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EXPLORATION DIVISION

ECONOMIC STUDY OF THE SAN RAFAEL RIVER DESERT MINING DISTRICT EMERY AND GRAND COUNTIES, UTAH

by

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Frontispiece. View looking west across Tidwell mineral belt toward San Rafael Swell

ECONOMIC STUDY
OF THE SAN RAFAEL RIVER DESERT MINING DISTRICT
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ABSTRACT

Uranium deposits occur in the San Rafael River Desert in eastern Emery County and western Grand County in southeastern Utah. Outcropping units in the Desert include the Carmel, Entrada, Curtis, Summerville, and Morrison formations of Jurassic age and the Cedar Mountain, Dakota, and Mancos formations of Cretaceous age. Uranium is found primarily in the Salt Wash sandstone member of the Morrison, and the largest deposits are found in a thick sandstone unit near the top of the member in the Tidwell mineral belt near the western edge of the Desert.

The basic structure of the Desert is that of a broad northward plunging syncline which is actually a thumb-like projection of 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-west trending anticlinal folds, which occur on the west flank of the Desert, 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 Desert, 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 in mid-Tertiary to late Tertiary time, are recognized in the Desert and adjacent areas.

Uranium was first discovered in the Desert in 1880, and since that time approximately 60,000 tons of ore have been shipped for their radium, uranium, and vanadium content. At present most mining is in the Tidwell mineral belt, where 11 mines are operating at depths as great as 300 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--ranging up to about 5,000 tons--but several may occur in clusters totalling 10,000 to 20,000 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, meta-tyuyamunite, 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. Previously present asphaltic material may have been made corrosive by alpha bombardment from uranium minerals which had originally been precipitated by the asphaltic material.

It is believed that uranium-bearing solutions originated at depth, rose along fractures until they encountered permeable Salt Wash, and proceeded to move laterally. 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 premineralization 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 San Rafael River Desert mining district is in eastern Emery County and western Grand County in southeastern Utah (fig. 1). Bounded roughly on

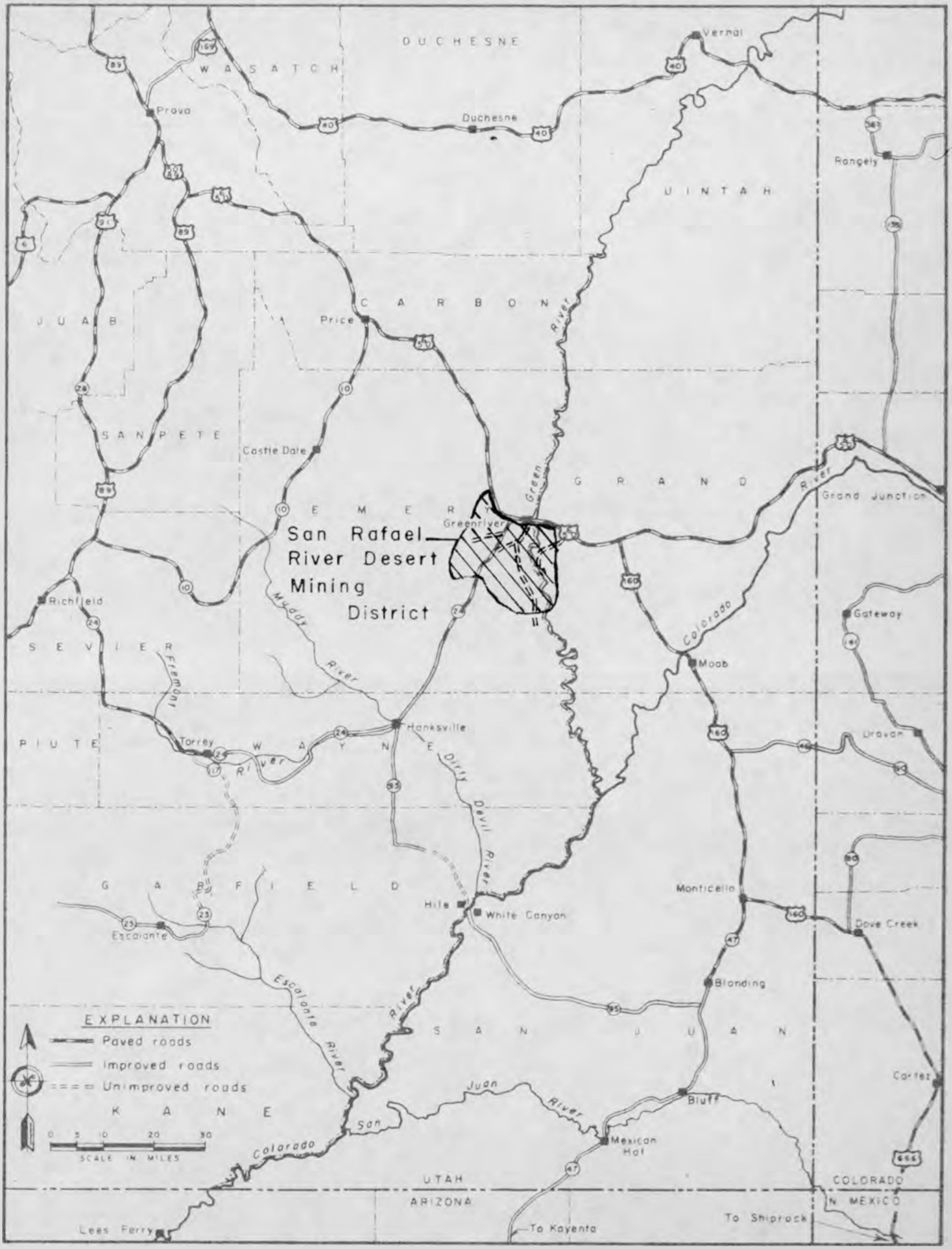


Figure I. Index map, San Rafael River Desert area, Emery and Grand Counties, Utah the south by the San Rafael River and on the east by the Green River, it extends westward to the steeply dipping east flank of the San Rafael Swell. Its northern boundary coincides roughly with U. S. Highway 6-50. Approximately 350 square miles are included in the district.

Purpose and Scope

It is the purpose of this report to assemble and present all pertinent geologic data on an area in which important uranium deposits are present. Field studies were made to obtain details on structural and stratigraphic relations throughout the area.

Field Work

Field work on this project was begun in February 1956 and completed in December of that year. It consisted of detailed mine mapping, measuring of numerous sections, correcting minor errors in a U. S. Geological Survey photogeologic map, 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 edges 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 U. S. 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 logging unit logged many holes in the area. The majority of these were along the western margin in the Tidwell mineral belt.

Acknowledgments

The writers wish to express their appreciation to the many residents and mine operators of the area who granted access to their properties and who were extremely cooperative in supplying invaluable information and assistance.

Geography

Topographic Features

Fenneman (1931) does not recognize the San Rafael River Desert as a separate entity but 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 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 great elevations. The San Rafael River Desert does not include deep canyons or high plateaus, but is a somewhat dissected area of moderate relief whose average elevation decreases gradually from about 4,500 feet at the southern edge to about 4,100 feet near the town of Green River, Utah. Total topographic relief in the area is about 1,200 feet with the maximum elevation of about 4,800 feet occurring along the western edge 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.

Near the eastern boundary of the area, the Green River flows southward through a broad valley near Green River, but just south of the town 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 it has a gradient of about 3.2 feet to the 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 Jurassic Carmel, Entrada, and Summerville formations for about three miles before changing its course to a southeasterly direction. 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

Only two perennial streams are present in the area; the Green and San Rafael Rivers.

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 18 to a minimum of 820 second-feet on November 28. Some water is diverted from the Green River 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, measured 15 miles southwest of the town of Green River, shows a mean of 94.3 second-feet for the period 1909-1950. 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-foot on March 18 and 19.

Climate and Vegetation

The climate of the Desert 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 in the Desert 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. Rabbitbrush, greasewood, black sagebrush, salt sagebrush and Tamarisk (salt cedar) are common, particularly in the bottomlands, and blackbrush, mormon tea, and leadbush are common on higher ground. Many other plants such as shadscale, yucca, bottle weed, loco weed, and a few grasses are found in the desert but are nowhere abundant. The entire area has been overgrazed and this, coupled with unevenness of 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 in the area 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 CO_2-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 (1875) who explored the Canyon Country in 1869 and 1871 and applied many of the geographic names now in use.

The general geology of this region has received much attention from geologists in the excellent works of such men as Emery (1918), Gilluley and Reeside (1928), McKnight (1941), and Baker (1946).

Oil and gas possibilities of this 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 most important papers dealing with this area is included in this report.

STRATIGRAPHY

General Features

Formations exposed in the San Rafael River Desert range in age from the late Jurassic Carmel formation to the late 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 Jurassic Entrada and Morrison and the Cretaceous Cedar Mountain and Dakota. Marine formations include the Jurassic Carmel, Curtis, and Summerville; and the Cretaceous Mancos. 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, Entrada, Curtis and Summerville formations, listed in ascending order, is named for exposures near the northern end of the San Rafael Swell (Gilluley and Reeside, 1928, p. 73). Units of this group form the surface rocks over a large portion of the southern part of the Desert (figs. 3 and 4). 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.

<u>Carmel formation</u> - The oldest formation exposed in the Desert is the Carmel named by Gregory and Moore (1931, p. 69) for exposures near the town of Mt. Carmel in southern Utah. Along the western margin of the Desert the Carmel consists of a lower unit of interbedded greenish-gray, buff, red or lavender mudstone, cross-bedded 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

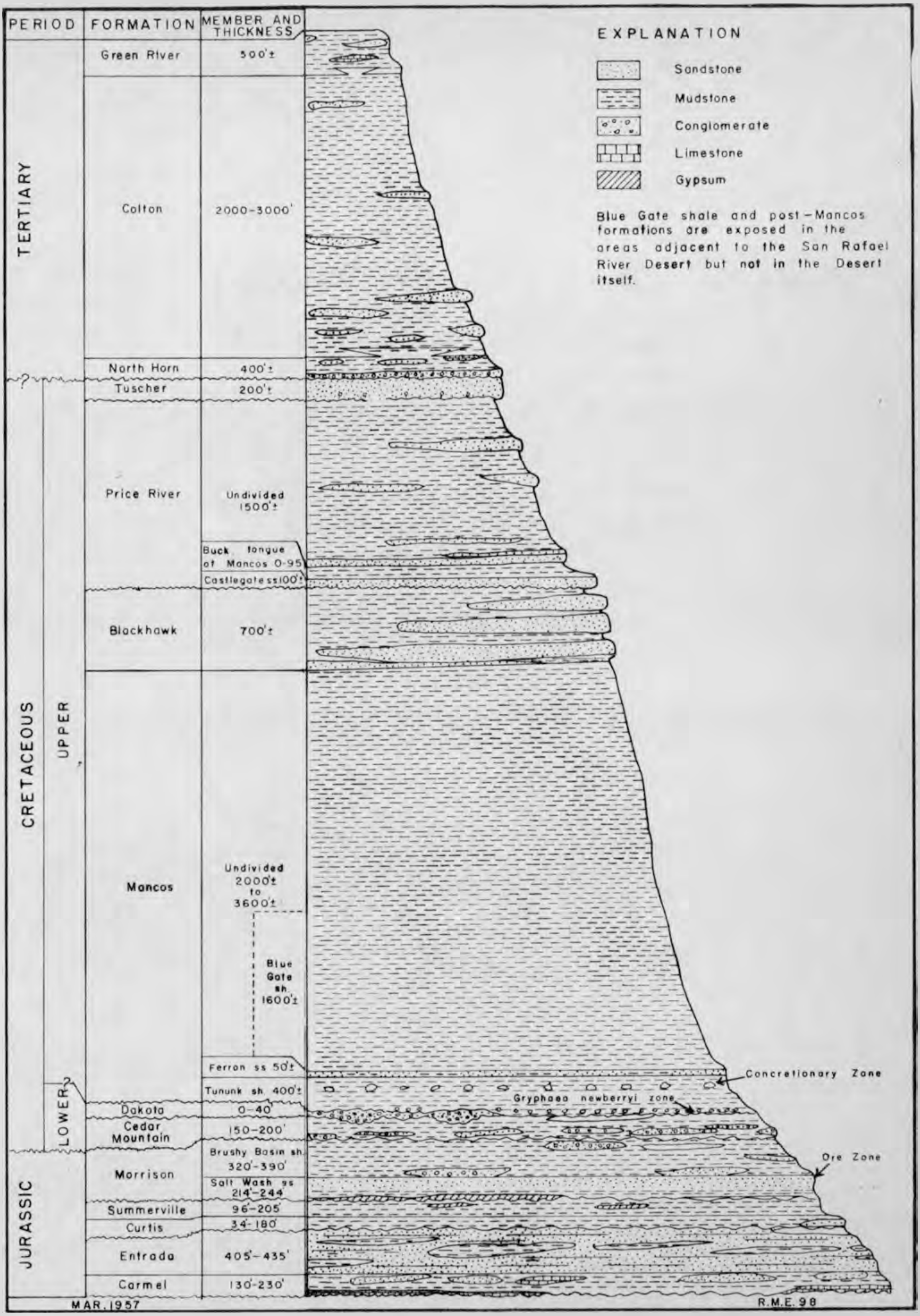


Figure 2. Generalized stratigraphic column, San Rafael River Desert area, Emery and Grand Counties, Utah

