Uranium Resources of the Green River and Henry Mountains Districts, Utah A Regional Synthesis

By HENRY S. JOHNSON, JR.

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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URANIUM RESOURCES OF THE GREEN RIVER AND HENRY MOUNTAINS DISTRICTS, UTAH—A REGIONAL SYNTHESIS

By Henry S. Johnson, Jr.

ABSTRACT

This report presents the results of a study of the uranium resources of the Green River and Henry Mountains districts, Utah, and is part of a series of similar reports synthesizing the geologic relations of uranium deposits in all formations on the Colorado Plateau.

Sandstone-type uranium deposits or weakly mineralized uranium-bearing rock occur in the Hermosa, Cutler, Moenkopi, Chinle, Carmel, Entrada, Curtis, Summerville, Morrison, and Mancos formations in the Green River and Henry Mountains districts; but the Chinle and Morrison formations are the only units containing important ore deposits and having large potential resources. Through 1955, about 24 percent of the total uranium ore mined in the two districts had come from the Chinle formation and about 76 percent from the Morrison formation. About 22 percent of the indicated and inferred reserves in the two districts is thought to be in the Chinle formation and about 78 percent in the Morrison formation.

Potential resources for the Green River and Henry Mountains districts are thought to be many times the combined production and indicated and inferred reserves. Primary sedimentary features such as regional pinch outs, trunk channel systems (traces of large streams that meandered on fan deposits), individual channels, and sandstone lenses that are thicker than average are thought to be the principal ore controls. Significant uranium deposits are most likely to be found in the following places:

1. In the Shinarump member of the Chinle formation on the flanks of channels in the Circle Cliffs and Capitol Reef areas, and in a belt of relatively favorable ground 10 to 20 miles wide, related to and paralleling the northwestward-trending line of regional pinchout of this member in the Henry Mountains district.

2. In the Monitor Butte member of the Chinle formation in sandstone lenses having a thickness of 30 feet or more in a belt of relatively favorable ground 25 miles wide, parallel to and bounded by the northeastern line of pinchout of the member.

3. In the Moss Back member of the Chinle formation along the inferred southeastern extension of the Temple Mountain channel system and in a belt of relatively favorable ground, 10 miles wide, bounded by and paralleling the

northeastern pinchout of this member in the area between the Green and Colorado Rivers.

4. In an inferred narrow belt of more sandy sediments in the basal Chinle on the southwest flank of the Moab anticline.

5. Along the northward extensions of two favorable belts or channel systems in the Salt Wash member of the Morrison formation in T. 21, 22, and 23 S., R. 14 E. (Salt Lake meridian) in the Green River district.

6. In the Salt Wash member of the Morrison formation along the northwestward extension of a narrow favorable belt or channel system trending about N. 60° W. through Farmers Knob in T. 32 S., R. 11 E. (Salt Lake meridian) in the Henry Mountains district.

The Brushy Basin shale member of the Morrison formation contains very low grade uranium-bearing carbonaceous siltstone in the northern part of the Green River district and may have large potential resources of this rock averaging about 0.02 percent U_3O_8 in the Green River district and in the Uinta Basin.

INTRODUCTION

PURPOSE OF THE REPORT

This report presents the results of an appraisal of the geologic relations of the uranium resources of the Green River and Henry Mountains districts in parts of Grand, Emery, Wayne, San Juan, Garfield, and Kane Counties, Utah (fig. 9). The report is part of a series of similar reports synthesizing the geologic relations of uranium deposits in all formations on the Colorado Plateau. The history, general geology, and uranium occurrences of the Green River and Henry Mountains districts are briefly reviewed, and an attempt is made to appraise the relative favorability of potentially ore-bearing geologic formations for significant uranium deposits. Expected deposit size, depth to ore, ore controls, and major controlling factors of favorable ground are also discussed.

Fieldwork was done during the summers of 1954 and 1955 by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

GEOGRAPHY

The Green River and Henry Mountains districts include parts of Grand, Emery, Wayne, San Juan, Garfield, and Kane Counties, Utah, and are in the west-central part of the Colorado Plateaus physiographic province. The Green River district is bounded on the north by U. S. Highway 50, on the east and southeast by U. S. Highway 160 and the Colorado River, on the southwest by the Dirty Devil and Muddy Rivers, and on the west by the hogbacks formed by the steeply dipping Navajo sandstone on the east side of the San Rafael Swell. The Henry Mountains district is contiguous to the Green River district and is bounded on the northeast by the San Rafael Swell and the Muddy and Dirty Devil Rivers, on the southeast by the Colorado River, on the southwest by the Escalante

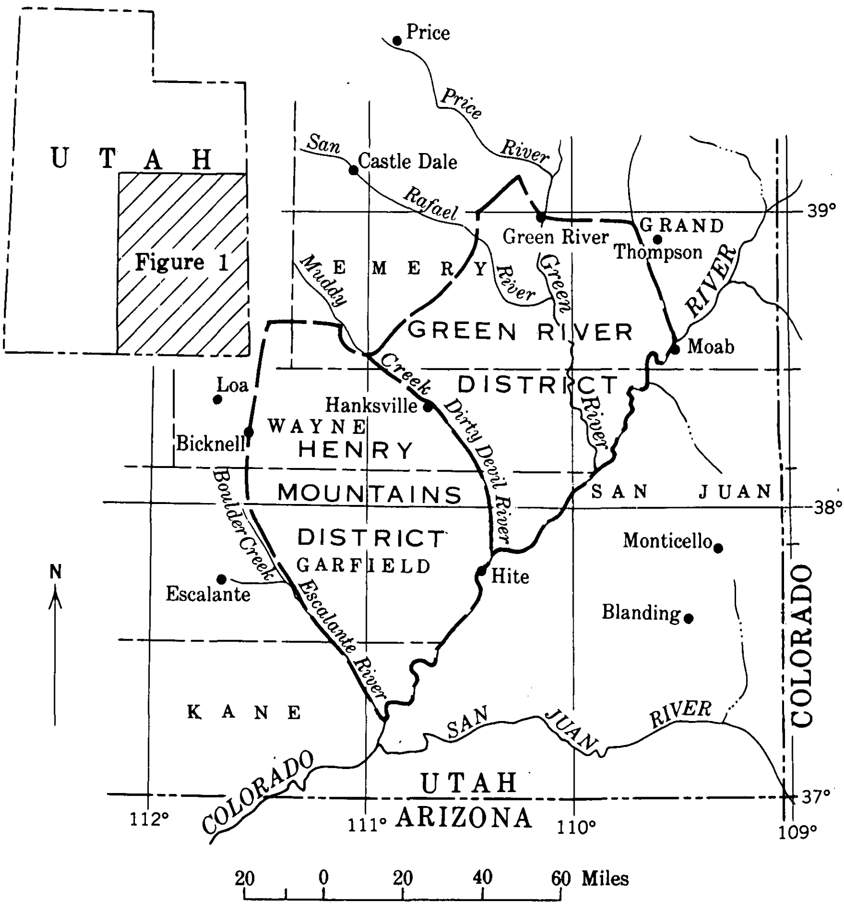

FIGURE 9.—Index map part of Utah showing location of Green River and Henry Mountains districts.

River and Boulder Creek, on the west by a line from the headwaters of Boulder Creek through Bicknell to Utah State Route 72, and on the north by Utah State Route 72 and an east-west line between State Route 72 and the junction of the Muddy River with the west side of the San Rafael Swell. Poor to fairly good graded dirt roads provide access to most parts of the two districts. The total permanent population of the two districts, mostly in small towns or communities, is probably less than 1,500.

The Green River and Henry Mountains districts are in the Canyon Lands section of the Colorado Plateaus and are characterized by high windswept plateaus and deep intricately cut canyons. Except for the canyon bottoms, most of the country is from 4,000 to 10,000 feet above sea level. The Colorado River and its tributaries drain the area; and the Henry Mountains, Circle Cliffs, and Capitol Reef are the principal topographic features.

The climate of the two districts is semiarid to arid and temperature ranges from extremes of heat in the summer to extremes of cold in the winter. The average annual rainfall is about 6 inches and occurs mostly as local thundershowers in the late summer and light-to-medium snowfalls in the winter. Vegetation is sparse over the whole area and consists largely of sagebrush, juniper, and piñon with very sparse yellow pine in the higher parts of the Circle Cliffs and Henry Mountains.

Water in limited amounts is available in springs and rivers at many places in the two districts. Labor and mining supplies must for the most part be brought in from the town of Green River on the northern edge of the area or from Bicknell and Loa on the western edge.

DATA SOURCES AND METHODS OF STUDY

Data used in this study include records of production maintained by the Grand Junction operations office of the U.S. Atomic Energy Commission, estimates of uranium reserves made by the U.S. Atomic Energy Commission as a result of exploratory drilling, reserve estimates and geologic observations made by the writer, and the accumulated data contained in many published reports and in files of the U.S. Atomic Energy Commission and U.S. Geological Survey.

Fieldwork consisted of reconnaissance of most of the known uranium deposits in the two districts. At each deposit an attempt was made to determine the stratigraphic position of the ore-bearing unit; lithologic, stratigraphic, and structural controls affecting the deposit; indicated and inferred reserves and the size range of the deposit; ore and (or) channel trends; potential sources of ore in the immediate deposit area; and the desirability of further exploration in the area of the deposit.

HISTORY OF THE DISTRICTS

McKnight (1940), Baker (1946), and Hunt (1953) have given detailed accounts of early exploration and geologic work done in the Green River and Henry Mountains districts. Major J. W. Powell, in the course of his exploration of the Green and Colorado Rivers by boat in 1869 and 1871, was probably the first geologist to study the region. In 1875 and 1876, Gilbert (1877) studied the Henry Mountains. During the period from 1915 through 1923, Gregory and Moore (1931) made intermittent geologic investigations in the western parts of the Henry Mountains district. In the summers of 1926 and 1927, McKnight made a thorough investigation of the area between the Green and Colorado Rivers (McKnight, 1940). In 1930 and 1931, Baker studied the Green River Desert-Cataract Canyon region (Baker, 1946); and during the summers of 1935 through 1939, Hunt (1953) remapped the Henry Mountains, scene of Gilbert's classic work.

Deposits of uranium and vanadium ores were mined on a small scale in part of the Green River district in 1904 (Boutwell, 1905). These deposits were in the Salt Wash member of the McElmo formation, now termed Morrison formation, about 15 miles southwest of the town of Green River and contained carnotite in association with carbonized vegetable matter and silicified logs. Similar but less well developed deposits were also known in 1904 in the Salt Wash member on Little Wild Horse Mesa, about 10 miles north of the town of Hanksville. Boutwell reports that as early as 1904 a shipment of 30,000 pounds of carnotite ore had been made to Germany. The producers had not received payment for this ore at the time of Boutwell's report, however, and probably did not feel encouraged to continue production.

Prior to 1948, there was only intermittent small-scale mining for vanadium and uranium ores in the Green River and Henry Mountains districts. During World War I there was increased prospecting and mining activity in the Morrison formation southwest of Green River. The ore deposits in the Salt Wash member on the east slopes of the Henry Mountains were also prospected and mined to some extent during this period, but the combined production for the Green River and Henry Mountains districts was probably not much over 100 tons of ore averaging about 1 percent U_3O_8 and 3 percent V_2O_5. There were several attempts to mine vanadium from these deposits in the late 1930's, and a small mill was built in the Trachyte Creek area of the Henry Mountains (Richard P. Fischer, oral communication). Production was negligible, however. During World War II, a few hundred tons of vanadium ore was produced from the Trachyte Creek area and from the deposits in the Morrison formation southwest of Green River. In 1948 the U.S. Atomic Energy Commission began to buy uranium ore; and prospecting, mining, and production of uranium ore has increased steadily from that time to the present.

