GEOLOGY OF THE GREEN RIVER
MINING DISTRICT, EMERY
AND GRAND COUNTIES, UTAH

By
R. G. Young
Isadore Million
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September 1960

Production Evaluation Division
Grand Junction Operations Office, AEC
Grand Junction, Colorado
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View looking west across Tidwell mineral belt toward San Rafael Swell, Utah.
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GEOLOGY OF THE GREEN RIVER MINING DISTRICT
EMERY AND GRAND COUNTIES, UTAH

ABSTRACT

Uranium deposits have been known since the 1880's in the Green River district of eastern Emery County and western Grand County in southeastern Utah. Outcropping rocks include the Entrada sandstone and the Carmel, Curtis, Summerville, and Morrison formations of Late Jurassic age; the Cedar Mountain formation of Early Cretaceous age, the Naturita formation of probable Late Cretaceous age in this area, and the Mancos shale of Late Cretaceous age. Uranium is found chiefly in the Salt Wash sandstone member of the Morrison, and the largest deposits occur in a thick sandstone unit near the top of the member in the Tidwell mineral belt near the western edge of the district.

The basic structure of the district is that of a broad northward-plunging syncline which projects thumblike from the southern margin of the Uinta Basin, bounded on the east by the Green River nose of the Cane Creek anticline, on the south by the Nequoia arch, and on the west by the San Rafael Swell. Superimposed on this structure are a few minor flexures, some of which may reflect early compressional folding not related to Laramide structures. Several small east-trending anticlinal folds, which occur on the west flank of the district, are believed to have been formed by north-south compressional forces during the Late Jurassic. Most prominent of these is the Tidwell nose in the Tidwell mineral belt. Two zones of graben-forming normal faults cross the northern portion of the district, but otherwise faulting is rare. All rocks are highly jointed, but most joints are believed to have formed in response to minor crustal adjustments and thus are difficult to use in interpreting structural history. Six periods of uplift, following Salt Wash deposition and prior to the major period of uplift from mid-Tertiary to late Tertiary, are recognized in the district and adjacent areas.

Since the 1880's approximately 200,000 tons of ore containing radium, uranium and vanadium have been shipped from the district. At present most mining is in the Tidwell mineral belt, where 22 mines are operating at various depths to as great as 380 feet. The first ore discovered was in small bodies at the outcrop, but later drilling showed ore to exist in larger bodies at greater depths. Individual ore bodies are not large — less than 5,000 tons — but several may occur in clusters totalling 10,000 to 100,000 tons.
Primary minerals, identified from Salt Wash ore zones, include coffinite, uraninite, montroseite, sphalerite, pyrite, marcasite, chalcopyrite, and clausthalite. Coffinite is the most common uranium mineral. Secondary ore minerals include corvusite, hewettite, tyuyamunite, metatyuyamunite, uranopilite, liebigite, and schroeckingerite. Most common secondaries are tyuyamunite and uranopilite. Secondary gangue minerals include barite, clay, carbonates, quartz, and chalcedony, apatite, ilsemannite, halotrichite, and alunogen.

At and near the outcrop, ores are gray to limonitic brown with coatings of secondary minerals; but at depth they become dark gray to black, largely because associated carbonaceous matter is not obscured by weathering products. Origin of this material is not definitely known. Some is definitely plant material while some is asphaltic matter of humic or petroliferous origin. A third type consists of disseminated microscopic carbon; interpreted as a residue of petroleum, a humic hydrosol or a residue of humic acids. Asphaltic material fills cell centers, and commonly surrounds and appears to corrode and replace quartz grains and ore minerals. A review of evidence concerning the origin of this material indicates that it may have been derived, in part from woody materials, and in part from petroliferous material, which may be both pre- and post-mineralization. Corrosion of other minerals may not necessarily indicate a later age for the asphalt. Asphaltic material may have been made corrosive by alpha bombardment from uranium minerals which had originally been precipitated by the asphaltic material.

Uranium-bearing solutions may have been hydrothermal solutions which originated at depth, rose along fractures until they encountered permeable Salt Wash, and proceeded to move laterally, or they may have been circulating ground waters which transported the uranium from a distant granitic or magmatic source. These solutions moved more freely through those areas of thick permeable Salt Wash, such as that in the Tidwell mineral belt. Where these solutions came in contact with reducing agents, such as humic or petroliferous material, precipitation of uranium occurred. The largest deposits occur where favorable belts of Salt Wash coincide with pre-mineralization structures such as the Tidwell nose. Here, permeability is further increased by intense fracturing of the ore horizon.

Bleaching of Salt Wash sandstone is believed to be the result of the leaching action of circulating ground waters charged with humic acids, and may be unrelated to mineralizing solutions.
INTRODUCTION

Location and extent

The Green River mining district is in eastern Emery County and western Grand County in southeastern Utah (fig. 1). Bounded roughly on the south by the San Rafael River and on the east by a line corresponding to 110° W. long., it extends westward to the steeply dipping east flank of the San Rafael Swell. Its northern boundary coincides roughly with U. S. Highway 6-50 and the Denver and Rio Grande Western Railroad. The area is 350 square miles.

Purpose and scope

The purpose of this report is to present all pertinent geologic data on an area in which relatively important uranium deposits are present. It was prepared in March 1957, and has been revised only to incorporate later stratigraphic terminology and production data. Field studies were made to obtain details on structural and stratigraphic relations throughout the area.

Field work

Field work was begun in February 1956 and completed in December of that year. It consisted of detailed mine mapping, measuring numerous sections, and an altimetry survey for the construction of a structure map.

Small critical areas were mapped with telescopic alidade and plane table which were also used in measurement of sections and obtaining some elevation control.

Mine mapping was largely by Brunton and tape methods but in some instances the transit was employed.

Primary horizontal and vertical control were afforded by an Atomic Energy Commission triangulation net along the western and southern margins of the area, while vertical control in the remainder of the area was provided by U. S. Geological Survey bench marks. Secondary vertical control, obtained from Geological Survey phototopographic maps of the area, was utilized in the altimetry survey in preparation for the structure map. "Leap frog" and two-base methods were employed in the altimetry survey.

An Atomic Energy Commission gamma-ray unit logged many holes in the area. The majority of these were along the western margin in the Tidwell mineral belt.

Acknowledgements

The writers wish to express their appreciation to the many residents and mine operators who granted access to their properties and who were extremely cooperative in supplying invaluable information and assistance.
Figure 1. Index map Green River District, Emery and Grand Counties, Utah.
Geography

Topographic features

The Green River Desert is not recognized as a separate entity in the physiographic classification by Fenneman (1931), who treats it as a part of the Canyon Lands section of the Colorado Plateau province which includes a large area in southeastern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado. Baker (1946, p. 6) includes it in the Green River Desert-Cataract Canyon region. The Plateau province as a whole is characterized by plateaus, cliffs, mesas, and hundreds of remarkable canyons. These youthful features are the result of erosion of a thick sequence of nearly flat-lying rocks which occur at relatively high elevations. The Green River Desert does not include deep canyons or high plateaus, but is a somewhat dissected area of moderate relief where the average elevation decreases gradually from about 4,500 feet at the southern boundary to about 4,100 feet near the town of Green River, Utah. Total relief in the area is about 1,200 feet with the maximum elevation of about 4,800 feet occurring along the western margin of the area where the strata dip steeply off the San Rafael Swell. Lowest elevations are about 4,000 feet near the confluence of the Green and San Rafael Rivers. The crest of the San Rafael Swell to the west has a maximum elevation of about 7,000 feet and thus is about 2,500 feet higher than most of the Desert.

The Green River flows southward through a broad valley at the northeastern boundary of the area, but just south of the town of Green River it bisects the Green River structural nose and becomes slightly entrenched with the canyon deepening slightly to the south. In the 30 miles between the town of Green River and the mouth of the San Rafael River, the river gradient is approximately 3.2 feet per mile. The San Rafael River enters the northwest corner of the area through a deep narrow canyon cut through the steep saw-tooth ridge or Reef on the eastern flank of the San Rafael Swell. Immediately upon leaving the Reef it makes a right-angle turn to the south and flows in a strike valley cut in the Carmel, Entrada, and Summerville for approximately 3 miles before turning southeasterly. This slightly entrenched course is maintained for a distance of about 12 miles before it again changes direction and flows eastward for about 12 miles to its junction with the Green. The gradient for this stream in the 40 miles between the Swell and its mouth is about 7.3 feet per mile.

Drainage

The Green and San Rafael Rivers are the only two perennial streams in the area.

The Green River, which flows near the eastern edge of the area, heads in the mountains of northwestern Colorado and southwestern Wyoming and is the largest tributary of the Colorado River. Its flow in recent years has exceeded that of the Colorado. Records for the period 1894-1953 show that the maximum flow of the Green River occurs in late May or early June and the minimum occurs in November, December, or January. Mean runoff for this
period was 6,737 second-feet with a minimum of 355 second-feet per day November 26, 1931, and a maximum of 68,100 second-feet June 27, 1917. The stream flow as recorded in 1952-53 ranged from a maximum of 28,500 second-feet on June 12 to a minimum of 820 second-feet on November 28. Some water is diverted above the town of Green River for irrigation but none is removed between there and the San Rafael River.

Stream flow of the San Rafael, which rises in the Wasatch Plateau to the west, shows a mean of 94.3 second-feet for the period 1909-1950, measured 15 miles southwest of the town of Green River. Maximum flow was 8,640 second-feet August 22, 1947, and the river has ceased to flow on several occasions. In the water years 1952-1953, the maximum was 1,220 second-feet on June 14, and the minimum 0.4 second-feet on March 18 and 19.

Climate and vegetation

The climate of the area is semiarid to arid. Records of the United States Weather Bureau at Green River show the average rainfall during the period 1945-1950 to be 5.81 inches. Slightly more precipitation falls during the summer months than during the winter and much of this is in the form of torrential thunderstorms which play havoc with roads and irrigation systems.

Temperatures at Green River in the period 1945-1955 ranged from a maximum of 108°F on July 20, 1947, and August 1, 1949, to a low of -23°F on January 22, 1955. Annual mean for this period was 52°F.

Vegetation is representative of the upper Sonoran life zone of the Colorado Plateau. The only trees are scattered groves of cottonwood along the streams and a few junipers at higher elevations. Rabbit brush, greasewood, black sagebrush, salt sagebrush and tamarisk (salt cedar) are common, particularly in the bottom lands; and blackbrush, Mormon tea, and leadbrush are common on the higher ground. Other plants such as shad scale, Yucca, bladderstem, locoweed, and a few grasses are found in the desert but are nowhere abundant. The entire area has been overgrazed and this, coupled with irregular rainfall, has accelerated erosion.

Population

In recent years, many marginal ranches along the San Rafael and Green Rivers have been abandoned. As a result, almost the entire population of the area is concentrated in the town of Green River. An unofficial census taken in 1955 showed the population of the town to be 583 persons.

Farming and mining are the two principal industries of the area. Farming is confined to the irrigated bottom lands near the town of Green River and along some portions of the San Rafael River. Mining is largely in the so-called "Tidwell mineral belt" along the west side of the area about 12 miles west of town (see frontispiece). Tourist trade is important, especially in the summer months.
Accessibility and routes of travel

Access to the area is afforded by the main line of the Denver and Rio Grande Western Railroad and by United States Highway 6-50 which form the arbitrary boundary on the north. The highway is an all-weather oiled road from which several lesser roads lead west and southwest (fig. 1). Most important of these lesser access roads is Utah Highway 24, an oiled highway which leaves Highway 6-50 about 4 miles west of Green River and leads southwest toward Hanksville. About 2 miles south of Highway 6-50, an Atomic Energy Commission gravel access road leaves Utah 24 and leads west for about 6 miles to the major mining area at the western edge of the Desert.

Another gravel access road (old Utah 24) leads southwest from the town of Green River. About 3 miles south of town, it branches into a west fork which joins the present Utah 24 near the San Rafael River bridge, and an east fork which leads south to Saucer Basin and the uplands of the Green River Desert south of the San Rafael River. Access to the eastern side of the Green River is by a gravel road which leaves Highway 6-50 about 4 miles east of the town of Green River and leads southwest for about 5 miles to Crystal geyser, a cold-water CO₂-propelled geyser on the bank of the Green River. A dirt road continues for a few miles south along the river to Little Valley, an abandoned farming area. Numerous unmarked seismograph and jeep trails are present throughout the area and give access to most outcrops.

Previous investigations

Broad geologic features of this area were described by early-day explorers such as Gunnison, who led an expedition through the area in 1853, and Powell, who explored the Canyon Country in 1869 and 1871 and applied many of the geographic names now in use (Powell, 1875).

The general geology of this region has received much attention from geologists in the excellent works of such men as Emery (1918), Gilluly and Reeside (1928), McKnight (1940), and Baker (1946).

Oil and gas possibilities of the area have been treated by Lupton (1914), Anonymous (1952), Hansen and Bell (1952), and Hager (1956).

