Geology and Ore Deposits of the White Canyon Area San Juan and Garfield Counties, Utah

GEOLOGICAL SURVEY BULLETIN 1125

Prepared on behalf of the U.S. Atomic Energy Commission

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By ROBERT E. THADEN, ALBERT F. TRITES, JR., *and* TOMMY L. FINNELL

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GEOLOGY AND ORE DEPOSITS OF THE WHITE CANYON AREA, SAN JUAN AND GARFIELD COUNTIES, UTAH

By Robert E. Thaden, Albert F. Trites, Jr., and Tommy L. Finnell

ABSTRACT

The White Canyon area includes about 700 square miles in the west-central part of San Juan County and the eastern part of Garfield County, southeastern Utah, near the center of the Colorado Plateau province. It is bounded by 37°30′00″ and 37°52′30″ north latitude and by 110°00′ and 110°30′ west longitude.

Sedimentary formations that range in age from Pennsylvanian to Jurassic crop out in the area. The rock units from oldest to youngest are the Hermosa formation of Pennsylvanian age; the Rico formation of Pennsylvanian and Permian(?) age; the Cedar Mesa sandstone member, the Organ Rock tongue, and the White Rim sandstone member of the Cutler formation of Permian age; the Hoskinnini member and the upper member of the Moenkopi formation of Triassic(?) and Early and Middle(?) Triassic age; the Shinarump member, the mudstone-sandstone unit, the Moss Back member, the limy unit, and the sandstone-siltstone unit of the Chinle formation of Late Triassic age; the Wingate sandstone, Kayenta formation, and Navajo sandstone of the Glen Canyon group of Late Triassic and Jurassic age; and the Carmel formation and Entrada sandstone of the San Rafael group of Early and Middle Jurassic age.

The White Canyon area is on the west flank of the Monument upwarp, and strata have a regional dip of 2° to 3° westward. Low-amplitude flexures locally modify the regional dip of the strata. Vertical and steeply dipping normal faults in the southwestern part of the area trend northeast, north, and northwest. In the northwestern part of the area, grabens and horsts are bounded by normal faults that trend mostly N. 60°–80° W., and dip 65° to vertical, but some trend N. 50°–60° E. The most conspicuous joints in the area are nearly vertical and trend N. 65° W., N. 35° E., N. 65° E., and north.

Mineral deposits in the area are copper-uranium and copper deposits in the Shinarump member of the Chinle formation. Most of the uranium and copper is localized in medium- to coarse-grained and conglomeratic sandstone interbedded with mudstone that fills channels cut into the Moenkopi formation. Seventy-five channels were mapped—16 of them contain at least 1 uranium deposit having a grade of 0.10 percent or more U_3O_8. At least eight additional channels contain uraniferous material. Channels range in width from 30 to 1,000 feet and are as much as 50 feet deep.

The principal uranium ore minerals are uraninite, uranophane, metatorbernite, phosphuranylite, metazeunerite, and a zippeitelike mineral. Minor quantities of uranopilite, johannite, meta-autunite, cuprosklodowskite, and becquerelite occur locally. The ore minerals replace fossil plant material, quartz, clay, and feldspar; fill fractures in quartz grains; and are disseminated in sandstone. Primary sulfide minerals associated with the uranium minerals are pyrite, chalcopyrite, sphalerite, galena, and bornite; supergene sulfides are chalcocite, covellite, and marcasite. Secondary copper minerals found in the uranium deposits are native copper, cuprite, melaconite, azurite, malachite, chalcanthite, antlerite, and brochantite. Other minerals associated with the uranium deposits, but not restricted to them, are goethite, gypsum, jarosite, calcite, hematite, opal, psilomelane, alunite, dolomite, ilsemannite, pickeringite, allophane, erythrite, gibbsite, barite, sepiolite, and native sulfur.

Uranium ore bodies are as much as 10 feet thick, but they average about 3.5 feet in thickness. They generally are tabular and follow the crossbedding of the enclosing rocks, although they cut across the bedding in detail. In plan view, the deposits generally are elliptical and range in width from 10 to 500 feet and in length from 50 to 1,000 feet.

Guides to ore deposits are (a) channels, (b) 10 to 30 percent siltstone and claystone beds in the Shinarump member of the Chinle formation that fill the channels, (c) concentrations of fossil plant material in channel sediments, and (d) interstitial mudstone in sandstone. Local structural terraces and subtle changes in dip of the surface on which the Shinarump member was deposited may have been important factors in the location of channels and the formation of rock types favorable for uranium deposition.

Oxidation of copper-uranium deposits that crop out has released uranium, copper, and iron to be supergenetically redeposited in the unoxidized parts of the deposits. Nine selected uranium deposits are described in detail.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND CULTURE

The White Canyon area includes about 700 square miles; it is bounded by 37°30′00″ and 37°52′30″ north latitude and by 110°00′ and 110°30′ west longitude. The area is in the west-central part of San Juan County and the eastern part of Garfield County in southeastern Utah (figs. 1, 2) and is near the center of the Colorado Plateau.

The area is about 35 miles by road west of Blanding, Utah, and about 40 miles by road southeast of Hanksville, Utah. These two towns are connected by Utah State Highway 95, a graded dirt road, which passes through the White Canyon area. This highway is passable by all types of motor vehicles throughout the year.

The small settlements of Hite and White Canyon are near the west edge of the area. Hite, with a population of about 10, is on the west bank of the Colorado River; White Canyon, with about 100 inhabitants, is on the east side (1954). Transportation between the two settlements is by ferry. White Canyon has a trading post and receives mail service from Blanding. It is expected that these communities eventually will be inundated by the water impounded behind the Glen Canyon dam. A trailer camp (fig. 2) was established in 1955 at the junction of Utah State Highway 95 and the wash in Fry Canyon near Fry Point; this camp also has a small store and a service station. Cabins have been built at many of the mines in the area.

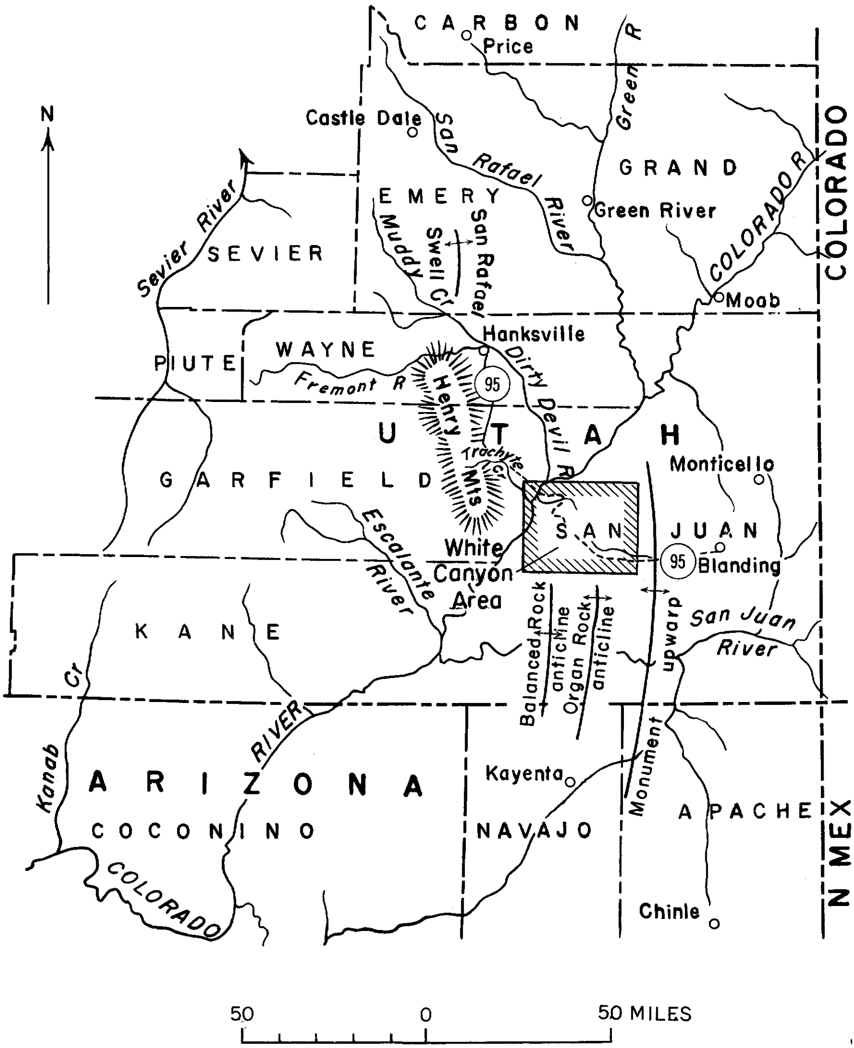

FIGURE 1.—Index map of southeastern Utah showing location of the White Canyon area.

Drinking water that is bacteriologically safe is available from wells at the White Canyon settlement and from several springs in the area. Notable among the springs is the one near the head of Fry Canyon. Several springs flow in Red Canyon, but the water is chemically undesirable for drinking.

PHYSICAL FEATURES

The White Canyon area has been described as part of the Colorado Plateau by Gregory (1938, p. 6). In general, the area consists of a gently westward-dipping plateau that has been deeply cut by White, Red, and Dark Canyons and their tributaries. The physiography of the area, from north to south, is as follows (fig. 2; pl. 3): In the northeastern part of the area a plateau has been deeply trenched by Dark Canyon. Black Point, Lower Horse Flats, and Upper Horse Flats are all a part of this plateau surface. Between Dark Canyon Plateau and White Canyon, many mesas extend southwestward between canyons tributary to White Canyon. Fortknocker, Short, Long, Gravel, Cheesebox, Hideout, and K and L Canyons are all part of this system of tributary canyons. Deer Flat, in the extreme east-central part of the area, is the most prominent of the mesas and is about 1.5 miles in its northwest dimension and over 8 miles in its northeast dimension. In addition to the mesas are many small buttes which stand as monuments. A high divide separates White Canyon from Red Canyon. The divide extends from a point about 4 miles south of the mouth of Fry Canyon northwestward to Blue Notch Canyon, a distance of nearly 15 miles. This divide has a relatively straight northeast side, but on the southwest side it has southwest-trending fingerlike projections; it is bounded by precipitous rock walls on both sides. Toward the southeast the divide breaks down to isolated erosion remnants. The Tables of the Sun are three remnant buttes which are alined parallel to the main divide, and Moss Back Butte, an isolated erosional remant near the head of Fry Canyon, is also one of this series. Isolated buttes also extend westward from the northwest end of the divide. The Red Rock Plateau (termed "Mancos Mesa" on the map) lies southwest of Red Canyon and extends to the southwest corner of the White Canyon area. Sheer cliffs rise to the level of the Red Rock Plateau along the south side of Red Canyon. The surface of the plateau has been cut by many canyons, including Moki and Cedar Canyons, all of which trend westward toward the Colorado River. The Grand Gulch Plateau occupies the extreme southeastern part of the White Canyon area. The surface of this plateau has been entrenched by many impassable canyons which drain southwestward into the San Juan River.

CLIMATE AND VEGETATION

The precipitation pattern in the White Canyon area varies greatly with altitude. The mean annual precipitation decreases from an estimated high of 15 inches on Deer Flat, which adjoins Elk Ridge on the east side of the area, to a low of about 7 inches at Hite, Utah. The amount of precipitation has a wide annual range. The annual rainfall at Hite ranged from 3.12 to 12.36 inches within the 12-year interval tabulated by Gregory (1938, p. 18). The distribution is also seasonal, although the range in monthly rainfall from year to year

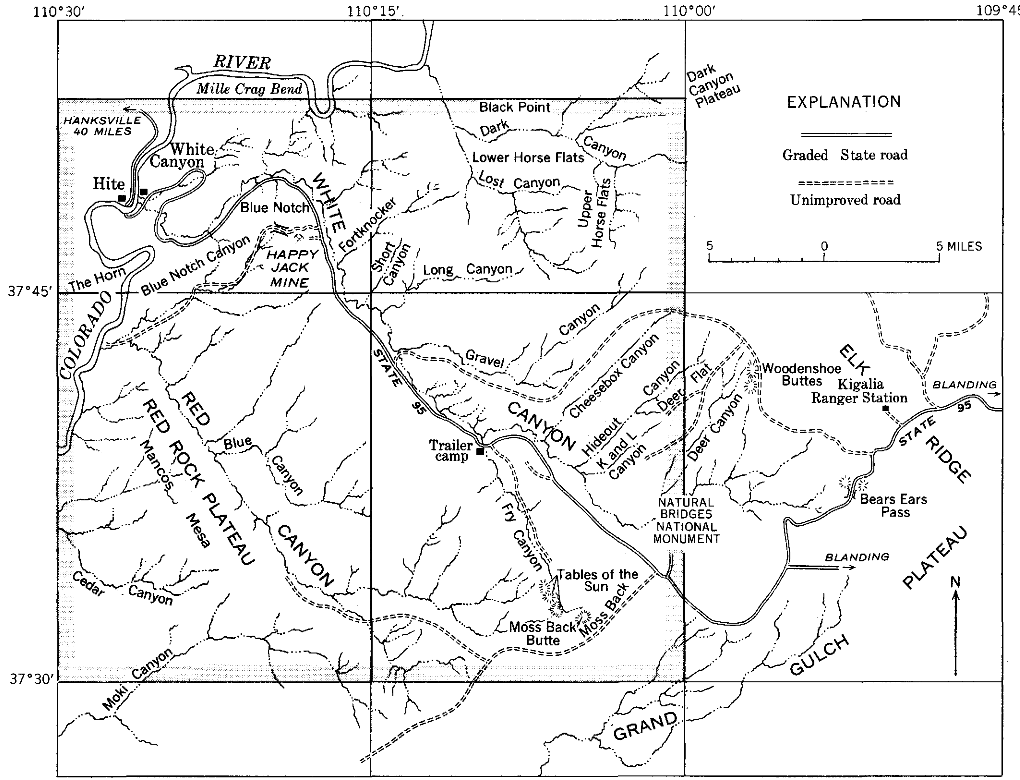

FIGURE 2.—Map showing general geographic relations near the White Canyon area.

is so great that few generalities may be made. November is reported by Gregory to be the wettest month at Hite, and the seasons, listed in order of decreasing abundance of precipitation, are fall, winter, spring, and summer.

Snow covers the Deer Flat area and many of the higher ridges above White and Red Canyons during the winter. Snowfalls in Fry Canyon and in the upper part of the White Canyon have been observed by the writers as late as May. Snow also has fallen near Hite in December, but seldom remains for more than a few days.

June, July, and August are the warmest months; December and January are the coldest. Temperatures in excess of 100°F are normal for the summer months and in July 1953 the authors recorded a temperature of 127°F in the lower reaches of Red Canyon. The reading was obtained on an analytical thermometer placed 4 feet above the ground in the shade of a white canvas tarpaulin. The lowest winter temperature recorded at Hite was −1°F, as reported by Gregory (1938, p. 20). Temperatures in the higher altitudes are in general much lower; they seldom exceed 90°F on the warmest summer days on Deer Flat and commonly drop below 0°F in this area on cold winter nights.

Showers are frequent during July, August, and September. These showers seldom last more than an hour, but are marked by precipitation far in excess of 1 inch per hour for brief rains and about 1 inch per hour for longer rains. During the more intense rains small gullies quickly fill with water, discharging into the main canyons which become the scenes of flash floods. Bores 8 feet high are not uncommon at peak discharge, and bores 30 feet high were seen at constricted places in some canyons.

Various types of vegetation cover the area and are controlled by the altitude, topography, amount of water available, and type of rock or soil. Gregory (1938, p. 24–26) has listed the kinds of plants found between 4,000 and 8,000 feet of altitude between the Colorado River and Elk Ridge. In the highest part of the area, on Deer Flat, Ponderosa pine (*Pinus ponderosa*) and Aspen (*Populus tremuloides*) are growing. These two varieties increase in abundance eastward toward the Elk Ridge area. Piñon pine (*Pinus cembroides edulis*) extends southward from Deer Flat to about the center of the White Canyon area. Utah cedar or juniper (*Juniperus utahensis*) probably has the widest range of all the trees and is found in all parts of the area except for the extreme west edge along the Colorado River. This tree is especially abundant on the erosional surface above the inner gorge of White Canyon. A few stands of cottonwood (*Populus angustifolia*) occur in the lower end of White, Red, and Farley Canyons. Except for a few cottonwoods, the lower half of Red Canyon is nearly barren of trees.

Sagebrush (*Artemisia tridentata*) is abundant in the higher altitudes in the northeastern part of the area, giving way to bitterbrush (*Cowania neomexicana*) in the lower altitudes in the central and west-central part of the area. Many types of flowering herbs grow throughout the area and present a colorful display during May and June. Various types of grasses grow moderately well except in the extreme western part of the area. The grass cover is especially good on Deer Flat where the U.S. Bureau of Land Management has made several plantings. The White Canyon and Red Canyon areas are used for the winter ranging of cattle, and a few head are found in these areas throughout the year. The Deer Flat area is used for summer grazing range and is abandoned before the first snowfalls of winter.

Nearly all the area, except Deer Flat and the alluvial strip along the Colorado River, is unsuitable for agriculture because of the severe shortage of water and the general lack of soil. Owing to irrigation, however, fine vegetable crops are raised along the Colorado River.

PREVIOUS GEOLOGIC WORK

Although some of the early Spanish explorers who in the 1700's passed through what is now southeastern Utah may have had glimpses of some of the easternmost part of the White Canyon area, the first description of any of the area was by J. W. Powell in 1875. Exploring parties under the direction of Powell made their way by boat down the Colorado River during the summers of 1869 and 1871. Powell (1875a, b) described many of the physical and geological features in the area along the river. Mille Crag Bend was named by the Powell party during their trip.

A later boat trip was made by a party of members of the U.S. Geological Survey during the summer and fall of 1921 (Longwell and others, 1923). This trip was undertaken to gather topographic and geologic data related to proposed dam construction at Lees Ferry. Rock formations in the western part of the White Canyon area were studied by the party.

The first geologic examination of the entire White Canyon area was made by Gregory (1938). Very little subsequent geologic work was done until 1948, when the uranium potential of the area became apparent. The next geologic report on the area was of a preliminary nature (Benson and others, 1952) and summarized the early geologic work by the U.S. Geological Survey under the uranium program. The occurrence of uranium minerals and the mineralogy of some of the deposits have been described in papers by Kerr (1951) on the occurrence of sooty pitchblende at the Happy Jack mine, by Stieff and Stern (1952) on the age of the uraninite at the Happy Jack mine, by Stern and Weeks (1952) on the occurrence of bayleyite at the Hideout mine, and by Rosenzweig and others (1954) on the occurrence and character of pitchblende in the deposits. Other papers include one by Miller (1955) describing the uranium deposit at the Happy Jack mine, by Trites and Chew (1955) giving the results of preliminary studies by the U.S. Geological Survey at the Happy Jack mine, and by Garrels (1955a) describing the weathering of uranium deposits at the Happy Jack mine. Descriptions of some of the uranium minerals occurring in the area are given by Gruner and others (1954) and by Weeks and Thompson (1954).

FIELDWORK AND ACKNOWLEDGMENTS

The present investigations were begun in the White Canyon area in July 1951, and the fieldwork was completed in September 1954. The geology was first compiled in the field on aerial photographs at a scale of 1:31,680 and then transferred partly by planetable and alidade and partly by inspection to a topographic base at a scale of 1:48,000.

Several geologists of the U.S. Geological Survey mapped parts of the area during the course of the study, and their respective contributions are shown on the index map on plate 1. The work was originally under the leadership of William E. Benson, who left the project in the spring of 1952. Trites then became party chief. In 1953 the Deer Flat area was made a separate project under the leadership of Finnell, who conducted an exploratory program of diamond drilling. Trites resigned from the U.S. Geological Survey in the spring of 1955, at which time Thaden and Finnell assumed the responsibility for completing the manuscript, the illustrations, and the analytical work.

Detailed studies were made at the Happy Jack mine by Trites and R. T. Chew III; at the White Canyon No. 1 mine by Trites, Charles F. Lough, and George A. Hadd; at the Jomac mine by Trites and Hadd; at the Blue Lizard mine by Trites, Thaden, Earl J. Ostling, and George E. Wales; at the Markey mine by Thaden and Wales; at the Fry No. 4 mine by Ostling; and at the Bell mine by Trites. In the Deer Flat area the Hideout mine was studied by Finnell and others, and the W. N. mine was mapped by Paul C. Franks and David A. Brew.

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

STRATIGRAPHY

PENNSYLVANIAN SYSTEM

HERMOSA FORMATION

About 600 feet of the upper part of the Hermosa formation of Pennsylvanian age is exposed in the inner gorge of Dark Canyon and its tributaries (fig. 3).

The total thickness of the Hermosa formation is not exposed in the White Canyon region; its thickness, therefore, can only be estimated from drill records. A drill hole in Reservoir Canyon, a south fork of Dark Canyon, just east of the area, penetrated 1,165 feet of rock probably assignable to the Hermosa.

In Dark Canyon, where it crops out as vertical cliffs, the Hermosa consists largely of thick-bedded dark-gray to brown limestone separated by thin beds of slope-forming sandstone. The uppermost bed of the Hermosa throughout much of the western part of Dark Canyon is a dark-grayish-brown limestone that ranges in thickness from 12 to 20 feet. This bed forms a prominent bench beneath the gentle slopes of the lower part of the Rico formation.

PENNSYLVANIAN AND PERMIAN(?) SYSTEMS

RICO FORMATION

The Rico formation of Pennsylvanian and Permian(?) age is exposed in only two places in the White Canyon area—in the walls of Dark Canyon and its tributaries and in Cataract Canyon of the Colorado River. The formation tends to erode to slopes between the underlying cliff-forming Hermosa formation (Pennsylvanian) and the overlying cliff-forming Cedar Mesa sandstone member of the Cutler formation (Permian). However, the lower part of the Rico is eroded at most places to gently sloping fanlike remnants upon the bench held up by the uppermost beds of the Hermosa, and the upper part, nearly everywhere protected by the overlying Cedar Mesa, tends to form a nearly vertical cliff.

Fossils were not found in the Rico formation of the White Canyon area, but Richard Q. Lewis, Sr. (oral commun., 1957), found fossils in the lower part of the Rico in the Elk Ridge area a few miles east; he reports that the fossils have been determined to be early Permian in age.

In the White Canyon area the Rico formation consists dominantly of a sequence of beds of very fine grained to coarse-grained poorly sorted sandstone and thin beds of siltstone. On outcrop the formation has the appearance of alternating red and white stripes; the sandstone beds are varicolored, although mostly light, and the silt-

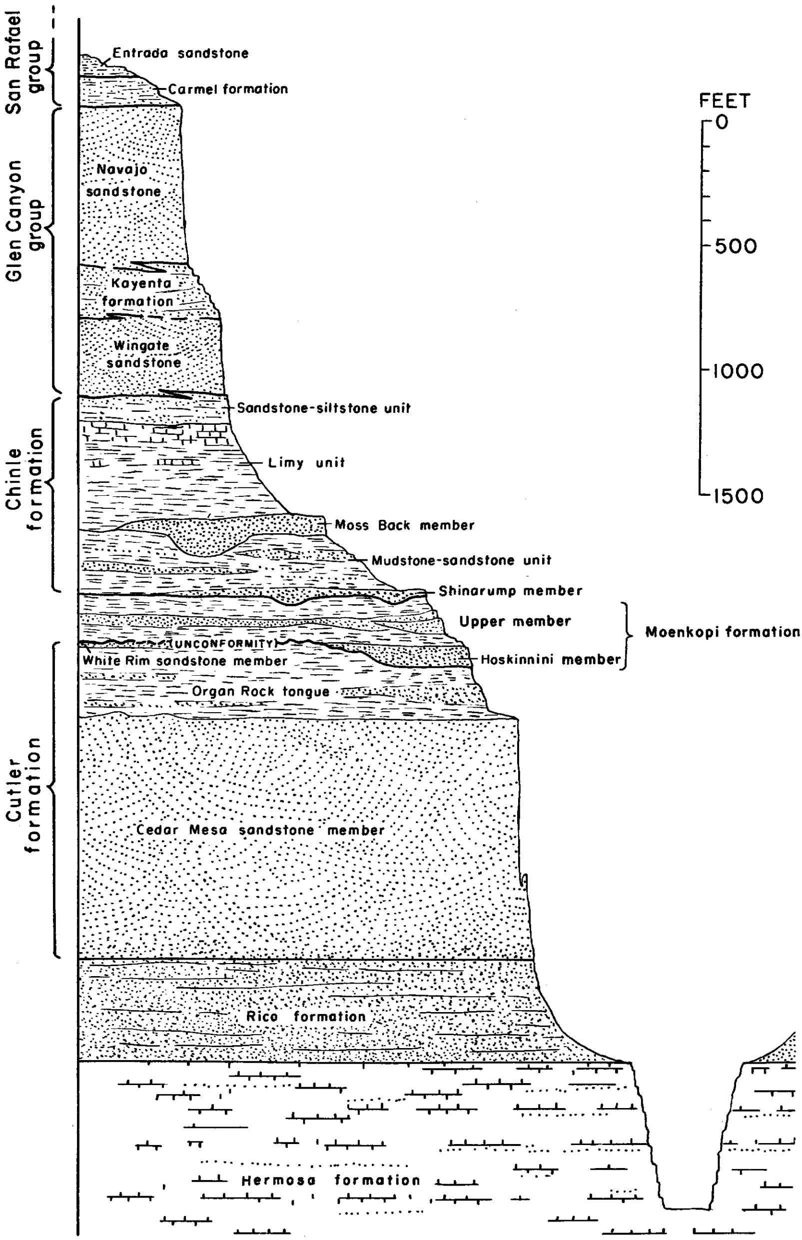

FIGURE 3.—Generalized profile of the sedimentary units exposed in the White Canyon area.

stone beds are mostly dark. (See measured section below.) Limestone was not seen in the Rico at any place in the White Canyon area where the formation is accessible, nor was limestone seen in the drill-hole cuttings from which the partial section was compiled. Miser (Gregory, 1938, p. 64–65) indicates about 10 percent limestone in a section of Rico at Honaker Trail on the San Juan River, and Baker (1946, p. 34) indicates little more than that in a section of Rico along the Spanish Trail at the head of Cataract Canyon of the Colorado River. Just 5 miles north of the northeast corner of the White Canyon area, at the head of Gypsum Canyon, a few gray (*N* 5)[1] and brownish-gray (5*YR* 4/1) limestone beds a few feet thick were observed near the top of the formation. One of these beds is lithographic. The others contain pods and streaks of yellowish-orange to dark-brown jasper which, judging by the large quantities of artifacts in the vicinity, was used extensively by the prehistoric and protohistoric Indian cultures in the manufacture of implements.

The Rico formation is thin to thick bedded, with irregular, horizontal, and gently inclined tangential cross strata. The beds are lenticular, and many grade laterally from one lithology or color to another in distances of a few hundred feet. They also grade laterally in degree of cementation and in resistance to weathering; one bed may be exposed as a cliff at one place and a slope at another.

Clear colorless grains of quartz predominate in the Rico formation, but substantial percentages of yellow and pink grains have been found in a few beds. Small grains are angular and large ones are round; all are polished. Accessory minerals are rare. Calcite seems to be the principal cementing material in the upper and lower parts of the Rico, and secondary silica is the principal cement in the middle part. Cementation is poor except at the top of the formation.

The following partial section of the Rico formation is representative of the upper part of the formation in the White Canyon area. From outcrop evidence, it is likely that the lower part of the formation is much the same.

Partial section of the Rico formation from a drill hole near Utah State Highway 95 in the vicinity of the Happy Jack mine, San Juan County, Utah

	Thickness (feet)
Cedar Mesa sandstone member of the Cutler formation.	
Rico formation:	
Sandstone, grayish-orange-pink (3*YR* 7/2), coarse-grained, very poorly sorted; subround to round polished quartz grains and minor muscovite; well cemented, calcareous. Contains a few seams of grayish-red (2*YR* 5/2) very fine grained sandstone	28

[1] All bracketed color designations are based on the Rock-Color Chart by Goddard, E. N., and others (1948).

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Rico formation—Continued	Thickness (feet)
Sandstone, grayish-orange-pink (5*YR* 7/2), coarse-grained, very poorly sorted; subangular to round polished quartz grains; poorly cemented, calcareous. Contains minor amounts of unidentified material, possibly pumice or other volcanic material (n=1.495)	10
Sandstone, pale-pinkish-orange (6*YR* 7.5/2), very poorly sorted; angular to round clear colorless polished quartz grains; poorly cemented, calcareous and siliceous	10
Sandstone, very pale orange (8*YR* 8/2), well-sorted; subround to round clear colorless polished quartz grains and rare accessory smoky quartz grains; poorly cemented, siliceous and weakly calcareous	10
Sandstone, pale-yellowish-gray (5*Y* 8/1) and light-brown (3*YR* 6/4), medium-grained, fairly well sorted; clear colorless to yellow subround polished quartz grains; poorly cemented, calcareous and siliceous. Contains a few inches of grayish-red (10*R* 4/2) siltstone	10
Sandstane, very pale orange (10*YR* 7.5/3), fine-grained, very well sorted; round clear colorless polished quartz grains; poorly cemented, siliceous. Contains virtually no accessory grains	40
Sandstone, light-brown (5*YR* 6/3), medium-grained, fairly well sorted; subround clear colorless polished quartz grains; poorly cemented, siliceous. Contains virtually no accessory grains	40
Sandstone, grayish-orange-pink (5*YR* 7/2), fine-grained, poorly sorted; subangular to round clear colorless to orange quartz grains and rare black accessory grains; poorly cemented, calcareous. Contains about 2 ft of grayish-red (10*R* 4/2) to pale-brown (5*YR* 5/2) siltstone	10
Sandstone, very pale pinkish orange (8*YR* 8/2), fine-grained, poorly sorted; subangular to round clear colorless and rare orange and pink quartz grains; poorly cemented, siliceous. Contains no accessory grains	10
Sandstone, light-pinkish-brown (3*YR* 6/4), fine-grained, poorly sorted; small angular and large subround clear colorless and pale-yellow polished quartz and rare green and black accessory mineral grains, poorly cemented, siliceous	10
Sandstone, pale-pinkish-orange (7*YR* 8/3), fine-grained, fairly well sorted; subangular to subround clear colorless and pale-yellow polished quartz and rare black and green accessory mineral grains; poorly cemented, siliceous. Slightly calcareous near bottom	20
Sandstone, light-brown (4*YR* 6/4), fine-grained, fairly well sorted; subround to round clear colorless and yellow polished quartz and rare platy green accessory mineral grains; poorly cemented, calcareous and siliceous. Contains about 3 ft of grayish-red-brown (2*YR* 4/2) ferruginous and calcareous siltstone	10
Claystone, silty, grayish-orange-pink (7*YR* 7/2); highly calcareous	10
Sandstone, pale-orange (10*YR* 7.5/2), medium-grained, poorly sorted; angular to round clear colorless and pink polished quartz grains; poorly cemented, silicious and calcareous. Small grains are angular; large grains are round. Contains about 2 ft of pale-brown (5*YR* 5/2) calcareous sandstone	10

Rico formation—Continued	*Thickness (feet)*
Claystone, silty and calcareous, grayish-orange-pink (5*YR* 7/2)	10
Sandstone, pale-orangish-pink (5*YR* 9/3), very fine grained, very poorly sorted; angular to subangular clear colorless polished quartz and rare muscovite and unidentified black accessory mineral grains; fairly well cemented, calcareous	30
Sandstone, silty, pale grayish-orange-pink (5*YR* 8/2), very fine grained, very poorly sorted; clear colorless or pale-yellow angular to subround quartz grains; well cemented, calcareous	15
Total thickness of Rico formation penetrated by drill hole	283

Gross thickness measurements of the Rico formation in Dark Canyon range from about 375 feet at the junction of Dark and Lost Canyons to about 460 feet at the east edge of the area. South of the White Canyon area the formation thins, and is only 314 to 324 feet thick at Honaker Trail on the San Juan River (Gregory, 1938, p. 64–65). Northeast of the White Canyon area, in the vicinity of Moab, Utah, it is 575 feet thick (Baker, 1946, p. 33).

An unconformity was not seen at the top of the Rico formation in the White Canyon area, nor is it even possible to identify the contact between the Rico and the overlying Cedar Mesa sandstone member of the Cutler formation at most places. Not only are the uppermost beds of the Rico indistinguishable from the lowest beds of the Cedar Mesa sandstone member in some places, but the contact is nearly everywhere inaccessible. In the drill hole, the cuttings from which the sections of the Rico and Cedar Mesa (p. 11, 17) were compiled, the contact apparently is an abrupt transition from poorly sorted grayish-orange-pink coarse-grained well-cemented calcareous sandstone of the Rico to fairly well sorted pale-orange fine- to medium-grained poorly cemented calcareous sandstone of the Cedar Mesa. Changes in lithology as abrupt as this, however, are common within the Rico itself, and the contact was placed at this depth primarily for lack of such changes higher in the section.

PERMIAN SYSTEM

CUTLER FORMATION

The Cutler formation is extensively exposed in the northeastern part of the White Canyon area where it forms the steep lower slopes of mesas and broad flats into which are cut deep narrow canyons (pl. 1). In the drainage basin of Red Canyon in the southwestern part of the area, the formation is largely covered by younger rocks. Three units of the Cutler formation, aggregating about 1,300 feet in thickness, are differentiated. The basal unit is a thick light-colored sandstone, the Cedar Mesa sandstone member. This unit is overlain, successively, by the dark-reddish-brown Organ Rock tongue and by the extremely thin light-colored White Rim sandstone member. The White Rim is not everywhere present. It thins and grades out to the east into the Organ Rock tongue. Other units of the Cutler formation are absent or unrecognizable in the White Canyon area.

The Halgaito tongue of the Cutler formation as recognized by Baker and Reeside (1929, p. 1443)—the basal member of the Cutler formation in Monument Valley—is not recognized in White Canyon. It has been recognized as far north as Comb Wash—west of Blanding, Utah (Sears, 1956, p. 181)—but presumably it pinches out near the axis of the Monument uplift east of White Canyon. Indeed, Gregory (1938, p. 43) states that in Arch Canyon, "only a few feet of red beds lie between the plane of unconformity [Halgaito-Cedar Mesa contact] and limestones that contain a fauna which has the facies of the Rico formation"; and that "in Dark Canyon the few red beds among the gray sandstones and fossiliferous limestones that lie below the Cedar Mesa are quite unlike those in the Halgaito of the San Juan Valley," implying a total absence of Halgaito in Dark Canyon.

The DeChelly sandstone member of Gregory (1917, p. 31), a thick cliff-forming cross-stratified sandstone whose stratigraphic position in Monument Valley is next above the Organ Rock tongue, likewise is absent in the White Canyon area. Although the DeChelly is 500 to 800 feet thick in northeastern Arizona and northwestern New Mexico, it pinches out rapidly to the northwest (Baker, 1936, p. 36; Lewis and Trimble, 1959, p. 109) along a line near the San Juan River.

Fossils were not found in the Cutler formation in the White Canyon area, but a Permian age for the formation has been fairly well established, as noted by Baker (1946, p. 37) and by Gregory (1938, p. 41, 42) from fossils collected in other areas.

CEDAR MESA SANDSTONE MEMBER

The Cedar Mesa sandstone member of the Cutler formation is exposed as a broad flat that floors the White Canyon drainage system. Perched upon this flat are mesas composed of rocks of the upper part of the Cutler formation and beds of Triassic age. Narrow vertically walled inner gorges, which are in places several hundred feet deep, cut into the flat. The name "White Canyon" is derived from the contrast between the brilliant nearly white floor (Cedar Mesa) of the canyon and the mesas of overlying "red beds." The Cedar Mesa also crops out as a tremendous vertical wall on the rims of Dark

Canyon and its tributaries. It forms broad platforms extending away from the rims of canyons which, like the flat formed on the Cedar Mesa in the White Canyon drainage system, represent its slightly eroded upper surface.

Erosion of the exposed Cedar Mesa sandstone member produces a topography of small hillocks and knolls and of vertical cliffs. In places the cliffs weather back on the boundary surfaces of the cross strata to form steep giant stairways. Canyons incised in the upper few hundred feet of the member are, in places, deeper than they are wide, and have smooth, fluted, and undercut walls (fig. 4).

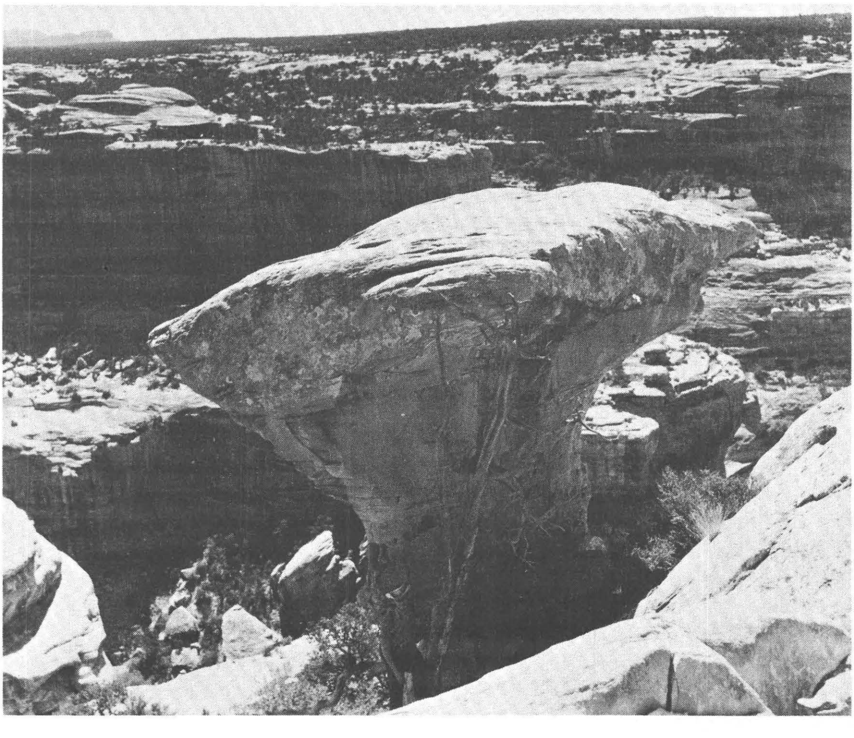

FIGURE 4.—Photograph of the gorge of White Canyon cut in the Cedar Mesa sandstone member of the Cutler formation near Sipapu Bridge, Natural Bridges National Monument. Vertical and overhanging cliffs of Cedar Mesa are characteristic. The upper surface of the Cedar Mesa, shown at the top of the photograph, is the floor of White Canyon.

The lithology of the Cedar Mesa, so far as exposures provide evidence, does not change across the area. It is dominantly a light-colored fine-grained poorly sorted calcareous quartz sandstone. Very thick wedge-shaped sets of tangential cross strata dipping southeastward are the rule rather than the exception. The cross strata are

½ to 3 inches thick and are terminated by flat and by curved surfaces of erosion. The average thickness of the sets is 10 to 30 feet, but some sets are as thin as 1 foot and others are nearly 100 feet thick.

Interbedded with the sandstone beds are lenticular beds of gray, green, red, and brown sandy siltstone. These siltstone beds average less than 1 foot thick although a few more than 10 feet thick were seen. Normally, the siltstone lenses are aggregates of paper thin, horizontal laminae. Some lenses, however, are trough cross stratified, the cross strata inclined a few degrees. Contacts with the enclosing sandstone are sharp; but the lower laminae of any siltstone lens contain coarse grains probably reworked from the underlying sandstone, and the overlying sandstone contains abnormal amounts of dark fine-grained material probably derived from the siltstone lens.

The quartz grains of the Cedar Mesa sandstone member are largely clear and colorless. Only a small percentage are a clear light yellow. The grains are poorly sorted, averaging about 0.2 mm in diameter but ranging from 0.08 to 0.75 mm. Small grains are angular or subangular and large grains are subround. All are frosted and nearly all have a moderate overgrowth of secondary silica. Silt-sized grains are abundant in some beds. Neither the silica overgrowth nor a small amount of iron oxide stain contributes much to cementing the sandstone. Calcite is the principal cement: it varies from 1 or 2 percent in the upper part of the member to about 5 percent of the bulk volume of the rock in the basal 200 to 300 feet. Locally, gypsum(?) is important as a cementing material. The iron oxide surface coating on the grains, together with the yellow quartz grains, gives the rock a color that varies in hue from about 5*Y* to 5*YR* and is also variable through light values and medium saturations. An average color for the Cedar Mesa would be about 2*Y* 8/4, a pale orangish yellow.

The sandy siltstone lenses are composed of very poorly sorted subround quartz grains that range in diameter from 0.005 to 0.1 mm. Generally, the smaller the grain, the more highly polished is its surface. Calcite and abundant interstitial iron oxide both act as cementing materials, and the iron oxide, in addition, gives the siltstone its dark-reddish-brown (2*YR* 4/2) color. Variation in the amount, or in the degree of hydration or oxidation or of other chemical change, of the iron oxide stain probably accounts for the blue and green coloration of some of the siltstone lenses.

The following section shows the lithology of the Cedar Mesa sandstone member in a hole drilled near Utah State Highway 95 in the vicinity of the Happy Jack mine.

Section of the Cedar Mesa sandstone member of the Cutler formation from a drill hole near Utah State Highway 95 in the vicinity of the Happy Jack mine

Organ Rock tongue of the Cutler formation.

Cedar Mesa sandstone member:

	Thickness (feet)
Eroded	12
No sample	20
Sandstone, in part silty and in part micaceous, grayish-orange, fine- to medium-grained, fairly well sorted; includes few very thin light-grayish-green to light-grayish-blue micaceous siltstone seams; poorly cemented, calcareous. Sparse light-colored limonite[2] speckles throughout unit	10
Sandstone, silty, grayish-orange to light-brown, fine-grained, poorly sorted; dark-reddish-brown and light-grayish-green to light-grayish-blue siltstone seams decrease from about 5 percent at base of unit to 1 percent at top; fairly well cemented, calcareous. Grain size decreases near top of unit	70
Sandstone, silty, pale-grayish-orange to pale-grayish-yellow, very fine grained to fine-grained, poorly sorted; sparse light-grayish-green claystone seams near middle of unit and sparse moderate-reddish-brown siltstone seams in upper 10 ft of unit; poorly cemented, calcareous, except that bottom 10 ft has thin seams well cemented with limonite and top 10 ft is largely cemented by gypsum (anhydrite?). Middle of unit has sparse rose and citrine quartz grains	50
Sandstone, silty, very pale orange to very pale orangish pink, very fine grained to fine-grained, poorly sorted; poorly cemented, calcareous and possibly gypsiferous	40
Sandstone, very pale yellowish orange, very fine grained, well-sorted; well cemented, calcareous. Includes about 15 percent dark-brown, light-brown, dark-reddish-brown, and light-grayish-green clayey siltstone and sandy siltstone	10
Sandstone, very pale orange, fine-grained, fairly well sorted; poorly cemented, calcareous. Includes several feet of dark-reddish-brown sandy siltstone and sparse light-grayish-green siltstone in middle 10 ft	30
Sandstone, very pale orange to moderate-orangish-pink, fine-grained, fairly well sorted; poorly cemented, calcareous. Unit has several inches of dark-reddish-brown siltstone seams in bottom 10 ft, top 20 ft, and throughout the middle 40 ft. Middle of unit also has about 1 ft of moderate-reddish-brown micaceous sandy siltstone	120
Sandstone, silty, light-brownish-pink, very fine grained, poorly sorted; poorly cemented, calcareous and gypsiferous(?). Contains about 3 percent light-greenish-blue and dark-brown siltstone	10
Sandstone, light-brown to very pale orangish pink, fine-grained, fairly well sorted; poorly cemented, calcareous and gypsiferous(?); speckled with sparse light-brown limonitic stain. Contains thin seams of light-brown and light-reddish-brown very sandy siltstone	30

[2] "Limonite" is used throughout this report to denote poorly defined hydrous iron oxides of the general formula $Fe_2O_3 \cdot nH_2O$ which may be mixed with hematite (Fe_2O_3) and with salts of iron such as jarosite ($K_2Fe_6(OH)_{12}(SO_4)_4$).

Cedar Mesa sandstone member—Continued	*Thickness (feet)*
Sandstone, grayish-orange, medium-grained, very poorly sorted; poorly cemented, calcareous	40
Sandstone, silty, grayish-orange, very fine grained to fine-grained, poorly sorted; poorly cemented, calcareous. Includes a few thin limonitic zones stained dark yellowish-orange and light brown	40
Sandstone, pale- to moderate-orangish-pink, very fine grained, poorly sorted; very poorly cemented, gypsiferous and calcareous; gypsum is about 4 percent. Unit has sparse moderate-brown limy siltstone pebbles and seams in upper 10 ft	20
Sandstone, silty, very pale orange, very fine grained, poorly sorted; fairly well cemented, gypsiferous near the base, calcareous near the top. Unit has few thin dark-brown calcareous clayey siltstone seams	40
Sandstone, very pale pinkish orange, medium-grained, very poorly sorted; fairly well cemented, calcareous	10
Sandstone, very pale orange, medium-grained, fairly well sorted; poorly cemented, calcareous	10
Sandstone, very pale orange, medium-grained, very poorly sorted; well cemented, calcareous	10
Sandstone, moderate-orangish-pink, fine- to medium-grained, poorly sorted; poorly cemented, calcareous. Unit has streaks of light-brown limonitic stain and accompanying weak iron oxide cementation	10
Sandstone, slightly silty, very pale orange, very fine grained to medium-grained, poorly sorted; poorly cemented, calcareous. Unit has streaks of light-yellow sandy siltstone in basal 10 ft; about 6 in. of dark-reddish-brown sandy siltstone about 155 ft above base; zone of gray to blue, tightly cemented limy sandstone pebbles and seams about 185 ft above base	230
Sandstone, white to very pale orange, fine-grained, well-sorted; poorly cemented, gypsiferous and calcareous	20
Sandstone, silty, very pale orange, very fine grained to medium-grained, very poorly sorted; poorly cemented, gypsiferous and calcareous	10
Sandstone, pale-yellowish-orange, very fine grained to medium-grained, poorly sorted; poorly cemented, calcareous	10
No sample	20
Sandstone, silty and clayey, very pale orange, very fine grained, poorly sorted; poorly cemented, calcareous	10
Sandstone, pale-grayish-orange, very fine grained to medium-grained, poorly sorted; well cemented, calcareous; grain size increases from bottom to top of unit. Unit has sparse chloritelike accessory mineral grains in middle 10 ft	30
Sandstone, grayish-orange and very pale orange, very fine grained, well-sorted; well cemented, calcareous. Contains about 15 percent dark-brown siltstone in lower 10 ft decreasing to about 1 percent in upper 10 ft of unit	20
Silstone, limy, moderate-grayish-brown; well cemented, ferruginous and calcareous. Includes about 1 ft of very pale orange very fine grained well-sorted calcareous sandstone and few pale-orange concretions of limy siltstone as much as 0.2 in. in length	10

	Thickness (feet)
Cedar Mesa sandstone member—Continued	
Sandstone, very pale orange, fine- to medium-grained, fairly well sorted; poorly cemented, calcareous. Contains about 0.1 in. of dark-brown siltstone	10
No sample	32
Total Cedar Mesa sandstone member	984
Rico formation (Pennsylvania and Permian?); top bed is grayish-orange-pink very poorly sorted very well cemented calcareous coarse-grained sandstone.	

The Cedar Mesa sandstone member appears to maintain a thickness of about 980 feet throughout the White Canyon area. Parallax measurements on vertical aerial photographs indicate no thinning or thickening of the member along the rim of Dark Canyon. Baker's section along the Spanish Trail some miles to the north (Baker, 1946, p. 39) is only 747 feet, but the Cedar Mesa there includes larger quantities of limestone and shale than it does in White Canyon. Probably, as Baker (1946, p. 40) suggests, the Cedar Mesa is largely a windblown sand derived from the northwest, with intercalated silty and clayey lenses deposited by westward or southwestward flowing streams. To the southeast the Cedar Mesa is thinner and more limy, silty, and clayey. On the east flank of the Raplee anticline it is only 610 feet thick (Gregory, 1938, p. 68), and in Monument Valley, Ariz., it is largely claystone and siltstone and is only about 370 feet thick (Witkind and Thaden, 1963).

Contact of the Cedar Mesa with the overlying Organ Rock tongue of the Cutler formation is an irregular surface having a relief as much as 40 feet. The irregularity appears to be largely depositional. At many places, particularly in the western part of White Canyon, are longitudinal or transverse dunes of sandstone of the Cedar Mesa which project above its mean upper surface. These dunes are bounded and overlain by sediments of the Organ Rock. In a few places the surfaces of the dunes were extensively reworked, their tops were truncated, and large quantities of the sand from the Cedar Mesa was incorporated in silt of the Organ Rock. In other places the Organ Rock flanks the dunes with sharp contacts, indicating little or no reworking. At the beginning of deposition of the Organ Rock, temporary fluctuation between Organ Rock environment and Cedar Mesa environment resulted in the deposition of small dunes of the Cedar Mesa on previously deposited beds of Organ Rock (fig.5).