Geologic investigations of the uranium deposits of the Green River and Henry Mountains districts began when Boutwell (1905) visited the deposits in the Morrison formation southwest of Green River in 1904. Hess (1913) visited the same deposits in 1911, and Emery (1918) also observed them a short time later. Butler (Butler and others, 1920) in the course of investigations of the ore deposits of Utah, visited the Trachyte Creek area of the Henry Mountains in 1913. These geologists all noted the intimate association of disseminated uranium and vanadium in fluvial sandstone and as replacements or cavity fillings in carbonized plant remains.

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During World War II, the Union Mines Development Corp., on behalf of the Manhattan Engineer District, made thorough investigations of uranium deposits in the Green River and Henry Mountains districts as part of a general evaluation of uranium resources of the Colorado Plateau. As a result of this study, several detailed reports were prepared on the more promising mining areas, and it was concluded that small amounts of relatively high grade uranium and vanadium ore reserves were available in many small deposits in the Morrison formation southwest of Green River and on the east flank of the Henry Mountains. No estimates of reserves were made in any unit other than the Salt Wash member of the Morrison formation, although it was recognized that uranium did occur in rocks of Triassic age in the Circle Cliffs and in the area between the Green and Colorado Rivers.

Since 1948, the U.S. Atomic Energy Commission and the U.S. Geological Survey have carried on extensive geological investigations and exploration of the uranium-bearing formations in the Green River and Henry Mountains districts as part of a general appraisal of the uranium resources of the Colorado Plateau.

GEOLOGIC SETTING

Sedimentary rocks exposed in the Green River and Henry Mountains districts have an aggregate thickness of about 8,000 to 9,000 feet and range in age from Pennsylvanian through Tertiary (see following table). Except for thick sequences of evaporite deposits, black shale, and limestone of Pennsylvanian age and dark-gray marine shale of Cretaceous age, most of these rocks are of continental origin and consist of interbedded sandstone, siltstone, and mudstone. In most parts of the two districts the rocks are nearly flat lying or have gentle regional dips. In a few places asymmetrical anticlinal folds, steep monoclines, or the forcible intrusion of salt or igneous rocks cause dips as much as 90°. Faulting in the two districts is limited to minor normal faults. Igneous rocks are few and are largely dikes, sills, flows, stocks, and laccoliths in the western and central parts of the Henry Mountains district.

STRATIGRAPHY

In the following section, units that contain significant uranium deposits in the Green River and Henry Mountains districts are discussed in more detail than those that do not contain ore.

HERMOSA FORMATION

The Hermosa formation of Pennsylvanian age is the oldest stratigraphic unit that crops out in the area of this report. It is exposed only in a narrow strip along the easternmost edge of the Green

Generalized stratigraphic section of sedimentary rocks exposed in the Green River and Henry Mountains districts, Utah

[In part after McKnight (1940), Baker (1946), Hunt (1953), and Luedke (1954)]

System	Series	Group and formation	Member	Thickness (feet)	Character of rocks	
Tertiary(?)		Wasatch(?) formation			White, locally fossiliferous limestone interbedded with white biotitic tuff and tuffaceous sediments; conglomerate.	
		——Unconformity——				
Cretaceous	Upper Cretaceous	Mesaverde formation		300–400	Yellowish-gray cliff-forming sandstone containing thin interbeds of shale.	
		Mancos shale	Masuk	600–800	Lenticular sandstone, shale, carbonaceous shale, and shaly limestone. Mostly continental in origin, but some is marine.	In the Green River district the formation is predominantly dark-blue-gray marine shale.
			Emery sandstone	0–250	Lower part is yellowish-gray massive sandstone. Upper part is lenticular gray sandstone, shale, carbonaceous shale, and coal. Present only in Henry Mountains district.	
			Blue Gate shale	1, 500	Blue-gray marine shale.	
			Ferron sandstone	10–300	Yellowish-brown lenticular sandstone, shale, carbonaceous shale, and coal. Lower part grades eastward into Tununk shale member.	
			Tununk shale	500–650	Blue-gray marine shale; many thin beds of bentonite.	
	Upper and Lower(?) Cretaceous	Dakota sandstone		0–50	Yellowish-brown to gray cliff-forming conglomeratic sandstone; locally contains carbonaceous shale and thin coal beds.	
		——Unconformity——				
Jurassic	Upper Jurassic	Morrison formation	Brushy Basin shale	300–500	Variegated green, gray, purple, and red bentonitic mudstone locally containing thin fresh-water limestone beds; siliceous conglomeratic sandstone and varicolored chert pebble conglomerate beds near top. The upper third of the Brushy Basin shale member has been separated and named Cedar Mountain formation by Stokes (1952) in the northwestern part of the Green River district.	
			Salt Wash	200–600	Yellowish-brown to gray-white fine-grained to conglomeratic lenticular sandstone with interbedded red and green mudstone.	

Generalized stratigraphic section of sedimentary rocks exposed in the Green River and Henry Mountains districts, Utah—Continued

System	Series	Group	Formation	Member	Thickness (feet)	Character of rocks
Jurassic	Upper Jurassic	San Rafael group	—Unconformity— Summerville formation		50–250	Thin evenly bedded reddish-brown sandstone and shale; minor amounts of greenish-white sandstone, gypsum, and limestone.
Jurassic	Upper Jurassic	San Rafael group	Curtis formation		0–235	Evenly bedded greenish-gray to brown glauconitic(?) sandstone and shale; locally contains siliceous geodes and nodules and thin beds of gypsum; mostly marine; grades eastward into the Summerville.
Jurassic	Upper Jurassic	San Rafael group	—Unconformity— Entrada sandstone		300–700	Silty red sandstone grading eastward to pink to grayish-white massive crossbedded sandstone; the Moab sandstone member, 0–115 feet thick, lies at the top of the Entrada and is whiter and more massive than most of the Entrada.
Jurassic	Upper and Middle Jurassic	San Rafael group	Carmel formation		100–600	Pink to reddish-brown sandstone, shale, and gray fossiliferous sandy limestone, highly contorted bedding and local unconformities in upper part; thick beds of gypsum in western part of Henry Mountains district.
Jurassic and Jurassic(?)		Glen Canyon group	—Unconformity— Navajo sandstone		160–800	Buff to light-gray massive crossbedded sandstone with a few thin beds of fresh-water limestone.
Jurassic(?)	Lower Jurassic(?)	Glen Canyon group	Kayenta formation		160–320	Reddish sandstone and shaly sandstone; irregularly bedded, in part massive; minor amounts of red shale, green clay, and thin fresh-water limestone.
Triassic	Upper Triassic	Glen Canyon group	Wingate sandstone		210–380	Red to buff massive crossbedded cliff-forming sandstone.
Triassic	Upper Triassic		Chinle formation	Church Rock	0–350	Reddish-brown to light-brown very fine grained sandy siltstone.
Triassic	Upper Triassic		Chinle formation	Owl Rock	0–250	Pale-red to reddish-brown siltstone and thin local limestone beds.
Triassic	Upper Triassic		Chinle formation	Petrified Forest	0–100	Variegated red, purple, green and yellow bentonitic claystone and clayey sandstone; reddish orange in Circle Cliffs; intertongues with Owl Rock member to the north.
Triassic	Upper Triassic		Chinle formation	Moss Back	0–150	Yellowish-gray to greenish-gray fine- to medium-grained to conglomeratic cliff-forming sandstone, shale, and limy siltstone pebble conglomerate.
Triassic	Upper Triassic		Chinle formation	Monitor Butte	0–200	Greenish-gray and minor amounts of pale reddish-brown bentonitic mudstone or clayey sandstone. Often has highly contorted and slumped bedding.

Triassic			Shinarump	0–200	Yellowish-gray medium-grained to conglomeratic sandstone and conglomerate containing clear to milky or pink quartz pebbles; carbonaceous material and silicified wood abundant in places.
			Mottled siltstone beds [1]	0–50	Purplish-red siltstone to coarse gray-white sandstone, conglomeratic in places; frequently characterized by a mottled purple, red, white, yellow, and brown color phenomena known locally as purple-white; present locally in Circle Cliffs and between Green and Colorado Rivers.
	Middle(?) and Lower Triassic	——Unconformity—— Moenkopi formation		0–900	Reddish-brown evenly bedded ripple-laminated siltstone and fine sandstone, gray-green in some areas; wedges out in eastern Utah; includes Sinbad limestone member in Circle Cliffs and Capitol Reef areas.
Permian		——Unconformity—— Kaibab limestone		0–350	White, buff, and light-gray limestone and limy sandstone containing siliceous concretions.
		Coconino(?) sandstone		400–800	White to buff, fine-grained, massive, crossbedded sandstone; present in western part of Henry Mountains district and thought to grade eastward into White Rim and Cedar Mesa sandstone members of the Cutler formation (Hunt, Averitt, Miller, 1953).
		Cutler formation		1,000±	Red to purplish-brown to light-gray arkosic sandstone and micaceous sandy shale; in southeastern part of Green River district, white crossbedded sandstone 0–230 feet thick (White Rim sandstone member) in upper part of formation; red siltstone, arkosic sandstone, and sandy shale (Organ Rock tongue) and light-gray to buff crossbedded sandstone (Cedar Mesa sandstone member) are in lower part of formation.
Permian(?) and Pennsylvanian		Rico formation		0–585	Brown to red and purple sandstone; red and purple coarse arkose, and gray, brown, red, and purple shale; gray to greenish-gray fossiliferous limestone.
Pennsylvanian		Hermosa formation	Upper member	900–1,800	Blue, greenish, and gray fossiliferous limestone interbedded with white, gray, and greenish sandstone and gray to green shale; well-log data indicates lower half contains more limestone than upper half.
			Paradox	2,000±	Salt, anhydrite, and gypsum with interbedded gray, black, and brown shale and a little limestone and sandstone. Crops out only in intrusive masses in breached salt anticlines.

[1] Not given member status in this report.

River district in the vicinity of Moab, Utah, and in the bottom of the canyons of the Colorado and Green Rivers near and south of their junction. The highly gypsiferous Paradox member is exposed only in small intrusive masses in Cataract Canyon a few miles below the junction of the Green and Colorado Rivers. Several oil wells in the eastern part of the Green River district have been drilled through a considerable thickness of the Paradox member, but the unit has not been found in the western part of the district (Baker, 1946, p. 24–25). An oil well drilled on the Circle Cliffs anticline is reported to have cut 685 feet of limestone, dolomite, and siltstone of the Hermosa formation (Steed, 1954). The Hermosa formation is not known to contain economic uranium deposits in the Green River and Henry Mountains districts, but gamma-ray logs for oil wells suggest that some of the black shale of the Paradox member is probably weakly uraniferous.

RICO FORMATION

The Rico formation of Pennsylvanian and Permian(?) age conformably overlies the Hermosa formation and probably wedges out or grades westward into rocks exposed in the San Rafael Swell that are tentatively correlated with the Hermosa. In the eastern part of the Green River district the Rico is exposed in the upthrown block of the Moab fault and along the canyons of the Green and Colorado Rivers. Upper beds of the Rico grade laterally from southwest to northeast into the lower beds of the Cutler formation (McKnight, 1940, p. 36). No uranium deposits were known in the Rico formation in the Green River and Henry Mountains districts as of March 1956.

CUTLER FORMATION

The Cutler formation of Permian age conformably overlies the Rico formation and is exposed in the upthrown block of the Moab fault and along the canyons of the Green and Colorado Rivers. It is thought to grade westward into the Coconino sandstone of the San Rafael Swell and the western part of the Henry Mountains district (Baker, 1946, p. 37). South of the junction of the Green and Colorado Rivers, the lower part of the Cutler formation is predominantly thick crossbedded yellowish-white sandstone with thin interbedded red beds. Within a few miles northeastward the red beds become predominant and the whole Cutler formation is principally arkosic red beds from there eastward into Colorado. On the Moab and Cane Creek anticlines in the eastern part of the Green River district, the Cutler was anticlinally folded and eroded prior to deposition of the overlying Moenkopi formation (McKnight, 1940, p. 51–52). Several small uranium deposits occur in the Cutler in the transition zone from predominantly white sandstone to predominantly arkosic red beds in the Green River district.