Manganese deposits in the area have been described by Pardee (1922) and Baker, Duncan, and Hunt (1952).

Many reports dealing in part with uranium deposits of the area have been written. However, only those by Hess (1913), Hill (1945), Jensen (1953), and Million (1957) deal primarily with this area.

A bibliography of the more important papers dealing with the area is included in this report.
STRATIGRAPHY

General features

Formations exposed in the Green River District range in age from the Upper Jurassic Carmel formation to the Upper Cretaceous Mancos shale and a few patches of Tertiary or Quaternary deposits near present-day streams. The generalized stratigraphic column (fig. 2) includes, in addition, post-Mancos strata present in surrounding areas. They are included because they were a part of the sedimentary cover, in the region under discussion, at the time of uranium deposition and because they record significant events in the geologic history of the area. Exposed rocks include both marine and continental units. Continental formations include the Upper Jurassic Entrada sandstone and Morrison formation and the Cretaceous Cedar Mountain and Naturita formations. Marine formations include the Upper Jurassic Carmel, Curtis, and Summerville formations, and the Upper Cretaceous Mancos shale. Generalized outcrops of each of these units are shown in figure 3.

Jurassic system (Upper Jurassic series)

San Rafael group

The San Rafael group, which includes the Carmel formation, Entrada sandstone, Curtis and Summerville formations, listed in ascending order, is named for exposures near the northern end of the San Rafael Swell (Gilluly and Reeside, 1928, p. 73). Units of this group comprise the surface rocks over a large portion of the southern part of the Desert (fig. 3 and pl. 1). They also crop out in a narrow band along the western edge and in a small area along the Little Grand fault a few miles south of the town of Green River.

Carmel formation. The oldest formation exposed in the District is the Carmel, named by Gregory and Moore (1931, p. 69) for exposures near the town of Mount Carmel in southern Utah. Along the western margin of the District the Carmel consists of a lower unit of interbedded greenish-gray, buff, red or lavender mudstone, crossbedded sandstone, and some fossiliferous limestone, and an upper unit of easily eroded, brownish-red silty sandstone and mudstone with abundant interbedded red, buff or gray sandstone, and a few thin beds of red to gray limestone. Eastward, the lower unit grades into red muddy sandstone or mudstone indistinguishable from the upper unit. The lower unit is exposed only along the western margin, but the weaker upper unit floors broad areas of low relief at the base of the cliffs formed by Entrada sandstone. In outcrops south of the San Rafael River, the Carmel contains interbedded gypsum. Solution and flowage of the gypsum have produced much distortion in the upper part of the Carmel and in the overlying Entrada. However, this distortion does not extend into the Summerville, indicating that the distortion occurred during or following deposition of the Entrada and prior to deposition of Summerville.

The Carmel is about 230 feet thick along the western margin of the
Figure 2. Generalized stratigraphic column, Green River District, Emery and Grand Counties, Utah.

Blue Gate shale and post-Mancos shale formations are exposed in the areas adjacent to the Green River District but not in the District itself.

Dakota group includes Naturita and Cedar Mountain formations.
Figure 3. Generalized geologic map, Green River District, Emery and Grand Counties, Utah.
District (Baker, 1946, p. 73) but decreases in thickness toward the east to about 130 feet near the mouth of the San Rafael River and on the Green River structural nose near the town of Green River.

Marine mollusks present near the base of the formation, along the western boundary of the District, indicate that the Carmel is Middle to early-Late Jurassic in age (Imlay, 1952). Its true relation to type Carmel is not known, but it is possible that only the basal fossiliferous portion of the formation in the Green River District area is equivalent to the entire section of type Carmel (Craig and Dickey, 1956, p. 98).

The Carmel rests disconformably on the underlying Navajo sandstone. One to four feet of yellow-brown sandstone at the base, locally containing chert pebbles, probably represents a zone of reworked Navajo. The gradational contact between the Carmel and overlying Entrada seems to indicate continuous deposition.

**Entrada sandstone.** The massive cliff-forming Entrada sandstone was named by Gilluly and Reeside (1928, p. 76) for exposures in the northern part of the San Rafael Swell. Exposures of the Entrada in the Green River District are found only in a relatively narrow band along the western and southern margins (figs. 3, 4, pl. 1) and at an isolated outcrop along the Little Grand fault near the town of Green River.

The Entrada consists primarily of even-bedded gray, tan, or orange-brown, earthy sandstone and siltstone with small amounts of reddish-brown sandstone and occasional beds of red shale. Unlike the "slick-rim" Entrada of adjacent areas the Entrada of this area commonly weathers into smooth bluffs or relatively gentle slopes composed of a series of rounded ledges rising above benches of the underlying Carmel. Disintegration of the Entrada has resulted in the production of thick deposits of dune sand along the San Rafael River.

Near the mouth of the San Rafael River, the thickness of the Entrada is 435 feet and it is 405 feet at Black Dragon Canyon (fig. 1) on the western boundary of the District (Baker, 1946, p. 77). Though unfossiliferous, the Entrada is dated as Late Jurassic because of its position between the fossiliferous Carmel and Curtis formations. Its contact with the underlying Carmel is gradational, but it is separated from the Curtis by a marked unconformity. In spite of the pronounced break in many places, it probably represents only a short hiatus since Curtis grades into Summerville which in turn intertongues with Entrada (Moab tongue) to the east of this area.

Over much of the Colorado Plateau the Entrada is eolian, but because of the even-bedded nature of the unit in the Green River District it is thought to be water laid and may be marginal marine (Baker, Dane and Reeside, 1936).

**Curtis formation.** The name Curtis formation was applied by Gilluly and Reeside (1928, p. 78-79) to a greenish-gray unit exposed on the south face of Cedar Mountain at the north end of the San Rafael Swell. In the
Jurassic rocks near Black Dragon Canyon; Navajo sandstone (Jn), Carmel formation (Jc) Entrada sandstone (Je), and Curtis (Jcu), Summerville (Js) and Morrison (Jm) formations.

Figure 4.

Basal gypsum (g) of Salt Wash member (Jms) resting unconformably on Summerville formation (Js) near San Rafael River bridge.

Figure 5.
Green River District, it consists largely of relatively soft calcareous shales and a few thin beds of fine- to medium-grained glauconitic sandstone.

The Curtis crops out in a narrow band along the western and southern margins of the District (figs. 3 and 4 and pl. 1) and in a small area along the Little Grand fault. This unit is normally slightly more resistant to erosion than the underlying Entrada and thus it commonly forms a broad bench capping the Entrada and slumping upward toward the base of the Summerville, into which it grades.

In general, the Curtis is thickest (about 180 feet) along the western margin of the District and thins eastward and southward to 34 feet along the Little Grand fault and to 103 feet near the mouth of the San Rafael River (Baker, 1946, p. 82-83).

No fossils have been collected from the Curtis in the Green River District but marine fossils of late Jurassic age occur near the type locality (Gilluly and Reeside, 1928, p. 106-107).

The Curtis is believed to have been deposited in a sea which invaded this area from the northwest. As previously stated, the Curtis in this area is unconformable on the Entrada, with notable angularity in some places, and its upper contact is gradational.

Summerville formation. The Summerville formation named by Gilluly and Reeside (1928, p. 79-80) for exposures on Cedar Mountain consists predominantly of thin, reddish-brown, even-bedded mudstone and intercalated shale with some interbedded, slabby fine-grained buff sandstone. Gypsum is common and occurs as nodular masses and as veinlets cutting across bedding.

Nearly everywhere along the western and southern margins of the District and along Little Grand fault, the Summerville forms steep slopes or finely fluted vertical cliffs capped by the massive gypsum at the base of the Salt Wash sandstone member of the Morrison formation (figs. 4 and 5).

Thicknesses of the unit decrease from 205 feet near Tidwell Ranch to 118 feet along Little Grand fault, and to 96 feet near the mouth of the San Rafael River (Baker, 1946, p. 85).

Because of its close relationship to the Curtis formation and the nature of its lithology, the Summerville is considered a marginal marine deposit laid down during withdrawal of the Curtis sea to the west and northwest in Late Jurassic time.

Morrison formation

Overlying the Summerville is a sequence of continental deposits belonging to the Morrison formation named by Cross (1894, p. 2) for exposures near the town of Morrison, Colorado.
Salt Wash member. In this area the Morrison formation can be subdivided into the lower Salt Wash member and the upper Brushy Basin member. These members are differentiated on the basis of lithology, but because of some intertonguing and gradation between them, the contact between the two is not everywhere at the same horizon. Outcrops of these units form a broad crescentic band around the western, southern and eastern margins of the District (fig. 3 and pl. 1).

Lupton (1914, p. 127) named the Salt Wash for exposures along Salt Wash just east of the District. It consists, in the District, of a basal gypsum and limestone unit, a middle mudstone unit, and an upper cliff-forming sandstone unit.

The lower unit is commonly a persistent massive gypsum bed as much as 20 feet thick. Near the mouth of the San Rafael River, the gypsum is absent and in its place is a nodular cherty limestone, up to 5 feet thick. At other places, the contact is marked only by the change from the flat bedding of the Summerville to the lenticular bedding of the Morrison. In places, a foot or so of Summerville beneath the gypsum has been bleached to gray green (fig. 5). In other places, Salt Wash scours have been cut through the gypsum and into the Summerville (fig. 6).

Reddish-brown, purple, and light greenish-gray mudstones together with a few relatively thin lenses of sandstone, siltstone, and impure limestone comprise the middle unit of the Salt Wash. Although these deposits most commonly are largely restricted to the basal portion of the Salt Wash, variegated mudstones are scattered throughout the member and in the vicinity of Tank Springs constitute the entire Salt Wash, with the exception of a few lenticular sandstones near the top. Average thickness of the unit is about 150 feet.

The upper unit of the Salt Wash is a cliff-forming sandstone which ranges from 20 to 80 feet in thickness. It is not a single massive sandstone but a group of relatively thin channel-fill sandstones separated in many places by thin partings of red or green mudstone. The sandstone is white, gray, buff, and light brown, and ranges from coarse-grained conglomeratic to fine grained. Sandstone grains consist largely of quartz and much varicolored argillaceous chert, which in some coarser beds has been largely altered to clay imparting a white speckled appearance to the sandstone (fig. 7). Sorting is poor, and angular to subangular chert pebbles up to 1 inch in diameter are present in some conglomeratic lenses. Individual sandstone beds range in thickness from less than 1 foot to more than 10 feet. Cementing material is usually calcite or dolomite, but in places is clay. Beds are cross laminated and show pinch out, truncation, and in many cases irregular scour surface at the base. These old scour fills are mostly short segments several hundred feet long, but a few can be traced for greater distances. Short northeast-trending segments predominate in the mining area along the western margin of the District, whereas those found in most of the remainder of the area can be traced for greater distances in many cases and appear to have no such definite trend (fig. 8). In the Tidwell mineral belt, a thick relatively persistent sandstone near the top of the Salt Wash is the principal ore-bearing unit (fig. 9).
Figure 6. Sandstone-filled scour (s) at base of Salt Wash member (Jms) near San Rafael River bridge.

Figure 7. Montmorillonite (white particles) replacing chert in sandstone.
Thicknesses of the Salt Wash are quite constant in the District, ranging from 214 feet along the western boundary to 244 feet on the Green River nose (fig. 10).

In the Green River District, the Salt Wash rests with slight angular discordance on the underlying Summerville, though in surrounding areas there is no marked discordance of beds. This is interpreted as indicating local deformation prior to Salt Wash deposition.

Plant remains in the form of carbonized leaves, twigs, and logs are common throughout the sandy portion of the Salt Wash (figs. 11 and 12). Associated with the carbon trash in some areas are silicified logs 2 or more feet in diameter.

Fossils are rare in the Salt Wash. Dinosaur bones occur in some localities and several specimens of a fresh-water pelecypod, found near the base of the unit at one locality near the San Rafael River bridge, were identified during this study by J. B. Reeside, Jr., as Unio stewardi utahensis Yen (1956). Mitchell (1956, chart opposite p. 108) records the presence of characteristic charophytes in nearby localities.

This member was deposited by streams flowing northward from southern Utah, probably as part of a broad alluvial fan (Craig and others, 1955, p. 135-152).

**Brushy Basin member.** Overlying the Salt Wash member is a shale unit, the Brushy Basin member of the Morrison formation.

The Brushy Basin (Gregory, 1938, p. 59) consists of red, reddish-brown, purple, and gray mudstone containing varying amounts of siltstone and some lenticular conglomeratic sandstones (figs. 13 and 14). Much of the Brushy Basin consists of impure bentonitic clay of volcanic origin. Elongate sandstone lenses are as much as one-half mile in length and 100 feet in width (fig. 14); they probably are remnants of clastic fill of old stream channels. Channel trends are closely parallel to those of the Salt Wash and generally trend northeast. The contact with the underlying Salt Wash does not occur at a constant horizon because of intertonguing between the two members but is usually placed at the top of the uppermost, relatively persistent massive sandstone. However, in some areas, a rather poorly cemented conglomeratic sandstone consisting largely of chert and quartzite grains rests on typical Salt Wash sandstone. This unit closely resembles the "Christmas Tree Conglomerate" (Craig and others, 1955, p. 156) which marks the base of the Brushy Basin in much of southeastern Utah and southwestern Colorado and is here included in the Brushy Basin.

