Geology and Mineralogy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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

By

Henry S. Johnson, Jr.

August 1957

Trace Elements Investigations Report 554

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

USGS - TEI-554

GEOLOGY AND MINERALOGY

Distribution	No. of copies
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Austin.	1
Division of Raw Materials, Casper.	1
Division of Raw Materials, Denver.	1
[illegible]	[illegible]
Division of Raw Materials, Rapid City.	1
Division of Raw Materials, Salt Lake City.	1
Division of Raw Materials, Spokane	1
Division of Raw Materials, Washington.	3
Exploration Division, Grand Junction Operations Office	6
Grand Junction Operations Office	1
Technical Information Service Extension, Oak Ridge	6
U. S. Geological Survey:	
Foreign Geology Branch, Washington	1
Fuels Branch, Washington	1
Geochemistry and Petrology Branch, Washington.	1
Geophysics Branch, Washington.	1
Mineral Classification Branch, Washington.	1
Mineral Deposits Branch, Washington.	2
P. C. Bateman, Menlo Park.	1
A. L. Brokaw, Grand Junction	2
N. M. Denson, Denver	1
R. L. Griggs, Albuquerque.	1
W. R. Keefer, Laramie.	1
E. M. MacKevett, Menlo Park.	1
L. R. Page, Washington	1
P. K. Sims, Denver	1
Q. D. Singewald, Beltsville.	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver.	2
TEPCO, RPS, Washington, (including master)	2
	45

CONTENTS

Page

Page

ILLUSTRATIONS

TABLE

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.

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 reserves. 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 two districts' indicated plus inferred reserves is thought to be in the Chinle formation and about 78 percent in the Morrison formation.

Potential reserves for the Green River and Henry Mountains districts are thought to be many times the combined production and indicated plus inferred reserves. Primary sedimentary features such as regional pinchouts, trunk channel systems, individual channels,

and thicker-than-average sandstone lenses are thought to be the principal ore controls; and 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 10- to 20-mile wide belt of relatively favorable ground related to and paralleling the northwesterly 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 25-mile wide belt of relatively favorable ground 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 10-mile wide belt of relatively favorable ground 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 northerly 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 northwesterly extension of a narrow favorable belt or channel system trending about N. 60° W. through Farmer's Knob in T. 32 S., R. 11 E., (Salt Lake meridian) in the Henry Mountains district.

The Brushy Basin 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 reserves of this rock averaging about 0.02 percent U_3O_8 in the Green River district and in the Uinta Basin.

INTRODUCTION

Purpose of report

This report presents the preliminary results of geologic reconnaissance and office compilation leading to 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. 1). 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 controls of favorable ground are also discussed.