ORGAN ROCK TONGUE

The Organ Rock tongue of the Cutler formation is the lowest member of the upper Permain and Triassic red-bed sequence. It forms steep slopes and cliffs at the base of the many mesas in White Canyon

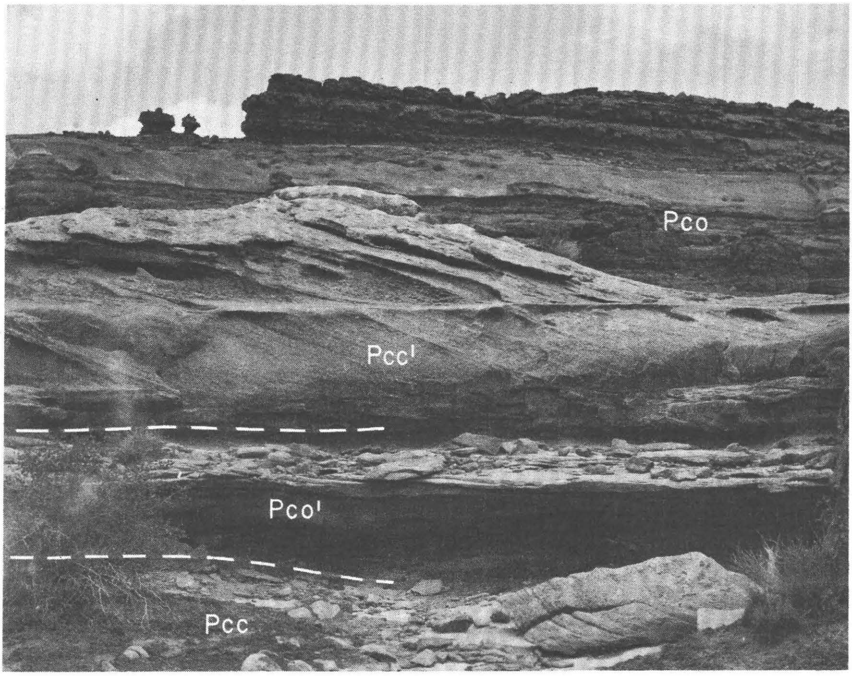

FIGURE 5.—Photograph showing dune of the Cedar Mesa sandstone member of the Cutler formation (Pcc') overlying a seam representing the lowermost deposition of the Organ Rock tongue of the Cutler formation (Pco'). Extreme foreground shows the top of the main body of Cedar Mesa (Pcc): background is Organ Rock (Pco). About 5 miles northwest of the Happy Jack mine.

and forms the lowest part of the high wall of sedimentary rocks that parallels the wash in White Canyon (pl. 1). Utah State Highway 95 is built on the lower part of the Organ Rock between the Natural Bridges National Monument and the settlement of White Canyon on the Colorado River. The Organ Rock is also exposed around the base of Moss Back and in the middle and upper reaches of Red Canyon.

Weathering of the Organ Rock tongue produces a variety of surface textures and structures. Massive-weathering vertical cliffs (fig. 6) may give way laterally and vertically to spheroidally weathered cliffs whose surface textures are not unlike those described graphically by Dean (1945, p. 86, 87). The weathering takes place along bedding planes and irregular joints. In other places massive-weathering cliffs grade laterally to cliffs of small interlocking polyhedra in distances less than 1 foot. Slopes are covered with small curved flakes of siltstone.

The Organ Rock tongue consists of three indistinctly bounded units in the western part of the area and two units in the eastern part. The lowest unit everywhere in the White Canyon area is a sequence of

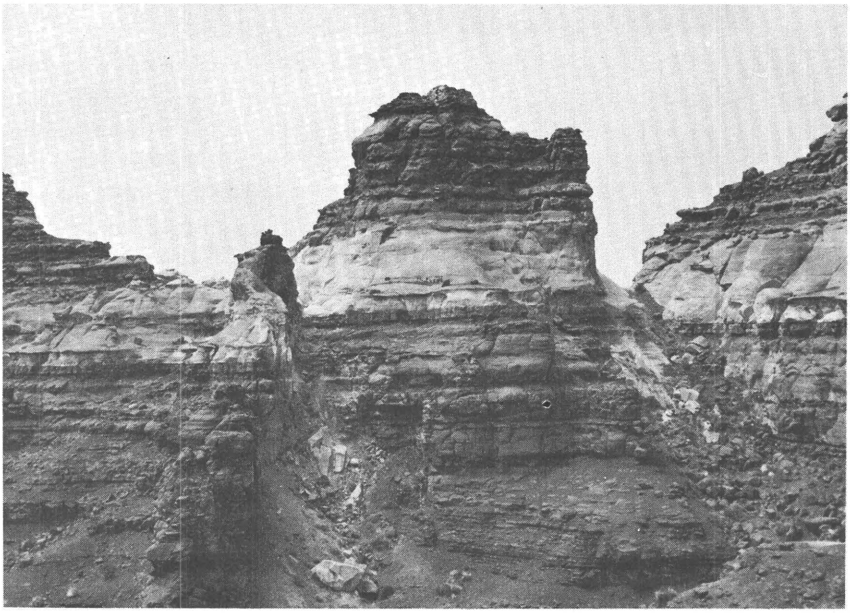

FIGURE 6.—Photograph of Organ Rock tongue of the Cutler formation (faulted) about 4 miles southwest of Mille Crag Bend of the Colorado River. Light-colored unit is the conspicuous pink band of medium-grained sandstone, about 30 feet thick here, which is extensive over much of the western part of the White Canyon drainage. The massive-weathering sandstone grades upward to spheroidal-weathering siltstone.

more or less regularly alternating pale- to dark-reddish-brown (10*R* 3–5/4) and grayish-red (10*R* 4/2) micaceous siltstone and micaceous silty sandstone beds ranging in thickness from less than 1 foot to about 15 feet. In general, the siltstone stands as low cliffs and the silty sandstone weathers to slopes. Horizontal laminae, locally apparent, are less than 1 inch thick.

The middle unit is present only in the western part of the area and is best developed in the lower part of the White Canyon drainage. It is a sequence of reddish-brown cliff-forming spheroidal-weathering micaceous siltstone and low-angle trough cross-stratified massive-weathering medium-grained sandstone beds. The sandstone beds are as much as 40 feet thick and are light brownish pink (5*YR* 7/4). They grade laterally in color, grain size, and weathering characteristics to siltstone typical of the Organ Rock tongue over distances of several hundred to several thousand feet. The sandstone beds are rather persistent and one 35-foot thick bed, in particular, forms the most prominent of several pink bands in the middle part of the Organ Rock throughout the lower part of the White and Farley Canyon drainages (fig. 6). The sandstone beds are not everywhere present, but where there are several, they may be superposed or they may be separated by few to many feet of siltstone. Although most of the light-colored sandstone beds are in the middle third of the Organ Rock, about 6 miles north of the Happy Jack mine the Organ Rock contains a sandstone bed that is within 20 feet of the base. Typically, the lower contact of the sandstone beds with the siltstone beds is marked by an abrupt change in grain size. The siltstone is bleached below the contact for several tenths of an inch and along diagonal fractures extending 1 foot or more down into the siltstone. Only at a few places is the bottom fraction of 1 inch of the sandstone bleached. In many places this fraction contains small platy fragments of siltstone irregularly scattered in bedding planes. The upper contact of the sandstone beds is gradational in color and in grain size to siltstone typical of the Organ Rock. The gradation normally takes place through 2 or 3 inches. Very few of the sandstone beds have sharp grain-size discontinuties with the overlying siltstone beds; the sandstone at these contacts is bleached for about 0.2 inch.

The upper unit of the Organ Rock tongue, both in the western and in the eastern parts of the area, is composed of siltstone beds like those in the lower unit.

The lower unit and, where present, the middle unit, contain a variety of concretionary structures and bleached zones. The pink bands of sandstone, particularly, are filled at various places with concentrically banded well-cemented cylindrical masses as much as 8 inches in diameter. Some of these masses are cemented by limonite. Others are cemented by calcite. Many of the calcite-cemented concretions have hollow centers filled, or partly filled, with dogtooth spar. At some places the concretions intersect one another at right angles, at intervals of 1 to 3 feet, to form three-dimensional lattices. Concretions in the plane of the bedding have spread, in a few places, to form sheets of highly calcareous or ferruginous well-cemented material several inches thick. The lower unit also contains rare pods of barite crystals as much as 4 inches in diameter. Bleached zones and bleached fractures are common. The bleached zones do not necessarily accompany changes in grain size, nor is any particular zone very extensive. Most bleached zones are 1 to 3 feet thick and extend laterally 100 to 200 feet.

The average size of siltstone grains in the Organ Rock tongue is about 0.04 mm; the grain size ranges from 0.02 to 0.8 mm. The sandstone grains average about 0.12 mm and are as large at 1.0 mm. Sorting is poor throughout the Organ Rock. The grains are dominantly subangular clear polished quartz. Calcite is the principal cement and constitutes as much as 50 percent of the volume of the rock, but abundant iron oxide also acts as a cement. Accessory minerals are muscovite, magnetite, feldspars (largely microcline), chert, and, in places, gypsum.

The following three sections illustrate the character of the Organ Rock tongue in the White Canyon area:

Section of the Organ Rock tongue of the Cutler formation about 1 mile east of the Happy Jack mine

Hoskinnini member of the Moenkopi formation.
Unconformity (erosional disconformity).

	Thickness (feet)
Organ Rock tongue:	
Siltstone, pale-reddish-brown (10*R* 6/4), thin-bedded	35.5
Siltstone, pale-reddish-brown (10*R* 6/4), micaceous. Beds average about 3 ft thick, and the laminae are horizontal, thin, and uniform in thickness. Some beds are lenticular and weather spheroidally. Unit contains some lenticular masses of interstitial calcite. About 10 ft above base of unit is a lenticular conglomerate 1 ft thick and 20 ft long of ⅛- to 2-in. siltstone fragments in a grayish-orange (10*YR* 7/4) to pale-reddish-brown (10*R* 6/4) siltstone matrix. Fragments constitute 50 percent of the lens. The conglomerate lens weathers light brown (5*YR* 6/4)	27.0
Siltstone, grayish-red (5*R* 4/2), very fine grained. Weathers to conchoidal pieces as much as 6 in. in diameter	1.0
Siltstone, pale-reddish-brown (10*R* 6/4); includes some sand grains, muscovite, and black interstitial stain (petroliferous material?). Unit weathers by spheroidal exfoliation. Some white bleaching in 6-in. zone parallel to the bedding about 10 ft below top of unit. Beds are 5 to 15 ft thick; stratification is not apparent	40.0
Covered interval; probably similar in lithology to other slope-forming units	5.5
Siltstone, grayish-red (5*R* 4/2); weathers pale reddish brown (10*R* 6/4); dark color apparently due in part to black stain (petroliferous material?) in small patches. Contains spheres of interstitial calcite as much as one-fourth of an inch in diameter. Sets are about 3 in. thick at base of unit and 1 ft thick at top of unit	4.0
Siltstone, pale-reddish-brown (10*R* 6/4); contains calcite veinlets, muscovite, and a trace of biotite. Parting planes are three-eights of an inch apart	11.0
Siltstone, pale-reddish-brown (10*R* 6/4); contains calcite veinlets one-sixteenth of an inch thick and small patches of interstitial calcite	2.5
Siltstone, pale-reddish-brown (10*R* 6/4); unit has parting planes half an inch apart	3.0
Siltstone, pale-reddish-brown (10*R* 6/4), micaceous; becomes lighter in color and contains less mica near top of unit. Bedding is not apparent but has parting planes 2 to 4 in. apart near bottom. Unit has few lenticular calcite veinlets as much as 3 in. long. Lower part of unit weathers to small pieces	11.0
Siltstone, pale-reddish-brown (10*R* 6/4); contains black interstitial stain (petroliferous material?) but no large quartz grains or muscovite flakes	4.0
Covered interval; probably similar in lithology to other slope-forming units	2.0

	Thickness (feet)
Organ Rock tongue—Continued	
Siltstone, sandy, pale-reddish-brown (10*R* 6/4), coarse-grained; contains muscovite flakes and patches of calcite	2.0
Siltstone, dark-reddish-brown (10*R* 3/4). Weathers to slope of small fragments	3.5
Siltstone, pale-reddish-brown (10*R* 5/4); has less than 0.5 percent muscovite flakes. Stratification is not apparent	6.5
Siltstone, dark-reddish-brown (10*R* 3/4); weathers dark reddish brown (10*R* 3/4) to moderate reddish orange (10*R* 6/6); very thin laminae. Contains few large quartz grains, muscovite, one thin stringer of gypsum, and patches of calcite as much as one-fourth of an inch in diameter. Weathers to a steep slope or cliff faced with small hemispheroidal bumps	6.0
Sandstone, silty and clayey, pale-reddish-brown (10*R* 5/4) to dark-reddish-brown (10*R* 3/4), fine-grained; contains some coarse citrine quartz grains. Weathers to soil-covered slope	16.5
Siltstone, pale-reddish-brown (10*R* 5/4); contains a few muscovite flakes 0.25 to 0.5 mm across; structureless	5.0
Sandstone, silty, pale-reddish-brown (10*R* 5/4) to dark-reddish-brown (10*R* 3/4), fine-grained. Weathers to soil-covered slope	5.5
Siltstone, pale-reddish-brown (10*R* 5/4); contains muscovite flakes 0.25 to 0.5 mm across; structureless	2.0
Siltstone, pale-reddish-brown (10*R* 5/4); weathers pale reddish brown (10*R* 5/4) to grayish red (10*R* 4/2); contains less than 0.5 percent muscovite flakes; locally contains large citrine quartz grains and spheroidal and hexahedral patches of interstitial calcite as much as 1½ in. in diameter	2.5
Sandstone, silty, pale-reddish-brown (10*R* 5/4) to dark-reddish-brown (10*R* 3/4), fine-grained. Weathers to soil-covered slope	1.5
Sandstone, silty, pale-reddish-brown (10*R* 5/4); has a few large quartz grains. Structureless	0.5
Sandstone, silty, pale-reddish-brown (10*R* 5/4) to dark-reddish-brown (10*R* 3/4), fine-grained. Weathers to soil-covered slope	9.0
Sandstone, silty, grayish-orange-pink (5*YR* 7/2); weathering light brown (5*YR* 6/4); contains less than 0.5 percent dark accessory (biotite or chlorite?). Unit is uniformly textured and structureless. Weathers to 2-in. polyhedra at some places on the upper surface of the unit	1.0
Siltstone, pale-reddish-brown (10*R* 5/4) to dark-reddish-brown (10*R* 3/4); contains less than 1 percent muscovite flakes. Laminae are horizontal and are ¼ to ½ in. thick. Weathers to dark-reddish-brown (10*R* 3/4) slope of disaggregated material	4.5
Sandstone, silty, pale-reddish-brown (10*R* 5/4); has few flakes of muscovite. Unit is structureless and weathers to rounded ledge	1.0
Sandstone, moderate-brown (5*YR* 4/4), very fine grained, poorly cemented. Forms slope covered with small chips and flakes	5.5
Total Organ Rock tongue	210.0
Cedar Mesa sandstone member; uppermost bed is yellowish-gray (5*Y* 7/2) uniformly textured silty sandstone about 2 ft thick.	

Section of the Organ Rock tongue of the Cutler formation about 1½ miles south of Mille Crag Bend of the Colorado River

	Thickness (feet)
White Rim sandstone member.	
Unconformity (erosional disconformity).	
Organ Rock tongue:	
Sandstone, pale-reddish-brown (10*R* 5/4), very fine grained, massive-bedded. Upper 3 ft light brown (5*YR* 5.5/4). Irregular bleaching in upper 3 ft to very pale orange (10*YR* 8/2) and pale olive (10*Y* 6/2). Pale-olive sandstone is micaceous. Bleaching is in streaks as much as 6 ins. thick. Weathers to blocky cliff	50.4
Siltstone, light-pinkish-brown (3*YR* 5.5/4), micaceous, massive-bedded. Forms cliff	17.8
Siltstone, reddish-brown (10*R* 4/4), micaceous. Forms slope	5.6
Sandstone, pale-reddish-brown (10*R* 5/4). Forms cliff	33.5
Siltstone, pale-reddish-brown (10*R* 5/4). Forms slope interrupted by a ledge	17.9
Sandstone, light-pinkish-brown (3*YR* 6/5), very fine grained, structureless. Upper 1 ft is bleached pale red (10*R* 6/2) and very pale orange (10*YR* 8/2). Upper 1 ft contains less mica and more mafic accessories than remainder of unit and is more calcareous. Forms cliff or steep smooth slope	10.0
Sandstone, light-pinkish-brown (3*YR* 5.5/4); weathers light brown (3*YR* 7/5); very fine grained; contains mica and mafic accessories. At top is an irregularly bleached zone 6 in to 2 ft thick. Bleached color is very pale orange (10*YR* 8/2). Weathers to cliff covered with small mounds	9.5
Sandstone, pale-red (10*R* 6/2) to pale-reddish-brown (10*R* 5/4), very fine grained. Bleached in upper 2½ ft to grayish orange pink (10*R* 8/2). Contains pebbles of siltstone, especially near top. Weathers to smooth rounded cliff with small round knobs	15.6
Siltstone, reddish-brown (10*R* 5.5/5), coarse-grained; contains no mafic accessories and less than 0.5 percent of muscovite. Upper 0.3 ft is irregularly bleached very pale orange (10*YR* 8/2) and has much calcareous cement. Unit weathers to rounded cliffs, each as much as 5 ft high	25.5
Siltstone, pale-reddish-brown (10*R* 6/4), very fine grained, structureless. Locally contains lenses of fine-grained calcareous sandstone with very small siltstone pebbles. Weathers to rough-surfaced cliff	5.6
Siltstone, reddish-brown (10*R* 5.5/5), micaceous	16.8
Sandstone, light-pinkish-brown (3*YR* 5.5/4), very fine grained. Forms cliff	4.1
Siltstone, grayish-red (10*R* 4/2). Forms slope	5.8
Sandstone, grayish-red (10*R* 4/2), very fine grained; much calcareous cement. Has clusters of interstitial calcite crystals as much as 3 in. in diameter. Forms slope	1.6
Sandstone, light-yellowish-brown (10*YR* 6/4), very fine grained, micaceous. Unit is bleached 1 to 3 in. at base. Forms cliff	5.1
Siltstone, pale-reddish-brown (10*R* 4.5/3); contains 1 percent muscovite and less than 0.5 percent mafic accessories. Forms cliff	5.8

	Thickness (feet)
Organ Rock tongue—Continued	
Siltstone, grayish-red (10*R* 4/2) and pale-reddish-brown (10*R* 5/4), micaceous; contains large yellow quartz grains; structureless. Forms slope	34.7
Sandstone, pale-reddish-brown (10*R* 6/4), very fine grained; lenticular beds. Top of unit is bleached. Forms cliff	2.0
Siltstone, pale-reddish-brown (10*R* 5/4), structureless. Forms slope	2.0
Sandstone, reddish-brown (10*R* 6/4), very fine grained; lenticular beds. Forms cliff	1.0
Siltstone, pale-reddish-brown (10*R* 5/4), structureless. Forms slope	6.7
Sandstone, moderate-reddish-orange (10*R* 6/6) to moderate-reddish-brown (10*R* 4/6), very fine grained, structureless. Contains nodules of barite in rootlike ferruginous concretions. Forms cliff	4.5
Siltstone, pale-reddish-brown (10*R* 5/4), to pale-reddish-brown (10*R* 5/4), very fine grained structureless sandstone. Forms cliff	5.1
Sandstone, light-reddish-brown (3*YR* 6/5), very fine grained, calcareous. Contains barite and calcite concretions. Forms cliff	3.0
Sandstone, pale-reddish-brown (10*R* 5.5/3), very fine grained. Contains calcite and barite concretions. Forms cliff	10.6
Sandstone, moderate-orange-pink (5*YR* 8/4), very fine grained, calcareous. Has small limonite freckles. Variable from 2 to 4 ft thick and has gradational contacts. Forms cliff	2.2
Siltstone, moderate-brown (5*YR* 4/4). Forms slope	4.5
Sandstone, light-brown (5*YR* 6/4), very fine grained, micaceous. Forms cliff	1.5
Siltstone, pale-reddish-brown (10*R* 5/4) to grayish-red (10*R* 4/2), micaceous. Forms slope	11.2
Total Organ Rock tongue	319.6
Cedar Mesa sandstone member.	

Section of the Organ Rock tongue of the Cutler formation about 2½ miles south of Mille Crag Bend of the Colorado River

White Rim sandstone member; entire 4.5 ft of unit is sandstone, very pale orange (10*YR* 8/2), very fine grained, well-sorted; well cemented, siliceous; consists of coset of medium-scale tangential cross strata dipping southwest to southeast.

Unconformity (erosional disconformity).

	Thickness (feet)
Organ Rock tongue:	
Siltstone, light-reddish-brown (3*YR* 5.5/4). Upper 0.7 ft is bleached pale olive (5*Y* 6.5/1.5)	2.1
Sandstone, moderate-orange-pink (10*R* 7/4), very fine grained. Forms cliff	4.0
Siltstone, very pale orange (10*YR* 8/2), thinly laminated near top of unit, apparently structureless near bottom. Unit bleached lower 1.5 ft. Forms cliff	4.0
Sandstone, silty, reddish-brown (10*R* 5.5/5), very fine grained, micaceous. Lower 1 ft is bleached. Forms cliff	31.6

Organ Rock tongue—Continued	*Thickness (feet)*
Siltstone, reddish-brown (10*R* 4/4). Lower 0.5 ft is bleached to very pale orange (10*YR* 8/2). Forms cliff	13.2
Siltstone, pale-reddish-brown (10*R* 5.5/3); includes lenses of grayish-red (10*R* 4/2) siltstone-pebble conglomerate. Lower 1 ft is bleached. Forms cliff	3.6
Siltstone, pale-reddish-brown (10*R* 5/4), micaceous. Bottom 1 ft is bleached. Forms cliff	12.2
Sandstone, silty, pale-reddish-brown (10*R* 4.5/3). Forms slope	13.2
Sandstone, silty, pale-reddish-brown (10*R* 4.5/3). Forms cliff	15.5
Sandstone, pale-reddish-brown (10*R* 5/4) to moderate-reddish-orange (10*R* 6/6). Bottom 0.5 ft is bleached. Forms slope	8.0
Siltstone, light-reddish-brown (3*YR* 5.5/4). Forms cliff. Bottom 1 ft is bleached and forms slope	15.7
Siltstone, pale-reddish-brown (10*R* 5/4). Lower 1 ft and 0.5-ft zone 2 ft above base are bleached. Two-ft bed 14.4 ft above base of unit is like 9.7 ft thick unit below. Forms slope	20.4
Sandstone, pale-reddish-brown (10*R* 5.5/3), very fine grained. Forms cliff	3.6
Sandstone, grayish-orange-pink (5*YR* 7.5/3); weathers moderate reddish orange (10*R* 6/4) and light brown (5*Y* 6/4). Tangential cross-strata dip south to southeast. Fills mud cracks in top of underlying unit. Forms cliff	9.7
Siltstone, pale-reddish-brown (10*R* 5/4), and pale-reddish-brown (10*R* 5/4), very fine grained sandstone. Bottom 1 to 5 in. is bleached. Top 1 to 2 ft is irregularly bleached in seams 1 to 2 in. thick. Top surface is mud cracked in polygons about 1 ft across	17.7
Sandstone, light-reddish-brown (3*YR* 5.5/4), very fine grained	18.9
Siltstone, light-reddish-brown (3*YR* 5.5/4). Forms slope	11.7
Sandstone, pale-reddish-brown (10*R* 4.5/3), very fine grained, and little pale-reddish-brown (10*R* 5/4) siltstone. Bottom bleached to moderate orange-pink (5*YR* 8/2). Forms cliff	2.2
Siltstone, pale-reddish-brown (10*R* 5/4), micaceous. Forms slope	14.6
Siltstone, reddish-brown (10*R* 4.5/5), micaceous. Forms cliff	3.0
Sandstone, pale-reddish-brown (10*R* 5/4), very fine grained, micaceous. Forms slope	10.3
Sandstone, reddish-brown (10*R* 5.5/5), very fine grained, structureless. Forms cliff	1.5
Siltstone, pale-reddish-brown (10*R* 4.5/3), micaceous. Forms cliff	7.6
Siltstone, pale-reddish-brown (10*R* 4.5/3), micaceous. Forms slope	38.8
Sandstone, light-pinkish-brown (4*YR* 6/4), very fine grained. Top 1 ft is bleached. Contains calcite concretions. Forms cliff	9.6
Siltstone, moderate-olive-brown (5*Y* 4/4), micaceous. Forms slope	11.4
Sandstone, reddish-brown (10*R* 5.5/5), very fine grained, micaceous. Forms cliff	0.5
Siltstone, pale-reddish-brown (10*R* 4.5/3), micaceous. Forms slope	13.0
Sandstone, very pale orange (10*YR* 8/2) and grayish-orange-pink (5*YR* 7/2), very fine grained. Freckled with limonite. Forms cliff	1.0

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	Thickness (feet)
Organ Rock tongue—Continued	
Siltstone, light-reddish-brown (3*YR* 5.5/4). Forms slope	19.9
Sandstone, very pale orange (10*YR* 8/2), very fine grained. Forms cliff	1.0
Siltstone, moderate-reddish-brown (10*R* 4/4), micaceous, structureless. Forms slope	5.6
Total Organ Rock tongue	345.1
Cedar Mesa sandstone members.	

Measured thicknesses of the Organ Rock tongue in White Canyon range from about 220 to about 350 feet. Baker (1946, pl. 8) interprets the Organ Rock as tonguing rather extensively with the Cedar Mesa sandstone member in the Green River Desert-Cataract Canyon area and therefore changing rapidly in thickness from place to place. In general, it appears to thin and pinch out north and west of White Canyon and to thicken to the northeast and the southeast. The Cutler formation becomes red northeast of White Canyon, and most of the red beds are called Organ Rock (Baker, 1933, p. 30–32; 1946, p. 43, 44). To the southeast, in Monument Valley, Ariz., the Organ Rock is clearly separable from other members of the Cutler formation and is nearly 700 feet of red clayey siltstone (Witkind and Thaden, 1963).

Overlying the Organ Rock tongue in the western part of the area is the White Rim sandstone member of the Cutler formation. The contact is gradational over several inches. Apparently some material from the Organ Rock was reworked and incorporated into the White Rim. Below the contact for 1 foot or more the Organ Rock has been bleached to pale grayish orange and pale greenish gray. Although the White Rim is a mappable unit in many places, particularly north of the White Canyon area in the Green River Desert where it attains a thickness greater than 200 feet (Baker, 1946, p. 45, 46), Baker (1946, p. 46) cites one locality where the White Rim grades laterally into Organ Rock. In another area, north of the Cove (about 9 miles north of Mille Crag Bend), Baker observed red siltstone as much as 60 feet thick overlying the White Rim. These red beds are lithologically identical with the siltstone of the Organ Rock and were therefore included in the Cutler formation. They were too thin to separate from the White Rim on Baker's map, so he included them in the White Rim unit.

In the eastern part of the White Canyon area, where the Organ Rock tongue is overlain by the Hoskinnini member of the Moenkopi formation, the contact is sharp, if not everywhere distinct. The Organ Rock is mottled by bleaching to a light yellowish green at many places for tenths of an inch to several feet below the contact, and the overlying Hoskinnini contains sparse to abundant large yellow quartz grains which are lacking in the Organ Rock. In places, the Hoskinnini is a siltstone which, except for the presence of the large quartz grains, is identical with the Organ Rock; in other places it is a pebble conglomerate of reworked Organ Rock; and elsewhere it is a fine- to medium-grained orangish-brown sandstone with large quartz grains. At several places the contact is obviously an erosion surface with relief of several inches; at the pinchout of the Hoskinnini the relief is about 80 feet. There are also places where sandstone of the Hoskinnini has been deposited in cracks in the surface of the Organ Rock, forming polygonal networks of clastic dikes.

WHITE RIM SANDSTONE MEMBER

The White Rim sandstone member of the Cutler formation crops out throughout the northwestern part of the White Canyon area as a thin white stripe high up on the Permian and Triassic red-bed cliffs. Only along the Colorado River near the settlements of Hite and White Canyon is the White Rim at the base of the cliffs. It dips below the surface at Hite and at The Horn of the Colorado River, several miles south of Hite.

The White Rim sandstone member characteristically stands as a smooth-surfaced vertical cliff and, because it is relatively well cemented and homogeneous, it is in many places the resistant cap rock of erosion remnants.

The member is a very pale orange (10*YR* 8.5/2) to pale-yellowish-orange (10*YR* 7.5/4), apparently structureless, silty quartz sandstone. There is essentially no differential mineral content or grain size or color change to make stratification apparent. Only a close inspection of the slight differential weathering reveals horizontal laminae and gently inclined tangential cross-laminae, most of which are less than one-half inch thick. The cross-strata dip southwest to southeast. At a few places sets of cross-strata about 5 inches thick were seen. At other places the entire unit appeared to be a single set of laminae.

Grain size of the White Rim sandstone member varies from place to place from fairly well sorted sandy siltstone to fairly well sorted silty very fine grained sandstone. The grains are from 0.02 to about 0.2 mm in diameter and, depending upon the locality, will average from 0.06 to 0.12 mm. The grains are clear colorless quartz; the small ones angular, the large one subround. Partial polishing of previously frosted surfaces on the large grains and polished surfaces on the small grains may indicate water redeposition of windblown sand as suggested by Baker (1946, p. 46). The grains are well cemented by extensive overgrowths of secondary silica. Calcareous and ferruginous cementing material are largely absent, as are accessory minerals.

The greatest thickness of the White Rim sandstone member in the White Canyon area is along the Colorado River north of the settlement of White Canyon. There it is about 20 feet thick. It thins to the east to about 2 feet along a line extending northeast from the Happy Jack mine. Where the White Rim thins to about 2 feet, it grades laterally in distances of less than 1 mile to red siltstone inseparable from the Organ Rock. The White Rim attains a thickness greater than 200 feet in the Green River Desert country north of White Canyon, but there, too, it apparently grades laterally to Organ Rock to the east (p. 28). It is correlated with the upper part of the Coconino sandstone (Permian) to the west of White Canyon and is possibly correlative with the DeChelly sandstone member of the Cutler formation to the south (Baker, 1946, p. 47, pl. 8; Gregory, 1938, p. 47).

Nowhere in White Canyon is recognizable White Rim sandstone member directly overlain by sediments of the Hoskinnini member of the Moenkopi formation. The Hoskinnini pinches out to the northwest along a line only fractions of a mile east of the narrow zone in which the White Rim grades to Organ Rock. Where the White Rim is present in White Canyon, therefore, it is overlain by the upper member of the Moenkopi formation of Early and Middle(?) Triassic age. At most places, the contact is marked by a disconformity of very low relief and by an abrupt transition from the very fine grained sandstone of the White Rim to micaceous siltstone or chert-pebble and limestone-pebble conglomerate of the upper member of the Moenkopi formation.

TRIASSIC SYSTEM

TRIASSIC(?) AND LOWER AND MIDDLE(?) TRIASSIC SERIES

MOENKOPI FORMATION

The Moenkopi formation of Triassic(?) and Early and Middle(?) Triassic age crops out extensively in the White Canyon area. It normally forms the upper cliffs and shelving tops of mesas but forms only cliffs where it is protected by the overlying Shinarump member of the Chinle formation, also of Triassic age. Where it overlies the White Rim, it is readily recognized as a thin-bedded slabby-looking chocolate-colored formation at the top of the thick sequence of Permian red beds. Where the White Rim is absent, the presence of the Hoskinnini member at the base of the formation renders difficult its recognition from the Permian red beds, as the Hoskinnini is not pronouncedly different in color, lithology, or weathering characteristics from the underlying Permian rocks. In fact, the Hoskinnini was long assigned as a tongue of the underlying Cutler formation of Permian age. Although the Hoskinnini is known to grade laterally into the DeChelly sandstone member of the Cutler formation in southern Utah (T. E. Mullens, written commun., 1958), recent work by Stewart (1959) and by Shoemaker and Newman (1959) in eastern Utah and western Colorado, areas considered by them critical for dating the Hoskinnini and for determining its stratigraphic affinities, indicates that the Hoskinnini may be at least partly a lateral equivalent of the Tenderfoot member, the basal member of the Moenkopi formation in these areas. On this basis Stewart redefined the Hoskinnini as a member of the Moenkopi formation and proposed that its age be considered questionably Triassic, to conform to the age of the Moenkopi. Lack of known fossils in the member precludes any positive age assignment.

HOSKINNINI MEMBER

The Hoskinnini member of Triassic(?) age is the lower member of the Moenkopi formation. In the White Canyon area it crops out high on the red-bed cliffs throughout the eastern part of the White Canyon drainage and in the middle and upper reaches of Red Canyon. It pinches out rapidly to the northwest along a line extending northeast from the Happy Jack mine. Exposures in the central part of Red Canyon may represent an outlier of the Hoskinnini, for there it is exposed as a belt only 1 mile wide which pinches out both to the east and to the west.

The Hoskinnini member forms vertical and nearly vertical cliffs at most places. It tends to weather to a series of rounded ribs about 1.5 feet thick. The ribs are interrupted in places by irregular fractures spaced 1 to 4 feet apart, producing a cliff that has the aspect of a stack of pillows. Short and discontinuous slopes at places along the outcrop of the Hoskinnini are produced by lenses of poorly cemented sandstone.

A pale- to moderate-reddish-brown (10*R* 4–7/4–6) color, somewhat redder than the overlying upper member and somewhat more brilliant than the underlying Organ Rock tongue of the Cutler formation, is characteristic of the Hoskinnini member and makes it easily recognizable at most places. This brilliantly colored member can be separated into two units, the upper somewhat less brilliantly colored than the lower. The lower unit comprises two-thirds to five-sixths of the member. It is a very poorly sorted calcareous sandstone with lenses, streaks, and pods of coarse and fine material which grade into one another. Laminae, where apparent, are irregular and discontinuous, and are fractions of 1 inch thick. Sets of strata are bounded by horizontal planar surfaces averaging about 1½ feet apart but which may be entirely absent or unrecognizable. The upper unit of the Hoskinnini is similar to the lower unit in stratification except that the sets of strata average less than 1 foot thick. It is fairly well sorted and contains patches and lenses of extremely limy yellow sandstone. This upper unit of the Hoskinnini has, in places, several kinds of intraformational slump or compaction structures. The structures take several forms: perforate and imperforate upward warps and blowouts, asymmetric and recumbent folds, and involution with or without collapse (fig. 7). The disturbed areas do not affect the attitude of the bedding of the overlying upper member of the Moenkopi formation nor of the underlying lower unit of the Hoskinnini except that, where the upper beds of the Hoskinnini are severely involuted, wedges and "cannon balls" of the upper unit and sediments of the overlying upper member of the Moenkopi may be faulted downward. The lower unit, under areas of severe disturbance, is irregularly fractured in unusual patterns as though from unequal loading or unequal compaction, possibly resulting from partial solution of either the upper or lower unit of the member (fig. 7). The fact that the upper member of the Moenkopi is involved in some of the disturbances may indicate that the adjustments within the Hoskinnini took place over a considerable period extending into the time of deposition of the upper member.

Near its pinchout, some beds of the Hoskinnini member are impregnated with a black hydrocarbonaceous material. The amount of this material increases toward the pinchout over a distance of several miles and is confined largely to the coarse-grained and weakly calcareous beds. These beds weather to a light-brown color that contrasts with the reddish brown of the unimpregnated beds and gives the Hoskinnini a striped appearance.

The Hoskinnini member also contains angular chert fragments in approximately the same distribution as the hydrocarbonaceous material but unrelated to it. In a few places the fragments constitute as much as 10 percent of the rock, but they are absent more than 4 miles from the pinchout.

Sorting is poor throughout the Hoskinnini member, but is poorer in the lower unit than in the upper unit. The lower unit is largely a medium-grained calcareous silty sandstone of clear colorless polished angular to subangular quartz grains which contains 5 to 15 percent of colorless to orange clear round frosted quartz grains as much as 3 mm in diameter. This sandstone grades over distances of fractions of 1 inch to sandy siltstone and micaceous siltstone. A moderate overgrowth of secondary silica is the principal cement. The upper unit is fairly well sorted. It is dominantly a fine- to medium-grained sandstone of a nearly uniform texture. The quartz grains are clear colorless or yellow, polished, and angular to subangular. Patches, streaks, and lenses of light-colored sandstone grade into

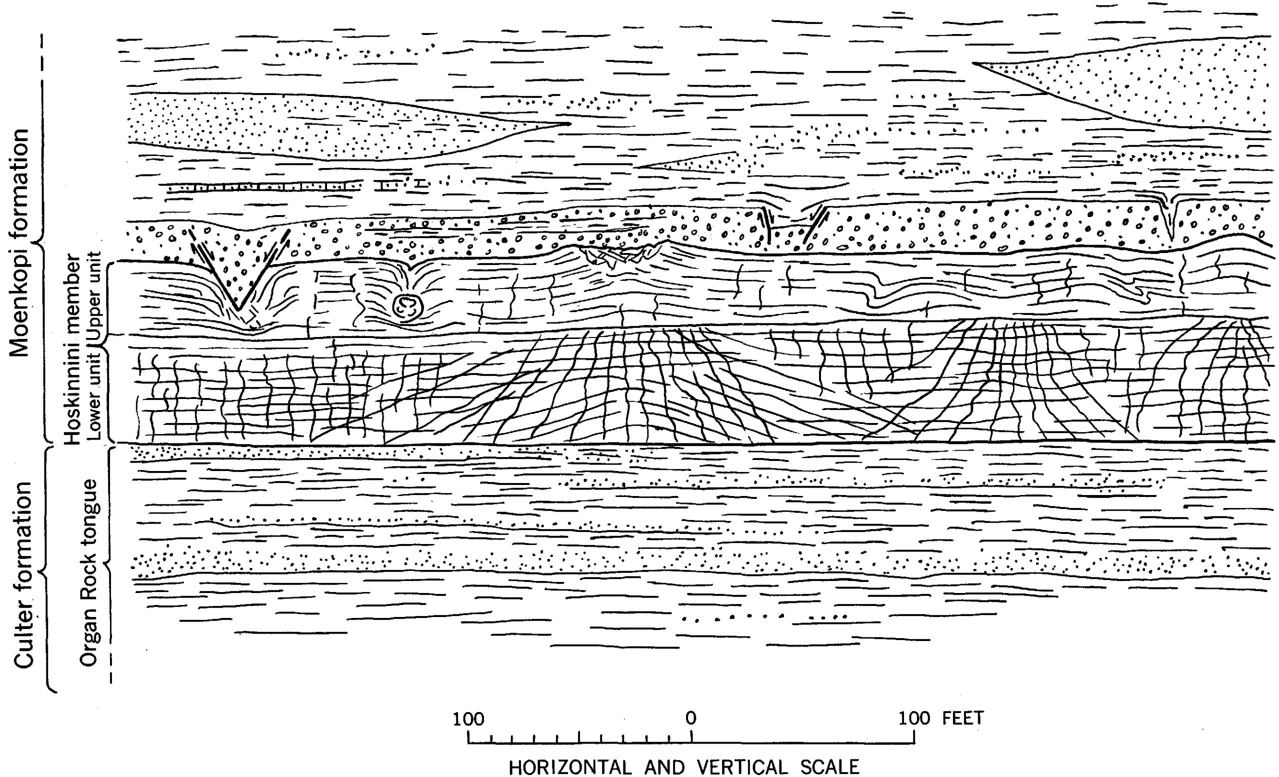

Figure 7.—Generalized diagram illustrating attitudes of the bedding in the upper unit of the Hoskinnini member of the Moenkopi formation in areas of disturbance and the probably related fracture patterns developed in the lower unit of the Hoskinnini member.

each other and into normal reddish-brown beds through distances of fractions to several inches. These light-colored areas are very calcareous, but the lightness is due to lack of surface stain of iron oxide. An extensive overgrowth of secondary silica is the principal cement in the upper unit, even in the calcareous light-colored areas.

The following sections illustrate various lithologies of the Hoskinnini member in the White Canyon area (see also section on p. 40):

Section of the Hoskinnini member of the Moenkopi formation at Fry Point

	Thickness (feet)
Upper member, Moenkopi formation.	
Hoskinnini member:	
Sandstone, moderate-orangish-pink (10*R* 7/4) to moderate-reddish-orange (10*R* 6/6), fine-grained; 2 percent calcite cement; grains are subround, well sorted, with a few coarse grains and less than 1 percent muscovite flakes. Beds are about 3 ft thick but are thinner in top 6 in. Forms cliff	5.5
Sandstone, moderate-reddish-orange (10*R* 6/6) to pale-reddish-brown (10*R* 5/4), with moderate-reddish-orange (10*R* 6/6) lenses about 2 in. long and ⅛ in. thick, fine-grained; 10 percent calcite cement; grains are subangular, well sorted, with trace of mafic accessories and mica. Forms cliff	9.6
Sandstone, yellowish-gray (5*Y* 8/1), fine-grained; contains streaks of medium-grained sandstone; 30 percent calcite cement; trace of mafic accessories and muscovite; grains are poorly sorted, subangular to subround; structureless. Forms cliff	.5
Sandstone to siltstone, grayish-red (10*R* 4/2) to dark-reddish-brown (10*R* 3/4), very fine grained; trace of muscovite. Breaks into small chips. Forms slope	2.8
Sandstone, very pale orange (10*YR* 8/2) very fine grained to fine-grained; 15 percent calcite cement; grains are subangular well-sorted quartz; less than 1 percent mafic accessories. Forms cliff	1.0
Sandstone, pale-reddish-brown (10*R* 5/4), with streaks of grayish-red siltstone (10*R* 4/2) and patches and seams of light-greenish-gray (5*GY* 8/1) sandstone; 10 to 15 percent calcite cement; contains few coarse amber quartz grains, no mafic accessories, and trace of small muscovite flakes. Forms cliff	3.0
Sandstone, white (*N* 9), fine-grained, well-sorted; 15 percent calcite cement; grains are subround; contains a few large quartz grains, no mafic accessories. Forms cliff	.5
Sandstone, very fine grained to fine-grained; consists of irregular seams and lenses of moderate reddish-orange (10*R* 6/6) and moderate reddish-brown (10*R* 4/6) as much as 5 in. thick. About 10 percent of medium to coarse quartz grains are scattered throughout unit and are concentrated in thin discontinuous layers. Unit contains 2 percent muscovite, trace of black accessories, and is noncalcareous except where calcite cements coarse-grained pods. Matrix is 10 to 15 percent clay. Grains are subround and many large ones are amber colored. Unit has a few small bleached spots one-sixteenth inch in diameter. Unit forms cliff and weathers to rounded forms	40.8
Total Hoskinnini member	63.7

Unconformity (erosional disconformity).
Organ Rock tongue of the Cutler formation.

Section of the Hoskinnini member of the Moenkopi formation on the northeast side of Moss Back

	Thickness (feet)
Upper member, Moenkopi formation.	
Unconformity (erosional disconformity; see p. 36).	
Hoskinnini member:	
Sandstone, moderate-reddish-brown (approx 10*R* 4.5/5), fine-grained; bleached white near top of unit in layers as much as 6 in. thick; subround, well sorted; 20 percent calcite cement; rare accessories. Forms slope	36.0
Sandstone, white (*N* 9), fine-grained, with few coarse grains, subround to round, poorly sorted; 25 percent calcite cement; rare accessories. Unit has contorted bedding. Forms cliff	2.0
Sandstone, moderate reddish-orange (10*R* 6/6), very fine grained, with medium-size grains scattered throughout unit, subround; 5 percent calcite cement; contains about 1 percent muscovite flakes in massive beds. Forms cliff	41.2
Total Hoskinnini member	79.2
Unconformity (erosional disconformity).	
Organ Rock tongue of the Cutler formation.	

Measured sections of the Hoskinnini member throughout the White Canyon area indicate that it maintains a fairly constant thickness of about 80 feet. At the mouth of Fry Canyon, the member is slightly more than 100 feet thick, and about 3 miles southeast of the pinchout line, it approaches or exceeds 100 feet in thickness at places. The pinchout line, in general, trends from the mouth of the Green River southward through White Canyon and thence, probably southwestward toward the junction of the San Juan and Colorado Rivers. To the south and east of White Canyon, the Hoskinnini thins gradually and is less than 10 feet thick in the eastern part of Monument Valley, Ariz. (Witkind and Thaden, 1963).

The pinchout of the Hoskinnini member in White Canyon is abrupt. On a butte about 5 miles northeast of the Happy Jack mine the Hoskinnini thins from about 80 feet to a pinchout in a horizontal distance of less than 1,000 feet. Where the thinning begins, the lower 60 feet of the Hoskinnini is a breccia of blocks 3 by 10 inches to 2 by 15 feet in size (fig. 8). This unit thins to the west progressively from the bottom to the top, through a distance of several hundred feet, against an erosion surface cut in the underlying Organ Rock, and its position is taken laterally by the Organ Rock. Several hundred feet westward the upper 20 feet of the Hoskinnini thins abruptly, in a fashion similar to that of the lower part, leaving only 1½ feet of Hoskinnini. About 200 feet farther to the west these beds thin in like manner, and the Hoskinnini pinches out completely.

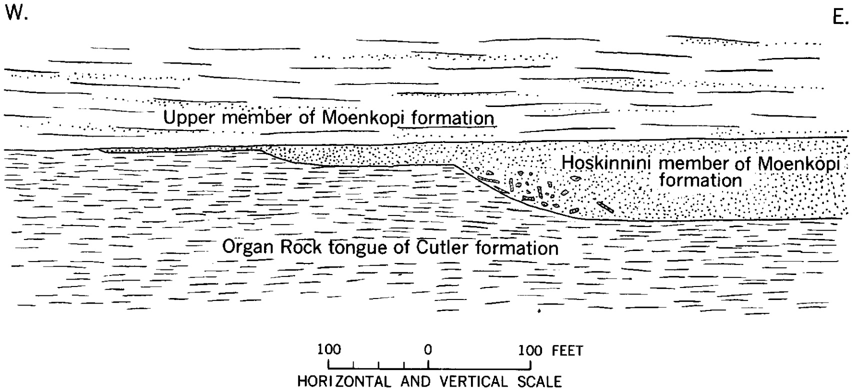

FIGURE 8.—Generalized diagram illustrating the pinchout of the Hoskinnini member of the Moenkopi formation on a butte about 5 miles northeast of the Happy Jack mine.

Although the field relations are unclear because of atypical exposures—owing to the presence of abundant reworked sediments in the base of the Hoskinnini member, the presence of hydrocarbonaceous material which may be stagnant inspissated petroleum, and the broken nature of the Hoskinnini near the pinchout—yet it can be seen that the Hoskinnini was deposited against a deep cut eroded in the top of the Organ Rock. The breccia probably represents a penecontemporaneous adjustment to the rapid thickening or to the superincumbent loading of the wedge edge of the Hoskinnini. The upper member of the Moenkopi rests on an extremely flat surface of erosion, a surface to which the tops of the Organ Rock and the Hoskinnini have been reduced to a common level.

The contact between the Hoskinnini member and the overlying upper member of the Moenkopi formation is not everywhere clearly marked. At most places the basal beds of the upper member are dark-reddish-brown micaceous siltstone or silty sandstone or are chert-pebble conglomerate. These may include material reworked from the Hoskinnini, making a gradational contact. There also are places, however, where a basal conglomerate in the upper member rests on an erosion surface or on a surface made irregular by slumping (fig. 7). Relief on this upper surface of the Hoskinnini member, although mostly only a few inches in magnitude, may be as great as 25 feet.

UPPER MEMBER

In general, the outcrop of the upper member of the Moenkopi presents a slabby appearance. Alternating light-colored sandstone and dark-colored siltstone beds produce a striped cliff, the sandstone projecting and the siltstone recessed. A medial zone of thick sandstone lenses stands as overhanging massive-weathering cliffs (fig. 9).

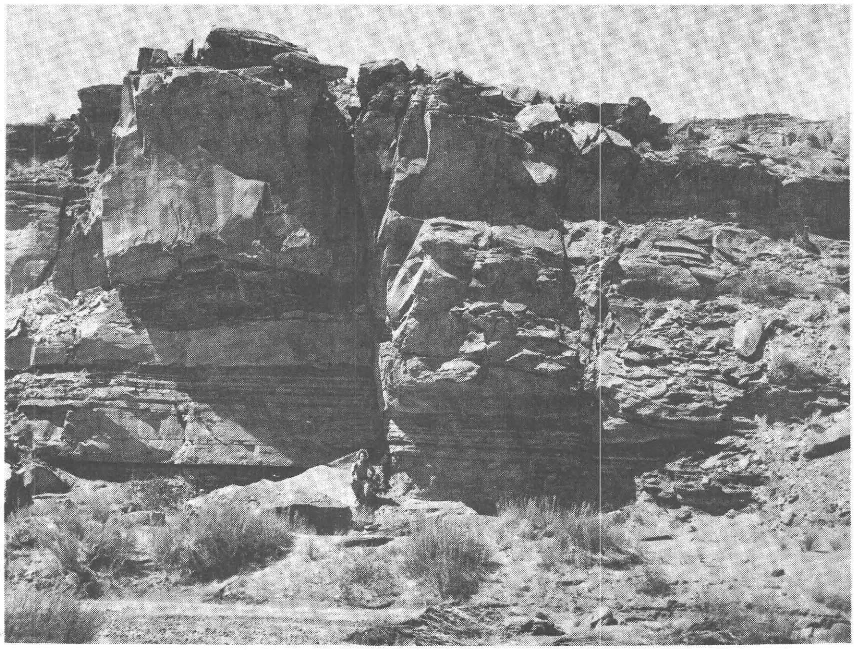

FIGURE 9.—Photograph showing middle part of the upper member of the Moenkopi formation where a fault zone crosses Blue Canyon wash. View looking south. Lenticular medial sandstone and siltstone beds are shown overlying persistent thin-bedded siltstone and sandstone beds.

Where the upper member is not protected by overlying formations, it weathers to form gentle slopes that contain small ledges and are covered by a mantle of rock chips and flakes.

The upper member of the Moenkopi formation in White Canyon, and in the adjacent regions to the south and to the northeast, is in three rather distinct units, each of which represents about one-third of the member. The lower and upper units are dominantly thin bedded and consist of alternating siltstone and sandstone. The lower unit contains some thin sandy limestone and siltstone-pebble conglomerate beds. The middle unit is a sequence of thick-bedded very fine grained lenticular sandstone beds separated by thin seams of siltstone and thin beds of limy sandstone. The dip of cross-strata and orientation of current ripple marks in the thick sandstone beds indicate a northerly and northwesterly direction of sediment transport in the White Canyon area.

The siltstone beds are grayish red (10*R* 4/2) to dusky red (10*R* 2/2) and are horizontally, irregularly, or ripple laminated in paper-thin layers of slightly varying color. The sets average less than 1 inch thick. The sandstone beds are 1 to 5 feet thick and are irregularly or ripple laminated, horizontally stratified, or tangentially and torrentially cross stratified in strata from ¼ to 5 inches thick. Most are lighter colored than the siltstone and somewhat yellower. An average color for the sandstone is a pale reddish brown (2*YR* 5.5/2–3).