The thickness of the Brushy Basin ranges from a maximum of 391 feet on the Green River nose to a minimum of 319 feet near Horse Bench Reservoir (fig. 10). Its average thickness is about 360 feet. Variations in thickness are due in part to a general thinning to the southeast and in part to pre-Cedar Mountain erosion.
Figure 8. Aerial view of Salt Wash channel sandstones east of San Rafael River bridge. Upper lens measures about 300 feet long, 30 feet wide, and 10 feet thick.

Figure 9. Ore sandstone in Tidwell mineral belt.
Figure 10. Correlation of measured sections, Green River District, Emery and Grand Counties, Utah.
Figure 11. Unmineralized wood fragments from ore horizon, incline No. 6 mine.

Figure 12. Small mineralized woody fragments along bedding planes, incline No. 5 mine.
Figure 13. Cedar Mountain formation (Kcm) resting disconformably on Brushy Basin shale (Jmb) near San Rafael River bridge.

Figure 14. Channel sandstones in Brushy Basin member in Tidwell mineral belt. Thin sandstone near middle of slope is about 3 feet thick and 50 feet wide.
Petrified dinosaur bones and wood fragments are common in the Brushy Basin and some exhibit radioactivity. Other fossils are rare but freshwater gastropods and algae have been reported from a few localities (Craig and others, 1955, p. 156).

The age of the Morrison is generally considered to be Late Jurassic, but absence of diagnostic fossils in the upper 200 to 300 feet of Brushy Basin prevents an accurate age assignment to that portion of the formation.

Cretaceous system

Dakota group

The Dakota group of the Green River District can be subdivided into two formations on the basis of carbonaceous content. The lower non-carbonaceous unit, the Cedar Mountain formation, constitutes the bulk of the group. Remnants of the carbonaceous upper unit, the Naturita formation, are present in a few areas.

Cedar Mountain formation. Stokes (1944, p. 965-966) proposed the name Buckhorn conglomerate for a unit of formational rank overlying the Brushy Basin in the vicinity of Buckhorn Reservoir on the west flank of the San Rafael Swell. At the same time, he applied the name Cedar Mountain shale formation to the slope-forming unit overlying the Buckhorn and underlying the "Dakota" formation in the Cedar Mountain area at the north end of the Swell. Later, Stokes became convinced that the Buckhorn was too thin and discontinuous to warrant formational rank and proposed that it be considered a member of the Cedar Mountain formation (1952, p. 1774). Thus, as defined by Stokes, the Cedar Mountain consists of the basal Buckhorn conglomerate member and an overlying variegated shale member.

In the Green River District, the Cedar Mountain consists largely of variegated bentonitic mudstones which are not as brightly colored as those of the subjacent Brushy Basin. Pastel shades of green, red and purple predominate. The formation is characterized by abundant siliceous limestone nodules (fig. 15), minor lenses of gray to green siliceous sandstone and limestone, and numerous "gastroliths" or polished chert and quartzite pebbles. The siliceous nodules are extremely resistant to weathering and tend to clothe gentle slopes and to obscure contacts (fig. 13). Botryoidal forms of varicolored chalcedony and septarian nodules filled with chalcedony are common. Lenses of coarse conglomeratic sandstone occur throughout the formation but are most common in the lower half. In places, two or more lenses are present in the lower 50 to 75 feet, whereas, in other places, conglomerate is entirely absent. The lowermost of these conglomerates is probably the Buckhorn conglomerate of Stokes. The conglomerates consist largely of gray to black chert pebbles with lesser amounts of siliceous limestone, quartz, and quartzite pebbles. Fragments of dinosaur bones are common in some lenses.

Near the top of the formation are a few persistent channel sandstones. One of these forms a sinuous, resistant ridge which can be traced almost continuously for an east-west distance of more than 10 miles (fig. 16).
Figure 15. Siliceous limestone nodules on weathered outcrop of Cedar Mountain formation in Tidwell mineral belt.

Figure 16. Channel sandstone near top of Cedar Mountain formation. View looking west from near Green River. Sandstone is 15-30 feet thick, averages 300 feet in width, and can be traced for about 10 miles.
The Cedar Mountain crops out in a relatively broad east-west belt crossing the District about midway between its northern and southern limits. It is also present in a small crescentic band around the Green River nose (fig. 3 and pl. 1).

The Cedar Mountain varies in thickness from about 150 feet on the western margin of the District to about 200 feet near Horse Bench Reservoir (fig. 12). Variations in the thickness of the unit are due largely to pre- and post-Cedar Mountain erosion. Eastward, near the Colorado River, the Cedar Mountain grades laterally into equivalent deposits of the Burro Canyon formation.

Age of the lower portion of the Cedar Mountain has been determined as Early Cretaceous (pre-Aptian) and possibly Late Jurassic in part (Katich, 1954, p. 44), but lateral tracing by Young has indicated that the uppermost portion is probably Late Cretaceous (Cenomanian). Fossils are sparse but Katich (1951) reported ganoid fish scales, fresh-water ostracods, and fresh-water pelecypods from about 50 feet below the Naturita on the west side of the Swell. Stokes (1952, p. 1768) recorded numerous microfossils indicative of Early Cretaceous age. Mitchell (1956, chart opp. p. 108) lists certain charophytes characteristic of the Cedar Mountain, but since none are known either from the upper part of the Brushy Basin or near the base of the Cedar Mountain, the exact Jurassic-Cretaceous boundary is unknown.

Nearly everywhere, the contact between the Cedar Mountain and Brushy Basin is disconformable. Where a conglomerate lens is present at the base of the Cedar Mountain, the conglomerate commonly fills a scour in the older unit and the contact is readily discerned. Where conglomerate is absent, the contact is indistinctly marked by a change from brightly colored Brushy Basin shales to the softer pastel shades of the Cedar Mountain. In some localities the contact is somewhat angular (fig. 13), while, in others, a few inches of the uppermost Brushy Basin is iron stained. Throughout the District, the Cedar Mountain is disconformably overlain either by lenses of Naturita sandstone or by Mancos shale.

The lithology of the Cedar Mountain indicates that it is largely an inland flood-plain deposit. It is probable that the conglomerates were derived from Carboniferous and Permian rocks exposed to the west. Stokes (1944) stated that they might be lag gravels but later (1950) suggested that they are pediment deposits. It seems more likely that they were merely fanlike deposits of streams with steep gradients. These streams originated in the highland or piedmont area to the west and dropped their loads of coarse material upon entering the lowland areas. It is possible that originally the color of this formation was various shades of red and purple, but large areas were bleached to light gray to green by downward percolating solutions during Naturita time.

Naturita formation. At a few localities in the District, there occur small patches of conglomerate and sandstone, which are remnants of the Naturita formation. Naturita formation is a term applied by Young (1960)
to the upper carbonaceous portion of the Dakota group. It takes its name from exposures near Naturita in southwestern Colorado. In this District, the Naturita consists of thin lenses of crossbedded yellowish-brown conglomerate and sandstone with a few small lenses of interbedded gray carbonaceous shale. Pebbles of the conglomerate are largely gray quartzite with some black to red chert and range up to 2 inches in diameter. These remnants are found filling north-trending scours up to 40 feet deep in the Nine Mile Wash area about 3 to 5 miles north and northwest of the Horse Bench Reservoir, and on the Green River nose. Because of their resistive nature, these channel fills stand up as low ridges on Cedar Mountain exposures. In the remainder of the area, where no Naturita is present its former presence is suggested by scattered pebbles along the unconformity between the Mancos and Cedar Mountain. In some areas, these pebbles form a desert pavement on Cedar Mountain.

A few plant fragments have been noted in the area. Richardson (1909, p. 14) collected fossil plants near the town of Green River, which were identified by F. H. Knowlton as species of Late Cretaceous (?) age. Erdmann (1934, p. 27) reports plant fossils of Early Cretaceous age from carbonaceous shales in the area south of the Book Cliffs in eastern Utah and western Colorado, but in the same area he collected marine fossils of Late Cretaceous age from sandstones near the top of the formation. Pelecypods and ammonites collected by Reeside (1927) near Delta, Colorado, indicate early Late Cretaceous age for the upper part of the unit in that area. Young (1960) has collected late Greenhorn pelecypods from this unit a few miles to the north in the area of Woodside, Utah. In view of the age of the marine fossils in adjacent areas, it seems likely that the Naturita remnants in this area are also of Late Cretaceous age.

The depositional history of the Naturita is complex, but studies by Young (1960) indicate that the Naturita of the Colorado Plateau consists of intertonguing marine and nonmarine units laid down at and near the margins of the westward-advancing Mancos Sea. The remnants in the Green River District are interpreted as channel deposits laid down in lowland areas at some distance from the shore by streams draining inland areas to the southwest and west. These deposits fill scours in the Cedar Mountain (fig. 17) which represent the inland floodplain deposits of the Dakota group, and are in turn disconformably overlain by Mancos shale (fig. 18). It is probable that thin lagoonal and lowland deposits of the Naturita covered most of this area at one time but were removed by erosion prior to Mancos-shale deposition leaving only the resistant scour fills. Further evidence of its former presence in a large part of the District are the gray-green hues of the underlying Cedar Mountain. These colors are believed to be the result of bleaching by humic materials derived from the Naturita or carried by surface waters in pre-Naturita time.

**Mancos shale**

Overlying the Naturita and Cedar Mountain in this area is the Mancos shale, a thick unit of dark-gray calcareous marine shale. This is the outcropping unit in the northern one-third of the District. It was named
Figure 17. Naturita (Kn) formation resting disconformably on Cedar Mountain (Kcm) formation at Nine Mile Wash.

Figure 18. Tununk shale member of Mancos shale (Kmt) disconformably overlying Cedar Mountain formation (Kcm) and patches of Naturita sandstone (Kn) on Green River nose.
first by Cross and Purington (1899, p. 4) for exposures near the town of Mancos and along the Mancos River valley in southwestern Colorado. Only the three basal members of the formation are present within the area: the basal Tununk shale (Gilbert, 1877, p. 4), the Ferron sandstone (Lupton, 1916, p. 31), and the Blue Gate shale (Gilbert, 1877, p. 4).

In this area, the Tununk is a weak blue-gray to black shale which weathers to a drab gray. Near the middle of the member is a conspicuous zone, or in some areas two zones, of large calcareous ironstone concretions, which contain numerous fossils. The zone in which these dark brown-weathering spheroidal masses occur ranges from 20 to 40 feet in thickness and represents the seaward continuation of sandstone tongues of the lower part of the Ferron member present farther to the west. Thickness of the member ranges from approximately 300 feet in the northern part of the District to a maximum of about 400 feet in its most southwestern exposure (fig. 10). Nearly everywhere in the area the fossil pelecypod *Gryphaea* sp., closely resembling *Gryphaea newberryi* Stanton, is present within a few feet of the base of the member. *Gryphaea* is missing on the Green River nose, suggesting some uplift of this structural feature prior to Tununk deposition. The presence of *Gryphaea newberryi* and *Inoceramus labiatus* in the shale beneath the concretionary zone indicates that this portion of the Mancos is Greenhorn in age (Cobban and Reeside, 1952). Fossils in the upper portion of the member include *Collignoniceras woolgari* and *C. hyatti* of lower Carlile age (Katich, 1956, p. 118). The Tununk thins westward beyond the District by intertonguing at the base with the Naturita and intertonguing at the top with nonmarine deposits of the Ferron member.

The Ferron member of this area is a thin shaly sandstone unit about 30 feet thick. It is the easternmost extension of the upper portion of a thick wedge of nonmarine deposits present to the west. The concretionary zones in the Tununk are seaward extensions of lower sandstones in this same nonmarine wedge. Because of its relatively resistant nature, the Ferron forms a low outward-facing cuesta conspicuous in the gently rolling topography developed on the shales of the Mancos (fig. 18). From this member Katich (1956, p. 118) reports *Prionocyclus wyomingensis*, *Scaphites warreni*, *Inoceramus dimidius*, and *Ostrea lugubris* characteristic of Frontier or middle Carlile age and a few *Scaphites sp.* believed by W. A. Cobban to be of upper Carlile age.

Overlying the Ferron, with a possible slight disconformity, is the Blue Gate shale, a pale blue-gray shale unit containing many thin sandy zones and an occasional thin discontinuous limestone. This unit probably exceeds 2,000 feet in thickness in the area, and, on the basis of fossil evidence, much of the Blue Gate is considered to be Niobraran (Spieker and Reeside, 1925, p. 438).