COCONINO(?) SANDSTONE

A thick sequence of white to buff massive crossbedded sandstone crops out in the San Rafael Swell and the Circle Cliffs and Capitol Reef areas of the Henry Mountains district and has been correlated with the Coconino sandstone of Permian age (Baker, 1946, p. 49; Hunt, 1953, p. 46). Steed (1954) and Davidson (1956) have suggested that in the Circle Cliffs this unit may be more correctly correlated with the White Rim sandstone member of the Cutler formation. As of March 1956, no uranium deposits were known in this unit in the Green River or Henry Mountains districts.

KAIBAB LIMESTONE

The Kaibab limestone of Permian age conformably overlies the Coconino(?) sandstone and crops out in the Circle Cliffs and Capitol Reef areas of the Henry Mountains district. As of March 1956, the Kaibab was not known to be uranium bearing in the area of this report.

MOENKOPI FORMATION

The Moenkopi formation of Early and Middle(?) Triassic age unconformably overlies the Kaibab limestone in the western part of the Green River and Henry Mountains districts and overlies the Cutler formation where the Kaibab is absent in the eastern part of the two districts. Over the crests of the Cane Creek and Moab anticlines in the area between the Green and Colorado Rivers the Moenkopi thins markedly and in some places was completely eroded prior to deposition of the Chinle formation (McKnight, 1940, p. 62).

The Moenkopi is dominantly a red-bed series of sandstone, siltstone, and mudstone; and locally it contains lenses of white to buff sandstone. In parts of the Circle Cliffs and San Rafael Swell and along the canyons of the Green and Colorado Rivers, however, there are large areas where the Moenkopi is greenish gray or buff rather than the typical reddish brown (McKnight, 1940, p. 54–55; Baker, 1946, p. 55). In some places the boundary between gray and red Moenkopi is very abrupt and is across bedding planes (Baker, 1946, p. 55). Gilluly and Reeside (1928, p. 65) and Gilluly (1929, p. 86) have postulated that the gray-green Moenkopi may have been deposited under reducing conditions as opposed to oxidizing conditions for the normal red-brown parts of the formation. The apparent spatial relationship between gray-green Moenkopi and collapse structures in the San Rafael Swell and at Upheaval dome (a probable cryptovolcanic structure in the Green River district) have caused some speculation as to the possible bleaching of large areas of normal red-brown Moenkopi by hydrothermal solutions. The association of petroliferous material, pyrite, and gypsum in the gray-green Moenkopi, however, suggests that the change in color was largely due to the reduction of original ferric iron and formation of pyrite in petroliferous parts of the formation. Several small uranium deposits are known in the Moenkopi in southeastern Utah.

CHINLE FORMATION

The Chinle formation of Late Triassic age unconformably overlies the Moenkopi formation. The Chinle can be divided, in ascending order, into the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock members in various parts of the Green River and Henry Mountains districts. Locally in these two districts, the basal beds of the Chinle formation are similar in lithologic character, stratigraphic position, and probably origin to the unit in the San Rafael Swell, Utah, named the Temple Mountain member of the Chinle formation by Robeck (1956). In the present report these beds are referred to as mottled siltstone beds. The mottled siltstone beds and the Shinarump, Monitor Butte, and Moss Back members were included in the Shinarump conglomerate of earlier reports (McKnight, 1940; Baker, 1946; and Hunt, 1953). The Chinle formation is of particular interest and is discussed in some detail because it is one of the two principal uranium-bearing formations in the Green River and Henry Mountains districts.

MOTTLED SILTSTONE BEDS

Mottled siltstone beds as much as 50 feet thick occur locally in the Capitol Reef and Circle Cliffs areas of the Henry Mountains district and in the eastern part of the Green River district. They lie at the base of the Chinle formation and consist of purplish-red to gray-white siltstone, sandstone, and conglomeratic sandstone similar lithologically and in stratigraphic position to the Temple Mountain member (Robeck, 1956) of the Chinle formation in the San Rafael Swell. These beds appear to have been formed partly from reworked sediments of the Moenkopi formation intermixed with sands similar to those of the Shinarump member. Baker (1933, p. 37–38) and Dane (1935, p. 56 and 64) have described a remarkable deposit of grit and conglomerate exposed in the canyon of the Colorado River near the Big Bend, about 6 miles north-northeast of Moab. This deposit, though coarser, probably corresponds to the mottled siltstone beds in the Green River and Henry Mountains districts. At many places the mottled siltstone beds contain red chert in the upper few feet of the unit. This chert is in discontinuous layers as much as 10 inches thick and commonly is weakly radioactive.

Mottled siltstone beds are commonly characterized by a mottled purple, red, yellow, brown, and white color that has been locally termed the purple-white (Finch, 1953; Johnson, 1957) and that may represent an ancient soil or laterite zone. In his report on the area between the Green and Colorado Rivers, McKnight (1940, p. 62) describes this peculiar mottled coloration and relates it to an old erosion surface.

In the Green River and Henry Mountains districts the mottled siltstone beds unconformably overlie the Moenkopi and fill channels cut into its surface. These beds are in turn overlain unconformably by the Shinarump member of the Chinle formation in the western part of the Henry Mountains district and by the Moss Back member in the area between the Green and Colorado Rivers. Channel-fill deposits in the overlying unit tend to follow channel-fill mottled siltstone beds in some places (for example, in the "A" group mine area near the junction of Mineral Canyon with the Green River). Mottled siltstone beds are uranium-bearing in some parts of the Green River district but are not known to contain significant ore deposits.

SHINARUMP MEMBER

The Shinarump member of the Chinle formation is composed principally of yellowish-gray to buff medium- to coarse-grained sandstone and may be as much as 200 feet thick in the Green River and Henry Mountains districts. The rock is largely made up of clear subangular quartz grains; but lenses of conglomeratic sandstone and conglomerate containing rounded pebbles of clear to milky and pink quartz, quartzite, and chert are common. Interbedded mudstone lenses and carbonized plant remains are abundant in some places. The Shinarump member unconformably overlies the Moenkopi formation or, in some places, the mottled siltstone beds. Commonly the Shinarump is thickest where it fills channels cut into the underlying unit.

The Shinarump member crops out in the Circle Cliffs and Capitol Reef areas of the Henry Mountains district and is the principal ore-bearing unit there. It underlies the southern part of the Henry Mountains district but wedges out to the northeast along a line extending northwesterly from near Hite, Utah, through the area between Capitol Reef and the San Rafael Swell (pl. 6). Near this regional pinchout the Shinarump becomes thin and is present only in channels cut in the underlying unit.

MONITOR BUTTE MEMBER

The Monitor Butte member of the Chinle formation (I. J. Witkind and R. E. Thaden, written communication) occurs throughout the Henry Mountains district and in the southern part of the Green River district (Stewart and others, 1959). It conformably overlies the Shinarump member where that unit is present. Where the Shinarump is absent, the Monitor Butte member lies unconformably on the Moenkopi formation.

The Monitor Butte member is composed principally of greenish-gray and reddish-brown bentonitic mudstone and clayey sandstone. The member locally contains lenses of fine- to coarse-grained grayish-white sandstone similar lithologically to sandstone beds of the Shinarump member. The unit ranges in thickness from about 200 feet in the southern part of the Henry Mountains district to a wedge edge along a northwestward-trending line in the southern part of the Green River district (pl. 6). The Monitor Butte is uranium-bearing but no large ore deposits had been found in it in the Green River and Henry Mountains districts as of March 1956.

MOSS BACK MEMBER

Except where locally absent, the Moss Back member of the Chinle formation (Stewart, 1957) overlies the Monitor Butte member over most of the southern part of the Green River district and the northern part of the Henry Mountains district. Northeast of the regional pinchout of the Monitor Butte in the southern part of the Green River district, the Moss Back lies unconformably on the Moenkopi formation or on the mottled siltstone beds. In the area between the Green and Colorado Rivers the Moss Back wedges out along a northwestward-trending line (pl. 6) approximately coextensive with the crest of the Cane Creek anticline.

The Moss Back member is composed principally of yellowish-gray to greenish-gray fine-grained to conglomeratic sandstone. In many areas it contains thick beds of limy siltstone pebble conglomerate. Green mudstone and carbonized plant remains are also abundant locally. The Moss Back averages about 50 feet thick over most of its outcrop in the Green River and Henry Mountains districts, but may reach thicknesses of as much as 150 feet where it fills channels cut into the underlying unit (Stewart and others, 1959). Over large areas the Moss Back is a thick cliff-forming unit of relatively uniform lithology. Near its line of pinch out in the area between the Green and Colorado Rivers it becomes thin and relatively discontinuous. In the southern part of the Green River district and in the southeastern part of the San Rafael Swell the Moss Back is thin and in some places absent. Probably these areas were relatively high during deposition of the Moss Back and caused diversion of streams that deposited the unit (Stewart and others, 1959). The Moss Back contains significant uranium deposits in the San Rafael

Swell and near the line of pinch out of the member in the northeastern part of the Green River district (pl. 6).

PETRIFIED FOREST MEMBER

Stewart and others (1959) have correlated a reddish-orange facies of the Chinle formation in the Circle Cliffs and Capitol Reef areas with the Petrified Forest member, named by Gregory (1950, p. 67) from exposures in the Zion Park region of Utah. Typically this unit consists of variegated bentonitic claystone and clayey sandstone. It is not known to contain significant uranium deposits in the Green River and Henry Mountains districts.

OWL ROCK MEMBER

The Owl Rock member of the Chinle formation (I. J. Witkind and R. E. Thaden, written communication) crops out in the southern part of the Green River and Henry Mountains districts and grades laterally to the north into the Church Rock member near the junction of the Green and Colorado Rivers and also between Capitol Reef and the San Rafael Swell (Stewart and others, 1959). Typically the Owl Rock is composed principally of reddish-brown structureless siltstone and thin interbedded limestone. Significant uranium deposits are not known in the Owl Rock member in the Green River and Henry Mountains districts.

CHURCH ROCK MEMBER

The Church Rock member of the Chinle formation (I. J. Witkind and R. E. Thaden, written communication) lies on the Chinle over most of southeastern Utah except for the Capitol Reef area and large parts of the Circle Cliffs area in the western part of the Henry Mountains district (Stewart and others, 1959). Typically the Church Rock member is composed of reddish-brown to light-brown sandy siltstone. In some places it contains fine-grained sandstone beds that can be correlated over wide areas. Carbonized plant remains and interbedded green mudstone are abundant locally in sandstone beds of the Church Rock member in the area between the Green and Colorado Rivers. Several small uranium deposits are known in the northeastern part of the Green River district in a sandstone bed that is informally called the Black Ledge.

WINGATE SANDSTONE

Overlying the Chinle formation is the Wingate sandstone of Late Triassic age. The Wingate is composed principally of red to buff massive crossbedded fine-grained well-sorted sandstone. It is very uniform, averages about 300 feet in thickness over most of southeastern Utah, and characteristically forms a sheer cliff. No uranium deposits are known in the Wingate in the Green River and Henry Mountains districts.

KAYENTA FORMATION

The Kayenta formation of Early Jurassic(?) age overlies the Wingate sandstone throughout the Green River and Henry Mountains districts except where removed by erosion. The Kayenta is composed principally of reddish fine-grained sandstone, shaly sandstone, and minor amounts of red and green shale. No uranium deposits are known in the Kayenta in the Green River and Henry Mountains districts.