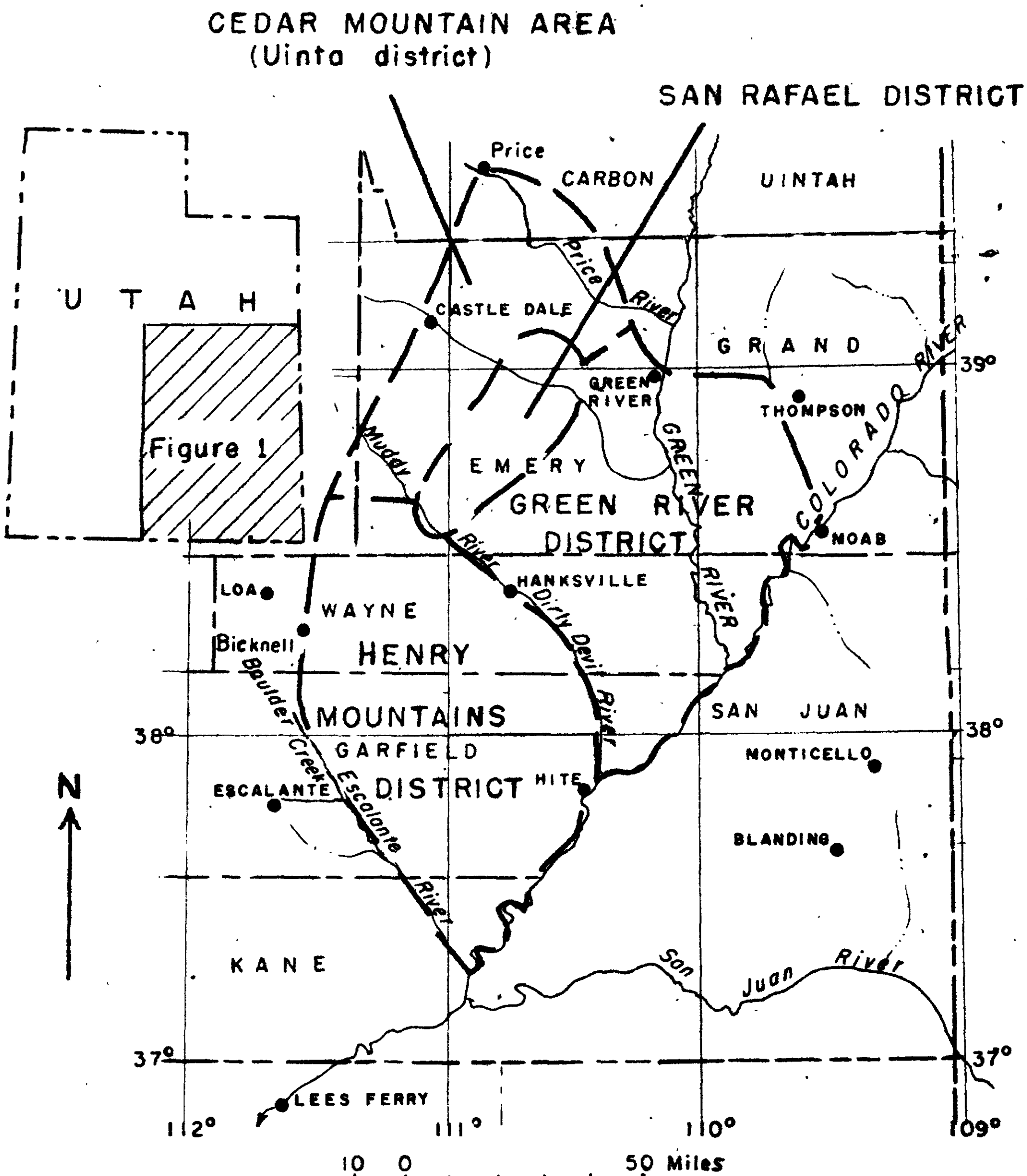

FIGURE 1.--INDEX MAP OF PART OF UTAH SHOWING LOCATION OF GREEN RIVER AND HENRY MOUNTAINS DISTRICTS AND ADJACENT DISTRICTS.

Field work was carried on 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 Plateau . 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 reef 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 River and Boulder Creek, on the west by a line from the headwaters of Boulder Creek through Bicknell to Utah Highway 72, and on the north by Utah Highway 72 and an east-west line between Highway 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 Plateau 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. 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 pinyon 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 production records maintained by the Grand Junction Operations Office of the U. S. Atomic Energy Commission, reserve estimates 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 numerous published reports and in U. S. Atomic Energy Commission and U. S. Geological Survey files.

Field work consisted of reconnaissance visits to 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; ore potential in the immediate deposit area; and the desirability of further exploration in the area of the deposit.

Office work consisted chiefly of compilation and synthesis of available data in an attempt to appraise the uranium ore potential of the Green River and Henry Mountains districts.

HISTORY OF THE 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) carried out his classic studies of the Henry Mountains. During the period from 1915 through 1923, Gregory and Moore (1931) carried on intermittent geologic investigations in the western parts of the Henry Mountains district. In the summers of 1926 and 1927, McKnight conducted 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 earlier work.

Deposits of uranium and vanadium ores were reported by Boutwell (1905) as being prospected and mined on a small scale in part of the Green River district in 1904. 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 were 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 have 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 and others (1920), in the course of his 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 uranium and vanadium as disseminations in fluvial sandstone and as replacements or cavity fillings in carbonized plant remains.

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 Colorado Plateau uranium resources. As a result of this study, several detailed file 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 reserves were estimated in any formation 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 (table 1). Except for thick sequences of evaporites, 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. Over most of the two districts the rocks are nearly flat lying or have gentle regional dips. In a few places asymmetrical anticlinal folds, sharp monoclines, or the forcible intrusion of salt or igneous rocks cause dips up to 90°. A few small normal faults cut the rocks in the two districts. Igneous rocks form a few 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 which do not contain ore.

Hermosa formation

The Hermosa formation of Pennsylvanian age is the oldest stratigraphic unit that crops out in the area covered by this report. It is exposed only in a narrow strip along the easternmost edge of the Green River district in the vicinity of Moab, Utah, and in the bottom of the Colorado and Green River Canyons 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 drilled in the eastern part of the Green River district have penetrated 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 oil well gamma-ray logs suggest that some of the black shales of the Paradox member are 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 are 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 bands of interbedded red beds. Within a few miles northeastward the red beds become predominant and the whole Cutler sequence 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). In the Circle Cliffs, Steed (1954) and Davidson (1956) have suggested that this unit may be more correctly correlated with the White Rim 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

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 covered by 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 cut out by erosion prior to Chinle deposition (McKnight, 1940, p. 62).

The Moenkopi is dominantly a red bed series of sandstone, siltstone, and mudstone and locally contains lenses of white to buff sandstone. In parts of the Circle Cliffs and San Rafael Swell and along the Green and Colorado River Canyons, however, there are large areas where the Moenkopi is greenish gray or buff rather than the typical red-brown color (McKnight, 1940, p. 54-55; Baker, 1946, p. 55). In some places the boundary between gray and red Moenkopi is very abrupt and crosses 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

Unconformably overlying the Moenkopi formation is the Chinle formation of Late Triassic age. This formation 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 lithology, stratigraphic position, and probably origin to the unit named Temple Mountain member of the Chinle formation by Robeck (1956) in the San Rafael Swell, Utah. In this 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 are present 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 occur 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 in part 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 "mottled siltstone beds" in the Green River and Henry Mountains districts. At many places "mottled siltstone beds" contain red chert in the upper few feet of the unit. This chert is in discontinuous layers up to 10 inches thick and commonly is weakly radioactive.

"Mottled siltstone beds" are frequently characterized by a mottled purple, red, yellow, brown, and white appearance that has been locally termed the "purple-white" (Finch, 1953) and which 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.