**Quaternary system**

Terrace gravels are present at various places along the Green and San Rafael Rivers. Especially prominent near the mouth of the San Rafael River, they are present at several levels up to approximately 350 feet.
above the present river (Baker, 1946, p. 94). In places, these terrace gravels are cemented by caliche to form resistant beds up to 10 feet thick.

STRUCTURE

General features

The basic structure of the Green River District is a broad shallow syncline plunging gently northward, with dips up to 11 degrees on the western side but varying from 2 to 3 degrees in the rest of the area (pl. 1 and figs. 19 and 20). It is a southward projection of the Uinta Basin, bounded on the west by the San Rafael Swell uplift, on the east by a northwest extension of the Cane Creek anticline, and on the south by a northwest projection of the Monument uplift. The extension of the Monument uplift is the Nequoia arch, a broad northwest-trending structure which gently domed the sediments south of the San Rafael River and imparted a gentle northward dip to sediments in the southern portion of the District. The extension of the Cane Creek anticline is a broad north-trending arch lying near the eastern border of the District. This arch plunges to the north and culminates in the Green River nose. The Green River flows along the crest of this arch for many miles.

Folds

Superimposed on the large structural features are a few minor flexures which may, in part, reflect folding prior to that which produced the present structural configuration.

Along the western border of the District, several small anticlinal folds or noses plunge generally eastward off the steeply dipping flank of the San Rafael Swell. These folds are readily visible in the Morrison and older formations but die out rapidly eastward and are usually not visible in Cretaceous rocks. The apparent rapid eastward termination of these folds may be due in part to flattening from the steep dips of the east flank of the Swell to the relatively low dips in the desert to the east (figs. 20 and 21), or to dying out in the incompetent shales, but may also be explained by postulating that the folds were pre-Cretaceous and were subdued by post-Morrison erosion and deposition. That these folds were not formed by the same forces responsible for formation of the Swell is suggested by their nearly east-west trend in contrast to the N. 10°-20° W. trend of the Swell in this area. Stokes (1954) concluded that northeast channel trends in the Salt Wash of this area reflect the influence of an ancestral San Rafael Swell. These Salt Wash channels tend to curve to the right (east) when viewed looking downstream.

Although at least three of these small folds have been recognized along the western edge of the District, the best known is the Tidwell nose (fig. 21 and frontispiece) which trends about S. 65° E. just north of the Tidwell Ranch. Other small flexures have been noted along the southern margin of the area and most of them are apparently confined to
Figure 19. Structure contour map of Green River mining district, Emery and Grand Counties, Utah.
Figure 20. Aerial view of southern portion of Green River mining district looking southeast.

Figure 21. Aerial view of Tidwell nose and mining area looking westward toward San Rafael Swell. Diagonal fractures parallel crest of nose in Salt Wash (Jms). Brushy Basin (Jmb) and Cedar Mountain (Kcm) in foreground.
pre-Cretaceous sediments. One such structure, near Highway 24, is visible in the Brushy Basin, but is truncated by post-Brushy Basin erosion and unconformably overlain by Cedar Mountain beds (fig. 13). Because of their small amplitude, these folds are poorly shown by the structure map (fig. 19). However, the Tidwell nose does stand high topographically, perhaps because the Salt Wash sandstone here contains abundant CaCO₃ introduced by mineralizing solutions.

All of these features seem to point to the presence of structural highs in this area prior to the main period of uplift of the San Rafael Swell, and probably of the Monument upwarp, in Late Cretaceous time. Additional evidence for uplift here during late Early or early Late Cretaceous time is the absence of the Naturita in large areas, either as the result of erosion or nondeposition.

Other later movements must have occurred in this area; but, because of the absence of deposits younger than Mancos, evidence for them is lacking in the District. Evidence is present, however, in younger deposits in the Book Cliffs, just to the north. Book Cliffs deposits are not discussed in this paper but their thicknesses and stratigraphic positions are shown in figure 2. Disconformities present between certain of these units reflect movements which surely must have also affected the Green River District. Disconformities are present between (1) the Blackhawk and Price River formations, (2) the Price River and the lower North Horn formation, and (3) the lower and upper North Horn.

There is no apparent angularity between any of these units and all dip uniformly into the Uinta Basin at relatively low angles, indicating that the major Laramide orogeny in this area must have occurred subsequent to deposition of the Eocene Green River formation.

Fractures

Faulting is largely confined to two northwest-trending zones of normal faults which have formed numerous grabens (fig. 19). The northernmost fault zone crosses the Green River about 4 miles south of the town of Green River. The largest fault in this zone, the Little Grand fault (fig. 22) curves in an arc from near Crescent Junction, where it joins the Salt Valley graben fault zone, westward to the San Rafael Swell. Where it crosses the Green River nose, displacement on the fault is about 900 to 950 feet with Brushy Basin faulted against Entrada. Because of this fault, strata on the nose, to the south of the fault, dip 30° N. while those north of the fault dip 2° N. (Hager, 1956, p. 181). Displacement decreases westward to termination against the flank of the Swell.

The second fault zone lies about 3 to 5 miles south of the first. In the western part of the District, the two fault zones are parallel, but east of the Green River the southern zone continues southeastward to a junction with the Moab and Spanish Valley fault zones instead of swinging
Figure 22. Trace of Little Grand fault 4 miles south of town of Green River. Tununk shale (Kmt) in foreground in contact with Brushy Brushy shale (Jmb). View looking northwest.

Figure 23. Longitudinal fractures in Navajo sandstone (Jurassic) on east flank of San Rafael Swell. View looking north.
northward as does the northern zone. In this area, the average trend of the southern zone of graben-forming faults is N. 65° W. This trend can be traced into the Tidwell mineral belt where some of the faults follow the axis of the Tidwell nose (fig. 21). On the Tidwell nose the maximum displacement on any of these faults is about 10 feet, but near the Green River one fault block has been down-dropped about 200 feet (fig. 19).

A third zone of normal faulting, with a N. 15° W. trend, appears to connect the two major zones a short distance east of the Green River. A few other small faults with random orientation are also present in the area (fig. 19).

Age of these faults is not known but it is probable that they formed during or following formation of the Monument upwarp and the San Rafael Swell in Late Cretaceous or early Tertiary time.

Joints

Nearly all the rocks exposed in the Green River District are thoroughly jointed and the trends of many of these joints are shown in plate 1. Before attempting to interpret any fracture or joint pattern, it is necessary to review some probable modes of formation of these joints.

It is probable that during or soon after lithification most sediments become broken by joints. These joints result from minor crustal adjustments, local settling, differential compaction and perhaps dessication. As a result each lithologic unit, whether thick or thin, develops its own characteristic joint pattern which differs from place to place and is commonly completely different from that of overlying and underlying units (fig. 14). In most sediments, early joints form vertically but occasionally incline somewhat from the normal. Many early joints are healed by cementing materials but may be still visible. An example of early jointing is the N. 35°-45° W. joint set developed in caliche-cemented Quaternary gravels near the mouth of the San Rafael River.

Other joints are undoubtedly formed as the result of lateral compression and vertical uplift. However, fractures or joints formed in this way are not recognizable in the Green River District.

In the event of compression, longitudinal and shear joints should be present but neither have as yet been recognized.

Vertical uplift can result in many different types of fractures. Most common are tension joints and faults which tend to form along crests or around margins of those areas undergoing greatest uplift. The origin of these features may later be obscured by subsidence following uplift, such as apparently occurred in the Swell. Subsidence following the uplift resulted in the downdropping of the central portion of the Swell along numerous vertical faults whose inward sides are now downthrown. Some of these cross the Swell nearly normal to its axis while others parallel the axis. Those that parallel the axis are most common on the flanks of the
Swell and a few are present on its boundary with the Green River District (fig. 23).

Rim joints are formed parallel to the outcrop by removal of support during erosion. Some channels exhibit patterns formed in this way (fig. 8).

Detailed fracture studies in the mines of the Tidwell mineral belt show that the major joint set in the ore-bearing sandstone strikes about N. 50° W. (fig. 26), is normal to the bedding, and is largely restricted to that unit. A few vertical joints and faults with a N. 65° W. strike penetrate the entire exposed stratigraphic section (fig. 21). Three less prominent joint sets striking N. 40°-50° E., north-south, and east-west are recognizable in the ore-bearing sandstone.

Several types of material filling fractures have been noted in the District. Joints in the Quaternary gravels near the mouth of the San Rafael River are filled with caliche (mostly CaCO₃). A few fractures in the Tidwell mining area contain fillings or coatings which were probably formed in the present erosion cycle. Some exhibit films of tyuyamunite on CaCO₃ coatings on sandstone (fig. 24). Others have a thin coating of chalcedony on manganese-stained sandstone (fig. 25). In some outcrops, CaCO₃ coatings are present on chalcedony indicating that the chalcedony is the oldest and tyuyamunite the latest of the coatings.

GEOLOGIC HISTORY

In order to present a clearer picture of the geologic history of the Green River District, the following outline of major geologic events, subsequent to deposition of the Navajo sandstone, has been constructed from data obtained in this District and adjacent areas:

1. Invasion of Carmel Sea from the west in Middle Jurassic time.
2. Deposition of sandstone of basal Carmel formation from reworked Navajo sandstone, followed by marine mudstones and limestones, and evaporites, chiefly anhydrite.
3. Gradual retreat of Carmel Sea with deposition of marginal marine upper Carmel and Entrada sandstones in early Late Jurassic time.
4. Hydration and flowage of Carmel evaporite deposits resulting in local contortion of Carmel and Entrada.
5. Advance of Curtis Sea from west and truncation of small contorted structures.
7. Broad, gentle upwarp of large part of central Utah accompanied by slight erosion.
Figure 24. Thin coatings of tyuyamunite (t) and CaCO$_3$ (C) on fracture surface.

Figure 25. Chalcedony and manganese oxide on fracture surface, Tidwell nose.
Figure 26 in pocket
8. Deposition of fluviatile Salt Wash sandstone and Brushy Basin shale members of Morrison formation by northeastward-flowing aggrading streams. Volcanic activity in Mesocordilleran region to west and southwest indicated by bentonitic material of Brushy Basin.

9. Small east-trending folds formed by north-south compressional forces in Late Jurassic or Early Cretaceous time.

10. Possible accumulation of petroleum in Salt Wash sandstones on small structures.


12. Deposition of fluviatile Cedar Mountain formation by east-flowing streams in late Early and early Late Cretaceous.

13. Local upwarp accompanied by erosion (mid-Cretaceous orogeny?).

14. Deposition of conglomeratic fluviatile Naturita formation, largely as channel fill. Bleaching of Cedar Mountain mudstones by swamp waters.

15. Local upwarp with nearly complete erosion of Naturita in Green River District in early Late Cretaceous.

16. Deposition of major portion of marine Mancos shale and associated nonmarine "Mesa Verde" deposits (including Ferron sandstone member of Mancos shale and Blackhawk formation) during general eastward retreat of Mancos Sea punctuated by small-scale westward transgressions.

17. Upward of ancestral San Rafael Swell (early Laramide orogeny) accompanied by erosion.

18. Deposition of nonmarine Late Cretaceous Price River formation and upper Mancos shale.

19. Further uplift of San Rafael Swell followed by some erosion.

20. Deposition of lower portion of fluviatile North Horn formation and its probable equivalent, the Tuscher formation, of latest Cretaceous age.

21. Renewed uplift of the Swell and accompanying erosion at end of Cretaceous.

22. Deposition of the upper or Paleocene portion of the North Horn formation, the fluviatile and lacustrine Eocene Colton and Green River formations, and probably other younger units.
23. Major period of uplift beginning in Miocene and continuing until early Quaternary and accompanied by deep erosion and dissection.

24. Deposition of terrace gravels and silts along stream channels during Pleistocene.

25. Renewed stream erosion in Recent time.

No attempt has been made to incorporate in this sequence the period or periods of uranium deposition in the District. If the age of these deposits is similar to that of most others on the Colorado Plateau, they were probably emplaced some time after Salt Wash time and prior to the pre-Flagstaff movement in Late Cretaceous and early Tertiary time. Some collateral evidence from adjacent areas may be of significance in determining the age of these deposits. Small primary deposits of uranium have been found in the upper or Paleocene portion of the North Horn formation on the Wasatch Plateau to the west of the Swell. Other primary deposits have been found in the Eocene Colton formation a few miles northeast of the town of Green River, suggesting that some Green River deposits could possibly be late Eocene or younger.

