and anticlinal axes. No direct relationship between structure and uranium deposits indicated. Dips, generally under 10°.	Ore in thick sandstone lenses near top of member. Largest ore bodies always in lenses over 40 feet thick, rare in lenses under 20 feet thick. Tabular ore bodies, irregular in outline in heterogeneous rock, oval in homogeneous rock; average 3 feet thick, up to 250 feet long. Roll ore bodies, plentiful, up to 5 feet thick by 15 feet wide by several hundred feet long. Ore body long dimension crossing local trends. Ore associated with carbonaceous material and other channel debris, and with impermeable boundaries at edges of elongate sandstone lenses.	Ore oxidized in near-surface occurrences. Deeper mines report unoxidized minerals. Deposits mined for uranium and vanadium, have been mined for radium. Ore, mainly sandstone impregnated with uranium-vanadium minerals – carnotite (a fine-grained, vanadium-bearing, micaceous mineral), tyuyamunite, montroseite, corvusite, hewettite, uraninite. Pyrite, galena, some copper sulfides, green and blue copper staining, and selenides in some mines.	Authors report vanadium-uranium ratios from 1:1 to 20:1 at mines, average 8:1, 1956-1965 average, 7.1:1. Ores also contain up to 0.3 percent copper, 0.018 percent lead, 0.0014 percent cobalt, 0.0008 percent nickel, 0.022 percent zinc, 0.021 percent arsenic, 0.0044 percent molybdenum, and 0.0001 percent antimony. Copper and lead most abundant adjacent to Dolores fault zone.	1956 57,712 tons 1957 58,881 tons 1958 106,733 tons 1959 138,122 tons 1960 155,385 tons 1961 113,450 tons 1962 103,962 tons 1963 95,843 tons 1964 111,913 tons 1965 114,118 tons (Area west of Dolores River only)	1. Most ore in uppermost stratum of Salt Wash. 2. Central or thicker parts (40 feet or more) of stratum most favorable. 3. Relatively coarse-grained sandstone more favorable than thin- or even-bedded, fine-grained sandstone. 4. Light-yellow-brown sandstone speckled with limonite stain more favorable than red or reddish-brown sandstone. 5. Where concentrations of carbonized fossil plant material exist. 6. Sandstone with considerable amounts of altered gray mudstone or underlain by much altered gray mudstone favorable.	Roll ore bodies, plentiful, elongate masses, curve across bedding planes. Margins of ore bodies, vaguely or sharply defined. When margins are vaguely defined, mineralized sandstone may extend far beyond the ore limit. When boundaries are sharply defined, high-grade ore is separated from barren sandstone by thin line. Narrow zones of ore deposits oriented almost parallel to trends of principal faults.	U.S. Bureau Mines RI 3930, p. 18-24, 1946. U.S. Geol. Survey GB 64, 66, 68, 1955. U.S. Geol. Survey TEI 540, p. 38-39, 1955. U.S. Geol. Survey TEI 590, p. 28-29, 1955. U.S. Geol. Survey TEI 620, p. 45-47, 1956. U.S. Geol. Survey TEI 640, p. 36-46, 1956. U.S. Geol. Survey TEI 690, p. 41-66, 1957. Econ. Geol., v. 54, p. 395-415, 1959.