In the western part of the White Canyon area the upper member contains one or more beds of chert and limestone-pebble conglomerate at or near the base, which are more or less in the same areal distribution as the conglomerate in the Hoskinnini member (p. 32). The chert pebbles are white to gray, and the limestone pebbles are gray to light blue. Pebbles more than 1 inch long are rare. They are in a matrix of clear colorless angular medium- to coarse-grained quartz sandstone that is cemented by silica. The conglomerate may aggregate more than 40 feet in thickness, but at most places there is less than 20 feet of conglomerate. Others have noted conglomerate in the Moenkopi, and Baker (1946, p. 57) and Hunt and others (1953, p. 46, 53) postulate that the chert and limestone pebbles were derived from the once subjacent or laterally proximate, but now eroded, Kaibab limestone of Permian age. Some of the chert pebbles were probably derived from reworking of pebbles in the Hoskinnini member.

Grain size of the siltstone in the upper member ranges generally from about 0.005 to about 0.04 mm and averages about 0.02 mm. Grading within any bed, however, can nearly juxtapose very fine grained clayey siltstone and coarse-grained sandy siltstone; average grain-size figures, therefore, cannot be meaningful for any part of the member or even for one bed at any locality. Silt-sized grains are mostly clear colorless and yellow angular polished quartz. There is some iron oxide surface stain and varying, but small, amounts of calcite. An overgrowth of secondary silica is the dominant cement, although both iron oxide and calcite are also cements at some places. Muscovite and biotite are the only notable accessory minerals. They are 4 to 8 times the size of the accompanying quartz grains, and they lie in the bedding planes, contributing greatly to the ability of the member to split into paper-thin sheets.

Sandstone, which is confined largely to the middle part of the member, mostly is very fine grained. Sorting is poor to excellent. The limy sandstone beds, in particular, are very well sorted, whereas the clayey and highly ferruginous beds are poorly sorted. The average grain size is about 0.08 mm. The grains are clear colorless subround to round quartz and are polished. Throughout the White Canyon area frosted grains were seen in only 1 sandstone bed, a limy sandstone about 1 foot thick. There are virtually no accessory mineral grains in the sandstone. A minor surface stain of iron oxide can be found in all but the most calcareous units, and a moderate overgrowth of secondary quartz is ubiquitous. Secondary silica is the primary cement even in beds in which calcite represents as much as 30 percent of the rock volume. In these, of course, calcite also acts as a cement.

The following four sections demonstrate the variability in lithology of the upper member of the Moenkopi formation:

Section of the Moenkopi formation one-half mile east of the Blue Lizard mine

Shinarump member of the Chinle formation.
Unconformity (erosional disconformity).

	Thickness (feet)
Upper member, Moenkopi formation:	
Siltstone, moderate-grayish-brown (4*YR* 4/2), micaceous, alternating with silty dusky-red (10*R* 3/2) very fine grained sandstone. Sandstone is in lenses as much as 2 ft thick. Upper 1 ft of unit is bleached light greenish gray (5*G* 7/1). Weathers to alternating slopes and cliffs	34.0
Sandstone, pale-red (10*R* 5/2) to pale-pinkish-brown (4*YR* 6/3), very fine grained; partly structureless, partly ripple laminated, in lenticular beds 1 to 8 ft thick; separated by thin seams of pale-red (10*R* 6/2) micaceous siltstone and siltstone conglomerate; limy pale-pinkish-orange (3*YR* 6/2) sandstone, as much as 0.3 ft thick; and silty pale-yellowish-brown (2*Y* 7/2) to pale-yellowish-green (5*GY* 7/2) very fine grained sandstone, in beds as much as 2 ft thick. Weathers to blocky cliffs and steep massive slopes interrupted by ledges	39.5
Siltstone, very dusky red (10*R* 2/2), micaceous; ripple laminated on a very small scale. Forms cliff where protected by overlying beds	6.9
Sandstone, silty, pale-reddish-brown (1*YR* 5.5/3), very fine grained. Lower 40 to 45 ft of unit is lenticular coset of tangentially cross stratified sets as much as 3 ft thick. Most of the cross-stratification dips northwestward. Upper 15 to 20 ft of unit is massive-weathering lenticular cosets of horizontally stratified sets as much as 2 ft thick, separated by thin seams of very dusky red (10*R* 2/2) micaceous siltstone. Upper 3 ft of unit is silty and weathers to flaggy surface. Unit forms cliff interrupted by short slopes	51.9
Siltstone, grayish-red (10*R* 4/2), micaceous; thin lenses of clayey and sandy dark-brown (2–4*YR* 4/2) siltstone; and clayey yellowish-gray (5*Y* 7/2) siltstone. The thin lenses form ledges 0.05 to 0.3 ft thick. Unit weathers to slope interrupted by ledges	24.8
Sandstone, conglomeratic, pale-brown (5*YR* 5.5/2), very fine to medium-grained, very poorly sorted; and dusky-red (10*R* 3/2) siltstone. Unit consists of 4 beds, each about 4 ft thick, separated by siltstone in seams as much as 0.5 ft thick. Lower three beds are structureless conglomeratic sandstone with siltstone pebbles as much as one-half inch across. Upper bed is ripple-laminated siltstone, grading in places to silty dusky-red (10*R* 3/2) medium-grained very poorly sorted sandstone, containing probable fish scales. Upper bed is capped, in places, by lenses of limy pale-yellowish-brown (8*YR* 6.5/3) medium-grained poorly sorted sandstone, as much as 0.5 ft thick. Unit forms a cliff	15.9

	Thickness (feet)
Upper member, Moenkopi formation—Continued	
Siltstone, sandy, very dusky red (10*R* 2/2); interbedded with limy yellowish-gray (3*Y* 7/2) sandstone, in beds as much as 1 ft thick. From 7.2 to 8.1 ft above base of unit is a silty and limy yellowish-brown (10*YR* 7/3) very fine grained sandstone, which contains small light-greenish-gray (5*G* 7/1) clayey siltstone pebbles. Unit forms alternating ledges and slopes	9.7
Sandstone, limy, pale-yellowish-brown (8*YR* 6.5/3), medium- to coarse-grained, very poorly sorted; composite set of tangentially cross-stratified and ripple-daminated sets as much as 2 in. thick; overlain by thin seam of very dusky red (10*R* 2/2) micaceous siltstone	1.5
Siltstone, grayish-red (10*R* 4/2), micaceous; lenticular cosets several feet thick of ripple-laminated sets; interbedded with limy light-orange-brown (7*YR* 6.5/4) to grayish-orange (9*YR* 7/2) sandstone and siltstone. Contains small included light greenish-gray (5*G* 7/1) clay and silty clay fragments in beds 0.6 to 0.8 ft thick. Forms alternating ledges and slopes	48.0
Total Upper member	232.2
Unconformity (erosional disconformity).	
Hoskinnini member:	
Sandstone, slightly silty, grayish-red (10*R* 4/2) to dark-reddish-brown (2*YR* 4/2), medium-grained, fairly well sorted; composed of angular to subangular polished quartz grains; well cemented, siliceous; irregularly stratified in sets of fractions of 1 ft thick. Unit contains small to large patches, lenses, streaks, and pods of grayish-orange (10*YR* 7/3) sandstone which have no iron oxide stain but more (as much as 5 percent) interstitial calcite than normal Hoskinnini. Grades to normal Hoskinnini over distances of fraction of 1 in. to several feet. Bedding is contorted in places. Unit weathers to smooth steep slope or ribbed cliff	26.0
Sandstone, pale-reddish-brown (10*R* 5/3) to grayish-red (10*R* 4/2), medium- to coarse-grained, very poorly sorted; composed of angular to subangular clear colorless polished quartz, 10 to 15 percent very coarse grains of subround to round clear yellow frosted quartz, and rare accessory pink chert grains and muscovite flakes; well cemented, siliceous; irregularly ripple laminated sets and trough sets of small-scale cross-strata in sets about 1½ ft thick. Unit weathers spheroidally along bedding truncations and irregular fractures to form knobby cliff. Unit contains about 2 percent calcite and moderate overgrowths of secondary quartz	53.0
Total Hoskinnini member	79.0
Total Moenkopi formation	311.2
Unconformity (erosional disconformity).	
Organ Rock tongue of the Cutler formation.	

Section of the upper member of the Moenkopi formation in Fry Canyon

Shinarump member of the Chinle formation.
Unconformity (erosional disconformity).
Upper member, Moenkopi formation:

	Thickness (feet)
Sandstone, pale-reddish-brown (10*R* 5/4), very fine grained; with some grayish-orange-pink (10*R* 8/2) beds; faintly laminated. Weathers to gentle slope of thin angular fragments	40.0
Sandstone, pale-red (10*R* 6/2), fine-grained; composed of clear colorless quartz with many clear orange grains; well cemented, calcareous. Weathers to blocky cliff, except top 6 ft which weathers to flaggy fragments	36.0
Sandstone, pale-red (10*R* 6/2), fine-grained; and grayish-red (10*R* 4/2) siltstone; with a few thin light-colored sandstone beds; thinly laminated. Weathers to gentle slope	24.0
Sandstone, clayey, pale-red (10*R* 6/2), fine-grained; grains are well rounded. Unit contains spots of dense iron oxide stain and a few dark accessories; calcareous	1.5
Sandstone, clayey, pale-red (10*R* 6/2), fine-grained; contains a few thin beds of clayey grayish-red (10*R* 4/2) siltstone. Grains in sandstone are clear colorless and yellow quartz and minor black accessory grains. Stratification in sandstone is irregular, with many curved truncation surfaces (scours) and some cross-stratified sets. Some sandstone units in scours have balls and pebbles of siltstone at their base. Forms blocky cliff	62.5
Siltstone, grayish-red (10*R* 4/2), fine-grained; with interbedded light-brown (5*YR* 6/4) coarse-grained siltstone and some fine-grained light-colored sandstone. Grayish-red siltstone is shaly splitting and contains a few thin light-greenish-gray laminae. Sandstone is small-scale cross stratified in tabular sets	10.1
Sandstone, pale-brown (5*YR* 5/2) to pale-red (10*R* 6/2), fine- to medium-grained; with a few beds of very pale orange (10*YR* 8/2). Contains patches of calcite. Unit is trough cross stratified and ripple laminated; strata inclined northward. Contains rare to abundant clay balls. Forms hard-surfaced slope	10.0
Siltstone, clayey, grayish-red (10*R* 4/2); with some beds of medium- to coarse-grained clay-ball-bearing sandstone. Forms soft-surfaced slope	35.0
Sandstone, very pale orange (10*YR* 8/2), medium- to coarse-grained; with very thin sets of laminated grayish-red (10*R* 4/2) claystone, each set not more than 2 in. thick. Sandstone weathers with pockets that appear to have contained light-greenish-gray (5*G* 8/1) clay balls. Unit contains calcite crystals and veinlets around the clay balls. Sandstone is cross stratified and ripple laminated, with foresets inclined northwestward to northeastward. Forms cliff	7.2
Siltstone, clayey, grayish-red (10*R* 4/2); contains 2 or 3 thin sandstone beds	13.0
Sandstone, very pale orange (10*YR* 8/2), medium- to coarse-grained, fairly well sorted; grains are round clear colorless or orange quartz; a few dark accessory grains. Unit contains some clay balls. Sandstone is ripple laminated and cross stratified. Forms cliff	2.8

	Thickness (feet)
Upper member, Moenkopi formation—Continued	
Siltstone, clayey, grayish-red (10*R* 4/2); contains a few thin beds of light-colored sandstone as much as 0.8 ft thick	18.5
Sandstone, very pale orange (10*YR* 8/2), very fine grained, poorly sorted, very calcareous, ripple-laminated	1.8
Siltstone, clayey, grayish-red (10*R* 4/2), lenticular	2.2
Total upper member, Moenkopi formation	264.6

Unconformity (erosional disconformity?).
Hoskinnini member of the Moenkopi formation.

Section of the upper member of the Moenkopi formation near the Happy Jack mine

Shinarump member of the Chinle formation; secondary copper minerals at the contact of the Shinarump member of the Chinle and Moenkopi formations.
Unconformity (erosional disconformity).

	Thickness (feet)
Upper member, Moenkopi formation:	
Siltstone, grayish-orange (10*YR* 7/4), thin-bedded; ripple marked near top of unit	35.0
Sandstone, silty, very pale orange. Beds are about 6 in. thick. Some crossbedding near top of unit	4.0
Siltstone, pale-red. Beds are 1 in. to 3 ft thick. Unit has at least three thick beds separated by thin beds	69.0
Siltstone, dark-reddish-brown, thin-bedded. Top 1 ft of unit is yellowish-gray siltstone with lenses of pale-blue-green (5*BG* 7/2) claystone and dark-reddish-brown siltstone which have pale-blue-green (5*BG* 7/2) claystone rims. Claystone and siltstone lenses are as much as 4 in. long	9.0
Siltstone, pale-reddish-brown. Unit has few streaks of dark-reddish-brown siltstone. Beds average 3 to 5 ft in thickness	28.0
Siltstone, pale-orange and dark-reddish-brown. Beds are about 1 in. thick	7.0
Siltstone, pale-reddish-brown, slightly micaceous. Beds are 3 ft thick at bottom of unit, becoming 3 in. thick at top of unit	8.0
Siltstone, interbedded pale-reddish-brown, dark-reddish-brown, and pale-orange. Dark-reddish-brown siltstone is irregularly patched and streaked along joints by the pale-orange siltstone. Beds average about 3 in. thick	6.0
Siltstone, pale-red; has black stain on the grains in streaks parallel to bedding; massive weathering	2.0
Siltstone, dark-reddish-brown, interbedded with pale-reddish-brown siltstone. The dark-reddish-brown siltstone contains pebbles of the pale-reddish-brown siltstone. Thin laminae of grayish-yellow (5*Y* 8/4) siltstone interbedded with the dark-reddish-brown siltstone produce a distinctive banding. A 1-ft bed of grayish-yellow (5*Y* 8/4) siltstone about 8 ft above the base of the unit contains claystone pebbles as much as 2 in. in diameter. The beds are as much as 3 ft thick, but average 3 to 6 in. in thickness	23.0
Siltstone, grayish-orange, micaceous	.7

	Thickness (feet)
Upper member, Moenkopi formation—Continued	
Conglomerate, contains quartz pebbles as much as three-eighths of an inch across	0.5
Siltstone, very pale orange	.8
Total upper member, Moenkopi formation	193.0

Disconformity?
Hoskinnini member of the Moenkopi formation.

Section of the upper member of the Moenkopi formation near the mouth of Blue Canyon

Shinarump member of the Chinle formation.
Unconformity (erosional disconformity).

	Thickness (feet)
Upper member, Moenkopi formation:	
Sandstone, light-brown (5*YR* 6/4), very fine grained; contains about 5 percent limonite, trace of manganese dioxide; ripple laminae and cross laminae are less than one-quarter of an inch thick; splits parallel to bedding in units one-quarter of an inch or more thick. Forms alternating cliffs and slopes	47.5
Siltstone, grayish-red (10*R* 4/2); contains lenses and pods of pale-red (10*R* 6/2) very fine grained sandstone; as much as 2 ft long. Siltstone contains about 5 percent muscovite, and sandstone contains about 5 percent muscovite and trace of black accessory minerals. The siltstone, thinly laminated, is draped over the sandstone lenses. Lower 2 ft of unit is entirely siltstone and has bleached bands as much as one-quarter inch thick. Forms slope	4.0
Siltstone, moderate-brown (5*YR* 4/4); contains about 1 percent muscovite and 2 percent black accessory minerals; unit composed of paper-thin flat laminae, irregular laminae, and ripple laminae; shaly splitting. Forms cliffs and slopes	29.5
Siltstone and sandstone, pale-red (10*R* 6/2), very fine grained; indistinct horizontal bedding; splits poorly; fractures conchoidally. Forms cliff	6.0
Siltstone and sandstone, grayish-red (10*R* 4/2), very fine grained; contains trace of muscovite; composed of paper-thin horizontal laminae; splits along bedding. Unit has about 10 percent bleached zones as much as one-half inch thick. Forms slope	3.5
Siltstone and sandstone, pale-red (10*R* 6/2), very fine grained; contains about 1 percent muscovite; shaly to flaggy splitting. Forms cliffs and slopes	32.5
Siltstone and sandstone, pale-red (10*R* 6/2), very fine grained; contains trace of muscovite, about 2 percent black accessory mineral grains, and about 30 percent ferruginous(?) cement; unit is cross stratified in laminae about one-quarter of an inch thick; flaggy splitting. Forms cliff	25.0
Sandstone, conglomeratic, grading in upper part to siltstone; grayish-red (10*R* 4/2); conglomerate pebbles are siltstone ½ to 2 in. across and comprise about 15 percent of the unit; poorly defined thin horizontal laminae; splits irregularly to plates ½ to 4 in. thick; contains trace of muscovite and black accessory minerals and pods of interstitial calcite as much as 3 in. across. Forms cliff	2.0

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Upper member, Moenkopi formation—Continued	Thickness (feet)
Siltstone, light-brown (5*YR* 6/4), and very pale orange (10*YR* 8/2) medium-grained very poorly sorted sandstone. Sandstone is about 20 percent of unit. Siltstone has trace of muscovite and white salts as accessory minerals. Sandstone has trace of black accessories and 30 percent clay cement. Siltstone stratification is horizontal thin laminae in very thin beds; splitting is papery to flaggy	6.0
Sandstone, conglomeratic, pale-red (10*R* 6/2), very fine grained; included pebbles are claystone as much as 4 in. in diameter; contains 15 percent calcite cement and trace of black accessory minerals. Forms cliff	2.0
Siltstone, pale-red (10*R* 6/2), and grayish-orange-pink (10*R* 8/2) very fine grained to fine-grained well-sorted sandstone. Siltstone contains minor siltstone pebbles and about 1 percent muscovite. Sandstone contains rare siltstone pebbles, about 1 percent muscovite, trace of black accessories, and about 30 percent calcite cement. Forms slope and small cliff	3.5
Sandstone, conglomeratic, grayish-orange (10*YR* 7/4); weathers pale brown (5*YR* 5/2); matrix is fine grained; composed of round quartz grains and 15 percent calcite, 10 percent clay, less than 1 percent iron oxides, and trace of black accessory grains. Flat pebbles of claystone as much as 1½ in. across constitute 15 percent of the unit. Unit is thin bedded and weathers to massive cliff	1.0
Siltstone, pale-reddish-brown (10*R* 5/4); contains about 2 percent muscovite; very thin bedded, with shaly bedding-plane splitting. Forms slope	5.5
Sandstone, conglomeratic, very pale orange (10*YR* 8/2), fine- to medium-grained; contains flat clay pebbles as much as 2 in. long, 5 percent clay, 25 percent calcite, and trace of black accessories; argillaceous and calcareous cement; cross stratified in beds 2 to 5 in. thick; flaggy splitting. Forms cliff	2.0
Siltstone, grayish-red (10*R* 4/2) to very dusky red (10*R* 2/2); contains 2 percent accessory muscovite. Forms slope	1.0
Sandstone, conglomeratic, pale-brown (10*YR* 5/2) to grayish-red (10*R* 4/2), and minor very pale orange (10*YR* 8/2), interbedded; silty to coarse grained, very poorly sorted; contains minor siltstone and 10 percent chert pebbles as much as 2½ in. long, 15 percent clay, 5 percent calcite, and about 1 percent black accessories; well cemented, argillaceous and calcareous; cross stratified; laminae average about 1 in. thick and dip southwestward; splits platy to massive. Bottom contact is gradational. Forms cliff	3.5
Sandstone, conglomeratic, very pale orange (10*YR* 8/2), fine- to medium-grained; contains 10 percent chert granules and pebbles as much as 2½ in. in diameter, 15 percent clay, 5 percent calcite, and trace of black accessories; well cemented, argillaceous and calcareous	.5
Total upper member, Moenkopi formation	175.0

Unconformity (erosional disconformity?).

Hoskinnini member of the Moenkopi formation.

Thickness measurements of the Moenkopi formation in the White Canyon area range from about 175 to nearly 375 feet. The average thickness of the formation in this area is about 300 feet where the Hoskinnini member is present and 220 feet where it is absent. There appear to be places within the central part of the area in which the upper member is relatively thinner than it is elsewhere. In the vicinity of the settlement of White Canyon the upper member is considerably thicker than 200 feet, as it is also in parts of Fry Canyon and in the upper part of Red Canyon. The sections measured near the Happy Jack mine and near the mouth of Blue Canyon, however, indicate that the thickness of the upper member at these places is less than 200 feet. Similar observations have also been made by Gregory (1938, p. 70–73) and by McKee (1954, p. 23, 27). Regional thinning is to the southeast, and the formation is absent in northeastern New Mexico (McKee, 1954, p. 23). The formation reaches its maximum thickness in southwestern and central Utah, where thicknesses of more than 2,000 feet have been recorded (Reeside and Bassler, 1922, p. 60).

Contact of the Moenkopi formation with the overlying Shinarump member of the Chinle formation of Late Triassic age is a surface of erosion everywhere in the White Canyon area. Local relief on this surface is only a few feet except where channels have been incised. Some channels are more than 1,000 feet wide and have been cut as much as 50 feet into the surface of the Moenkopi. In general, they trend westward and southwestward in the eastern part of the area and northwestward in the western part (pl. 1). They represent about 4 percent of the total area of contact between the Moenkopi and overlying Shinarump. Although no single channel has been traced long distances, it is probable that some extend many miles.

An angular relationship may exist between the Moenkopi formation and the Shinarump member of the Chinle formation in places in the White Canyon area, but the discordance is too small to be recognized anywhere except on Deer Flat (p. 90, 96–97). There, and perhaps elsewhere, fold structures in the Moenkopi may have been instrumental in the formation of local features, such as channels and small areas of nondeposition of the Shinarump member; but they do not appear to have influenced greatly the areal distribution of the Shinarump as a whole.

The uppermost beds of the Moenkopi formation are nearly everywhere bleached for several inches to several feet below the contact with the Shinarump member of the Chinle formation. Generally, the bleaching is thicker below channels than elsewhere. The bleached beds are light yellow or green and probably represent alteration of the iron-bearing minerals that normally give the Moenkopi its dark-reddish-brown color.

UPPER TRIASSIC SERIES

CHINLE FORMATION

The Chinle formation in the White Canyon area is similar in general character to the Chinle in surrounding regions. It is composed of a thick sequence of brilliantly colored limestone, claystone, siltstone, sandstone, arkose, and conglomerate beds, many of which contain petrified logs, coal seams, and concretionary nodules of various compositions. Generally, the lower part is sandy, clayey or muddy, conglomeratic, and carbonaceous; the middle part is clayey and limy; and the upper part is sandy (arkosic) and silty. The Chinle erodes to form slopes between the underlying cliff-forming red beds and the overlying cliff-forming Glen Canyon group; the slopes are covered in most places by talus breccia and landslide blocks. It is also structurally weak, and if it is unstable when dry it is more unstable when wet, owing to the presence of volcanic material in many beds. It is not surprising, therefore, that single landslide blocks more than 1½ miles in length have formed in places where oversteepening by lateral erosion has been accompanied by an abundance of water in the Chinle, as along the Colorado River near the mouth of Red Canyon.

For mapping in the White Canyon area, the Chinle formation has been divided into five units: the Shinarump member, the mudstone-sandstone unit, the Moss Back member, the limy unit, and the sandstone-siltstone unit. These units are not entirely correlative with the A, B, C, and D divisions of the Chinle of Gregory (1917, p. 42, 43) or with the units, approximating those of Gregory, which have recently been named (Witkind and Thaden, 1963; Stewart, 1957). Gregory's units, however, are by no means unidentifiable throughout most of the White Canyon region, and an attempt has been made in one measured section (p. 63) to make the correlation and to indicate the differences between the present divisions of the Chinle and its division according to Gregory.

SHINARUMP MEMBER

The Shinarump member is the most important uranium-bearing unit in the district. It is persistent in a broad belt, ranging in width from 8 to 15 miles, that trends northwestward across the White Canyon area. This belt extends from beyond Deer Flat on the east to beyond the Colorado River on the west, a distance of more than 30 miles. The Shinarump is present in lenses and isolated patches beyond the limits of the main belt.

The thickness of the Shinarump member ranges from less than 1 foot to as much as 80 feet. The member is generally thicker and more uniform in thickness within the main belt, where it ranges from 8 to 80 feet, although locally it is absent; it rarely exceeds 30 feet in thickness in lenses outside the main belt.

The Shinarump member characteristically weathers to form cliffs of bare rock which are in contrast to the more rounded and disaggregated slopes of the overlying units. In many places the cliff formed of the Shinarump rests upon a gentle slope of the Moenkopi formation, but in a few places, such as at the Markey mine in Red Canyon, it immediately overlies and is continuous with a formidable cliff of the Moenkopi. In a few places, such as at the Posey mine and at the North Point claim, the overlying mudstone-sandstone unit has been eroded back from the rim several hundred feet. At these places the Shinarump forms a broad bench.

The Shinarump member is composed principally of interstratified sandstone, siltstone, and conglomerate. The sanstone is mostly very pale orange, grayish yellow, white, and gray. It ranges from very fine grained to very coarse grained and commonly grades into conglomerate. The sandstone commonly consists of lenticular trough sets of cross strata that range in thickness from less than 1 foot to about 7 feet. They normally form ledges and cliffs. The sandstone of the Shinarump member is distinguished from bleached sandstone of the underlying Moenkopi formation by poor sorting, larger grain size, and carbonized vegetal fragments. The Shinarump is gradational with the overlying mudstone-sandstone unit in many places, and the contact, in places, must be placed arbitrarily at the top of the uppermost sandstone that grades downward into recognizable sandstone of the Shinarump. The sandstone of the Shinarump is distinguished from the sandstone of the overlying mudstone-sandstone unit by its thicker laminae and smaller amounts of clay and lime cement.

Siltstone strata in the Shinarump member commonly lie between sandstone strata, but in some places rest upon the Moenkopi formation to form the base of the member. The siltstone strata grade laterally and vertically to, and are interbedded with, lenses of claystone and clayey sandstone. The siltstone is greenish gray, gray, and pale olive; the claystone is gray; and the clayey sandstone is light gray to light brown. These silty beds are commonly lenticular, and range in length from a few inches to 300 feet and from a fraction of 1 inch to 10 feet in thickness. Stratification is generally horizontal though locally trough cross-stratification is present.

Conglomerate is common in the basal part of the Shinarump member, and thin stringers of conglomerate are interbedded with sandstone at many places. Conglomerate occurs in beds as much as 5 feet in thickness and is generally of about the same color as the sandstone. Most of the pebbles are less than 3 inches across, although cobbles as much as 5 inches across have been found; angular fragments of siltstone as much as 3 feet across were noted in a few places. Most of the pebbles consist of quartz, quartzite, limestone, and siltstone; a few are sandstone, chert, and red jasper (table 1). The matrix of the conglomerate includes fine-grained to very coarse grained sandstone. In general, conglomerate containing large pebbles has a coarse-grained matrix and conglomerate containing small pebbles has a fine-grained matrix.

Stratigraphic sections of the Shinarump member in the White Canyon area follow.

TABLE 1.—*Composition of pebbles in the Shinarump member of the Chinle formation in the White Canyon area*

Locality	Percent total pebbles—					
	Red jasper	Quartzite and rock quartz	Limestone	Sandstone	Siltstone	Chert
2 miles east of The Horn of the Colorado River	------	10	25	25	15	25
2½ miles east of The Horn of the Colorado River	20	5	15	20	20	20
1¼ miles east of The Horn of the Colorado River	3	------	60	5	30	2
3 miles southeast of The Horn of the Colorado River	------	100	------	------	------	------
2½ miles southeast of The Horn of the Colorado River	------	------	------	------	100	------
4½ miles south of The Horn of the Colorado River	------	35	30	------	35	------
4¼ miles south of The Horn of the Colorado River	------	------	100	------	------	------
4 miles south of The Horn of the Colorado River	------	------	35	------	65	------
1¾ miles west of the Blue Lizard mine	------	100	------	------	------	------
6½ miles north of the Posey mine	------	100	------	------	------	------

Section of the Shinarump member of the Chinle formation in a channel 2 miles east of The Horn of the Colorado River (which is approximately at long 110°26′ W., lat 37° 46′30″ N.)

	Thickness (feet)
Mudstone-sandstone unit (lowest beds are light-blue claystone).	
Shinarump member:	
Sandstone, pale-yellowish-brown (10*YR* 6/2); weathers yellowish brown (8*YR* 5/3); coarse-grained, poorly sorted; composed of clear colorless angular polished quartz and common orange, red, and black quartzite and chert accessory grains. Unit includes many small spots of yellow iron oxides and carbon. Unit is well cemented, very calcareous and siliceous. Forms cliff	4.0
Sandstone, conglomeratic, yellowish-brown (10*YR* 4.5/3), medium- to coarse-grained, fairly well sorted; composed of clear colorless subround qartz and minor carbon fragments. Pebbles are dominant subround silty limestone and minor decayed white chert as much as 1 in. in diameter. Unit is well cemented, highly calcareous, with many small spots of milky white and pale-green calcite. Includes rare thin seams of secondary copper minerals. Forms cliff	3.5

	Thickness (feet)
Shinarump member—Continued	
Sandstone, pale-yellowish-orange (10*YR* 8/6) to dusky-yellowish-brown (10*YR* 2/2), fine-grained, poorly sorted. Unit contains abundant carbonized plant fragments as much as several inches in length and abundant gypsum as boxworks in the plant fragments and as seams in the sandstone. Unit also contains abundant yellow to red iron oxides. Forms cliff	0.5
Sandstone, conglomeratic, coarse-grained, well cemented, highly calcareous. Much like overlying and underlying units. Forms cliff	.5
Sandstone, silty and conglomeratic; poorly cemented. Unit contains abundant carbonized plant fragments as much as 2 by 8 in. in size and abundant yellow to red iron oxides. Forms slope	1.7
Claystone, yellowish-gray (6*Y* 7/2). Bottom 0.8 ft contains small carbon flakes. Top 0.3 ft is streaked with yellow to red iron oxide. Forms slope	3.1
Sandstone, dark-yellowish-brown (10*YR* 4.5/2), medium- to coarse-grained, poorly sorted; composed of subangular to round clear colorless and pink translucent quartz and abundant spots of pale- to dark-yellow iron oxides; well cemented, highly calcareous and gypsiferous. Unit contains a few small limy siltstone pebbles and small spots of carbon. Forms cliff	1.1
Claystone, sandy; contains thin flakes of carbon. Forms slope	.5
Sandstone, dark-yellowish-brown (10*YR* 4/4), medium- to coarse-grained, poorly sorted; composed of angular to round clear colorless quartz and small spots of iron oxide; well cemented, calcareous and gypsiferous. Forms cliff	.3
Claystone, sandy, pale-olive-gray (5*Y* 6/2); contains thin flakes and seams of carbon	.3
Sandstone, dark-yellowish-brown (10*YR* 4/4), coarse-grained; composed of subround to round clear colorless quartz and abundant small spots of yellow iron oxide; well cemented, calcareous and gypsiferous	.5
Total Shinarump member	16.0

Unconformity (erosional disconformity with relief in the immediate vicinity greater than 6 ft).

Moenkopi formation.

Section of the Shinarump member of the Chinle formation at the Happy Jack mine

Mudstone-sandstone unit of the Chinle formation (lowest beds are gray siltstone).

	Thickness (feet)
Shinarump member:	
Sandstone, grayish-yellow (5*Y* 8/4) and light-brown (5*YR* 5/6), very coarse grained; cross-strata laminae 1 to 2 in. thick dip northwestward; consists of 86 percent subangular to subround quartz grains, 5 percent carbonized wood fragments as much as one-fourth of an inch in length, 5 percent clay cement, 3 percent microcline grains, and 1 percent iron oxides; moderately well cemented. Quartz grains tightly packed and have insignificant amount of authigenic overgrowths. Carbonized wood most abundant in upper 3 ft. Forms a steep slope	5.0

Shinarump member—Continued	Thickness (feet)
Sandstone, very pale orange (10*YR* 8/2) and moderate-brown (5*YR* 4/4), medium- to coarse-grained; cross-strata 2 to 3 in. thick dip 13° N. 10° W.; consists of 88 percent subangular to subround quartz grains, with authigenic overgrowths, 10 percent clay cement, 1 percent white to pink microcline grains, 1 percent limonite, and less than 1 percent hematite. The grains are well sorted and well cemented. Contains local hematite streaks, 1 to 3 in. wide. Forms a cliff	2.3
Sandstone, conglomeratic, dark-yellowish-orange (10*YR* 6/6) and moderate-red (5*R* 5/4), coarse-grained to very coarse grained; cross-strata 1 to 1½ in. thick, poorly developed, dip 8° S. 70° W.; consists of 88 percent quartz grains, subround to subangular with authigenic overgrowths, 5 percent clay cement, 3 percent limonite, 2 percent pale-yellow microcline, 1 percent claystone pebbles as much as 1 in. across, 1 percent carbonized wood fragments half an inch across, and a trace of quartz pebbles three-fourths of an inch in diameter. Grains are fair to poorly sorted. Unit is more conglomeratic in upper 6 in. Forms a cliff	1.8
Sandstone, light-brown (5*YR* 5/6) and grayish-yellow (5*Y* 8/4), coarse-grained; cross-strata 1 to 3 in. thick dip 40° N. 40° E.; consists of 75 percent quartz grains, subround with minor amount of authigenic overgrowth, 15 percent clay cement, 5 percent limonite, 3 percent hematite, and 2 percent carbonaceous matter in knifelike streaks 1 in. long. Unit contains honeycomb boxworks of limonite and abundant pale-blue and green secondary copper minerals. Conspicuous parting has been formed along planes between laminae. Forms a platy cliff	1.0
Sandstone, conglomeratic, light-brown (5*YR* 5/6) and grayish-yellow (5*Y* 8/4), very coarse grained; cross laminae 1 in. thick dip 14° S. 54° E.; consists of 91.5 percent subround to subangular quartz grains with authigenic overgrowths, 5 percent clay matrix, 2 percent flattened claystone pellets, ⅛ to ½ in. long, 1 percent limonite, and 0.5 percent pale-yellow microcline grains. Grains are poorly to moderately well sorted and are poorly cemented. Unit contains pale-blue chalcanthite on surface. Forms a cliff	3.7
Sandstone, conglomeratic, grayish-yellow (5*Y* 8/4) and light-brown (5*YR* 5/6); laminae ¾ to ½ in. thick dip S. 70° W.; consists of 92 percent quartz grains, subround to subangular with abundant authigenic overgrowths, 3 percent light-yellow microcline grains, 3 percent clay cement, 1 percent limonite, 0.5 percent quartz pebbles as much as one-fourth inch across, 0.5 percent charcoal stringers one-sixteenth inch thick, and a trace of gray claystone pebbles, as much as one-half inch in diameter. Grains are poorly sorted and poorly cemented. Unit contains pale-blue and pale-green secondary copper minerals on surface. Forms a cliff	1.9
Sandstone, grayish-yellow (5*Y* 8/4) and light-brown (5*YR* 5/6), very coarse grained; cross laminae 1 in. thick dip 8° N. 60° W.; consists of 93 percent quartz grains, subangular to subround with abundant authigenic overgrowths, 3 percent clay matrix, 2 percent limonite, 1 percent charcoal in fragments as much as 2 in. long, 0.5 percent jarosite, and 0.5 percent light-yellow feldspar grains. Limonite	

	Thickness (feet)
Shinarump member—Continued	
and hematite dissemination emphasize the bedding; hematite occurs in spots, half an inch in diameter, in lower 3 in. of unit. Grains are moderately well sorted. Unit contains pale-blue chalcanthite. Forms a cliff	0.8
Total Shinarump member	16.5
Unconformity (erosional disconformity with relief in the immediate vicinity of at least 10 ft.)	
Moenkopi formation (beds bleached for more than 1 ft beneath the contact; impregnated with pale-blue chalcanthite).	

Section of the Shinarump member of the Chinle formation in a channel three-fourths mile southwest of Soldier Crossing in White Canyon

	Thickness (feet)
Mudstone-sandstone unit (lowest beds are light-gray siltstone). Shinarump member:	
Sandstone, conglomeratic, yellowish-gray; contains quartz pebbles ¼ to 1 in. across which have authigenic quartz overgrowths and green copper minerals which have replaced wood. Forms a cliff	7.0
Siltstone, light-gray; intercalated with fine-grained sandstone. Forms a smooth slope and bench	25.0
Sandstone, conglomeratic, light-gray, cross-stratified; contains quartz grains, clay pebbles, and brown iron oxide stained sandstone grains. A small amount of gray carbonaceous material in 6-in. bed of siltstone 4½ ft from bottom; 4-in. seam of green copper minerals near bottom. Contains jarosite in places. Forms a cliff	10.0
Total Shinarump member	42.0
Unconformity (erosional disconformity with relief in the immediate vicinity greater than 3 ft).	
Moenkopi formation.	

Section of the Shinarump member of the Chinle formation in a small channel in Blue Canyon 2 miles north of the Chocolate Drop

	Thickness (feet)
Mudstone-sandstone unit (lowest beds are gray mudstone, poorly exposed).	
Shinarump member:	
Sandstone, very light gray (*N* 8), very fine grained; consists of about 70 percent quartz grains, 30 percent clay cement, and less than 1 percent iron oxide; well cemented. Unit contains a few carbonaceous streaks	2.0
Sandstone, very pale orange (10*YR* 8/2), limonite-freckled, medium- to coarse-grained; laminae 3 in. thick dip 3° northwest. Consists of 90 percent quartz grains, 8 percent clay cement, and 2 percent iron oxides. Quartz grains have many authigenic overgrowths. Unit contains a few laminae of poorly cemented very coarse grained sandstone	4.0
Sandstone, pinkish-gray (5*YR* 8/1), very coarse grained; consists of about 95 percent quartz grains, 5 percent clay matrix, and less than 1 percent iron oxide; well cemented; cross stratified. Quartz grains have much authigenic overgrowth	2.0

	Thickness (feet)
Shinarump member—Continued	
Siltstone, gray; contains 10 percent charcoal lenses which average 4 in. long and half an inch in width, 5 percent jarosite, 3 percent iron oxide, and 2 percent massive gypsum	2.5
Siltstone, gray, carbonaceous	1.5
Total Shinarump member	12.0
Unconformity (erosional disconformity with relief in the immediate vicinity of at least 4 ft).	
Moenkopi formation.	

Section of the Shinarump member of the Chinle formation 1¾ miles west of Soldier Crossing

	Thickness (feet)
Mudstone-sandstone unit (lowest beds are light-gray siltstone).	
Shinarump member:	
Sandstone, gray, fine-grained; beds average 3 ft thick; dips suggest slumping; contains a trace of carbonized wood	4.5
Claystone, sandy, yellow; contains abundant carbonized wood	2.5
Sandstone, silty, and intercalated fine-grained cross-stratified sandstone. Silty beds have an average thickness of 2 ft, sandstone beds 1 ft. Forms a slope	30.0
Siltstone, light-gray, and interbedded fine-grained sandstone; contains abundant jarosite	5.5
Sandstone, conglomeratic; contains quartz and claystone pebbles; also contains carbonized wood and jarosite	2.0
Sandstone, dark-grayish-brown, coarse-grained; contains lenses of light-gray siltstone; cross stratified; contains less than 5 percent quartz pebbles as much as 1½ in. across	4.0
Total Shinarump member	48.5
Unconformity (erosional disconformity with minor relief in the immediate vicinity).	
Moenkopi formation.	

Section of the Shinarump member of the Chinle formation 1 mile west of Jacobs Chair

	Thickness (feet)
Mudstone-sandstone unit (lowest beds are light-gray siltstone).	
Shinarump member:	
Sandstone, very pale orange (10*YR* 8/2); weathers yellowish gray (5*Y* 7/2); maculate, medium grained; in beds one-fourth of an inch thick	1.0
Sandstone, grayish-red (5*R* 4/2), medium-gray; weathers brownish gray to grayish black	1.5
Sandstone, gray to grayish-yellow (5*Y* 8/4); weathers yellowish gray (5*Y* 7/2) to moderate reddish brown (10*R* 4/6); medium to coarse grained; beds 1 to 6 in. thick, slightly cross stratified; contains carbonized wood	2.5
Sandstone, gray, fine-grained; contains much carbonized vegetal material and jarosite; laminae average one-fourth of an inch thick	4.0

	Thickness (feet)
Shinarump member—Continued	
Conglomerate, gray to red, with 40 percent Moenkopi fragments as much as 2 in. across in a siltstone matrix; contains gypsum and iron oxides on bedding surfaces	1.0
Total Shinarump member	10.0

Unconformity (erosional disconformity with relief in the immediate vicinity less than 3 ft).
Moenkopi formation.

Section of the Shinarump member of the Chinle formation in Blue Canyon 3 miles north of the Chocolate Drop

Mudstone-sandstone unit of the Chinle formation (lowest beds are light-gray siltstone).

	Thickness (feet)
Shinarump member:	
Sandstone, grayish-orange (10*YR* 7/4), medium-grained; laminae average 1 in. thick; consists of 57 percent quartz grains without overgrowths, 30 percent clay matrix, 5 percent jarosite, 5 percent carbonaceous seams, and 3 percent iron oxides. Joint surfaces coated with desert varnish. Forms a slope	16.0
Sandstone, pale-greenish-yellow (10*Y* 8/2), fine-grained; cross laminae average half an inch thick, dip 8° northwestward; consists of 77 percent subround quartz grains, 20 percent clay matrix, 2 percent carbonaceous streaks, and less than 1 percent iron oxides	6.0
Total Shinarump member	22.0

Unconformity (erosional disconformity with relief in the immediate vicinity less than 2 ft).
Moenkopi formation.

Sedimentary structures in the Shinarump member include cross-stratification, contorted strata, and current lineation. Cross-stratification is very common in the Shinarump, though horizontal and structureless strata also are present. The cross-stratification consists dominantly of lenticular trough sets and subordinate wedge-shaped planar sets. The trough sets have been produced by channeling of the underlying beds and subsequent deposition. The direction of dip of the cross-stratification in the lower beds is different from that in the upper beds of the Shinarump member in some places, suggesting a shift in the stream direction during the period of deposition.

Planar cross-stratification is common in conglomerate and in sandstone that overlies siltstone beds, especially in the lower part of the Shinarump member. The direction of dip of planar cross-strata is generally nearly parallel to the direction of plunge of the axes of the trough sets and is in the direction of streamflow. Planar cross-strata in the White Canyon area dip from about 5° to as much as 25° to the northwest.

Contorted strata are common in the Shinarump member, and are believed to have resulted from the collapse of steep channel sides due to water saturation. These slump features occur especially in thin fine-grained sandstone and siltstone beds.

Current lineation (Stokes, 1947) was observed in siltstone and thin-bedded fine-grained sandstone in some places in the Shinarump member. This feature is believed by Stokes to indicate laminar flow. It is the result of a streaming of sand particles in windrowlike ridges parallel to the current direction.

Part of the Shinarump member was deposited as fillings in channels cut into the Moenkopi formation. Most of these channels are within the main belt of Shinarump, though some outlying patches of Shinarump may be channel fillings or may contain them. Seventy-five channels have been mapped in the White Canyon area and their trends are shown on plate 1. These channels range in width from 30 to at least 1,000 feet and in depth from more than 2 to 50 feet. A list of the channels is shown in table 3.

Most of the uranium deposits are in these channels, and the emplacement of the deposits probably was controlled largely by the physical and chemical properties of the sediments that fill the channels.

The dip of cross-stratification and the trend of current lineation indicate that the Shinarump was deposited by northwestward-flowing streams in the western part of the White Canyon area and by southwestward- to westward-flowing streams in the eastern part.

MUDSTONE-SANDSTONE UNIT

The mudstone-sandstone unit of the Chinle is mainly an impure mudstone with many sandstone beds, and is probably correlative, in part, with the Monitor Butte member of the Chinle in northern Arizona. It ranges in thickness from about 120 to 250 feet and contains from less than 1 to 60 percent sandstone. The underlying Shinarump member, the mudstone-sandstone unit, and the overlying Moss Back member together represent a period of virtually continuous deposition in which the deposition of coarse material predominated during the early (Shinarump) and late (Moss Back) stages. The upper beds of the Shinarump member, where it is present, are gradational with the lowermost beds of the mudstone-sandstone unit, and many of the sandstone beds of the Shinarump are similar in texture and composition to sandstone in the mudstone-sandstone unit. Likewise, the Moss Back member, largely sandstone and conglomerate, is similar in physical character to coarse strata in the mudstone-sandstone unit and also to the Shinarump member. It has been separated from the mudstone-sandstone unit by recent changes in nomenclature (Stewart, 1957).

The sandstone beds of the mudstone-sandstone unit are lenticular, and none is extensive throughout the area. One rather persistent sandstone bed occurs locally in an interval between 35 and 130 feet above the base of the Chinle formation, and is often referred to as the "50-foot sand" because of its tendency to occur roughly 50 feet above the base of the formation. This sandstone is represented in lower Blue Notch Canyon and vicinity by a medium-grained micaceous sandstone lens as much as 40 feet thick. It is also represented by thick sandstone lenses on Deer Flat and on Moss Back.

All the sandstone lenses of the mudstone-sandstone unit are "channel sands." They are all cross-stratified in the manner of stream-laid sediments, and contain conglomerate and mudstone splits. Many of these sandstone lenses, like the Shinarump member, locally fill channels cut into the underlying beds.

The composition of the included conglomerate pebbles is highly variable. About 1½ miles northeast of the mouth of Red Canyon is a conglomeratic sandstone about 10 feet above the top of the Shinarump member. Conglomerate pebbles in this sandstone vary, through a distance of only 600 feet along the outcrop, from 40 percent quartz and 60 percent chert to 15 percent siltstone and 85 percent claystone.

Mudstone and claystone occur between the sandstone lenses of the mudstone-sandstone unit of the Chinle. The mudstone and claystone are in thin horizontal laminae in thin beds and are various tints and shades of many colors with grays predominating. Some claystone is sandy. Many of the beds contain montmorillonite clay derived from volcanic material and swell when wet. These beds weather to a frothy surface that resembles popped corn. Other beds contain carbon as spots, disseminated flakes, or thin seams. The mudstone even contains local lenses of coal several feet thick and several hundred feet in lateral extent (fig. 10).

MOSS BACK MEMBER

The Moss Back member of the Chinle formation caps the mudstone-sandstone unit, and locally fills channels cut into it. The Moss Back, like the sandy units in the Chinle beneath it, is not continuous over the area. On Moss Back, the mesa from which the member name was derived, the member is about 200 feet above the base of the Chinle formation and is about 90 feet thick. On Deer Flat (fig. 11) the Moss Back is 160 feet above the base of the Chinle and is 50 to 90 feet thick. At The Gap in Blue Notch Canyon, a thick sandstone lens in the upper part of the mudstone-sandstone unit has filled channels cut deeply into underlying claystone beds and is only 100 feet or so above the base of the Chinle, but is nearly 200 feet thick. Only

FIGURE 10.—Photograph of coal bed in the mudstone-sandstone unit of the Chinle formation near the Four Aces mine. *A*, weathered claystone covered with talus. *B*, 0.3-foot yellowish-gray claystone with white surface efflorescence of water-soluble mineral salts. *C*, 1.6-foot yellowish-brown claystone with much low-grade coal in thin seams along the bedding planes. *D*, 2.1-foot coal bed with gypsum in vertical fractures. Fracture surfaces coated with jarosite. Includes large limestone concretions and has many voids filled, or partly filled, with water-soluble salts, such as starkeyite, hexahydrite, copiapite, and an unknown pale-green mineral which contains more than one-tenth of one percent thallium. *E*, 0.5-foot bright-yellow claystone with low-grade coal as seams along bedding planes. *F*, 1.1-foot bright-yellow claystone. *G*, 0.3-foot light-brown claystone with white surface efflorescence of water-soluble salts. *H*, buff to dark-yellowish-orange claystone.

at those places where the sandstone capping the mudstone-sandstone unit is of considerable thickness, where it is similar to the sandstone which caps Moss Back Butte in physical character, including color, and where its base is near the arbitrarily selected interval of 200 feet

FIGURE 11.—Photograph taken from Deer Flat, looking southwest across White Canyon (beyond line of trees). The Moss Back member of the Chinle formation forms the broad bench followed by road. Moss Back and Tables of the Sun in middle distance.

above the base of the formation, has it been mapped as the Moss Back member in the White Canyon area (pl. 1).

The Moss Back member consists of very pale orange cross-stratified fine- to medium-grained sandstone and a few lenses and thin beds of siltstone and conglomerate. The composition of the conglomerate pebbles is highly variable. Three-fourths of a mile west of Blue Notch the pebbles in a conglomeratic sandstone in the Moss Back are 5 percent limy claystone and 95 percent siltstone. In the central part of Blue Notch Canyon they are 5 percent chert and 95 percent quartzite. Secondary silica is the main cement, although locally calcite also is a cement.

LIMY UNIT

The limy unit of the Chinle formation includes a lower part that is largely claystone and an upper part that is alternating claystone, siltstone, and limestone. These units are approximately correlative with the Petrified Forest member and with the Owl Rock member of the Chinle (Witkind and Thaden, 1963), respectively, in northern Arizona.

The lower part of the limy unit (Petrified Forest member?) is mostly pale-yellow to pale-brown, light-blue, and light-purple claystone. Siltstone and sandstone beds are rare but, where present, are cemented with secondary silica. The whole sequence appears to by very siliceous, for there are abundant silicified logs and concretionary nodules of chalcedony and opal throughout. Only at the base of the sequence is there any large amount of calcite, and it is largely confined to calcite and calcite-barite concretions. Carbonized plant fragments are far from rare, but they are neither so plentiful nor so widely disseminated stratigraphically as they are in the mudstone-sandstone unit. Some beds are bentonitic and swell when wet to a puffy surface, but the sequence, in general, forms gentle hard-surfaced convex slopes.