ECONOMIC GEOLOGY

History

Uranium-vanadium occurrences have been known in eastern Utah since the 1880's. Uranium-bearing outcrops, discovered at that time by sheepherders 12 miles southwest of Green River, Utah, about one mile east of the San Rafael River gorge, were subsequently prospected and claimed by Judge J. W. Warf of Price. The rate of subsequent development is unknown but deposits of this area were described by Boutwell (1905), as having been thoroughly worked and a shipment of 15 tons of ore had been sent to Germany. The workings were prospect pits and test cuts on "carnotite-bearing conglomerate debris." Deposits, then as now, were found at various horizons in a 20- to 80-foot section of coarse sandstone and fine conglomerates near the top of the Salt Wash sandstone member of the Morrison formation. Several other geologists have reported on the uranium deposits in the Green River District since Boutwell first described them. In 1911, F. L. Hess (1913) visited the area and made a report on the "carnotite" deposits. Moore and Kithil (1914) noted the association of "carnotite" and black ore with carbonaceous material. Van Voorhis (1914) and Hill (1915) examined the area for the Union Mines Development Corporation and made evaluations of uranium potential. A recent report by Clark and Million (1956) deals primarily with uranium occurrences in the Tidwell mineral belt.

Jensen (1953) recommended that the Atomic Energy Commission drill this area in order to stimulate private activities. A Commission drilling program was successfully carried out in 1954 and 1955 with 5,422 feet of hole drilled (Million, 1957). As a result, private drilling was greatly increased and subsequently, considerable ore was discovered.
Production

Uranium and vanadium deposits in the area were first exploited about 1905. Hand-sorted "carnotite" ore and fossil logs, containing as much as 3 percent uranium oxide, were sold on European markets for the radium content. In 1911, about 2 tons of ore were mined from the Little Bessie and Little Vernon claims in the northwestern part of the District, and a carload of ore shipped by a Mr. Ward and his associates is reported to have contained more than 6 percent of combined vanadium-uranium oxides (Hess, 1913). Moore and Kithil (1914, p. 16) reported that vanadium ore shipped in 1912 ranged from 1 to 2 percent U₃O₈ and from 2 to 8 percent V₂O₅. A few tons of uranium ore were sold to eastern buyers and to H. W. Balsley of Moab during the period 1920-1945 (Hill, 1945). Slightly more than 250 tons of uranium ore were sold to the Metals Reserve Company at Thompsons, Utah, in 1943 (Hill, 1945), but shipments could not be maintained because the vanadium content fell below the minimum grade of 1.25 percent specified by the buyer. The low grade of vanadium, generally less than 1 percent, retarded development of the district, and Van Voorhis (1944) reported no production in 1944. Irregular shipments of "carnotite" ore from small pits continued until 1948, when higher prices for uranium spurred greater production.

Annual production since 1948 is given in Table 1. Production records prior to 1948 are incomplete, but total production to date has been approximately 200,000 tons of ore averaging about 0.25 uranium oxide and 0.25 vanadium oxide.

Table 1. Green River District uranium ore production, 1948-1959.

<table>
<thead>
<tr>
<th>Year</th>
<th>Producing mines or claims</th>
<th>Tons of ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948</td>
<td>9</td>
<td>661</td>
</tr>
<tr>
<td>1949</td>
<td>30</td>
<td>2,071</td>
</tr>
<tr>
<td>1950</td>
<td>38</td>
<td>2,139</td>
</tr>
<tr>
<td>1951</td>
<td>18</td>
<td>365</td>
</tr>
<tr>
<td>1952</td>
<td>21</td>
<td>717</td>
</tr>
<tr>
<td>1953</td>
<td>19</td>
<td>1,038</td>
</tr>
<tr>
<td>1954</td>
<td>24</td>
<td>5,245</td>
</tr>
<tr>
<td>1955</td>
<td>26</td>
<td>16,202</td>
</tr>
<tr>
<td>1956</td>
<td>22</td>
<td>30,665</td>
</tr>
<tr>
<td>1957</td>
<td>18</td>
<td>38,433</td>
</tr>
<tr>
<td>1958</td>
<td>17</td>
<td>38,975</td>
</tr>
<tr>
<td>1959</td>
<td>20</td>
<td>39,659</td>
</tr>
</tbody>
</table>

Mining development

Most of the mines are located in the northwestern part of the area in a belt approximately 2 miles long and 1 mile wide (the Tidwell mineral belt). This belt includes nearly all of secs. 22 and 27, T. 21 S., R. 14 E. (pl. 1). A few small mines and prospects are located in Tps. 22 and 23 S., R. 14 E., the so-called Acerson area.
Size of the workings ranges from small prospect pits to shafts over 300 feet deep and inclines several hundred feet long. Prior to 1953, all the workings were small surface pits or strippings. After 1953, with the discovery of larger and deeper bodies, the mines increased in size and depth. At present, one mine is producing ore from a depth of 380 feet. The largest mine is the Outwest, comprising the former Inclines 1, 2 and 7. The next largest mine is Incline No. 6 of the Four Corners Uranium Company (fig. 26), which had approximately 2,600 feet of the underground workings in early 1957. There have been four types of operations in the area: shafts, inclines, stripping operations, and drifts, but in 1960, there are 16 inclines and 7 shafts in operation. Shafts range from 80 to 380 feet deep and inclines range from 60 to 200 feet deep. The diversity of operations is due to the many lessees on the properties and to varying depth and size of ore bodies. Principal claim owners are Four Corners Uranium Company and Uranium Prospectors Limited. Both companies lease small areas to individual operators. The ore is now trucked into Green River, Utah, loaded on railroad cars and shipped to Salt Lake City for milling.

Progress of discovery

Prior to 1949-1950, all ore bodies were discovered by surface prospecting or by very shallow long-steel drilling. In 1949-1950 Walter Gramlich, using a wagon drill, discovered a few small ore bodies, none of which exceeded 200 tons or lay at depths greater than 40 feet. In the Spring of 1953, the Atomic Energy Commission drilled a series of six deep holes, three of which encountered mineralized Salt Wash. During the same period, two lessees on the Four Corners Uranium property drilled out, by long steel, an ore body containing 700 tons of ore averaging 0.85 percent uranium oxide at a depth of 25 feet. The area then began to receive more attention. Thousands of feet of exploratory drilling was done from 1953 to 1956, most of it in 1954 and 1955. While the average drilling depth was about 160 feet, some core holes reached a depth of 760 feet, resulting in the discovery of ore bodies downdip, many of them beneath the water table. A few of the deep clusters of ore bodies probably contain up to 100,000 tons of ore while most of the shallow ore bodies contain less than 1,000 tons. The water table, which is encountered at variable depths, dips slightly to the east (fig. 27). The depth variation is probably due in part to topography and in part to perched water tables. The Uranium Prospectors Limited shaft, which reached a depth of 300 feet, pumped 40 to 60 gallons of water per minute. Shattuck-Denn's Jerry Boy shaft now pumps about the same amount from a depth of 380 feet.

All mines use the room-and-pillar method of mining. Only one mine still uses track, while the other operations use either rubber-tired shuttle buggies of about 3 tons capacity, or smaller tracked vehicles. Air slushers were formerly used in most of the mines, but front-end loaders and mucking machines are now most common.
Figure 27. Contour map on top of water table, Four Corners Uranium claims, Green River District, Emery County, Utah.
**MINERALOGY**

**Barren zones**

**Detrital constituents**

The mineralogic composition of Salt Wash sandstones in the Green River District is shown in Table 2. Quartz and chert grains are the principal detrital constituents, making up 80 percent or more of unmineralized sandstone; chert content ranges from 1 to 26 percent. Detrital grains of feldspar and felsic volcanic rocks are present in amounts usually less than 3 percent. Feldspar varieties include sodic plagioclase, orthoclase, and microcline. Most of the feldspar was considerably altered to sericite and clay, while felsitic rocks, including trachytic and dacitic varieties, are moderately altered to sericite and clay. Biotite, hornblende, titanite, and garnet occur in trace amounts.

Quartz and chert grains are rounded to subangular. Quartz grains range in size from 0.05 to 0.3 millimeters, while chert grains may be as much as several centimeters in diameter. Many quartz grains exhibit foliated strain shadows suggestive of a metamorphic origin. Authigenic quartz overgrowths commonly occur around quartz grains.

Chert varieties range from cryptocrystalline chalcedonic to microcrystalline quartzitic and may contain argillaceous or calcareous material. This extraneous material largely determines the type of alteration and weathering of the chert. Impure chert is commonly bleached in ore zones and crumbly along surface exposures (fig. 7), whereas dense quartzitic varieties may remain fresh even adjacent to ore zones.

**Cementing constituents**

Sandstone interstices are filled with clay, carbonate, and organic matter. Interstitial clay of montmorillonitic composition ranges from 4 to 14 percent in barren zones but may exceed 50 percent in some mineralized zones. Much of the clay is indigenous, but some of it was probably formed during alteration by mineralizing solutions. Carbonates occur as well-developed rhombs of calcite or dolomite between sand grains in both barren and ore zones. Carbonate cement ranges from 11 percent along the crest of the Tidwell nose to 1 percent elsewhere in the Tidwell belt. Organic matter in the form of asphaltic material and lignite is usually present in trace amounts in unmineralized sandstone but occurs in mineralized zones more abundantly.

**Ore zones**

**Primary ore minerals**

Primary minerals identified from the ore zones of Salt Wash sediments in the Green River District include coffinite, uraninite, montroseite, sphalerite, pyrite, marcasite, chalcopyrite, and clausthalite.
Table 2. Mineralogic composition of Salt Wash sandstone in Green River Mining district

<table>
<thead>
<tr>
<th>Locality</th>
<th>Detrital Components</th>
<th>Interstitial Components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quartz</td>
<td>Chert</td>
</tr>
<tr>
<td>Old workings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four Corners Uran. Co. (unmineralized)</td>
<td>76</td>
<td>7</td>
</tr>
<tr>
<td>Salt Wash outcrop</td>
<td>54</td>
<td>26</td>
</tr>
<tr>
<td>4 mi. S. of Desert Moon mine (unmineralized)</td>
<td>77</td>
<td>2</td>
</tr>
<tr>
<td>Incline 6 mine near ore zone. (slightly mineralized)</td>
<td>62</td>
<td>1</td>
</tr>
<tr>
<td>Smith Lucas mine in ore zone. (mineralized)</td>
<td>58</td>
<td>11</td>
</tr>
<tr>
<td>McDougall shaft in ore zone. (mineralized)</td>
<td>18</td>
<td>1</td>
</tr>
</tbody>
</table>

Thin sections of samples from representative localities were examined under the petrographic microscope. Three hundred particles were identified and classified from each section by the point-count method.
Coffinite. Coffinite \((U(SiO_4)_{1-x}(OH)_{4x})\) is the most abundant ore mineral (primary or secondary) in the District and has been identified in all of the mines for which mineralogical studies have been made.

Coffinite was first identified and studied by X-ray by Stieff, Stern and Sherwood of the U. S. Geological Survey and described by them as a uranium silicate similar in structure to thorite (1955). Optical and physical properties have not yet been fully determined.

In the present study, polished thin sections were made of samples from which coffinite had been identified by X-ray analysis. Sections were studied microscopically, and autoradiographs and photomicrographs were made. Radioactive material, presumably coffinite, occurs in translucent lignitic material as rims around pyrite (figs. 28, 29, and 30). It also rims quartz (figs. 31 and 32), and appears to be translucent on very thin edges, relatively high in relief, and moderately to poorly reflective. It does not appear to be visibly anisotropic nor pleochroic in reflected light.

Uraninite. Uraninite \((UO_2, UO_3)\) is second in importance only to coffinite as an ore mineral in the District and has been identified from many of the mines. Uraninite is commonly associated with coffinite and montroseite and nearly always occurs as wood replacements or disseminations in "asphaltite". Cell walls of fossil wood are usually replaced by uraninite, which appears to have been subsequently replaced by asphaltic material (figs. 33 and 34). In many cases, uraninite is difficult to distinguish from uraniferous "asphaltite" because of similarities of reflectivity. Both uraninite and "asphaltite" are light gray in reflected light and have reflective intensities of approximately 16 percent. They may in some cases be distinguished by differences in reflected anisotropism. Uraninite is invariably isotropic, whereas "asphaltite" may be anisotropic.

Montroseite and paramontroseite. Montroseite \((VO(OH))\) and paramontroseite \((V_2O_2)\) are the primary vanadium minerals in the District. These minerals are grouped together in this report since they cannot be differentiated optically.

Montroseite, originally described by Weeks and others (1953), has been found only in Plateau-type deposits. Paramontroseite has been described by Evans and Mrose (1955) as a paramorph after montroseite.

In this District, montroseite occurs as concretionary halos around logs and as disseminations in sandstone rich in organic matter. Montroseite is usually bladed, acicular, or occasionally spherulitic (figs. 35, 36, and 37). It replaces quartz and is sometimes imbedded in vanadium clay. The hardness of montroseite is about 2 and it takes a good polish. Reflection colors are medium to light gray and the reflected anisotropism varies from dark blue to brownish gray.

Sulfides and selenides

Sphalerite (variety cleiophane). Sphalerite \((ZnS)\) occurs locally in
Figure 28. Autoradiograph of figures 29 and 30.

Figure 29. Pyrite (py) cubes in lignite, Four Corners Uranium Company. 150 X. Transmitted light. Pyrite partially replaced by coffinite (cof).