Where present 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 (e.g. 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" and commonly 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 (fig. 4). Near this regional pinchout the Shinarump becomes thin and discontinuous 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) is present throughout the Henry Mountains district and in the southern part of the Green River district (Stewart and others, written communication). 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 bentonitic mudstone or clayey sandstone that is chiefly greenish gray and reddish brown. The member locally contains lenses of fine- to coarse-grained grayish-white sandstone similar lithologically to sandstones of the Shinarump member. The unit ranges from a thickness of about 200 feet in the southern part of the Henry Mountains district to a wedge edge along a northwesterly trending line in the southern part of the Green River district (fig. 4). The Monitor Butte is uranium bearing but has not been found to contain large ore deposits in the Green River and Henry Mountains districts to date.

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 "mottled siltstone beds." In the area between the Green and Colorado Rivers the Moss Back wedges out along a northwesterly trending line (fig. 4) 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 attain thicknesses of as much as 150 feet where it fills channels cut into the underlying unit (Stewart and others, written communication). Over large areas the Moss Back is a thick, blanketlike cliff-forming unit of relatively uniform lithology. Near its line of pinchout 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 locally absent. Probably these areas were relatively high during deposition of the Moss Back and caused diversion of streams which deposited the Moss Back (Stewart and others, written communication). The Moss Back contains significant uranium deposits in the San Rafael Swell and near the line of pinchout of the member in the northeastern part of the Green River district (fig. 4).

Petrified Forest member.--Stewart and others, (written communication) 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 or Henry Mountains districts.

Owl Rock member.--The Owl Rock member of the Chinle formation (I. J. Witkind and R. E. Thaden, written communication) is present 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, written communication). Typically the Owl Rock is composed principally of reddish-brown structureless siltstone and thin interbedded limestones. 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) is present at the top of 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, written communication). 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. The unit is a thick blanketlike deposit of very uniform lithology that averages about 300 feet thick over most of southeastern Utah and characteristically forms a shear cliff on weathering. No uranium deposits are known in the Wingate in the Green River and Henry Mountains districts.

Kayenta formation

The Kayenta formation of Jurassic(?) age overlies the Wingate sandstone throughout the Green River and Henry Mountains districts except where removed by erosion. The Kayenta is principally composed of reddish fine-grained sandstone, shaly sandstone, and minor 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 is present everywhere in the Green River and Henry Mountains districts except where removed by erosion. The Navajo is principally composed of buff to light-gray massive crossbedded sandstone and is a blanketlike 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

Overlying the Navajo sandstone is the Carmel formation of Middle and Late Jurassic age. 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 the Carmel 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 is a thick blanketlike deposit of 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 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 uranium occurrences are known in the Curtis in the Green River and Henry Mountains districts.

Summerville formation

Conformably overlying the Curtis formation is the Summerville formation of Late Jurassic age. 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

Unconformably overlying the Summerville formation is the Morrison formation of Late Jurassic age. The Morrison, in the area covered by this report, may be divided in ascending order into the Salt Wash and Brushy Basin members and is present in the central and northwestern parts of the Henry Mountains district and in the northern part of the Green River district. The Morrison formation is one of the two principal uranium-bearing formations in southeastern Utah. Figure 5 shows the location of known ore deposits in the Morrison formation in the Green River and Henry Mountains districts.

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 sandstones and interbedded red and green mudstones. 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 (fig. 2). Near the apex of the fan the Salt Wash member is composed principally of thick blanketlike 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 up to 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 (fig. 2). 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 present in the member (fig. 5). The term trunk channel system is not meant to imply a well-defined river channel which maintained its position throughout deposition of the Salt Wash, rather it is intended to represent the trace of one or more large braided streams which 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 member.--The Brushy Basin member of the Morrison formation is principally composed of variegated green, gray, purple, and red bentonitic mudstone and minor 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 northwest part of the Green River district, Stokes (1952) has separated the upper third of the Brushy Basin member and named it the Cedar Mountain formation. For simplicity the Cedar Mountain formation of Stokes 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 Late Cretaceous age unconformably overlies the Brushy Basin member of the Morrison formation and crops out intermittently around the Henry Mountains and in the northern part of the Green River district. Where best developed it attains a maximum thickness of about 50 feet and is composed principally of yellowish-brown to gray conglomeratic sandstones. Locally, carbonaceous shale and thin coal beds are present. 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. 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. To the east it thins to a thickness of 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 sandstone, is present in the central part of the Henry Mountains district. The Emery sandstone is composed principally of gray massive to lenticular sandstone, shale, carbonaceous shale, and thin coal beds and is as much as 250 feet in thickness. 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 Mancos 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 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 blanket-like 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 Mountain districts.

Wasatch(?) formation

Other than Quaternary gravel deposits, the Wasatch(?) formation of Tertiary age is the only sedimentary rock unit younger than Late Cretaceous age 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 (fig. 5) in the extreme western part of the Henry Mountains district and are composed of pink and white limestones and tuffaceous shales, sandstones, and conglomerates

(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 anticlinal or domal structures related to the flowage of salt or the intrusion of igneous bodies (fig. 3). Faults are mainly high-angle normal faults and steep faults that bound grabens.