The upper part of the limy unit (Owl Rock member?) is mostly pale-red beds of claystone and limestone. Near the top the claystone grades upward to siltstone. All the claystone and siltstone beds are very limy, and many contain large patches of crystalline milky-white calcite. Bedding has been distorted in places, particularly in and just above beds of siltstone-pebble conglomerate; however, these are local in extent, as the conglomerate beds are lenticular.

The limestone beds are as much as 20 feet thick. They are pale red to pale reddish purple, with pale-yellow-green spots and streaks. All are clayey and many have rare to abundant small included siltstone pebbles. In places the limestone is a mass of broken, slightly displaced, and rewelded fragments—a limestone breccia.

SANDSTONE-SILTSTONE UNIT

The sandstone-siltstone unit of the Chinle formation is dominantly pale-reddish-brown siltstone, in beds 2 to about 40 feet thick. The laminae are irregular, discontinuous, and about 1 mm thick, and each grades at the top to a paper-thin film of more ferruginous material. Although the lower half of the unit is very calcareous, it stands, as does the upper part of the unit, as alternating cliffs and steep slopes. This unit of the Chinle probably is correlative with the Church Rock member of the Chinle in Monument Valley (Witkind and Thaden, 1963).

At a few places, principally in Moki Canyon and near the Blue Lizard mine in Red Canyon, the upper part of the sandstone-siltstone unit is in a 30- to 40-foot interval of pale to dark grayish- and purplish-red arkosic and conglomeratic sandstone (fig. 12). This interval of rock is sometimes called the Hite bed of Stewart and others (1959). The basal 3 feet or so contains small rounded and angular fragments of reddish-brown siltstone and pinkish limy claystone in quantities as much as 20 percent of the volume of the rock. The matrix is very coarse to granule size poorly sorted angular polished quartz with small quantities of muscovite, feldspar, quartzite, and other accessory grains. This conglomeratic zone grades upward to a medium-grained angular fairly well sorted arkosic and micaceous sandstone that is tightly cemented by secondary silica. This unit appears not to be widely deposited, for it has been reported only from the Clay Hills area south of White Canyon (Thomas E. Mullens,

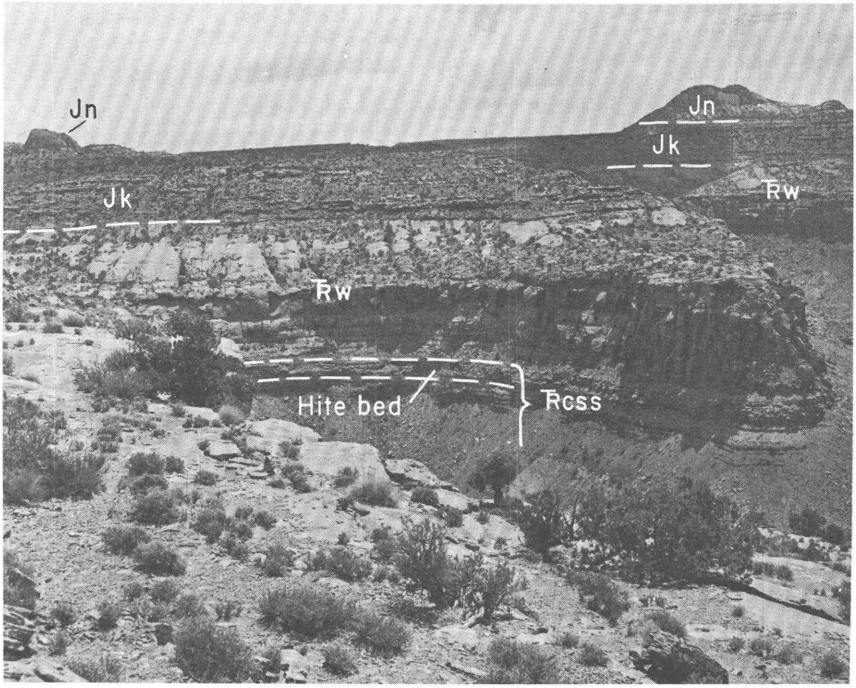

FIGURE 12.—Photograph of north wall of Moki Canyon showing the light-colored slope and underlying cliff of the Wingate sandstone (R̄w), overlain by the ledgy Kayenta formation (Jk), and underlain by a dark knobby cliff of very coarse grained and conglomeratic arkosic sandstone, the Hite bed of Stewart and others (1959), which, where present, is the upper part of the sandstone-siltstone unit (R̄css) of the Chinle formation. Remnants of the Navajo sandstone (Jn) are on the skyline at left and right.

oral commun., 1955) and from the Green River Desert country (Baker, 1946, p. 61). However, rock of somewhat similar physical character has been noted at the same stratigraphic interval in the Marsh Pass, Navajo, Piute Canyon, and Monument Valley areas of northern Arizona (Forrest G. Poole and Richard F. Wilson, written commun., 1957).

The lower and upper contacts of the Hite bed of Stewart and others (1959) are eroded surfaces, the lower one much more pronounced than the upper. Relief of the lower contact is not greater than about 10 inches, and relief of the upper contact appears to be small.

The following partial sections are characteristic of the Chinle formation near where they were measured, but they also illustrate the variable lithology and thickness of the upper part of the Chinle through lateral distances of only a few miles.

732-420 O—64——5

Partial section of the Chinle formation on mesa separating Fry and White Canyons

[Measured by W. E. Benson, 1951]

Wingate sandstone (Triassic). The basal 2-ft bed is cross-stratified very pale orange (10*YR* 8/2) sandstone, grading upward to moderate orange pink (5*YR* 8/4). Laminae are of alternating fine, medium, coarse, and very coarse quartz grains.

Unconformity (slight erosional disconformity).

Chinle formation:

	Thickness (feet)
Sandstone-siltstone unit (Church Rock member?):	
Siltstone, moderate-reddish-orange (10*R* 6/6) to moderate-reddish-brown (10*R* 4/6), laminated to structureless	22.5
Claystone, dark-reddish-brown (10*R* 3/4); grades upward into overlying unit	16.8
Sandstone, clayey and conglomeratic, light-greenish-gray (5*GY* 8/1), coarse-grained; pebbles are mostly green claystone and siltstone as much as 4 in. across. Few cherty limestone fragments	1.4
Claystone, pale-red (10*R* 6/2)	3.8
Siltstone, light-greenish-gray, calcareous	1.0
Siltstone, and claystone, pale-red (5*R* 6/2 to 10*R* 6/2), interstratified. Some of the siltstone is sandy and has conglomerate stringers of chert fragments	38.0
Limestone, silty, light-brownish-gray to greenish-gray, very hard, laminated	1.1
Limestone, greenish-gray, impure; 3 in. thick; grades upward to pale-reddish-brown (10*R* 5/4) very hard calcareous siltstone	9.2
Claystone, slightly silty, pale-red (5*R* 6/2); interstratified with light-green siltstone and light-green cherty hard nodular calcareous limestone	13.1
Siltstone and very fine grained sandstone, moderate-reddish-orange (10*R* 6/6), with light-greenish-gray mottling interstratified in lower half with dark-reddish-brown (10*R* 3/4) claystone. Lower part forms slope; upper part forms cliff	97.0
Total sandstone-siltstone unit (Church Rock member?)	203.9
Limy unit (Owl Rock and Petrified Forest members?):	
Claystone, pale-reddish-brown (10*R* 5/4)	10.5
Siltstone, light-greenish-gray (5*G* 8/1), and light-greenish-gray (5*G* 8/1) very fine grained very hard very calcareous sandstone. Makes resistant cliff	2.1
Siltstone, sandy and clayey, pale-reddish-brown (10*R* 5/4); extensive light-greenish-gray mottling. Forms steep hard rough slope	18.0
Claystone, pale-reddish-brown (10*R* 5/4), with light-greenish-gray mottling. Forms steep hard rubbly slope with thin ledges	11.5
Claystone, pale-red (5*R* 6/2) to pale-reddish-brown (10*R* 5/4); contains a few thin lenses of chert-pebble conglomerate as in unit below. Forms rough hard slope	56.1

Chinle formation: Sandstone-siltstone unit (Church Rock member?)—Continued

Limy unit—Continued	*Thickness (feet)*
Claystone, pale-red, interbedded with claystone, conglomeratic. Conglomerate pebbles are gray and grayish-green chert	3.2
Claystone, pale-red (5*R* 6/2)	15.0
Claystone, slightly silty, light-greenish-gray (5*GY* 8/1), conglomeratic; contains granules of quartz and pebbles of clay, limestone, and sandstone as much as 0.5 in. across; interbedded with silty pale-red (5*R* 6/2) claystone	5.4
Claystone, pale-reddish-brown (10*R* 5/4). Weathers to form smooth hard slope	17.2
Claystone, limy, moderate-reddish-orange (10*R* 6/6), with light-greenish-gray mottling; hard. Forms cliff	2.7
Limestone, clayey, pale-red (5*R* 6/2) with light-greenish-gray mottling: grades into overlying unit. Forms cliff	3.0
Claystone, pale-reddish-brown (10*R* 5/4), becoming purplish in upper 4 ft; light-greenish-gray mottling; hard. Weathers to form hard steep slope	21.4
Claystone, grayish-red-purple (5*RP* 4/2); moderately hard when fresh. Weathers to form soft slope covered by small chips	17.1
Limestone, grayish-red-purple (5*RP* 4/2), with light-greenish-gray mottling; possibly cherty. Contains a few quartz grains, and a few clayballs as much as 0.25 in. across. Forms persistent low cliff. (Base of Owl Rock member?)	2.0
Claystone, slightly silty, pale-red (10*R* 6/2); calcareous. Has hard zone about 15 ft above base. Weathers to hard-surfaced slope	25.2
Sandstone, moderate-reddish-orange (10*R* 6/6); fine-grained at base grading to siltstone at top. Weak calcareous cement. Some zones of calcite(?) concretions	7.7
Claystone, silty in part, pale-reddish-brown (10*R* 5/4) to grayish-red (10*R* 4/2). Has several discontinuous zones of light-greenish-gray sandstone concretions that weather brown	12.4
Sandstone, moderate-pink (5*R* 7/4), flecked with light-greenish-gray. Contains calcite(?) concretions. Weathers brown	.8
Claystone, silty, pale-red-purple (5*RP* 6/2); a few beds are grayish red-purple (5*RP* 4/2) and light brownish gray (5*YR* 6/1). A thin pale-red-purple (5*RP* 6/2) conglomeratic sandstone is about 6 ft above base of unit. Conglomeratic sandstone contains concretions and clayballs. Weathers to hard slope covered with rubble of spherical concretions ("ball bearings")	30.0
Sandstone, light-gray (*N* 7) and yellowish-gray (5*Y* 8/1), fine- to medium-grained; overlain by pale-red-purple (5*RP* 6/2) medium- to coarse-grained slightly conglomeratic sandstone; pebbles of clay, chert, and quartz. Both sandstone sets are poorly sorted, clayey, and are mostly composed of milky quartz and pink, orange, green, and black accessories. Lower sandstone set is poorly cemented and forms slope. Abundant fossil wood and some reptile bone fragments in upper sandstone set. Upper 6 ft of upper sandstone set has alternating very hard and soft beds. Gradational contact zone about 1 ft thick ranges from 12 to 31 ft above the base of the unit. Both sandstone sets are cross stratified	37.4

Chinle formation: Sandstone-siltstone unit (Church Rock member?)—Continued

	Thickness (feet)
Limy unit—Continued	
Claystone, grayish-red (10*R* 4/2) to pale-brown (5*YR* 5/2), with few light-greenish-gray patches; hard; calcareous. Weathers to soft grayish-red slope	14.2
Claystone, grayish-red (10*R* 4/2), with greenish-gray (5*GY* 6/1) mottling; hard; calcareous(?). Weathers to soft grayish-red slope	1.6
Claystone, silty, light-gray (*N* 7); composed of very thin laminae; slight reddish stain on bedding surfaces. Forms slope	2.5
Siltstone, clayey, and light-gray (*N* 7) to greenish-gray (5*GY* 6/1) very fine grained micaceous clayey sandstone; thinly laminated, with some ripple laminae and small-scale cross laminae; consists of milky quartz grains and some pink and black accessories	9.0
Total limy unit (Owl Rock and Petrified Forest members?)	326.0
Moss Back member:	
Sandstone, light-gray (*N* 7) to very pale orange (10*YR* 8/2), medium-grained; cross stratified at base, grading upward to finer grained, horizontally stratified at top. Has local conglomeratic strata made up mostly of chert pebbles. Conglomeratic strata also contain colorless, opaque white, and opaque orange quartz pebbles and green and black accessories. Unit has much fossil wood and greenish-gray clay in the conglomeratic beds. Unit has calcite cement. Forms cliff	51.0
Total Moss Back member	51.0
Mudstone-sandstone unit (Monitor Butte member?):	
Unexposed	20.0
Claystone, mostly nonsilty but with a few silty beds, variegated gray, yellowish-gray, yellowish-green, shades of brown, moderate red-purple, and purplish-gray. Weathers to a frothy surface that suggests presence of montmorillonite clay. At 63 ft above base of unit is a 0.5-ft greenish-yellow sandy limestone	114.4
Sandstone, clayey, dusky-yellowish-green (10*GY* 3/2), medium- to coarse-grained; consists of colorless and yellow clear well-rounded quartz grains. Weathers to dark green and black. Forms cliff	4.3
Claystone, sandy and silty, light-gray (*N* 7); stained yellow in lower 4 ft; has thin grayish-red-purple (5*RP* 4/2) stripes in upper few feet. Contains a few thin limonite rich seams	29.0
Sandstone, dark-olive-green, medium-grained to very coarse grained; grains are rounded; stratification is lenticular and discontinuous. Weathers to dark green and black	1.0
Claystone, slightly sandy and silty, light- to medium-gray; minor pale-red-purple (5*RP* 6/2) mottling. Upper 1 ft has dusky yellow (5*Y* 6/4) surface staining. Weathers to smooth hard slope	24.2
Total mudstone-sandstone unit (Monitor Butte member?)	192.9
Total partial Chinle formation	773.8

Shinarump member of Chinle (Triassic) unmeasured.

Partial section of the Chinle formation three-fourths mile north of the Blue Lizard mine

Wingate sandstone (Triassic). Lowest beds are very fine grained well-sorted poorly cemented moderate-reddish-brown (10*R* 5/6) sandstone.

Unconformity (probable slight erosional disconformity).

	Thickness (feet)
Chinle formation:	
Sandstone-siltstone unit (Church Rock member?; Unit A of Chinle?, Gregory, 1917):	
Hite bed of Stewart and others (1959):	
Sandstone, grayish-red (5*R* 5/2), medium-grained, fairly well sorted; contains common feldspar, quartzite, and muscovite accessory grains; well cemented, siliceous. Forms vertical cliff	37.0
Sandstone, conglomeratic, pale- to grayish-red (5–10*R* 4–6/2), coarse-grained to granule size, very poorly sorted; composed of subangular to round clear colorless polished quartz and minor feldspar and quartzite accessory grains. About 5 percent of unit is angular claystone and clayey siltstone fragments as much as 1 in. long. Grades into overlying unit. Forms vertical massive-weathering cliff	3.0
Total Hite bed	40.0
Siltstone, pale-reddish-brown (10*R* 6/4); has irregular laminae about 1 mm thick. Basal 5 ft of unit is cliff. Other cliffs between 25 to 27, 31.5 to 38.5, and 49.5 to 83 ft above base of unit. Remainder of unit forms slope	83.0
Siltstone, limy; pale reddish brown (10*R* 5/4) in lower 20 ft, purplish in upper 60 ft; coarse grained. Lower 3 ft and interval from 17.5 to 20 ft above base of unit are cliffs. Rest of unit forms slopes	80.0
Total sandstone-siltstone unit (Church Rock member?; Unit A of Chinle?, Gregory, 1917)	203.0
Limy unit (Owl Rock and Petrified Forest members?):	
Owl Rock member? (Unit B of Chinle?, Gregory, 1917):	
Siltstone, limy; like 7.0 ft unit below. Forms slope	5.5
Limestone; like 11.0 ft unit below. Forms cliff	5.5
Siltstone, limy; like 7.0 ft unit below. Forms slope	4.0
Limestone; like 11.0 ft unit below. Forms cliff	15.0
Siltstone, limy, pale-reddish-brown (10*R* 5/3), fine-grained. Forms slope	7.0
Limestone, pale-red (5*R* 5/2), with spots of pale yellowish green (10*GY* 7/2) as much as 0.4 in. across. Has short streaks and spots of colorless calcite. Forms cliff	11.0
Siltstone, limy, pale-reddish-brown (10*R* 5/3). Weathers spheroidally. Forms steep rubbly slope	62.5
Conglomerate, limy-claystone pebble, grayish-red (5*R* 5/2). Forms rubbly cliff	19.5
Conglomerate, limy-claystone and limy-siltstone pebble, pale-grayish-red (5*R* 6/2). Upper 10 ft is grayish red (5*R* 4/2). Pebbles are angular, as much as 1 in. in size, and represent at least 90 percent of the unit. Forms rubbly cliff	42.5

Limy unit—Continued
Owl Rock member—Continued
Chinle formation—Continued

	Thickness (feet)
Claystone, limy; and mottled pale-grayish-green (5*GY* 8/2) and pale-red (7*R* 6.5/2) clayey limestone. Contains about 20 percent pebbles of reddish-brown siltstone as much as 0.5 in. across. Forms rubbly cliff or steep rubbly slope	8.0
Claystone, limy, mottled pale-red (6*R* 6/2) and pale-grayish-yellow-green (5*GY* 8/2). Upper few feet of unit is dark reddish brown (10*R* 3/2). Forms rubbly cliff	38.5
Sandstone, grayish-red (5*R* 5/2), medium-grained, well-sorted; well cemented, ferruginous, and calcareous. Forms cliff	4.0
Claystone, limy, mottled pale-yellowish-green (10*GY* 7/2) and pale-red-purple (5*RP* 7/2). Upper 4 ft is dark reddish brown (10*R* 3/2). Forms rubbly cliff	27.5
Limestone, pale moderate-grayish red-purple (8*RP* 5/3); coarsely crystalline at base of unit grading upward to clayey limestone and limy claystone in beds as much as 3 ft thick. Unit contains abundant nodules of chalcedony and chalcedonized wood. Forms rubbly cliff	18.5
Total Owl Rock member? (Unit B of Chinle?, Gregory, 1917)	269.0
Petrified Forest member? (Unit C of Chinle?, Gregory, 1917):	
Claystone; light purplish brown in upper 30 ft, light purplish gray in lower 16 ft. Swells when wet. Forms slope	55.0
Sandstone, pale-pink (5*RP* 9/1) to pale-yellowish-green (10*GY* 8/1), fine-grained, poorly sorted; poorly cemented, argillaceous and siliceous; contains abundant muscovite, biotite, unidentified platy green mineral, and gypsum. Has abundant carbon fragments as much as 5 by 20 mm in size. Forms cliff	10.0
Claystone, dark-grayish-red (5*R* 3/2), grading in upper 4 ft to yellowish brown (2*Y* 5/3). Forms convex slope	44.0
Claystone, light-blue and light-purple. Lower 5 ft of unit are light-blue claystone which swells when wet. From about 20 to 25 ft above base of unit are thin-bedded light-colored sandstone, sandy siltstone, and siltstone beds which are cemented by silica and which contain concretions of chalcedony, carbonized logs as much as 0.5 ft in diameter, and fractures filled with jarosite and gypsum. Forms gentle convex slope interrupted by ledges	27.5
Siltstone, sandy, moderate-brown (5*YR* 3/3), very fine grained. Unit contains abundant nodules of chalcedony and opal and much chalcedonized wood. Upper 3 ft is a conglomerate of siltstone pebbles cemented by secondary silica. Pebbles are as much as 5 in. across. Forms steep slope	14.0
Claystone, dark-yellowish-brown (10*YR* 3/2). Contains layers of calcite, barite, and calcite-barite concretions as	

Chinle formation—Continued
Limy unit—Continued
Petrified Forest member—Continued

	Thickness (feet)
much as 4 in. across. Swells when wet. Forms gentle slope	32.0
Total Petrified Forest member? (Unit C of Chinle?; Gregory, 1917)	182.5
Total Limy unit (Owl Rock and Petrified Forest members?; (Units B and C of Chinle?, Gregory, 1917)	451.5
Mudstone-sandstone unit (Monitor Butte member?; Unit D of Chinle, Gregory, 1917):	
Top of beds possibly correlative with part of the Moss Back member:	
Sandstone, clayey and silty; and claystone, silty, yellowish-gray (5*Y* 6–8/2), fine- to medium-grained, poorly sorted; composed of subround grains of clear colorless polished quartz and common muscovite and biotite; principal cement is abundant overgrowth of secondary silica. Lower 20 ft of unit is principally sandstone in beds as much as 6 ft thick. Upper 19 ft is interbedded sandstone and claystone. Forms cliffs and steep ledgy slopes	39.0
Total of beds possibly correlative with Moss Back member	39.0
Claystone, dark-grayish-red (2*R* 3/2), mottled with light-bluish-gray spots. Upper 5 ft is very dark grayish red. Swells when wet. Forms steep slope	58.0
Claystone, light-bluish-gray (5*B* 7/1), grading in upper 5 ft to bluish gray (5*B* 5/1). Swells when wet. Forms steep rubbly slope	25.5
Claystone, dark-purple; swells when wet; grades with overlying unit. Forms slope	2.0
Sandstone, limy and clayey, yellowish-gray (5*Y* 6/2), fine-grained; contains minor muscovite. Forms cliff	8.0
Claystone, carbonaceous, light-gray to very dark gray (*NY*3–7), grading near top to yellow and red highly ferruginous claystone. Carbon is in paper-thin flakes in seams parallel to bedding. Forms steep convex slope	5.0
Sandstone, limy, medium-gray (*N* 5), with patches of reddish-gray, fine-grained; grades laterally to yellow claystone. Grades in upper half of unit to light-green, light-blue, light-purple, and black claystone. Claystone swells when wet. Forms cliff at base, steep slope at top	9.8
Claystone, gray to brown; basal 4.5 ft is in places purple. Unit grades to yellowish-gray (5*Y* 7/2) in upper 4 ft. Unit contains gypsum in bedding partings and in low-angle fractures. Forms steep slope	8.5
Limestone, olive-gray (5*Y* 4/1); contains very small pyritic nodules disseminated throughout. Forms cliff	.4
Claystone, medium-light-gray (*N* 6); swells when wet. Forms steep slope	1.5

	Thickness (feet)
Chinle formation—Continued	
Mudstone-sandstone unit (Monitor Butte member?; Unit D of Chinle, Gregory, 1917)—Continued	
Carbon seam; has vertical and low-angle fractures and bedding partings filled with jarosite and gypsum	0.3
Claystone, medium-gray (*N* 5); contains gypsum-filled fractures. Swells when wet. Forms steep slope with rubbly surface	5.0
Sandstone, silty, light-olive-gray (5*Y* 5/2), fine-grained, poorly sorted; contains abundant muscovite and biotite flakes in bedding planes, and minor calcite; well cemented, argillaceous; very thin to thin lenticular trough sets of low-angle cross-strata and thin ripple-laminated sets: flaggy splitting. Forms series of benches	8.0
Total mudstone-sandstone unit (Monitor Butte member?, Unit D of Chinle, Gregory, 1917)	171.0
Total partial Chinle formation	825.5
Shinarump member of Chinle (Triassic). Unmeasured.	

Partial section of the Chinle formation near the Happy Jack mine

Wingate sandstone (Triassic).

Lowest beds are very fine grained cross-stratified reddish-brown (10*R* 5/6) sandstone.

Unconformity (probable erosional disconformity).

	Thickness (feet)
Chinle formation:	
Sandstone-siltstone unit:	
Sandstone, grayish-orange-pink (5*YR* 7/2), fine-grained; composed of quartz grains and pale-green and black accessory grains. Forms vertical cliff	1.5
Conglomerate, limy siltstone pebble, dark-reddish-brown (10*R* 3/4). Contains a few laminae of fine-grained sandstone. Forms vertical cliff	1.0
Siltstone, pale-red (5*R* 6/2); poorly exposed; forms a slope	24.0
Sandstone, pale-red (5*R* 6/2), very fine grained; laminae about half an inch thick. Forms poorly exposed slope	17.5
Sandstone, pale-red (5*R* 6/2), very fine grained; thinly laminated; composed of quartz grains and abundant pale-green and black accessory grains. Contains a bed, 6 in. thick, of light-greenish-gray (5*GY* 8/1) very fine grained sandstone. Forms a cliff	17.0
Sandstone, pale-reddish-brown (10*R* 5/4), very fine grained. Top 3 in. is a mottled pale-yellowish-green (10*GY* 7/2), pale-red (10*R* 6/2), and dark-greenish-yellow (10*Y* 6/6) claystone. Forms a narrow bench	6.5
Sandstone, grayish-orange-pink (10*R* 8/2), very fine grained; laminae 2 to 4 in. thick. Contains patches of light-greenish-gray (5*GY* 8/1) very fine grained sandstone. Forms a cliff	10.5
Siltstone, limy, pale-reddish-brown (10*R* 5/4); contains a few thin beds (average 2 in. in thickness) of light-greenish-gray (5*GY* 8/1 siltstone. Weathers to spheroidal fragments, 8 in. across, near the top. Grades into the unit above. Forms a slope	4.0

Chinle formation—Continued Sandstone-siltstone unit—Continued	*Thickness (feet)*
Siltstone, limy, pale-reddish-brown (10*R* 5/4); parallel laminae one-fourth inch thick. Individual sets as much as 4 ft thick. Slabby parting near both top and bottom. Forms a cliff	6.0
Siltstone, limy, interbedded pale-red (5*R* 6/2) and light-greenish-gray (5*GY* 8/1); laminae 1 to 3 in. thick. Forms a steep slope	11.0
Siltstone, limy, pale-red (10*R* 6/2); contains irregular patches of light-greenish-gray (5*GY* 8/1) siltstone and stringers of red iron oxides. Forms a cliff	5.5
Siltstone, limy, pale-reddish-brown (10*R* 5/4). Weathers both to spheroids as much as 10 in. across and to angular to subangular fragments as much as 3 in. across. Forms a slope	1.0
Total of sandstone-siltstone unit	105.5
Limy unit:	
Siltstone, limy, light-greenish-gray (5*GY* 8/1); bottom of bed gradational with limy siltstone below. Forms a cliff	1.0
Siltstone, limy, light-greenish-gray. Top 3 in. thinly laminated with laminae surfaces coated by a pale-green clay mineral. Weathers into spheroidal masses as much as 6 in. in diameter. Forms a slope	1.0
Claystone, limy, moderate-reddish-orange (10*R* 6/6); upper 5 ft is pale red, (10*R* 6/2). Weathers into small fragments 1 in. across. Forms a slope	43.0
Limestone, grayish-yellow (5*Y* 8/4), and interbedded pale-red (10*R* 6/2) limey siltstone. Forms a slope	11.0
Claystone, pale-reddish-brown (10*R* 5/4). Forms a slope	11.5
Limestone, silty, grayish-yellow-green (5*GY* 7/2). Forms a slope	1.0
Claystone, limy, pale-red (10*R* 6/2). Forms a slope	6.0
Conglomerate, limestone-pebble, light-greenish-gray (5*GY* 8/1). Limestone pebbles ⅛ to 1½ in. in diameter comprise 70 percent of the rock	.5
Claystone, pale-red (10*R* 6/2). Forms a slope	4.5
Mudstone, light-greenish-gray (5*GY* 8/1); contains pebbles of fine-grained sandstone 3 in. in diameter. Forms a cliff	3.0
Claystone, pale-red (10*R* 6/2) and grayish-yellow-green (5*GY* 7/2). Forms a slope	35.0
Claystone, pale-red (10*R* 6/2) and grayish-yellow-green (5*GY* 7/2); contains 2 thin beds of light-gray (*N* 7) very fine grained sandstone, about 5 in. thick. Forms a cliff	12.0
Claystone, pale-red (10*R* 6/2) and grayish-yellow-green (5*GY* 7/2). Forms a slope	31.0
Limestone, mottled pale-red (5*R* 6/2) and greenish-gray (5*GY* 6/1). Contains calcite in lenses 1 in. long and irregular masses of pale-blue chert one-fourth of an inch across. Calcite coats bedding surfaces in upper 3 ft. Forms a cliff	9.0
Claystone, limy, pale-red (10*R* 6/2) and grayish-yellow-green (5*GY* 7/2); forms a slope	25.0

	Thickness (feet)
Chinle formation—Continued	
Limy unit—Continued	
Limestone, light-brownish-gray (5*YR* 6/1), very finely crystalline; contains intercalated claystone. Weathers into rounded fragments. Forms a slope	8.0
Claystone, pale-red (10*R* 6/2) to grayish-yellow-green (5*GY* 7/2). Forms a slope	47.0
Limestone, light-greenish-gray (5*GY* 8/1) and pale-red (5*R* 6/2), granular. Contains limestone and green claystone pebbles. Forms a cliff	1.0
Claystone, pale-red (5*R* 6/2). Forms a cliff	4.5
Covered; slope	24.0
Total of limy unit	279.0
Moss Back member:	
Sandstone, yellowish-gray (5*Y* 7/2), very fine grained; beds 6 to 18 in. thick. Forms a series of ledges	22.0
Sandstone, yellowish-gray (5*Y* 7/2), very fine grained; beds 3 to 15 in. thick; contains a few pebbles of white to gray claystone. Forms a cliff	11.5
Conglomerate, limy claystone-pebble and quartzite-pebble, pale-greenish-yellow (10*Y* 8/2) and pale-red (6*R* 6/2). Contains abundant limonite replaced wood fragments. Forms a cliff	2.0
Sandstone, limy, very pale orange (10*YR* 8/2), fine-grained; with calcite cement; composed mainly of quartz grains with a few green accessory minerals; thinly laminated. Forms a cliff	4.5
Total of Moss Back member	40.0
Mudstone-sandstone unit:	
Mudstone, gray. Mainly covered. Forms a slope	36.0
Sandstone, silty: grayish-red (5*R* 4/2); contains dark-green streaks of concentrated mafic accessory minerals and patches of claystone. Forms a cliff	.3
Mudstone, gray. Mainly covered slope	10.0
Sandstone, fine-grained, grayish-orange-pink (5*YR* 7/2); cross laminae one-eighth inch thick. Forms a cliff	2.0
Sandstone, grayish-orange-pink (5*YR* 7/2), fine-grained; interbedded with dusky-brown (5*YR* 2/2), claystone- and siltstone-pebble conglomerate. Conglomerate contains limonitized wood fragments. Forms a cliff	2.5
Mudstone, gray. Mainly covered slope	26.0
Sandstone, yellowish-gray (5*Y* 7/2), fine- to medium-grained, with interbedded claystone-siltstone pebble conglomerate. Abundant iron oxides in conglomerate. Forms a cliff	5.0
Sandstone, pale-greenish-yellow (10*Y* 8/2), fine-grained to very fine grained. Contains quartz grains and a few pebbles of white and pale-green claystone and 1 bed of pale-red (5*R* 6/2) limy siltstone-pebble conglomerate 4 in. thick	1.0
Covered; slope	6.5
Sandstone, speckled very pale orange (10*YR* 8/2) and olive-gray (5*Y* 3/2), very fine grained; cross laminae ⅛ to ½ in. thick. Forms a slope	5.5

Chinle formation—Continued Mudstone-sandstone unit—Continued	*Thickness (feet)*
Sandstone, speckled very pale orange (10*YR* 8/2) and olive-gray (5*Y* 3/2), very fine grained, cross-stratified; composed of quartz and chert grains and a few dark green accessory grains and contains silicified wood fragments. Unit contains lenses of limonitic clay-pebble conglomerate	2.0
Mudstone, light-gray (*N* 7); poorly exposed on slope	37.0
Sandstone, white (*N* 9) to medium-gray (*N* 5) very fine grained; cross laminae one-fourth of an inch thick; contains abundant clay matrix	10.0
Mudstone, gray; poorly exposed on slope	31.5
Conglomerate, limestone-pebble and claystone-pebble, very light gray (*N* 8) to medium-gray (*N* 5). Consists of 80 percent gray limestone pebbles 1/32 to 1 in. across, 5 percent white claystone pebbles one-sixteenth of an inch across, and 15 percent calcite cement	1.0
Limestone, pale-olive (10*Y* 6/2), finely crystalline; contains patches of white calcite rimmed with light-brown calcite	.5
Mudstone, gray; poorly exposed on slope	7.0
Total of mudstone-sandstone unit	183.8
Total of partial Chinle formation	608.3
Shinarump member: (Unmeasured).	

Thickness of the Chinle formation in the White Canyon region ranges from about 610 to 630 feet near the mouth of Red Canyon and near the Happy Jack mine to about 850 feet in upper Red Canyon. Its average thickness is about 780 feet in the southern and eastern parts of the area and tends to thin north and west. It ranges in thickness from 800 to 1,000 feet in the region south of White Canyon (Gregory, 1938, p. 50; Witkind and Thaden, 1963), and thins rather rapidly north and west of White Canyon to 265 feet at Temple Mountain (Baker, 1946, p. 62) and 350 feet at Capitol Reef (Hunt, and others, 1953, p. 55).

The contact of the Chinle formation and Wingate sandstone is sharp in the White Canyon area, but in some places it is hard to locate, especially where the arkosic unit (Hite bed of Stewart and others, 1959) of the upper part of the Chinle is missing. Not only does the reddish-brown siltstone of the Chinle contrast little with the reddish-brown sandstone of the Wingate, but there are many places where the Chinle evidently has been reworked and some material has been incorporated into irregularly laminated strata at the base of the Wingate. These strata resemble the even-stratified Chinle formation more than the typically cross-stratified Wingate.

The contact between the Chinle and Wingate has a local relief of a few inches except where the formations intertongue. In the vicinity of Blue Notch there are two places where a tongue of siltstone of the

Chinle projects into the Wingate to the north or east. Each tongue is about 10 feet thick and more than 150 feet long. About 10 feet of Wingate underlies each tongue.

TRIASSIC AND JURASSIC SYSTEMS

GLEN CANYON GROUP

The Glen Canyon group of Triassic and Jurassic age is named from Glen Canyon of the Colorado River, situated just west and south of the White Canyon area. In the type area, as in White Canyon, the group consists of three formations. The basal formation is the Wingate sandstone of Triassic age, the middle formation is the Kayenta formation of Jurassic(?) age, and the upper formation is the Navajo sandstone of Jurassic and Jurassic(?) age. The 3 formations stand together as a nearly vertical cliff more than 1,000 feet high along the major drainages and form the extensive uplands in the southwestern part of the area. The uplands are deeply incised, not only by streams, but also along joints. Large areas are covered with unconsolidated dune sand.

The total thickness of the group is about 1,200 feet in Red Canyon, the only place in White or Red Canyons where the entire group is exposed. The thickness probably increases to the west, because Gregory (1938, pl. 7) gives a thickness for the Navajo sandstone of more than 1,600 feet at the mouth of Moki Canyon, just southwest of the area, and a thickness of the Navajo of about 2,280 feet (Gregory, 1950, p. 83) in Zion Canyon, farther to the west. Sections measured by Hunt and others (1953, p. 57–60) in the Henry Mountains are only slightly thicker than the Red Canyon section, and in the Green River Desert country the Glen Canyon group is thinner by only 100 to 200 feet, owing to thinning of the Navajo sandstone to the north (Baker, 1946, p. 64–69). As far south as northeastern Arizona, the group is nearly identical in thickness and in lithology to that in the White Canyon country.

WINGATE SANDSTONE

The Wingate sandstone, the lowest formation of the Glen Canvon group, probably is the most striking single formation in the White Canyon region. It forms an unscalable vertical cliff 300 feet high along the southwest side of White Canyon and on both sides of Red Canyon. A wall of Wingate effectively hides Red Canyon (pl. 1) and makes its access from White Canyon difficult. The principal landmarks of the area, Jacobs Chair, the Tables of the Sun, Moss Back Butte, the Bears Ears (just east of White Canyon), and the walls of Moki Canyon are all of Wingate sandstone.

The Wingate sandstone is dominantly a pale-reddish-brown (10*R* 6/4) fine-grained fairly well sorted quartz sandstone. The average grain size is about 0.2 mm. Some beds contain coarse grains, either dispersed or in layers. Thin discontinuous layers of silty sandstone, somewhat darker than the main body of the rock, are common in the planes of stratification. The grains are polished, angular to subround, coated with iron oxides, and are well cemented by secondary silica. The formation is slightly calcareous nearly everywhere. Rare muscovite is the only notable accessory mineral.

Bedding planes in the Wingate sandstone are 3 to 100 feet apart, and most strata show sweeping high-angle cross-stratification. The Wingate fractures conchoidally in places through the entire thickness of the formation. New rockfalls from the cliff can be differentiated from the old by the amount of desert varnish which accumulates on and darkens stable outcrops.

The following section is typical:

Section of the Wingate sandstone on the north side of Moss Back Butte

Kayenta formation (Jurassic?); basal bed is a conglomerate of limestone pebbles in a matrix of coarse-grained sandstone 3 ft thick. The pebbles are as much as 3 inches in diameter. This basal bed fills cracks in the surface of the Wingate. The conglomerate lenses grade laterally into even-bedded moderate reddish-brown (10*R* 6/6) very fine grained poorly cemented slightly calcareous sandstone.

Local scour surface with as much as 10 ft of relief.

Wingate sandstone:	*Thickness (feet)*
Sandstone, silty, moderate-orange-pink (10*R* 7/4) to moderate-reddish-orange (10*R* 6/6); contains patches of lime-cemented pebbles in some places, the lime cement composing as much as 40 percent of the volume of the rock. Unit is horizontally stratified in beds about 3 ft thick. Unit includes several beds of moderate-reddish-brown (10*R* 4/6) to moderate-reddish-orange (10*R* 6/6) very fine grained sandstone which are more friable, less calcareous, and contain more silt-sized particles than the main part of unit. Forms cliff	24.0
Sandstone, moderate-reddish-orange (10*R* 6/6) to moderate-reddish-brown (10*R* 4/6), very fine grained; thinly laminated (one-sixteenth of an inch), cross stratified with dip directions variable but mostly southeast; the sandstone is clean, and contains minor amounts of mafic accessories; slightly calcareous; quartz grains are subangular and have unstained surfaces. Lower half of unit forms series of cliffs, upper half of unit forms slope	61.6
Sandstone, light-brown (5*YR* 5/6), very fine grained; contains as much as 80 percent limy sandstone concretions as much as three-eighths of an inch in diameter; cross stratified in sets 2 to 6 ft thick; concretions contain calcite and much black mafic accessories. Beds grade from pure sandstone to sandstone containing limy sandstone concretions. Sandstone is friable, poorly cemented, and poorly sorted. Forms cliff	152.8

	Thickness (feet)
Wingate sandstone—Continued	
Sandstone, moderate-reddish-orange (10*R* 6/6), very fine grained; thinly laminated (one-sixteenth of an inch); cross-strata dip as much as 25° southeastward; sets of cross-strata are 3 to 6 ft thick; well sorted; friable, with no cement visible; quartz grains are subround to round. Unit contains 0.5 percent mafic accessory minerals. Forms cliff	34.1
Sandstone, moderate-reddish-orange (10*R* 6/6), very fine grained to coarse-grained. Unit contains scattered coarse quartz grains and thin layers of coarse and medium grains. Unit is moderately calcareous in places. Forms cliff	27.5
Sandstone, yellowish-gray (5*Y* 8/1) to pinkish-gray (5*YR* 8/1), very fine grained to coarse-grained. Unit contains thin layers of coarse to medium grains. Forms cliff	4.0
Total Wingate sandstone	304.0
Chinle formation (Triassic).	

The Wingate sandstone ranges in thickness from about 280 to about 320 feet in the White Canyon area. Regional trends of thickening are not apparent. Variations in thickness are erratic and may be due largely to local disconformities at the lower and upper contacts, to intertonguing between the Wingate and the Chinle formations, or to lateral gradation or intertonguing between the Wingate and the Kayenta formations.

Contact of the Wingate sandstone with the overlying Kayenta formation is in places gradational, in other places an intertonguing relationship, and in still other places a sharply defined scour surface having a relief of several feet. Where the contact is not gradational, the uppermost Wingate may be bleached for a few inches. The overlying basal beds of the Kayenta are generally coarser grained and darker than the Wingate.

KAYENTA FORMATION

The Kayenta formation, the middle formation of the Glen Canyon group, is a sequence of lenticular sandstone beds. The beds range in thickness from 10 to 40 feet. Some beds form cliffs and others form slopes. The outcrop, in most areas, is marked by unscalable cliffs as much as several miles long that are separated laterally by steep slopes. To climb through the formation requires much traversing. Where it forms the caprock, as on the divide between White and Red Canyons, and over much of the Red Rock Plateau (Mancos Mesa), the Kayenta shelves back a considerable distance from the underlying cliff formed of the Wingate sandstone. Where it crops out on a cliff involving all the Glen Canyon group, it forms only a minor offset in the rock wall (fig. 12). Many of the units are cross-stratified at low angles, others are even bedded, and a few are structureless.

The grain size of the Kayenta formation is somewhat larger than that of the enclosing formations, ranging in size from 0.1 to 0.3 mm or more and averaging near the higher figure. The grains are angular to subangular clear colorless quartz, but minor to abundant iron oxide stain gives the rock a pale-red to grayish-red (5–10*R* 5–6/2) color with a distinct purplish cast. Sorting is poor. Accessory minerals are muscovite, feldspar, minor calcite, and secondary silica. Silica is the principal cement in the Kayenta, as in the Wingate sandstone, but the cementation is, in general, much weaker. Several beds contain streaks and seams of claystone and siltstone, and some beds are conglomeratic. The pebbles range from sparse disseminated granules of highly ferruginous siltstone to abundant round claystone and limestone pebbles as much as 3 inches in diameter concentrated in layers. The pebbles are concentrated near or at the base of the formation.

The normal thickness of the Kayenta formation in the White Canyon region is about 225 feet. It thickens to about 300 feet in the northwestern part of the area, but it maintains a thickness of 185 to 250 feet for many miles to the south. It thins eastward and southeastward and is only about 45 feet thick on Comb Ridge at the Utah-Arizona border.

Contact of the Kayenta formation with the overlying Navajo sandstone is gradational and intertonguing. In places, more than 100 feet of section may be questionably assigned to one formation or the other. Although the Kayenta long has been considered to be of fluvial origin and the Navajo of eolian origin, the bedding of each formation assumes, in places, the normal character of the other in the vicinity of the contact. Some of the lower beds of the Navajo are horizontally or irregularly stratified, whereas some of the upper beds of the Kayenta have high-angle large-scale tangential cross strata. In general, the contact drawn in the White Canyon area is at the bottom of the lowest bed showing high-angle large-scale cross-stratification, above which there are few, if any, coarse-grained dark-colored lenticular sandstone beds with intercalated claystone and siltstone seams.

NAVAJO SANDSTONE

The Navajo sandstone is the upper formation of the Glen Canyon group. Where it is exposed in its entire thickness, it forms a massive unscalable vertical cliff more than 600 feet high. It is extensively exposed on the uplands of the Red Rock Plateau (Mancos Mesa) in the southwestern part of the White Canyon area, where it weathers to large rounded knobs (fig. 12).

Strata at the base of the formation tend to be flat bedded, and the laminae are less than 1 inch thick. The beds are a few feet to 20 feet thick and are tabular. A thick middle part of the formation is a sequence of composite sets bounded by planar surfaces of erosion a few feet to more than 300 feet apart vertically. The lowest sets of each composite set are horizontally stratified and are tabular. These are succeeded upward by sets of increasingly large-scale steeply inclined trough-type crossbeds. Laminae within the trough-type beds are 1 to several inches thick. The top 30 to 40 feet of the formation tends to be horizontally stratified. Stratification near the top is indistinct, and the beds are tabular.

The Navajo sandstone is yellowish gray (5*Y* 8/2) to very pale orange (10*YR* 9/2), and near the top becomes reddish orange (10*R* 7/6). It is very fine to fine grained and very well sorted. The quartz grains are mostly round, although there are many broken grains. All grains are frosted and have a coating of secondary silica. The grains range in size from 0.1 to about 0.25 mm. Accessory minerals are rare; only a few magnetite, feldspar, chalcedony, and zircon grains were noted. The rock is lightly colored by iron oxides. There is only a little calcite and it is not a cementing agent; the only cement is secondary silica and it cements the rock weakly.

In Red Canyon the Navajo sandstone is 634 feet thick. This thickness is about the same as to the northwest, to the south, and for some distance to the east. It is known to thicken rapidly to the southwest (p. 70).

The contact of the Navajo sandstone with the overlying Carmel formation of Jurassic age is sharp and planar at those few places where it can be seen. Many of the beds in the upper 30 to 40 feet of the Navajo are even bedded and are slightly darker than normal, suggesting temporary inundations in places near the end of the time of the deposition of the Navajo and just before the main advance of the Carmel sea. No relief was seen at the contact, which is marked by an abrupt color and grain-size change.

JURASSIC SYSTEM

SAN RAFAEL GROUP

The White Canyon area has a cover of Jurassic rocks of the San Rafael group whose areal extent is just in excess of 1 square mile. These rocks are exposed as three small erosion remnants on the Red Rock Plateau (Mancos Mesa) in the southwestern part of the area and as two large erosion remnants on the west side of the Colorado River northwest of the mouth of Red Canyon. The remnants are low, nearly flat topped areas bounded by ledgy slopes. They are in striking contrast to the surrounding areas of deeply and steeply incised Navajo sandstone. The contrast is strengthened by an abrupt change in color; the Navajo sandstone is nearly white, whereas most of the rocks of the San Rafael group are red.

The two large remnants expose the entire thickness of the basal formation of the San Rafael group, the Carmel formation, and the lower part of the overlying Entrada sandstone. The Carmel has three distinctive lithologic units. The lower unit is a fine-grained to very fine grained reddish-brown (2*YR* 5/6) silty sandstone which forms a slope. The lower part of this unit is horizontally laminated and the upper part is irregularly laminated. Small thin streaks of dark-reddish-brown siltstone are common on the lamination planes. The middle unit is pinkish brown to grayish orange and forms a cliff about 15 feet high. It is a fine-grained well-sorted sandstone. The upper unit is like the lower except that it is slumped in some places, distorting the bedding to shallow open folds having a few feet of relief.

Overlying the Carmel formation with comformable, and in places gradational, contact is the basal part of the Entrada sandstone. It consists of a sequence of thin- to thick-bedded white to reddish-brown silty and clayey sandstone beds which stand as a series of low cliffs separated by short shallow slopes and flats. In general, the white and yellowish-brown beds form the cliffs. Low-angle tangential cross-strata are present in most of the sets, but some are structureless. The sets are lenticular and tabular.

The greatest thickness of rocks of the San Rafael group which are exposed on the erosion remnants is about 200 feet. Photogrammetric measurements indicate a thickness of the Carmel formation of about 107 feet. The upper 90 feet, or so, of the exposed rocks of the San Rafael group is the basal part of the Entrada sandstone.

QUATERNARY SYSTEM

Quaternary deposits in the area include landslides, talus breccia, sand dunes, gravel, lake beds, colluvium, tufa, and alluvium. The oldest of these probably are Pleistocene in age.

LANDSLIDES

Landslides are confined largely to the steep slopes of the Chinle formation beneath the cliffs formed of the Wingate sandstone. They extend locally to the base of the Chinle. They are especially well developed along the south side of Red Canyon. Many of the landslides are surrounded and covered by talus, and some of them partly overlap other landslides. Some of these overlapping landslides are indistinguishable and have been mapped as single slides. Most individual landslide blocks are 1/8 to 1 mile long and several hundred feet wide, but the largest is 1½ miles long and half a mile wide.

Most of the landslides are composed of Wingate sandstone and the upper part of the Chinle formation. The bedding commonly is preserved, and commonly dips toward the cliff face. Dips range from a few degrees to more than 30°.

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TALUS BRECCIA

Talus breccia covers many of the slopes of the Chinle formation, concealing much of the upper part of the formation. Thinner and less continuous talus breccia has accumulated locally on the slopes of the Organ Rock member of the Cutler formation; most of these are too small to be shown on the geologic map. A few large bodies of talus breccia have accumulated in the Cedar Mesa sandstone member of the Cutler formation in Dark Canyon and along the Colorado River. Some landslides are covered by it, and some areas mapped as talus breccia may actually be partially disaggregated landslides. In general, the talus breccia contains a more finely comminuted and heterogeneous assemblage of rock fragments than do the landslides; also it contains no preserved stratification, except in individual fragments.

Some of the talus breccia is tightly cemented by carbonate, especially beneath the cliff formed of the Hoskinnini member of the Moenkopi formation near the head of Fry Canyon. Recent erosion has formed gullies in many of these consolidated cones of talus breccia sculpturing many small erosion remnants such as demoiselles. Erosion has removed most of the talus breccia in the western part of White Canyon, leaving a boulder here and there balanced atop another boulder or atop a pedestal of sandstone.

SAND DUNES

Sand dunes have been deposited locally on the tops of some of the plateaus and terraces and along the floors of some of the washes. The largest dunes are longtiudinal dunes on the top of the Red Rock Plateau (Mancos Mesa) south of Red Canyon; patches of sand in this area are as much as 3 miles long and more than 1 mile wide. Smaller dunes have been deposited on the floors of White Canyon and Red Canyon, especially in the western part of the area, and on the flats formed on the Cedar Mesa in the northern part of the area. Thin sheets of sand occur in many places in the area, but are not shown on the map.

GRAVEL

Gravel, presumably of Quaternary age (Gregory, 1938, p. 63), lies on many of the rock-cut terraces along the Colorado River and in the lower reaches of White and Red Canyons. These terraces represent two or more ages. The older, higher deposits rest upon terraces cut in the Moenkopi formation near the village of White Canyon and in the Moenkopi and the lower part of the Chinle formation near the mouth of Red Canyon. These terraces are as much as 300 feet above the Colorado River. Lower gravel terraces rest upon the Cutler formation along the river in the extreme northwestern part of the area, upon the Moenkopi from Hite to the mouth of Red Canyon, and upon the Chinle south of Red Canyon.