Figure 30. Same view as figures 28 and 29 in reflected light. 150 X.
Figure 31. Coffinite (?) (cof) rimming quartz (qt). 1500 X. Reflected light.

Figure 32. Translucent properties of coffinite (?) (cof). Same field as figure 31 with transmitted light. 1500 X.
Figure 33. Uraninite (ur), "asphaltite" (asp), and pyrite (py) in a clay and quartz (qt) matrix. 250 X. Reflected light.

Figure 34. Uraninite (ur) replacing fossil wood. Clay, quartz (qt), and pyrite (py) in matrix. 250 X. Reflected light.
Figure 35. Montroseite (mr) spherulites in clay replacing mudstone (ms). 250 X. Reflected light.

Figure 36. Same field as figure 35 in transmitted light. 250 X. Reflected light.

Figure 37. Montroseite (mr) and pyrite (py) filling cells in wood. 1500 X. Reflected light.
ore zones in most of the mines in the area (figs. 38, 40). Associated
minerals are commonly coffinite, uraninite, and pyrite. In transmitted
light, sphalerite is colorless to pale yellow, isotropic, and has high
relief. In reflected light, it is very light gray, isotropic, and dis-
plays internal reflection. These properties suggest a very low iron
content for the sphalerite, and thus it might more properly be referred
to as the nearly iron-free variety, cleiophane.

Pyrite. Pyrite (FeS\textsubscript{2}) occurs abundantly in all the mines in the
District. It replaces cell walls in wood, fills cell centers (fig. 39),
and surrounds some logs as concretionary halos. It disseminates through
all ore horizons, and nearly every primary mineral from the area is associ-
ated with pyrite at one place or another. It often contains appreciable
amounts of arsenic. Spectrographic analysis (table 3) reveals nearly 10
percent arsenic in one pyrite sample from the Waterson shaft.

Marcasite. Marcasite (FeS\textsubscript{2}) is almost as abundant as pyrite with
which it is closely associated. Laths of marcasite are often embedded
in a pyritic groundmass. Like pyrite, it commonly replaces wood, fill-
ing cell centers and occasionally replacing cell walls. Marcasite is
associated with most of the primary minerals and is readily recognizable
by its reflected optical properties. Reflection colors of marcasite are
white to cream and polarization colors vary from greenish yellow to red
to purple. Some of the material considered as marcasite may actually
be ferroselite (FeSe\textsubscript{2}) which closely resembles marcasite. This may
account for the large amount of selenium present in marcasite and pyrite
samples.

Chalcopyrite. Chalcopyrite (CuFeS\textsubscript{2}) occurs sparsely, often associ-
ated with pyrite, montroseite and sphalerite (fig. 40) as wood replace-
ments. It has been identified only from two localities, the Black mine
and the Big Bend Uranium Company's open-pit mine, both of which are near
the southern margin of the District.

Clausthalite. Clausthalite (PbSe) occurs sparsely, associated with
pyrite, montroseite, and coffinite in asphaltite, and has been identified
only in the Black mine of the Union Oil and Mining Company, located near
the southwestern edge of the District (pl. 1). Selenium may also occur
as ferroselite but this mineral has not yet been identified.

Secondary ore minerals

Supergene alteration of the primary assemblage has resulted in a
number of secondary minerals which occur as impregnations in weathered
outcrops and coatings on mine walls. These minerals include corvusite,
hewettite, tyuyamunite and metatyuyamunite, uranopilite, liebigite, and
schroeckingerite.

Corvusite. Corvusite (V\textsubscript{2}O\textsubscript{4}.6V\textsubscript{2}O\textsubscript{5}.nH\textsubscript{2}O) occurs as thin bluish-black
coatings on mine walls and impregnations in sandstone. It is commonly
associated with montroseite, from which it has been derived as an alteration
product, and with tyuyamunite.
Figure 38. Sphalerite (sp) embedded in chalcedony (ch). "Asphaltite" (asp) at bottom. 250 X. Reflected light.

Figure 39. Pyrite (py) replacement of cell centers in wood surrounded by "asphaltite" (asp) that passes into veinlets. Sandstone host is largely quartz (qt). 250 X. Reflected light.
### Table 3. Spectrographic analyses of Salt Wash samples.

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**Sample Localities:**
- Sandstone samples:
  - No. 24353a - Mineralized zone around log, Waterson shaft
  - No. 35 - Silicified zone in log, Waterson shaft
  - No. 36 - Asphalted rim around log, Waterson shaft
  - No. 37 - Silicified zone in log, Waterson shaft
  - No. 38 - Inner asphalted zone, Waterson shaft
  - No. 39 - Inner silicified zone, Waterson shaft
  - No. 40 - Incline No. 6 mine
  - No. 41 - Incline No. 6 mine
  - No. 42 - Smith-Lucas mine
  - No. 43 - Outcrop on Midwell mine
  - No. 44 - McDougall Incline mine
  - No. 45 - Desert Moon mine
  - No. 46 - Waterson shaft

- Clay samples:
  - No. 243018 - Incline No. 6 mine

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-58-
Hewettite. Hewettite ($\text{CaV}_4\text{O}_{16} \cdot 9 \text{H}_2\text{O}$) is rare but has been noted in some of the mines where it occurs in isolated nodular aggregates and as coatings on fractures close to pods of black high-vanadium ore. It is commonly associated with hematite along the fractures and is reported by local residents to occur on Salt Wash outcrops on the Green River structural nose just south of the town of Green River.

Tyuyamunite and metatyuyamunite. Tyuyamunite ($\text{Ca(UO}_2)_2(\text{VO}_4)_2 \cdot 7-10\frac{1}{2}\text{H}_2\text{O}$) and its partially dehydrated equivalent metatyuyamunite ($\text{Ca(UO}_2)_2(\text{UO}_4)_2 \cdot 5-7\text{H}_2\text{O}$) are the most abundant secondary minerals in the area. They do not occur where primary vanadium minerals are absent and are commonly associated with corvusite. They may occur as bright-yellow coatings on mine walls and carbonaceous matter, as veinlets in corvusite and montroseite halos around logs, and as coatings on fracture surfaces (fig. 25).

Schroeckingerite. Schroeckingerite ($\text{NaCa}_3(\text{UO}_2)(\text{CO}_3)_3 \cdot (\text{SO}_4)F \cdot 10\text{H}_2\text{O}$) is common in most mines in the area but especially so in those in which the ore is high in carbonate. It coats walls in the older portions of damp mines and is present on some pillars which show no trace of other uranium minerals. In the No. 6 Incline, it commonly occurs in a blue clay at the base of the ore zone. Schroeckingerite is yellow and shows relatively weak yellowish-green fluorescence.

Uranopilite. Uranopilite ($\text{(UO}_2)_6(\text{SO}_4)(\text{OH})_{10} \cdot 12\text{H}_2\text{O}$) is abundant where primary vanadium minerals are sparse and sulfide is common. It may occur where pyrite is oxidized in the vicinity of primary uranium minerals and is sometimes associated with gypsum. Uranopilite is quite similar in color to tyuyamunite but can be differentiated by its bright yellow-green fluorescence.

Liebigite. Liebigite ($\text{Ca(UO}_2)(\text{CO}_3)_3 \cdot 10-11\text{H}_2\text{O}$) apparently occurs where carbonates are more abundant than sulphates and vanadates. It occurs as pale yellowish-green coatings, of scaly habit, on mudstone, and fluoresces a bright, light green.

Secondary gangue minerals

Secondary gangue minerals are common in all deposits and include barite, clay, carbonates, quartz and chalcedony, apatite, ilsemannite, halotrichite, and alunogen.

Barite. Barite ($\text{BaSO}_4$) occurs sparsely along certain ore-bearing strata in the Salt Wash. It is usually euhedral and may be yellow to light brown. Associated minerals are pyrite, marcasite, and clay. In some areas, it occurs as fracture fillings in carbonized logs and is associated with chalcedony.

Clay. Montmorillonite-chlorite mixed-layer clay occurs near mineralized zones as (1) interstitial fillings around corroded sand grains, (2) seams of green clay, (3) vertical fillings along fault zones, and (4) galls in the ore horizon.
Figure 40. Sphalerite (sp) rimmed by chalcopyrite (cy). 500 X. Reflected light.

Figure 41. Quartz (qt) grains with overgrowths. Interstitial calcite (ca). 500 X. Transmitted light, crossed nicols.
A vanadium-bearing clay is sometimes associated with montroseite around replaced quartz grains.

The high tin content of some of these clays is indicated in table 3.

Carbonates. Calcite (CaCO$_3$) and dolomite (CaMg(CO$_3$)$_2$) are found locally, predominantly above but also partly within ore zones, especially in those mines near the crest of the Tidwell nose. Carbonates occur interstitially between sand grains (fig. 41), as replacements of quartz grains, and as coatings on fractures.

Quartz and chalcedony. Much of the silicification of woody material in the Salt Wash appears to have been nearly contemporaneous with mineralization. Chalcedony coatings on fractures in the Tidwell mineral belt (fig. 25) however, are apparently much more recent. Chalcedony and quartz in ore bodies are intimately associated with many primary minerals including montroseite (fig. 42), pyrite, sphalerite and marcasite. Much of the chalcedony and quartz is stained brown by later introduction of asphaltic material.

Apatite (dahllitic variety). Apatite was identified microscopically as dahllite (Ca$_7$(CO$_3$)(PO$_4$)$_4$.4H$_2$O) and by X-ray as a fluorapatite variety (Ca$_4$(CaF)(PO$_4$)$_3$). It occurs with ore minerals in mineralized reptilian bone (fig. 43).

Ilsemannite. Ilsemannite (MoO$_3$.SO$_3$?) occurs in a few of the mines in the District. It commonly effloresces on walls and floors of damp mines in which sulfides are abundant, and is usually associated with alunogen, uranopilite, and halotrichite. The source of the molybdenum is not certainly known, but, in some ore deposits of other areas, molybdenum occurs in pyrite (S. R. Austin, oral communication).

Hydrous sulfates. The hydrous sulfates halotrichite (FeAl$_2$(SO$_4$)$_4$.2H$_2$O) and alunogen (Al$_2$(SO$_4$)$_3$.18H$_2$O) commonly occur in wet mines in the presence of sulfides. These highly soluble salts effloresce and commonly form silky hairlike growths on fractures and mine walls. Associated minerals are uranopilite and ilsemannite.

Paragenesis

Relationship of "asphaltite" to lignitic matter. Organic matter in the Salt Wash deposits of the District may be divided into four types: (1) lignitic matter possessing well-preserved cell structure (figs. 44 and 45); (2) asphaltic ("asphaltite") veinlets which transect mineralized sandstones, ores, and wood remains (fig. 46); (3) hybrid combinations of (1) and (2) whose identity is obscured by the gradational changes between lignitic and asphaltic materials; and (4) disseminated carbonaceous material much of which is of microscopic size.

Black opaque organic material, usually devoid of cell structure and resembling both asphaltic and coaliferous matter, often surrounds and
Figure 42. Chalcedony (ch) veinlet containing montroseite (mr) in silicified wood. 250 X. Transmitted light.

Figure 43. Pyrite (py) as veinlets and cell replacement in mineralized bone. Cells replaced by fluorapatite (ap). 250 X. Reflected light.
Figure 44. Lignitic matter containing marcasite (mc). 250 X. Reflected light.

Figure 45. Same field as figure 44. 250 X. Transmitted light.
Figure 46. "Asphaltite" veinlet (black, running NW-SE) cutting quartz veinlet (white) in silicified wood. 250 X. Transmitted light.
appears to replace quartz grains and ore minerals. The black organic matter often merges into asphaltic veinlets that transect surrounding sediments and fill interstices around corroded quartz grains (fig. 39).

It is apparent that asphaltic ("asphaltite") veinlets grade imperceptibly into lignite that has not moved appreciably since deposition. Both "asphaltite" and lignite have similar optical properties and undergo similar changes in optical properties when mineralized. Lignite and "asphaltite" appear to be related physically and perhaps chemically but not necessarily genetically.

There are two plausible explanations for similarities of properties of lignite and "asphaltite": (1) the lignite was the source of the "asphaltite", or (2) the lignite acted as host for asphaltic fractions of petroleum.

Data supporting lignite as the source for the "asphaltite":

1. Up to 80 percent by weight of wood can be removed, in the form of tar, by steam distillation. Hot mineralizing solutions may have distilled asphaltic tar from wood.

2. Experiments have shown that small amounts of petroliferous substances can be derived from lignitic materials subjected to moderate temperatures and pressures and that much larger volumes can be obtained from boghead and cannel coals. It is possible that some petroliferous materials were not derived from the plant material proper but from animal matter deposited with the humic material.

3. The volume of lignite, in the Salt Wash of the District, could amply supply the volume of "asphaltite" that occurs in the ore zones.

4. Figure 39 may be interpreted as follows: mineralizing solutions deposited pyrite in the cell centers and displaced resinous material from wood or lignite, forcing it into veinlets in the surrounding sandstone.