In the southern part of the Green River district, regional structure is controlled by the northerly plunging Monument upwarp. To the west the district is bounded by the steep eastern limb of the San Rafael Swell. Beds in the northern part of the district dip gently northward toward the Uinta Basin, and the eastern part of the district is characterized by local anticlines and synclines related to salt flowage (e.g. Cane Creek anticline and Moab anticline). Earliest movement on the salt structures 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

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TRACE ELEMENTS
INVESTIGATIONS REPORT 554

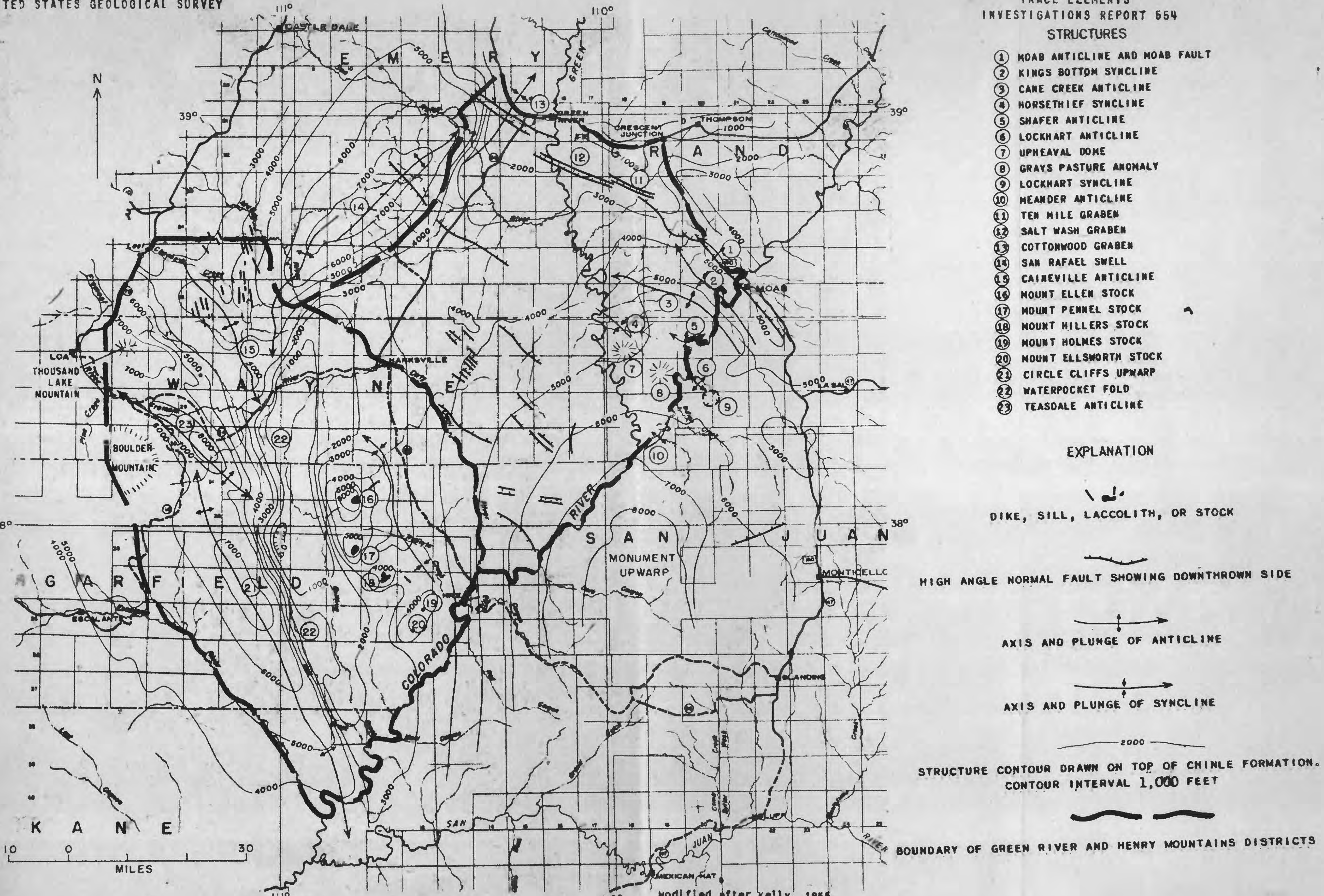

Figure 3.--TECTONIC MAP OF THE GREEN RIVER AND HENRY MOUNTAINS DISTRICTS, UTAH.

of these structures 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 northeasterly 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 canyon cutting 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 structure, about 8.5 miles southeast of the Grays Pasture anomaly. Although there seems to be no magnetic anomaly associated with Lockhard syncline (James W. Aubrey and Donald F. Plouff, oral communication, March 1956), one cannot help considering the possibility that it too may be related to igneous activity (possibly hydrothermal solution of underlying limestones or gaseous explosion and collapse) if the Grays Pasture anomaly and Upheaval Dome structure 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 monocline called the Waterpocket fold. 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 structurally higher than the trough of the Henry Mountains basin (Hunt, 1953, p. 88) but contain in their breached interiors 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 mainly normal faults of 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, faults rarely have displacements greater than a few hundred feet.

Igneous rocks

The stocks and laccolithic intrusives of the Henry Mountains constitute the principal igneous rocks of the Green River and Henry Mountains districts (fig. 3). These intrusives 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 and Boulder Mountains in the extreme western part of the Henry Mountains district.

The only igneous rock cropping out in the Green River district is a northwesterly 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 is a 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.

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. Figures 4 and 5 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 good general descriptions of these deposits. Uranium, usually accompanied by 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 from 1,000 to about 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 in size are known as of March 1956.

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, no vein-type or fracture-controlled uranium deposits are known in the Green River and Henry Mountains districts.

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. Traces of cobalt, nickel, molybdenum, and silver are present in these deposits.