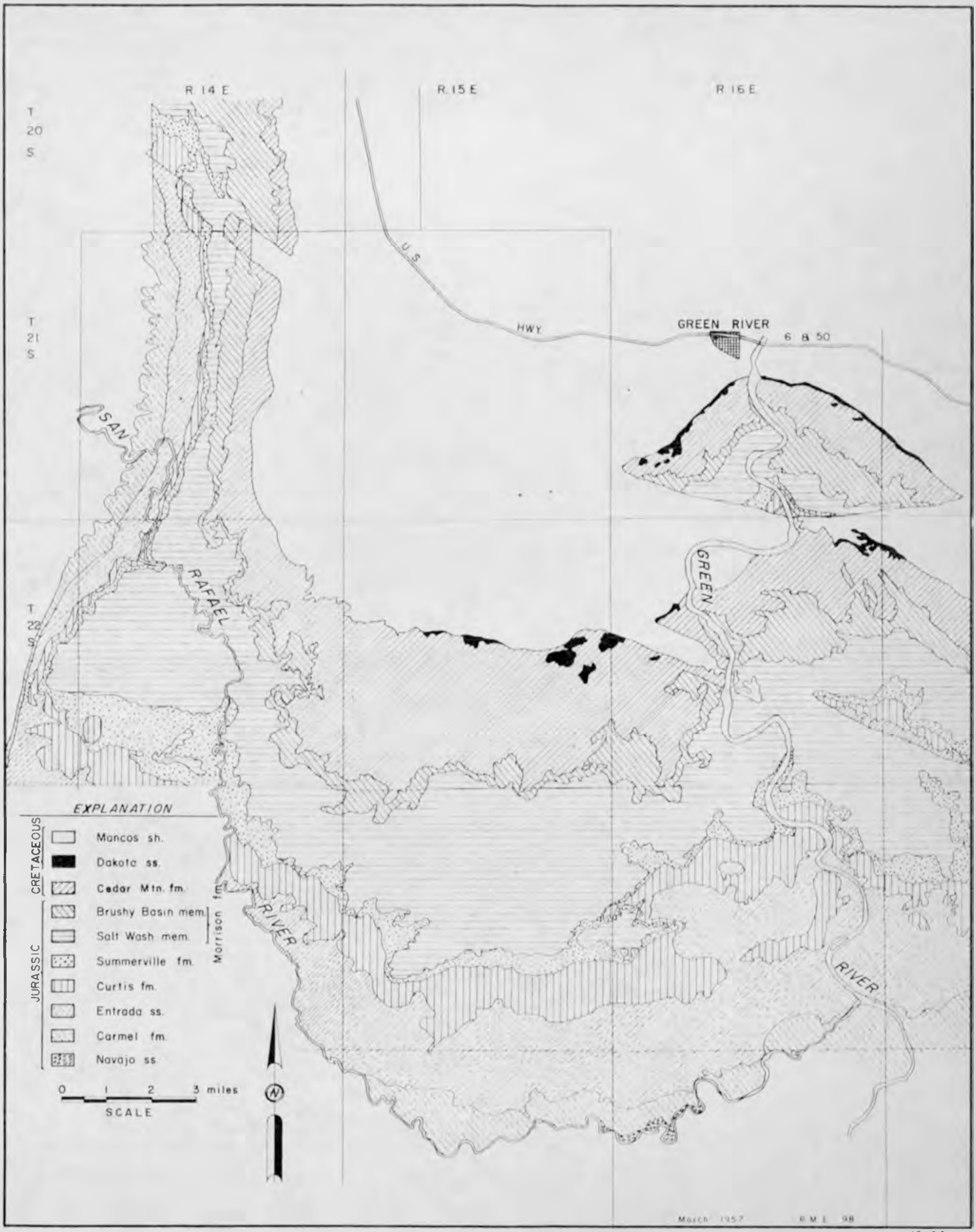


Figure 3. Generalized geologic map, San Rafael River Desert area, Emery and Grand Counties, Utah

of red to gray limestone. Traced eastward the lower unit grades into red muddy sandstone or mudstone indistinguishable from the upper portion of the formation. 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 river it 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 soon following deposition of the Entrada and prior to deposition of Summerville.

The Carmel is about 230 feet thick along the western edge of the Desert (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 nose near the town of Green River.

Marine mollusks present near the base of the formation, along the western edge of the Desert, indicate that the Carmel is late-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 San Rafael Desert 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 4 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 Gilluley and Reeside (1928, p. 76) for exposures in the northern part of the San Rafael Swell. Exposures of the Entrada in the San Rafael River Desert are found only in a relatively narrow band along the western and southern edge of the Desert (figs. 3, 4, and 5) 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 Entrada has a thickness of 435 feet and is 405 feet thick at Black Dragon Canyon (fig. 5) on the

Figure 5. Jurassic units near Black Dragon Canyon; Navajo (Jn), Carmel (Jc), Entrada (Je), Curtis (Cu), Summerville (Js), and Morrison (Jm).

western edge of the Desert (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 Desert it is thought to be water laid and may be marginal-marine.

Curtis formation - The name Curtis formation was applied by Gilluley 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 Desert 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 sides of the Desert (figs. 3, 4 and 5) 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 sloping upward toward the base of the Summerville, into which it grades.

In general, the Curtis is thickest (about 180 feet) along the western edge of the Desert 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 Desert but marine fossils of late Jurassic age occur near the type locality (Gilluley 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 contact between Curtis and Entrada in this area is unconformable with notable angularity in some places, and its upper contact is gradational.

Summerville formation - The Summerville formation named by Gilluley and Reeside (1928, p. 79-80) for exposures on Cedar Mountain consists predominantly of reddish-brown thin evenly 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 margin of the Desert, 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 member of the Morrison formation (figs. 5 and 6).

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, 1948, p. 85).

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

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 two members of the formation are recognized: the lower named the Salt Wash and the upper the Brushy Basin. 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 sides of the Desert (figs. 3 and 4).

Lupton (1914, p. 127) named the Salt Wash for exposures along Salt Wash just east of the Desert. It consists, in the Desert, 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 up to 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. 6). In other places Salt Wash scours have been cut through the gypsum and into the Summerville (fig. 7).

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

Figure 6. Basal gypsum (g) of Salt Wash sandstone (Jms) resting unconformably on Summerville formation (Js) near San Rafael River bridge.

Figure 7. Sandstone filled scours at base of Salt Wash (Jms) near San Rafael bridge.

Figure 8. Montmonilonite (white particles) replacing chert in sandstone.

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 varies from 20 to 80 feet thick. It is not a single massive sandstone but is 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 varies from coarse-grained conglomeratic to fine-grained. Sandstone grains consist largely of quartz and much vari-colored argillaceous chert, which in some coarser beds has been largely altered to clay imparting a white speckled appearance to the sandstone (fig. 8). Sorting is poor, and angular to subangular chert pebbles up to one inch in diameter are present in some conglomeratic lenses. Individual sandstone beds vary in thickness from less than one foot to more than ten feet. Cementing material is usually calcite or dolomite, but in places is clay. Beds are cross-laminated and show pinchout, 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 edge of the Desert, whereas those found in most of the remainder of the area can in many cases be traced for greater distances and appear to have no such definite trend (fig. 9). In the Tidwell mineral belt a thick relatively persistent sandstone near the top of the Salt Wash is the principal ore-bearing unit (fig. 10).

Thicknesses of the Salt Wash in the Desert are quite constant, ranging from 214 along the western edge to 244 feet on the Green River nose (fig. 11).

In the Desert 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. 12 and 13). Associated with the carbon trash in some areas are silicified logs two 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 <u>Uni stewardi utahensis</u> Yen. Mitchell (1956, chart opposite page 108) records the presence of characteristic charophytes in nearby localities but no attempt was made to collect them here.

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

Figure 9. Aerial view of Salt Wash channel sandstones east of San Rafael River bridge. Lens on right about 300 feet long, 30 feet wide, and 10 feet thick.

Figure 10. Ore sandstone in Tidwell mineral belt.

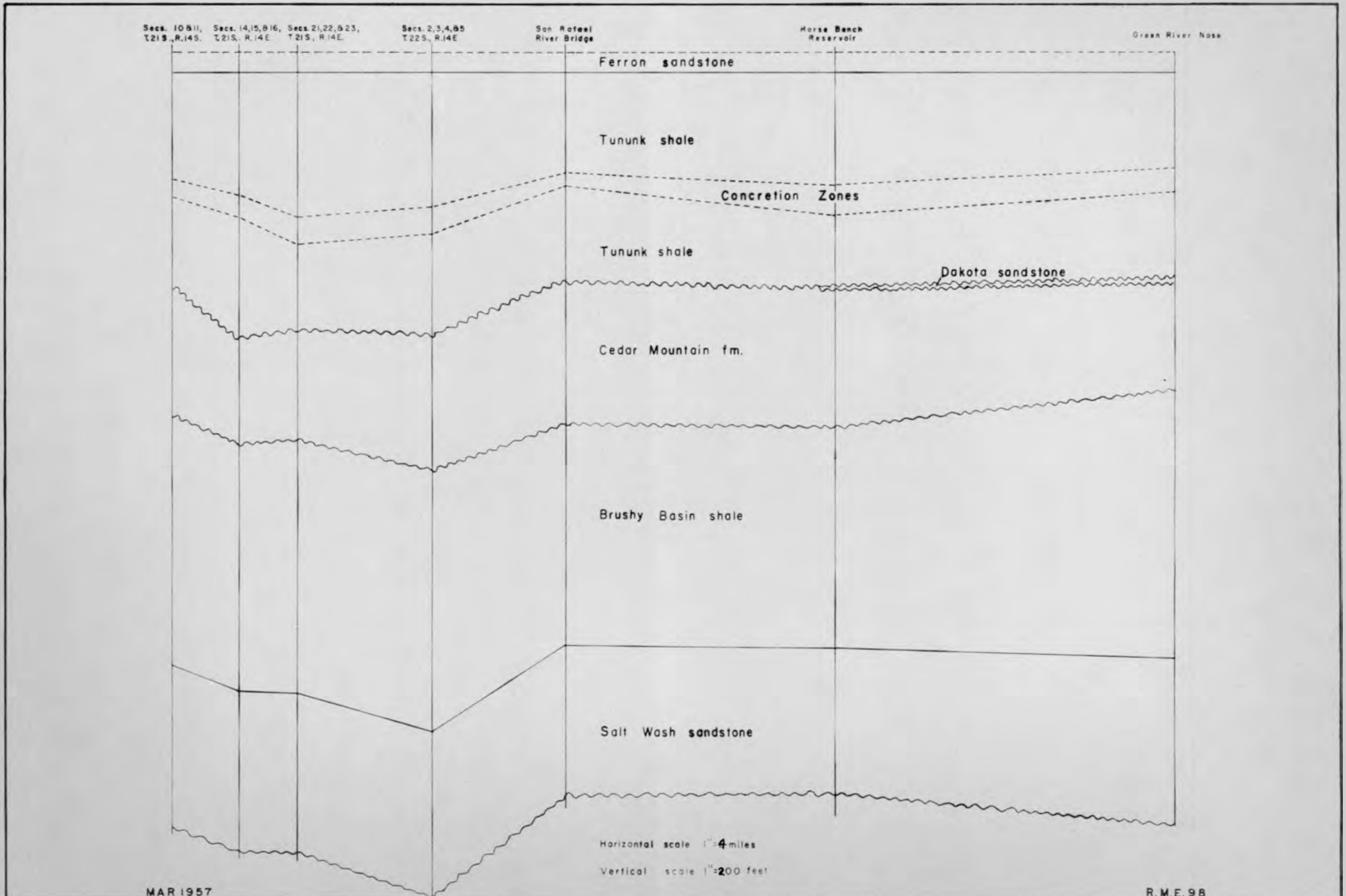


Figure 11. Correlation of measured sections, San Rafael River Desert area, Emery and Grand Counties, Utah

Figure 12. Unmineralized wood fragments from ore horizon, Incline No. 6 mine.

Figure 13. Small mineralized woody fragments along bedding planes, Incline No. 5 mine.

Brushy Basin member - Overlying the Salt Wash is a predominantly shale unit—the Brushy Basin member of the Morrison.

The Brushy Basin (Gregory, 1938, p. 59) consists predominantly of red, reddish-brown, purple, and gray claystone containing varying amounts of siltstone and some lenticular conglomeratic sandstones (figs. 14 and 15). Much of the Brushy Basin consists of impure bentonitic clay of volcanic origin. Sandstone lenses are elongate up to one-half mile in length and up to 100 feet in width (fig. 15); they probably are remnants of clastic fill of old stream channels. Channel trends are closely parallel to those of the Salt Wash with the average trend being 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 southeast Utah and southwest Colorado and is here included in the Brushy Basin.

The thickness of the Brushy Basin varies from a maximum of 391 feet on the Green River nose to a minimum of 319 feet near Horse Bench Reservoir (fig. 11). 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.

Petrified dinosaur bones and wood fragments are common in the Brushy Basin and some exhibit radioactivity. Other fossils are rare but fresh water gastropods and algae have been reported from a few localities (Craig and others, 1955, p. 156).

Cretaceous System

Lower Cretaceous Series

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 now recognized, the Cedar Mountain consists of the basal Buckhorn conglomerate member and an overlying variegated shale member.

Figure 14. Cedar Mountain resting disconformably on Brushy Basin near San Rafael River bridge.

Figure 15. Channel sandstones in Brushy Basin in Tidwell mineral belt.

In the Desert 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. 16), 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. 14). 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, while in other places conglomerate is entirely absent. Because of the discontinuous nature of these lenticular deposits, the Buckhorn member is not recognized in the Desert. The conglomerates consist largely of gray to black chert pebbles with lesser amounts of siliceous limestone, quartz, and quartzite pebbles. Fragments of dinosaur bone are common in some lenses.

Near the top of the formation are a few very 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. 17).

The Cedar Mountain crops out in a relatively broad east-west belt crossing the Desert about midway between its northern and southern limits. It is also present in a small crescentic band around the Green River nose (figs. 3 and 4).

The Cedar Mountain varies in thickness from about 150 feet on the western edge to about 200 feet near Horse Bench Reservoir (fig. 11). 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 Cedar Mountain has been determined as Lower Cretaceous (pre-Aptian) and possibly late Jurassic in part (Katich, 1954, p. 44). Fossils are sparse but Katich (1951) reported ganoid fish scales, fresh water ostracods, and fresh water pelecypods from about 50 feet below the Dakota on the west side of the Swell. Stokes (1952, p. 1768) recorded numerous microfossils indicative of Lower Cretaceous age. Mitchell (1956, chart opp. page 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.

Figure 16. Siliceous nodules on weathered outcrop of Cedar Mountain formation in Tidwell mineral belt.

Figure 17. Channel sandstone near top of Cedar Mountain formation. View looking west from near Green River about 8 miles south of town of Green River. Sandstone is 15-30' thick, averages 300' in width, and can be traced for about 12 miles.

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. 14) while in others a few inches of the uppermost Brushy Basin is iron stained. Throughout the Desert the Cedar Mountain is disconformably overlain either by lenses of Dakota 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 fan-like 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 Dakota time. These solutions charged with humic acids were derived from carbonaceous material in the Dakota.

Dakota Formation

At a few localities in the Desert there occur small patches of conglomerate and sandstone believed to be remnants of the Dakota sandstone named by Meek and Hayden (1861, p. 419) for exposures near the town of Dakota, Nebraska. The old term Dakota sandstone has now been largely discarded in favor of the term Dakota formation, a term more appropriate for a unit which in many areas consists of sandstone, shale, coal and other lithologic types. In the Desert the formation consists of thin lenses of cross-bedded 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-south 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 Dakota 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.

No fossils other than 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 Upper Cretaceous (?) age. Erdmann (1934, p. 27) reports plant fossils of Lower 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 Upper Cretaceous age from sandstones near the top of the formation. Pelecypods and ammonites collected by Reeside (1927) near Delta, Colorado, indicate an early Upper Cretaceous age for the upper portion of the unit in that area. In view of the age of the marine fossils in adjacent areas, it seems likely that the Dakota remnants in this area are also of Upper Cretaceous age.

The depositional history of the Dakota is complex, but studies by Young (in preparation) indicate that the Dakota 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 Desert are interpreted as inland flood plain deposits laid down at some distance from the shore by streams draining highland areas to the southwest and west. These deposits in the Desert fill scours in the Cedar Mountain (fig. 18) and are in turn disconformably overlain by Mancos shale (fig. 19). It is probable that thin inland flood plain deposits of the Dakota 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 Desert 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 Dakota.

Upper Cretaceous Series

Mancos Shale

Overlying the Dakota and Cedar Mountain in this area is the Mancos shale, a thick unit of dark gray calcareous marine shale. The formation, which is the outcropping unit in the northern one-third of the Desert, was named by Cross (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. 92), and the Blue Gate shale (Gilbert, 1877, p. 4).