NAVAJO SANDSTONE

The Navajo sandstone of Jurassic and Jurassic(?) age overlies the Kayenta formation and occurs everywhere in the Green River and Henry Mountains districts except where removed by erosion. The Navajo is composed principally of buff to light-gray massive crossbedded sandstone and is a continuous cliff-forming unit several hundred feet thick and of very uniform lithology. No uranium deposits are known in the Navajo in the Green River and Henry Mountains districts.

CARMEL FORMATION

The Carmel formation of Middle and Late Jurassic age overlies the Navajo sandstone. The Carmel is partly marine in origin (Baker, 1946, p. 75) and is composed of reddish-brown sandstone and shale, gray fossiliferous sandy limestone, and gypsum beds. Near its upper contact, the Carmel commonly contains contorted beds and local angular unconformities, which are probably due to plastic deformation that took place prior to consolidation of the rock. Only minor uranium occurrences are known in this formation in the Green River and the Henry Mountains districts.

ENTRADA SANDSTONE

The Entrada sandstone of Late Jurassic age overlies the Carmel formation and is composed principally of red to grayish-white massive crossbedded sandstone. The Entrada sandstone is a thick continuous, and relatively uniform lithology and is present everywhere in the Green River and Henry Mountains districts except where it has been removed by erosion. Only minor uranium occurrences are known in the Entrada in these two districts.

CURTIS FORMATION

The Curtis formation of Late Jurassic age unconformably overlies the Entrada sandstone in most of the Green River district and pinches out to the southward near the central part of the Henry

Mountains district. The Curtis is composed principally of greenish-gray sandstone and shale and is probably marine in origin. Only minor occurrences of uranium are known in the Curtis in the Green River and Henry Mountains districts.

SUMMERVILLE FORMATION

The Summerville formation of Late Jurassic age conformably overlies the Curtis formation. The Summerville is composed principally of thin-bedded reddish-brown shale and sandstone and is present in the central and northwestern parts of the Henry Mountains district and in the northern part of the Green River district. Elsewhere it has been removed by erosion. No significant uranium deposits are known in the Summerville in the Green River and Henry Mountains districts.

MORRISON FORMATION

The Morrison formation of Late Jurassic age overlies the Summerville formation unconformably. The Morrison, in the area of this report, may be divided in ascending order into the Salt Wash and Brushy Basin shale members in the central and northwestern parts of the Henry Mountains district and in the northern part of the Green River district. It is one of the two principal uranium-bearing formations in southeastern Utah. Plate 7 shows the location of known ore deposits in the Morrison formation.

SALT WASH MEMBER

The Salt Wash member of the Morrison formation may be as much as 600 feet thick and is composed principally of yellowish-brown to grayish-white fluvial sandstone beds and interbedded red and green mudstone beds. According to Craig and others (1955, p. 125), it was formed as a large alluvial plain or fan by a system of aggrading braided streams that diverged to the north and east from an apex in south-central Utah (pl. 8). Near the apex of the fan the Salt Wash member is composed principally of thick continuous layers of coarse sandstone and conglomerate with a minimum of interbedded mudstone. Near the outer edges of the fan the Salt Wash is dominantly mudstone with minor amounts of sandstone in relatively discontinuous lenses. Between the inner coarse sandstone and conglomerate facies and the outer mudstone facies is an intermediate facies in which the Salt Wash is composed of interbedded sandstone and mudstone, either of which may constitute as much as 75 percent of the unit. The approximate position and trend of ancient trunk channel systems on the fan formed by the Salt Wash may be inferred from the thicker lobes shown on an isopach map of the member (pl. 8). In the field the trace of these trunk channel systems is indicated in some places by a greater total thickness of the member, a greater percentage of sandstone in the member, and a greater than normal thickness of the thickest uninterrupted sequence of sandstone in the member (pl. 7). The term "trunk channel system" is not meant to imply a well-defined river channel that maintained its position throughout deposition of the Salt Wash. Rather it is intended to represent the trace of one or more large braided streams that meandered back and forth within certain poorly defined limits on the fan formed by the Salt Wash. Significant deposits of uranium ore occur in the Salt Wash member at many places in the Green River and Henry Mountains districts.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin shale member of the Morrison formation is composed principally of variegated green, gray, purple, and red bentonitic mudstone and small lenses of grayish-white sandstone and conglomerate in the Green River and Henry Mountains districts. At a few localities thin beds of carbonaceous shale or siltstone occur. In the northwestern part of the Green River district, Stokes (1952) has distinguished the upper third of the Brushy Basin member and named it the Cedar Mountain formation. For simplicity the Cedar Mountain formation is included in the Brushy Basin member in this report. Low-grade uranium deposits are known at several places in the Brushy Basin in the Green River district.

DAKOTA SANDSTONE

The Dakota sandstone of Early(?) and Late Cretaceous age unconformably overlies the Brushy Basin shale member of the Morrison formation and crops out intermittently around the Henry Mountains and in the northern part of the Green River district. It has a maximum thickness of about 50 feet and is composed principally of yellowish-brown to gray conglomeratic sandstone beds. Locally, it contains carbonaceous shale and thin coal beds. No significant uranium deposits are known in the Dakota in the Green River and Henry Mountains districts.

MANCOS SHALE

Overlying the Dakota sandstone is the Mancos shale of Late Cretaceous age. The Mancos is 3,000 to 4,000 feet thick and is composed predominantly of dark-gray marine shale of the Tununk, Blue Gate, and Masuk members. About 500 feet above the base of the Mancos is the Ferron sandstone member. The Ferron is as much as 300 feet thick in the western part of the Henry Mountains district and is composed of yellowish-brown sandstone, carbonaceous shale, and coal beds. Eastward it thins to about 10 feet in the northeastern part of the Green River district. About 2,500 feet above the base of the Mancos shale another sandstone member, the Emery, is exposed in the central part of the Henry Mountains district. The Emery sandstone member is composed principally of gray massive to lenticular sandstone, shale, carbonaceous shale, and thin coal beds and may be as much as 250 feet thick. The Ferron and Emery sandstone members had their source to the west and southwest in western Utah and Nevada and represent shoreline and coastal plain deposits laid down during temporary retreats of the sea. Only minor uranium occurrences are known in the Mancos shale in the Green River and Henry Mountains districts, and these are in the Ferron and Emery sandstone members.

MESAVERDE FORMATION

The Mesaverde formation of Late Cretaceous age conformably overlies the Mancos shale in the central part of the Henry Mountains district. The Mesaverde is composed principally of thick massive sandstone beds separated by thin shaly partings. Presumably an upper carbonaceous and coal-bearing sandstone and shale facies of the Mesaverde was originally present in the Henry Mountains district but has been removed by erosion (Hunt, 1953). No significant uranium deposits are known in the Mesaverde formation in the Green River and Henry Mountains districts.

WASATCH(?) FORMATION

Other than gravel deposits of Quaternary age, the Wasatch(?) formation of Tertiary age is the only sedimentary rock unit younger than Late Cretaceous that occurs in the Green River and Henry Mountains districts. These Tertiary rocks crop out in poor exposures on the upper slopes of Boulder Mountain (pl. 7) in the extreme western part of the Henry Mountains district and are composed of pink and white limestone and tuffaceous shale, sandstone, and conglomerate (Luedke, 1954). The total thickness of the Wasatch(?) formation in the western part of the Henry Mountains district is several hundred feet; but outcrops are obscured by lava flows, landslides, glacial deposits, and vegetation. No significant uranium deposits were known in this formation as of March 1956.

STRUCTURE

The regional structure of the Green River and Henry Mountains districts is characterized for the most part by gentle dips on the flanks of major upwarps or synclinal basins. These gentle dips are abruptly steepened in a few places by sharp monoclinal folds, asymmetrical anticlines, and local anticlines or domes related to the flowage of salt or the intrusion of igneous bodies (pl. 9). Faulting is limited to high-angle normal faults and the formation of grabens.

In the southern part of the Green River district, regional structure is controlled by the northward-plunging Monument upwarp. To the west the district is bounded by the steep eastern limb of the San Rafael Swell. The northern part of the district dips gently northward toward the Uinta Basin, and the eastern part of the district is characterized by local anticlines and synclines related to salt flowage (for example, Cane Creek anticline and Moab anticline). Earliest movement on the salt structural features probably began during late Permian time as is indicated by an angular unconformity between the Cutler and Moenkopi formations over the crest of the Cane Creek and Moab anticlines. Thinning of the Moenkopi formation on the crests of these structural features and, in some places, a slight angular unconformity between the Moenkopi and Chinle formations indicate that movement continued intermittently during Triassic time. Meander anticline, a narrow northeastward-trending arch essentially coextensive with the inner canyon of the Colorado River near its junction with the Green River, is probably related to salt flowage after cutting of the canyon caused release of load in geologically recent time (McKnight, 1940, p. 130).

Another local feature of considerable interest, but uncertain origin, in the Green River district is Upheaval dome in the area between the Green and Colorado Rivers. This small circular dome has been interpreted as being related to a salt intrusion (McKnight, 1940, p. 128) and also as due to igneous forces (Bucher, 1936, p. 1066). Results of recent geophysical work indicate a strong magnetic anomaly and a small positive gravity anomaly under Upheaval dome and suggest that the structure may be related to an igneous plug (Joesting, Byerly, and Plouff, 1955, p. 95). Another magnetic anomaly of similar magnitude, the Grays Pasture anomaly, occurs about 8.5 miles southeast of Upheaval dome (Henry R. Joesting, and Donald F. Plouff, oral communication, March 1956) and a line through Upheaval dome and the Grays Pasture anomaly intersects Lockhart syncline, a circular collapse feature, about 8.5 miles southeast of the Grays Pasture anomaly. Although there seems to be no magnetic anomaly associated with Lockhart syncline (James W. Aubrey and Donald F. Plouff, oral communication, March 1956), the possibility must be considered that it, too, may be related to igneous activity (possibly hydrothermal solution of underlying limestone beds or gaseous explosion and collapse) if the Grays Pasture anomaly and Upheaval dome are so related.

Regional structure in the Henry Mountains district is dominated by the Henry Mountains structural basin in the eastern and central parts of the district and by the Circle Cliffs and Capitol Reef upwarps in the western part of the district. Separating the structural basin from the two upwarps is the sharp Waterpocket Fold monocline. The Henry Mountains structural basin is one of the major structural lows of the Colorado Plateau and is probably the counterpart of the Circle Cliffs and San Rafael Swell upwarps (Hunt, 1953, p. 88). The basin is sharply asymmetric and has its principal trough crowded against the steeply dipping west flank. The Circle Cliffs and Capitol Reef upwarps are as much as 8,500 feet higher structurally than the trough of the Henry Mountains basin (Hunt, 1953, p. 88); but in their breached interiors, they contain extensive exposures of rocks of Triassic age that show little effect of the anticlinal folding. According to Hunt (1953, p. 90), the Circle Cliffs upwarp, Waterpocket Fold monocline, and Henry Mountains structural basin were formed during Late Cretaceous or early Eocene time.

Faults in the Green River and Henry Mountains districts are normal faults, most having relatively small displacement. The largest faults are in the northern part of the Green River district where displacements as great as 1,000 and 2,500 feet occur along Salt Wash graben and the Moab fault respectively. Elsewhere in the two districts, few faults have displacements greater than a few hundred feet.

IGNEOUS ROCKS

The stocks and laccolithic intrusive bodies of the Henry Mountains constitute the principal igneous rocks of the Green River and Henry Mountains districts (fig. 3). These intrusive bodies are composed mainly of diorite porphyry and monzonite porphyry and are probably late Miocene or early Pliocene in age (Hunt, 1953, p. 212; and Hunt, 1956). Gilbert (1877) and Hunt (1953) have given detailed descriptions of the petrography, form, and mode of emplacement of these rocks.