Subore grade (contains < 0.10 percent U_3O_8) uranium-bearing carbonaceous siltstones of the Brushy Basin member of the Morrison formation in the northern part of the Green River district contain 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 lithofacies, trunk channel systems, stratigraphic pinchouts, individual channels, thick sandstone lenses, carbonaceous material, favorable host-rock lithology, and, in a few places, by local fractures. Tectonic structures 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 structures 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 (fig. 2). Uranium deposits occur principally in the intermediate sandstone and mudstone facies. Possibly the thick blanketlike beds of relatively clean sandstone 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, on the other hand, 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 while, at the same time, less permeable interbedded mudstones would tend to cause concentration of the solutions in the sandstones and might also trap the passing solutions where sandstone layers lens out into mudstones. 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 present. 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 ore control in the Salt Wash member of the Morrison formation (Coffin, 1921, p. 184; and Weir, 1952, p. 26).

Regional pinchouts of ore-bearing units seem to be a major control of 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 which 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 (i.e. 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 an almost unquestioned 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. This idea might be informally termed "the gutter theory."

Thicker-than-average sandstone lenses have long been noted as an apparent ore control in uranium deposits in sandstone of the Colorado Plateau (Coffin, 1921, p. 184; and Weir, 1952, p. 26). Probably the presence of thicker sandstone lenses is an important factor in the controls exerted by trunk channel systems and individual channels in the Green River and Henry Mountains districts. 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 minerals 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 confined to 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 which have formed and migrated short distances upon oxidation of the primary deposits. In the Circle Cliffs, however, unoxidized uranium deposits commonly are confined 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 in fracture zones or faults of minor displacement 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, in the Green River district. 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 lithofacies, trunk channel systems, stratigraphic pinchouts, individual channels or scours, thick sandstone lenses, carbonaceous material, and favorable host rock lithologies--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 useful, 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. Normally brown or reddish mudstone seams or lenses are usually altered gray-green in the vicinity of ore deposits. Ore-bearing units are commonly a bleached out light-gray to buff color 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 as yet not 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 owing to the forcible intrusion of the igneous rocks, are 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 are the major controls of ore deposits and favorable ground. If tectonic structures should be the major control, the uranium ore potential of the Green River and Henry Mountains districts may be considerably different from that suggested in this report.

Assuming, as is generally agreed, that the uranium-bearing solutions traveled for the most part laterally through the beds, blanket-like sandstones 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 sands would tend to cause concentration of the ore-bearing solutions in the thicker, more permeable parts of sandstone lenses. Interfingering sandstones and mudstones provide permeability traps, 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 sandstones 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 limestones of Mississippian age may possibly be favorable hosts for uranium deposits, especially if hypogene solutions should be the source of the ore. As of 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. Trace amounts of uranium are present, however, in what is thought to be Hermosa at the Big Chance claim about 2 miles west-northwest of Moab (fig. 4). Also, oil wells in the area between the Green and Colorado Rivers have penetrated weakly anomalous radioactivity in shales and limestones of the upper Hermosa and in black shales of the Paradox member. If the uranium deposits of the Colorado Plateau were formed from hypogene solutions, the limestones 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 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 is considered to have 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 1.00 percent copper and occur in the northeast corner of T. 28 S., R. 19 E., Salt Lake meridian, in the Green River district (fig. 4). These deposits 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 to the southwest to predominantly arkosic red beds to the northeast. Possibly the interfingering of the two different facies in this transition zone has formed a stratigraphic trap which slowed down or dammed laterally moving uranium-bearing solutions and promoted the precipitation of the ore minerals. At any rate the northwest-trending transition zone appears to be relatively favorable for low-grade uranium-copper deposits up to about 500 tons in size.

Coconino(?) sandstone

The Coconino(?) sandstone is not known to be ore-bearing in the Green River and Henry Mountains districts and consequently is thought to have little or no potential for significant uranium deposits there. Probably the massive clean sandstone of this unit does not provide permeability traps 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 are present in this unit on Miner's Mountain in the Capitol Reef area (fig. 4);

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 (fig. 4). At Fort Bottom about 4.5 miles west of Upheaval dome in the Green River district, a small bedded uranium deposit containing up to 0.74 percent U_3O_8 occurs in asphaltic sandstone about 200 feet below the contact of the Chinle and Moenkopi formations. In the Circle Cliffs area, a 1-foot thick 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 1-inch thick seam of carbonaceous or asphaltic material 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 Miner's Mountain in the Capitol Reef area, but no uranium has been found in these deposits. The general absence of uranium on widespread Moenkopi outcrops 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 reserves the Chinle may be more important than any of the other ore-bearing formations in the two districts. Accordingly, the uranium-bearing members of the Chinle are discussed in some detail below.

"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 do contain minor amounts of uranium in red chert layers near the top of the unit in the southern part of the Green River district and the area between the Green and Colorado Rivers. 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. 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 (fig. 4).

In the Circle Cliffs area, significant uranium deposits in the Shinarump member are confined to channels and commonly occur only on channel flanks. The preferred host rock for ore is 1) a siltstone cobble conglomerate composed of fragments of siltstone from the Moenkopi in a matrix of typical sandstone of the Shinarump, or 2) 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 in part due to the lack of favorable host rock in the Shinarump. Most of the sands of the Shinarump which fill channels are relatively clean. Mud and carbonaceous material are not abundant. 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 siltstones of the Moenkopi formation in the fracture zone along the channel bank. At any rate, the occurrence of ore deposits larger than about 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 which 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 closely 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 (fig. 4) the Shinarump member is a thick, blanketlike 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 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 blanketlike Shinarump near the pinchout suggest that there is a 10- to 20-mile wide belt of relatively favorable ground roughly paralleling the northwesterly trending regional pinchout of the Shinarump across the Henry Mountains district (fig. 4). Ore deposits that contain 100,000 or more tons of ore are probably 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 that 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 too low grade to be of appreciable importance. Possibly Monitor Butte sandstone lenses 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 pinchout of the member suggests that a belt up to 25 miles wide and parallel to the regional pinchout may be relatively favorable for uranium deposits (fig. 4). Even if this is so, deposits over a few hundred tons in size do not seem likely except where relatively thick continuous 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 throughout much of this postulated relatively favorable belt may hamper exploration for such ore deposits as may be present.