In this area the Tununk is a soft blue-gray to black shale which weathers to a drab gray. Near the middle of the member there occur one, or in some areas two, conspicuous 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

Figure 18. Dakota formation resting disconformably on Cedar Mountain formation at Nine Mile Wash.

Figure 19. Mancos shale Tununk member (Kmt) disconformably overlying Cedar Mountain (Kcm) and patches of Dakota (Kd) on Green River nose.

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 varies from about 300 feet in the northern portion of the Desert to a maximum of about 400 feet in its most southwestern exposure (fig. 11). Nearly everywhere in the area the fossil pelecypod 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 newberri 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 toward the west beyond the Desert, by progressive onlap at the base and because of 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. 19). 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 this 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. They are especially prominent near the mouth of the San Rafael River where they are present at several levels up to about 350 feet above present river level (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 San Rafael River Desert is a broad shallow syncline plunging gently northward with dips up to 11 degrees on the western side but varying from one to 3 degrees in the rest of the area (figs. 4, 20 and 21). It is actually a southward projecting thumb 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 northwestward projection of the Monument uplift. The extension of Monument uplift is the Nequoia arch, a broad northwest-trending structural arch 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 Desert. The northwest extension of the Cane Creek anticline is a broad north-trending arch lying near the eastern border of the Desert. 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 described above 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 Desert, 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 the flattening of the beds from the steep dips of the east flank of the Swell to the relatively low dips of the Desert (figs. 21 and 22), or to dying out in the incompetent shales, but may be more easily 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 degrees W trend of the Swell in this area. Stokes (1954) concluded that northeastward 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 down stream.

Although at least three of these small folds have been recognized along the western edge of the Desert, the best known is the Tidwell nose (fig. 22 and frontispiece) which trends about S 65 degrees E just north of the Tidwell Ranch. Other small flexures have been noted along the southern margin of the area and most of them also are apparently confined

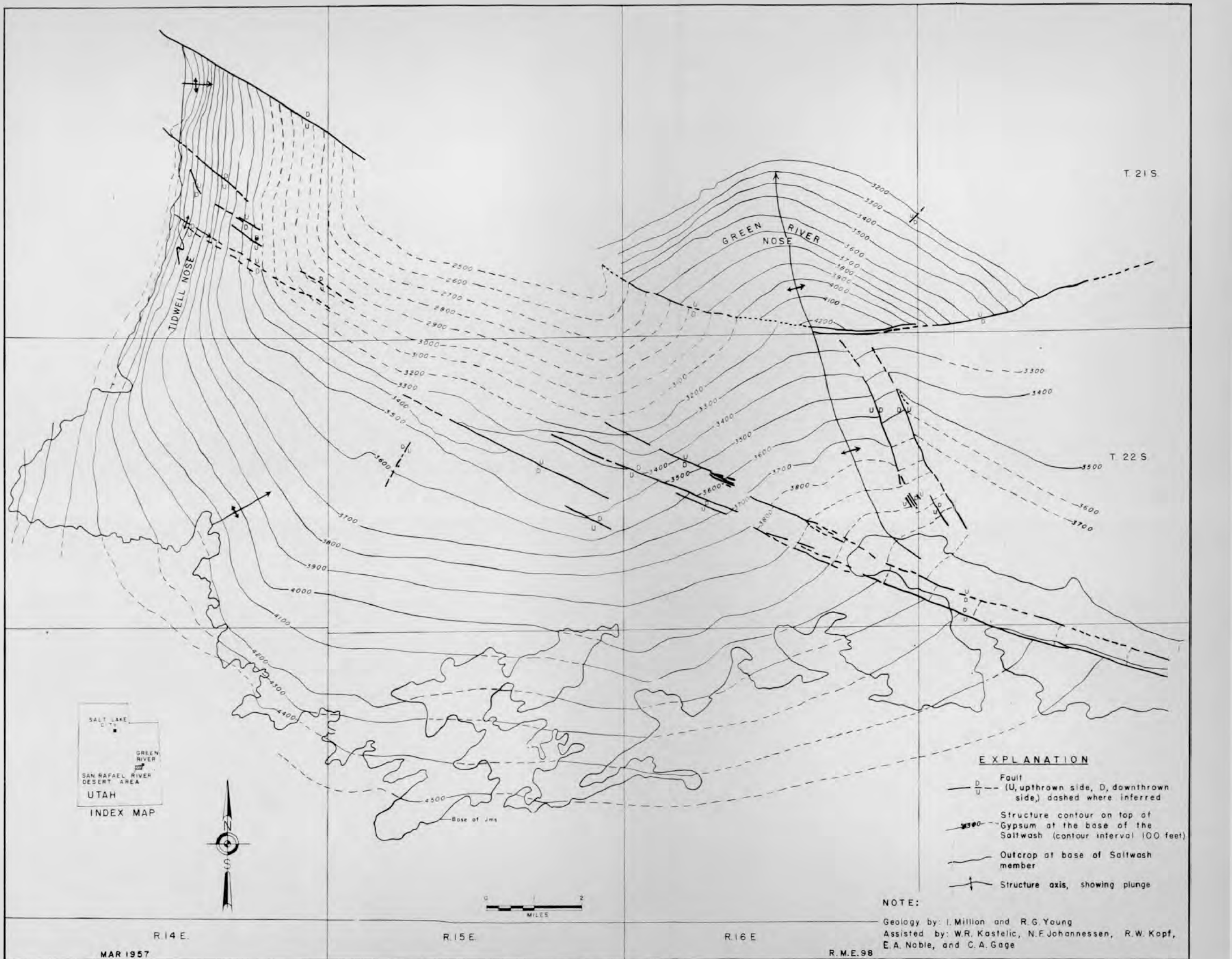


Figure 20. Structure Contour Map of San Rafael Desert Mining District, Emery and Grand Counties, Utah

Figure 21. Aerial view of southern portion of San Rafael River Desert looking southwest.

Figure 22. 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.

to 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. 14). Because of their small amplitude these folds are poorly shown by the structure map (fig. 20). However, the Tidwell nose does stand high topographically, perhaps because the Salt Wash sandstone here contains abundant $CaCO_3$ introduced by mineralizing solutions.

All of the above 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 in this area in late Jurassic or early Cretaceous time is the absence of Dakota in large areas, either as the result of erosion or non-deposition.

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 Desert. Evidence is present, however, in younger deposits in the Book Cliffs just north of the Desert. Deposits of the Book Cliffs 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 Desert. Disconformities are present between the (1) Black hawk and Price River formations, (2) the Price River and the lower portion of the North Horn formation, and (3) the lower and upper portions of the North Horn.

There is no apparent angularity between any of these units and all dip uniformly toward 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

Faults

Faulting is largely confined to two northwest-trending zones of normal faults which have formed numerous grabens (fig. 20). 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. 23) 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 3 degrees north while those north of the fault dip 2 degrees north (Hager, 1956, p. 181). Displacement decreases westward to termination against the flank of the Swell.

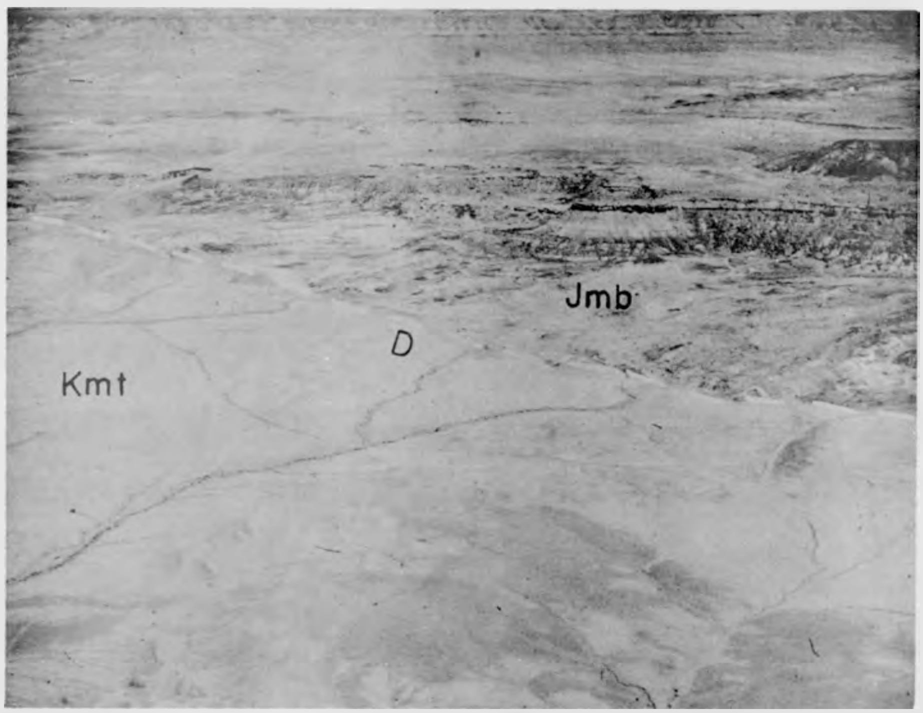


Figure 23. Trace of Little Grand fault 4 miles south of town of Green River. Tununk shale (Kmt) in foreground in contact with Brushy Basin shale (Jmb).

The second fault zone lies about 3 to 5 miles south of the first. In the western part of the Desert, 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 northward as does the northern zone. In this area the average trend of the southern zone of graben-forming faults is about north 65 degrees west. This trend can be traced into the Tidwell mineral belt where some of the faults follow the axis of the Tidwell nose (fig. 22). 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. 20).

A third zone of normal faulting, with a north 15 degrees west 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 present in the area (fig. 20).

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 of the units exposed in the San Rafael Desert are thoroughly jointed and the trends of many of these joints are shown in Figure 4. 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. 15). 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 north 35-45 degrees west 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. Inasmuch as deformation of this type is largely lacking in the Desert, fractures or joints formed in this way are believed to be minor. However, the steeply dipping beds adjacent to the San Rafael Swell have undoubtedly undergone uplift and possibly some compression.

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 Desert (fig. 24).

Rim joints are formed parallel to the outcrop by removal of support during erosion. Some channels exhibit patterns formed in this way (fig. 9).

Detailed fracture studies were made in the mines of the Tidwell mineral belt in an attempt to relate them to the uranium ore. It was found that the major joint set in the ore-bearing sandstone of this area strikes about north 50 degrees west (fig. 25), is normal to the bedding and is largely restricted to that unit. A few vertical joints and faults with a north 65 degrees west strike penetrate the entire exposed stratigraphic section (fig. 22). Three less prominent joint sets striking north 40 to 50 degrees east, north-south, and east-west are recognizable in the ore-bearing sandstone of the Tidwell mineral belt.

Several types of material filling fractures have been noted in the Desert. Joints in the Quaternary gravels near the mouth of the San Rafael River are filled with caliche (mostly $CaCO_3$). 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 $CaCO_3$ coatings on sandstone (fig. 26). Others have a thin coating of chalcedony on manganese-stained sandstone (fig. 27). In some outcrops $CaCO_3$ 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 San Rafael River Desert, the following outline of major geologic events, subsequent to deposition of the Navajo sandstone, has been constructed from data obtained in the Desert and adjacent areas.

1. Invasion of Carmel sea from the west.

2. Deposition of basal Carmel sandstone from reworked Navajo, followed by marine mudstones and limestones.

Figure 24. Longitudinal fractures in Navajo sandstone on east flank of San Rafael Swell. View looking north.

Figure 25. Inclines No. 4,5,&6 of Four Corners Uranium Corporation, near Green River Utah

K7-5-10

Figure 26. Coating of tyuyamunite on $CaCO_3$ coating fracture surfaces,

Figure 27. Chalcedony and manganese oxide on fracture surface, Tidwell nose.

3. Gradual retreat of Carmel sea with deposition of marginal marine sandstones of upper Carmel and Entrada.

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.

6. Deposition of marine Curtis and marginal marine Summerville during slow retreat of Curtis sea.

7. Broad gentle upwarp of large portion of central Utah accompanied by slight erosion.

8. Deposition of fluviatile Salt Wash and Brushy Basin by northeastward-flowing aggrading streams. Volcanic activity in Mesocordilleran region to west and southwest indicated by bentonitic material of Brushy Basin.

9. Small east-west trending folds formed by north-south compressional forces.

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

11. Relatively short period of subaerial erosion.

12. Deposition of fluviatile Cedar Mountain by eastward-flowing streams.

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

14. Deposition of conglomeratic fluviatile Dakota, largely as channel fill.

15. Possible local upwarp with nearly complete erosion of Dakota in Desert area.

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

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

18. Deposition of nonmarine late Cretaceous Price River formation and upper portion of 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.

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 suring 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 Desert. If the age of these deposits is similar to that of most other Colorado Plateau deposits, they were probably emplaced some time between the early Laramide orogeny and 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. This occurrence would seem to add weight to the assumed age of the Desert deposits. However, other primary deposits have been found in the Eocene Colton formation a few miles northeast of the town of Green River, suggesting that some of the Desert deposits could possibly be late Eocene or younger.

ECONOMIC GEOLOGY

History

Uranium-vanadium occurrences have been known in eastern Utah since 1880. Uranium-bearing outcrops, discovered in that year by sheepherders twelve miles southwest of Green River, Utah about a 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 that a shipment of 30,000 pounds of ore had been sent to Germany. At that time, the workings were prospect pits and test cuts on "carnotite-bearing conglomerate debris". Deposits, then as now, were found at two or three horizons in a 20- to 80-foot section of coarse sandstone and fine conglomerates near the top of the Salt Wash member of the Morrison formation. Several other geologists have reported on the uranium deposits in the San Rafael River Desert since Boutwell first described them. In 1911 F. L. Hess 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 (1944) and Hill (1945) 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. About two tons of ore were mined from the Little Bessie and Little Vernon claims in the northwestern San Rafael River Desert in 1911.

A carload of ore shipped by a Mr. Ward and his associates in 1911 is reported to have contained over 6 percent of combined vanadium-uranium oxides (Hess, 1913). Only incomplete production records are available on shipments of either vanadium or uranium ore from the San Rafael Desert area prior to 1945. Moore and Kithil (1914, p. 16) reported that vanadium ore shipped in 1912 ranged from 1 to 2 percent U_3O_8 and from 2 to 8 percent V_2O_5. 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 shipped in 1941, 1942, and 1943. Several truckloads of vanadium ore were sold to the Metals Reserve Company at Thompsons, Utah, in 1943 (Hill, 1945). Shipment could not be maintained, however, because the vanadium content of the ore fell below the minimum grade of 1.25 percent vanadium as specified by the buyer. The low grade of vanadium, generally under 1 percent, retarded development of the district, and Van Voorhis (1944) reported no recent production in that year. Irregular shipments of "carnotite" ore from small pits continued until 1948, when higher prices for uranium spurred greater production. Sixty thousand five hundred and eighty-five tons of uranium-vanadium ore were produced from the San Rafael Desert area in the period 1948-1956. Of this amount only 11,830 tons were shipped from 1948 through 1954. The average grade of the ore shipped was 0.25 uranium oxide and 0.44 vanadium oxide. Yearly shipments are as follows:

Year	Tons of Ore
1948	667
1949	2,134
1950	2,139
1951	364
1952	769
1953	554
1954	5,202
1955	20,430
1956	28,325

Mining Development

The majority of mines are located in the northern part of the area forming a belt approximately two miles long and one mile wide (the Tidwell mineral belt). This belt includes nearly all of secs. 22 and 27, T. 21 S., R. 14 E. (fig. 4). A few small mines and prospects are located in twps. 22 and 23 S., R. 14 E., the so-called Acerson area.