ELK RIDGE DEER FLAT 	Chinle Formation, Triassic: Shinarump Member, 0-80 feet thick, mineralized in channels only. Monitor Butte Member, mudstone-sandstone unit, 120-250 feet thick, and Moss Back Member, 0-200 feet thick, also fill channels, but contain no important deposits to date.	Chinle Formation: lower sandstone lenses of lower mudstone unit most important ore-bearers. Lenses cross-bedded, medium-to very coarse-grained, sometimes conglomeratic, sandstones. Normally, lenses less than 20 feet thick; carbonaceous matter (twigs and tiny fragments) interstitial to sand grains abundant locally. Ore generally in lenses adjacent to underlying Moenkopi Formation that are capped by impermeable lenses of mudstone or siltstone. Moss Back Member: continuous massive bed of sandstone and conglomeratic sandstone; resembles lower sandstone lenses lithologically; contains ore in northern part of Elk Ridge area where lower mudstone unit is absent.	Deposits, on either side and top of Elk Ridge anticline. Dips gentle, except at Comb monocline where dips up to 30° occur. Faults and small anticlinal and synclinal warps, plentiful, but apparently do not influence ore deposits. Structural low of Chinle time, only apparent structural control; provided path for westward-flowing streams that deposited host lenses. Most ore deposits localized along Chinle-Moenkopi unconformity. Slight flexure of Triassic age may have localized ore in Deer Flat area.	Ore deposits, roughly tabular to lenticular, range from a few tons to more than 15,000 tons in size. Bodies elongate, parallel channels in Moenkopi Formation, thickest in central part, ore grade varies throughout body. Largest deposits, 2-10 feet thick, 50-150 feet wide, and 300-500 feet long.	Ore, uranium-copper type. Vanadium, galena, sphalerite present in trace amounts. Most ore, unoxidized. Chief mineral, uraninite. Pyrite abundant. Chalcopyrite, bornite, domeykite, tennantite also present. Ore minerals interstitial to sand grains, locally replace carbon fragments, calcite, silica cement, or sand grains. Uranium-bearing asphaltite locally abundant, may be important ore constituent. Many secondary minerals – andersonite, zippeite, coffinite, uranophane, metazeunerite, schroeckingerite, uranothallite, liebigite, bayleyite, azurite, chalcocite, chalcanthite, cyanotrichite, metazeunerite, ilsemannite, jarosite, erythrite, limonite, hematite, bieberite.	No zoning evident in ore bodies. Copper up to 3.22 percent, generally less than 1 percent. Other elements present in trace amounts – lead, zinc, molybdenum, cobalt, vanadium. Alteration of rock near ore bodies not pronounced locally, but Moenkopi bleached near ore bodies and along fractures.	1956 50,070 tons 1957 27,461 tons 1958 38,259 tons 1959 36,577 tons 1960 56,842 tons 1961 47,966 tons 1962 34,745 tons 1963 35,243 tons 1964 39,214 tons 1965 49,268 tons (Deer Flat area produced about 44 percent of total)	1. Most ore in sandstone lenses adjacent to Moenkopi Formation, especially where channels exist. 2. Intersections of channels and local structural flexures may be favorable indications. 3. High radioactivity and visible (secondary) uranium minerals.	Ore minerals, fine-grained, usually unidentifiable in hand specimen. Ore, most easily identified by radioactivity. Channels in Elk Ridge area, thinner, not as well developed as those in Monument Valley area. Increased radioactivity common anywhere along Chinle-Moenkopi contact.	U.S. Geol. Survey TEI 490, p. 30-32, 1954. U.S. Geol. Survey TEI 540, p. 31-34, 1955. U.S. Geol. Survey TEI 590, p. 54-55, 1955. U.S. Geol. Survey TEI 620, p. 68-72, 1956. U.S. Geol. Survey TEI 690, p. 129-142, 1957. Econ. Geol., v. 53, n. 8, p. 949-957, 1958. Econ. Geol., v. 54, p. 119-129, 1959. U.S. Geol. Survey Bull. 1085-B, 1960. Econ. Geol., v. 56, p. 111-131, 1961. U.S. Geol. Survey Prof. Paper 474-B, 1965.