The deposits range from 1 foot to as much as 50 feet in thickness. The thickest known deposits are seen from Utah State Highway 95 where it crosses them northeast of the village of White Canyon. The gravel at this location remains as mounds in an abandoned meander of the Colorado River. The material ranges from less than 1 inch to boulders 1 foot in diameter, and consists of sandstone, quartzite, limestone, and various kinds of porphyries and other crystalline rocks, presumably from the Abajo Mountains, the Henry Mountains, and perhaps the La Sal Mountains. The pebbles, cobbles, and boulders are well rounded; many of them are tabular. Cementation is well developed at three localities: namely, along the Colorado River 1¼ miles north of Hite; on the mesa, capped with Moenkopi, three-fourths mile northeast of the village of White Canyon; and at the spring in Red Canyon 2¼ miles east of its mouth. At these places the gravels are cemented by calcareous tufa.

LAKE BEDS

Lacustrine deposits have been formed in an abandoned meander of the Colorado River 2 miles east of the village of White Canyon. The water probably was impounded by landslides (pl. 1) from what is now the south side of White Canyon. The creek in the bottom of White Canyon flows in part of this old meander. The lake deposits are about 30 feet thick and consist of thinly laminated partly consolidated silt and very fine sand.

COLLUVIUM

Colluvium, as mapped in the White Canyon area, consists of fine to coarse debris not strictly classifiable as talus, landslide, or gravel. Much of the colluvium has been deposited upon pediment surfaces, some of which have rather steep slopes. The material consists mainly of silt and sand and of admixed pebbles, cobbles, and boulders. Part of it has been deposited by gravity, although some no doubt was transported by water and by wind. Most of it could be considered slope wash of fine-grained reworked talus breccia. Some deposits of colluvium are overlain by dune sand, and many grade into windblown sand deposits.

TUFA

Calcareous tufa has been deposited on the bench formed on the Moenkopi formation overlooking the east side of the White Canyon landing strip, on the west bank of the Colorado River north of the landing strip, and on the surface of the Moenkopi above the warm spring near the mouth of Red Canyon. It also has been deposited, and may now be depositing, at the warm springs—some of which smell strongly of sulfur dioxide—near the mouth of Dark Canyon.

Much of these deposits is a cementation of talus or of alluvium and sand, although moderate quantities of relatively pure moderately porous light-gray to pale-yellow tufa have been found.

ALLUVIUM

Alluvium occurs along the Colorado River and along many of the canyons in the area. It ranges in thickness from a thin veneer along the canyon bottoms to tens of feet along the Colorado River. Most of the alluvium shown on the geologic map is made up of silt- and sand-sized particles containing subangular to round pebbles, cobbles, and boulders. Boulders are strewn along nearly all the canyon floors, and no attempt has been made to map these small accumulations.

STRUCTURE

The White Canyon area is on the west flank of the Monument upwarp (fig. 1). The beds have a regional dip of 2° to 3° westward, and strike generally north. The Monument upwarp has been described by Gregory (1938, p. 85–86) as the largest structural feature of the San Juan country. Gregory has described the upwarp as follows:

> Beginning 30 miles south of the San Juan River with dips of 8° to 20°, the axis of the Monument upwarp slopes gently upward to the top of Elk Ridge, 30 miles north of the river, then descends with steepened dips into Beef Basin and the valleys tributary to Indian Creek. Throughout its length the crest of the upwarp is poorly marked; over large areas the cap rocks lie nearly flat. The eastern flank is clearly marked by Comb Ridge, a monocline with dips exceeding 50°. The western flank is a region of plateaus and cliffs in which the strata, with dips of ½° to 2°, extend 30 to 50 miles to the Colorado River and continue beyond the river as features of the downwarp in which rest the sediments of the Kaiparowits Plateau.

FOLDS

The White Canyon area is on the gently dipping west flank of the northward-trending Monument upwarp. The regional dip is a fairly persistent 2°, though south of White Canyon are two folds on the west flank of the Monument upwarp and subsidiary to it, the Balanced Rock and Organ Rock anticlines (fig. 1). Superposed on the gentle westerly dip in the White Canyon area are numerous shallow flexures. One set of flexures is approximately normal to the Monument upwarp; the other set is approximately parallel to it. The flexures normal to the Monument upwarp are difficult to perceive on the ground, but are expressed as sinuosities in the structure contours. Those parallel to the upwarp are expressed as structural terraces, because most of them are so shallow that the regional dip removes what little closure they would otherwise have.

FAULTS

Two parts of the White Canyon area are faulted, the northern part and the southwestern part. Normal faults and en echelon normal fault zones trend northward and are vertical or dip steeply to the west in the southwestern part of the White Canyon area. Displacements range from a few feet to more than 240 feet; in general, the west blocks have been dropped with respect to the east blocks. Horizontal movement along the faults was uncommon, but where it occurred, the east blocks moved northward short distances relative to the west blocks. No single fault extends more than about 5 miles, except for a few near the mouth of Red Canyon.

Owing to the small size of the area studied, the available data are insufficient to determine the origin of the faulting. However, the faults may be related to adjustment of the rocks to the Henry Mountains uplift to the west, and to the development of the Organ Rock and Balanced Rock anticlines to the south, here assumed to be the result of lateral compression.

Faults near the mouth of Red Canyon trend northwestward and are axial to the Henry Mountains uplift. Faults south of Red Canyon trend north-northeastward and are en echelon systems cutting the steep east flanks of the Balanced Rock and Organ Rock anticlines, and of other northward-trending anticlines south of the White Canyon area. The few faults between these two group might be considered transitional on the basis of trend. The transitional faults tend to "horsetail" to the northwest or to the northeast at one or both ends.

These groups of faults are in much the same relationship to the southern end of the Henry Mountains as are many faults near the north end. Hunt (Hunt and others, 1953, p. 89) suggested that those at the north end might be related to shearing on the south side of an eastward thrust that resulted in a bodily translocation of the San Rafael Swell eastward with respect to the Henry Mountains. The en echelon faulting near the southern end of the Henry Mountains may have resulted from a similar, though less well defined, relative eastward movement of rocks south of the White Canyon area with consequent development of the Balanced Rock and Organ Rock anticlines, the axes of which trend northward.

Normal faults cut the Cutler and Moenkopi formations in the northern part of the area. Most of the faults trend N. 60°–80° W., and dip from 65° NE., through vertical to 65° SW.; some trend N. 50°–60° E., and dip NW., and one vertical fault trends N. 30° E. Two or three of the faults displace the beds as much as 100 feet, but most displacements are less than 40 feet. The red beds cut by the faults may be altered to yellow and orange for several feet from the fault surfaces (fig. 6). Many of the fault surfaces are coated with silica, calcite, limonite, limonite pseudomorphs after pyrite, or combinations of these. Joints with the same general trends as the faults also have similar color alteration and surface coating.

Several northwest-trending faults along the south side of White Canyon are nearly vertical, and the Moenkopi and Cutler formations are thrown down as much as 50 feet on the southwest. About 9,200 feet northeast of these faults, a series of closely spaced normal faults form a complex graben that contains several small grabens and horsts (fig. 6). The area between these two fault zones is a broad horstlike uplift as much as 9,200 feet wide and 19,500 to 24,500 feet long. This uplift is bounded on the northwest by a poorly defined shallow syncline and on the southeast by a vertical fault that trends N. 30° E. The Cutler is thrown down as much as 8 feet on the northwest side.

All the faults that do not terminate against other faults have decreasing throw longitudinally from the middle part of the fault trace, where maximum displacements commonly occur, and as can be seen on the geologic map (pl. 1), few of the faults are more than 2 miles long. For instance, displacement may decrease so rapidly along the fault trace that, on a fault with throw of 100 feet at the center, measurable offset cannot be found 3,000 feet from the point of maximum throw. Some faults that crop out on the mesa sides exhibit less and less displacement upward until no displacement is visible in the higher beds and the fault passes into a joint. The faults pass laterally into strong joints. Along Browns Rim about 1,200 feet north of vertical angle bench mark 5,390 (approximately long 110°19′10″ N., lat 37°52′00″ W.), a northeast-trending fault throws down the White Rim sandstone member of the Cutler formation about 6 feet on the northwest. This fault passes upward into a series of branching vertical faults and southeast-dipping high-angle reverse faults with a few inches displacement, and finally into a monoclinal flexure (fig. 13). Perhaps many of the faults pass thus into folds. Several faults of the northwest set can be traced downward into the Hermosa formation, a vertical distance of about 1,700 feet, with no more diminution of displacement than might be due to lateral rather than vertical change.

The fault zones are similar to the collapse structures that develop where salt bodies are dissolved by ground water (Stokes, 1948, p. 32–34; Cater, 1954). They are also similar to structures that Baker (1933, p. 73–74) believes are related to salt flowage. The White Canyon area is thought to be near the edge of deposition of the salt of the Paradox member of the Hermosa formation (Wengerd and Strickland, 1954, p. 2180–2181), and if the salt were thin, any faulting caused by salt flowage probably would be less spectacular than that described

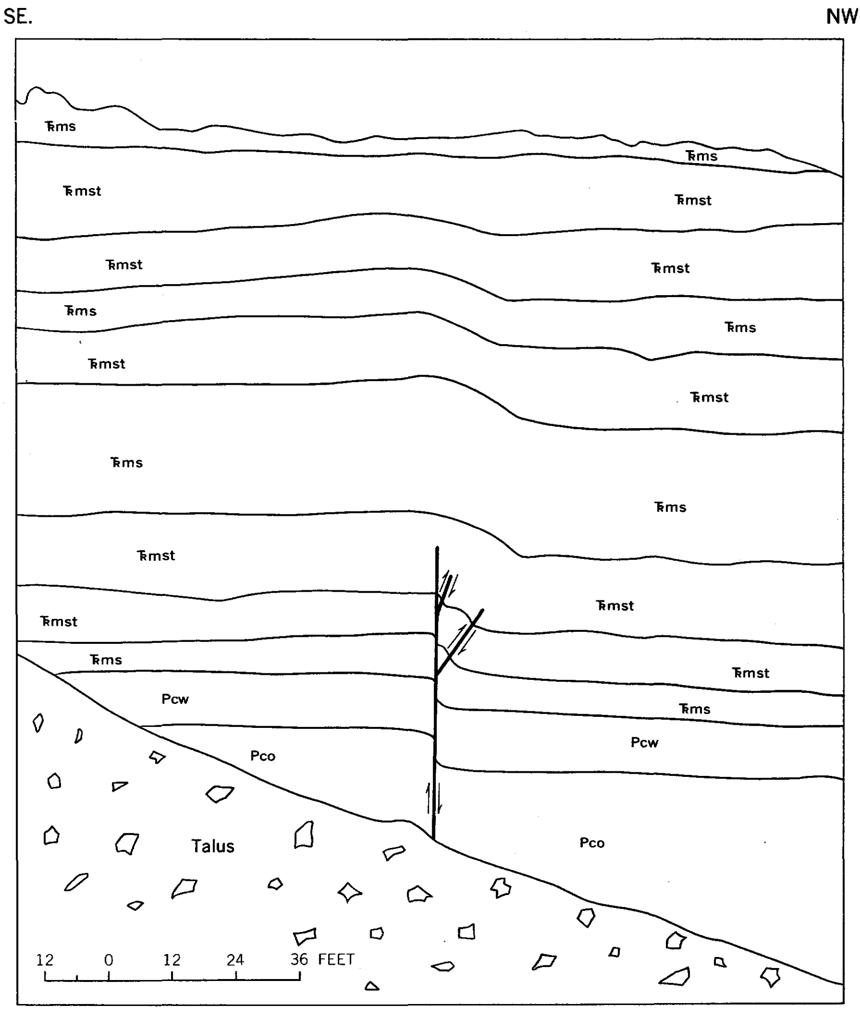

FIGURE 13.—Sketch of section showing small fault, south of Mille Crag Bend of the Colorado River, that passes upward into a monoclinal flexure with almost as much structural relief as the fault. Short reverse faults dip toward the upthrown block. Organ Rock tongue (Pco) and White Rim sandstone member (Pcw) of the Cutler formation; siltstone (Ꞧmst) and sandstone (Ꞧms) of the Moenkopi formation. View is southwest.

by Baker to the northeast where the salt probably was thicker. If the faults are related to salt flowage, they may not extend below the Paradox member.

Samples of altered and unaltered siltstone near faults and joints were collected to study the cause of the change from reddish brown to pale yellowish orange and grayish orange. Thin sections reveal that the cement in the reddish-brown rock is red (hematitic) and that in the orange rock is yellow ("limonitic"). No other mineralogic differences were noted between the different colored rocks. Partial chemical analyses (table 2) indicate that iron has been removed from the altered samples. According to Weeks (1951, p. 15), the removal of iron from red clays might be accompanied by removal of alumina and addition of silica, though her data are based upon analyses of sandstone from the Salt Wash member of the Morrison formation (Jurassic) and not of the Cutler formation (Permian), which might be chemically and mineralogically different from the Salt Wash member (Alice D. Weeks, written communication, 1957). Alumina and silica were analyzed by a semiquantitative spectrographic method. In this procedure a weighed amount of the sample mixture is burned in a controlled direct-current arc and the spectrum recorded on a photographic plate. Selected lines on the resulting plate are visually compared with those of standard spectra prepared in a manner similar to that for the unknowns. The standard spectra were prepared from mixtures of materials containing 68 elements in the following concentrations (expressed in percent): 10, 4.6, 2.2, 1.0, 0.46, etc. These values were chosen so that the concentrations of the elements decrease from 10 percent to about 0.0001 percent by a factor of the reciprocal of the cube root of 10. This factor provides a geometric concentration series having three members for each order of magnitude, which is consistent with the relation between the blackness of the spectral line and the amount of an element present. By means of a comparator showing enlarged adjacent images of the sample spectra and the standard spectra, visual estimates are made of concentrations of the elements in the sample which are then reported as being between two standards in the following manner: x indicating the middle portion (5–2) of an order of magnitude; x+ the higher portion (10–5); and x− the lower (2–1).

The above method of reporting is used because the inherent limitations of this particular method of spectrographic analysis make the precision of the determinations less than the precision attained in preparing the standards. Major sources of error are (a) chemical and physical differences between the samples and the standards, (b) the omission of complete quantitative procedures for sample preparation and plate calibration, and (c) lack of duplicate determinations. Experimental work has shown that about 60 percent of the reported results fall within the proper portion of an order of magnitude.

The spectrographic analyses indicate some variation of the aluminum content and no variation of the silicon content; however, the silica variations reported by Weeks (1951) are within the range of the spectrographic reporting class for the White Canyon samples, and some silica may have been added without being detected. The aluminum changes in value from one reporting unit to the next lower reporting unit in 2 of 5 altered siltstones, suggesting that some aluminum has been removed from the altered rock.

A polished section of a 1-inch-thick fracture coating of limonite from a fracture in the Cedar Mesa sandstone member of the Cutler formation revealed relict pyrite near the center of square-shaped limonite masses. Chemical analyses of the Cedar Mesa sandstone member adjacent to and away from fractures (table 2, field Nos. TLF–25–52, TLF–26–52, and TLF–27–52) bear out the field observation that iron is concentrated along the fractures. It is possible that calcium carbonate is also concentrated along the fractures, but the data are conflicting. Two fracture fillings (table 2, field Nos. TLF–29–52 and TLF–49–52) are rather high in iron content but low in manganese.

The age of the faulting is unknown; the Moenkopi formation of Triassic(?) and Early and Middle(?) Triassic age is the youngest unit cut by the faults. Doubtless, younger formations were faulted, but they have since been eroded away. A west-trending dry canyon is incised 15 to 20 feet in the Cedar Mesa sandstone member on the hanging wall of a normal fault (100-ft displacement) about 10,500 feet slightly east of south of vertical angle bench mark 5,390. Overhanging ledges and small caves along this canyon contain evidence of human occupation. Debris slopes near the occupation sites are littered with flint chips. Scattered flint arrowheads, potsherds, and fragments of metates suggest that the sites were occupied by prehistoric Indians. The scarcity of pottery, type of points, and abundant evidence of flintwork are suggestive of the Fremont culture (Alice Hunt, oral communication, 1956; and 1953, p. 20) which flourished in this region about A.D. 1000. The Indians may have lived along the canyon because the streambed contained a supply of water, and they may have abandoned the canyon when the water was cut off either by faulting or by stream piracy. They may also have lived in the canyon because it was remote.

It is possible that the canyon was beheaded by movement along the fault, but the upstream block would have moved down and formed a closed depression. The sediments that should have been deposited in the depression must have been removed by erosion, for no trace of them could be found. Furthermore, the graben does not form a closed basin; it is drained by ephemeral streams that flow northwest to join a major tributary to White Canyon. A more reasonable explanation is that the dry canyon once had a rather extensive drainage net on the northeast side of the fault and that the headwaters were captured by a tributary of the main drainage as it eroded its way headward in the relatively soft shale and siltstone of the Organ Rock tongue of the Cutler formation. If the faulting had diverted the drainage to the

TABLE 2.—*Partial chemical and semiquantitative spectrographic analyses, in percent, and measured radioactivity of 15 samples from the Organ Rock tongue and Cedar Mesa sandstone members of the Cutler formation in the White Canyon area*

[Semiquantitative spectrographic determinations made by the rapid visual-comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Analysts (all U.S. Geological Survey): Radiation, S. P. Furman; chemistry, G. W. Boyes, Jr., R. F. Dufour, J. S. Wahlberg, and E. C. Mallory; spectrography, R. G. Havens]

Laboratory sample	Field No.	Equivalent uranium	Total iron as Fe_2O_3	$CaCO_3$	Mn	Selected elements detected spectrographically		Remarks
						Si	Al	
D-80523	TLF-23-52	0.002	1.33	2.3	0.011	>21.5	2.15-4.64	Pale-yellowish-orange siltstone of the Organ Rock adjacent to northwest-trending fault.
80524	24-52	.003	2.14	4.6	<.005	>21.5	2.15-4.64	Reddish-brown siltstone of the Organ Rock 6 ft along bed southwest of previous sample.
80543	15-52	.002	.89	7.0	.027	>21.5	1.0 -2.14	Grayish-orange siltstone of the Organ Rock adjacent to northwest-trending joint.
80544	16-52	.001	1.61	5.2	.018	>21.5	2.15-4.64	Reddish-brown siltstone of the Organ Rock 2 in. from sample 80543.
80545	17-52	.002	2.76	1.8	.011	>21.5	4.65-9.99	Pale-yellowish-orange siltstone of the Organ Rock adjacent to northwest-trending fault.
80546	18-52	.002	3.42	2.1	.011	>21.5	4.65-9.99	Reddish-brown siltstone of the Organ Rock adjacent to sample 80545.
80549	25-52	.002	7.08	7.1	.034	>21.5	.46-0.99	Brown sandstone of the Cedar Mesa with abundant limonite-filled fractures adjacent to northwest-trending fault.
80550	26-52	.001	.69	9.3	.016	>21.5	.46-0.99	Light-yellowish-brown sandstone of the Cedar Mesa about 6 in. along bed from sample 80549.
80551	27-52	.000	.29	2.7	.005	>21.5	.46-0.99	Very pale orange sandstone of the Cedar Mesa about 6 ft along bed from sample 80550.
80552	29-52	.002	87.06	.9	.013	1.0-2.14	.10-0.21	Brownish-black fracture filling in northwest-trending fault that cuts Cedar Mesa sandstone member.

80556	47–52	. 002	1. 41	9. 8	. 014	>21. 5	2. 15–4. 64	Pale-yellowish-orange siltstone of the Organ Rock adjacent to northwest-trending joint.
80557	48–52	. 001	2. 30	9. 8	. 026	>21. 5	2. 15–4. 64	Reddish-brown siltstone of the Organ Rock 1 ft along bed from sample 80556.
80558	49–52	. 002	6. 80	5. 9	. 027	>21. 5	2. 15–4. 64	Joint filling and adjacent grayish-orange siltstone of the Organ Rock about 2 ft below sample 80557.
80562	53–52	. 002	1. 97	13. 0	. 032	>21. 5	1. 00–2. 14	Pale-yellowish-orange siltstone of the Organ Rock adjacent to northwest-trending joint.
80563	54–52	. 001	2. 82	12. 8	. 039	>21. 5	2. 15–4. 64	Reddish-brown siltstone of the Organ Rock about 3 in. along bed from sample 80562.

northwest, the stream course should follow the fault trace rather closely, as it does. This relation may be only a fortuitous one caused by downdip migration of the drainage or by delicate control exerted by the incompetent beds on the tributary streams.

JOINTS

Jointing is common throughout the area; joints are especially conspicuous in thick sandstone such as the Cedar Mesa sandstone member of the Cutler formation, the Hoskinnini member of the Moenkopi formation, the Wingate sandstone, and the Navajo sandstone. The strongest joint sets strike N. 65° W., N. 35° E., N. 65° E., and due north; all have nearly vertical dips. Such joints form large flat surfaces on the cliff formed of the Hoskinnini and are important in the formation of the sides of buttes and mesas.

The rims formed of the Shinarump member of the Chinle formation commonly contain many conspicuous joints; they become less conspicuous and more widely spaced behind the rim. Joints are poorly formed in less competent rock, such as siltstone and mudstone of the Chinle, and the siltstone, conglomerate, and the fine-grained sandstone of the Shinarump member. Many of the quartz and quartzite pebbles of the conglomeratic beds of the Shinarump are fractured, and the rock is easily broken along fracture planes.

Many of the joints cutting the red beds of the Organ Rock member of the Cutler formation and the Hoskinnini member of the Moenkopi formation are bordered by zones of bleaching from a fraction of 1 inch to 3 feet in thickness. Some of the joint surfaces are coated with secondary gypsum, calcite, or iron oxides.

URANIUM DEPOSITS

Uranium ore deposits in the White Canyon area, like those throughout most of the rest of the Colorado Plateau, are small. The large Mi Vida mine in the Moab district, the Monument No. 2 mine in the Monument Valley district, and the Happy Jack mine in the White Canyon district are exceptions; most of the ore deposits are from a few thousand to about 50,000 tons in size. Only in the Grants and Laguna districts of New Mexico are large ore bodies found in large number.

Most of the ore bodies in the White Canyon district are assemblages of uranium-bearing and copper-bearing minerals, and the district is characterized by the presence of copper in the uranium ores. In contrast, the deposits of western Colorado and northern Arizona carry uranium and vanadium, and the large deposits in northwestern New Mexico carry only uranium.

HISTORY OF MINING

The advent of new commercial uses and the consequent great demand for uranium have ushered in a profitable era of prospecting and exploration in the White Canyon area. The profound difference between the economic value of the mineral resources of the area in 1925 when Gregory (1938) studied the area and today is indicated clearly by the opening sentence of Gregory's chapter (1938, p. 107) on economic geology: "The San Juan country is poorly supplied with minerals of economic interest."

Gold was known to be a constituent of the gravel along the Colorado River; it is reported by Gregory (1938) to have been discovered near the mouth of Trachyte Creek by Cass Hite in 1883. Gregory stated that between 1886 and 1889 claims were mined on 21 bars along the Colorado River from the mouth of Red Canyon to Lees Ferry. During the period 1889–1927 only sporadic work was done on the most promising claims. Except for minor work in the gold properties during the depression years, the placers have not been worked.

Prospecting for copper in the White Canyon area is stated by Gregory (1938, p. 107) to have begun possibly as early as 1880. Activity was especially intense during 1906 and 1907 when it was stimulated by an unusually high price for copper. Plans had been laid in 1907 for the erection of a copper processing plant near Fry's cabin, which presumably was in what is now called Fry Canyon. However, the plan did not materialize, and the area remained relatively inactive until 1916 when copper ore was shipped from the Blue Dike prospect (now called the Happy Jack mine) and the Dolly Varden claim (now called the Four Aces claim) to the mill for testing (Gregory, 1938, p. 107; Butler and others, 1920, p. 621–622).

The properties in the area apparently remained idle again until 1948, when their possible value as sources of uranium ores was recognized. Two truckloads of copper ore from the Happy Jack mine were sent to the smelter in Garfield, Utah, in 1946. However, the ore was not acceptable at the mill because of its uranium content. Another truckload was sent from the mine to the U.S. Atomic Energy Commission mill at Monticello, Utah, in 1948, but the ore was not accepted because of its copper content. In spite of the discouragements of marketing the uranium ore, intensive prospecting was conducted throughout the area by a few companies and various local individuals from 1948 until 1951, and a large part of the rim exposures was staked. The first diamond-drilling exploratory program in the area was conducted by the Vanadium Corporation of America in deposits of the Shinarump member of the Chinle formation on Fry Point. The Vanadium Corporation of America established a small mill at the

Colorado River at the settlement of White Canyon and began receiving uranium ore from the Happy Jack mine in 1949. This mill received virtually all the production from the Happy Jack mine from 1949 until late 1953, when the mill was abandoned. A few shipments from the Hideout mine were received at the mill at White Canyon during 1949.

Mining was begun at several other claims in 1951; among these claims were the Posey, Joe Bishop, Yellow John, Jomac, Jerry, and the White Canyon No. 1. All the ore from these claims was shipped to the mill at Monticello.

Little prospecting for uranium was done during 1952 and the early part of 1953. The U.S. Atomic Energy Commission began diamond drilling in the White Canyon area during the summer of 1951, and exploratory drilling by private company under contract to the U.S. Geological Survey started on Deer Flat in the fall of 1953. Promising ore discoveries resulting from this exploration resulted in a new wave of prospecting during 1953 and 1954. Ground was claimed wherever possible behind the rims formed of the Shinarump member of the Chinle formation, and most of the area overlying the Shinarump member, both accessible and relatively inaccessible, is now claimed. Since 1954, private industry has taken more interest in diamond drilling and other exploratory work throughout the area.

A buying station for the U.S. Atomic Energy Commission was erected on a site in White Canyon near the Happy Jack mine. This station received all the ore produced from the White Canyon area in 1955 and 1956.

PRODUCTION

The first uranium ore produced from the area was in 1949, when ore from the Happy Jack mine was shipped to the Vanadium Corporation of America mill in the settlement of White Canyon, Utah. In that year small amounts of ore were shipped to the mill at White Canyon from the North Point claim and the Hideout mine. However, receipts of cre shipments from all except the Happy Jack mine were soon discontinued at that mill, and nearly all the production of the White Canyon area between 1949 and 1951 was from the Happy Jack. The ore produced from the Happy Jack mine during this period was of small tonnage of regular shipments. Ore was shipped from the Posey mine to the U.S. Atomic Energy Commission mill at Monticello, Utah, in 1950, but significant amounts did not come from the Posey until 1951.

Following the intensive prospecting in 1951, production soon was forthcoming from the Bell, Fry No. 4, Jerry, Joe Bishop, Jomac, Scenic No. 4, Yellow John, and the White Canyon No. 1 properties, in addition to regular production from the Happy Jack and Posey mines and sporadic production from the Hideout mine. The production from some of these properties was short lived; the Bell and the Jerry claims have been idle since 1951.

As a result of exploration from 1951 to 1954 by the U.S. Atomic Energy Commission, U.S. Geological Survey, and private companies, partly with financial assistance from the Defense Minerals Exploration Administration, production has begun (1954) at the Blue Lizard, Gonaway, Maybe, Gismo, and Spook mines, many of which have been making regular shipments. Increased tonnages of reserves have been found by the U.S. Atomic Energy Commission at the Happy Jack mine and by the U.S. Geological Survey at the Hideout mine. A loan by the Defense Minerals Exploration Administration enabled the owners of the Jomac mine to block out substantial reserves, and this mine continues to produce (1954).

With the establishment of the Government receiving station in lower White Canyon and the resulting shorter haulage, it is probable that production will increase in the future, provided the market remains favorable and new supplies of ore continue to be found.

Most of the production to date has come from the Happy Jack mine, but there are now at least four other major producing mines. Copper is the principal byproduct of the ores at present; it varies greatly in amount in the ores from the same mine as well as from different mines.

LOCATION AND GEOLOGIC SETTING

Most of the known uranium ore bodies are in the eastern, western, and southern parts of the White Canyon area (pl. 1). Access to the central part of the area, especially in the vicinity of Blue Canyon, has been difficult, and the remoteness of that area may account for its apparent lack of deposits.

Nearly all the deposits are in the Shinarump member of the Chinle formation, but a few low-grade ore bodies, like the one at the Jerry claim, are in sandstone or conglomerate beds near the base of the mudstone-sandstone unit. Some mines, such as the Posey, Joe Bishop, and Gonaway, are relatively near the surface, beneath benches formed of the Shinarump; but many of the high-grade uraninite-sulfide deposits are in beds of the Shinarump beneath 1,000 feet or more of overlying rocks, including the upper part of the Chinle formation, the Wingate sandstone, and part of the Kayenta formation.

Practically all the uranium deposits occur in channels that have been cut into beds of the Moenkopi formation and filled by sandstone, siltstone, claystone, and conglomerate of the Shinarump member. Most of these channels are within a broad belt of Shinarump ranging in width from 8 to 15 miles. This belt extends across the area from beyond Deer Flat on the east to beyond the Colorado River on the west, a distance of more than 30 miles. The north edge or pinchout of the belt of Shinarump, which, in general, is irregular, has many small outlying lenses. The southeast edge of the belt of Shinarump (near head of Red Canyon, pl. 1) is fairly regular, and has a trend of N. 80° E.

SIZES AND SHAPES

The exploratory drilling completed by the U.S. Atomic Energy Commission and by private company under contract to the U.S. Geological Survey has not been intended to completely outline ore bodies, and for that reason it is difficult to determine the size, and especially the shape, of the bodies on existing information. The ore bodies that have been mined generally are between 2 and 5 feet thick, though some are as much as 10 feet thick. A lower thickness limit of 1.0 foot was used in determining the sizes of the deposits, using a minimum grade cutoff of 0.1 percent U_3O_8. Although the uranium values diminish slightly along the edges of the ore bodies, gradation between ore-bearing and subore grade rock is minor, and the ore bodies have rather sharp boundaries. Lithologic differences determine the position of the edges of most of the ore bodies; the ore-bearing sandstone either pinches out or is cut out by siltstone or claystone at the edge of the ore body.

The ore deposits are generally tabular and follow the bedding of the enclosing rocks. They range from 50 to 1,000 feet in length and from 10 to 500 feet in width. Their shape generally is elliptical, and the major axis is oriented in the same direction as the trend of the channel in which they occur.

FACTORS IN THE LOCALIZATION OF ORE

The geologic study of the White Canyon area has indicated that the most important factors in ore localization are channels and the heterogeneity of the sedimentary rock within these channels. Detailed geologic studies and exploratory drilling in the Deer Flat area (Finnell and others, 1963) have suggested that local structures, such as changes in the regional dip, may be important in determining both the position of channels and the location of uranium deposits in the channels. No significant ore deposits have been found outside the channels in this area.

CHANNELS

Seventy-five channels have been mapped in the White Canyon area. Sixteen of these are known to contain at least 1 uranium deposit having a minimum grade of 0.10 percent U_3O_8; at least 8 additional channels contain low-grade uraniferous material. The channels mapped range in width from 30 to 1,000 feet and in depth from more than 2 to 50 feet. Their trends are shown on plate 1. Smaller channels are present in the White Canyon area, but only those with depths greater than 2 feet are shown. Table 3 lists all the known channels in the area and gives their trends, widths, and depths. Various channel trends were found in the area, but there was evidence of a slightly greater abundance of N. 10° E. to N. 50° W. trends and N. 70° E. to S. 80° E. trends. The greatest number of deposits occur in the channels that trend N. 70° E. to S. 80° E., though deposits have been found in channels of nearly every trend. Commercial deposits have not been found in channels having depths less than 4 feet and widths less than 100 feet. However, the exploratory drilling by private company under contract to the U.S. Geological Survey on Deer Flat (Tommy L. Finnell, oral commun., 1956) indicates that channels can widen by tens of feet and deepen by more than 10 feet in as short a distance as 500 feet along their trend. No optimum width, depth, or ratio of width to depth has been found for the occurrence of the ores.

The lithology of the sediments in the channels probably was important in controlling the migration of the mineralizing fluids and the rate of deposition of the ore minerals. Channels filled dominantly with sandstone or with siltstone are apparently unfavorable for mineralization, whereas channels filled with sandstone and conglomerate with interbedded siltstone or claystone are most favorable for deposition. This probably explains why most of the ore occurs in the basal part of the channel fills where there is an abundance of siltstone interbedded with coarse-grained sediments and not in the upper part of the Shinarump member of the Chinle formation where the sandstone beds are continuous and contain fewer interbeds of siltstone. The most favorable parts of the Shinarump contain 10 to 30 percent siltstone and claystone and 70 to 90 percent sandstone and conglomerate. Most of the uranium deposits are in sandstone or conglomerate beds just overlying impermeable siltstone beds of the Moenkopi formation or of the Shinarump member, or interbedded with siltstone beds of the Shinarump member. An extremely favorable site for deposition would be a sandstone bed resting on the Moenkopi formation in the deeper part of a channel, bounded by interbedded siltstone along one edge of the channel, and on the other edge, and also overlain, by a large lens of claystone. Such a condition probably localized the ore deposits at the Blue Lizard and the White Canyon No. 1 mines.

Deposition of ore minerals is likely to be favored at intersections and bends in channels; this is demonstrated at the Gismo, Blue Lizard, Spook, and other mines. Abundant fine-grained sediments and vegetal remains have been deposited at places where channels change course, tending to produce favorable lithologic and chemical conditions for the deposits. Some ore deposits seem to be localized in deep

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TABLE 3.—*Data on channels filled by the Shinarump member of the Chinle formation in the White Canyon area*

[Channels 1-4 may be part of the same channel]

Channel No. on pl. 1	Name	Trend	Width (feet)	Depth (feet)	Lithology	Minerals	Estimated grade of rock (percent)
1	Bell No. 1	N. 75° W	100–150	<10	Sandstone and minor siltstone	Secondary uranium and copper minerals, pyrite, chalcocite.	0.10+ U_3O_8; 1.0+ Cu; 7.5 lime
2	Yellow John	West	150	7±	Sandstone and mudstone	Secondary uranium and copper minerals, iron oxides.	0.22 U_3O_8; 0.73 Cu
3	Not known	N. 17° E	100–150	<10	do	Secondary copper minerals	0.01 U_3O_8; 1.0 Cu; 5.0 lime
4	Fry No. 4	N. 85° E	100±	5–14	Sandstone, mudstone, and minor conglomerate.	Uraninite, secondary uranium minerals, chalcopyrite, bornite, chalcocite, pyrite, secondary copper minerals.	0.24 U_3O_8; 0.72 Cu
5	Ears	N. 50° E. branching to N. 30° E. and N. 70° E.	30–100+	14–50	Sansdtone, siltstone, and conglomerate.	Uraninite, secondary uranium minerals, chalcopyrite, pyrite.	0.10–0.25 U_3O_8
6	White Canyon No. 1	N. 30° E	150	5–22	Sandstone, conglomerate, and siltstone.	Uraninite, secondary uranium minerals, chalcopyrite, covellite, pyrite.	0.10–0.27 U_3O_8; 0.10–1.50 Cu
7	Bee	N. 75° W	100±	10±	do	Secondary copper minerals, jarosite.	<0.10 U_3O_8
8	Point	N. 74° W	400	30±	Sandstone, siltstone, and conglomerate.	Uraninite, chalcopyrite, secondary copper minerals.	Trace to 0.25 U_3O_8; 0.01–0.50 Cu
9	Nash Car	N. 40° E	400–600	20±	Sandstone, mudstone, and conglomerate.	Secondary uranium minerals, secondary copper minerals.	<0.10 U_3O_8
10	North Point No. 6	Bends N. 15° W.–N. 55° W.	300–600	15–30	Sandstone, siltstone, and conglomerate.	do	<0.10 U_3O_8
11	Rarin No. 2	N. 40° W	100±	2.5±	Sandstone conglomerate	Secondary copper minerals, jarosite.	<0.05 U_3O_8
12	G.P. No. 17	N. 65° E	100±	4.0±	Sandstone	Iron oxide, jarosite	<0.01 U_3O_8
13	Not known	N. 22° W	100±	3+	Conglomeratic sandstone	Secondary copper minerals, jarosite, gypsum, bornite.	<0.05 U_3O_8
14	do	N. 80° E	50±	3±	Sandstone and conglomerate	Bornite, pyrite, secondary copper minerals, jarosite, iron oxide.	<0.05 U_3O_8
15	14 JB	N. 60° E	100±	5±	do	Sulfide minerals, secondary copper minerals.	<0.05 U_3O_8
16	Sunrise-Uracop	N. 12° E	150±	30–35	Sandstone, siltstone, and conglomerate.	Secondary uranium minerals, sulfide minerals, secondary copper minerals.	0.18–0.27 U_3O_8; <0.05 Cu
17	Gonoway-North Point.	N. 60° W.–N. 70° W	300±	30	do	Secondary uranium minerals, secondary copper minerals.	0.10–0.25 U_3O_8; 0.10–1.0 Cu

18	Happy Jack	N. 75° W	100–250	4–10	Sandstone, siltstone, and conglomeratic sandstone.	Uraninite, chalcopyrite, covellite, bornite, pyrite, galena, sphalerite, secondary uranium minerals, secondary copper minerals, iron oxide, jarosite.	0.20–0.55 U_3O_8; 0.20–2.0 Cu
19	Four Aces (Dolly Varden).	N. 87° E	100+	2+	Sandstone, siltstone, and conglomerate.	Secondary copper minerals	0.002 U_3O_8; 3.15 Cu
20	Jomac	Bends N. 23° W	200–400	4–7	do	Secondary uranium minerals, secondary copper minerals, pyrite, chalcopyrite, jarosite, gypsum.	0.23 U_3O_8
21	Mountain Sheep No. 4.	N. 80° E	60–80	6+	Sandstone, siltstone, and conglomeratic sandstone.	Secondary copper minerals, jarosite.	0.004 U_3O_8; 0.01 Cu
22	Horseshoe	N. 40° W	400	10	Conglomeratic sandstone	Copper sulfides, secondary copper minerals, jarosite.	0.002 U_3O_8
23	The Gap	N. 20° W	500–600	30+	Sandstone and siltstone	Jarosite, gypsum	<0.005 U_3O_8
24	M. R. Waters, et al	N. 18° W	100–150	4	do	Secondary copper minerals	0.02–0.05 U_3O_8
25	Pour Off	N. 18° W	150	8	do	Pyrite, jarosite, gypsum	<0.005 U_3O_8
26	Windy Gap	N. 80° E.–N. 80° W	200	15	do	Secondary copper minerals, gypsum, jarosite.	0.005–0.01 U_3O_8
27	Saratoga	N. 3° E	60	3–4	do	Secondary copper minerals, jarosite, gypsum.	0.005–0.01 U_3O_8
28	Not known	N. 30° W	120	6	do	Jarosite	>0.005 U_3O_8
29	do	N. 30° W.(?)	100±	4–5	do	Not known	Not known
30	do	N. 10 W.(?)	Not known	Not known	do	do	<0.005 U_3O_8
31	do	Due north	75	5.5	Conglomeratic sandstone, siltstone, and conglomerate.	Gypsum, jarosite	<0.005 U_3O_8
32	do	N. 5° E	60	6	Sandstone and siltstone	Jarosite, gypsum	<0.005 U_3O_8
33	do	N. 35° W.–N. 84° E	80–200	4–10	do	Jarosite, iron oxide	<0.005 U_3O_8
34	do	N. 25° W	40–50	5	do	Iron oxide	<0.005 U_3O_8
35	do	N. 40° E	125	5	Sandstone	Secondary copper minerals, iron oxides.	<0.005 U_3O_8
36	do	N. 80° W	200+	9	Conglomeratic sandstone	do	<0.005 U_3O_8
37	do	Due north—N. 15° E	300	5–10	do	Secondary copper minerals	<0.005 U_3O_8 [1]
38	do	N. 30° E	300	10	Sandstone and conglomerate at north end; limestone and sandstone at south end.	Iron oxides at north end; chalcopyrite, secondary copper minerals, iron oxides, gypsum at south end.	<0.10 U_3O_8 [2]
39	do	N. 7°–52° W. (bend?)	300±	10	Sandstone	Secondary copper minerals	<0.01 U_3O_8 [1]
40	do	N. 55° W. (bend)	400	11	Sandstone, conglomerate, and siltstone.	Secondary copper minerals, iron oxides, jarosite.	<0.05 U_3O_8 [1]
41	do	N. 26° W	500±	5–15	Sandstone and siltstone	Secondary copper minerals	<0.05 U_3O_8 [1]
42	do	N. 87° W	450–550	12+	Sandstone	Iron oxides, jarosite, secondary copper minerals.	<0.01 U_3O_8 [1]
43	do	N. 45° E	300	16	Sandstone, siltstone, and conglomerate.	Secondary copper minerals	>0.01 U_3O_8 [1]
44	do	N. 25° W	40±	4	Sandstone	None	<0.005 U_3O_8 [1]
45	do	N. 49° W	200±	8+	Sandstone and conglomerate	Chalcopyrite and secondary copper minerals.	<0.005 U_3O_8 [1]
46	do	N. 43° W	50	4	do	None	>0.005 U_3O_8 [1]

See footnotes at end of table.

TABLE 3.—*Data on channels filled by the Shinarump member of the Chinle formation in the White Canyon area*—Continued

Channel No. on pl. 1	Name	Trend	Width (feet)	Depth (feet)	Lithology	Minerals	Estimated grade of rock (percent)
47	Blue Lizard-Markey	N. 35°–52° E	400+	18–25	Sandstone, conglomerate, and siltstone.	Uraninite, chalcopyrite, covellite, bornite, pyrite, secondary uranium minerals, secondary copper minerals.	0.20–0.50 U_3O_8[3]
48	Simplot	N. 32° W	230	8	Sandstone	Jarosite, gypsum	<0.10 U_3O_8[1]
49	Posey	Bends N. 80° E.–N. 45° W.	200–300	9–30	Sandstone, conglomerate, and siltstone.	Secondary uranium minerals, secondary copper minerals, iron oxides, jarosite.	0.10–0.40 U_3O_8[3]; 0.10–4.00 Cu; 0.10–3.00 lime
50	Not known	N. 52° E	300	6	Sandstone and siltstone	Secondary uranium minerals, secondary copper minerals, iron oxides.	<0.10 U_3O_8[1]
51	do	N. 70° E	200	10	Sandstone and conglomerate	Iron oxides, jarosite	<0.05 U_3O_8[1]
52	do	N. 88° W	200–300	10	Conglomeratic sandstone	do	<0.05 U_3O_8[1]
53	do	Bends N. 30°–65° W	100–300	10–20	Sandstone	Uraninite, chalcopyrite, pyrite	0.20 U_3O_8[1]
54	do	Bends N. 55° E	100–300	10–50	do	do	0.20 U_3O_8[4]
55	Saddle	N. 30° E	100	35±	Sandstone, conglomerate, and siltstone.	Uraninite, sulfide minerals, secondary copper minerals, iron oxides.	0.05–0.25 U_3O_8[4]; 1.00 Cu
56	Not known	N. 30° W	100+	7±	Conglomeratic sandstone	Iron oxides	<0.05 U_3O_8[1]
57	do	N. 65° W	100+	5+	Sandstone, siltstone, and conglomerate.	Chalcopyrite, pyrite, bornite, covellite, secondary uranium minerals, secondary copper minerals; iron oxides.	0.11 U_3O_8[3]
58	do	N. 67° W	80	7	Sandstone	Iron oxides	<0.05 U_3O_8[1]
59	Dead Buck	N. 15° W	50	8	Medium to coarse sandstone; sparse carbon, 10 percent mudstone.	Chalcopyrite, bornite, malachite, green fluorescent mineral.	0.06 U_3O_8[3]; 0.35 Cu
60	W. N	S. 80° W.–W	700–1,000	15	Medium to coarse sandstone; abundant carbon, 28 percent mudstone.	Uraninite, chalcopyrite, pyrite, galena.	0.40 U_3O_8[4]; 1.90 Cu
61	Camel	N. 80° W	150–250	10	Medium to coarse sandstone; sparse carbon, 25 percent mudstone.	Malachite, uranophane	0.15 U_3O_8[3]; 0.075 Cu
62	Bridges No. 2	N. 85° W	700	5–8	Medium to coarse sandstone; sparse carbon, 2–5 percent mudstone.	Malachite, azurite; sparse	<0.02 U_3O_8[1]
63	Able No. ?	N. 80° W	Not known	Not known	Medium to coarse sandstone; sparse mudstone.	Not known	Not known.
64	Camel No. 1	N. 80° W.–W	350	10	Medium to coarse sandstone; 30 percent mudstone, sparse carbon.	Chalcopyrite, malachite	0.20 U_3O_8[2]; 0.95 Cu

65	Hideout No. 1	N. 70° W.–S. 80° W	350–500	12–15	Medium to coarse sandstone; 30 percent mudstone, abundant carbon.	Uraninite, uranophane, chalcocite, chalcopyrite, bornite, calcite, bayleyite, schroeckingerite.	0.56 U_3O_8 [4]; 2.34 Cu
66	Yoke	N. 80° W	60	4	Medium to coarse sandstone; 10 percent mudstone, abundant carbon.	Malachite, jarosite	0.05 U_3O_8 [1]; 0.25 Cu
67	Zebra No. 1	N. 50° W	200	5	Medium to coarse sandstone and conglomerate, sparse carbon.	Radioactive carbon, kaolinite, jarosite.	0.05 U_3O_8 [1]
68	Yoke No. 5	N. 80° W	450	8	Medium to coarse sandstone; conglomerate.	Hematite, limonite	<0.01 U_3O_8 [1]
69	Zebra No. 5	S. 88° W	Indeterminable	Indeterminable	Medium to coarse sandstone; 10 percent mudstone.	Jarosite	<0.01 U_3O_8 [1]
70	Able-Sam Hill	S. 80° W	500	5	Medium to coarse sandstone; 15–20 percent mudstone, sparse carbon.	Chalcopyrite, malachite, azurite, uranophane(?).	0.12 U_3O_8 [1]; 1.0 Cu
71	Zebra No. 15	W.–S. 70° W	200–250	4	Medium to coarse sandstone; 5–10 percent mudstone, sparse carbon.	Hematite, limonite	<0.02 U_3O_8 [1]
72	Baker No. 10	S. 30° W	100	3	Coarse to very coarse and conglomeratic sandstone; 15 percent mudstone, sparse carbon.	Limonite	0.05 U_3O_8 [1]
73	Baker No. ?	S. 31° W	50	5	Medium to coarse sandstone; sparse carbon.	Not known	<0.02 U_3O_8 [1]
74	Camel No. 5	N. 50° W	200	5?	Medium to coarse sandstone; 10 percent mudstone, sparse carbon.	Malachite	0.20 U_3O_8 [2]; 2.8 Cu
75	Not known	S. 44° E	Not known	Not known	Not known	Not known	Not known.

[1] Estimated from radioactive examination of rim.
[2] Assays of chip samples.
[3] Ore received at mill.
[4] Assays of diamond core.

scours in channel floors, perhaps because carbonaceous material was preserved in such scours and because solutions may have moved more slowly in the sandstone filling the scours.

In places mineralizing solutions apparently have been impounded in sandstone that is intertongued with siltstone. At the Happy Jack and several other mines, tabular beds of ore-bearing sandstone contain abundant interstitial clay; these beds have a permeability intermediate between that of the relatively impermeable siltstone or claystone and the relatively permeable sandstone. This intermediate permeability probably favored the deposition of the ore minerals. An increase in the interstitial clay content would impede the movement of the mineralizing solutions through the sandstone. The impedence probably would alter the physical environment that held the ore elements in solution and would allow time for a change in the chemical character of the ore-bearing fluid by solution of wall-rock constituents. On pages 46–54 the general characteristics of the Shinarump member are discussed in detail, and the lithologies associated with barren and ore-bearing channels are described.

The mineralogic composition within the Shinarump member of the Chinle formation controlled the chemical environment and probably was a more important factor in the precipitation of the ore deposits than were the changes in the physical environment induced by the lithologic changes. Fossil wood fragments, clay, feldspar, and other constituents of the mineralized beds have been replaced by uraninite and the sulfide minerals. Extremely rich ore in parts of the Happy Jack and Blue Lizard mines, and in several other deposits, is in clayey sandstone containing abundant degraded vegetal material or "trash." [3]

The grade of the uranium deposits seems to be independent of the thickness of the sandstone beds containing them, though most of the beds containing ore deposits are 2 to 5 feet thick. Deposits as much as 10 feet thick have been mined, but most of these are within two or more adjacent beds of sandstone.

LOCAL STRUCTURES

Studies by Tommy L. Finnell (written commun., 1959), and by Finnell and Gazdik (1958) have shown that several of the deposits in channels filled with the Shinarump member of the Chinle

[3] The Shinarump member of the Chinle formation contains abundant fossil vegetal material. Much is silicified, but some, particularly that in channel fills, has been degraded to soft black charcoallike material and to coal. Some coaly logs 4 to 6 inches in diameter and several feet long have been seen. Most of the vegetal material in channel fills, however, consists of carbonized chips, sticks, perhaps leaves, and other small fragments. Material of this sort is termed "trash." It commonly is found filling shallow scours at the base of sandstone beds where it forms "trash pockets" or "trash deposits" (Trites and Chew, 1955, p. 141, 142).

formation on Deer Flat are on structural terraces downdip from monoclinal flexures. Generally the Shinarump consists of finer grained material downdip from these flexures (in the areas of flat dip), than it does on the flexures. This difference in the sediments of the Shinarump suggests that the surface over which the streams that deposited the Shinarump flowed was controlled by these minor flexures. Where the gradient was steep, streams flowed at great velocity, deep scours were cut, and coarse material was deposited. Where the gradient was shallow, as in the areas of flat dip, stream velocity was less, cutting was shallow, and fine-grained sediments were deposited. A ponding condition with subsequent deposition of interbedded sandstone and siltstone could have been produced in the areas of shallow dip. The Happy Jack and Fry No. 4 mines are both on such structural flexures.

MINERALOGY

A list of the minerals in the uranium deposits in the White Canyon area is given below. Many of the minerals are very fine grained and can be recognized only under the microscope. Mineral identifications were verified by X-ray, provided sufficiently pure material was available.