Size of the workings ranges from small prospect pits to shafts 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 over 300 feet. The largest mine in the area is Incline No. 6 of the Four Corners Uranium Company (fig. 25), with approximately 2,600 feet of underground workings. There are four types of operations in the area: shafts, inclines, stripping operations, and drifts. At present there are seven inclines, three shafts, and one drift in operation. Shafts vary from 80 to 300 feet deep and inclines range from 60 to 140 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 lessees. At present the ore is 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, utilizing 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, at a depth of 25 feet an ore body containing seven hundred tons of ore averaging 0.85 percent uranium oxide. The area then began to receive the attention it deserved. Thousands of feet of exploratory drilling was undertaken in 1953, 1954, 1955 and 1956, with most of the drilling being done 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 down-dip, many of them beneath the water table. A few of the deep ore bodies probably contain up to 50,000 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. 28). The depth variation is probably due in part to topography and in part to perched water tables. The Uranium Prospectors Limited shaft, which reaches a depth of 300 feet, pumps between 40 to 60 gallons of water per minute.

All mines use the room and pillar method of mining. Four mines use track, while the other operations use either rubber-tired or tracked vehicles. A few air slushers are used in some of the mines.

MINERALOGY

Barren Zones

Detrital Constituents

The mineralogic composition of Salt Wash sandstones in the San Rafael River Desert is shown in Table 1. Quartz and chert grains are the principal detrital constituents of the Salt Wash, making up 80 percent or more of unmineralized sandstone; chert content varies from 1 to 26 percent. Detrital grains of feldspar and felsitic 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 mm., 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 crypto-crystalline chalcedonic to micro-crystalline 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. 8) whereas dense quartzitic varieties may remain fresh even adjacent to ore zones.

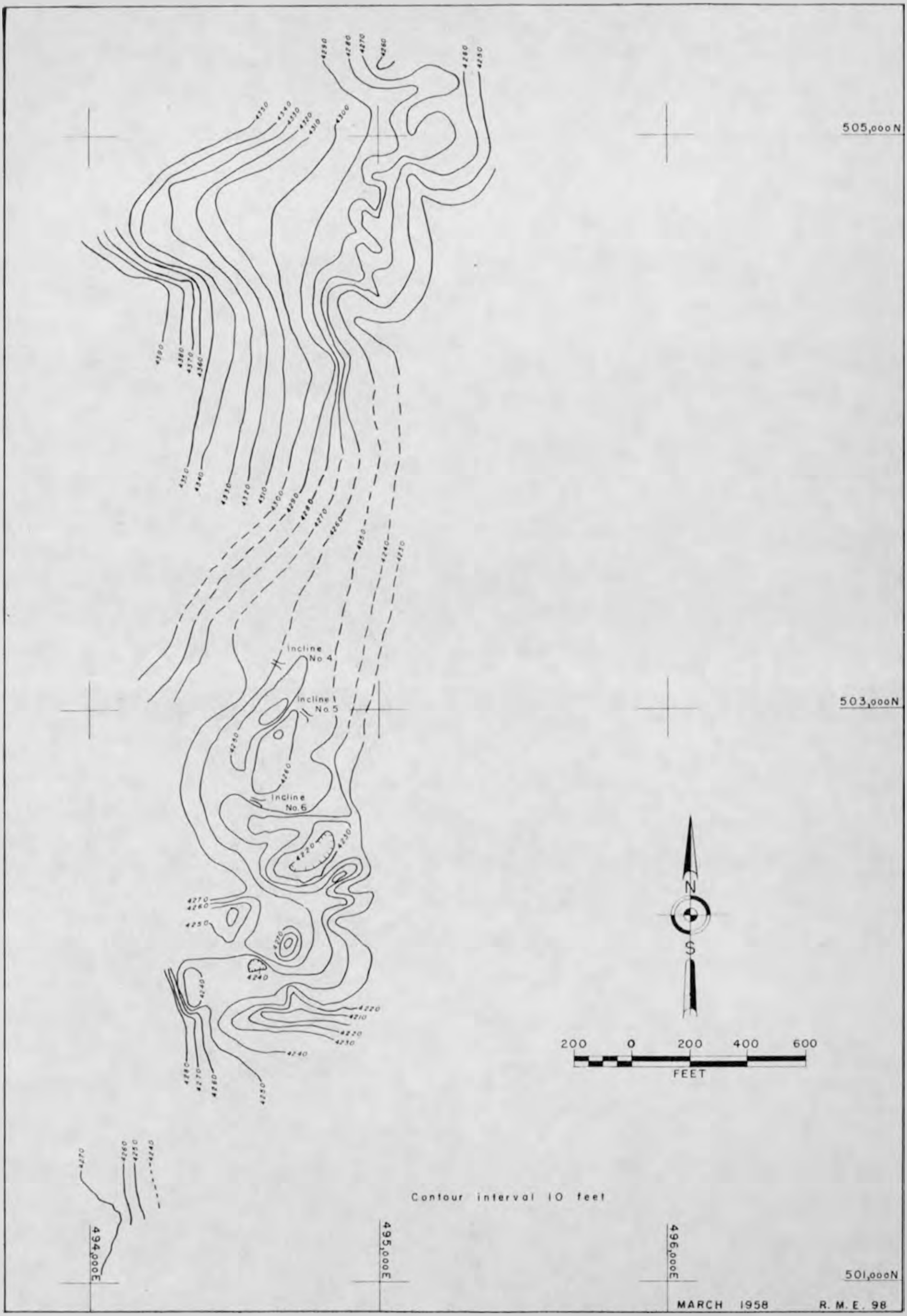


Figure 28. Contour map on top of water table, Four Corners Uranium Claims, San Rafael River Desert, Emery County, Utah

TABLE 1

Mineralogic Composition of Salt Wash Sandstone in San Rafael River Desert Mining District

Locality	Detrital Components				Interstitial Components					
	Quartz	Chert	Feldspar	Aphanitic Rocks	Heavies	Carbonate	Clay	Organic Matter	Metallic Minerals	Total
Old Workings 4-Corners Uranium Co.(Unmineralized)	76	7	2	0	Tr	11	4	0	0	100
Salt Wash Outcrop 4 mi. S. of Desert Moon Mine (Unmineralized)	54	26	3	2	0	1	14	0	0	100
Incline No. 6 Mine near Ore Zone. (Slightly mineral-ized).	77	2	2	1	Tr	3	14	1	T	100
Smith Lucas Mine in Ore Zone (Mineralized)	62	1	1	Tr	0	4	24	6	2	100
McDougall Shaft in Ore Zone. (Mineralized)	58	11	1	Tr	0	T	27	1	2	100
Waterson Shaft in Ore Zone. (Mineralized)	18	1	0	0	0	0	70	2	9	100

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.

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.

Ore Zones

Primary Ore Minerals

Primary minerals identified from the ore zones of Salt Wash sediments in the San Rafael River Desert include coffinite, uraninite, montroseite, sphalerite, pyrite, marcasite, chalcopyrite, and clausthalite.

Coffinite

Coffinite ($U(SiO_4)_{1-x}(OH)_{4x}$) is the most abundant ore mineral (primary or secondary) in the Desert and has been identified in all of the mines examined to date.

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

An effort has been made in the present study to coordinate petrographic and autoradiographic studies with X-ray from the Denver laboratories of the U. S. Geological Survey. 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. 29, 30 and 31). It also rims quartz (figs. 32 and 33), 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

In the Desert, uraninite (UO_2, UO_3) is second in importance only to coffinite as an ore mineral and has been identified from many of the mines.

Figure 29. Autoradiograph of Figures 30 and 31.

Figure 30. Pyrite (py) cubes in lignite. Four Corners Uranium Company 150 X Transmitted light. Pyrite partially replaced by coffinite (cof).

Figure 31. Same view as figures 29 and 30 in reflected light. 150 X

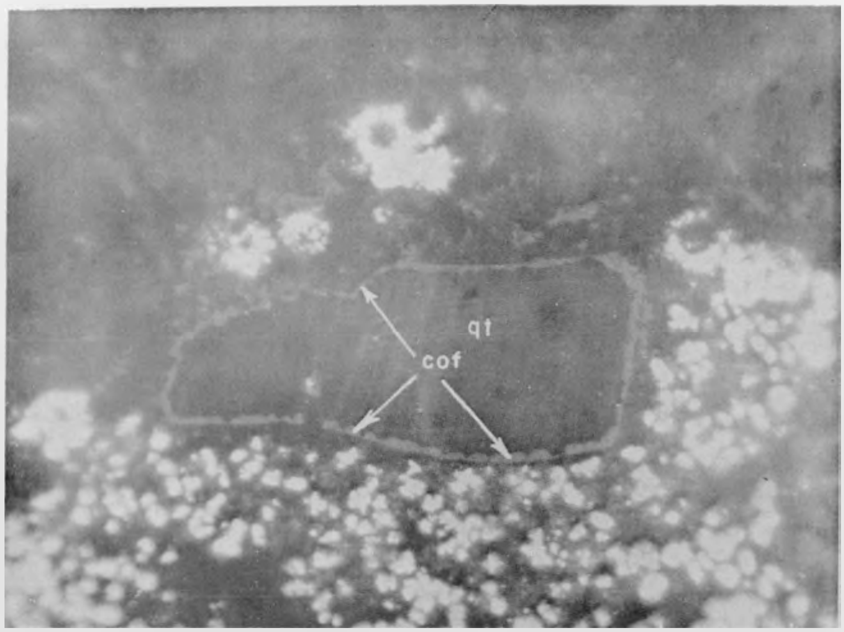


Figure 32. Coffinite (cof)? rimming quartz (qt) 1500X incident light.

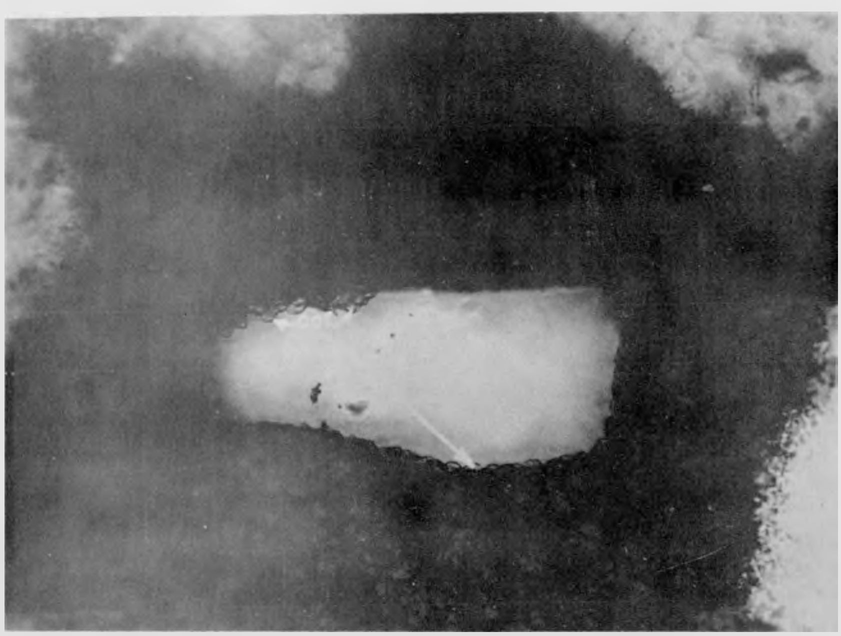


Figure 33. Translucent properties of coffinite (cof)? Same field as figure 32 with transmitted light. 1500X

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. 34 and 35). In many cases uraninite is difficult to distinguish from uraniferous asphaltite because of similarities of reflectivity. Both uraninite and asphaltite are light gray in incident light and have reflective intensities around 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 (VO_2) are the primary vanadium minerals in the Desert. These minerals are grouped together in this report since they cannot be differentiated optically.

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

In the Desert montroseite occurs as concretionary halos around logs and as dissemination in sandstone rich in organic matter. Montroseite is usually bladed, acicular, or occasionally spherulitic (figs. 36, 37, and 38). 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 (fig. 39) (ZnS) occurs locally in ore zones in most of the mines in the area. 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 displays 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_2) occurs abundantly in all the mines in the Desert. It replaces cell walls in wood, fills cell centers (fig. 40) and surrounds some logs as concretionary halos. It disseminates through all ore horizons. Nearly every primary mineral from the area is associated with pyrite at one place or another.

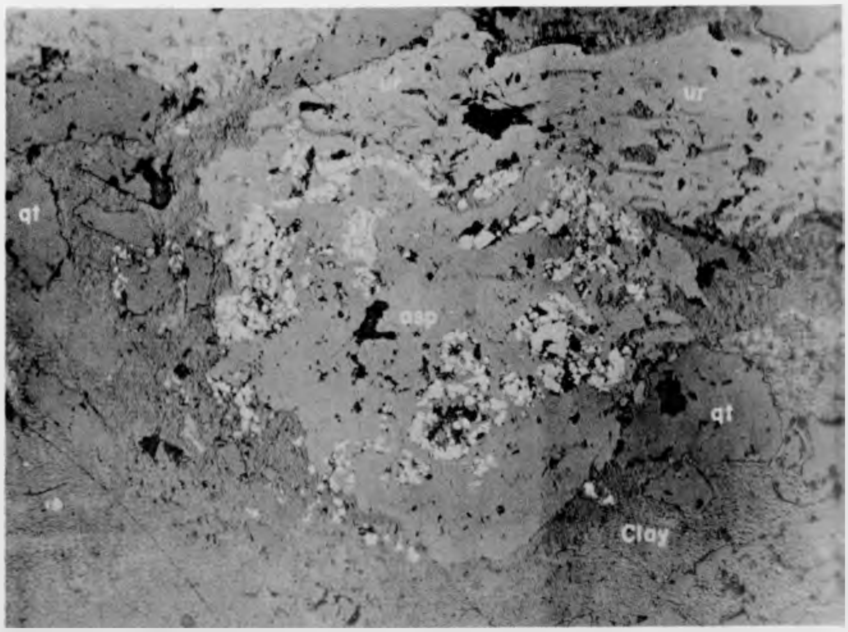


Figure 34. Uraninite (ur), asphaltite (asp), and pyrite (py) in a clay and quartz (Gt) matrix. 250 X Incident light.

Figure 35. Uraninite (ur) replacing fossil wood. Clay, quartz (qt), and pyrite (py) in matrix. 250 X Incident light.

Figure 36. Montroseite (mr) spherulites in clay replacing mudstone (ms) 250 X Incident light.