In the northwestern part of the Henry Mountains district, swarms of analcite-biotite diabase and syenite dikes and sills have been described by Gilluly (1929, p. 120). The dikes cut rocks of the Morrison formation and were probably intruded during the Tertiary period. Flows of andesitic and basaltic lava of Tertiary age top Thousand Lake Mountain and Boulder Mountain in the extreme western part of the Henry Mountains district.

The only igneous rock cropping out in the Green River district is a northwesterward-trending dike in the vicinity of the Flattops in the west-central part of the district. According to Eugene M. Shoemaker (oral communication, March 1956), this dike is of highly potassic altered alkaline basalt. In the area between the Green and Colorado Rivers, geophysical data suggest that Upheaval dome may be underlain at shallow depth by an igneous plug.

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The only ore deposits directly associated with igneous rocks in the Green River and Henry Mountains districts are small fissure deposits of gold, silver, and copper in stocks on Mount Ellen and Mount Pennell in the Henry Mountains.

ORE DEPOSITS

Uranium occurs with vanadium and (or) copper in deposits of economic size and grade in the Chinle and Morrison formations in the Green River and Henry Mountains districts. Minor uranium deposits or occurrences are also known in the Hermosa, Cutler, Moenkopi, Carmel, Entrada, Curtis, and Mancos formations in the two districts. Plates 6 and 7 show the location and relative size of known ore deposits. The ore deposits are principally bedded deposits in fluvial sandstone lenses and are commonly associated with carbonaceous or petroliferous material. Several minor uranium occurrences, however, are known in silicified or calcified fracture zones and faults.

MODE OF OCCURRENCE

Bedded uranium deposits in the Green River and Henry Mountains districts are similar to those elsewhere on the Colorado Plateau. Fischer (1942) and Finch (1955) have given general descriptions of these deposits. Uranium, usually accompanied by greater or lesser amounts of vanadium and (or) copper, occurs in fairly well defined tabular elongate deposits, which are, for the most part, oriented parallel to bedding and sedimentary trends in the host rock. Carbonaceous material is usually present and in many uranium deposits appears to have played an important part in the precipitation of the ore minerals.

Ore deposits in the Chinle and Morrison formations in the Green River and Henry Mountains districts range from about 1 to 3 feet in thickness, and most of the ore is in deposits 1,000 to 25,000 tons in size. A cluster of closely spaced ore bodies joined by weakly mineralized ground is considered to be one deposit. No deposits larger than about 25,000 tons were known as of March 1956.

No vein-type or fracture-controlled uranium deposits are known in the Green River and Henry Mountains districts except for minor occurrences of uranium associated with copper in fracture zones in the Entrada sandstone about 3 miles east of the town of Hanksville and along a fault separating the Carmel and Entrada formations in sec. 24, T. 24 S., R. 13 E. Salt Lake meridian.

MINERALOGY

Uranium deposits in the Green River and Henry Mountains districts may be classed according to metal content as vanadium-uranium deposits (vanadium content greater than uranium) or as uranium deposits with lesser amounts of copper and (or) vanadium. Ore deposits in the Morrison formation are commonly vanadium-uranium deposits in which the average $V_2O_5:U_3O_8$ ratio is about 2:1 in the Green River district and 5:1 in the Henry Mountains district. Ore deposits in the Chinle formation in the two districts are, with a few exceptions, classed as uranium deposits with minor amounts of vanadium and (or) copper. The principal exceptions to this rule are represented by several ore deposits in the Church Rock member of the Chinle formation in the area between the Green and Colorado Rivers. These deposits have $V_2O_5:U_3O_8$ ratios of about 5:1. Also, the Temple Mountain deposits in the Chinle formation just west of the Green River district contain about twice as much vanadium as uranium, and similar ore deposits may be present at depth along the western edge of the Green River district.

Most of the known vanadium-uranium deposits in the Morrison formation in the Green River and Henry Mountains districts are on or close to the outcrop and are relatively oxidized. Carnotite-type secondary uranium minerals and high-valent vanadium minerals are the principal constituents of these deposits. Weeks and Thompson (1954, p. 19) have given a general description of this oxidized vanadium-uranium ore. Recently, exploration and mining at greater depth have found relatively unoxidized deposits that are composed principally of uraninite, coffinite, and low-valent vanadium minerals.

Most of the uranium deposits in the Chinle formation in the Green River and Henry Mountains districts contain minor amounts of copper and vanadium and oxidize to form a wide variety of yellow, orange, green, and blue carbonates, sulfates, phosphates, arsenates, silicates, and hydrated oxides. Weeks and Thompson (1954, p. 21) have described these oxidized relatively nonvanadiferous ores. Commonly these deposits are oxidized only within 100 feet or so of the outcrop. Where unoxidized, the uranium occurs as uraninite and coffinite and is associated with minor amounts of pyrite, chalcopyrite, bornite, chalcocite, galena, and sphalerite and traces of cobalt, nickel, molybdenum, and silver.

Uranium-bearing carbonaceous siltstone (containing less than 0.10 percent U_3O_8) of the Brushy Basin shale member of the Morrison formation in the northern part of the Green River district contains uranium disseminated through the rock, probably in the form of uraninite. Trace amounts of molybdenum are also present.

CONTROLS

In the Green River and Henry Mountains districts uranium deposits and (or) ground relatively favorable for their occurrence seem to be controlled to some extent by a favorable sandstone-mudstone facies, trunk channel systems, stratigraphic pinchouts, individual channels, thick sandstone lenses, carbonaceous material, favorable host rocks, and, in a few places, possibly by local fractures. Tectonic structural features do not appear to exert any direct control over the localization of the great majority of uranium deposits but may indirectly control the position of relatively favorable ground inasmuch as some structural features influenced sedimentation during deposition of the ore-bearing units.

Lithofacies studies of the Salt Wash member of the Morrison formation by Craig and others (1955, p. 137) have shown that the fan formed by the Salt Wash may be divided into a conglomeratic sandstone facies near its apex, an intermediate sandstone and mudstone facies, and a claystone and lenticular sandstone facies near its outer margin (pl. 8). Uranium deposits occur principally in the intermediate sandstone and mudstone facies. Possibly the thick continuous beds of relatively clean sandstone (that is, sandstone containing no interbedded mudstone and very little interstitial clay) in the conglomeratic sandstone facies allowed the laterally moving ore-bearing solutions to be flushed easily through them and dispersed instead of concentrated. The claystone and lenticular sandstone facies is, however, relatively impermeable, and ore-bearing solutions probably could not pass through these rocks in appreciable quantities. The intermediate sandstone and mudstone facies may have provided optimum conditions for the localization of ore deposits in that the sandstone lenses are sufficiently continuous to allow passage of large quantities of the ore-bearing solutions, whereas, less permeable interbedded mudstone would tend to cause concentration of the solutions in the sandstone beds and might also trap passing solutions where sandstone layers lens out into mudstone. At any rate, the sandstone and mudstone facies of the Salt Wash member seems to be one of the major controls of ground favorable for significant uranium deposits in the Green River and Henry Mountains districts.

At some places in the Green River and Henry Mountains districts, the approximate position of ancient trunk channel systems in the Salt Wash member of the Morrison formation may be inferred from a greater total thickness of the member, a greater percentage of sandstone in the member, and a greater than normal thickness of the thickest uninterrupted sandstone sequence. These inferred trunk channel systems are essentially coextensive with clusters of known ore deposits, and it is probable that trunk channel systems are one of the major controls of ground favorable for significant uranium deposits in the Morrison formation in the Green River and Henry Mountains districts. The principal factor in this control may be that sandstone lenses within the trunk channel system tend to be appreciably thicker than sandstone lenses outside it. Thicker than average sandstone lenses have long been recognized as an apparent control of deposition of ore in the Salt Wash member of the Morrison formation (Coffin, 1921, p. 184; Weir, 1952, p. 26).

Regional pinchouts of ore-bearing units seems to indicate ground favorable to significant uranium deposits in the Chinle formation in the Green River and Henry Mountains districts. In theory, any feature of the ore-bearing units that would tend to restrict or concentrate the flow of the laterally moving ore-bearing solutions might well be expected to influence the localization of ore. Regional pinchouts of these ore-bearing units could restrict or concentrate laterally moving solutions in two ways. First there might be a damming of the solutions where the aquifer feathers out into less permeable rocks. Then too, near a regional pinchout, blanketlike formations tend to become relatively discontinuous; and laterally moving solutions probably tend to concentrate in the few remaining thick sandstone lenses (that is, in channel-fill deposits). The significant ore deposits in the Chinle formation in the Green River and Henry Mountains districts appear to be grouped within a few miles of the northeastern regional pinchouts of the Shinarump, Monitor Butte, and Moss Back members.

Individual channels cut into an underlying less permeable unit and filled with fluvial sediments are common loci for uranium deposits in rocks of Triassic age (Wright, 1955, p. 140–142; Miller, 1955, p. 164; and Witkind, 1956). This relation of uranium deposits to channels is so well established in the Shinarump member of the Chinle formation as to constitute almost a law. Possibly in some places the thicker and more permeable channel-fill unit provided a better passageway for laterally moving ore solutions than did less permeable rocks surrounding it. The tendency for uranium deposits to occur near the base of channels suggests that the ore-bearing solutions may have gravitated into these structures and then traveled along them.

Sandstone lenses that are thicker than average have long been noted as favorable to deposition of uranium in the Colorado Plateau (Coffin, 1921, p. 184; Weir, 1952, p. 26). Probably the presence of thicker sandstone lenses is an important factor in the deposition of ore in trunk channel systems and individual channels in the Green River and Henry Mountains districts. In some places in the Chinle formation, thicker sandstone lenses, which were apparently deposited by an aggrading stream, seem to be equal in importance as an ore control to sandstone deposits that fill channels. Possibly the greater transmissivity of these thicker than average units is one of the more important controlling factors. In the Morrison formation of the Green River and Henry Mountains districts, individual sandstone lenses less than about 35 to 40 feet thick seldom contain ore deposits of any appreciable size. Significant ore deposits are not uncommon in the Morrison, however, where the sandstone lenses are 40 feet or more thick.

Carbonaceous material in the form of carbonized wood fragments, leaves, or stems has long been recognized to be intimately associated with uranium mineralization on the Colorado Plateau (Boutwell, 1905, p. 209; Hess, 1914, p. 680; Weir, 1952, p. 22–23). Apparently carbonaceous material in the host rock helped provide a reducing environment conducive to the precipitation of uranium and other metals. Carbonaceous material alone may not have been a strong ore control, however, as it is also common in nonmineralized rock.

In the Shinarump member of the Chinle formation in the Circle Cliffs, uranium deposits commonly are found only in remnant patches of siltstone cobble conglomerate on the flanks of channels. This siltstone cobble conglomerate consists of fragments of Moenkopi, probably from caving stream banks, in a matrix of typical sands of the Shinarump member. It seems to be a preferred host rock for uranium in channel-fill units that are otherwise dominantly clean sandstone. Possibly fragments of the Moenkopi, being chemically different from the normal Shinarump, helped cause precipitation of the ore minerals.

As a general rule, local fractures do not control unoxidized uranium deposits in the Green River and Henry Mountains districts but may localize small bodies of secondary minerals that have formed and migrated short distances upon oxidation of the primary deposits. In the Circle Cliffs, however, unoxidized uranium deposits commonly are limited to the flanks of channels and, in some places, seem to be coextensive with local fracture zones in the top 2 or 3 feet of the Moenkopi formation at the breakoff point in the channel bank. Possibly these local fracture zones are related to ancient slumps on the channel bank or were formed because of differential compaction between the thicker, sandier channel-fill unit and muddier nonchannel sediments.

Tectonic structures do not appear to have had any direct control on the great majority of uranium deposits in the Green River and Henry Mountains districts. Trace amounts of uranium do occur, however, in association with weakly mineralized copper-bearing rock. About 3 miles east of the town of Hanksville such deposits are found in fracture zones or faults of minor displacement in the Entrada sandstone and along a fault separating the Carmel and Entrada formations in sec. 24, T. 24 S., R. 13 E., Salt Lake meridian. Also, salt anticlines in the eastern part of the Green River district were rising during the Triassic period and may have deflected streams depositing the Chinle formation so as to cause a concentration of stream deposits (and, therefore, relatively favorable ground) on and parallel to the flanks of the structures.