Moss Back member and basal Chinle beds

The Moss Back member of the Chinle formation commonly contains traces to small amounts of uranium and/or copper near its base wherever the unit is present in the Green River and Henry Mountains districts. Significant ore deposits, however, are known only in areas where the Moss Back is variable in thickness and lithology. Blanketlike Moss Back of uniform thickness and lithology is 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 (Johnson, 1957) in the San Rafael Swell indicates that 1) the Moss Back is blanketlike and relatively unfavorable northeast of Temple Mountain; 2) the Temple Mountain deposits (totaling over 100,000 tons in size) are clustered in and probably controlled by a broad, shallow northwesterly trending channel or channel-system; and 3) the Moss Back southwest of Temple Mountain is generally favorable for uranium deposits up to 10,000 to 20,000 tons or so in size wherever there are channels scouring sharply into the underlying Monitor Butte member or Moenkopi formation.

Projection 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 reserves in this favorable belt may well be large enough to justify exploration of this ground in spite of the 1,500 feet or so of depth to the ore horizon. In the Green River district southwest of the Temple Mountain channel-system the smaller size of ore bodies expected, the lack of knowledge regarding extensions of favorable ground, and the 1,500 feet or so of depth to the ore horizon will probably hamper exploration for uranium deposits, even though the ground may be relatively favorable.

In the area between the Green and Colorado Rivers the Moss Back member is relatively discontinuous and contains significant uranium deposits in a northwesterly trending belt that is about 9 miles wide and parallels the regional pinchout of the member (fig. 4). The southwestern boundary of this relatively favorable belt is a rather sharp line between the blanketlike 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 which deposited the Moss Back may have been unable to cross over the rising structure. Uranium deposits in the Moss Back member in this relatively favorable belt are confined to channel-fill sediments. These sediments may fill channels cut in the surface of the Moenkopi as in the "C" group channel (fig. 4) or they may have been built up in a sandpiling process along the trend of pre-Moss Back streams as in the "A" group channel (fig. 4). The size of known ore deposits in this relatively favorable belt ranges from 100 to 1,000 tons with occasional deposits in the 1,000- to 10,000-ton size range. Hidden deposits may be expected to be in these same size ranges. Depths of 1,000 feet or more to the ore horizon may hamper 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 (fig. 4), 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 (fig. 3). The lack of sandstone channel-fill 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 which 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 mudstones, limy siltstones, and lime pebble conglomerates 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 good sandstone host rocks and good aquifers in the Chinle at this point.

Because the Moab anticline rose just prior to deposition of the Chinle formation, rose again after Chinle time, and may well have been slowly rising during deposition of the Chinle, it seems likely that Chinle drainage was influenced by the structure and that there may be a concentration of sandy stream deposits paralleling the axis of the anticline somewhere down the southwest flank. These more sandy sediments could provide more favorable host rocks for large uranium deposits than the mudstones, siltstones, and lime pebble conglomerates higher up on the anticline. Analogy to an area of similar geology on the southwest flank of the Lisbon Valley anticline in southeastern Utah suggests that ore deposits larger than 100,000 tons in size may well be present in the postulated sandy belt, and potential reserves 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 mudstones, siltstones, and fine-grained sandstones 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 (fig. 4). A 15-foot thick lens of sandstone and limestone pebble conglomerate about 150 to 200 feet above the base of the Chinle, is weakly mineralized in the western part of the Circle Cliffs area. Anomalous radioactivity about 10 times normal background occurs in the Chinle formation in Long Canyon about 15 miles east of Boulder, Utah, and is confined to purplish chert pebble conglomerate and crossbedded sandstone about 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 ore bodies are apparently controlled in detail by the junction of crossbedding 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 potential ore reserves 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 sandstones 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 sandstones and carbonaceous material) and the lack of mineralized rock on extensive outcrops indicate that these formations contain little or no potential uranium reserves.

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 (fig. 5), 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 normally reddish-brown Carmel is altered to greenish-gray to 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 it has little or no potential uranium reserves 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 northwesterly 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 present 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 reserves 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 reserves 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 radioactivity 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 reserves 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 two districts' indicated plus inferred reserves. 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 (fig. 2) and, therefore, is at least partly favorable for vanadium-uranium deposits. The important ore deposits, however, are clustered in certain northerly 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 north-trending belts or channel systems in Tps. 21, 22, and 23 S., and R. 14 E., Salt Lake meridian (fig. 5). Within these favorable channel systems, the ore-bearing sandstone lenses in the upper part of the Salt Wash commonly are 40 feet or more in thickness 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 50-foot or greater vertical range 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 lenses and no significant ore deposits.