Reasons favoring lignite as the host for asphaltite:

1. "Asphaltite" appears in some cases to be the latest substance introduced into the ore zones. Lignitic, silicified, and mineralized wood structures are transected by asphaltic veinlets and appear to be hosts rather than sources.

2. The end product of steam distillation is carbonized wood. No carbonized wood has as yet been found in the ore deposits by the writers.
3. Figure 39 may be interpreted as follows: after pyritization, asphalt migrated into the space around the fossil wood and was polymerized by reaction with the sulfide.

Disseminated organic material occurs throughout the ore zones in the Tidwell mineral belt and imparts a brown to black cast to some ore in which no megascopic carbonaceous material is visible (fig. 47). Not only is this material common in and near ore zones in deeper mines, but it is also present in sandstone at the outcrop (fig. 48). Here, it appears as a sooty carbon residue in sandstone from which most of the uranium has been leached. In many places, it appears as haloes around organic remains. The origin of this material is puzzling. It may be a residue of petroleum, which accumulated in Late Jurassic or Cretaceous times in the Tidwell structure and other traps, or, it may represent finely disseminated humic material, derived from lignitic materials. It is possible that this humic material was actually a colloid or hydrosol which, like petroleum, was structurally controlled. A further possibility is that it may represent the residue of humic acids, which when subjected to radioactive bombardment break down to water and carbon.

Factors favoring a petroleum origin for this material are: (1) It is largely confined to a thin zone in the host sandstone, roughly corresponding to the ore zone. The regular nature of this thin zone and its apparent disregard of bedding planes and lithologic variations suggests an oil-water interface although it may represent an ancient ground-water level. (2) Samples of this material from the ore zone are partially soluble in ether. (3) The relative abundance of this material and its confinement to the ore zone suggest that a considerable volume was present and was trapped in that unit. At other localities in the District where uranium is present in sandstone containing abundant woody material, no evidence of this disseminated material is seen.

Factors favoring a humic origin for the material are: (1) it is commonly associated with large volumes of plant material; (2) ground waters are capable of taking into colloidal suspension large quantities of lignitic material. In some cases, as much as 80 percent of lignite or peat may go into colloidal suspension, forming a hydrosol or hydrogel, and be transported for considerable distances (Gill, 1956). It is believed that ground water has little or no effect on woody material after it has passed the peat and lignite stages in the coalification process. Just how this material could be trapped in an anticlinal structure is not known, but perhaps it would be subject to gravity separation much as oil and water. It is also possible that it could have accumulated in structural lows.

Paragenesis of mineralized wood. Wood in the Salt Wash sandstones appears to have been (1) lignitized, (2) silicified, (3) mineralized, and (4) asphaltized. This sequence of alteration occurred in approximately the order listed. Much of the lignitic material retains a brownish woody appearance and displays excellently preserved cell structures (figs. 11, 44, and 45). Lignite was locally silicified in part, and commonly grades
Figure 47. Concentration of dark ore around asphaltic (?) material (a). Ore sample from below water.

Figure 48. Disseminated carbon in sandstone from outcrop of ore horizon, Tidwell nose.
into wholly silicified wood. Silicification and mineralization show a large overlap (fig. 42).

Silicification in its early stages filled veinlets and cell centers with chert and chalcedony. In this stage, cell walls retain their lignitic composition. As silicification proceeded, both cell centers and cell walls were gradually filled and replaced by microcrystalline quartz. In places where silicification is advanced, recrystallization of chalcedony to quartz tends to destroy relic silicified wood structures (fig. 49). Quartz veinlets cut both silicified and unsilicified lignite.

Early chalcedonic veinlets in silicified wood are commonly cut by later quartz veinlets (fig. 50) which in turn are cut by still later "asphaltite" veinlets (fig. 46). Spherulitic growths of montroseite are distributed along quartz veinlets (fig. 42) and are cut by them in some cases (fig. 51).

Paragenesis of mineralized bone. Well-preserved saurian bones have been mineralized and asphaltized. Veinlets of sulfides, consisting largely of pyrite, marcasite, and sphalerite, transect bone structures (fig. 43) and rim cell walls. Bone cells are commonly filled with dahllite, but locally they are completely filled with sulfides.

Veinlets of uraniferous "asphaltite" (fig. 52) penetrate bone along apparently pre-existing veinlets of sulfides, and locally fill centers of bone cells (fig. 53). Uraniferous "asphaltite" is typically anisotropic in mottled shades of gray to brown, and shows reflection colors as high as light gray.

Paragenesis of primary and secondary minerals. Though not all minerals described are found at any one locality in the District, there is sufficient overlapping of mineral assemblages to permit outlining a probable order of deposition as shown in table 4.

The wide range in age indicated for asphaltite reflects a possible dual origin of the mineral. The earlier asphaltic material may have been derived from migrating petroliferous materials, and the later material may have been derived from carbonaceous matter. Another possibility is that all of the asphaltic material was derived from petroliferous fractions present before entry of ore solutions and served as precipitants of uranium. Alpha bombardment by the precipitated uranium may later have activated the petroliferous fractions and caused them to attack and corrode the uranium and other minerals with which they came in contact.

Nature and origin of mineralizing solutions

Features of ore deposition. Ore is largely confined to the vicinity of organic matter. It commonly occurs in areas of extensive argillization where quartz and chert grains in the host sediments are corroded or entirely replaced by clay (figs. 54, 55, 56, and 57). Asphaltite is often associated with uranium concentrations and is in contact with the previously corroded borders of the clay and quartz (fig. 54).
Figure 49. Recrystallization of chalcedony (ch) to quartz tending to destroy wood structures in silicified wood (Si wood). 250 X. Transmitted light.
Figure 50. Chalcedony (ch) veinlets cut by later quartz (qt) veinlets in silicified wood.

Figure 51. Montroseite (mr) spherulite cut by quartz (qt) veinlet in silicified wood (Si wood).
Figure 52. "Asphaltite" (asp) veinlet cutting mineralized bone. 250 X. Reflected light.

Figure 53. Uraniferous "asphaltite" (asp) filling cell centers in mineralized bone. 250 X. Reflected light.
Table 4. Paragenesis of primary and secondary minerals.

<table>
<thead>
<tr>
<th>Time</th>
<th>Syngenetic</th>
<th>Diagenetic</th>
<th>Epigenetic</th>
<th>Supergene</th>
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<td>Authigenic SiO₂</td>
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Figure 54. Corrosion of quartz (qt) by clay-producing solutions, with later "asphaltite" (asp). 500 X. Transmitted light.

Figure 55. Same field as figure 54. 500 X. Reflected light.
Figure 56. Replacement of quartz by clay in vicinity of area of mineralization. Corroded quartz (qt) grains surrounded by clay. 250 X. Transmitted

Figure 57. Corroded quartz (qt) grains surrounded by clay and "asphaltite" (asp). "Asphaltite" later than clay and not responsible for quartz corrosion. 250 X. Reflected light.
In the case of mineralized logs, silicification and mineralization overlap in time sequence. Silica and ore minerals have replaced most lignitic matter. A halo of clay extends radially outward from many organic remains. Quartz grains in this halo have been extensively corroded and interstices filled with clay, often vanadium bearing. Asphaltic matter may occur either within or outside of logs, but usually in the vicinity of uraninite or coffinite.

**Source of mineralizing solutions.** There is no conclusive evidence as to the source of the mineralizing solutions in the Green River District but the mineral assemblage and related alteration effects are similar to those which are believed by some workers to be of hydrothermal origin at nearby Temple Mountain in the San Rafael Swell (Hausen, 1959).

It is possible that mineralizing solutions originated at depth, perhaps from a buried stock or other igneous mass, and rose vertically until they reached a permeable horizon at which they could spread laterally. Assuming that the Salt Wash was saturated with water at that time, such mineralizing solutions would have moved through it laterally. It would be expected that such solutions would be warmer than the ground water filling the host rock, and hence that they would also rise, following the structure upward from the point of entry.

Another possibility is that the mineralizing solutions were merely circulating ground waters which obtained their uranium from weathering of distant granitic masses or from magmatic or juvenile waters associated with intrusives to the south of the Plateau. These solutions could have moved through the Morrison during late Morrison time and prior to deposition of the Naturita formation in Late Cretaceous time in this District.

Many students of uranium solutions believe that uranium moves as complex carbonate and sulfate ions (McKelvey, Everhart, and Garrels, 1956; Gruner, 1956), which can pass through nearly any rock type without being precipitated. The nemesis of these solutions is the reducing environment which apparently causes uranium to precipitate. Laterally moving ore solutions, regardless of origin, apparently encountered reducing environments in certain areas rich in organic matter, and precipitation resulted. It appears that the precipitants in this area were organic materials present in sandstone-filled scours on or near the Tidwell nose.

**URANIUM ORE DEPOSITS**

Both primary and secondary uranium ores are mined from the Salt Wash and Brushy Basin members of the Morrison formation in the Green River mining district. In most cases, ore mined from small pits and drifts on or near the outcrop consists largely of the yellow secondary uranium minerals, tyuyamunite and uranopilite. They occur as interstitial material in sandstone, as coatings on fractures and sand grains, and as veinlets in, and disseminations around, pods of dark ore. In these shallow deposits, the ore is apparently closely associated with carbonaceous trash, ranging
from microscopic fragments of leaves and twigs to tree trunks 50 feet long and several feet in diameter. In a few places, such as in the shallow prospects along the outcrop in the Tidwell mineral belt, some ore is associated with disseminated carbonaceous material of microscopic size. Many portions of the ore-bearing sandstone are thoroughly impregnated with this material, much of which is only weakly mineralized. Mineralization is typically discontinuous and scattered through various horizons in the vicinity of carbonaceous material and along channels and pinch outs. Sediments in the vicinity of ore zones often appear bleached. Iron oxide is present in the ferrous state; clay seams in the vicinity of ore are white to green and are often higher in vanadium near the outcrop.

In the Tidwell mineral belt, it is possible to study the progressive change in the nature of the ore horizon from the outcrop to depths below the present ground-water table. Traced down dip, the light-brown to dull-gray limonitic sandstone with yellow secondaries gradually gives way to a dark-gray to dark-brown or black sandstone containing such minerals as corvusite, coffinite, and uraninite (fig. 58). The darkest ore is usually present at or below the ground-water table.

It is probable that much of the dark color of the fresh ore is due to the presence of asphaltic material and that it is largely the residue of this material which imparts the dark-gray color to much of the ore-bearing sandstone at the outcrop.

Carbonized logs and carbonized vegetal trash are associated with uranium and vanadium minerals in areas of dark ore but the number of logs is not great. The darkest and highest-grade ore encloses small lenses or veinlets of vitreous asphaltic carbonaceous material (fig. 47). These lenses usually parallel laminae, but some appear to cut across them. In some mines, ore occurs in a horsetail pattern following minute crosslaminae (fig. 59).

The average ore contains 0.25 percent U₃O₈ and 0.25 percent V₂O₅, but high-grade pods of black ore assay as high as 15 percent U₃O₈. In general, the relative amount of vanadium decreases with depth, probably because of removal of some uranium nearer the surface.

**Configuration of ore bodies**

Individual ore deposits are tabular or lens-shaped bodies, usually lying parallel to the bedding although they do cut across bedding in some places. Ore bodies may pinch or swell without any apparent structural or lithologic control. Boundaries of ore bodies are poorly defined and mineralized rock may extend beyond the limits of ore-grade material. Individual ore bodies range in size from irregular masses containing only a few tons to large tabular deposits containing several thousand tons. They may occur singly or in clusters aggregating 10,000 to 100,000 tons. The long axes of most ore bodies are oriented in a northeast direction parallel to Salt Wash channel trends (fig. 60). Maximum ore thickness is 27 feet, but the average thickness is only 5.5 feet. Clark and Million (1956, p. 157) report ore rolls in the Tidwell mineral belt, but no
Figure 58. Sequence of ore samples from outcrop to below water table in Tidwell mineral belt. Sample at left from outcrop, middle sample from about 50 feet above water table, and sample on right from below water table.
Figure 59. Ore exhibiting horsetail pattern.
Identifiable ore rolls were mapped by Commission geologists during this study.

**Ore-bearing strata**

A few small uranium deposits occur in channel sandstones near the base of the Brushy Basin, but most deposits are in sandstones in the upper Salt Wash.

Channel sandstones near the base of the Brushy Basin are thin and discontinuous. Ore deposits in these sandstones are small, of low grade, and are associated with carbonaceous material at or near the base of the sandstone. Only a few such deposits are known.

In the Tidwell mineral belt, uranium occurs in a massive, cross-bedded, conglomeratic sandstone with a thickness ranging from 40 to 80 feet. Locally, a few large gray to green mudstone boulders are present (fig. 61). Though this unit is very conspicuous in the mining area, it cannot be recognized east of Highway 24. This thick sandstone probably represents the deposits of a single stream which traversed this region in Salt Wash time.