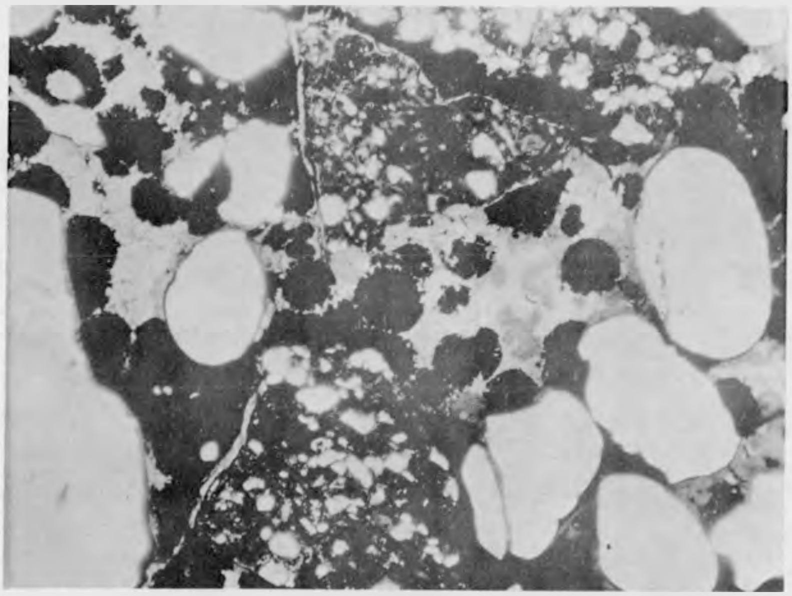


Figure 37. Same field as figure 36 in transmitted light. 250 X Incident light.

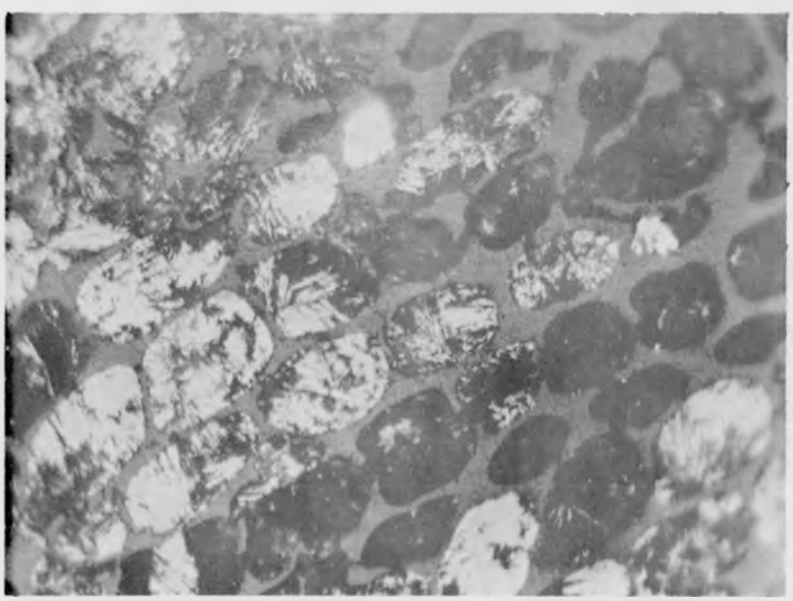


Figure 38. Montroseite (mr) and pyrite (py) filling cells in wood. 1500 X Incident light.

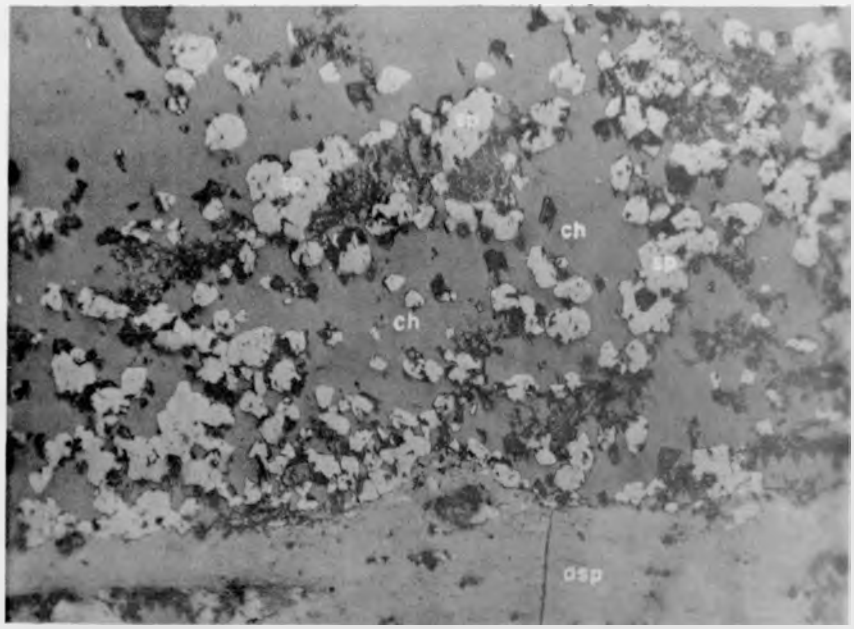


Figure 39. Sphalerite (sp) embedded in chalcedony (ch). Asphaltite (asp) at bottom. 250 X Incident light.

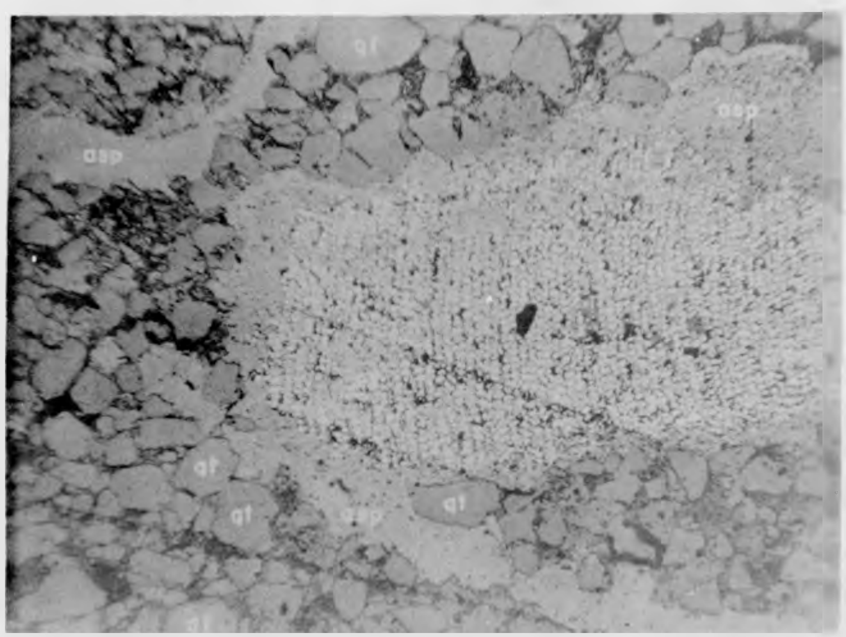


Figure 40. Pyrite (py) replacement of cell centers in wood surrounded by asphaltite (asp) that passes into veinlets. Sandstone host is largely quartz (qt). 250 X Incident light.

Pyrite from the Desert often contains appreciable amounts of arsenic. Spectrographic analyses (table 2) reveal nearly 10 percent arsenic in one pyrite sample from the Waterson shaft.

Marcasite

Marcasite (FeS_2) is almost as abundant as pyrite with which it is closely associated. Laths of marcasite often occur embedded in a pyritic ground mass. Like pyrite, it commonly replaces wood, filling 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 identified as marcasite may actually be ferroselite ($FeSe_2$) which closely resembles marcasite. This may account for the large amount of selenium present in marcasite and pyrite samples.

Chalcopyrite

Chalcopyrite ($CuFeS_2$) (fig. 41) occurs sparsely, often associated with pyrite, montroseite and sphalerite as wood replacements. 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 located near the southern margin of the Desert.

Clausthalite

Clausthalite (Pb Se) 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 Desert (fig. 4). 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 ($V_2O_4 \cdot 6V_2O_5 \cdot n\,H_2O$) 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.

TABLE 2

Spectrographic Analyses of Salt Wash Samples

Lab. No.	243534	35	36	37	38	39	243038	39	40	41	42	43	44	45	46	242621
Si	M*	7.	3.	M	3.	M	M	M	M	M	7.	M	M	M	M	.7
Al	1.5	.7	1.5	.15	1.5	.15	M	3.	1.5	3.	7.	M	M	M	7.	1.5
Fe	M	M	7.	3.	1.5	3.	.7	.7	.3	.7	3.	1.5	1.5	1.5	1.5	M
Mg	1.5	.3	.7	.03	.3	.07	1.5	1.5	.7	1.5	3.	1.5	3.	3.	3.	.07
Ca	.3	.15	.15	.015	.07	.015	7.	.03	<.01	.03	.3	.07	.07	.07	.3	.07
Na	.15	.15	.3	Tr	<.5	.07	1.5	.7	.3	.3	<.5	.7	.7	1.5	.7	Tr
K	1.5	>1.	>1.	0	3.	0	7.	3.	0	0	0	1.5	7.	7.	.7	0
Ti	—	.015	.07	.015	.015	.007	.15	.15	.15	.15	1.5	.3	.7	.7	.07	.007
Mn	.015	.015	.003	.03	.003	.03	.07	.007	.0015	.003	.015	.007	.007	.015	.007	.0015
As	.15	.3	.3	0	.15	.15	0	0	0	0	0	0	0	0	.3	10.
B	0	0	0	.003	0	0	.007	.003	.003	.003	.003	.003	.015	.015	Tr	0
Ba	.003	.003	.0015	.003	.0015	.0015	.007	.015	.0015	.0015	.015	.07	.015	.015	.015	.015
Be	.00015	0	.00015	0	.00015	0	.00015	.0003	0	0	.0015	Tr	.0003	.0007	.00015	0
Cd	<.1	<.1	<.1	0	<.1	0	0	0	0	0	0	0	0	0	0	0
Co	.007	.007	.03	.0015	.007	.007	.0015	0	0	.003	.015	.0015	.0015	.0007	.003	.0015
Cr	.003	.003	.0015	.007	.0007	.003	.003	.003	.0015	.003	.003	.007	.007	.007	.003	0
Cu	.07	.015	.0015	.015	.0007	.015	.003	.0007	.0003	.0015	.015	.015	.003	.003	.007	.0003
Ga	Tr	Tr	Tr	0	Tr	0	.003	.0007	0	0	0	.0015	.007	.003	Tr	—
Mo	.03	.07	.03	.015	.03	.003	0	.0015	0	0	.015	0	Tr	.015	.007	.03
Ni	.015	.007	.015	.003	.007	.007	.003	.0007	.0007	.003	.015	.0015	.003	.0015	.003	.0015
Pb	Tr	.003	.03	0	.003	Tr	.0015	.0015	0	0	.07	.003	.003	.0015	.007	0
Sn	0	0	0	0	0	0	.007	.15	.07	.015	.07	.07	.03	.03	.03	0
Sr	.0015	.0007	.003	0	.0015	Tr	.007	.0015	<.00015	.0015	.015	.003	.003	.007	.003	0
U	0	.15	.3	.15	.15	0	.07	0	0	0	7.	0	0	.07	.3	0
V	M	1.5	7.	.3	.3	.3	.015	.3	.15	.15	M	.07	.15	.07	.7	.07
Y	0	.003	.015	0	0	0	.0015	0	0	0	.07	.0015	.015	.003	.003	.003
Yb	0	<.005	<.005	<.005	<.005	<.005	.0003	<.003	<.003	<.003	<.015	<.003	.0015	.0003	<.002	<.002
Zn	0	0	0	.15	7.	.03	0	0	0	0	0	0	0	0	0	0
Zr	<.005	.007	.015	<.005	.007	<.005	.015	.03	.015	.03	.07	.015	.015	.03	.007	0

*M = >10%

Table 2 [illegible]t'd)

Sample Localities:

Sandstone Samples

No. 243534 - Mineralized zone around log, Waterson shaft
35 - Mineralized zone near log, Waterson shaft
36 - Asphaltized rim around log, Waterson shaft
37 - Silicified zone in log, Waterson shaft
38 - Inner asphaltized zone, Waterson shaft
39 - Inner silicified zone, Waterson shaft

Clay Samples

No. 243038 - Incline No. 6 mine
39 - Incline No. 6 mine
40 - Incline No. 6 mine
41 - Incline No. 6 mine
42 - Smith-Lucas mine
43 - Outcrop on Tidwell nose
44 - McDougall Incline mine
45 - Desert Moon mine
46 - Waterson shaft

Pyrite Sample

No. 242621 - Pyrite and marcasite, Waterson shaft

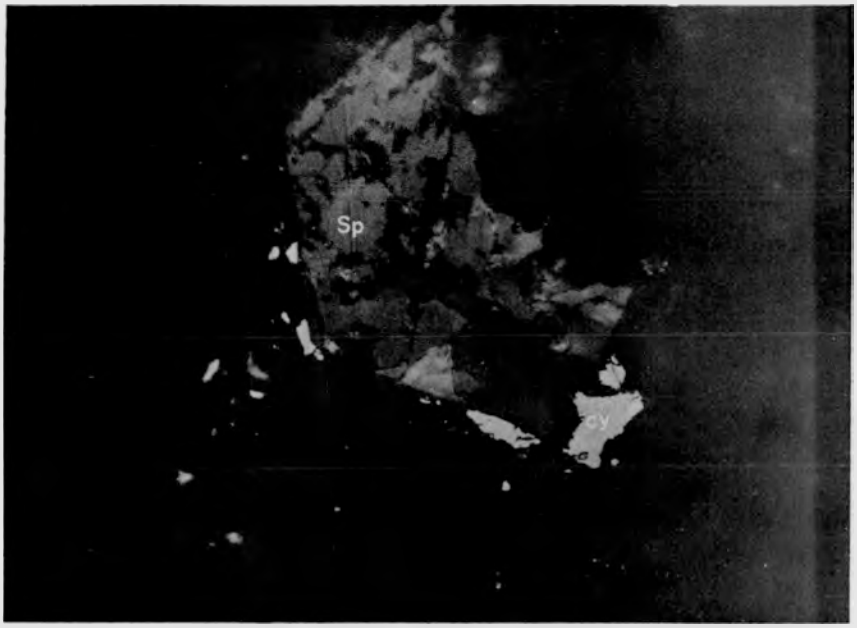


Figure 41. Spahlerite (Sp) rimmed by chalcopyrite (cy). 500X Incident light.

Hewettite

Hewettite ($Ca\ V_6O_{16} \cdot 9\ H_2O$) is rare in the Desert 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 nose just south of the town of Green River.

Tyuyamunite and Metatyuyamunite

Tyuyamunite ($Ca(UO_2)_2\ (VO_4)_2 \cdot 7\text{-}10\frac{1}{2}\ H_2O$) and its partially dehydrated equivalent, metatyuyamunite ($Ca\ (UO_2)_2(UO_4)_2 \cdot 5\text{-}7\ H_2O$) 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. 26).