Mineral	*Formula*
Elements:	
Copper	Cu
Sulfur	S
Sulfides:	
Bornite	Cu_5FeS_4
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Covellite	CuS
Galena	PbS
Marcasite	FeS_2
Pyrite	FeS_2
Sphalerite	ZnS
Oxides:	
Becquerelite	$7UO_3 \cdot 11H_2O$
Chalcedony	SiO_2
Cuprite	Cu_2O
Gibbsite	$Al_2O_3 \cdot 3H_2O$
Goethite	$Fe_2O_3 \cdot H_2O$
Hematite	Fe_2O_3
Ilsemannite	$Mo_3O_8 \cdot nH_2O$(?)
Melaconite	CuO
Opal	$SiO_2 \cdot nH_2O$
Psilomelane(?)	$MnO_2 \cdot nH_2O$
Quartz	SiO_2
Schoepite	$8UO_3 \cdot 20H_2O$(?)
Uraninite	$3UO_2 \cdot 7UO_3$

Mineral	*Formula*
Carbonates:	
Azurite	$2CuCO_3 \cdot Cu(OH)_2$
Bayleyite	$Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$
Calcite	$CaCO_3$
Dolomite	$(Mg, Fe, Mn)CO_3$
Malachite	$CuCO_3 \cdot Cu(OH)_2$
Manganosiderite	$(Fe, Mn)CO_3$
Schroeckingerite	$NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$
Sulfates:	
Alunite	$K_2Al_6(OH)_{12}(SO_4)_4$
Antlerite	$CuSO_4 \cdot 2Cu(OH)_2$
Barite	$BaSO_4$
Betazippeite	$(UO_2)_2(SO_4)(OH)_2 \cdot 4H_2O$
Brochantite	$CuSO_4 \cdot 3Cu(OH)_2$
Chalcanthite	$CuSO_4 \cdot 5H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$
Jarosite	$K_2Fe_6(OH)_{12}(SO_4)_4$
Johannite	$Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$
Pickeringite	$MgSO_4 \cdot Al_3(SO_4)_3 \cdot 22H_2O$
Uranopilite	$(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$
Phosphates:	
Meta-autunite	$Ca_2(UO_2)_4(PO_4)_4 \cdot 5\text{–}13H_2O$
Metatorbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$
Phosphuranylite	$Ca(UO_2)_7(PO_4)_4(OH)_4 \cdot 10H_2O$(?)
Arsenates:	
Erythrite	$(Co, Ni)_3(AsO_4)_2 \cdot 8H_2O$
Metazeunerite	$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Silicates:	
Allophane	$Al_2SiO_5 \cdot nH_2O$
Chlorite	
Cuprosklodowskite	$Cu(UO_2)_2Si_2O_7 \cdot 6H_2O$
Hydrous mica	$H_2KAl_3(SiO_4)_3$
Kaolinite	$H_4Al_2Si_2O_9$
Microcline	$KAlSi_3O_8$
Muscovite	$H_2KAl_3(SiO_4)_3$
Sepiolite	$H_4Mg_2Si_3O_8$
Tourmaline	$H_8Na_2(Mg, Fe, Al\text{-}Li)_6B_6Al_{12}Si_{12}O_{62}$
Uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_6 \cdot 5H_2O$
Zircon	$ZrSiO_4$

For discussion in this paper, the minerals found in the White Canyon area are divided into two main groups—those associated with the ores and those found in the host rocks. The primary ore minerals are discussed first, then those which are produced by supergene enrichment, and finally those minerals produced by secondary alteration and oxidation. The host rock minerals include those which were originally deposited when the Shinarump member of the Chinle formation was laid down, those of authigenic origin, and those formed by more recent alteration.

ORES

URANINITE AND PRIMARY SULFIDES

URANINITE

Uraninite is the most abundant uranium mineral and the only known primary uranium mineral in the White Canyon area. It has been found in the unoxidized ore in nearly every mine, and is closely associated with the sulfide minerals. Coffinite, the uranous silicate, has not been reported from this area.

Uraninite has replaced fragments of carbonized wood and small bits of organic matter; it has generally replaced the cell walls in preference to the cell lumens (fig. 14), although uraninite has completely replaced some wood. Cellular structure of some of the uraninite that has been disseminated in sandstone apparently represents the replacement of finely divided organic material, perhaps individual wood cells. Locally, it is disseminated as discrete grains in sandstone, conglomerate, and siltstone, has rimmed grains of quartz, has partly replaced grains of feldspar along cleavage planes, and has partly filled microscopic veinlets cutting quartz grains (fig. 15).

The exact chemical formula of the uraninite is not known, but the analysis of 4 samples of uraninite from the Happy Jack mine reported by Hoekstra and Katz (1956) yielded O/U ratios of 2.46, 2.46, 2.39, and 2.40.

Two distinct types of uraninite have been observed in polished sections. The more common type is gray and is normally associated with pyrite. The other type is brownish gray and is intimately intermixed with chalcopyrite. Admixed copper or copper minerals in the uraninite may have produced the brownish color.

Sooty pitchblende has been identified at the Happy Jack mine by Kerr (1951) who found it 50 to 100 feet from the portal in porous sandstone interbedded with mudstone.

PYRITE

Pyrite is the most widespread and abundant sulfide mineral in the White Canyon area and is present in nearly all the ores. It is commonly associated with chalcopyrite, uraninite, sphalerite (if present), galena (if present), and bornite in the unoxidized ore. It most commonly occurs as replacements of wood and fine-grained organic material. Pyrite that has replaced fine-grained organic material commonly is in the form of thin scalloped bands and small closely spaced blebs. Some pieces of wood have been completely replaced by pyrite (fig. 16); other pieces have been replaced by pyrite associated with other sulfides. Parts of the wood replaced by pyrite range from scattered cells to nearly complete replacement; the cell structure is commonly retained.

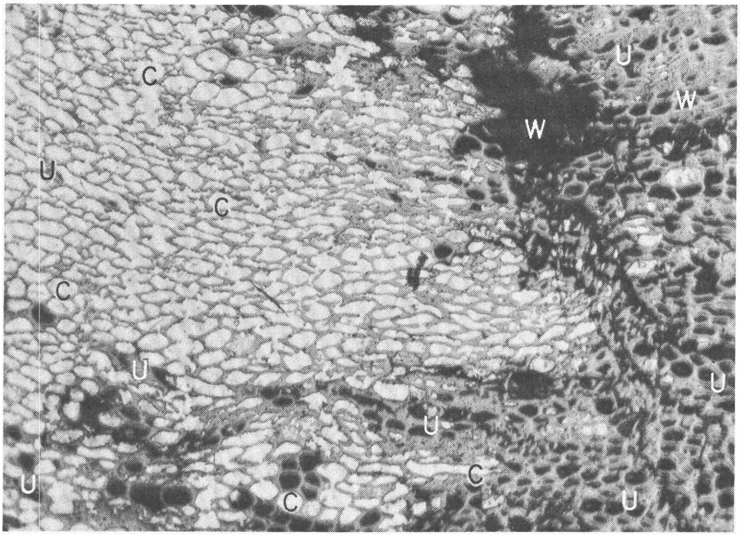

FIGURE 14.—Photomicrograph of a cross section of a carbonized wood fragment (W) partly replaced by uraninite (U) and chalcopyrite (C). × 145.

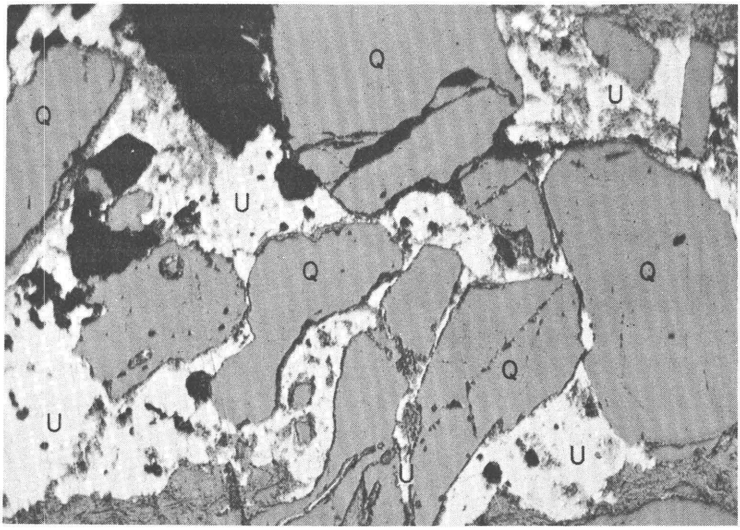

FIGURE 15.—Photomicrograph of uraninite (U) partly filling the spaces between quarts grains (Q) and filling fractures cutting the grains. × 145.

Pyrite disseminated in sandstone is especially abundant near pieces of pyritized wood, but it also is disseminated in sandstone, conglomerate, and siltstone away from organic material. It occurs in the sandstone, and in some places in the wood, as small rounded grains, irregular masses, and euhedral crystals. It commonly has been concentrated along the edges of quartz and other grains in the rock, embaying and partly replacing many of them. Many of the fractures in the rock are partly filled by pyrite, some of which is associated with chalcopyrite.

Crystals of pyrite, ranging from 0.01 to 0.1 inch in diameter, have been observed in most of the deposits. Both cubes and pyritohedra have been identified under the microscope. Four different types of pyrite crystals have been observed: simple homogeneous crystals, skeletal crystals (fig. 17) surrounding unreplaced organic matter, crystals with a pyrite core separated from a pyritic rim by unreplaced organic material or uraninite (fig. 18), and zoned crystals composed of alternating zones of yellow and pinkish-yellow pyrite (fig. 17).

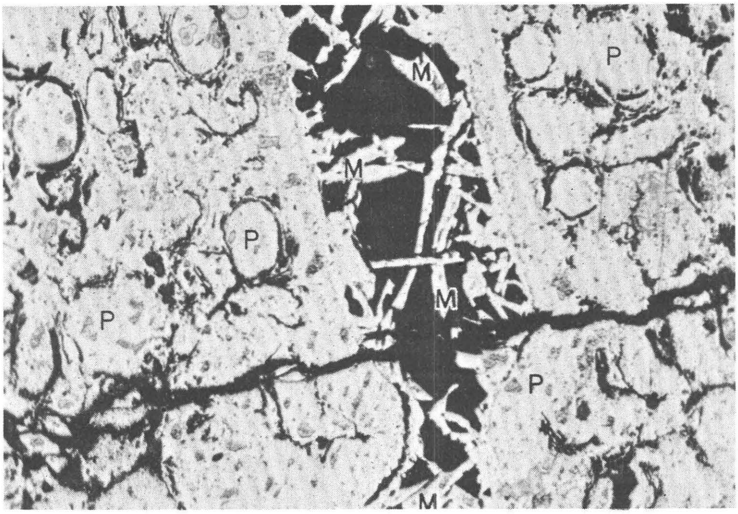

FIGURE 16.—Photomicrograph of marcasite (M) rimming a cavity in wood that has been replaced by pyrite (P). × 145.

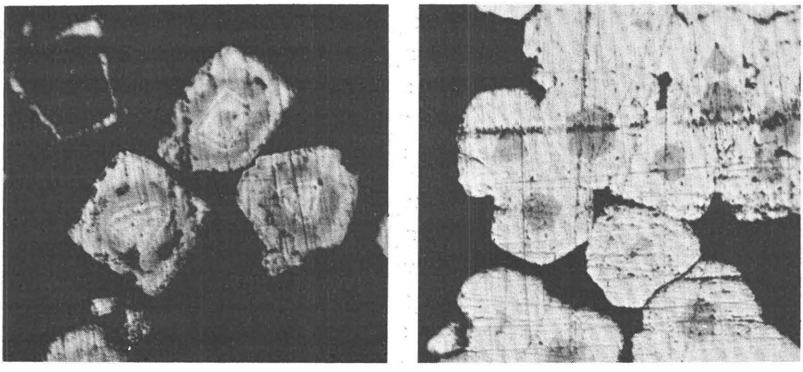

FIGURE 17.—Photomicrographs of complexly zoned pyrite crystals; the photograph at left shows in addition a skeletal pyrite crystal. × 710.

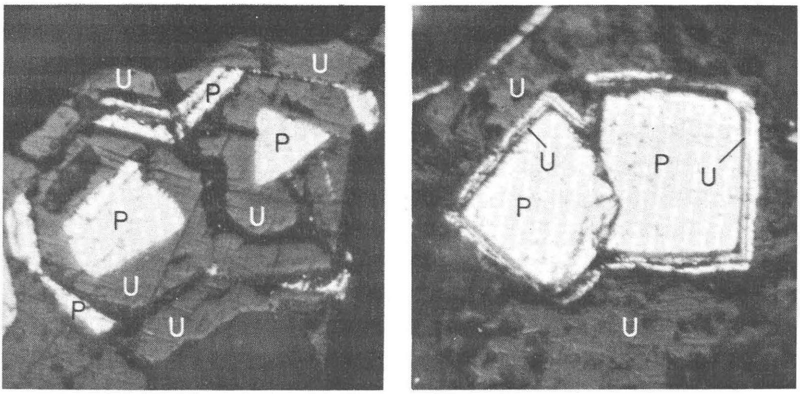

FIGURE 18.—Photomicrographs of uraninite (U) intergrown with pyrite (P) and replacing fine-grained organic material (black) in sandstone. × 710.

CHALCOPYRITE

Chalcopyrite is the most abundant copper sulfide mineral in the White Canyon area and is recognizable in nearly all the ores studied. Next to pyrite, it is the most abundant sulfide mineral. Chalcopyrite is commonly associated with pyrite, uraninite, bornite, and sphalerite.

Sandstone and conglomerate containing carbonized wood, siltstone, and claystone appear to have been favorable sites for the deposition of chalcopyrite. Chalcopyrite has replaced or rimmed fragments of carbonized wood and seams of carbonaceous siltstone, has replaced claystone, has filled fractures cutting sandstone and siltstone, and has partly replaced feldspar grains along their cleavages. It has partly filled fractures cutting quartz grains, and has partly replaced quartz grains, commonly removing nearly all the authigenic silica overgrowths and embaying the detrital quartz to form sharply angular quartz grains. The chalcopyrite ranges in amount from a few disseminated grains to a massive intersitial filling between the grains of sandstone (fig. 19). Much of the chalcopyrite has filled open spaces in sandstone and wood (fig. 20).

In the process of wood replacement, chalcopyrite probably filled or replaced the centers of the wood cells first and then replaced the cell walls. In the more uraniferous parts of the deposits the cell walls are commonly replaced by uraninite (fig. 15).

Megascopic veins and fracture fillings of chalcopyrite are not abundant, but they have been observed in some of the mines. Veinlets of chalcopyrite, less than 6 inches long and one-fourth inch across, cut siltstone beds in the Happy Jack mine; and veins of chalcopyrite cut sandstone beds in the Happy Jack and Blue Lizard mines. Secondary copper carbonates filling fractures in quartz cobbles in the Posey mine may represent chalcopyrite fillings that have been altered to secondary minerals.

SPHALERITE

Small quantities of sphalerite have been found at the Happy Jack, White Canyon No. 1, Fry No. 4, and W. N. mines in the White Canyon area. The sphalerite generally is associated with pyrite, uraninite,

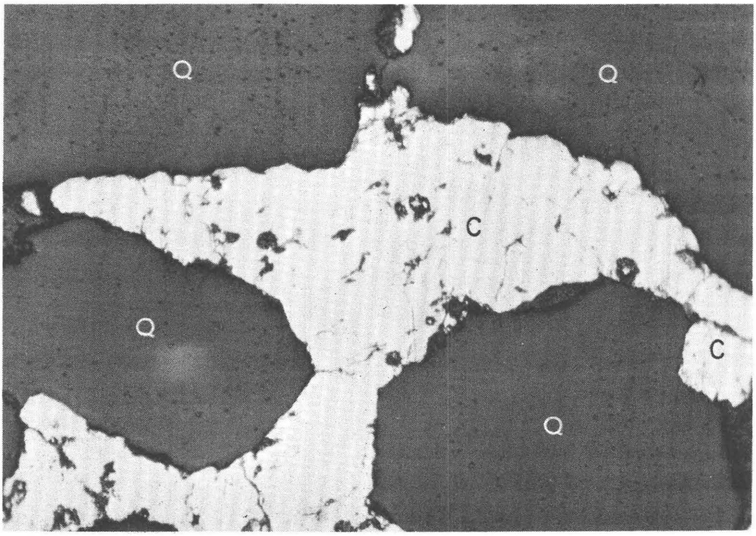

FIGURE 19.—Photomicrograph of chalcopyrite (C) cementing quartz grains (Q) in sandstone. × 145.

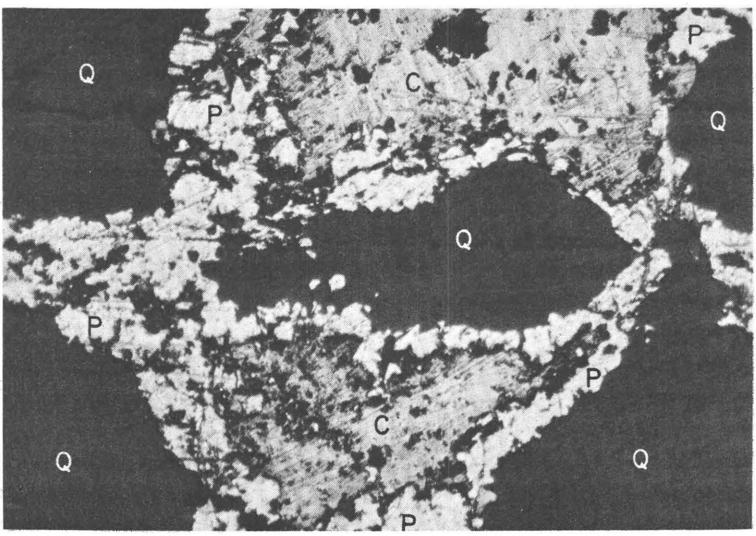

FIGURE 20.—Photomicrograph of pyrite (P) rimming quartz grains (Q) and chalcopyrite (C) filling the spaces between the grains. Blue filter. × 145.

and chalcopyrite in the unoxidized ore bodies; in ore that has undergone supergene enrichment it commonly is associated with chalcocite and covellite.

Sphalerite has been deposited as fracture fillings, as cavity linings in wood and sandstone, as disseminations in sandstone, and as replacements of wood. More sphalerite appears to have been deposited by fracture and cavity fillings than by replacement. Some pieces of wood that have been replaced by pyrite, chalcopyrite, or uraninite are transected by fractures filled by anhedral to euhedral crystals of sphalerite. Sphalerite apparently has extended into and replaced the pyrite, chalcopyrite, and uraninite, and locally contains a few unreplaced relicts of these minerals. In some wood fragments sphalerite has partly replaced the cell walls and chalcopyrite has replaced the cell lumens (fig. 21).

The sphalerite ranges from light gray to amber and forms crystals of microscopic size to 1 mm in diameter. The light-colored varieties are nearly free of iron and display yellow internal reflections.

GALENA

The only known occurrences of galena in the White Canyon area are in the Happy Jack, Hideout, and W. N. mines, where small crystals of the mineral are associated with pyrite, chalcopyrite, and uraninite. Most of the crystals are microscopic; occasionally one may be seen with the aid of a hand lens. Locally, galena has been deposited in

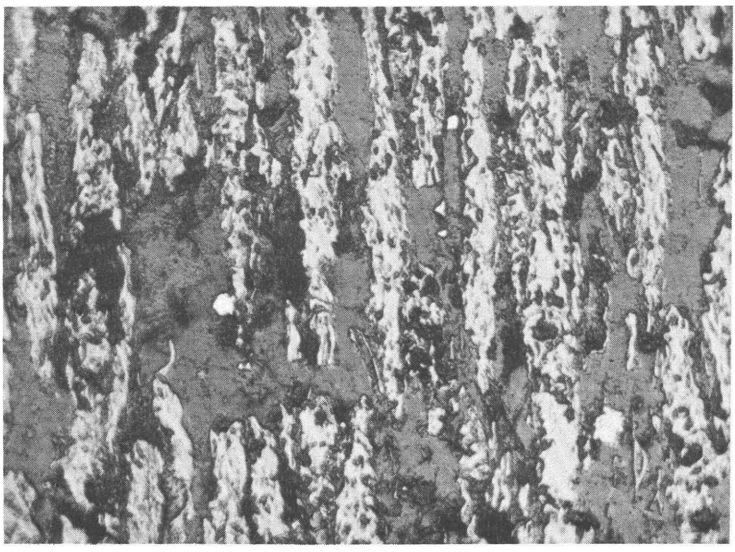

FIGURE 21.—Photomicrograph of sphalerite (dark) and chalcopyrite (light) replacing wood cells (longitudinal section of wood). Black is organic matter. × 145.

sufficient concentration in sandstone containing abundant carbonized wood to give selected hand specimens an extremely high specific gravity. In some of the uraniferous wood it fills open vugs; pseudomorphic wood-cell replacement by galena has not been observed.

The lead in the galena probably consists of old radiogenic lead and ordinary lead, both introduced by the ore solutions, rather than of radiogenic lead derived from radioactive disintegration of the uranium in the ore deposits. Lead isotope ratios of galena from the Happy Jack mine are similar to lead isotope ratios of lead minerals from nonuraniferous ore deposits of Tertiary age in and adjacent to the Colorado Plateau (Stieff and Stern, 1953, p. 1478–1479). Stieff and Stern (1953, p. 1478) indicate that addition of small amounts of old radiogenic lead, whose age is about one billion years, is suggested by systematic changes in the Pb^{206} and Pb^{207} content of the essentially uranium- and thorium-free lead minerals. Furthermore, ore textures in the Happy Jack mine indicate that the galena is a primary ore mineral, deposited earlier in the paragenetic sequence than the uraninite (fig. 23).

BORNITE

The amount of bornite varies considerably in the uranium deposits, though it commonly is present in unoxidized ore. The mineral is most abundant at the White Canyon No. 1 mine. The bornite occurs as (a) discrete irregular patches of pure bornite, (b) stringers and veinlets of bornite cutting chalcopyrite and shattered crystals of pyrite, and (c) intergrowths developed by simultaneous deposition with chalcopyrite, which are cut by later chalcopyrite along crystal and cleavage planes. Small irregular patches of pure bornite occur in a few places in chalcopyrite that has replaced wood, and are locally bounded by crystal faces of chalcopyrite. Small seams of bornite extend from some of these patches to partly surround crystals of chalcopyrite. Bornite also partly rims some grains of sphalerite contained in chalcopyrite. The bornite-chalcopyrite mixture occurs as replacements of some of the cells in wood fragments that have been replaced mainly by chalcopyrite and uraninite.

SUPERGENE SULFIDES

CHALCOCITE

Most of the uranium deposits exposed at the surface contain significant amounts of chalcocite in the oxidized zone. A little chalcocite occurs locally in the Happy Jack mine in the outer part of the unoxidized zone. Some of the copper solutions derived from the oxidation of chalcopyrite along the rim have moved into the sandstone behind the rim where secondary copper sulfides were deposited in local concentrations. The mineral occurs as crosscutting veinlets in chalcopyrite and bornite, as rims replacing the chalcopyrite and bornite along grain boundaries and extending as feathering-textured (Schwartz, 1951, p. 578–591) masses into these minerals, as rims around pyrite grains in chalcopyrite, and as closely spaced grains cementing sandstone.

Chalcocite is commonly associated with chalcopyrite, pyrite, covellite, and iron oxides near the boundary between the partially oxidized zone and the unoxidized zone with covellite, iron oxides, and secondary copper carbonates and sulfates in the outer part of the oxidized zone. The chalcocite studied with the reflecting microscope was anisotropic and was bluish-gray. The presence of chalcocite as an enriching mineral in the oxidized zone and its association with iron oxides and other oxidation products of iron and copper suggest that the chalcocite is of supergene origin.

COVELLITE

Microscopic "feathers" and small blades of covellite are characteristic of the supergene-enriched sulfide-bearing rock in many of the deposits. The mineral replaces chalcopyrite and bornite along small fractures and the edges of grains, rims and replaces galena, and apparently replaces chalcocite along indefinite veins. Some of the bladed covellite crystals seem to be twinned. The covellite is nowhere as abundant as chalcocite, but is more widely distributed in the unoxidized zone. Covellite forms a rim between bornite and uraninite to the extent that a direct bornite-uraninite contact has not been observed.

MARCASITE

Marcasite is a minor constituent in some of the ores that have undergone secondary enrichment; it has been observed at the Happy Jack and White Canyon No. 1 mines. Marcasite occurs chiefly as microscopic grains in veinlets cutting uraninite and most of the primary sulfide minerals and as cavity fillings in wood (fig. 16). The marcasite is cut and replaced by chalcocite and covellite; it probably is the earliest secondary sulfide mineral deposited. Cold acid solutions, such as are comon in the oxide and supergene zones of ore bodies, generally are considered to be favorable for the deposition of marcasite (Webber, 1929, p. 308). Such conditions could easily be attained by the oxidation of the uraninite-sulfide ore deposits of the White Canyon area.

SECONDARY MINERALS

URANIUM

Becquerelite and schoepite.—Brownish-yellow becquerelite was found by Weeks and Thompson (1954, p. 27) in a high-grade pocket associated with cuprosklodowskite near the portal of the Posey mine.

Gruner and Gardiner (1952, p. 17) have reported the mineral intimately mixed with schoepite from the Fry No. 4 mine. No other occurrences of becquerelite or schoepite are known in the White Canyon area.

Bayleyite.—Bayleyite occurs as light-yellow microscopic bladed or prismatic crystals on crusts of schroeckingerite at the Hideout No. 1 mine. Bayleyite is soluble in water, and it effervesces and dissolves quickly in cold dilute hydrochloric acid. The occurrence at the Hideout No. 1 mine was the second locality for bayleyite in the United States (Stern and Weeks, 1952, p. 1058–1060). It fluoresces faintly whitish green.

Schroeckingerite.—Schroeckingerite occurs in efflorescent coatings on mine walls at the Hideout No. 1 mine. Within a few weeks after mining the coatings form on sandstone that is cemented by calcite and dolomite. The schroeckingerite forms tiny greenish-yellow flakes in a crust that is coated with bayleyite on the outer surface. Schroeckingerite fluoresces vivid yellow green and is soluble in water and in cold dilute hydrochloric acid.

Johannite.—Johannite is a common mineral at the Happy Jack mine, and has been reported by Weeks and Thompson (1954, p. 30) to occur at the Fry No. 4 mine. At the Happy Jack mine the mineral occurs as light-green prismatic crystals and rounded aggregates of crystals coating the mine walls. Johannite generally coats the copper sulfide minerals, especially chalcopyrite, covellite, and uraninite. Much of it coats rich disseminations of sulfide minerals surrounding pods of uraninite, whereas the zippeitelike mineral coats the uraninite itself. The johannite is commonly associated with uraninite, the sulfide minerals, the zippeitelike mineral, uranopilite, brochantite, and chalcanthite. It is most abundant in the moist parts and at the outer boundary of the unoxidized zone.

A zippeitelike mineral.—A zippeitelike mineral, common on the Colorado Plateau, has been found at the Happy Jack and the Blue Lizard mines. The mineral occurs mainly as small balls of microscopic orange-yellow crystals that coat mine walls and fractures. This uranyl sulfate is especially abundant in the moist parts of the mine and is associated with uraninite, uranopilite, and johannite. It generally coats the uraninite; it is commonly intergrown with uranopilite and surrounded by johannite.

Uranopilite.—Uranopilite is a common secondary mineral of uranium at the Happy Jack mine where it is closely associated with the zippeitelike mineral and surrounded by johannite. It occurs as bright-yellow masses of microscopic prismatic or bladed crystals, many of which are in rosettes. Uranopilite may be distinguished from the zippeitelike mineral by its brighter and lighter yellow color and by its

732-420 O—64——8

brilliant yellowish-green fluorescence. The uranopilite commonly has formed coatings on the walls of the moist parts of the mines.

Meta-autunite.—Meta-autunite was found in the Posey mine. This mineral occurs as scaly aggregates, some of which are in rosettes, coating a fracture surface in siltstone. The meta-autunite is associated with goethite and an unnamed yellow uranium phosphate; it is pale greenish yellow and fluoresces an intense yellow green.

Metatorbernite.—Metatorbernite is a common secondary copper-uranium mineral in the White Canyon area; it has been found at the Posey, Joe Bishop, Jomac, White Canyon No. 1, Fry No. 4, W.N., and Markey mines. The mineral occurs in the oxidized parts of the deposits where it coats fracture surfaces, lines voids in sandstone, and is disseminated in coarse-grained sandstone; it coats parting surfaces in pieces of coal at the Jomac mine. It is most commonly associated with goethite, and in a few places with pyrite, chalcopyrite, metazeunerite, chalcanthite, and alunite.

The metatorbernite is bright green and is not fluorescent. It commonly occurs in sheaflike aggregates of tabular crystals; a few rosettes of crystals have been observed at the Jomac mine.

Phosphuranylite.—Phosphuranylite has been found at the Posey mine and at the North Point claim where it coats fracture surfaces and impregnates the sandstone and conglomerate near the surface. The mineral occurs as bright-yellow fibers that fluoresce an intense greenish yellow; it is commonly associated with goethite and manganese oxide.

Metazeunerite.—Metazeunerite occurs in small quantities at the Happy Jack, Markey, and Jomac mines; it has also been reported at the Sunrise claim (Gruner and Gardiner, 1952). Emerald-green tabular crystals of metazeunerite coat fracture surfaces in sandstone and bedding surfaces in siltstone; they are also disseminated in porous sandstone. It is commonly associated with secondary copper minerals and goethite.

Cuprosklodowskite.—Cuprosklodowskite has been identified at the Posey mine (Weeks and Thompson, 1954) and at the Fry No. 4 mine (Gruner and Gardiner, 1952). The mineral at the Posey mine is pale yellow green; it occurs in high-grade pockets as thin green veins in massive becquerelite and as a fracture coating with brochantite. Minute acicular crystals of the cuprosklodowskite, grouped in radial clusters, form a coating on the becquerelite.

Uranophane.—Uranophane occurs in significant amounts in the oxidized zones of many of the deposits in the area. Most of the uranophane is pale to bright yellow; a variety at the Yellow John mine is light green. The mineral is associated with secondary copper minerals, iron oxides, and manganese oxides in most places. It commonly forms coatings on the surfaces of fractures and lines voids in highly oxidized "limonitic" rocks. The mineral appears to be variable in form; botryoidal, massive, and fibrous forms have been observed. All specimens examined were nonfluorescent.

COPPER

Native copper.—A very small amount of native copper has been found in threadlike seams and in thin sheets in sandstone in the White Canyon No. 1 mine. The copper is in the oxidized zone where it is associated with brochantite and antlerite. A little may be present in the oxidized zones of other deposits, but it has not been recognized.

Cuprite.—Cuprite has been recognized in the oxidized zone at the Ears claim where it occurs as lenticular masses 0.5 inch long, encased in brochantite and blue allophane in the outcrop of a coarse-grained sandstone. The cuprite is veined by brochantite and formed earlier than the brochantite and allophane. Earthy cuprite has been reported (John H. Gruner, oral communication, 1953) to occur with the iron oxides at the Hideout mine on Deer Flat.

Melaconite.—Small amounts of black copper oxide and brown copper pitch occur with the copper carbonates and sulfates in the oxidized zone of several of the deposits. They are especially abundant in the more highly cupriferous area at the Posey mine in Red Canyon where they occur as small blebs in the other secondary copper minerals and as coatings on quartz and quartzite pebbles in highly mineralized conglomerate.

Azurite.—Azurite is a widespread copper mineral in the White Canyon area, but is seldom found in abundance. Most of the azurite occurs as botryoidal masses, balls, or as platy crystals associated with malachite, as coatings on fracture surfaces, or crystalline aggregates filling voids in coarse-grained rocks in some of the mines. Especially brilliant-blue crystals have been observed at the Posey mine.

Malachite.—Malachite is an abundant mineral in the oxidized zones of many of the ore deposits. It most commonly occurs as light- to dark-green very finely crystalline aggregates disseminated in, and filling voids in, sandstone and conglomerate, as coatings on the surfaces of cracks in wood replaced by other secondary copper minerals and iron oxides, and as coatings on fracture surfaces. Radiating fibrous clusters of brilliant crystals and mammillary forms have been observed. The malachite is normally associated with azurite, goethite, and hematite; it commonly is later than these minerals, resting upon them. Malachite rarely is directly associated with secondary uranium minerals.

Chalcanthite.—Chalcanthite is an abundant oxidation product of the copper sulfide minerals in the Happy Jack and Markey mines. The mineral occurs as light-blue to Berlin-blue fibrous and stalactitic groups of columns that coat the mine walls and impregnate the sandstone in the outer parts of the deposits.

Antlerite.—Antlerite occurs in small quantities in the outer oxidized parts of many of the mines. It is bright green and occurs as crystalline coatings on fracture surfaces and mine walls and as veins cutting hematite and other secondary copper and iron minerals. It is associated with hematite, brochantite, and at the Ears claim, with cuprite and allophane.

Brochantite.—Brochantite is one of the most abundant secondary copper minerals in the area. It occurs as light-green to emerald-green acicular crystals and botryoidal coatings on fracture surfaces, bedding planes, and in cavities in the outer parts of many of the uranium deposits. The mineral is associated with chalcanthite, malachite, azurite, antlerite, and goethite. The brochantite is interlayered with goethite and hematite in some of the deposits.

OTHER SECONDARY MINERALS

Sulfur.—Native sulfur has not been found in the White Canyon area by the writers, but has been reported from the Happy Jack mine by Gruner and Gardiner (1952, p. 15).

Hematite.—Hematite occurs in the oxidized ores in all the uranium deposits in the White Canyon area. Much of the iron oxide in surface exposures is red admixed hematite and goethite. Such coatings on fractures in sandstones exposed at the surface are similar to those commonly referred to as "desert varnish." The hematite has formed disseminations in sandstone, replaced sulfide minerals that have replaced wood fragments, and formed thin coatings on fractures.

The hematite has veined, embayed, and replaced the quartz grains in the sandstone; it forms the cement in sandstone in the high-grade sulfide-bearing rocks that have been oxidized. Some wood fragments are composed predominantly of this mineral and relict grains of chalcopyrite and pyrite.

The hematite is apparently an early oxidation product of the pyrite and chalcopyrite and commonly surrounds these sulfide minerals in incompletely oxidized ore. Pseudomorphic replacements of pyrite crystals by hematite have been noted; the hematite commonly grades outward into goethite.

Interstitial hematite and goethite are abundant in much of the oxidized rock, filling spaces between grains and surrounding sulfide mineral grains that have been only slightly oxidized. The large amount of this interstitial iron oxide and the relatively insignificant replacement or alteration of the pyrite and chalcopyrite suggest that the iron oxides were derived elsewhere in the deposit and were transported to and deposited in their present site.

The hematite commonly is associated with brochantite, antlerite, and malachite and commonly is either intergrown or veined by these secondary copper minerals. Some of the hematite is abnormally radioactive because of the presence of minute crystals of secondary uranium minerals such as uranophane.

Goethite.—Goethite probably is the most abundant secondary mineral in the oxidized zone of all the deposits. It has developed mainly as a result of the oxidation of minerals rich in iron, especially pyrite and chalcopyrite (fig. 22); some of it has been formed by the alteration of hematite and jarosite. The goethite forms disseminations in the sandstone and conglomerate, replaces sulfide minerals in both wood and the sedimentary beds, and fills fractures cutting all rock types of the Shinarump member of the Chinle formation. The mineral varies from orange to dark brown. Most of it is in fine-textured crystalline masses, though some spherulitic forms have been observed.

The goethite commonly is associated with gypsum and secondary minerals of copper, in addition to the iron minerals hematite and jarosite, in most of the ore deposits. Some of the geothite has filled cavities in wood and sandstone and has an "ice-cake" texture (Schwartz, 1951, p. 589). This goethite probably was transported in the colloidal state from the site where it was formed by the oxidation of other iron minerals.

Ilsemannite.—Ilsemannite occurs at the Happy Jack mine and the Fry No. 4 mine where it forms a dark-blue coating on the mine walls

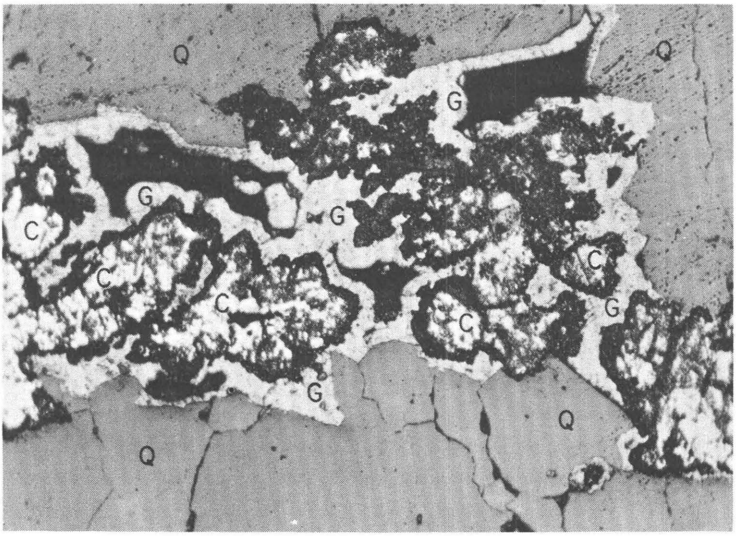

FIGURE 22.—Photomicrograph of goethite (G) coating chalcopyrite (C) and quartz grains (Q) in sandstone. ×145.

and is disseminated in the sandstone within a few inches of the walls of the workings. The ilsemannite is in the form of dark-blue microscopic crystals; it commonly is associated with chalcopyrite, pyrite, and the zippeitelike mineral. The original mineral that contained the molybdenum has not been found, but could have been molybdenite or jordisite.

Gibbsite.—White claylike gibbsite occurs in nodules and earthy coatings on allophane at the North Point claim. The gibbsite is of secondary origin, and may have resulted from the alteration of the allophane.

Calcite.—Calcite is abundant in some of the deposits in the eastern part of the White Canyon area where it has been found in the Bell and Jerry claims and in the Blue Lizard, Hideout, and W. N. mines (Finnell, and others, 1963). Small quantities of the mineral have been found in the western part of the area, as at the North Point claim where it has filled small fractures cutting the top of the Shinarump member of the Chinle formation, replaced wood, and cemented some siltstone, sandstone, and conglomerate.

The calcite in the deposits in the eastern part of the area has impregnated the sandstone, especially in the lowermost beds of the Shinarump member in which it locally cements the sandstone. Most of the calcite at the Blue Lizard mine is in the basal part of the Shinarump member where it cements sandstone containing concentrations of uraninite, chalcopyrite, bornite, and covellite. Cleavage faces as much as 3 inches in diameter have been observed in this rock, which is commonly termed "glass rock" by the miners. Calcite has also filled fractures in wood that has been replaced by sulfide minerals and uraninite.

The calcite at the Hideout mine is concentrated in the oxidized zone where it cements sandstone containing partly oxidized sulfide minerals. The calcite-bearing rock is bounded in at least one place by a steeply dipping fracture.

The calcite varies from white to brown and commonly is finely crystalline. A good share of the calcite probably was deposited in the Shinarump member from solutions that carried it from limy zones in the surrounding formations. The rest probably was introduced and deposited by the ore-bearing solutions.

Dolomite.—A small amount of dolomite is associated with the calcite in the ore-bearing sandstone at the Hideout mine (Finnell, and others, 1963). The amount of magnesium reported in spectrographic analyses from several of the mines is sufficiently high to suggest that magnesium is contained in much of the carbonate-bearing rock.

Manganosiderite.—Some of the darker colored carbonate at the Hideout mine was found by Tommy L. Finnell (Finnell, and others, 1963) to contain manganese, and because it yields an X-ray diffraction pattern almost identical with that of siderite, it is called mangano-siderite. It appears to be earlier than the uraninite and sulfide minerals in the deposit.

Barite.—Barite has been identified at the Happy Jack and Hideout mines, where it occurs with sphalerite as a replacement and cavity filling in carbonized wood. The barite is in the form of small white bladed crystals. Barite veinlets were found in uraninite and the carbonates at the Hideout mine. Most of the barite may have been introduced by the ore-bearing solutions or may be due to recent oxidation of the sulfide minerals in the mines. Some of it may originally have been present in the host rock.

Gypsum.—Gypsum is an abundant gangue mineral in most of the uranium deposits. The mineral commonly is associated with goethite, jarosite, hematite, manganese oxide, and secondary copper and uranium minerals. The gypsum generally is in the form of colorless or white fibrous crystals that have been deposited along fractures, interstitially in porous sandstone and conglomerate, in cavities, and in rims coating fragments of coal. Some of the crystals are in rosettes.

Most of the gypsum probably formed by the oxidation of sulfide minerals to free sulfate ions and the subsequent combination of the sulfate with calcium ions and water. This secondary gypsum probably formed continuously during the oxidation of the iron sulfides and concurrently with the iron oxides and jarosite.

Jarosite.—Jarosite occurs in abundance in nearly all the uranium deposits in the area. At the Jomac mine where the uranium occurs in pieces of coal near the base of the Shinarump member of the Chinle formation, the jarosite is a useful guide in the exploration of the deposit.

The jarosite is one of the earliest oxidation products of pyrite; it is most abundant where supergene copper sulfides have been deposited in the outer part of the unoxidized ore zone, though it also occurs in the oxidized zone. The jarosite forms the interstitial fillings of some of the sandstone, conglomerate, and siltstone, fills fractures cutting many of the grains of these rocks, and replaces feldspar grains along cleavage traces. The jarosite generally is earlier than the iron oxides that cut and replace it. Oxidation in arid rather than humid climate is believed to favor the deposition of jarosite (Locke, 1926, p. 107).

Pickeringite.—Cobaltous pickeringite occurs in abundant amounts at the Scenic No. 4 claim on Fry Point where it has been identified by Alice D. Weeks (written commun., 1952). The mineral occurs at the outcrop in nodular masses as much as 6 inches in diameter. These nodules are composed of pinkish-white long acicular crystals.

Alunite.—Fine-grained alunite occurs in the zone of oxidation at several of the deposits in the area. The mineral generally forms white to light-pink discontinuous patches on fractures cutting the Shinarump member of the Chinle formation; minor replacement of siltstone by alunite outward from the fractures has taken place.

The alunite could easily have been formed from the sulfate derived from the oxidation of pyrite and chalcopyrite; the potassium and aluminum contained could have been derived from the feldspar and clay minerals in the enclosing rock.

Erythrite.—Erythrite, pink cobalt bloom, has been found as coatings on some of the walls at the Happy Jack and Fry No. 4 mines. The mineral is particularly common as a coating on siltstone and coarser grained rocks containing abundant siltstone matrix; it commonly is associated with jarosite. The coatings are nowhere thick; they are a very pale pink and are not conspicuous. No primary cobalt-bearing minerals have been found in the mine.

Opal.—Light-brown and black opal has been identified at the North Point claim. The black opal occurs as a filling of small fractures cutting sandstone of the Shinarump member; it is surrounded by fluorescent light-brown opal that is disseminated in the same sandstone. Both the light and dark forms contain traces of uranium.

Sepiolite.—A small amount of very pale blue sepiolite was found coating a fracture surface in the oxidized zone at the Happy Jack mine. The mineral is compact and feels smooth. The sepiolite was examined by Robert S. Jones, of the U.S. Geological Survey, who found it to be a mixture of beta-sepiolite and alpha- or para-sepiolite.

Allophane.—Greenish-blue, blue, and yellow allophane is a late secondary mineral that has been deposited in the oxidized zone. The mineral has been identified at the North Point and Ears claims and at the Joe Bishop mine where it coats fracture surfaces. The allophane is associated with gibbsite and manganese oxides at the North Point claim, with cuprite and antlerite at the Ears claim, and with uranophane at the Joe Bishop mine. The mineral from the North Point claim fluoresces brilliant yellow under ultraviolet light, and the sodium fluoride flux test indicates traces of uranium. A trace of copper apparently imparts the greenish or bluish color to some of the allophane.

HOST ROCK MINERALS

DETRITAL

Quartz.—Quartz is overwhelmingly the most abundant host rock mineral in the uranium deposits. Most of the quartz occurs as round to subangular grains, ranging from the size of silt particles to cobbles in the Shinarump member of the Chinle formation. It is coarsely crystalline, colorless, and similar in appearance to that commonly found in pegmatites. Some of the grains of quartz have an undulating extinction, which suggests that they were subjected to stress before their removal from their source rocks. In some places the quartz appears light to medium gray; it is not known if this discoloration is due to radioactive bombardment or to dark sulfide minerals surrounding this quartz.

Chalcedony.—Grains of chalcedony make up a trace to nearly 5 percent of the sandstone in most of the ore bodies in the White Canyon area, and scattered pebbles of red chalcedony (var. jasper) have been found in the conglomerate at the Markey mine in Red Canyon.

The chalcedony grains range in diameter from 0.25 to 1.25 mm; they are subround to round and generally are more round than grains of quartz and feldspar. A slight amount of clay alteration has been noted in some of the chalcedony, but secondary silica has not been added to the grains. The red jasper pebbles are subround and are as much as an inch in diameter.

Feldspars.—Microcline is by far the most abundant feldspar in the host rocks. The other feldspars are present only in insignificant amounts. The microcline is common in sandstone and conglomerate of the Shinarump member of the Chinle formation and is present in all the uranium deposits. In the specimens studied, the microcline grains range in diameter from about 0.5 to 2.0 mm; they generally are more angular than other grains in the sandstone. Many of the microcline grains are cleavage fragments. Probably all the microcline was deposited with the sediments; some of it has been altered to hydrous mica and kaolinite.

Muscovite.—Flakes of muscovite are present locally in the Shinarump member of the Chinle formation, especially in the upper part. Muscovite is especially abundant in the sandstone beds above the ore-bearing strata at the Jomac mine where it constitutes as much as 3 percent of some of the rock. The muscovite appears to have been deposited with the other grains and shows very little alteration.

Hydrous mica.—Hydrous mica occurs in cobbles and pellets of clay and silty clay; as a cement of sandstone, conglomerate, and siltstone; and as pseudomorphs after grains of microcline. The color commonly is gray, which has been imparted by carbonized vegetal material; locally, the clay is colored yellow by jarosite and brown by goethite. No simple method has been found to distinguish between the clay minerals; the hydrous mica, therefore, is difficult to distinguish from kaolinite and other clay minerals in the field. Claystone and siltstone containing hydrous mica seem to be more plastic than similar rocks containing kaolinite, but the plasticity may depend principally upon the amount of quartz grains in the rock.

Kaolinite.—Kaolinite is present in both mineralized and barren strata of the Shinarump member in the area. It forms the cement in much of the sandstone, conglomerate, and siltstone, and commonly contains carbonized vegetal remains. The kaolinite contains disseminated grains of sulfide minerals in some of the deposits. Probably most of the kaolinite deposited as a sediment. Locally the kaolinite is associated with hydrous mica.

The kaolinite commonly is in the form of a mosaic of fine grains filling the spaces between the quartz grains.

Zircon.—Zircon is a common accessory mineral of the Shinarump member. Spectrographic analyses of samples of the Shinarump member show a relatively small range in the content of zirconium, indicating that the amount of zircon is fairly constant throughout the beds sampled.

Tourmaline.—Tourmaline is a common heavy mineral in the sandstone and conglomerate of the Shinarump member. The tourmaline occurs as elongate grains less than 0.5 mm long.

Chlorite.—Chlorite associated with kaolinite and quartz has been identified in clay beds at the North Point claim.

CEMENT AND AUTHIGENIC MINERALS

Pyrite.—Small blebs and crystals of authigenic pyrite are common throughout the Chinle formation.

Calcite.—Calcite is abundant throughout the Chinle as limestone and limy beds, as a cementing agent, and as crystalline fracture and cavity fillings. Most of the calcite was deposited as a limestone, but the calcite found in the sandstone and conglomerate of the Shinarump member probably has been transported and redistributed by circulating solutions.

Gypsum.—Gypsum fairly commonly is scattered throughout the Chinle formation as fracture fillings. Gypsum(?) also is found as a cementing agent in the Rico formation and possibly may be a minor cementing agent in the Chinle formation. Some of the gypsum may represent gypsum deposited as an evaporite during the time the sediments were laid down. The rest probably is of secondary origin, the sulfate coming from the oxidation of pyrite.

Quartz.—Secondary quartz, in optical orientation with the original grains, has been deposited on much of the detrital quartz. This authigenic quartz commonly is bounded by crystal faces and is especially well developed in medium-grained to very coarse grained sandstone that has only a small amount of clay cement. The authigenic quartz overgrowths have increased the angularity of most of the grains. The secondary quartz is embayed and replaced by uraninite, pyrite, and chalcopyrite, which tend further to increase the angularity of the quartz grains. Although high-grade uraninite-bearing ore nearly always is in sandstone or conglomerate containing abundant secondary silica overgrowths, the authigenic overgrowths are far more widespread in the area than are the uranium minerals.

Chalcedony.—Red chalcedony (jasper) occurs as small lenses near the base of the Chinle formation on Deer Flat and below the bench formed of the Moss Back member south of the head of Fry Canyon. Some of this jasper is slightly abnormally radioactive.

The jasper is interlayered with hematite and calcite, and much of it has a spherulitic or radiating aggregate texture of the type described by Schwartz (1951).

Opal.—Very small amounts of opal are in the Shinarump member of the Chinle formation throughout the White Canyon area both as detrital grains and as slightly uraniferous hyalitic opaline fracture coatings.

ALTERATION PRODUCTS

Hematite and goethite.—Hematite and goethite are widespread but not abundant throughout much of the Chinle formation. They occur as disseminated orange to brown cements and interstitial fillings and locally are abundant enough to give the rocks a reddish-brown color. They are concentrated on weathered surfaces and surround small pieces of partially oxidized pyrite.

Psilomelane.—Small amounts of black manganese oxide, probably psilomelane, have been found coating fracture surfaces and disseminated in sandstone and conglomerate in many places in the Shinarump member of the Chinle formation. The mineral commonly is associated with secondary copper minerals and goethite, and does not appear to be more concentrated in uranium deposits than elsewhere. The manganese oxide probably was derived from the oxidation of manganese that was contained in a carbonate in the beds. The results of semiquantitative spectrographic analyses made by J. N. Stitch, of the U.S. Geological Survey, of three samples of black manganese oxide from the North Point claim suggest that cobalt is contained in large amounts (table 4).