On Little and on 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 sandstones 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 lenses that contain no vanadium-uranium deposits larger than about 100 tons in size. The thin sandstones 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 200-foot thick unit containing thin lenses of clean sandstone 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 sandstones 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 blanketlike sandstones of the conglomeratic sandstone facies of the fan formed by the Salt Wash (fig. 2). These rocks contain only sparse amounts of interbedded mudstone and carbonaceous material, and uranium deposits larger than a few tons in size do not seem to be present.

Practically all the significant uranium deposits in the Salt Wash member in the Henry Mountains district are confined to the eastern edge of the Henry Mountains structural basin and are in the transition zone from thick massive blanketlike sandstone beds in the south to thin beds of clean sandstone north of North Wash (fig. 5). Clusters of small podlike ore bodies containing a few tons each are the common occurrence in the thick massive sandstones of the Shootaring Canyon and Delmonte areas. Production from these deposits has come from small highly selective mining operations. Farther north in the Woodruff Springs area sandstones are less massive and blanketlike, and ore bodies up to 100 tons or so in size are present. In the Trachyte Creek area thick lenticular sandstones contain thin podlike ore bodies clustered into deposits aggregating from 1,000 to 5,000 tons in size; and sedimentary trend indicators such as 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 northwesterly extension of this channel system may contain potential ore reserves equal to production through 1955 from the Trachyte Creek area, or possibly several times this figure. Ore deposits in the North Wash area north of Trachyte Creek are confined to many small deposits commonly less than 100 tons in size. Apparently the blanketlike lenses of rather clean sandstone are not favorable for larger ore deposits.

Brushy Basin member

The Brushy Basin member of the Morrison formation contains no known significant uranium deposits by present economic standards. It may, however, have fairly large potential reserves 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 thick carbonaceous siltstone layer about midway in the Brushy Basin member, is uranium-bearing over 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. Trace 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 indicated by the radioactivity of the rock, and 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 shales and siltstones 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 reserves, although weakly uraniferous carbonaceous shale may be present.

Mancos shale

The extensive dark-gray marine shales of the Mancos shale are not known to be uranium-bearing in the Green River and Henry Mountains districts and because of their relative impermeability and uniform lithology 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 member on the south side of Mt. Hillers in the Henry Mountains district (fig. 5). 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 thick layer of carbonized wood and sandstone at the top of the Ferron member along about 1,500 feet of outcrop. Similar uranium occurrences may be expected elsewhere in the Ferron and Emery members, but because of the relatively massive blanketlike character of these units of clean sandstone 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 minor occurrences similar to those in the Ferron sandstone member of the Mancos shale may be present in carbonaceous shale layers. The lack of uranium-bearing rock on the outcrop and the relatively clean, massive blanket-like character of the Mesaverde indicate it is unfavorable for significant ore deposits and has no appreciable potential reserves of uranium ore.

Wasatch(?) formation

Minor carnotite staining on joint surfaces in claystone is known to occur 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 have precluded thorough prospecting for uranium and also make 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 sandstones containing carbonaceous material suggest that this unit has little or no potential reserves.

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 plus inferred reserves is thought to be in this formation. Ore deposits over 10,000 tons in size have not yet been found; but potential reserves may be large, and analogy to the ore-bearing units in adjacent districts suggests that ore deposits 100,000 tons or more in size may be present at depth within the Green River and Henry Mountains districts. Primary sedimentary features, especially channels and the relative discontinuity of beds near regional pinchouts, are thought to be the principal ore controls; and significant uranium deposits are thought 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 10- to 20-mile wide belt of relatively favorable ground related to and paralleling the north-westerly trending line of regional pinchout of the member in the Henry Mountains district (fig. 4).

2) In the Monitor Butte member in sandstone lenses having a thickness of 30 feet or more in a 25-mile wide belt of relatively favorable ground parallel to and bounded by the northeastern line of pinchout of the member (fig. 4).

3) In the Moss Back member along the inferred southeastern extension of the Temple Mountain channel system and in a 10-mile wide belt of relatively favorable ground bounded by and paralleling the northeastern pinchout of the member in the area between the Green and Colorado Rivers (fig. 4).

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

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 plus inferred reserves for the two districts is thought to be contained in this unit. Ore deposits larger than about 20,000 tons in size have not been found and are not expected. 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 in the following places.

1) In the Salt Wash member 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).

2) In the Salt Wash member along the northwesterly extension of a narrow favorable belt or channel system trending about N. 60° W. through Farmer's Knob in T. 32 S., R. 11 E., Salt Lake meridian in the Henry Mountains district (fig. 5).

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 reserves of this type of uranium deposit in the northern Green River district and Uinta Basin.

Potential ore reserves of the Green River and Henry Mountains districts are thought to be many times the combined production and indicated plus 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 potential ore deposits.

LITERATURE CITED

Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841.

__________1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U. S. Geol. Survey Bull. 951.

Boutwell, J. M., 1905, Vanadium and uranium in southeastern Utah: U. S. Geol. Survey Bull. 260, p. 200-210.

Bucher, W. H., 1936, Cryptovolcanic structures in the United States: 16th Internat. Geol. Cong. Rept., v. 2, p. 1055-1084.

Butler, B. S., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111.

Coffin, R. C., 1921, Radium, uranium, and vanadium deposits of southwestern Colorado: Colo. Geol. Survey Bull. 16.

Craig, L. C., Holmes, C. N., Cadigan, R. A., Freeman, V. L., Mullens, T. E., and Weir, G. W., 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U. S. Geol. Survey Bull. 1009-E.

Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geol. Survey Bull. 863.