**Indicator plants**

*Astragalus pattersoni* and *A. preussi*, indicators of selenium, are found in abundance on or near Salt Wash outcrops in many parts of the Desert. They are most common along washes and gullies downstream from mineralized outcrops, old dumps, and old stripping operations. They are significant in that selenium commonly occurs with uranium, and their presence on or down dip from an outcrop can be evidence for the presence of uranium. The form in which the selenium is present in the mineralized areas is not definitely known, except that some is in the form of the lead selenide, clausthalite. The close association of selenium with pyrite in some mines suggests that it may occur as ferroselite, the iron selenide.

**Ore controls**

**Lithology**

Lithologic controls of uranium deposits in the Green River District are not fully understood but certain relationships suggest such controls.

To date all known large ore bodies are in the thick conglomeratic sandstone of the Salt Wash in the Tidwell mineral belt along the western edge of the District. A few small deposits occur in the Acerson mineral belt, a narrow, poorly defined, north-trending belt of relatively thick sandstones about 1 mile east of the San Rafael River bridge. Elsewhere in the District, sandstones are thinner, more discontinuous and separated by relatively thick red mudstones. In the mineralized areas, interbedded mudstones are thinner and commonly greenish. It thus seems apparent that uranium-bearing solutions could circulate more freely in those areas of
Figure 61. Mud boulder in ore horizon in Incline No. 6 mine.

Figure 62. High-grade ore in conglomeratic sandstone.
thick continuous sandstones; it is doubtful that they could move at all in many other areas. Also, there was much more carbonaceous debris, in the thick sandstones, to supply reducing agents for precipitating uranium from solution.

Further evidence for lithologic control is the configuration of individual ore bodies in the Tidwell mineral belt. The ore body at the Smith Lucas incline (fig. 60) was extremely narrow and sinuous. Subsequent mining outlined a small scour trending N. 15° E. Many other ore bodies in this belt show a similar trend which seems to be more than coincidence.

Smaller scale controls are more obvious but do not seem to be constant. In most ore bodies, the higher-grade ore is in the coarser sandstone (fig. 62), but, in a few cases, it is in fine-grained sandstone (fig. 63). Some of the highest-grade ore in a few mines is found in a silty to sandy blue-black mudstone. In long wall section C-C in Incline No. 6, ore is concentrated in coarse sandstone laminae separated by laminae of fine-grained sandstone (fig. 26).

In many places, the higher-grade ore occurs along bedding planes where woody materials were concentrated, often associated with asphaltic material. However, in a few cases, bands of ore cut across an exposed face with apparent disregard for bedding.

Structure

The role of structure in localization of ore deposits in the Green River District is largely conjectural.

Presence of uranium ore bodies in the vicinity of a rapid change in dip from the steep flank of the San Rafael Swell eastward to the gentler dips of the desert has led many people to attribute the ore deposition to the change in dip. Clark and Million (1956, p. 157) accepted this explanation and stated that it localized mineralizing solutions. They further stated that longitudinal folds developed rolls and that uranium deposition in several large ore bodies was controlled by intersection of those longitudinal folds with traverse folds.

Field mapping revealed no recognizable longitudinal folds in this area but did show the several transverse folds mentioned previously. It is probable that the longitudinal folds of Clark and Million are actually flanks of northeast-trending scours.

Several features noted in the Tidwell area are: 1) most uranium deposits occur where a thick belt of favorable Salt Wash sandstone crosses a transverse (N. 65° W.) fold or nose; 2) much of the Salt Wash on the nose contains considerable disseminated carbon which may represent a petroleum or a structurally controlled colloidal humic residue; 3) most uranium deposits are associated with woody trash and asphaltic (?) material; 4) most fractures in the ore horizon are normal to bedding;
Figure 63. Ore confined to bedding planes in fine-grained sandstone.

Figure 64. Probable post-ore fault with about 4 feet of throw in Incline No. 6 mine. Downthrown on right. Chalk marks outline ore zone.
5) the largest and highest-grade ore bodies occur in highly jointed areas; and 6) most faults are probably post-ore (fig. 64).

Utilizing these facts, the following working hypothesis is presented: Following deposition of the Morrison, and prior to deposition of the Cedar Mountain, numerous small anticlinal folds developed in the region now occupied by the San Rafael Swell. Axes of these folds trend slightly north of west, implying north-south compressional forces. Pre-Cedar Mountain erosion removed part of the crests of the folds, and subsequent deposits of the Cedar Mountain completely covered them. Renewed folding occurred in Early Cretaceous time, but the periods of erosion preceding and following deposition of Naturita and the subsequent thick shale deposits of the Mancos have further obscured the folds. It is possible that during this period petroleum accumulated in some of the small folds. It is also possible that humic hydrosols, formed by the interaction of ground water and peaty or lignitic material, accumulated in porous sandstones at this time. If petroleumlike substances were derived from humic materials during this period, they were probably in insignificant amounts and did not move far from their source.

The absence of the Naturita in most of the District and the absence of Gryphaea on the Green River nose suggest some upwarping and erosion in late Naturita-early Mancos time.

What is probably the first period of major uplift of the Swell is recorded in the Book Cliffs near Sunnyside, about 40 miles north of Green River. There the Blackhawk formation of Late Cretaceous age is disconformably overlain by the Castlegate sandstone member of the Price River formation also of Late Cretaceous age. This disconformity is present throughout the Book Cliffs but is most prominent near Sunnyside; it marks the beginning of the early Laramide orogeny (Spieker, 1949, p. 70).

In the Sunnyside area, two other unconformities, one just above and the other just below the Tuscher formation of Late Cretaceous age, reflect other movements in the Swell during the early part of the late Laramide orogeny. It is possible that, as the result of these movements, any petroleum trapped in the old structures could escape up dip or was flushed by circulating ground water. Small amounts of petroleum or colloidal material may have remained in some anticlinal structures and stratigraphic traps, but in others only an asphaltic residue was left.

It is probable that the structural configuration of the area, following these early movements, was essentially the same as today, except that structural relief was relatively low. Present structural relief is largely due to a major period of uplift during middle and late Tertiary time. Faulting undoubtedly occurred at various times during the various orogenies but the greatest period of faulting apparently followed the late Tertiary uplifting and continued into the Recent (Spieker, 1954, p. 13).

No age determinations have been made of uranium ore in the District, but assuming that it is of the same age as other deposits on the Colorado
Plateau, it must be on the order of 60 to 140 million years old. It appears that there is no relation between ore deposits formed in Late Cretaceous-early Tertiary time and the sharp change in dip east of the Swell, resulting largely from middle to late Tertiary uplift.

Numerous joints in the ore-bearing sandstone of the Tidwell area are roughly normal to bedding and thus are believed to have formed prior to, or during, the pre-Cedar Mountain folding or during the early Laramide orogeny. Since these early joints are most common where ore bodies are thickest, it is suggested that they served as ore controls by increasing permeability of the ore horizon. One prominent joint set is vertical and is parallel to small late Tertiary faults which follow the crest of the old east-west fold and apparently offset ore bodies. A few of these fractures are coated with secondary uranium minerals, calcite, and chalcedony, indicating movement of ground-water solutions following deposition of ore bodies. Physical evidence thus dates ore deposition as Late Jurassic to middle Tertiary.

Chemical

Ore solutions may have entered the area through fissures from a source at depth or may have been introduced as laterally moving solutions from adjacent areas. In either case, it is probable that mineralizing solutions moved laterally through the entire area. If the Salt Wash was not saturated with water, the solutions could have moved down dip; but it seems almost certain that it was saturated with water by Mancos time and thus any circulation of solutions would have been lateral, around the periphery of the incipient Uinta Basin, or upward because of their higher temperatures. Where these solutions encountered coarse carbonaceous trash, petroleum, asphaltic material, or humic colloids, precipitation of uranium ensued.

Apparently, the largest deposits formed where large amounts of reducing agent were present and where uranium solutions could circulate most freely in thick permeable sandstones. Such a situation existed in the Tidwell mineral belt where the thick belt of permeable Salt Wash sandstone lies athwart the small southeast-plunging nose. The relatively large amount of carbon trash, present in this thick sandstone belt, may have been supplemented on the fold by petroleum, or asphaltic residues of former accumulations of petroleum, as well as by asphaltic and resinous matter derived from woody material and by humic hydrosols. In addition, the more intense jointing along the old fold probably aided deposition by increasing permeability.

The immiscibility of oil and water has been cited as an objection to precipitation of uranium by petroleum, but it should be pointed out that large volumes of methane and ethane gas are known to occur in solutions in ground water in some areas. In the case of an asphaltic residue, immiscibility would probably not be of consequence if the permeability of the sandstone were not impaired, granting its wettability would be reduced. Furthermore, we do not know the nature of uranium ore solutions, and it is quite
possible that they would have commingled with petroleum more readily than does water. There would be no immiscibility problems in the case of aqueous colloidal solutions.

**Sedimentary trends**

Lineation of recognizable channels in the Salt Wash is commonly about N. 10°-20° E. Mapping of sedimentary structures such as lineation, festoon, rib and furrow, and crossbedding indicates a northeast direction of stream flow (Million, 1957; Stokes, 1954). The Tidwell mineral belt also shows elongation in a northeast-southwest direction.

**Summary of controls**

In summary, uranium solutions moving laterally through the Salt Wash came into contact with carbonaceous trash and possibly some petrolierous materials, and probably were precipitated from solution by such reducing agents as SO₂, H₂S, and H₂. Where sandstones were thin and of low permeability, little uranium was deposited, even where coarse carbon trash was abundant. Where relatively coarse carbonaceous material was abundant and sandstones were thick and permeable, a few relatively small uranium deposits were formed; but where asphaltic or colloidal humic material was present, in addition to the coarse carbon trash, larger deposits resulted. Thus, small structures, both synclines and anticlines, which originally controlled accumulation of petrolierous and probably some humic-derived materials, may have indirectly controlled deposition of uranium.

**Bleaching**

There is some evidence that much of the Salt Wash in the District has been altered, although alteration is not always readily recognizable because in some places the sandstones may have been originally light colored. Most Salt Wash sandstones and many siltstones and claystones are gray to green; almost all sandstones contain montmorillonite blebs believed to represent altered impure chert; and usually a few inches or feet of mudstone underlying or overlying Salt Wash sandstone beds have been bleached from red to green or gray.

Origin of the bleaching is unknown. It may have been produced by circulating ground waters made slightly acidic by humic products, or it may have been caused by the mineralizing solutions. The former presence of uranium-bearing solutions throughout the Desert is indicated by the widespread occurrence of uranium minerals, but the ability of these mineralizing solutions to bleach sediments is still in doubt.

One line of evidence tends to point to a ground-water origin for the bleaching. In many portions of the geologic column where sandstone units rich in humic matter overlie deposits rich in ferric iron, that portion of the underlying unit adjacent to the humic-rich deposit is bleached to a white, gray, or green. Examples of this in the Green River District are the Summerville-Salt Wash contact, where in some places the upper foot or so of the Summerville is bleached to gray green though this may be due in part to gypsum, and the Cedar-Mountain-Naturita contact where as much
as 100 feet of the underlying Cedar Mountain has been bleached to grays and greens.

FUTURE OF THE DISTRICT

A total of approximately 200,000 tons of uranium ore have been mined in the Green River mining district. This is less than the remaining known reserves of the district. At present the only sizeable indicated and inferred ore reserves are in the Tidwell mineral belt, where reserves approach 300,000 tons of indicated and inferred ore averaging about 0.35 percent U3O8. These calculations are based on an average thickness of $5 \frac{1}{2}$ feet of ore in ore bodies throughout the belt. Indicated ore was restricted to a $12\frac{1}{2}$-foot radius around each ore hole or beyond an ore face, inferred ore was projected between ore holes on the basis of sedimentary trends, or $12\frac{1}{2}$-feet beyond indicated ore.

Exploration has been confined to the margins of the District where the Salt Wash crops out or occurs at shallow depths. Much drilling has been done (pl. 1), mostly where Salt Wash is less than 1,000 feet below the surface. Few holes have been drilled below 1,000 foot depth because of the limited size of ore bodies and the presence of large volumes of water at depths of about 300 feet below the surface.

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Figure 15. Siliceous limestone nodules on weathered outcrop of Cedar Mountain formation in Tidwell mineral belt.

Figure 16. Channel sandstone near top of Cedar Mountain formation. View looking west from near Green River. Sandstone is 15-30 feet thick, averages 300 feet in width, and can be traced for about 10 miles.
Figure 60. Plan of Smith-Lucas Incline mine, Four Corners Uranium Corporation
Green River District, Emery County, Utah

EXPLANATION
- Ore
- Sandstone
- Mudstone
- Carbon fresh
- Conglomerate
- Vertical fracture
- Fracture and dip
- Festoon bedding
- Bottom of shaft
- Drill hole
- Elevation of floor
- Extent and thickness of ore

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