WHITE CANYON RED CANYON FRY CANYON 	Chinle Formation, Triassic: ore in lower mudstone-sandstone unit (Shinarump and Monitor Butte) and Moss Back Member. Lowermost ore-bearing unit, 0-60 feet thick. Moss Back Member, 55-150 feet thick. One report of mineralization from north part of area near contact of Rico-Cutler Formations, Permian. One report of radon gas from well in Hermosa Formation, Pennsylvanian, in south end of area.	Shinarump Member divided into three parts (upper and lower sandstone units and middle mudstone unit). Lowest unit, main ore-bearing horizon, found only in channels. It consists of light-yellowish-gray, poorly sorted, medium- to coarse-grained sandstone containing clay galls, carbonaceous vegetal debris, slump materials, and a few, thin, gray mudstone lenses. Other two units occasionally mineralized. Ore in channels; along bedding planes; where porous carbonaceous sandstone wedges out in impervious mudstone; in intrachannel scours; where sand lenses rest on lower Shinarump mudstone; and where channels change direction or intersect. Ore grade directly related to amount of carbon trash.	Deposits, on west flank of Monument upwarp. Upwarp dips to southwest 0°-5° in White Canyon area. Nearby faults and graben associated with salt deformation and Henry Mountains uplift to the west. These structures seem to have no bearing on distribution of uranium deposits. Subtle local changes in dip may have helped to localize some ore bodies. Triassic downwarp, which confined Shinarump streams to the area, only definite structural control.	Uranium ore bodies, average 3½ feet thick, 10-500 feet wide, 50-1,000 feet long. Long axes of ore bodies parallel channel directions. Average deposits as thick as 10 feet. Ore bodies, roughly tabular, have elliptical plan, sharp boundaries. Only a few low-grade ore bodies known.	In most deposits, ore, low-lime, copper-uranium type. Most deposits, unoxidized; a few contain only oxidized ore. Principal uranium minerals – uraninite, uranophane, metatorbernite, phosphuranylite, metazeunerite, and a zippeite-like mineral. Primary sulfides in ore – pyrite, chalcopyrite, sphalerite, galena, bornite. Ore minerals interstitial to sand grains, replace carbonaceous matter, calcite, silica cement, even quartz and feldspar grains. Other minerals with ore deposits – chalcocite, covellite, marcasite, native copper, cuprite, melaconite, azurite, malachite, chalcanthite (with some chalcocite), erythrite, many others.	Copper-uranium ratios, 1:1-18:1. Vanadium almost absent. Copper content increases to the west. Alteration of rock restricted to color bleaching in underlying Moenkopi Formation.	1956 95,220 tons 1957 97,864 tons 1958 148,761 tons 1959 154,181 tons 1960 123,627 tons 1961 131,423 tons 1962 127,985 tons 1963 57,729 tons 1964 53,637 tons 1965 36,351 tons White Canyon area: 55 percent. Red Canyon area: 40 percent. Fry Canyon area: 5 percent.	Ore is found: 1. At bottom, sides, and in scours of channels, especially where channels of irregular configuration change direction or intersect other channels; 2. Where lower Shinarump sandstones contain 10-30 percent siltstone and claystone in form of lenses, thin seams, cement, galls, or slump features; 3. Where carbonaceous material is abundant; 4. Where local structural terraces and subtle changes of dip are found; 5. Where covellite, massive or disseminated, and chalcopyrite occur in sandstones; 6. Where the zone of bleaching in the underlying Moenkopi Formation thickens appreciatively.	Red and Fry Canyon areas form portion of Monument mineral belt; only Happy Jack mine and White Canyon area excluded. Elk Ridge-White Canyon and Monument channel systems coalesce, widen to form huge alluvial fan or deltaic-type deposit. Coal beds, at wide, western end of deposit. Channels in area, 30-1,000 feet wide, up to 50 feet deep.	Econ. Geol., v. 50, p. 156-169, 1955. U.S. Geol. Survey Bull. 1009-H, 1955. Econ. Geol., v. 50, p. 797-798, 1955. U.S. Atomic Energy Comm. RME 105, 1958. U.S. Geol. Survey Bull. 1046-H, 1958. Econ. Geol., v. 54, p. 119-129, 1959. U.S. Geol. Survey Bull. 1125, 1964. Econ. Geol., v. 59, p. 850-873, 1964.