GUIDES TO ORE

The features that have been described as ore controls—favorable sandstone-mudstone facies, trunk channel systems, stratigraphic pinchouts, individual channels, thick sandstone lenses, carbonaceous material, and favorable host rocks—may also be used to some extent as guides to ore. Also, limonite stain, green and blue secondary copper minerals, a gray-green color alteration at the base of the ore-bearing unit and in mudstone seams in the ore-bearing unit, gray to buff as opposed to reddish sandstone, and the presence of iron and (or) copper sulfides may be used as guides to ore. On or near mineralized outcrops where oxidation has taken place, limonite and (or), in the case of ore deposits in the Chinle formation, green and blue secondary copper minerals are frequently useful as guides to ore. A gray-green color alteration in the top few feet of a normally brown or reddish unit immediately beneath the ore-bearing unit is also a guide, but the thickness of this alteration zone does not seem to be in direct proportion to the intensity of mineralization in the ore-bearing unit. Brown or reddish mudstone seams or lenses are usually altered gray green in the vicinity of ore deposits. Ore-bearing units are commonly bleached light-gray to buff in the vicinity of ore deposits as opposed to being tinged with red or brown away from ore. Where the ore-bearing unit is unoxidized, pyrite and (or), in the Chinle formation, copper sulfides are useful as an ore guide.

ORIGIN

The source of the metals in uranium deposits of the Colorado Plateau is not yet agreed upon. The metals may have been derived from detrital material, chemical precipitates, volcanic ash within the sediments, uraniferous petroleum, or hypogene solutions. Elmer V. Reinhardt (written communication, 1952) has suggested that the igneous stocks and laccoliths of the Henry Mountains may be the source of vanadium and uranium in that district. However, the occurrence of typical bedded vanadium-uranium deposits and the absence of fracture-controlled deposits in the Morrison formation on the south flank of Mount Hillers, where the beds dip 85° and are strongly fractured from the forcible intrusion of the igneous rocks, is evidence that the ore deposits were in place prior to the intrusion of the igneous masses. This agrees with Hunt's opinion (Hunt, 1953, p. 212; and 1956) that the intrusive bodies are late Miocene or early Pliocene in age, and, therefore, younger than the vanadium-uranium deposits, which have been dated by lead-uranium ratios (Stieff, Stern, and Milkey, 1953, p. 15) as about 65 million years old or Late Cretaceous or early Tertiary in age. Regardless of the source of the metals, however, it is probable that they were transported by solutions which were similar to ground water and which moved, for the most part, laterally through the rocks until a trap or favorable host rock caused precipitation of the ore minerals.

RELATIVE FAVORABILITY OF GROUND

The following is a brief discussion of the relative favorability of each potentially ore-bearing unit within the Green River and Henry Mountains districts. Geology and ore potential of unexposed units are of necessity extrapolated from adjacent areas where these units crop out. This discussion is based on the premise that primary sedimentary features such as regional pinchouts, trunk channel systems, individual channels, and thick sandstone lenses are the major controls of ore deposits and ground favorable to such deposits. If tectonic structures should be the major controlling factor, the uranium ore potential of the Green River and Henry Mountains districts may be considerably different from that suggested in this report.

Assuming that the uranium-bearing solutions traveled for the most part laterally through the beds, clean blanketlike sandstone beds are inferred to be unfavorable for ore deposits because the solutions would tend to be dispersed through them instead of concentrated. Relatively lenticular and discontinuous beds would tend to cause concentration of the ore-bearing solutions in the thicker, more permeable parts of sandstone lenses. Interfingering sandstone and mudstone beds provide traps for ore-bearing solutions, and carbonaceous material causes chemical environments conducive to the precipitation of ore minerals.

PRE-HERMOSA FORMATIONS

Formations older than the Hermosa formation of Pennsylvanian age are not exposed in the Green River and Henry Mountains districts. Accordingly, there is little evidence on which to base an appraisal of the uranium potential of these rocks. No sandstone units similar to the Shinarump and Moss Back members of the Chinle formation and the Salt Wash member of the Morrison formation (the principal known ore-bearing units on the Colorado Plateau) are known in the pre-Hermosa rocks; but limestone of Mississippian age may possibly be a favorable host for uranium deposits, especially if hypogene solutions should be the source of the ore. Through March 1956, there was no evidence of significant uranium deposits in these rocks.

HERMOSA FORMATION

The Hermosa formation is not known to contain significant uranium deposits in the Green River and Henry Mountains districts. However, traces of uranium occur in what is thought to be Hermosa at the Big Chance claim, about 2 miles west-northwest of Moab (pl. 6). Also, records of oil wells in the area between the Green and Colorado Rivers indicate that there is weakly anomalous radioactivity in shale and limestone beds of the upper Hermosa and in black shale of the Paradox member. If the uranium deposits of the Colorado Plateau were formed from hypogene solutions, the limestone beds of the Hermosa formation might conceivably provide a good host rock for ore, especially where fractured or brecciated in the vicinity of faults and sharp folds. Exposures and at least one drill hole in the Hermosa close to the Moab fault, however, show no mineralized rock or recrystallized limestone. Largely because of the lack of ore deposits on outcrops, the Hermosa is thought by the author to have little potential for significant uranium deposits in the Green River and Henry Mountains districts.

RICO FORMATION

No uranium deposits are known in the Rico formation in the Green River and Henry Mountains districts, and it does not contain carbonaceous sandstone lenses such as are generally most favorable for ore. Accordingly, it probably has little potential for ore in appreciable amounts. The brown, red, and purple colors of this formation and the lack of ore deposits where it is exposed suggest that ore-bearing solutions have either not passed through it or have not reacted with the rock in any way.

CUTLER FORMATION

The Cutler formation is not ore-bearing in the Green River and Henry Mountains districts except for several small uranium-copper deposits (commonly less than 100 tons in size) that average about 0.15 percent U_3O_8 and less than 1 percent copper. These deposits occur in the northeast corner of T. 28, S., R. 19 E., Salt Lake meridian, in the Green River district (pl. 6). They are in small lenses of bleached, white arkosic sandstone and, together with similar deposits across the Colorado River to the southeast, are in the transition zone where the Cutler changes from predominantly white sandstone toward the southwest to predominantly arkosic red beds toward the northeast. Possibly the interfingering of the two different facies in this transition zone has formed a stratigraphic trap that slowed down or dammed laterally moving uranium-bearing solutions and promoted the precipitation of the ore minerals. At any rate the southeastward-trending transition zone appears to be relatively favorable for low-grade uranium-copper deposits to a maximum size of about 500 tons.

COCONINO(?) SANDSTONE

The Coconino(?) sandstone is not known to be ore-bearing in the Green River and Henry Mountains districts and consequently probably has little or no potential for significant uranium deposits there. Probably the clean massive sandstone of this unit does not provide traps for ore-bearing solutions or favorable host rocks necessary for uranium deposits.

KAIBAB LIMESTONE

The Kaibab limestone is not known to contain uranium deposits in the area covered by this report. Small copper and lead deposits occur in this unit on Miners Mountain in the Capitol Reef area (pl. 6) but uranium has not been found in these deposits. The absence of exposures containing uranium suggests that the Kaibab has little or no potential for significant uranium deposits in this area.

MOENKOPI FORMATION

Several small uranium deposits are known in the Moenkopi formation in the Green River and Henry Mountains districts (pl. 6). At Fort Bottom about 4.5 miles west of Upheaval dome in the Green River district, a small bedded uranium deposit containing as much as 0.74 percent U_3O_8 occurs in asphaltic sandstone, about 200 feet below the contact of the Moenkopi and Chinle formations. In the Circle Cliffs area, a 1-foot asphaltic sandstone layer about 40 feet below the top of the Moenkopi contains a small uranium deposit, averaging 0.15 percent U_3O_8 or less. About 1.5 miles west of Torrey, in the Capitol Reef area, a small bedded uranium deposit occurs in association with a seam of carbonaceous or asphaltic material, 1-inch thick, about 400 feet below the top of the Moenkopi. Here the normally reddish brown Moenkopi is bleached white near the ore. Each of these small deposits is associated with asphaltic or carbonaceous material, and it is possible that the presence of this organic material makes the Moenkopi a favorable host rock for uranium in some places. Uranium ore in the top few feet of the Moenkopi, in deposits similar to those at the Rainy Day and Hope mines in the Circle Cliffs area, is so definitely related to a channel filled with Shinarump that this type of ore deposit is best considered as occurring in the Shinarump member of the Chinle rather than in the Moenkopi. Small copper and lead deposits occur in the Sinbad limestone member of the Moenkopi on Miners Mountain in the Capitol Reef area, but no uranium has been found in these deposits. The general absence of uranium on widespread outcrops of the Moenkopi throughout the Green River and Henry Mountains districts suggests that this formation has no appreciable potential for significant uranium deposits.

CHINLE FORMATION

Through 1955, about 24 percent of the total uranium ore production from the Green River and Henry Mountains districts came from the Chinle formation, and the Chinle is thought to contain about 22 percent of the total indicated and inferred reserves estimated for the two districts. In terms of potential resources the Chinle may be more important than any of the other ore-bearing formations in the two districts.

MOTTLED SILTSTONE BEDS

Mottled siltstone beds, occurring intermittently at the base of the Chinle formation, are not uranium bearing in the Circle Cliffs area (Davidson, 1954, p. 37). But, in the southern part of the Green River district and in the area between the Green and Colorado Rivers these beds contain minor amounts of uranium in red chert layers near the top of the unit. Uraninite(?), pyrite, chalcopyrite, chalcocite, covellite, galena, sphalerite, tetrahedrite(?) or tennantite(?), calcite, and yellow secondary uranium minerals have been identified in this radioactive red chert (Charles C. Hawley, oral communication, March 1956). In the area between the Green and Colorado Rivers, mottled siltstone beds commonly contain disseminated secondary uranium and copper minerals in the upper few feet of the unit, also. These minerals probably have been formed from uranium and copper leached from the overlying ore-bearing member of the Chinle. Possibly the lack of carbonaceous material in the mottled siltstone beds is responsible for the poor showing of this unit as a host for uranium ores. At any rate, the lack of significant uranium deposits throughout the fairly extensive outcrops of the mottled siltstone beds in the Green River and Henry Mountains districts strongly suggests that this unit has little potential for uranium ores.

SHINARUMP MEMBER

The Shinarump member of the Chinle formation is the principal uranium-bearing unit in the Circle Cliffs and Capitol Reef areas of the Henry Mountains district and is potentially ore-bearing at depth elsewhere in the district (pl. 6).

In the Circle Cliffs area, significant uranium deposits in the Shinarump member are limited to channels and commonly occur only on channel flanks. The preferred host rock for ore is a siltstone cobble conglomerate composed of fragments of siltstone from the Moenkopi in a matrix of typical sandstone of the Shinarump, or the top 2 to 3 feet of the Moenkopi formation in what appears to be a slumped or fractured zone at the breakoff point on the channel bank. The siltstone cobble conglomerate occurs principally in remnant patches on the channel flanks. Possibly the cobbles were swept away by fast currents in the central parts of the channels or were originally deposited only near caving channel banks. The ore in the Moenkopi on the channel banks may be controlled by a local fracture zone related to slumping on the bank of the ancient stream or to differential compaction between the channel-fill and nonchannel sediments.