Malachite.—Malachite is common in outcrops of the Shinarump member of the Chinle formation away from known ore deposits. The mineral also has been found locally in bleached fractures cutting fine-grained sandstone of the Organ Rock member of the Cutler formation and in one exposure of the basal conglomerate of the Moenkopi formation north of the Four Aces mine.

TABLE 4.—*Semiquantitative spectrographic analyses of manganese and iron oxides, North Point claim, White Canyon area*

[Semiquantitative spectrographic determinations made by the rapid visual-comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Analyst, J. N. Stitch]

Mineral	Percent		
	>10	1.0–10	0.1–1.0
Dull black manganese oxide coating fracture surface.[1]	Si, Co, Mn, Al	Ni, Ca, Na, Mg, Cu, Fe, Zn.	K, Zr, Ba
Black manganese oxide veinlet cutting basal Shinarump member of Chinle formation.[1]	Co, Mn, Si, Al	Cu, Ni, Zn, Mg, K, Fe, Ti, Na.	Pb
Shiny black manganese oxide coating fracture surface.[2]	Si	Co, Na, Mn, Al, K, Fe.	Ca, Ni, Mg.
Goethite coating fracture in siltstone of the Shinarump member of the Chinle formation.	Fe, Si	Al, Na, K, Mg.	Cu, Ca, Ti, Mo, Ba.

[1] Gives positive flux test for uranium.
[2] Gives negative flux test for uranium.

The malachite occurs as impregnations in sandstone, fracture coatings, and streaks in bedding-plane partings. It is intimately associated with carbonaceous material, azurite, jarosite, and gypsum.

Azurite.—Azurite occurs in the Shinarump member of the Chinle formation away from known ore deposits in a manner similar to that of malachite. It is very closely associated with the carbonaceous material in these occurrences.

Jarosite.—Jarosite is widely scattered throughout the Chinle formation. It occurs as light-yellow to yellow-brown earthy interstitial material and fracture fillings. It probably is an oxidation product of the authigenic pyrite in the sediments.

Kaolinite and hydrous mica.—Both kaolinite and hydrous mica have been formed by the alteration of microcline grains, and locally they are associated with each other. Pseudomorphs of hydrous mica after microcline grains have been observed. In a few places grains of chert have been partially replaced by kaolinite.

UNOXIDIZED ORE

An unoxidized ore zone is present in all the uranium deposits except those underlying benches developed on the Shinarump member of the Chinle formation, such as at the Posey mine, in which the entire ore deposit has been oxidized. The unoxidized ore consists of uraninite associated with pyrite, chalcopyrite, and bornite in most of the deposits, with sphalerite in some of the deposits, and with galena at the Happy Jack, Hideout, and W. N. mines.

With increased mining in the area and the discovery of new deposits thousands of feet behind the outcrop, the tonnage of unoxidized ore mined steadily increased until by 1955 it comprised a substantial part of the total output. Every deposit that has been mined to a distance of more than 50 feet from the outcrop, except those beneath benches formed of the Shinarump, has yielded some primary sulfide minerals, and those mined to distances of more than 200 feet from the outcrop have yielded abundant sulfide minerals and uraninite. Most of the unoxidized ore consists of high-grade zones separated by low-grade zones, and in most of the deposits the grade of the high-grade ore is sufficient to permit dilution by the low-grade material in mining. No primary zoning has been noted in the unoxidized zone, though there are local concentrations of chalcopyrite, uraninite, sphalerite, and galena in some of the deposits.

The size and shape of the unoxidized ore deposits (p. 90) probably have not been modified significantly since the time of mineralization, except in those deposits that have been exposed by dissection. Oxidation of the outer parts of the deposits appears to have had little effect in altering their size or shape.

The unoxidized deposits are thin and tabular, with roughly elliptical outline, except when bounded along an edge by a large siltstone or claystone lens such as at the Blue Lizard mine. Three types of ore deposit are recognized in the unoxidized zone, based on the mode of occurrence of the uraninite. They are (a) replacements of "trash" accumulations, (b) bedded deposits, and (c) replacement of large wood fragments. Each type is present at the Happy Jack mine, and they have been described by Trites and others (1959).

Replacement of "trash" accumulations is the most important type of deposit in most of the mines and has yielded the bulk of the ore from the unoxidized zone. The uraninite and sulfide minerals have replaced fragments and finely divided (powdery) organic matter, and are disseminated in sandstone in this type of deposit. The uraninite commonly is distributed throughout lenticular beds which range in length from 50 feet to several hundred feet, in width from 25 to 50 feet, and in thickness from a fraction of 1 inch to 3 feet. Deposits of this type contain as much as 5 percent U_3O_8 and 12 percent copper.

Bedded deposits are localized at lithologic contacts, where the ore minerals have replaced siltstone seams. Deposits of this type are common in many of the mines, but contribute only a small percentage of the total ore produced. Bedded deposits range in length from 1 to 25 feet, in width from 6 inches to 10 feet, and in thickness from 0 to slightly more than 1 foot. Samples collected from deposits of this type contained as much as 20 percent U_3O_8 and commonly less than 0.05 percent copper.

Large wood fragments occur sparsely in some of the "trash" replacement and bedded deposits; a few have been replaced by uraninite and sulfide minerals at the Happy Jack, Blue Lizard, and Hideout mines. Deposits of this type are insignificant in size compared to the other two types, and contribute very little of the ore produced in the area. They contain as much as 16 percent U_3O_8 and 10 percent copper.

PARAGENESIS OF THE ORE MINERALS

Paragenesis of the uraninite and sulfide minerals has been studied principally in specimens from the Happy Jack, White Canyon No. 1, and Hideout mines. The primary ore in most deposits consists mainly of pyrite, about one-tenth as much chalcopyrite, and smaller amounts of uraninite, sphalerite, and bornite. Galena is present locally in the Happy Jack, Hideout, and W. N. mines.

The uraninite and sulfide minerals probably were deposited in one stage of relatively short duration. Their paragenesis in the Happy Jack mine is given in figure 23.

Uraninite is associated with pyrite and chalcopyrite in most of the deposits, with bornite, marcasite, and sphalerite in a few of the deposits, and with galena at the Happy Jack mine. Uraninite that has replaced wood fragments and fine-grained organic matter commonly is associated with chalcopyrite and pyrite; in a few fragments in some deposits uraninite is closely associated with sphalerite. Crosscutting relations indicate that the uraninite is later than most of the sulfides, though it is partly simultaneous with some of the chalcopyrite and bornite. It is earlier than sphalerite in most of the deposits.

Pyrite probably is the earliest sulfide mineral to have been deposited in the ores of the White Canyon area, although pyrite of two generations has been noted at the Hideout mine. A second generation of pyrite was not seen in other deposits, but Robert G. Coleman (written communication, 1955) has found two generations of pyrite in many deposits elsewhere on the Colorado Plateau.

The pyrite has been replaced by uraninite, galena, and chalcopyrite in the unoxidized zone. It is embayed and veined by the chalcopyrite, and in places has an "exploding bomb" texture (Schwartz, 1951, p. 589). Where pyrite is largely replaced by chalcopyrite, it remains as small enclosed crystal fragments and blebs. Some pyrite is separated from the enclosing chalcopyrite by a rim of unreplaced carbonized wood.

Some remnants of pyrite are enclosed in supergene chalcocite that has replaced chalcopyrite; it also occurs in the zone of oxidation in various stages of replacement by hematite and goethite.

Chalcopyrite appears to be definitely later than the pyrite and the galena, and may be simultaneous with some of the bornite and uraninite. Chalcopyrite occurs as crystallographic intergrowths in some of the bornite. Intergrowths such as these have been attributed by some workers (Schwartz, 1931) to an unmixing of solid solution at relatively high temperatures (473°C) and by others (Ray, 1930) as replacement of bornite by chalcopyrite at low temperatures (90° to 100°C). Some of the bornite is in irregular veinlets cutting and replacing chalcopyrite and is definitely later than the chalcopyrite. At the Hideout mine, however, chalcopyrite completely surrounds some bornite grains and penetrates bornite along cleavage; the orientation of the replacement is determined by the orientation of the cleavage. Chalcopyrite commonly rims fragments of wood that have been replaced subsequently by uraninite, sphalerite, and supergene sulfide minerals. It has embayed many quartz grains.

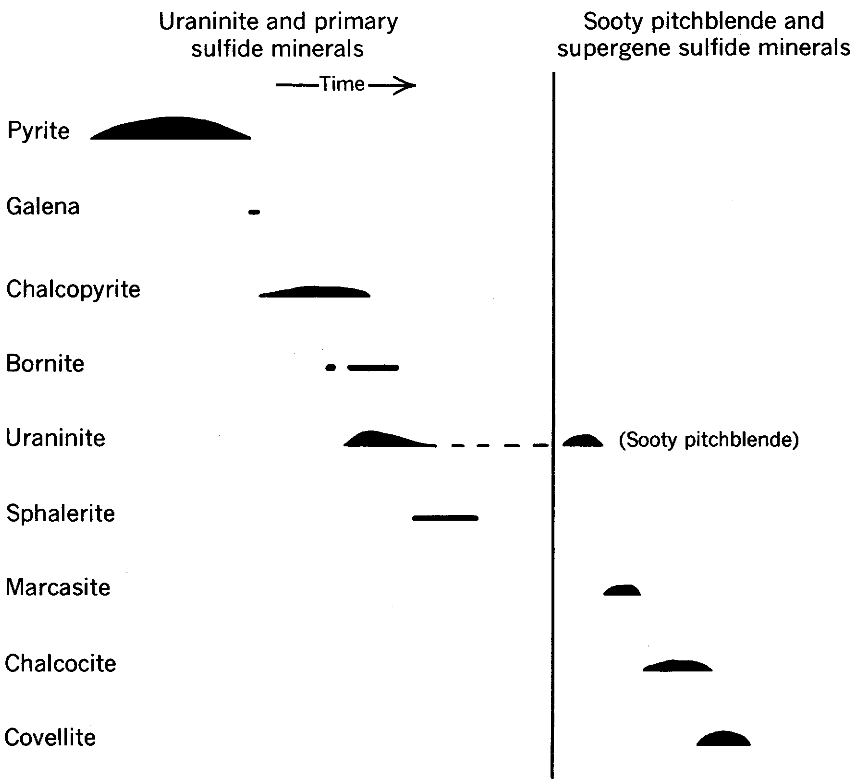

FIGURE 23.—Chart showing age relations of uraninite and sulfide minerals, Happy Jack mine, White Canyon area.

Chalcopyrite has been partly replaced by supergene chalcocite and covellite in a network of veinlets. Where supergene replacement has been extensive, small rounded or irregular masses of chalcopyrite remain in the chalcocite; some pseudomorphs of chalcocite after chalcopyrite crystals have been noted. Chalcopyrite containing relict pyrite has been replaced by chalcocite in preference to the pyrite so that similar-sized relicts of pyrite remain in both the chalcopyrite and chalcocite. Such preferential replacement of chalcopyrite over pyrite by chalcocite has been noted by Schwartz (1953, p. 36) in the San Manuel copper deposit in Arizona.

Many of the chalcopyrite masses and crystals in the oxidized ore bodies are rimmed and replaced by goethite and hematite. These iron oxides also occur as rims between relict pyrite grains and the enclosing chalcopyrite and apparently have replaced the chalcopyrite in preference to the pyrite. Most of the iron oxides replacing the chalcopyrite are light orange. Locke (1926) has described similar light-colored iron oxides and ascribes them to the oxidation of copper minerals.

Sphalerite probably is younger than the pyrite, chalcopyrite, and much of the uraninite, which it has veined and replaced. This is contrary to the observations of Bateman (1950, p. 107), who has stated that in many of the sulfide deposits of the world, sphalerite is one of the earliest sulfide minerals formed. It occurs principally as fracture fillings in uraninite and the other primary sulfides; it also fills fractures and cavities in carbonized wood. The sphalerite is veined and replaced by the supergene sulfides chalcocite and covellite.

Galena has been observed in a few specimens from the Happy Jack, Hideout, and W. N. mines, and its relationship with all the sulfide minerals has not been well established. It has not been found in contact with bornite or sphalerite, but it is apparently earlier than uraninite and all the primary sulfide minerals except pyrite; it is veined and replaced by chalcopyrite and is rimmed and partly replaced by supergene covellite.

Bornite seems to be both contemporaneous and slightly later than the chalcopyrite in the White Canyon area. The earliest bornite is intergrown with the chalcopyrite and was replaced by it; bornite continued to form after chalcopyrite deposition had ceased. The partial contemporaneity of the bornite with the chalcopyrite suggests that the bornite is a primary sulfide mineral and not supergene in origin. The bornite has been cut and replaced by the supergene sulfides chalcocite and covellite.

OXIDIZED ORE

The main factors which affect the extent and degree of oxidation of the ore deposits are—

1. (a) The proximity of the deposit to the outcrop,
   (b) The thickness of Chinle and higher beds overlying the ore deposit;
2. (a) The permeability of the Shinarump member of the Chinle formation between the deposit and the outcrop,
   (b) The amount and extent of fracturing of the Shinarump and enclosing rock in the deposits and adjacent to them,
   (c) The availability of meteoric and ground water,
   (d) The orientation of the regional structural trend with respect to the ore deposits,
   (e) The size and orientation of the drainage area in which a deposit is located,
   (f) The pH of ground water or meteoric water in, or moving through, a deposit;
3. (a) The amount of carbonized vegetal material in a deposit, and
   (b) The character of the unoxidized ore.

Oxidation has been extremely variable in most of the deposits; relict concentrations of uraninite and sulfide minerals remain locally within the oxidized ore and small areas of thorough oxidation are found within ore which otherwise shows little, if any, oxidation. However, all the uranium deposits at or near the surface have been oxidized. Deposits such as the Posey, Joe Bishop, and Yellow John, which underlie a bench formed of the Shinarump member, have been so completely oxidized that little, if any, uraninite and sulfide mineral material remains.

Deposits such as those at the Happy Jack, Hideout, Fry No. 4, and W. N. mines crop out in the sides of canyons, but they are covered by sufficient overburden that even though oxidized zones have been developed, some unoxidized ore remains within a few feet of the outcrop. Other deposits such as those at the Gismo, Blue Lizard, Spook, and Maybe mines, which are beneath thick cover thousands of feet from the nearest outcrop, have been oxidized weakly or not at all.

The permeability of the Shinarump member between the unoxidized ore and the outcrop also affects the depth of oxidation, and may produce irregular boundaries with the unoxidized zone. Impervious beds will seal off oxidizing solutions and thereby prevent parts of the ore from being oxidized. Relict concentrations of uraninite and sulfide minerals within the oxidized zone probably escaped oxidation because of the imperviousness of their enclosing rocks. The nature of most of the mineralized Shinarump, which commonly consists of sandstone with interbedded siltstone and claystone lenses, is such as to restrict locally the movement of oxidizing solutions and to produce erratic oxidation. Also, concentrations of uraninite and sulfide minerals lo-

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cally have sealed all pore spaces in the rock, making it impermeable to oxidizing fluids. Such concentrations of primary minerals remain unoxidized.

The amount and extent of fracturing in the Shinarump member and in the overlying beds probably controlled, to some extent, the distance that oxidation has advanced behind the rim. The Shinarump generally contains large closely spaced fractures near the outcrop and small widely spaced fractures away from the outcrop. The large fractures have produced avenues for the passage of oxidizing solutions and moist air to rock behind the outcrop, and oxidation has advanced outward from these fractures into the surrounding rock. The depth of oxidation is a function of the size, continuity, and trend of the principal fractures. Where the principal fractures strike at a slight angle or parallel to the outcrop of the Shinarump the oxidation does not advance as far, but its boundary is more regular than if the principal fractures strike at a large angle to the outcrop. Lenticular bodies of concentrated uraninite and sulfide minerals have been cut by fractures, on one side of which the sulfide minerals have been completely oxidized and the uraninite removed. Fracturing of the beds above the Shinarump member also has produced passageways for oxygen-charged meteoric water and probably explains some of the oxidized areas well within the sulfide zones.

Most of the ore deposits in the White Canyon area are on benches midway between the canyon floors and the overlying cliffs of the Glen Canyon group. The canyon cutting, to stratigraphic levels far below that of the ore deposits, has lowered the water table, leaving the deposits dry. In addition, the small annual precipitation, which normally occurs as cloudbursts with accompanying rapid runoff, coupled with the present small drainage areas above the ore bodies, contributes little aerated water to most of the ore deposits and causes little oxidation of them.

Oxidation of a deposit is not dependent primarily upon its location with respect to the outcrop, nor is it dependent primarily upon its orientation with respect to the regional dip. The deposit at the Blue Lizard mine is updip from the outcrop of the Shinarump at the rim, and may be expected to have had less meteoric water moving through it than a deposit downdip from the outcrop. The deposit at the Blue Lizard mine is, in fact, dry and is only slightly oxidized. Its dryness is probably attributable largely to the fact that it is deeply buried beneath impermeable sediments of the Chinle formation and is downslope from a small drainage area. On the other hand, the W. N. and other deposits on Deer Flat and the Fry No. 4 deposit, which are also updip from the outcrop of the Shinarump at the rim, show evidence of considerable leaching and considerable oxidation. These deposits have only a thin cover of overlying Chinle and all are at the downslope and generally downdip end of large drainage areas. Arguments comparable to these can also be made for deposits downdip from outcrops. For instance, the Happy Jack deposit is slightly downdip from the outcrop and should have a well-developed zone of oxidation. It does. Other deposits downdip from the outcrop may not be oxidized at all.

Ore deposits which are within channels that are parallel to the regional dip tend to have better developed zones of oxidation and to show evidence of more leaching than those which are normal to the dip. It is likely that meteoric and ground water can move easily in the direction in which the sediments are oriented, but only with difficulty where it must pass through them crosswise. Channels parallel to the dip also act as conduits for the passage of water trapped above the relatively impermeable Moenkopi, whereas water moving into channels that are normal to the regional dip are dammed by the downdip channel bank. Perhaps the fact that most of the channels in the White Canyon area are parallel to the regional dip also explains why most of the channels in the area contain no ore.

All channels studied in the White Canyon area have irregular floors. Scours several feet deep are cut below the mean level of the base of each channel. These scours originally were the sites of deposition of organic "trash." When the mineralizing solutions moved through, these scours became the loci of rich ore. They now tend to hold water as perched stagnant water tables above the underlying relatively impermeable Moenkopi. Sulfuric acid is produced by the action of the oxygen in the water with the pyrites of the ores, and the carbonaceous material probably also acts to maintain a reducing environment. This is suggested by the presence of ferrous iron as jarosite with abundant carbonized wood at the outcrop of some of the ore deposits. This stagnant acidified water tends to remain in the small scour basins while additional water, charged with carbonic acid derived from the overlying Chinle formation, moves through the upper part of a deposit leaching it, oxidizing it, and depositing metallic salts near the outcrop. Probably this is why the richest and least oxidized ore is in scour pockets at the base of most ore deposits and why the richest ore in many places is also the wettest ore. The reducing environment produced by vegetal material also may be important in preserving the relict concentrations of uraninite and sulfide minerals in parts of deposits which are otherwise oxidized. Areas of abundant carbonized material have not been nearly as well oxidized in the Happy Jack mine as areas with little or no carbonaceous material.

The most abundant uranium minerals in the oxidized zone are the hydrous phosphates metatorbernite, phosphuranylite, and meta-autunite; the hydrous arsenate metazeunerite; the hydrous sulfates uranopilite, johannite, and a zippeitelike mineral, and the hydrous silicate uranophane. The hydrous uranium carbonate bayleyite and the carbonate-sulfate schroeckingerite have been found in small amount coating mine walls at the Hideout mine, and small quantities of sooty pitchblende have been found at the Happy Jack mine. The secondary copper minerals include the sulfates chalcanthite, brochantite, and antlerite, the carbonates malachite and azurite, the oxide cuprite, and native copper, in addition to the combined copper-uranium minerals. Most of the secondary minerals have formed disseminations in sandstone, conglomerate, and siltstone; some have been deposited as coatings on fracture surfaces and on parting planes in siltstone. The sulfates johannite, chalcanthite, and the zippeitelike mineral form efflorescent coatings on the mine walls.

These secondary uranium and copper minerals generally are associated with goethite, hematite, jarosite, and gypsum. Most of the secondary iron minerals and the gypsum probably were derived mostly from the oxidation of the pyrite and chalcopyrite.

Jarosite likely was the first mineral formed during the solution of the primary iron-bearing sulfide minerals and is found in the oxidized zone and in the outer part of the unoxidized zone. Hematite is commonly formed around, or pseudomorphic after, grains of sulfide minerals. Both jarosite and hematite have been altered to goethite in the oxidized zone. Iron oxides have been disseminated in the sandstone, have been deposited along fractures, and have replaced wood fragments, some of which were at one time replaced by sulfide minerals. Jarosite commonly is in the sandstone as impregnations in the cement and as fillings between the grains of the sandstone. The gypsum commonly has coated the surfaces of fractures.

Uranium, copper, manganese, and other of the more soluble elements of the sulfide ore have been scattered by solution and redeposition along the outcrop and in the inner part of the Shinarump member of the Chinle formation, but have not materially affected the sizes and shapes of the deposits. Garrels (1955, p. 59) examined many deposits on the Colorado Plateau and concluded that oxidation did not greatly affect the volume of the ore body. He suggested that the increase in volume was not more than a factor of 0.2. The writers believe that the increase in the size of most of the deposits in the White Canyon area is less than 0.1. Where vanadium or other fixing agents, such as phosphate and arsenate, are not present to act as precipitants, much of the uranium may be lost to surface waters as carbonates or sulfates. Copper is combined with uranium in several of the secondary minerals, but all of these are relatively much more soluble than carnotite. The uranium-copper deposits, therefore, would not be expected to contain as extensive oxidized zones as do some of the uranium-vanadium deposits elsewhere on the Colorado Plateau.

SUPERGENE ENRICHMENT

Copper and perhaps uranium have been enriched in many of the deposits in the White Canyon area. Supergene enrichment has been particularly active in the Happy Jack, White Canyon No. 1, and Hideout deposits where the supergene sulfide minerals chalcocite and covellite occur in various stages of replacement of chalcopyrite, bornite, galena, and pyrite. Small remnants of unreplaced chalcopyrite are abundant in much of the chalcocite; pyrite has been replaced only slightly and commonly remains as unreplaced blebs in the chalcocite. The covellite is much less abundant than chalcocite and commonly occurs as feathery masses in chalcocite or unreplaced chalcopyrite. The relation between chalcocite and covellite is not clearly shown, but a few crosscutting relations suggest that the covellite is slightly younger than the chalcocite.

The limits of the enriched copper are poorly defined, and no attempt has been made to map them or to define a zone of supergene enrichment in any of the deposits. The presence of supergene chalcocite and covellite, rather than the amount of enrichment in copper content, is used to indicate the presence of enrichment in the deposits. The total amount of copper enrichment has not been great and has not materially affected the ore payments to the producers. The records of ore shipments from the Happy Jack, Hideout, and Posey mines show that the copper content of the ore increased from about 1 to 2 percent near the outcrop to about 3 to 4 percent from a few tens of feet to a few hundreds of feet from the outcrop; the content then diminished to a low, but more uniform, value of about 0.5 to 0.8 percent deep within the deposits.

The amount and distribution of the supergene copper minerals depend in many places upon the amount of the primary copper sulfide minerals, especially chalcopyrite. Secondary copper sulfides form only small scattered disseminations in the outer parts of those ore bodies that contain mainly pyrite with minor chalcopyrite as the primary sulfide minerals. Thus, differences in the amount of enrichment of copper may be explained by the differences of primary mineralization.

Also, in order for supergene enrichment to take place to any appreciable extent, it apparently is necessary for the deposit to be exposed at the surface. Deposits such as the Blue Lizard and the Maybe which occur several hundred feet behind the outcrop of the Shinarump member are oxidized to a small extent, but they show little, if any, supergene enrichment of copper. However, supergene enrichment of copper has been especially pronounced in deposits such as that at the Posey mine in which the Shinarump member is exposed as a bench. The copper has been enriched throughout the deposit; an especially high concentration is in an area less than 100 feet from the portal of the mine.

The degree to which supergene copper (and uranium) enrichment has developed in the deposits probably also depends upon the structural and stratigraphic setting of the deposits and the relation of this setting to topography. Certainly, a large part of the copper and most of the uranium that are freed from primary minerals by oxidation are lost to surface waters at the outcrop. Also, waters gaining access to the ore deposits by moving down through fractures near the outcrop will move, in part, outward toward the outcrop and in part deeper within the deposit. The movement of this water in the Shinarump member is governed largely by the slope of the base of the Shinarump and other controlling surfaces (such as the surfaces of siltstone seams and lenses). A deposit so located that most of the meteoric waters move deeper into it by virtue of the deeper part of the channel being behind the rim, will be in a favorable environment for enrichment. The Happy Jack deposit is an excellent example. It is both downdip and down the flank of the channel from the outcrop.

Enrichment of copper, iron, and perhaps uranium is well developed at the Happy Jack mine. The outer edge of the unoxidized ore zone is about 200 feet from the outcrop of the deposit and is roughly parallel to the outcrop, although relict lenses of unoxidized ore extend into the oxidized ore to within about 50 feet of the outcrop. Chalcocite and covellite, probably of supergene origin, have been deposited by replacement of primary sulfide minerals in the outer part of the unoxidized zone and especially in the inner parts of the oxidized zone where the relict lenses are concentrated. Iron may also have been slightly enriched by the deposition of marcasite in this deposit.

Uranium apparently has been enriched, both in sulfide-bearing sandstone and in siltstone, at the Happy Jack mine. The average ratio of uranium to equivalent uranium (U : eU) is significantly greater than 1.0 in siltstone throughout most of the mine, even in siltstone beds in the oxidized zone. Likewise, this ratio is greater than 1.0 in the outer parts of the unoxidized zone and in unoxidized relicts in the oxidized zone. The best interpretation, perhaps, is that uranium has been leached from the uraninite in permeable sandstone in the oxidized zone and reconcentrated in the nearby siltstone and unoxidized sulfide-bearing sandstone. Another good interpretation is that radioactive daughter products have been removed from the samples which contain much uranium. Radiochemical analyses indicate that this interpretation may be just as good as the first. The absence of the colorful secondary hydrous compounds of uranium in much of the siltstone and in the unoxidized ore bodies suggests that the uranium may have been deposited as sooty pitchblende. Uranium has greater solubility than copper. This suggests that some of the uranium would have traveled farther than the copper and thus secondary enrichment of uranium might be expected deeper within the unoxidized ore than secondary enrichment of copper. However, the enrichment of uranium evidently is small, for average uranium values in unoxidized ore are not significantly higher than those in oxidized ore.

Oxidation and enrichment of the copper-uranium deposits in the White Canyon area are in contrast with vanadium-uranium deposits elsewhere on the Colorado Plateau. No secondary enrichment zones have been described in the uranium-vanadium deposits. The oxidation of vanadium-uranium deposits have been described by Garrels (1955 a, b). The oxidation products of vanadium-rich ores, the vanadates and vanadium silicates, are only slightly soluble and persist for a long time in the oxidized zone if in a relatively dry environment.

SELECTED DEPOSITS

BELL CLAIM

The Bell claim is in the Shinarump member of the Chinle formation beneath a bench formed of the Moss Back member near the head of Fry Canyon at an altitude of about 6,420 feet. A rough steep mine road, passable only to four-wheel-drive vehicles, connects the workings with the graded road in Fry Canyon and a better mine road connects the workings with Utah State Highway 95 at a point near the Natural Bridges National Monument.

The mine workings consist of a main adit that extends N. 88° E. for 50 feet and a side drift that trends due south for 15 feet and then turns S. 56° E. for 105 feet. The side drift connects with the main adit about 15 feet from the portal. The workings were driven by William Randolph and Edward Baird in the summer of 1951 at which time the mine was first examined by members of the U.S. Geological Survey. Shipments were made until November 1951, when mining operations were suspended because of the low grade and the high calcium carbonate content of the ore. The mine has been idle since that time. A series of holes was drilled on the property in 1952 by the U.S. Atomic Energy Commission in an attempt to find additional reserves and to determine the trend of the channel. However, only a few holes were drilled and neither objective was achieved.

The mine workings were driven into a deposit in a channel that was cut into the top of the Moenkopi formation and filled with sediments of the Shinarump member of the Chinle formation. The channel has not been clearly defined, but the trend of cross-stratification and the orientation of the wood fragments suggest that it trends N. 80° W. It is from 100 to 150 feet wide and slightly less than 10 feet deep at the outcrop.

The Shinarump member is 25 to 30 feet thick at the outcrop; it consists of interbedded sandstone, siltstone, and conglomerate. The basal part of the Shinarump is a siltstone-pebble conglomerate, as much as 2.5 feet thick, composed of angular fragments of bleached siltstone of the Moenkopi formation in a matrix that varies from very fine grained sandstone to siltstone. This basal conglomerate is in most places overlain by a thick bed of pale-brown medium-grained sandstone that has an average thickness of about 5 feet; this bed is interlayered with other sandstone and siltstone beds in the main adit and it pinches out to the north near the face of the adit. The cross-stratification in this sandstone dips 6°–9° W. to N. 72° W. The sandstone consists of about 70 percent quartz grains and a small amount of clay cemented by calcite. The thick bed of sandstone is overlain by thinner beds of siltstone, sandy siltstone, conglomeratic sandstone, and conglomerate.

Small pieces of carbonized wood are abundant in some of the siltstone and fine-grained sandstone; larger pieces of wood that have been replaced by iron oxide, secondary copper minerals, and secondary uranium minerals occur locally in the coarse-grained sandstone. Much of the Shinarump member has been impregnated with geothite, hematite, and secondary copper minerals, and locally it contains seams of gypsum and calcite.

The regional dip is slightly less than 2° S. 80° W. at the Bell claim. The Shinarump member is broken by two sets of joints of about equal spacing and strength of development. One joint set strikes N. 40°–60° E. and the other set strikes north to N. 20° E.; both sets dip 75° NW. to vertical.

Visible uranium minerals occur in the basal 7 feet of the Shinarump member. The ore horizon is in the lower 4 feet of sandstone and conglomerate overlying the basal conglomerate. The principal uranium mineral is uranophane that has been disseminated in the sandstone and, together with the secondary copper minerals, has replaced some pieces of wood. The uranophane is associated mainly with malachite, azurite, geothite, and locally with hematite. Sparse disseminated grains of chalcopyrite and pyrite are present, but no uraninite has been observed. Gangue minerals include quartz, calcite, and iron oxides. The deposit contains an average amount of calcium carbonate in excess of the 6 percent maximum allowed without penalty in ore purchased by the mill. The highest grade rock probably is near the outcrop, because the tenor of the ore decreased as the workings advanced away from the portal.

BLUE LIZARD MINE

LOCATION, HISTORY, DEVELOPMENT, AND PRODUCTION

The Blue Lizard mine is on the north side of Red Canyon about 9 miles west of Moss Back at an altitude of about 4,800 feet. It is accessible by the Red Canyon road. The mine is among a group of properties that include the Red Canyon Nos. 1 and 2 and the Blue Lizard Nos. 1, 2, and 3 claims. The Red Canyon No. 1 claim was located in 1943 by J. Wiley Redd and Preston Redd, Blanding, Utah. The other four claims were located in 1948 by J. Wiley Redd and Preston Redd after they had formed a partnership known as the Red Canyon Mining Co. The property was owned in 1954, by the Red Canyon Mines which is a partnership of Preston Redd, Robert Redd, and Lyman Redd, Blanding, Utah; John Redd, Paradox, Colo.; and Donald T. Adams and Leon Adams, Monticello, Utah.

The property lay idle until 1951, and from 1951 to 1953 a few small shipments were made of ore from near the surface. A diamond-drilling program was conducted on the property by the U.S. Atomic Energy Commission during the spring of 1953, and a small amount of ore reserves was found. The drilling was abandoned because drill holes caved in the talus breccia overburden. An extensive exploratory program was begun by the company early in 1954 under a United States Government loan. This work consisted of a 925-foot exploratory drift along the east edge of the channel filled with the Shinarump member of the Chinle formation. The drift was opened from a point on the exposed ore rim to an intersection with a U.S. Atomic Energy Commission ore hole. Ore-grade material was found about 250 feet from the portal, and a high-grade uranium deposit was found at about 650 feet from the portal. The main drift was about 1,065 feet long, and about 350 feet of side drifts and crosscuts had been completed in the mine by September 1954. To date (1955) relatively constant production has been maintained from the mine since early in the summer of 1954.

GEOLOGIC RELATIONS

The Blue Lizard mine is in a channel that has been cut into the Moenkopi formation and filled with sediments of the Shinarump member of the Chinle formation. The data from surface mapping made it appear that the trend of the channel was N. 35° E., but the orientation of the slope of the contact between the Moenkopi and the Shinarump in the underground workings and the orientation of fossil logs suggests that the trend is N. 20° to 25° E. Underground data also indicate that the channel is more than 400 feet wide and 18 to 25 feet deep. The Shinarump consists of medium- to coarse-grained sandstone. Carbonized wood is abundant in the rocks exposed in the outer 400 feet of the mine workings; logs, 2 or 3 feet in diameter and more than 10 feet long, are exposed in the channel at the outcrop. Jarosite is associated with carbonaceous material in the deeper parts of the mine; calcite is abundant in the basal part of the Shinarump member and appears to be associated with the sulfide minerals and uraninite.

The regional strike of the beds of the Blue Lizard mine is about north and the dip is approximately 1°30′ W. Beds of the Shinarump member in the deeper parts of the mine have been cut by a principal joint set which strikes N. 60° to 80° W. and dips 75° SW. to 80° NE.

ORE DEPOSIT

The best ore occurs in medium- to coarse-grained sandstone and conglomeratic sandstone beds in the bottom part of the Shinarump member of the Chinle formation. These mineralized beds are between a thick siltstone lens near the center of the channel and interbedded siltstone and fine-grained sandstone along the east edge of the channel. This ore deposit ranges in thickness from 2 to 10 feet, depending upon the thickness of the sandstone unit between the basal sandy siltstone bed of the Shinarump and the next higher fine grained unit. The deposit has not been explored sufficiently to determine its shape and size, but it appears to be an ellipsoidal body several hundred feet long and at least 50 feet wide at its widest point. Small amounts of sulfide minerals, especially pyrite, and uraninite have been deposited in coal-bearing siltstone and sandy siltstone beds above the main ore horizon, but are of much lower grade than the ore. The main ore body appears to trend slightly more northeastward in the deeper part of the mine than near the portal.

The ore body apparently has been localized by ponding or stagnation of ore solutions in permeable sandstone between less permeable siltstone and claystone beds. The slight change in trend of the ore body near the end of the main drift suggests that the trend of the channel may change near this point, and that the favorable beds were deposited at a bend in the channel. The reducing environment produced by the abundance of plant fragments may also have been favorable for ore deposition. The uranium and sulfide minerals have been deposited both as replacements of wood and as disseminations in the enclosing rocks.

The ore at the Blue Lizard mine contains uraninite associated with pyrite, chalcopyrite, bornite, and covellite. The sulfide minerals, especially bornite, generally are in larger masses than in most other deposits in the area. Minerals associated with the host rock include quartz and feldspar grains, calcite, clay minerals, and a minor amount of iron oxides. The more intensely mineralized sandstone commonly is cemented by coarsely crystalline colorless to pale-pink calcite, and the amount of calcite seems to vary directly with the amount of sulfide minerals present. This calcite-impregnated rock is extremely difficult to drill. It has been termed "glass-rock" by the miners because of the sheen observed on cleavage faces.

FRY NO. 4 MINE

BY EARL J. OSTLING

Fry No. 4 mine is at the head of Fry Canyon in the NW¼NE¼ sec. 24, unsurveyed T. 37 S., R. 17 E., Salt Lake meridian. A bulldozed road with a very steep grade connects the mine with the main road in Fry Canyon, which in turn connects with Utah State Highway 95. The property was located before 1948 by Shumway Bros., Blanding, Utah, and is now held by the White Canyon Mining Co. Development work consists of about 180 feet of underground workings (pl. 2). The U.S. Atomic Energy Commission core-drilled a part of the Fry No. 4 channel in 1952. Several tons of ore was shipped from the property during the spring and summer of 1951, and a few small shipments were made in 1952 and 1953. Since 1953 the property has remained idle.

The uranium deposit at the Fry No. 4 mine is in the Shinarump member of the Chinle formation which has filled a scour cut into the underlying Moenkopi formation. The mine is a few hundred yards north of the projected pinchout of the Shinarump at the southern edge of the White Canyon area. The channel at the Fry No. 4 mine trends N. 70° E.; it is about 100 feet wide and 5 feet deep. Intraformational channeling is common within the Shinarump; many scours and fills have been noted in the beds. The Shinarump is about 16 feet thick and is composed of sandstone, siltstone, and conglomerate. The sandstone is composed principally of subangular to angular fine to coarse quartz grains in a matrix of clay, hematite, and limonite. Coarse-grained sandstone is in the upper part of the member; fine-grained sandstone is in the lower part.

Very fine grained to fine-grained sandstone in beds from 0.5 to 2.5 feet thick forms much of the lower part of the Shinarump member in the area. This sandstone is gray, with red and yellow hematite and limonite mottling. The coarse- and medium-grained sandstone forming the upper part of the Shinarump is dark red and contains abundant hematite. The quartz grains in this sandstone are angular, with large amounts of authigenic overgrowths of silica.

The siltstone grades into sandy siltstone and is commonly in small lenses nearly 1 foot thick. The siltstone is light to dark gray. Light-colored layers commonly contain darker thin layers. Small amounts of carbonaceous material are distributed throughout much of the siltstone. The poorly sorted conglomerate consists of coarse sand grains and well-rounded pebbles and cobbles of quartz and claystone in a matrix of claystone. The pebbles are as much as 3 inches in diameter and many of them are fractured. The basal conglomerate is not well developed and is present only in a small part of the mine workings.

Rocks in the general area of the Fry No. 4 mine strike approximately north and dip 2° W. The beds apparently have not been disturbed by faulting. Four sets of fractures were noted in the mine. The strongest set strikes north and dips vertically. The other three sets strike N. 65° E., N. 25° E., and N. 55° W. These sets dip 15° SE., 10° NW., and 7° NE., respectively.

The ore minerals have replaced wood fragments and clay pebbles and have impregnated some of the sandstone. Most of the ore has resulted from the replacement of wood by uranium and copper minerals. Pods and pockets of ore have been formed by the replacement of clay pebbles with uranium minerals. These pods range in diameter from ½ to 3 inches, and are in conglomerate and coarse-grained sandstone. Tabular impregnations of uranium have been noted in some of the sandstone interbedded with siltstone.

Uraninite is the principal uranium mineral found at the Fry No. 4 mine. It occurs near the surface, an unusual phenomenon in the White Canyon area. The uraninite is associated with secondary copper minerals and iron oxide, and much of it has been altered to secondary uranium minerals. Yellow and orange secondary uranium minerals commonly surround the uraninite and extend less than 1 inch into the enclosing wall rock. An unidentified white uranium-bearing mineral has formed coatings on many of the walls and has impregnated much of the sandstone and siltstone near uraninite masses. The mineral is fluorescent and one sample contained 0.015 percent uranium.

Chalcopyrite and pyrite are associated with uraninite and other uranium minerals in the replacement bodies of organic matter and clay pebbles. Both of these sulfide minerals are sparsely disseminated in some of the sandstone and siltstone. Small amounts of bornite and covellite have also been observed, together with malachite, antlerite, and unidentified green and blue copper minerals. Chalcanthite was found in the back at the main portal and on an unmapped rib. Hematite and limonite coat many of the quartz grains and locally form a large part of the cementing material. Most of the uraninite is surrounded by zones of hematite of varying thickness. Clay comprises about 35 percent of the conglomerate. Feldspar is sparse in both the sandstone and the conglomerate. Jarosite is found in minor amounts as grain coatings on most of the rocks; it commonly is concentrated with pieces of coalified wood. No calcite or gypsum was observed in the mine. Ilsemannite was identified by Alice D. Weeks, of the U.S. Geological Survey. This mineral impregnates the sandstone and is associated with chalcopyrite. A pink mineral, probably cobaltoan pickeringite, was found as a coating on the Shinarump member near the portal of the mine.

The best environments for the deposition of uranium at the Fry No. 4 mine are accumulations of organic material and clay pebbles in the sandstone and conglomerate, and within interbedded sandstone and siltstone. The most favorable host rock is sandstone overlain and underlain by siltstone. The most favorable beds are near the base of the Shinarump member.

Chalcopyrite and pyrite are the best ore guides at the mine. A thickening of the mottled sandstone to the exclusion of almost all other beds was noted around the ore body, and this mottled sandstone apparently has cut out favorable ore-bearing beds.

HAPPY JACK MINE

LOCATION, HISTORY, DEVELOPMENT, AND PRODUCTION

The Happy Jack mine is the largest known uranium deposit in the White Canyon area, San Juan County, Utah. It is in a deep reentrant in the southwest rim above White Canyon less than a mile west of Utah State Highway 95 in the western part of the area.

The mine is on the Happy Jack No. 1 claim which is contiguous with the Happy Jack Nos. 2, 3, 4, and 5 claims; the El Capitan Nos. 1, 2, 3, and 4 claims; and the Inspiration Nos. 1, 2, and 3 claims. In 1955, these unpatented claims were owned in partnership by Joe W. Cooper, Monticello, Utah, and Fletcher Bronson and Grant L. Bronson, Blanding, Utah. The Happy Jack No. 1 and several other of the claims were purchased by these owners as copper prospects.

Five main adits connected by crosscuts have been driven into the Shinarump at the Happy Jack mine. All the mine workings are on one level and consisted of more than 5,000 feet of drifts and crosscuts when the study was made (fig. 24). The deposit was explored by diamond drilling by the U.S. Atomic Energy Commission intermittently between 1951 and 1953; large tonnages of ore were discovered. The occurrance of copper minerals at the Happy Jack mine, previously called Blue Dike, has been described by Gregory (1938,

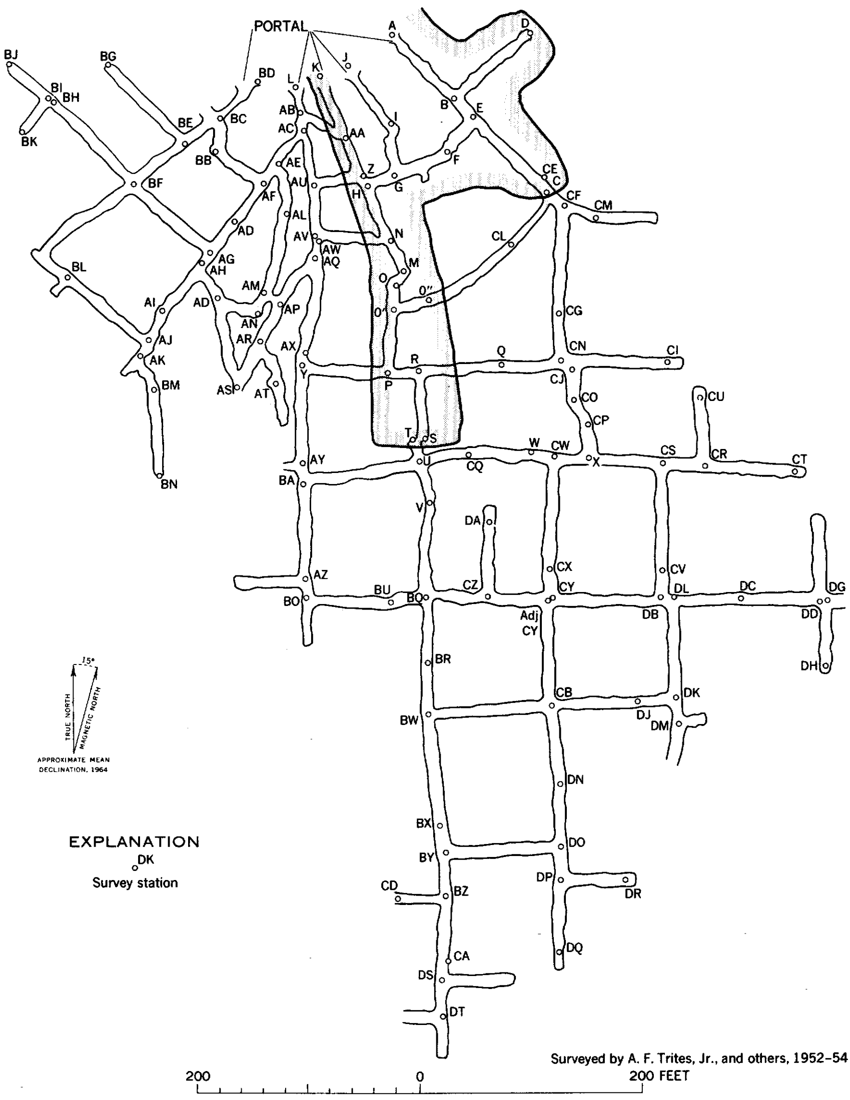

FIGURE 24.—Map of the Happy Jack mine, White Canyon area, 1954. Shaded outline area shown on plate 3.

p. 107). Gregory described the presence of chalcopyrite, covellite, and chalcocite, together with blue and green salts of copper, yellow salts of uranium, and a pink salt of cobalt. Uranium ore was first shipped from the mine in 1948, and constant production was maintained from 1951 to 1956.

GEOLOGIC RELATIONS

The uranium deposit at the Happy Jack mine is in the Shinarump member of the Chinle formation, the lower beds of which have filled a discontinuous channel that has been cut into the uppermost beds of the Moenkopi formation. This channel trends about due west and is more than 750 feet wide and 10 feet deep in the area of the mine workings. The channel apparently bends rather sharply toward the southwest near the southwest edge of the mine workings. The Shinarump member is from 16 to 40 feet thick at the mine; it pinches out half a mile northwest and 1¼ miles southeast of the mine.

The Shinarump member here consists of coarse- to fine-grained sandstone, conglomerate, siltstone, and claystone. The coarse-grained sandstone grades laterally into conglomerate and the fine-grained sandstone grades into siltstone. The sandstone beds are lenticular in shape and range in length from 1 to 100 feet and in thickness from a few inches to 4 feet. Most of the sandstone beds are cross stratified. The cross strata dip from less than 10° to more than 20° toward the northwest (pl. 3). The fine-grained sandstone and the coarse-grained conglomeratic sandstone contain abundant interstitial clay and silt; planar cross-stratification is common within these beds. Current lineation and small-scale slump features have also been observed in the Shinarump.

Thin-section studies have shown that the sandstone is composed mainly of quartz, and contains a trace to 5 percent of microcline and a trace of tourmaline and zircon(?). Authigenic quartz overgrowths were well developed before the deposition of the metallic minerals. Most of the quartz grains are corroded, and many are in part replaced by the ore minerals.

Siltstone and claystone constitute about 20 percent of the Shinarump member at the Happy Jack mine. These rocks occur in beds that range in length from 10 to 100 feet and in thickness from 1 to 4 feet. They also occur in thin layers ranging in length from 1 to 6 feet and in thickness from ⅛ to ½ inch.

Carbonaceous matter, ranging in size from finely comminuted organic material to logs as much as 3 feet long and 6 inches in diameter, is present in most of the beds. Such accumulations of organic material are especially abundant near the bottom of the Shinarump member.

The regional strike of the rocks near the Happy Jack mine is about N. 30° W., and the dip is about 3° SW. The Shinarump member at the mine has been cut by four sets of steeply dipping fractures which have the following mean strikes listed in order of decreasing prominence: N. 65° W., N. 60° E., N. 85° E., and north (pl. 3). Only two small faults were noted in the mine. One fault, about 30 feet from the portal, is vertical and has no vertical movement but has had a horizontal movement of about 1½ feet. The other is a reverse fault that dips northeast.

ORE DEPOSIT

LOCALIZATION

The interbedded siltstone and claystone in the channel evidently produced a decrease in the rate of movement of the mineralizing solution, causing it to deposit the primary iron, lead, copper, uranium, and zinc minerals. Deposition of these minerals was most pronounced in beds containing abundant vegetal remains, siltstone and claystone seams, and clay cement. The most favorable beds appear to be overlying or interbedded with lenses or beds of siltstone, and probably have a permeability intermediate between the extremely permeable clean sandstone and the relatively impermeable siltstone beds. Both plant material and clay minerals apparently had a chemical role in the deposition of the ore minerals.

ORE MINERALS

The primary ore consists of uraninite associated with the following sulfiide minerals, listed in order of decreasing abundance: pyrite, chalcopyrite, bornite, sphalerite, and galena (fig. 23). The uraninite has been deposited as replacements of wood, dissemination in sandstone, replacements of microcline along cleavage planes, and fillings of microscopic fractures in quartz grains. The sulfide minerals generally have replaced wood and finely divided organic material, have been disseminated in sandstone, and fill tiny fractures in the enclosing rocks; sphalerite, especially has formed fracture fillings. These minerals occur in a suite of nonmetallic minerals including quartz grains, feldspar (microcline) grains, clay, gypsum, and, locally, barite.

OXIDATION

Oxidation of the uraninite and sulfide minerals has produced a host of secondary uranium and copper minerals, and jarosite, hematite, and goethite. The ore deposit has been divided on the basis of mineral assemblages into an unoxidized zone and an oxidized zone. The effects of oxidation have extended at least 200 feet horizontally away from the outcrop of the Shinarump member, but relicts of uraninite and sulfide minerals extend from the outer boundary of the unoxidized zone to within 10 to 60 feet of the outcrop. The ore body in the vicinity of the outcrop has been completely oxidized.

The unoxidized zone contains uraninite and sulfide minerals with no appreciable amounts of goethite. The inner part of the oxidized zone contains abundant goethite and jarosite, together with relict concentrations of uraninite and sulfide minerals; the outer part of the oxidized zone contains abundant iron oxides, small amounts of jarosite, and insignificant amounts of sulfide minerals.