Davidson, E. S., 1954, Circle Cliffs area, Utah, in Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 36-38, issued by U. S. Atomic Energy Comm., Tech. Inf. Service Extension, Oak Ridge.

Davidson, E. S., 1956, Circle Cliffs area, Utah, in Geologic investigations of radioactive deposits, semiannual progress report, June 1 to November 30, 1955: U. S. Geol. Survey TEI-590, p. 51-53, issued by U. S. Atomic Energy Comm., Tech. Inf. Service Extension, Oak Ridge.

Emery, W. B., 1918, The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., v. 46, p. 551-577.

Finch, W. I., 1953, Geologic aspects of the resource appraisal of uranium deposits in pre-Morrison formations of the Colorado Plateau: U. S. Geol. Survey TEI-328A, issued by U. S. Atomic Energy Comm., Tech. Inf. Service Extension, Oak Ridge.

__________ 1955, Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of the Colorado Plateau region: U. S. Geol. Survey Mineral Inv. Field Studies Map MF 16.

Fischer, R. P., 1942, Vanadium deposits of Colorado and Utah: U. S. Geol. Survey Bull. 936-P.

Gilbert, G. K., 1877, Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Survey Rocky Mtn. Region Rept.

Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806-C, p. 69-130.

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell, and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150-D.

Gregory, H. E., 1950, Geology and geography of the Zion Park region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 220.

Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U. S. Geol. Survey Prof. Paper 164.

Hess, F. L., 1913, Carnotite near Green River, Utah: U. S. Geol. Survey Bull. 530, p. 161-164.

________1914, A hypothesis for the origin of the carnotites of Colorado and Utah: Econ. Geol., v. 9, p. 675-688.

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

Hunt, C. B., assisted by Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U. S. Geol. Survey Prof. Paper 228.

Joesting, H. R., Byerly, P. E., and Plouff, D. F., 1955, Geophysical investigations, regional studies, in Geologic investigations of radioactive deposits, semiannual progress report, December 1, 1954 to May 31, 1955: U. S. Geol. Survey TEI-540, p. 93-96, issued by U. S. Atomic Energy Comm., Tech. Inf. Service Extension, Oak Ridge.

Johnson, H. S., Jr., 1957, Uranium resources of the San Rafael district, Emery County, Utah, a regional synthesis: U. S. Geol. Survey Bull. 1046-D.

Kelley, V. C., 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: Univ. N. Mex. Pub. in Geology, No. 5.

Luedke, R. G., 1954, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah, in Geology of portions of the High Plateaus and adjacent Canyon Lands central and south-central Utah: Intermountain Assoc. Petroleum Geologists, 5th Ann. Field Conf., Guidebook, p. 59-62.

McKnight, E. T., 1940, Geology of the area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 908.

Miller, L. J., 1955, Uranium ore controls of the Happy Jack deposit, White Canyon, San Juan County, Utah: Econ. Geol., v. 50, p. 156-169.

Robeck, R. C., 1956, Temple Mountain member, new member of the Chinle formation in the San Rafael Swell, Utah: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 2499-2506.

Steed, R. H., 1954, Geology of Circle Cliffs anticline, in Geology of portions of the High Plateaus and adjacent Canyon Lands, central and south-central Utah: Intermountain Assoc. Petroleum Geologists, 5th Ann. Field Conf. Guidebook, p. 99-102.

Stewart, J. H., 1957, Proposed nomenclature of part of Upper Triassic strata in southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 441-465.

Stieff, L. R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some uranium ores of the Colorado Plateaus by the lead-uranium method: U. S. Geol. Survey Circ. 271.

Stokes, W. L., 1952, Lower Cretaceous in Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 1766-1776.

Weeks, A. D., and Thompson, M. E., 1954, Identification and occurrence of uranium and vanadium minerals from the Colorado Plateaus: U. S. Geol. Survey Bull. 1009-B.

Weir, D. B., 1952, Geologic guides to prospecting for carnotite deposits on Colorado Plateau: U. S. Geol. Survey Bull. 988-B.

Witkind, I. J., 1956, Uranium deposits at base of the Shinarump conglomerate, Monument Valley, Arizona: U. S. Geol. Survey Bull. 1030-C.

Wright, R. J., 1955, Ore controls in sandstone uranium deposits of the Colorado Plateau: Econ. Geol., v. 50, p. 135-155.

UNPUBLISHED REPORTS

Colman, A. H., Bryner, Leonid, and Hill, J. W., 1945, Report on Granite Wash district, Henry Mountains area, Utah: Union Mines Development Corp. unpublished report.

Eakland, E. H., Jr., 1945, Report on Waterpocket Fold district, Kaiparowits Plateau area, Utah: Union Mines Development Corp. unpublished report.

Grundy, W. D., 1954, Rosey claims, Garfield County, Utah: U. S. Atomic Energy Commission PRR ED-R-251.

Hill, J. W., 1945, Green River district, San Rafael Swell area, Utah: Union Mines Development Corp. unpublished report.

Mastrovich, A. M., 1945, Report on Little Rockies district, Henry Mountains area, Utah: Union Mines Development Corp. unpublished report.

Reinhardt, E. V., 1952, The distribution of uranium-vanadium deposits in the Colorado Plateau relative to Tertiary intrusive masses: U. S. Atomic Energy Commission RMO-816.

Smith, C. T., 1944, Report of field examination of the Inter-River district, Green River Desert area, Utah, Colorado Plateau region: Union Mines Development Corp. unpublished report.