Schroeckingerite

Schroeckingerite ($Na\ Ca_3(UO_2)\ (CO_3)_3(SO_4)\ F \cdot 10\ H_2O$) 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 ($(UO_2)_6(SO_4)(OH)_{10} \cdot 12\ H_2O$) 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 ($Ca(UO_2)(CO_3)_3 \cdot 10\text{-}11\ H_2O$) 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 ($BaSO_4$) 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.

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 2.

Carbonates

Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are found locally predominantly above but partly within ore zones especially in those mines near the crest of the Tidwell nose. Carbonate occurs interstitially between sand grains (fig. 42), as replacements of quartz grains and as coatings on fractures.

Quartz and Chalcedony

Much of the silification of woody material in the Salt Wash appears to be nearly contemporaneous with mineralization. Chalcedony coatings on fractures in the Tidwell mineral belt (fig. 27), however, are apparently much more recent. Chalcedony and quartz in ore bodies are intimately associated with many primary minerals including montroseite (fig. 43), 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 ($Ca_7(CO_3)(PO_4)_4 \cdot \frac{1}{2}H_2O$) and by X-ray as a fluorapatite variety ($Ca_4(CaF)(PO_4)_3$). It occurs with ore minerals in mineralized reptilian bone (fig. 44).

Ilsemannite

Ilsemannite $MoO_3 \cdot SO_3$(?) occurs in a few of the mines in the Desert. It commonly effloresces on walls and floors of damp mines in which sulphides

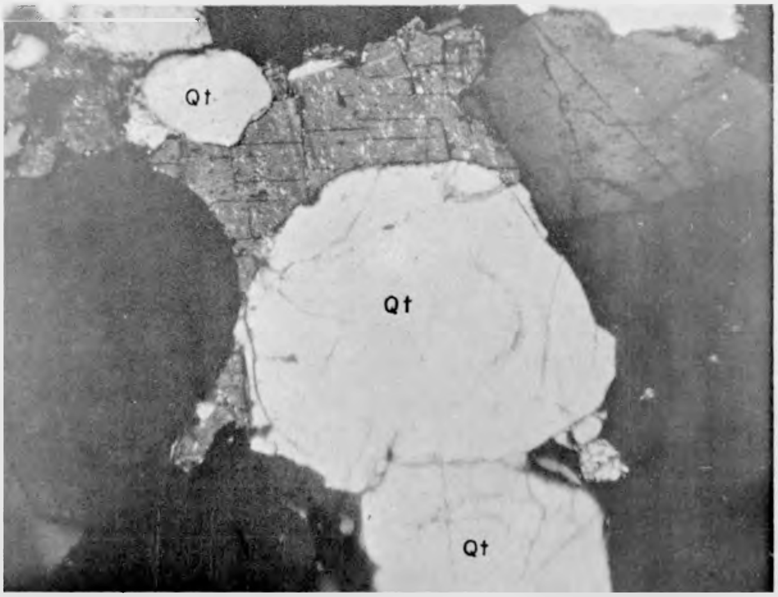


Figure 42. Quartz (qt) grains with overgrowths. Interstitial calcite (ca). 500 X Transmitted light crossed nicols.

Figure 43. Chalcedony (ch) veinlet containing montroseite (mr) in silicified wood. 250 X Transmitted light.

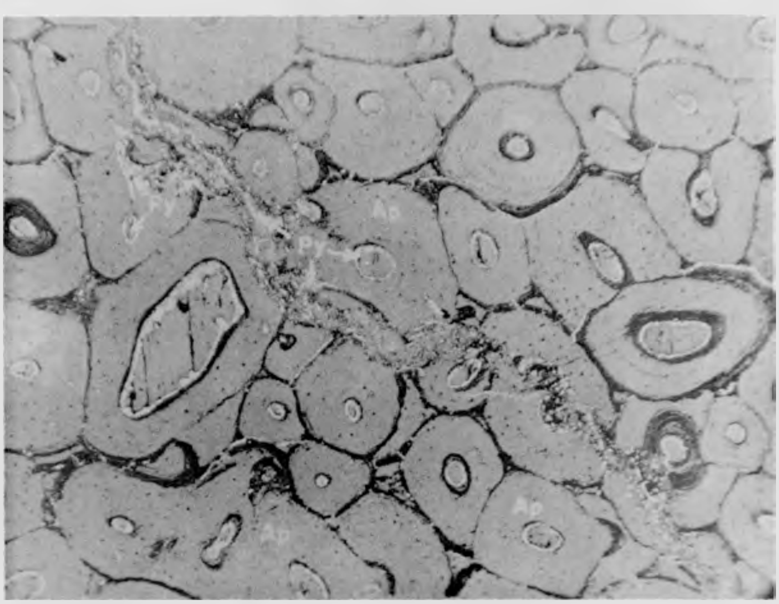


Figure 44. Pyrite (py) as veinlets and cell replacements in mineralized bone. Cells replaced by Fluorapatite (ap). 250 X Incident light.

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 (Austin, 1957).

Hydrous Sulfates

The hydrous sulfates halotrichite ($FeAl_2(SO_4)_4 \cdot 24\ H_2O$) and alunogen $Al_2(SO_4)_3 \cdot 18\ H_2O$ commonly occur in wet mines in the presence of sulfides. These highly soluble salts effloresce and commonly form silky hair-like 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 Desert may be divided into four types: (1) lignitic matter possessing well preserved cell structure (figs. 45, 46); (2) asphaltic veinlets which transect mineralized sands, ores, and wood remains (fig. 47); (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 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. 40).

It is apparent that asphaltic 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 by steam distillation in the form of tar. Hot mineralizing solutions may have distilled asphaltic tar from wood.

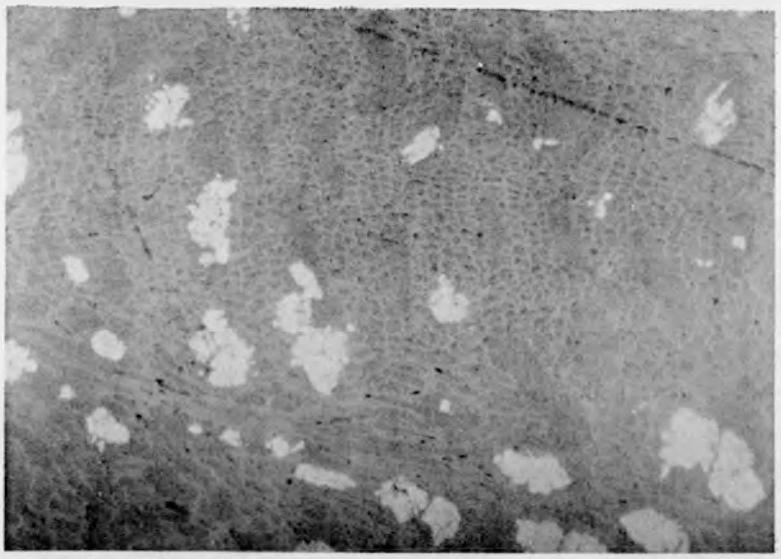


Figure 45. Lignitic matter containing marcasite (mc). 250 X Incident light.

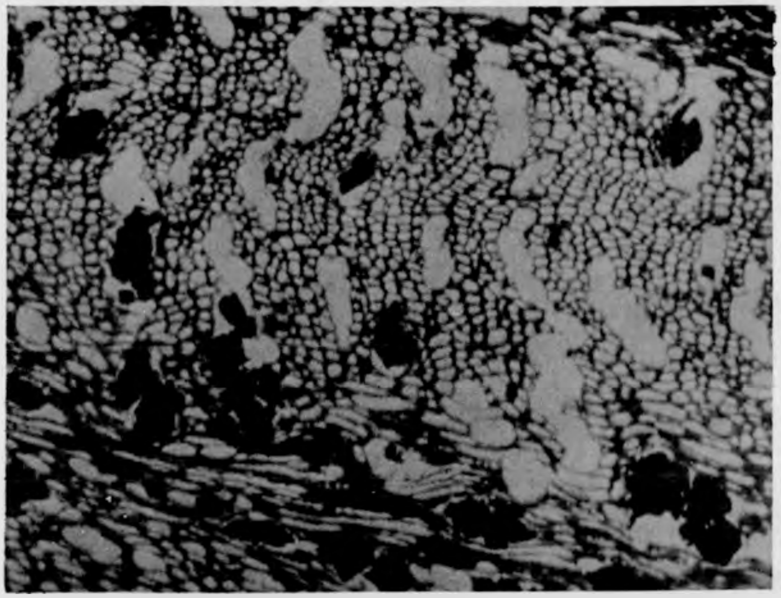


Figure 46. Same field as Figure 45. 250 X Transmitted light.

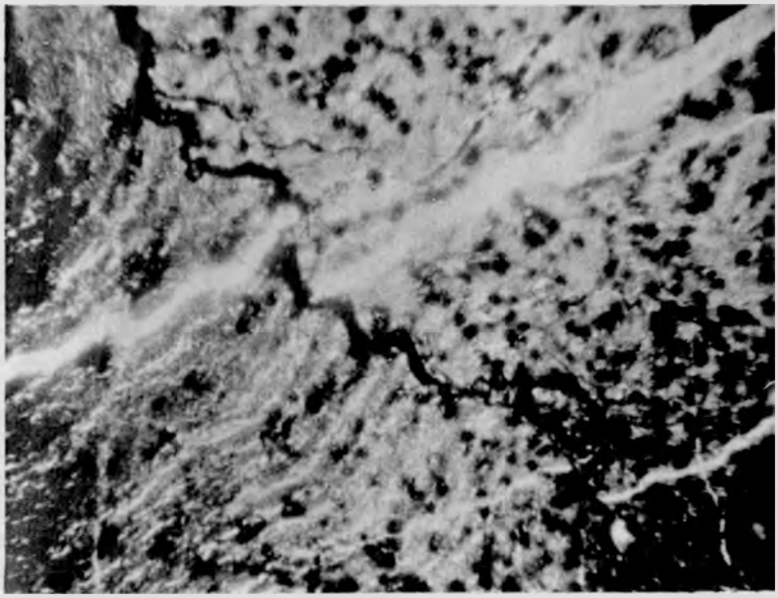


Figure 47. Asphaltite veinlet (black, running NW-SE) Cutting quartz veinlet (white) in silicified wood. 250 X Transmitted light.

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 bog head 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 Desert, could amply supply the volume of asphaltite that occurs in the ore zones.

4. Figure 40 may be interpreted as follows: mineralizing solutions deposited marcasite in cell centers and displaced resinous material from wood or lignite, forcing it into veinlets in the surrounding sandstone.

Reason for 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 40 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. 48). 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. 49). 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 as follows: (1) This material is largely confined to a narrow zone in the host sandstone

Figure 48. Concentration of dark ore around asphaltic (?) material (A), Ore sample from below H_2O table.

Figure 49. Disseminated Carbon in sandstone from outcrop of ore horizon, Tidwell nose.

roughly corresponding to the ore horizon. The regular nature of this thin zone, and its apparent disregard of bedding planes and lithologic variations, suggests an oil-water interface although it might possibly 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 horizon suggests that a considerable volume of the material was present and was trapped in that unit. At other localities in the Desert 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 as follows: (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 the 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. Perhaps it would be subject to gravity separation much as oil and water.

Paragenesis of Mineralized Wood

Wood remains in the Salt Wash sandstones appear to have been (1) lignitized, (2) silicified, (3) mineralized, and (4) asphaltized. This sequence of wood alteration occurred in approximately the order listed. Much of the lignitic material retains a brownish woody appearance and displays excellently preserved cell structures (figs. 12, 45, and 46). Lignite was locally silicified in part, and commonly grades into wholly silicified wood. Silicification and mineralization show a large overlap (fig. 43).

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. 50). Quartz veinlets cut both silicified and unsilicified lignite.

Early chalcedonic veinlets in silicified wood are commonly cut by later quartzitic veinlets (fig. 51) which in turn are cut by still later asphaltite veinlets (fig. 47). Spherulitic growths of montroseite are distributed along quartz veinlets (fig. 43) and are cut by them in some cases (fig. 52).

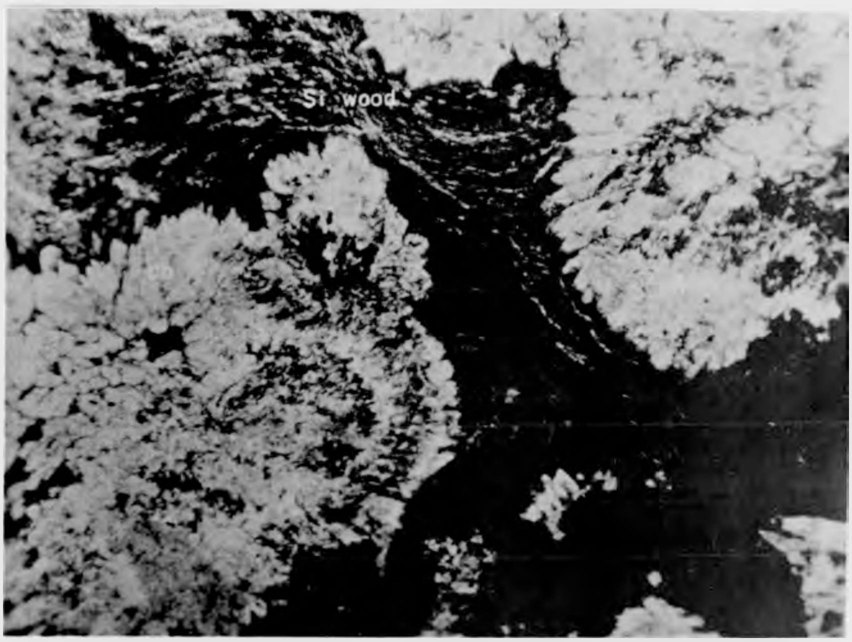


Figure 50. Recrystallization of chalcedony to quartz tending to destroy wood structures in silicified wood. 250X Transmitted light.

Figure 51. Chalcedony (ch) veinlets cut by later quartz (qt), veinlets in silicified wood.

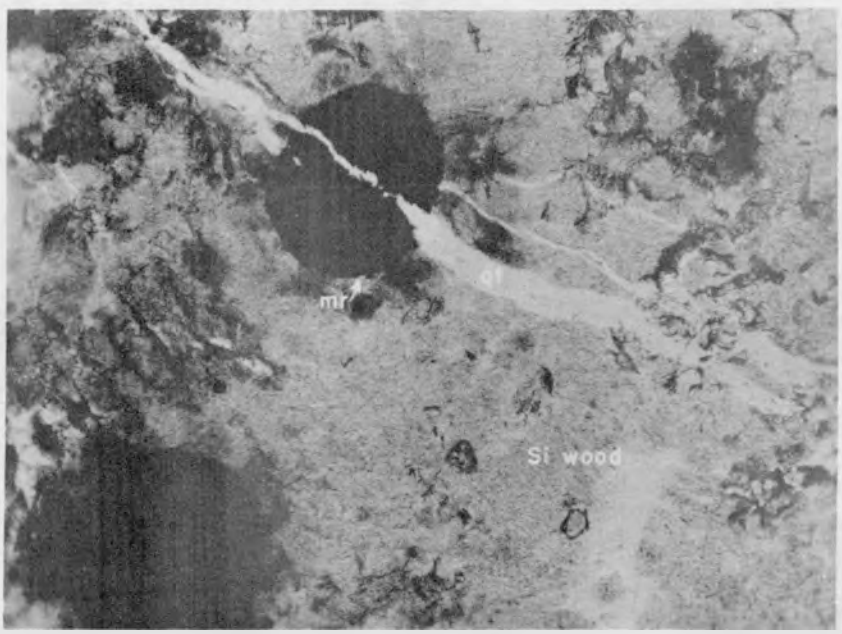


Figure 52. Montroseite spherulite cut by quartz veinlet in silicified wood.