MONUMENT VALLEY 	Chinle Formation, Triassic: Shinarump Member, 0-210 feet thick. Some ore in Moenkopi Formation, Triassic, and in DeChelly Sandstone, Permian, when these units directly underlie Shinarump Member.	Shinarump Member, most important uranium-bearer, consists of lenses of medium- to coarse-grained, light-gray sandstone, conglomerate, and mudstone. These sediments fill channels, 40-2,000 feet wide and from 20-200 feet deep, cut in Moenkopi Formation. Ore bodies localized at base of channels. Abundant carbonaceous material, coupled with 10-30 percent mudstone content in basal Shinarump sandstones, considered favorable for ore. Some ore in upper sand beds of Moenkopi and DeChelly Formations. Jasperoid pebbles always present in channels containing uranium ore.	A few small igneous dikes of minette present. Utah portion of Monument Valley district on west flank of Monument upwarp, which plunges southward. Several north-south trending anticlines and synclines in area, but structure and ore deposits seem unrelated. Uranium ore, on limbs of folds below middle level of a major structure and generally on gentle limb of an asymmetrical structure.	Ore bodies, roughly tabular to lenticular, up to 10 feet thick, 20 feet wide, and 200 feet long. Largest ore bodies in Arizona portion of district where DeChelly Sandstone underlies the Shinarump. Ore margins, generally sharp, pinch out on channel edges. Ground, weakly mineralized between clustered ore bodies. In a few mines, ore grade decreases gradually and weakly mineralized ground may extend far beyond commercial ore.	Ore, copper-uranium type in western part of district, uranium-vanadium type in eastern portion. Most important ore mineral, tyuyamunite. Uranophane, autunite, torbernite also common. Deposits, generally oxidized, some partially oxidized; small amounts of uraninite identified. Copper minerals – malachite, azurite, chalcanthite (with some chalcocite), chalcopyrite, bornite (in relatively deep mines). Vanadium minerals – corvusite, navajoite, hewettite, calciovolborthite.	Ore bodies zoned vertically and laterally. High-grade vanadium ore concentrated below and on the down-dip side of high uranium concentrations. Average vanadium-uranium ratio for district, 1.5:1, but vanadium content decreases westward as copper content increases.	1956 6,086 tons 1957 12,193 tons 1958 5,728 tons 1959 6,969 tons 1960 2,508 tons 1961 3,606 tons 1962 5,529 tons 1963 760 tons 1964 545 tons 1965 1,130 tons	Twenty-seven ore guides are listed by Mitcham and Evensen (Econ. Geol., v. 50, p. 173-175, 1955). Some not mentioned elsewhere are: 1. Channel widths of 300-1,000 feet more favorable than broad channels; 2. Meander bends in channels favorable; 3. Loci of rapid facies changes from sandstone to mudstone favorable; 4. Due to better permeability, upstream channel fillings more favorable than downstream fillings, which tend to contain excessive amounts of mudstone; 5. Subtle color differences due to alteration in upper Shinarump above large ore bodies; 6. Relative paucity of fractures in Shinarump should delineate channels.	Shinarump thins, disappears immediately north of Monument Valley area. Shinarump channels trend N. 60°W. Fluorescent silica commonly found near ore deposits. Silica does not fluoresce, unless ore bodies occur in area. Moenkopi bleached yellow, green, cream, and gray beneath ore bodies. Bleached zones up to 8 feet thick.	U.S. Atomic Energy Comm. RMO 982, 1952. Econ. Geol., v. 50, p. 173-175, 1955. Econ. Geol., v. 50, p. 797-798, 1955. U.S. Geol. Survey Prof. Paper 300, p. 263-269, 1956. Econ. Geol., v. 53, p. 639-662, 1958. U.S. Geol. Survey Bull. 1087-D, 1959. Econ. Geol., v. 59, p. 850-873, 1964.

SUMMARY INFORMATION ON URANIUM DISTRICTS AND AREAS, SAN JUAN AREA, UTAH AND COLORADO.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY since 1949 has been affiliated with the College of Mines and Mineral Industries at the University of Utah. It operates under a director with the advice and counsel of an Advisory Board appointed by the Board of Regents of the University of Utah from organizations and categories specified by law.

The survey is enjoined to cooperate with all existing agencies to the end that the geological and mineralogical resources of the state may be most advantageously investigated and publicized for the good of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-2,* describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineralogical Survey for the latest list of publications available).

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH. A modern library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance has been established by the Survey at the University of Utah. It was initiated by the Utah Geological and Mineralogical Survey in cooperation with the Departments of Geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists. This library was made possible in 1951 by a grant from the University of Utah Research Fund and by the donation of collections from various oil companies operating in Utah.

The objective is to collect, catalog, and systematically file geologically significant specimens for library reference, comparison, and research, particularly cuttings from all important wells driven in Utah, and from strategic wells in adjacent states, the formations, faunas, and structures of which have a direct bearing on the possibility of finding oil, gas, salines or other economically or geologically significant deposits in this state. For catalogs, facilities, hours, and service fees, contact the office of the Utah Geological and Mineralogical Survey.

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DIRECTORS:

William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961