The relatively small size and the sparseness of known ore deposits in the Circle Cliffs area may be due in part to the lack of favorable host rock in the Shinarump. Most of the sands of the Shinarump that fill channels are relatively free from mud and carbonaceous material. Ore-bearing solutions moving laterally through these passageways probably passed through, for the most part, without loss of uranium. In the few places where ore deposits do occur, it may be because the uranium-bearing solutions penetrated remnant patches of the favorable siltstone cobble conglomerate or seeped out into and reacted with siltstone of the Moenkopi formation in the fracture zone along the channel bank. At any rate, the occurrence of ore deposits larger than 10,000 tons in size does not seem likely; and the association of the ore with channel flanks results in ore bodies that may be hundreds of feet long but that have an average width of less than 30 feet. Exploration for ore bodies of this type may best be carried on by drifting along the channel bank in areas where depth of cover prohibits close-spaced drilling. Of the many large channels filled with Shinarump in the Circle Cliffs area, only a few have been well explored in the narrow favorable zone along the channel flank.

Uranium deposits in the Capitol Reef area of the Henry Mountains district are similar to those of the Circle Cliffs in that they also are commonly localized along the flanks of channels filled with Shinarump. Through March 1956, however, no deposits larger than a few hundred tons in size had been found. West of the Oyler mine in the Capitol Reef area (pl. 6) the Shinarump member is a thick, continuous sandstone unit of uniform lithology and is considered relatively unfavorable for significant uranium deposits. East of the Oyler mine, the Shinarump is thin and discontinuous and is thought to be relatively favorable for uranium deposits along the flanks of channels. Possibly the thin discontinuous Shinarump east of the Oyler mine is related to the regional pinchout of the Shinarump member a few miles to the northeast of the Capitol Reef area.

The apparent tendency for ore deposits in the Shinarump member on the Colorado Plateau to be grouped within a few miles of the regional pinchout of the member, and the theoretical favorableness of the less continuous Shinarump near the pinchout suggest that there is a belt of relatively favorable ground, 10- to 20-miles wide, roughly paralleling the northwesterward-trending regional pinchout of the Shinarump across the Henry Mountains district (pl. 6). Uranium deposits as large as 100,000 tons in size may be present in this belt, but exploration for these ore deposits may be discouraged by their depth of burial (greater than 1,000 feet).

MONITOR BUTTE MEMBER

The Monitor Butte member of the Chinle formation contains several small uranium deposits in the Poison Springs, Happy Canyon, and Hatch Canyon areas about 15 miles north of the junction of the Dirty Devil and Colorado Rivers. These deposits are in sandstone units which fill channels cut in the surface of the Moenkopi. As of March 1956, the ore deposits known in the Monitor Butte member in the Green River and Henry Mountains districts were too small and of too low grade to be of appreciable importance. Possibly the sandstone lenses of the Monitor Butte were too small and discontinuous to have allowed the free passage of large amounts of uranium-bearing solutions through the otherwise relatively impermeable mudstones of the member. However, the large ore deposit at the Delta mine in the San Rafael Swell is in a sandstone lens of the Monitor Butte member; and it is possible that similar thicker than average (30 feet or more thick) sandstone lenses may be present in the Monitor Butte and may contain significant uranium deposits in the Henry Mountains and Green River districts south and southeast of the Delta mine. Also, the apparent grouping of the few known ore deposits in the Monitor Butte in relation to the regional pinch out of the member suggests that a belt with a maximum width of 25 miles and parallel to the regional pinch out may be relatively favorable for uranium deposits (pl. 6). Even if this is so, deposits larger than a few hundred tons in size do not seem likely except where relatively thick sandstone lenses, similar in thickness to the one at the Delta mine, may occur. Depth of burial (greater than 1,000 feet) of the Monitor Butte member throughout much of this postulated relatively favorable belt may hamper exploration for such ore deposits as may be present.

MOSS BACK MEMBER AND BASAL BEDS OF THE CHINLE FORMATION

The Moss Back member of the Chinle formation commonly contains traces or small amounts of uranium and (or) copper near its base wherever the unit is exposed in the Green River and Henry

Mountains districts. Significant ore deposits, however, are essentially limited to areas where the Moss Back is variable in thickness and lithologic character. Continuous beds of Moss Back of uniform thickness and composition are apparently unfavorable for uranium deposits of any appreciable size.

Where the Moss Back member crops out in the eastern part of the Henry Mountains district and the southern half of the Green River district, it is predominantly blanketlike and contains only a few occurrences of weakly mineralized uranium-bearing rock. The sparseness and small size of known ore deposits and the blanketlike character of the Moss Back in this area indicate that it is relatively unfavorable for significant uranium deposits.

In the San Rafael Swell, just west of the Green River district, the Moss Back member contains several significant uranium deposits. Especially important is the large cluster of ore bodies in the vicinity of Temple Mountain. Previous work by the author in the San Rafael Swell (Johnson, 1957) indicates that the Moss Back is blanketlike and relatively unfavorable for uranium deposits northeast of Temple Mountain; the Temple Mountain deposits (totaling over 100,000 tons in size) are clustered in and probably controlled by a broad, shallow northwestward-trending channel or channel-system; and the Moss Back southwest of Temple Mountain is generally favorable for uranium deposits as large as 10,000 tons or so in size wherever there are channels cut sharply into the underlying Monitor Butte member or Moenkopi formation.

Extrapolation from the San Rafael Swell into the western edge of the Green River district suggests that there may be a southeastern extension of the Temple Mountain channel system in which clusters of significant uranium deposits are likely to occur (fig. 4). Potential resources in this favorable belt may be large enough to justify exploration of this ground in spite of the 1,500 foot or so depth to the ore horizon. Even though the ground may be relatively favorable in the Green River district southwest of the channel system at Temple Mountain, exploration for uranium deposits will be hampered by the smaller size of ore bodies, the lack of knowledge regarding extensions of favorable ground, and the 1,500 feet or so of depth to the ore horizon.

In the area between the Green and Colorado Rivers the Moss Back member is relatively discontinuous and contains significant uranium deposits in a northwestward-trending belt that is about 9 miles wide and parallels the regional pinchout of the member (pl. 6). The southwestern boundary of this relatively favorable belt is a rather sharp line between the continuous Moss Back member to the southwest and the discontinuous Moss Back to the northeast. The northeastern boundary of the belt coincides with the regional pinchout of the member. This line of pinchout is approximately coexistent with the crest of the Cane Creek anticline, and it appears as though streams that deposited the Moss Back may have been unable to flow over the rising structure. Uranium deposits in the Moss Back member in this relatively favorable belt are limited to channel-fill sediments. These sediments may fill channels cut in the surface of the Moenkopi as in the channel in which the "C" group claims are located (pl. 6) or they may have been deposited by aggrading streams that followed the course of pre-Moss Back streams as in the channel where the "A" group claims are located. The size of uranium deposits in this relatively favorable belt may be expected to range from 100 to 1,000 tons with occasional deposits in the 1,000- to 10,000-ton size range. Depths of 1,000 feet and more to the ore horizon may discourage exploration in the relatively favorable belt except where the Green and Colorado Rivers and their tributaries have removed most of the overlying rocks.

Northeast of the regional pinchout of the Moss Back member in the area between the Green and Colorado Rivers, several small, scattered uranium deposits are known along the outcrop of the basal beds of the Chinle formation between the Cane Creek and Moab anticlines (pl. 9). The lack of channel-fill sandstone units in this area suggests the sparseness and small size of the deposits may be due to the absence of favorable sandstone host rocks and aquifers that could have acted as passageways for the laterally moving ore solutions.

In the Seven Mile area in the easternmost part of the Green River district, small uranium deposits occur in mudstone, limy siltstone, and lime pebble conglomerate beds in the lower part of the Chinle formation where this unit is exposed high on the southwest flank of the Moab anticline. Ore deposits are in the form of small pods of uraninite and minor amounts of copper sulfides scattered through otherwise barren rock. The absence of large well-defined ore bodies may be due to the lack of sandstone host rocks and good aquifers in the Chinle at this point.

Because there is evidence that the Moab anticline was rising just prior to deposition of the Chinle formation and rose again after Chinle time, there is reason to think it may have been slowly rising during deposition of the Chinle. It seems likely that drainage during Chinle time was influenced by the rising structure and that there may be a concentration of sandy stream deposits paralleling the axis of the anticline somewhere on the southwest flank of the structure. These sandy sediments could provide more favorable host rocks for large uranium deposits than the mudstone, siltstone, and lime pebble conglomerate beds higher on the anticline. Uranium deposits larger than 100,000 tons in size may be present in the postulated sandy belt, and potential resources may be large. As of March 1956, the concept of a favorable belt on the southwest flank of the Moab anticline had not been thoroughly tested.

PETRIFIED FOREST, OWL ROCK, AND CHURCH ROCK MEMBERS

The mudstone, siltstone, and fine-grained sandstone beds of the Petrified Forest, Owl Rock, and Church Rock members of the Chinle formation contain only a few small uranium deposits in the Green River and Henry Mountains districts (pl. 6). A 15-foot lens of sandstone and limestone pebble conglomerate, 150 to 200 feet above the base of the Chinle, is weakly mineralized in the western part of the Circle Cliffs area. Anomalous radioactivity of about 10 times normal background occurs in the Chinle formation in Long Canyon, 15 miles east of Boulder, Utah, and is found only in purplish chert-pebble conglomerate and crossbedded sandstone, 150 feet below the top of the Chinle. In the area between the Green and Colorado Rivers several small vanadium-uranium deposits occur in the so-called Black Ledge unit of the Church Rock member. The deposits are apparently controlled in detail by the junction of cross-bedding in the sandstone. The small size and sparseness of uranium deposits on widespread outcrops and the lack of favorable carbonaceous sandstone host rocks and good aquifers (to serve as passageways for ore-bearing solutions) indicate that potential ore resources are very small in the upper part of the Chinle formation in the Green River and Henry Mountains districts.

WINGATE, KAYENTA, AND NAVAJO FORMATIONS

The Wingate, Kayenta, and Navajo formations are primarily clean massive sandstone beds and are not known to contain uranium deposits in the Green River and Henry Mountains districts. The absence of favorable host rocks (channel-fill units containing interfingering mudstone and sandstone and carbonaceous material) and the lack of mineralized rock on extensive outcrops indicate that these formations contain little or no potential uranium resources.

CARMEL FORMATION

The Carmel formation is weakly mineralized at several places in the Green River district. Minor amounts of uranium occur with copper along a fault separating the Carmel and Entrada formations in sec. 24, T. 24 S., R. 13 E., Salt Lake meridian. In the Saucer Basin area, 22 miles south of the town of Green River (pl. 7), small irregular pods of vanadium-uranium ore occur sparsely scattered through a 15-foot zone of gray limy siltstone about 25 feet below the top of the Carmel formation. The reddish-brown Carmel is altered to greenish-gray or white in the vicinity of the mineralized rock. The small size and sparseness of uranium-bearing outcrops and the lack of favorable carbonaceous sandstone host rocks in the Carmel formation indicate that it has little or no potential uranium resources in the Green River and Henry Mountains districts.

ENTRADA SANDSTONE

The Entrada sandstone contains no known bedded uranium deposits in the Green River and Henry Mountains districts, but minor amounts of uranium do occur with copper in a northwestward-trending fracture zone about 4 miles east of the town of Hanksville. Silver and gold are also reported from this ore deposit (Swanson, 1951, written communication). If the uranium in this fracture-controlled ore deposit was deposited by ascending solutions the uranium content could possibly increase with depth. Exploration below the surface workings might also provide further information regarding the origin of the uranium in this deposit. The general lack of uranium-bearing rock in outcrops and the absence of favorable carbonaceous host rocks strongly suggest that the Entrada contains little or no potential uranium ore resources in the Green River and Henry Mountains districts.