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. 44) and rim cell walls. Bone cells are commonly filled with dahllite, but locally they are completely filled with sulfides.

Veinlets of uraniferous asphaltite (fig. 53) penetrate bone along apparently pre-existing veinlets of sulfides, and locally fill centers of bone cells (fig. 54). 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 from the Desert are found at any one locality, there is sufficient overlapping of mineral assemblages to permit the outlining of a probable order of deposition as shown in Table 3.

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 while the later 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 of these petroliferous materials by the precipitated uranium may 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 deposition is largely confined to the vicinity of organic matter. It commonly occurs in areas of extensive argillation where quartz and chert grains in the host sediments are corroded or entirely replaced by clay (figs. 55, 56, 57 and 58). Asphaltite is often associated with uranium concentrations and is in contact with the previously corroded borders of the clay and quartz (fig. 55).

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 within or outside of logs but usually occurs in the vicinity of uraninite or coffinite.

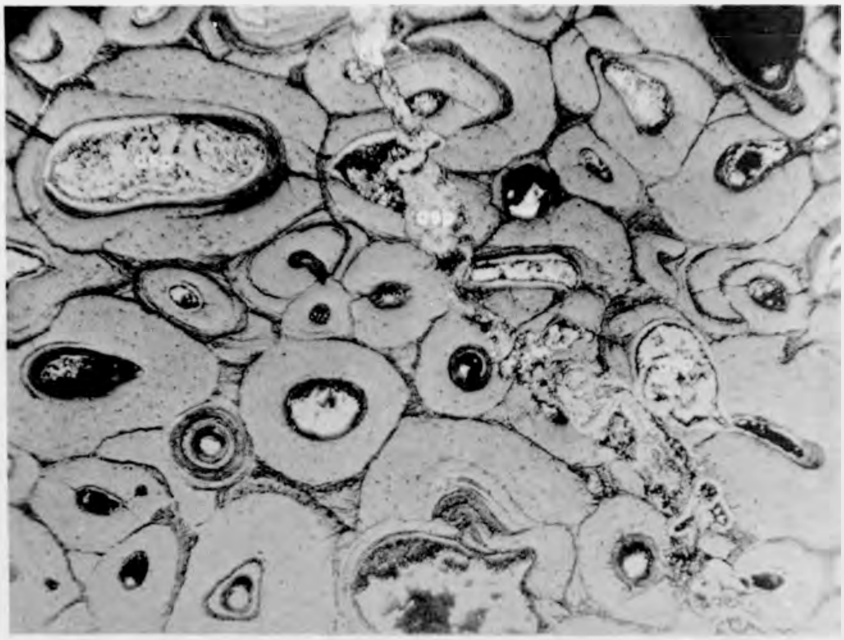


Figure 53. Asphaltite veinlet cutting mineralized bone. 250 X Incident light.

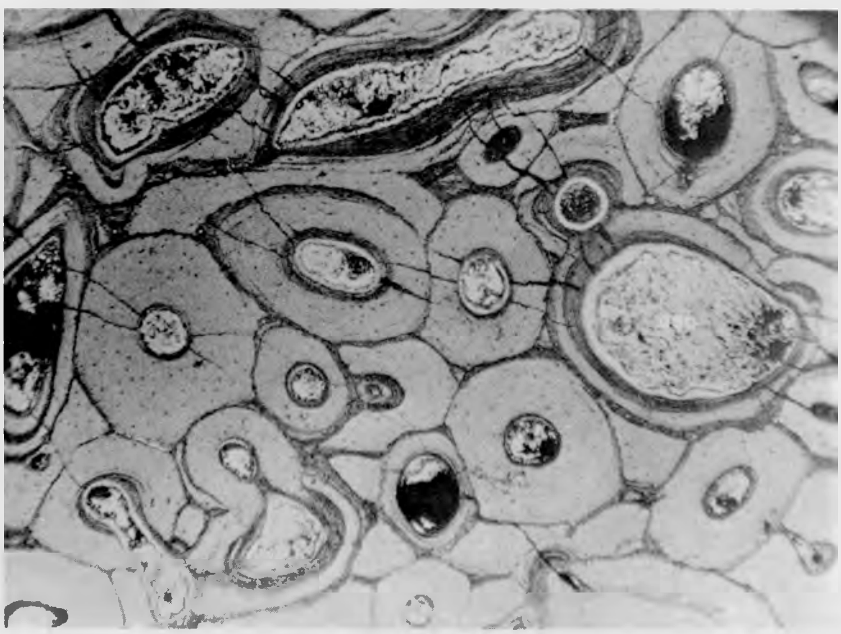
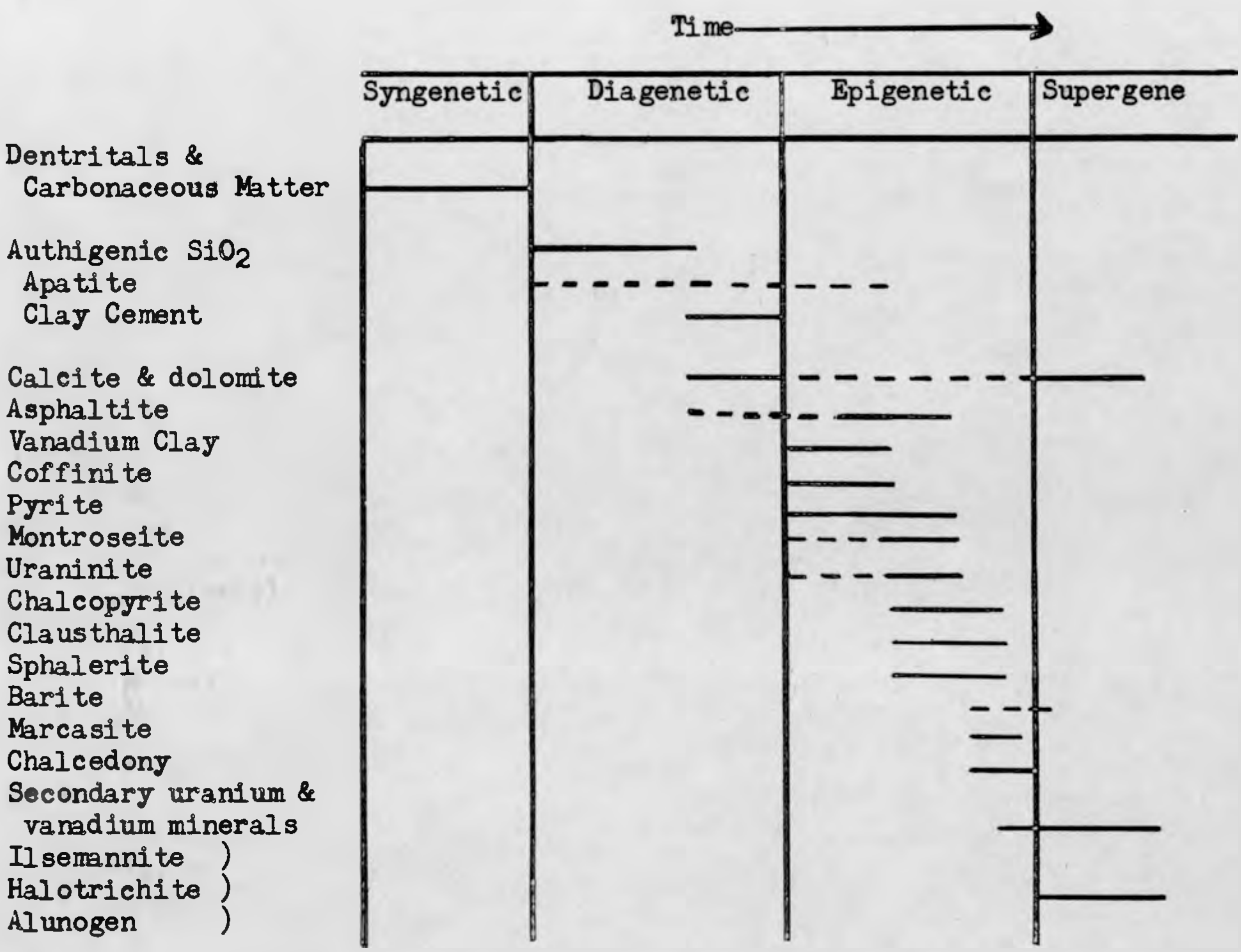


Figure 54. Uraniferous asphaltite (asp) filling cell centers in mineralized bone 250X Incident light.

TABLE 3

Paragenesis of Primary and Secondary Minerals



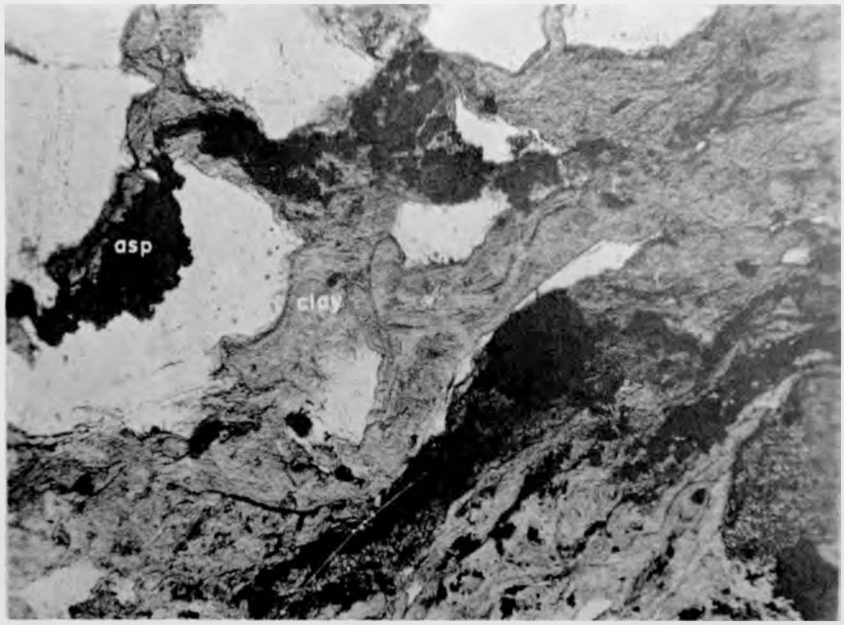


Figure 55. Corrosion of quartz (qt) by clay producing solutions, (transmitted light) 500 X with later asphaltite (asp).

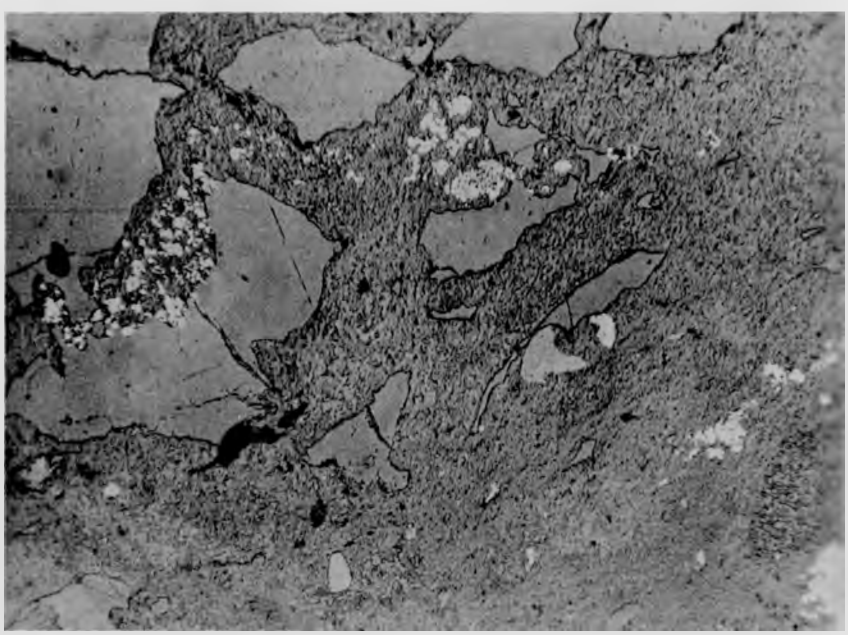


Figure 56. Same field as fig. 55 (incident light) 500 X

Replacement of quartz by clay in vicinity of mineralization

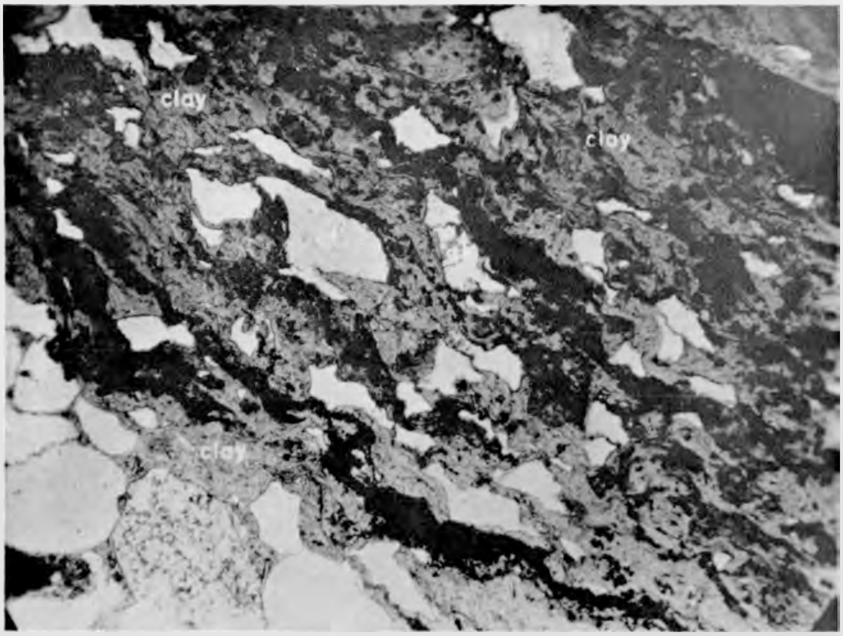


Figure 57. Corroded quartz grains surrounded by clay. 250X Transmitted light

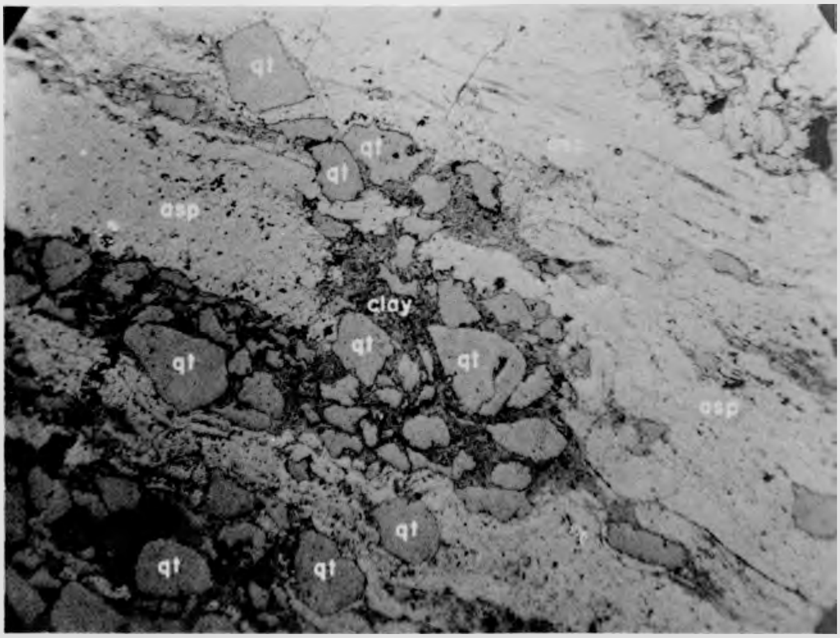


Figure 58. Corroded quartz grains surrounded by clay and asphaltite. Asphaltite later than clay and not responsible for quartz corrosion. 250 X Incident light.

Source of Mineralizing Solutions

The mineral assemblage and alteration effects resulting from uranium mineralization in the Desert suggest a hypogene source similar to that postulated for the Temple Mountain deposits in the San Rafael Swell.

It is probable that the mineralizing solutions originated at depth, from a buried stock or other igneous mass, and rose vertically until they reached a permeable horizon at which they could spread laterally. Modern students of uranium solutions believe that uranium moves as complex carbonate and sulphate ions (McKelvey, Everhart, and Garrels, 1946) (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, which passed through a large portion of the Salt Wash, apparently encountered reducing environments in certain areas rich in organic matter resulting in ore deposition. Assuming that the Salt Wash was saturated with water at that time, mineralizing solutions would have moved laterally and upward from the point of entry. This is based on evidence of present day circulating ground waters which do not move far downdip from outcrops before beginning to move laterally. It is probable that mineralizing solutions were also warmer than formation waters and thus would have had a tendency to rise structurally.

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 San Rafael River Desert mining area. 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 areas, such as in the shallow prospects along the outcrop in the Tidwell mineral belt, some ore is associated with disseminated carbon 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 pinchouts. Sediments in the vicinity of ore zones often appear bleached. Iron oxide is present in the ferrous state, and 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 downdip 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. 59). 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 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 is found to enclose small lenses or veinlets of vitreous asphaltic carbonaceous material (fig. 48). These lenses usually parallel laminae, but some appear to cut across them. In some mines, ore occurs in a horsetail pattern following minute cross-laminae (fig. 60).

The average Desert ore contains 0.25% U_3O_8 and 0.44% V_2O_5, but high grade pods of black ore assay as high as 15.0% U_3O_8. 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 cross 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 thousands of tons. They may occur singly or in clusters aggregating 10,000 to 20,000 tons. The long axes of most ore bodies are oriented in a northeast-southwest direction parallel to Salt Wash channel trends (fig. 61). Maximum ore thickness is six feet, but the average thickness is only 2.5 feet. Clark and Million (1956, p. 157) report ore rolls in the Tidwell mineral belt, but no identifiable ore rolls were mapped by Commission geologists, during this study.

Ore-bearing Strata

In the Desert a few small uranium deposits occur in channel sandstones near the base of the Brushy Basin but most deposits occur in sandstones in the upper portion of the Salt Wash.

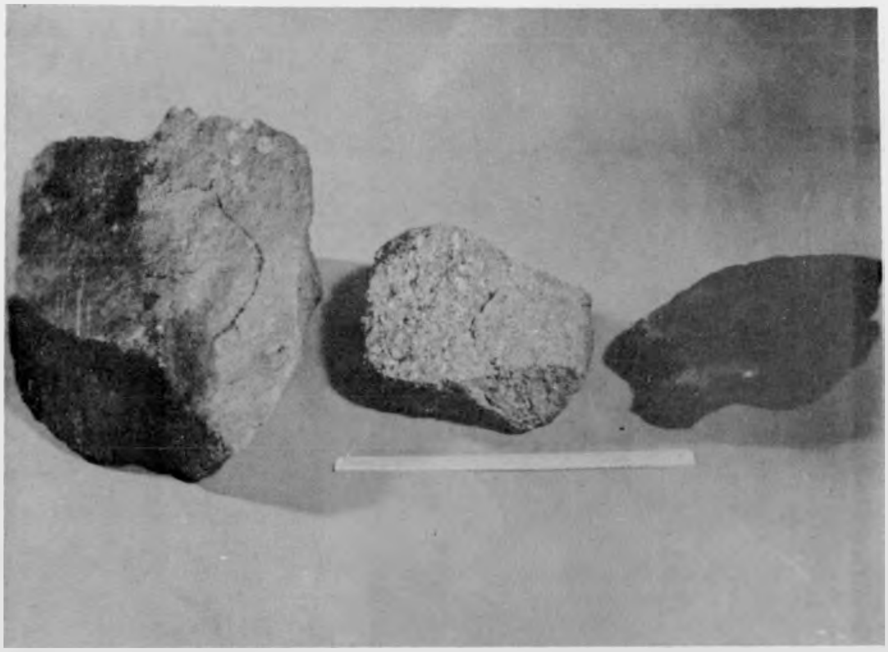


Figure 59. Sequence of ore samples from outcrop to below water table in Tidwell mineral belt. Sample at left from outcrop, middle sample from about 50 feet above water table, and sample on right from below water table.

Figure 60. Ore exhibiting horsetail pattern.

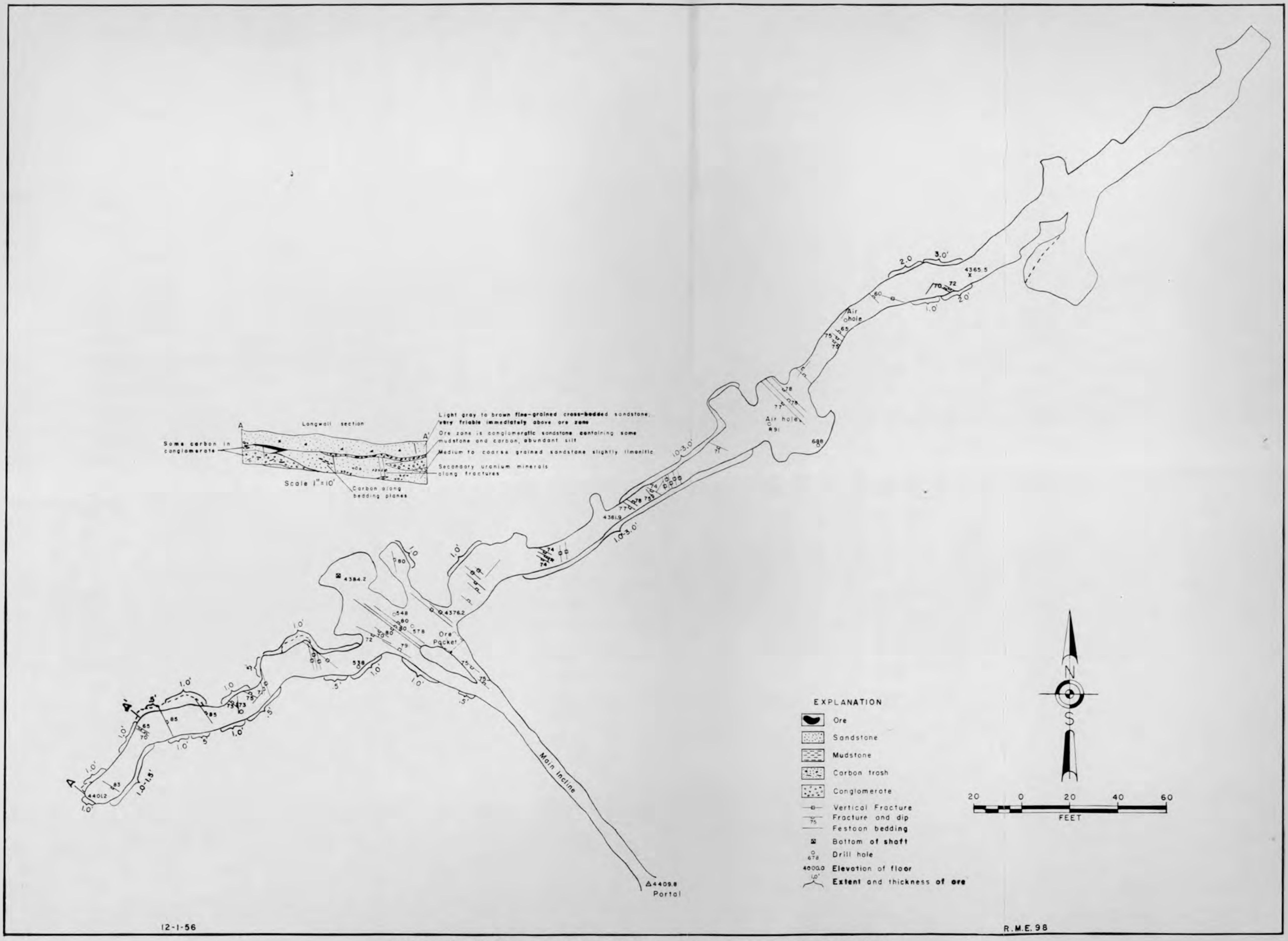


Figure 61. Smith-Lucas Incline Mine, Four Corners Uranium Corp.
San Rafael River Desert, Emery County, Utah

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 varying from 40 to 80 feet. Locally a few large gray to green mudstone boulders are present (fig. 62). 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 large braided 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 portions 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 downdip 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 but the lead selenide, clausthalite, does occur with uranium in this area. Its close association 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 Desert are not fully understood but certain relationships suggest such controls.

All large ore bodies found to date are in the thick conglomeratic sandstone of the Salt Wash in the Tidwell mineral belt along the western edge of the Desert. A few small deposits occur in the Acerson mineral belt, a narrow poorly defined north-trending belt of relatively thick sandstones about a mile east of the San Rafael River bridge. Elsewhere in the Desert sandstones are thinner, more discontinuous and more closely associated with red mudstones. It thus seems apparent that uranium-bearing solutions preferred those areas of thick continuous sandstones deposited by large streams where they could circulate more freely; it is doubtful that they could move at all in many areas. Here also there was much more carbonaceous debris 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 in the Smith

Figure 62. Mud boulder in ore horizon in Incline No. 6 mine.

Lucas incline (fig. 61) was extremely narrow and sinuous. Subsequent mining outlined a small scour trending north 15 degrees east. Nearly all other ore bodies in this belt show a similar trend which seems to be more than coincidence.

Finer 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. 63) but in a few cases it is in fine-grained sandstone (fig. 64). 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.

In many places the higher grade ore occurs along bedding planes where woody materials, often associated with asphaltic material, were concentrated. 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 Desert mining area 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 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 transverse folds.

Field mapping revealed no recognizable longitudinal folds in this area but did show the several transverse folds mentioned previously.

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 (north 65 degrees west) fold or nose; 2) Most uranium deposits are associated with woody trash and asphaltic (?) material; 3) Much of the Salt Wash on the nose contains considerable disseminated carbon which may represent a petroleum or a structurally controlled colloidal humic residue; 4) Most fractures in the ore horizon are normal to bedding; 5) The largest and highest grade ore bodies occur in highly jointed areas, and; 6) Most faults are probably postore (fig. 65).

Utilizing the above 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

Figure 63. High grade ore in conglomeratic sandstone

Figure 64. Ore confined to bedding planes in fine-grained sandstone.

Note:
Chalk marks outlining ore zones.

Figure 65. Probable post-ore fault with about 4 feet of throw in Incline No. 6 mine. Downthrown on right.

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 a portion of the crests of the folds and subsequent deposits of the Cedar Mountain completely concealed them. If renewed folding occurred in early Cretaceous time, the periods of erosion preceding and following deposition of Dakota and the subsequent thick shale deposits of the Mancos probably has obscured 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 action of ground water and peaty or lignitic material, accumulated in porous sandstones at this time. If petroleum-like 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 Dakota in most of the Desert and the absence of Gryphaea on the Green River nose suggests some upwarping and erosion in late Dakota-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. Here the medial Montana Blackhawk formation is disconformably overlain by the Castlegate sandstone member of the Price River formation of late Montanan age. This disconformity is present throughout the Book Cliffs but is most prominent near Sunnyside. This erosional break 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 probable latest 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 early Cretaceous structures could escape updip 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 day 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 Desert, 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 70 million years old. This would coincide roughly with the beginning of the late Laramide orogeny. It appears that there is no relation between ore deposits formed in late

Cretaceous - early Tertiary time and the sharp change in dip between the Swell and the Desert, 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 offsets 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 Cretaceous 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 downdip; but it seems almost certain that it was completely 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 wetability 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 north 10 to 20 degrees east. Mapping of sedimentary structures such as lineation, festoon, rib and furrow, and cross-bedding 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 petroliferous materials and were precipitated from solution by such reducing agents as SO_2, H_2S, and H_2. Where sandstones were thin and of low permeability, little ore grade 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, the small structures which originally controlled accumulation of petroliferous and probably some humic-derived materials, may have indirectly controlled deposition of uranium.

Bleaching

Though there are no usable guides for mapping of bleached Salt Wash sandstone, there is some evidence that much of the Salt Wash in the Desert has been bleached. (1) Most Salt Wash sandstones and many siltstones and claystones are gray to green, (2) almost all sandstones contain montmorillonite blebs believed to represent altered impure chert, and (3) 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 Desert are the Summerville-Salt Wash contact where the upper foot or so of the Summerville is bleached to gray-green though this may in part be due to gypsum, and the

Cedar Mountain-Dakota contact where as much as one hundred feet of the underlying Cedar Mountain has been bleached to grays and greens.

FUTURE OF THE DISTRICT

A total of approximately 61,000 tons of uranium ore were mined in the San Rafael River Desert mining district prior to January, 1957. It is believed that this represents only a small portion of the reserves of the district. At present the only sizeable indicated and inferred ore reserves are in the Tidwell mineral belt, where ore reserves are believed to total about 250,000 tons of indicated and inferred ore averaging about 0.35% U_3O_8. These calculations are based on an average thickness of $2\frac{1}{2}$ feet of ore in ore bodies throughout the belt. Indicated ore was restricted to a 10-foot radius around each ore hole and inferred ore to a 25-foot radius.

Exploration has been confined to the margins of the Desert where the Salt Wash crops out or is found at shallow depths. Much drilling has been done (fig. 4), mostly where Salt Wash is less than 700 feet below the surface. Deeper drilling has not been attempted because the small nature of ore bodies and the presence of large volumes of water at depths of about 300 feet below the surface do not make deep exploration feasible at this time.

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