CURTIS FORMATION

The Curtis formation contains no known significant uranium deposits in the Green River and Henry Mountains districts, but in the area northeast of the Capitol Reef scattered carbonized wood fragments in this unit are weakly radioactive and contain secondary copper minerals. The lack of favorable carbonaceous sandstone host rocks and the absence of ore deposits on the widespread outcrop of the Curtis formation indicate that this unit contains no appreciable potential uranium resources in the Green River and Henry Mountains districts.

SUMMERVILLE FORMATION

No significant uranium deposits are known in the Summerville formation in the Green River and Henry Mountains districts though a weak radioactive anomaly is present in the Summerville on the east side of Hall Mesa about 10 miles south of Shootaring Point in the southern part of the Henry Mountains district. The absence of ore deposits in the extensive outcrop and the lack of favorable carbonaceous sandstone host rocks in the Summerville indicate that it contains no potential uranium resources in the Green River and Henry Mountains districts.

MORRISON FORMATION

Through 1955, about 76 percent of the total production of uranium ore from the combined Green River and Henry Mountains districts came from the Salt Wash member of the Morrison formation, and this unit is thought to contain about 78 percent of the indicated and inferred reserves of the two districts. Because the Morrison formation is the most important ore-bearing formation in the two districts to date, it is discussed in some detail below.

SALT WASH MEMBER

The Salt Wash member in the northern part of the Green River district is within the sandstone-mudstone facies of the fan formed by the Salt Wash (pl. 6) and, therefore, is at least partly favorable for vanadium-uranium deposits. The important ore deposits, however, are clustered in certain northward-trending favorable belts, which are thought to be controlled by trunk channel systems. Between the Green River and the district's eastern margin the Salt Wash is characterized by thin (usually less than 40 feet thick) blanketlike sandstone beds and the absence of significant ore deposits. West of the Green River the Salt Wash member becomes thicker, and sandstone lenses in it increase in thickness and in uranium content until a maximum favorability for significant vanadium-uranium deposits is reached in two northward-trending belts or channel systems in Tps. 21, 22, and 23 S., and R. 14 E., Salt Lake meridian (pl. 7). Within these favorable channel systems, the ore-bearing sandstone lenses in the upper part of the Salt Wash commonly are 40 feet and more thick and there is a clustering of ore deposits. These ore deposits may be as large as about 20,000 tons and have an average grade of about 0.50 percent V_2O_5 and 0.25 to 0.30 percent U_3O_8. Outside the favorable channel systems, sandstone lenses in the ore-bearing part of the Salt Wash are commonly less than 40 feet thick and ore deposits are rarely over 100 tons in size. Extensions of these two favorable channel systems to the north under Mancos shale cover may contain fairly large potential ore reserves; but the thin spotty nature of the ore bodies, the tendency for the ore to occur on different horizons throughout a vertical range of 50 feet or more in the ore-bearing unit, and the 500 to 1,500 feet of depth of burial of the ore-bearing unit may hamper exploration and mining.

West of the two favorable belts mentioned above, the Salt Wash member contains thin blanketlike sandstone beds, and there are no significant ore deposits.

On Little and Big Flattop in the central part of the Green River district the upper ore-bearing part of the Salt Wash member has been removed by erosion. The remaining sandstone beds of the Salt Wash are thin and blanketlike and do not contain significant ore deposits.

In the Henry Mountains district and the westernmost part of the Green River district the Salt Wash crops out in a continuous band around the Henry Mountains structural basin. The northern half of this outcrop is characterized by thin (rarely over 40 feet thick) sandstone beds that contains no vanadium-uranium deposits larger than about 100 tons in size. The thin sandstone beds are relatively free of carbonaceous material and mudstone and, consequently, do not appear to be good host rocks for significant ore deposits.

Along the western edge of the Henry Mountains structural basin the Salt Wash member changes rather abruptly from a unit, 200 feet thick, containing thin clean sandstone beds in the north to thick massive blanketlike sandstone beds, totaling 400 to 500 feet in thickness to the south. Only a few small ore deposits are known along this lengthy outcrop and these are north of the rather abrupt change to thick massive sandstone. The sparseness and small size of ore deposits on the outcrop and the lack of thick lenticular sandstone strongly suggest that the Salt Wash is unfavorable for significant uranium deposits on the western edge of the Henry Mountains structural basin.

The southernmost quarter of the outcrop of the Salt Wash member in the Henry Mountains district is characterized by thick massive sandstone beds of the conglomeratic sandstone facies of the fan formed by the Salt Wash (pl. 8). These rocks contain only sparse amounts of interbedded mudstone and carbonaceous material, and no uranium deposits larger than a few tons in size were found.

Practically all the significant uranium deposits in the Salt Wash member in the Henry Mountains district are in the eastern edge of the Henry Mountains structural basin and are in the transition zone from thick massive sandstone beds in the south to thin beds of clean sandstone north of North Wash (pl. 7). Clusters of small podlike ore bodies containing a few tons each are the common occurrence in the thick massive sandstone of the Shootaring Creek and Delmont areas. Production from these deposits has come from small-scale highly selective mining operations. Farther north in the Woodruff Spring area, sandstone beds are less massive and blanketlike, and contain ore bodies as large as 100 tons or so in size. In the Trachyte Creek area, thick lenticular sandstone contains thin podlike ore bodies clustered into deposits aggregating from 1,000 to 5,000 tons; and crossbedding, stream lineation, and the orientation of fossil logs indicate that the most favorable ground is in a narrow channel system trending about N. 60° W. through Farmers Knob (fig. 5). The northwestward extension of this channel system may contain potential ore resources equal to production through 1955 from the Trachyte Creek area, or possibly several times this figure. In the North Wash area north of Trachyte Creek there are many small ore deposits that are commonly less than 100 tons in size. Apparently the rather clean blanketlike sandstone beds are not favorable for larger ore deposits.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin shale member of the Morrison formation contains no known uranium ore deposits by present economic standards. It may, however, have fairly large potential resources of very low grade uranium-bearing rock in the northern part of the Green River district.

In T. 22 S., R. 14 E., Salt Lake meridian, a 1-foot carbonaceous siltstone layer about midway in the Brushy Basin member is uranium bearing for about 3,000 feet of outcrop. The uranium appears to be rather evenly disseminated through the carbonaceous siltstone layer. The average grade of the rock is estimated to be about 0.02 percent U_3O_8; but small areas may average 0.05 to 0.10 percent U_3O_8, and select specimens assay as high as 0.30 percent U_3O_8. Traces to minor amounts of molybdenum and rare earths accompany the uranium. Barite seams and blebs are also common in the rock. Weathered specimens of the siltstone contain about 30 percent more uranium than is indicated by the radioactivity of the rock; possibly radioactive daughter products have been selectively leached near the outcrop. The relatively even distribution of uranium through the carbonaceous siltstone suggests a possible syngenetic origin for the uranium deposit, and the presence of similar uranium-bearing carbonaceous shale and siltstone near Vernal, Utah, encourages speculation that large bodies of uraniferous carbonaceous shale and siltstone may exist in the Brushy Basin member in the Uinta Basin.

Minor uranium deposits are also known in association with dinosaur bones in carbonaceous mudstone in the Brushy Basin a few miles south-southeast of Green River, Utah.

DAKOTA SANDSTONE

The lack of uranium deposits on the extensive outcrop of the Dakota sandstone in the Green River and Henry Mountains districts indicates that this unit contains no appreciable potential ore resources although it may include weakly uraniferous carbonaceous shale.

MANCOS SHALE

The extensive dark-gray marine shale beds of the Mancos are not known to be uranium bearing in the Green River and Henry Mountains districts and, because of their relative impermeability and uniform lithologic character, are not thought to be favorable for uranium deposits. The Ferron and Emery sandstone members, however, do contain minor uranium occurrences such as the one in the Ferron sandstone member on the south side of Mount Hillers in the Henry Mountains district (pl. 7). This deposit is reported by W. D. Grundy (written communication, 1954) to consist of uranium (grade = 0.02 percent U_3O_8) associated with hematite(?) in a 2-foot layer of carbonized wood and sandstone at the top of the Ferron sandstone member along about 1,500 feet of outcrop. Similar minor uranium occurrences may be expected elsewhere in the Ferron and Emery sandstone members, but because of the relatively clean blanketlike character of these sandstone units they are not thought favorable for significant uranium deposits.

MESAVERDE FORMATION

The Mesaverde formation is not known to contain significant uranium deposits in the Green River and Henry Mountains districts although there may be minor occurrences, similar to those in the Ferron sandstone member of the Mancos shale, in carbonaceous shale layers. The lack of uranium-bearing rock on the outcrop and the relatively clean, blanketlike character of the Mesaverde indicate that it is unfavorable for significant ore deposits, and has no appreciable potential resources of uranium ore.

WASATCH(?) FORMATION

Minor amounts of carnotite staining on joint surfaces in claystone are known in the Wasatch(?) about 2 miles north of Loa, Utah, just west of the Henry Mountains district. The lack of good exposures of this formation has precluded thorough prospecting for uranium and also makes it difficult to judge the ore potential of the unit. The sparseness and small size of known ore deposits on the outcrop and the lack of lenticular sandstone containing carbonaceous material suggest that this unit has little or no potential resources.

CONCLUSIONS

The Chinle formation of Triassic age and the Morrison formation of Jurassic age are the two important uranium-bearing formations in the Green River and Henry Mountains districts.

Through 1955 the Chinle formation was the source of 24 percent of the uranium ore mined in the two districts. About 22 percent of the districts' indicated and inferred reserves is thought to be in this formation. Primary sedimentary features, especially channels, and the relative discontinuity of beds near regional pinchouts, are thought to be the principal ore controls; significant uranium deposits are more likely to be found in the following places:

1. In the Shinarump member on the flanks of channels in the Circle Cliffs and Capitol Reef areas and in a belt 10 to 20 miles wide of relatively favorable ground, related to and paralleling the northwestward-trending line of regional pinchout of the member in the Henry Mountains district (pl. 6).

2. In the Monitor Butte member in sandstone lenses having a thickness of 30 feet and more in a belt 25 miles wide of relatively favorable ground, parallel to and bounded by the northeastern line of pinchout of the member (pl. 6).

3. In the Moss Back member along the inferred southeastern extension of the Temple Mountain channel system and in a belt of relatively favorable ground, 10-miles wide, bounded by and paralleling the northeastern pinchout of the member in the area between the Green and Colorado Rivers (pl. 6).

4. In an inferred narrow belt of coarser grained rocks in the basal Chinle on the southwest flank of the Moab anticline (pl. 6).

Through 1955, the Salt Wash member of the Morrison formation was the source of 76 percent of uranium ore mined in the Green River and Henry Mountains districts, and about 78 percent of the total indicated and inferred reserves for the two districts is thought to be contained in this unit. Ore deposits as large as 20,000 tons have been found. Primary sedimentary features, especially trunk channel systems and thicker-than-average sandstone lenses, are thought to be the principal ore controls; and significant uranium deposits are thought more likely to be found along the northerly extensions of two favorable belts or channel systems in Tps. 21, 22, and 23 S., R. 14 E., Salt Lake meridian, in the Green River district (fig. 5) and along the northwestward extension of a narrow favorable belt or channel system trending about N. 60° W. through Farmers Knob in T. 32 S., R. 11 E., Salt Lake meridian in the Henry Mountains district (pl. 7).

The Brushy Basin member of the Morrison formation contains fairly large amounts of very low grade uranium-bearing carbonaceous siltstone (averaging about 0.02 percent U_3O_8) in T. 22 S., R. 14 E., Salt Lake meridian, in the Green River district. Similar uraniferous siltstone and shale are known in the Brushy Basin near Vernal, Utah, and the Brushy Basin may contain appreciable potential resources of this type of uranium deposit in the northern Green River district and Uinta Basin.

Potential ore resources of the Green River and Henry Mountains districts are thought to be many times the combined production and indicated and inferred reserves, but depths of 1,000 feet or more to the ore-bearing unit in many of the more favorable areas may hamper exploration for these ore deposits.

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