The secondary uranium minerals include the sulfates, johannite, uranopilite, and a zippeitelike mineral; the silicate uranophane; a hydrous uranium oxide, schoepite; and the arsenate metazeunerite. These minerals impregnate the sandstone and siltstone beds in the oxidized zone. The hydrous sulfates beta-zippeite, uranopilite, and johannite occur as coatings on the mine walls in the more moist part of the workings. Secondary copper minerals include the hydrous sulfates, brochantite, antlerite, and chalcanthite, and the carbonates malachite and azurite. These minerals are especially abundant in sandstone and siltstone in the inner part of the oxidized zone.

The copper sulfides covellite and chalcocite appear to be localized near the boundary between the unoxidized and oxidized zones. Marcasite also is present locally in microscopic veinlets cutting and replacing the uraninite and most of the sulfide minerals in the same area. Covellite, chalcocite, and marcasite minerals are later than the primary sulfide minerals and appear to be of supergene origin because of their position within the deposit. Marcasite generally is considered to be deposited from cold acid solutions in the oxidized zone and is accompanied by the supergene sulfides.

JOMAC MINE

LOCATION, HISTORY, MINE WORKINGS, AND PRODUCTION

The Jomac mine is in the western part of the White Canyon area, about 13 miles northeast of the settlement of White Canyon, Utah. The property is reached from the settlement by traveling about 6 miles east along Utah State Highway 95, and then turning to the northeast on a bulldozer road that leads to the mine. The mine is on the southeast side of the hill below vertical angle bench mark 5,390, at an altitude of about 5,200 feet.

The Jomac mine is on an unpatented claim located in November 1950 by J. B. Plosser and A. N. McLeod. The property is now owned (1954) by the Ellihill Mining Co., White Canyon, Utah. It consists of three contiguous claims known as the Jomac 1, 2, and 3 in unsurveyed T. 34 S., R. 14 E., Salt Lake meridian.

The Jomac deposit is opened by two subparallel adits which in August 1953 were 315 and 130 feet long. These adits were connected by a 75-foot crosscut (figs. 25, 26). Another crosscut was being driven in adit 2 to intersect the extension of adit 1 at a point about 140 feet behind the rim. A short crosscut, 25 feet long, was also driven northward from adit 1. A large part of the ore body between the adits was removed by mining during 1953 and 1954. Between December 1952 and June 1953, 2,983.5 feet of exploratory diamond drilling was completed at the Jomac mine by the owners with financial assistance

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from the U.S. Government. The company also opened 200 feet of drift on adit 1 under the same contract (figs. 25, 26).

A few hundred tons of ore was shipped from the mine between May and November 1951. The property then lay idle until December

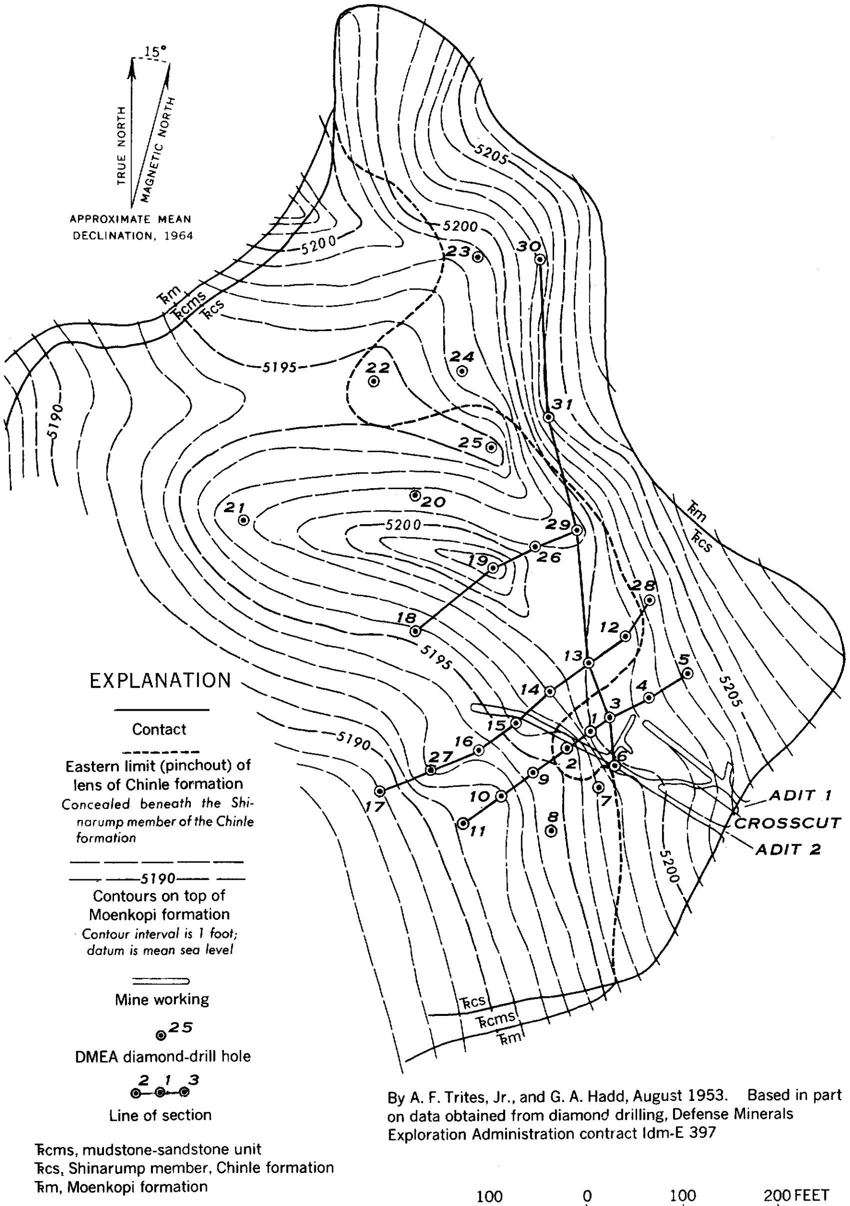

FIGURE 25.—Contour map of the top of the Moenkopi formation underlying Jomac Hill. Line of section refers to cross sections shown on plate 4.

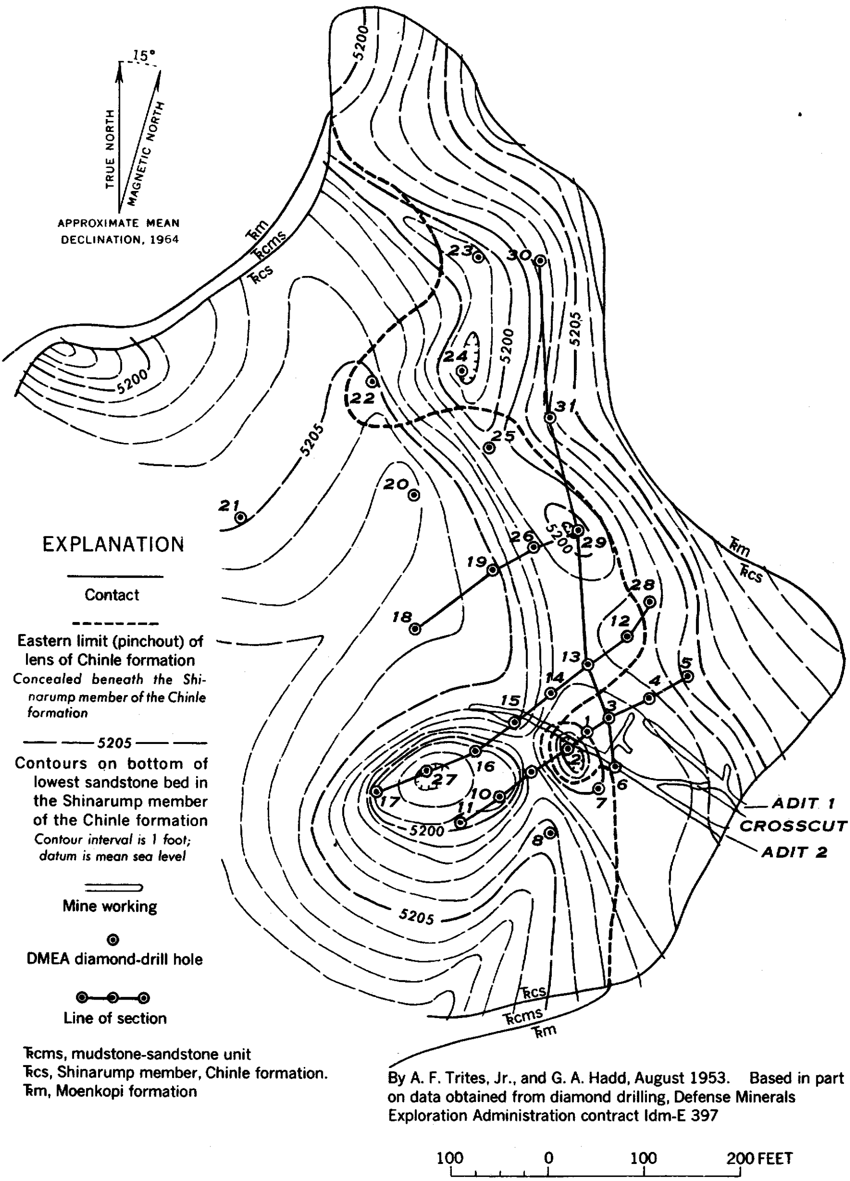

FIGURE 26.—Contour map of the base of the lowest sandstone bed in the Shinarump member of the Chinle formation underlying Jomac Hill. Line of section refers to cross sections shown on plate 4.

1952, when the contract work with the U.S. Government was begun. Production began in the fall of 1954 on the ore bodies discovered during the exploratory drilling.

GEOLOGIC RELATIONS

The ore deposit at the Jomac mine is in the Shinarump member of the Chinle formation, which fills a channel that has been cut into the Moenkopi formation on the east side of Jomac hill and into siltstone of the mudstone-sandstone unit of the Chinle formation west of the mine workings (Trites and Hadd, 1958). The Shinarump ranges in thickness from slightly more than 10 to 30 feet and consists of very fine grained to coarse-grained sandstone, conglomerate, siltstone, and claystone. The sandstone beds of the Shinarump are crossbedded and range in thickness from slightly less than 1 foot to 7½ feet. In general, the basal sandstone beds are coarser grained than those higher in the section. Many of the sandstone beds contain coalified wood fragments and wood that has been replaced by limonite and hematite. Many of the sandstone beds contain limonite and jarosite impregnations. Conglomerate beds occur at various places in the Shinarump and range in thickness from 0.5 to 5.0 feet. In general, the basal conglomerate occurs along the outer edges of the channel. The basal conglomerate beds are medium gray to grayish yellow and contain an average of 20 percent siltstone pebbles from the Moenkopi formation in a matrix of siltstone or fine- to coarse-grained sandstone. Pieces of coal are abundant in most of the conglomerate and are associated with jarosite, gypsum, limonite, and, locally, pyrite. Wood replaced by hematite and limonite is present in minor quantities. Thin beds of gray carbonaceous siltstone occur throughout the Shinarump and are especially abundant in the upper part of the congolmerate. Most of the siltstone beds are less than 1 foot thick.

The Shinarump member is underlain in part by, and interfingers with, variegated and carbonaceous siltstone and siltstone-pebble conglomerate of the mudstone-sandstone unit of the Chinle formation west of the mine workings. The channel that has been cut into the Moenkopi formation is 200 to 400 feet wide and 4 to 7 feet deep, and trends N. 24° W. from a point about 100 feet southwest of the portal of adit 2 to a point about 150 feet southwest of the north tip of the hill. This channel filled with Shinarump contains three elongate basinlike scours along the bottom (fig. 26). Scours range from 2 to 4 feet deeper than the channel, but closure on these scours is apparent only after regional dip is removed.

The mine is on the crest of a southwest-trending anticlinal fold which is on the west flank of a northward-trending syncline extending from a few hundred yards east of the mine to the south side of White Canyon. The closures on these flexures are too small to be shown on the structure contour map (pl. 1). The area around the mine has been faulted; most of the faults are steeply dipping, strike N. 50°–75° W., and have vertical displacements ranging from a few feet to more than 80 feet. The fault nearest to the Jomac mine is about a quarter of a mile north of the workings. This fault strikes N. 65° E. and dips vertically; it has a stratigraphic throw of about 10 feet with the north side of the fault downthrown. The Shinarump member at the mine has been cut by three sets of vertical fractures. These sets strike N. 70°–80° E., due north to N. 10° W., and N. 30°–40° E. Some of these fractures have been filled by secondary minerals.

ORE DEPOSIT

The uranium at the Jomac mine is contained mainly in carbonized wood in sandstone, conglomerate, or sandy siltstone in the lower part of the Shinarump member of the Chinle formation (pl. 4). The carbonized wood is probably a low-rank coal. It is dark gray to black, light weight, and has a silky sheen. The coal is generally associated with jarosite and gypsum. Metazeunerite coats many of the fracture surfaces in the coal and may account for a large part of the uranium. An unknown yellow fibrous uranium mineral in the upper sandstone beds and an unknown massive yellow uranium mineral in the basal sandstone beds occcur in the Shinarump. The unknown fibrous yellow mineral occurs as impregnations in sandstone beds; it fluoresces an intense yellowish green, and semiquantitative spectographic analysis suggests that the mineral is a silicate. The yellow massive mineral is in nodular masses as much as half an inch in diameter associated with carbonized wood and gypsum in the sandstone beds near the base of the Shinarump. Semiquantitative spectrographic analysis of this mineral suggests that it is a phosphate of uranium.

Pyrite is disseminated in some of the sandstone and siltstone of the Shinarump member, and minor amounts of chalcopyrite impregnate a sandstone lens in the basal sandstone near the end of adit 2. The pyrite also replaces pieces of carbonized wood. Secondary copper minerals include malachite, azurite, and chalcocite, which occur as impregnations near the base of the formation. The gangue minerals include quartz, feldspar, and clay minerals of the enclosing rocks, hydrous iron oxide, hematite, jarosite, gypsum, and manganese oxide. Secondary quartz overgrowths are common and are most abundant on the quartz grains in poorly cemented medium- to coarse-grained sandstone. Jarosite is closely associated with much of the uranium-bearing carbonized wood and forms a part of the cementing material in many of the rocks which contain the wood.

The principal ore guides are the channel filled with Shinarump, the elongate scours on the bottom of the channel (fig. 26), and jarosite-bearing coal. Jarosite is considered the best guide for exploratory drilling, especially in holes where pieces of uranium-bearing carbonized wood may not have been cut. The Jomac mine is the only deposit in the White Canyon area in which jarosite is considered a guide to ore.

POSEY MINE

LOCATION, HISTORY, DEVELOPMENT, AND PRODUCTION

The Posey mine is on the Posey group of claims, 15 in number, on a bench formed of the Shinarump member of the Chinle formation along the south wall of Red Canyon, about 8 miles west of Moss Back. The claims were staked by J. Wiley Redd and Preston Redd, Blanding, Utah, in 1943. The claims were owned (1954) by the Red Canyon Mines partnership.

A deposit has been opened up by two parallel adits which trend about S. 60° E. These adits have been connected by crosscuts and large areas have been stoped out. The mine workings from the portal to the deepest point are about 280 feet long and at the widest point are about 130 feet wide. The Posey channel was core-drilled by the U.S. Atomic Energy Commission in the spring of 1953. A total of 1,570 feet of drilling in 28 holes tested the channel for a distance of 2,800 feet southeastward from the mine workings. Four of these holes were shallow holes close to the mine workings and indicated abnormal radioactivity. The remaining 24 holes were drilled along the course of the channel and apparently did not penetrate significantly mineralized ground. Members of the U.S. Atomic Energy Commission believe that the channel may extend at least 3,800 feet beyond the last point drilled. An open pit and a small stripping operation were begun at the mine in the summer of 1951.

The first uranium ore produced at the Posey mine was shipped in the spring of 1950; several truckloads were shipped during that year. Regular shipments were made from the mine during 1951 and 1952. Production was discontinued during the first months of 1953, but was resumed in May of that year and was continuous until fall. Production of lower grade uraniferous rock was begun from the opencut at the top of the Shinarump member in the summer of 1954, and was continuing when the last examination of the property was made in September 1954.

GEOLOGIC RELATIONS

The uranium deposit at the Posey mine is in the Shinarump member of the Chinle formation that fills a channel that has been cut into the underlying Moenkopi formation. The Shinarump is as much as 50 feet thick at the mine workings and forms a prominent bench along the canyon.

Diamond drilling, by the U.S. Atomic Energy Commission, and cross-stratification studies have indicated that the channel has a trend of about N. 40° W. It is about 25 feet deep and more than 500 feet across. The Shinarump member is composed of interbedded fine-grained to very coarse grained sandstone, conglomerate, and siltstone. Individual sandstone beds range in thickness from about 2 to 4 feet. The coarse sandstone beds grade laterally into conglomeratic sandstone and conglomerate. The conglomerate beds range in thickness from 1 to 3 feet and consist of large siltstone fragments and blocks of claystone from less than 1 inch to 3 feet in diameter, in a matrix of very coarse grained sandstone. Quartz pebbles are also present in much of the conglomerate.

Siltstone beds are less abundant in the Posey mine than in most of the deposits in the White Canyon area. In general, the siltstone beds are less than 2 feet thick and are in the upper part of the Shinarump member. Very few are exposed by the underground workings.

The strongest joints at the Posey mine strike about N. 70° W. and dip nearly vertically. Many of the fractures are coated by secondary copper and uranium minerals, iron oxides, and manganese oxides.

ORE DEPOSIT

All the ore obtained at the Posey mine consists of secondary uranium minerals that have been deposited in the beds and along fractures cutting the Shinarump member of the Chinle formation. Most of the higher grade ore has been produced in the bottom 5 feet of the Shinarump, though much recent production has come from the upper part of the member. The ore deposit probably was a uraninite-sulfide deposit that has been completely oxidized because of exposure of the Shinarump on the bench above the deposit. Nearly all the secondary copper minerals are concentrated in the lower part of the Shinarump and may have resulted by enrichment downward from original copper sulfide minerals that were deposited in the upper beds of the Shinarump.

The secondary uranium minerals include the phosphates phosphuranylite, metatorbernite, and meta-autunite; the silicates cuprosklodowskite and uranophane; and the hydrous oxide becquerelite. In general, the secondary uranium minerals have formed disseminations in the sandstone and conglomerate beds, coatings on some of the fracture surfaces, and replacements of woody fragments. In addition to the combined uranium-copper minerals, the secondary copper minerals include brochantite, malachite, azurite, antlerite, and chalcocite.

The minerals of the host rock include quartz and feldspar grains, clay, calcite, gypsum, and iron and manganese oxides. The iron oxides are specially abundant in the lower part of the Shinarump member in the mine workings. Jarosite is abundant in the upper part of the Shinarump and is associated with carbonized wood.

WHITE CANYON NO. 1 MINE

LOCATION, HISTORY, DEVELOPMENT, AND PRODUCTION

The White Canyon No. 1 mine is on the northeast rim of the point northeast of Fry Canyon at an altitude of about 6,200 feet. The mine is on an unpatented claim owned by the White Canyon Mining Co. It is reached from Utah State Highway 95 by a bulldozer road that ascends the mesa at a point about 6½ miles west of the Natural Bridges National Monument. The claim was originally located by Shumway Bros., Blanding, Utah, and was purchased from them by the White Canyon Mining Co. in 1951.

The mine workings consist of about 300 feet of adit and crosscuts. The deposit has been opened by one main adit which has a trend of about S. 36° W. The crosscuts have been driven from this adit toward the northwest and the southeast.

A diamond-drilling program was conducted by the U.S. Atomic Energy Commission on the White Canyon No. 1 property and on much of the rest of the mesa during the latter part of 1951 and early in 1952. The White Canyon No. 1 channel was traced toward its exposure on the south side of the mesa, and additional reserves of uranium ore were inferred on the basis of this drilling. The first shipments of uranium ore from the White Canyon No. 1 mine were made by A. E. and Seth Shumway to the White Canyon mill. This ore was produced from the Shinarump member near the surface. A few shipments of ore were made during the summer months of 1951, and in September 1952 production was resumed and continued until July 1953. The 1952 shipments were made by Nielson and Jones, Blanding, Utah, under a lease contract with the White Canyon Mining Co. All other shipments, except those in 1949, were made by the White Canyon Mining Co. The property lay idle from late summer 1953 until early in 1954, when production was again resumed under a lease contract and continued for a short time during the early part of 1954.

GEOLOGIC RELATIONS

The Shinarump member of the Chinle formation at the White Canyon No. 1 mine has filled a channel that has been cut into the upper beds of the Moenkopi formation. This channel has a trend of N. 30° E., a width of 150 feet, and depth ranging from 5 to 22 feet. The sediments of the Shinarump filling the channel are composed of about 40 percent conglomerate, 5 percent conglomeratic sandstone, 5 percent very coarse grained to coarse-grained sandstone, 20 percent medium-grained sandstone, 20 percent fine-grained to very fine grained sandstone, and 10 percent siltstone and claystone. The conglomerate beds range in thickness from 1 to more than 10 feet. The conglomerate consists of about 30 percent siltstone fragments from the Moenkopi formation, averaging 3 inches and as much as 7 inches in diameter; 10 percent quartz pebbles, averaging three-fourths inch in diameter; 3 percent carbonized wood, one-half inch in diameter; 40 percent quartz grains, and 15 percent clay cement. Locally, the conglomerate contains abundant secondary copper minerals. Hematite occurs in elongate patches impregnating the conglomerate in the ore body; many of these hematite impregnations seem to be associated with the red fragments from the Moenkopi. In general, the conglomerate is in the basal part of the Shinarump. The conglomeratic sandstone locally grades into conglomerate and contains from 5 to 40 percent quartz and claystone pebbles in a gray to red matrix of very coarse quartz grains tightly cemented by clay. These beds range in thickness from 1.5 to 13.5 feet. The very coarse grained to coarse-grained sandstone beds range in thickness from 3 to 9 feet. These beds range from yellowish gray (5*Y* 7/2) to very pale orange (10*YR* 8/2). They are generally composed of about 60 percent quartz grains and 40 percent clay matrix. The degree of cementation ranges from very good to poor. Coalified wood fragments are common in the sandstone and are present in amounts as much as 5 percent and in fragments as large as 3 inches. Fine-grained to very fine grained sandstone occurs in beds from 0.5 to 10 feet thick. The sandstone commonly is light gray and is carbonaceous; many of the sandstone beds grade laterally into siltstone. Carbonized wood is present in spots and flattened pieces as much as 2 inches in diameter.

Siltstone and claystone beds range in thickness from 1 to 10 feet. Most of the siltstone is grayish green to gray in color. A thick claystone was penetrated near the end of the main adit and also in the crosscut driven toward the southeast. This claystone apparently transects diagonally the channel otherwise filled with the Shinarump member, and forms a barrier that restricted the passage of uraniferous solutions during the mineralization of the Shinarump.

ORE DEPOSIT

The uranium deposit at the White Canyon No. 1 mine mainly is confined to the basal 4 feet of the Shinarump member of the Chinle formation. The host rock is coarse-grained sandstone and conglomeratic sandstone along the base of channel-filling sandstone. Mineralized layers as much as 2 feet thick occur near fossil plant debris, and minerals also are disseminated in sandstone below a clay-pebble conglomerate that grades laterally to quartz-pebble conglomerate with a mudstone matrix.

The ore deposit is at least 50 feet wide and about 140 feet long, and seems to be on the northwest flank of a N. 30° E. trending channel near the deepest part of the scour. Another ore body, about 150 feet southwest of the deepest mine workings, was discovered by drilling done by the U.S. Atomic Energy Commission, but its size was not determined.

The ore minerals replace carbonized wood and impregnate the sandstone around the wood. The principal ore minerals are uraninite and its oxidation products, uranophane and metatorbernite. The sulfide minerals chalcopyrite, bornite, covellite, pyrite, marcasite, and sphalerite characterize the mineralized zones. Bornite and covellite are intimately associated with uraninite. Covellite forms a thin shell between uraninite and bornite even in microscopic grains. Native copper is associated with thin carbonaceous streaks. Minerals in the host rock are quartz, clay, feldspar, chalcanthite, malachite, limonite, gypsum, and calcite. Hematite cements the sandstone near sulfide minerals and apparently represents the oxidation product of former sulfide minerals. Secondary quartz overgrowths coat many quartz grains. Limonite locally cements the sandstone. Interstitial mudstone forms a large part of the matrix in the sandstone and conglomerate above the ore zone.

HIDEOUT NO. 1 MINE

The Hideout No. 1 mine is in sec. 14, T. 36 S., R. 17 E., on the southeast side of Deer Flat (pl. 1). The deposit was discovered in 1948 by J. Wiley Redd, Blanding, Utah, who sold the claim to A. E. Shumway, who in turn sold the claim to F. A. Sitton, Dove Creek, Colo. In 1949, Mr. Sitton shipped 128 short tons of ore to the mill at Monticello, Utah. The ore contained 0.18 percent U_3O_8 and 3.44 percent copper. The claim was sold to the White Canyon Mining Co. of Cortez, Colo., in late 1951 or early 1952, and the mine lay idle until late August 1952, when Burdett and Merwin Shumway began to mine ore from the southwest scour of the Hideout channel through the southwesternmost mine workings (fig. 27). By September 1953, the Shumways had shipped to the mill at Monticello, Utah, about 1,500 short tons of ore averaging 0.17 percent U_3O_8 and 1.74 percent copper. As the mining extended farther underground, the calcium carbonate content decreased from as much as 20 percent to less than 3 percent.

During June, July, and August 1952, part of the Hideout claim around the mine was mapped by geologists of the U.S. Geological Survey, and the area was recommended for exploration by diamond

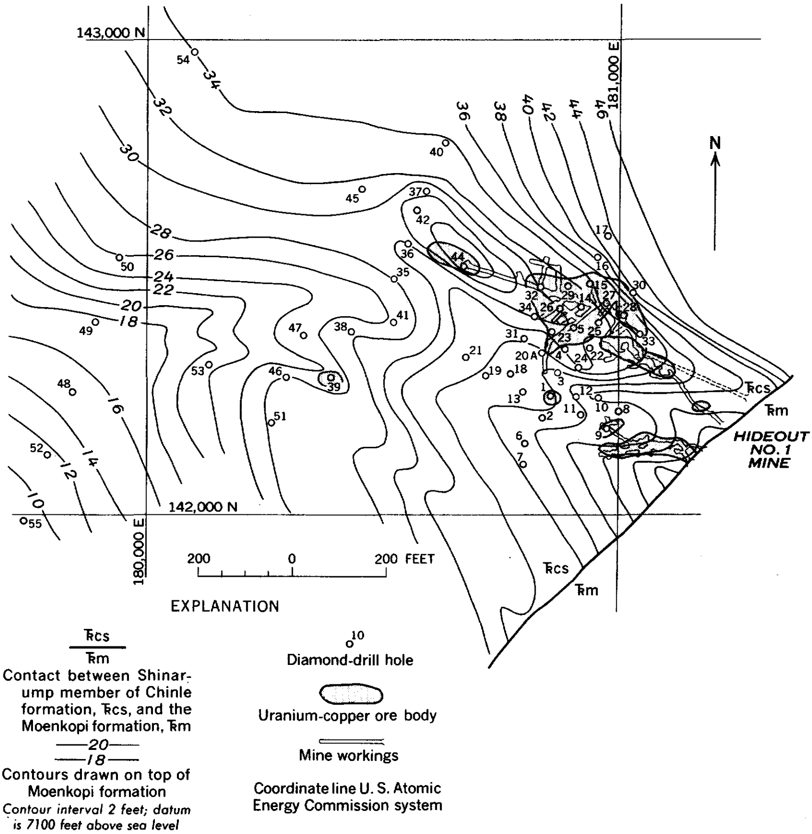

FIGURE 27.—Map showing contour of the top of the Moenkopi formation and location of ore bodies at the Hideout No. 1 channel, White Canyon area.

drilling (Tommy L. Finnell and others, written commun., 1952). On August 24, 1953, exploration of the Hideout No. 1 channel was begun by diamond drilling by a private company under contract to the U.S. Geological Survey. Drilling continued (except for a weather recess from Dec. 17, 1953, to Apr. 1, 1954) until June 10, 1954.

During September 1953, the Shumways began to drive tunnels to ore found by the drilling. In February 1954, mining supervision was assumed by Robert Hancock, Dove Creek, Colo., and mining was nearly continuous through July 1, 1955.

Diamond-drill holes 1 to 7 (fig. 27) were placed on 50-foot centers along a line normal to the inferred trend of the southwest scour of the Hideout channel. The line was placed 150 feet N. 70° W. of the deepest part of the mine workings because the channel had not turned within the 150 feet explored by the miners. The channel was known to be at least 120 feet wide, and it seemed unreasonable that the channel would turn so sharply that none of the holes would intercept it.

Holes 1 and 2 were drilled first, and they penetrated the Shinarump member of the Chinle formation near the middle of the southwest scour (fig. 27). Holes 4 and 5 indicate that the southwest scour is separated from the main channel by a low ridge 1 to 2 feet high on the channel floor, and holes 14 to 17 extend the line of holes to the northeast and define the northeast bank of the channel. Holes 35 to 40 are part of a line of holes on 75-foot centers about 400 feet N. 70° W. of the first line; these holes indicate that the channel is wider and shallower than it was to the southeast. A third line of holes on 150-foot centers along a line about 1,200 feet from the channel outcrop and about 500 feet N. 70° W. of the second line of holes shows that the channel has turned to the southwest and become shallow, and has a pronounced bank only on the north side (fig. 27). The ore cut by holes 4, 5, and 14 indicates a rather large ore body in the large scour, and offsets were drilled on 50-foot centers at the corners of equilateral triangles to determine the size of the ore body and its relation to the channel. The Hideout channel is 350 to 500 feet wide, is cut 15 feet into mudstone of the Moenkopi formation, and trends N. 70° W. for about 700 feet where it turns to about S. 70° W. and becomes shallow and indistinct within about 500 feet.

The Shinarump member of the Chinle formation is the ore-bearing formation; it ranges in thickness from 17 to 49 feet. The Shinarump consists of light-gray to light-yellowish-gray coarse- to medium-grained and conglomeratic sandstone with thin beds and lenses of siltstone and claystone that vary in color from light gray through gray and brown to red without regard for the proximity of ore deposits. The conglomerate pebbles, which are as much as 3 inches in diameter, are quartz, quartzite, siltstone, and altered volcanic ash(?). Some carbonized and limonitized wood is present. Calcite, silica, limonite, hematite, and clay cement the sandstone. The Shinarump becomes fine grained toward the top, where it grades into the variegated siltstone and fine-grained sandstone of the mudstone-sandstone unit of the Chinle formation.

The mudstone-sandstone unit of the Chinle formation is 120 to 160 feet thick, and consists of variegated mudstone, siltstone, and sandstone. The Moss Back Member of the Chinle formation is the caprock of Deer Flat above the Hideout mine and comprises 85 to 95 feet of yellowish-gray fine- to coarse-grained and conglomeratic sandstone with local lenses of siltstone and conglomerate.

The beds at the Hideout No. 1 mine dip 1°–3° S. 62° W. (a local terrace and monoclinal flexure superimposed on a regional dip of about 1°45′, S. 60° W.) (fig. 27). Two strong sets of joints cut the rocks. One set strikes N. 45°–70° E. and dips from 65° SE. to vertical. The other set strikes N. 35°–45° W. and dips 85° SW. through vertical to

72° NE. Normal faults with displacements as much as 6 inches cut the upper 14 feet of the Shinarump member. The faults with largest displacement strike north and dip 52°–65° W.; the faults with smaller displacement strike about N. 47° W. and dip 70°–75° NE. The ore-bearing parts of the Shinarump commonly contain fractured quartz grains, and some of the fractures are filled with ore minerals.

Uranium-copper deposits at the Hideout No. 1 mine are largely confined to the basal 10 feet of the Shinarump member where it fills the channel. Small subore grade deposits are present in sandstone and siltstone of the Chinle formation above the Shinarump member, and some sandstone of the Shinarump on the channel banks contains uranium and copper minerals. Ore bodies range from fusiform concentrations as much as 2.5 feet thick, 8 to 10 feet wide, and 20 to 30 feet long to irregularly shapped tabular bodies as much as 14 feet thick, 150 feet wide, and 250 feet long. Grades average 0.56 percent U_3O_8 and 1.9 percent copper.

Uranium and copper minerals replace fossil wood fragments, quartz, clay, and feldspar, and impregnate medium- to coarse-grained and conglomeratic sandstone. Uranium in mudstone seems to be concentrated in fossil plant fragments. Uranium minerals are mainly concentrated in sandstone beneath sandy mudstone or muddy sandstone. Uranium minerals at the Hideout mine are uraninite and its oxidation products—uranophane, bayleyite, and schroeckingerite. Copper minerals associated with the uranium minerals are chalcopyrite, bornite, chalcocite, covellite, malachite, azurite, and brochantite. Gangue minerals are calcite, dolomite, manganosiderite(?), jarosite, limonite, gypsum, pyrite, montmorillonite, and barite.

W.N. MINE

The W. N. mine is in the SE¼ sec. 21, T. 36 S., R. 17 E., on the west side of Deer Flat (pl. 1). The deposit was discovered in 1950 by A. E. Seth, and Lee Shumway, Blanding, Utah, and was sold in 1951 to the White Canyon Mining Co., Cortez, Colo. In December 1953 a trial shipment of 10 tons had a grade of 0.08 percent U_3O_8 and 0.5 percent copper. During 1954, only a few tons were shipped from the W. N. mine, and they averaged less than 0.10 percent U_3O_8. In April 1955 the White Canyon Mining Co. began to mine and ship ore from bodies discovered by drilling by a private company under contract to the U.S. Geological Survey, and by January 1, 1956, had shipped 2,170 short tons of ore averaging 0.20 percent U_3O_8 and about 0.39 percent copper.

During June, July, and August 1953, geologists of the U.S. Geological Survey mapped the W. N. area by planetable and alidade methods at a scale of 1:2,400, and in May 1954, the mine workings were mapped by Brunton compass and tape methods at a scale of 1:240. In June 1954 exploration of the W. N. channel by diamond drilling by a private company under contract to the U.S. Geological Survey was begun, and continued until August 1954. Drill holes were spaced 150 feet apart along 3 lines approximately at right angles to the channel trend (fig. 28) and progressively farther from the channel outcrop. Two holes were drilled east of the last line of holes to test for mineralized ground, and several holes were drilled on 300-foot centers to test for mineralized ground between the lines of holes. A total of 8,972 feet of drilling in 42 holes was done in the W. N. area.

The W. N. channel is 700 to 1,000 feet wide, 10 to 15 feet deep, and at least 2,000 feet long, and it trends west to S. 80° W. The floor of the channel is irregular, and the ore seems to be concentrated in sandstone that fills spoon-shaped scours in the channel floor. The channel banks are not well defined because of tributary channels (fig. 28).

The Shinarump member of the Chinle formation at the W. N. channel consists of 23 to 38 feet of light-gray to yellowish-gray fine- to coarse-grained crossbedded sandstone with interbedded lenticular conglomeratic sandstone, conglomerate, siltstone, and mudstone. Pebbles in the Shinarump are composed of mudstone, siltstone, chert, quartzite, and quartz—quartz being most abundant. Calcite, silica, and clay cement the Shinarump. Carbonized fossil plant material is common in the lower part of the Shinarump, and asphaltite(?) grains or blebs are disseminated in the sandstone locally. The Shinarump at the W. N. mine may be roughly divided into an upper unit that is dominantly sandstone and a lower unit that is dominantly mudstone with intercalated beds and lenses of sandstone. The lower unit fills the channel and extends beyond the channel banks to rest disconformably on the Moenkopi formation. The upper unit fills local channels in the lower unit and rests on the Moenkopi where the lower unit has been cut out by erosion. Sedimentary structure studies made by Paul C. Franks, of the U.S. Geological Survey, indicate that the channel fill was deposited by streams flowing westward along the W. N. channel, and that the upper unit of the Shinarump was deposited by streams flowing generally northwestward but widely divergent. The Shinarump becomes fine grained toward the top and locally grades into siltstone and fine-grained sandstone of the upper units of the Chinle.

The mudstone-sandstone unit of the Chinle formation is 120 to 160 feet thick and consists of variegated mudstone, siltstone, and sandstone. The Moss Back member of the Chinle formation caps Deer Flat above the W. N. mine and comprises 45 to 65 feet of yellowish-gray medium- to fine-grained crossbedded sandstone with local conglomerate lenses and siltstone. Conglomerate pebbles are siltstone,

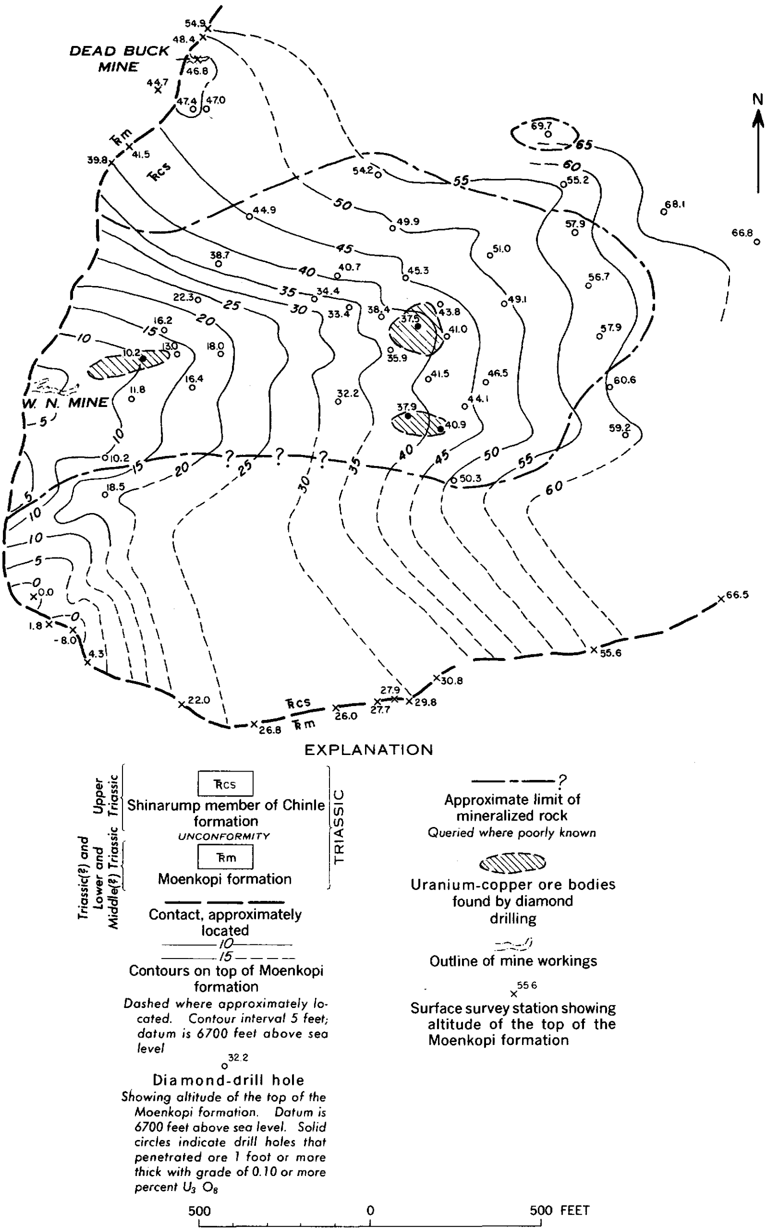

Figure 28.—Map showing contour of the top of the Moenkopi formation and position of the ore bodies at the W.N. channel, White Canyon area.

mudstone, quartzite, and chert. Carbonized and silicified wood is locally abundaant.

The beds strike N. 30° W. and dip about 2° SW. Two sets of vertical joints cut the rocks; one set trends N. 20°–50° E. and the other set trends N. 45°–68° W. Some penecontemporaneous slumping and faulting are present in the Shinarump member.

Uranium-copper deposits at the W.N. mine are fusiform bodies as much as 6 feet thick and 100 feet wide and long. Ore is confined largely to the basal 6 feet of the shinarump member where it fills spoon-shaped scours in the channel floor.

Uranium and copper minerals replace quartz, feldspar, clay, and fossil plant fragments, impregnate sandstone, and locally fill fractures in quartz grains. Uranium in mudstone seems to be concentrated in fossil plant fragments, but most of the uranium is in fine- to medium-grained sandstone beneath mudstone or siltstone and resting on mudstone of the Moenkopi formation. Uranium minerals are uraninite and its oxidation products—zippeitelike mineral and an unidentified uranium sulfate (Alice D. Weeks and Mary E. Thompson, written communication, 1955), torbernite, and metatorbernite. Copper minerals associated with the uranium minerals are chalcopyrite, chalcocite, bornite, and covellite. Gangue minerals are pyrite, galena, sphalerite, authigenic quartz, clay, limonite, calcite, gypsum, jarosite, and malachite.

FUTURE OF THE AREA AND SUGGESTIONS FOR PROSPECTING

About two-thirds of the uranium ore that has been produced from the White Canyon area has come from a few large (larger than 25,000 tons) medium-grade deposits. The remainder has come from smaller (many lower grade) deposits. Many of the deposits were being developed either by the U.S. Atomic Energy Commission, by the U.S. Geological Survey, or by private industry during the time the study was made in 1951–55. Few, if any, of these deposits have had their reserves determined completely, and many additional deposits undoubtedly will be discovered.

To date (1955) the daily production of most of the mines has been small, but with the establishment of the ore-buying station in White Canyon near the Happy Jack mine and the entry of several large mining companies in the area, the daily shipments from some of the mines undoubtedly will increase. Very few of the ore deposits have been exhausted, and revival of some of the properties now idle may be expected. This renewed activity may be brought about in some of the deposits of marginal grade of ore because of the shorter ore haulage to the new buying station. Carefully planned development work may reactivate other deposits, which initially yielded small tonnages near the surface and were abandoned because of the apparent exhaustion of ore or because of the encountering of such obstacles as mudstone lenses that cut out the ore. The White Canyon No. 1 mine is an example of a mine abandoned because of a mudstone lens.

A few deposits in sandstone beds in the mudstone-sandstone unit of the Chinle formation are not being mined because the calcium carbonate content exceeds the 6 percent maximum limit imposed by the mill. The uranium-bearing rock in most of these deposits is of insufficient grade to compensate for the payment penalties incurred for shipping "high-lime" ore. Further changes in the buying schedule of such ore may permit the shipping of small to moderate amounts of ore from these deposits. The Bankrupt claim below the bench formed of the Moss Back in the eastern part of the White Canyon area is a typical high calcium carbonate-bearing deposit.

The possibility of discovering new ore bodies in many of the known channels is promising if the exploratory work is carefully planned. Undiscovered channels may be found by detailed mapping of the base of the Shinarump member of the Chinle formation, and if considered favorable for ore deposits such channels should be traced by exploratory drilling. No geophysical, geochemical, or geobotanical methods are known that will show the existence of ore bodies in channels more than a few feet behind the outcrop of the Shinarump, and some method of drilling is required to discover these concealed deposits.

It is necessary for prospectors to understand that very little yellow uranium bloom shows on the outcrop in the White Canyon area, in contrast to the carnotite deposits of western Colorado. Leached outcrops in the White Canyon area can be expected to show only iron oxide impregnation, clay alteration, and copper, and, perhaps, cobalt bloom.

Although the most productive mines are in the central northeast-trending belt of the Shinarump member of the Chinle formation, the remainder of the area that is underlain by the Shinarump should not be discounted as unfavorable. The middle of the belt of Shinarump has not been explored as extensively by drilling as have the edges, partly because the middle part has been less accessible and partly because no high-grade deposits have been found at the outcrop. Equally as many low-grade uranium and copper occurrences have been seen in the middle of the belt as near the edges. Likewise, the isolated patches and lenses of Shinarump outside the belt of continuous Shinarump should not be ruled out as possible sites of uranium ore deposits. Some of these lenses of Shinarump, such as the one at the Four Aces claim, contain extremely abundant sec-

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ondary copper minerals at the surface, and these especially should be carefuly explored for uranium ore bodies.

The mudstone-sandstone unit of the Chinle formation has been found to contain a few uranium deposits. This unit probably is favorable for uranium deposits in areas where the Shinarump member is missing and where a sandstone bed of the mudstone-sandstone unit of the Chinle formation is not more than 20 to 50 feet above the Moenkopi formation. The Moss Back member of the Chinle formation contains large high-grade uranium deposits in some areas of the Colorado Plateau, but it is not known to contain significant amounts of uranium in the White Canyon area. However, the Chinle formation above the Shinarump member has not been extensively examined. Future work may uncover a few additional deposits, although no large high-grade ore bodies are expected.

It is probable that many, if not most, ore bodies occur in channels near local changes in the regional dip, near facies changes in the Shinarump member of the Chinle formation, and proximate to places where the Moenkopi formation has been thinned by Triassic erosion. These structural features can be used as large-scale guides for the exploration for uranium deposits; they should not be ignored during exploration.

LITERATURE CITED

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

——— 1936, Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U.S. Geol. Survey Bull. 865.

——— 1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U.S. Geol. Survey Bull. 951.

Baker, A. A., and Reeside, J. B., Jr., 1929, Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 13, p. 1413–1448.

Bateman, A. M., 1950, Economic mineral deposits: 2d ed., New York, John Wiley & Sons, 916 p.

Benson, W. E., Trites, A. F., Jr., Beroni, E. P., and Feeger, J. A., 1952, Preliminary report on the White Canyon area, San Juan County, Utah: U.S. Geol. Survey Circ. 217.

Butler, B. S., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111.

Cater, F. W., Jr., 1954, Geology of the Bull Canyon quadrangle, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ–33 (with text).

Dean, Abner, 1945, It's a long way to Heaven: New York, Farrar & Rinehart.

Finnell, T. L., Franks, P. C., and Hubbard, H. A., 1963, Geology, ore deposits, and exploratory drilling in the Deer Flat area, White Canyon district, San Juan County, Utah: U.S. Geol. Survey Bull. 1132.

Finnell, T. L., and Gazdik, W. B., 1958, Structural relations of the Hideout No. 1 uranium mine, Deer Flat area, San Juan County, Utah: Econ. Geology, v. 53, p. 949–957.

Garrels, R. M., 1955a, Weathering of uranium deposits: Mining Cong. Jour., v. 41, no. 5, p. 58–60.

——— 1955b, Some thermodynamic relations among the uranium oxides and their relation to the oxidation states of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 40, p. 1004–1021.

Goddard, E. N., chm., and others, 1948, Rock color chart: Washington, Nat. Research Council (repub. by Geol. Soc. America, 1951).

Gregory, H. E., 1917, Geology of the Navajo Country; a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geol. Survey Prof. Paper 93.

——— 1938, The San Juan country, a geographic and geologic reconnaissance of southeastern Utah: U.S. Geol. Survey Prof. Paper 188.

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

Gruner, J. W., and Gardiner, Lynn, 1952, Mineral associations in the uranium deposits of the Colorado Plateau and adjacent regions with special emphasis on those in the Shinarump formation: Annual report to the U.S. Atomic Energy Commission, RMO–566, Pt. 3, issued by Tech. Inf. Service, Oak Ridge, Tenn.

Gruner, J. W., Gardiner, Lynn, and Smith, D. K., Jr., 1954, Mineral associations in the uranium deposits of the Colorado Plateau and adjacent regions: U.S. Atomic Energy Comm. RME–3092, issued by Tech. Inf. Service, Oak Ridge, Tenn.

Hoekstra, H. R., and Katz, J. J., 1956, Isotope geology of some uranium minerals, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers. Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 543–547.

Hunt, A. P., 1953, Archeological survey of the La Sal Mountain area, Utah: Utah Univ. Anthropol. Paper 14, 248 p.

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

Kerr, P. F., 1951, Natural black uranium powder: Science, new ser., v. 114, p. 91–92.

Lewis, R. Q., Sr., and Trimble, D. E., 1959, Geology and uranium deposits of Monument Valley, San Juan County, Utah: U.S. Geol. Survey Bull. 1087–D, p. 105–131.

Locke, Augustus, 1926, Leached outcrops as guides to copper ore: Baltimore, Md., Williams & Wilkens Co., 175 p.

Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, 1923, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U.S. Geol. Survey Prof. Paper 132-A, p. 1–23.

McKee, E. D., 1954, Stratigraphy and history of the Moenkopi formation: Geol. Soc. America Mem. 61, 133 p.

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

Powell, J. W., 1875a, Exploration of the Colorado River of the West and its tributaries: Washington, 291 p., map.

———1875b, Physical features of the Colorado valley: Pop. Sci. Monthly, v. 7, p. 385–399, 531–542, 670–680.

Ray, J. C., 1930, Synthetic sulfide replacement of ore minerals: Econ. Geology, v. 25, p. 431–451.

Reeside, J. B., Jr., and Bassler, Harvey, 1922, Stratigraphic sections in southwestern Utah and northwestern Arizona: U.S. Geol. Survey Prof. Paper 129.

Rosenzweig, Abraham, Gruner, J. W., and Gardiner, Lynn, 1954, Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau: Econ. Geology, v. 49, p. 351–361.

Schwartz, G. M., 1931, Intergrowths of bornite and chalcopyrite: Econ. Geology, v. 26, p. 186–201.

——— 1951, Classification and definition of textures and mineral structures in ores: Econ. Geology, v. 46, p. 578–591.

Schwartz, G. M., 1953, Geology of the San Manuel copper deposit, Arizona: U.S. Geol. Survey Prof. Paper 256.

Sears, J. D., 1956, Geology of Comb Ridge and vicinity north of San Juan River, San Juan County, Utah: U.S. Geol. Survey Bull. 1021–E, p. 167–207.

Shoemaker, E. M., and Newman, W. L., 1959, Moenkopi formation (Triassic? and Triassic) in salt anticline region, Colorado and Utah: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 8, p. 1835–1851.

Stern, T. W., and Weeks, A. D., 1952, Second occurrence of bayleyite in the United States: Am. Mineralogist, v. 37, p. 1058–1060.

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

——— 1959, Stratigraphic relations of Hoskinnini member (Triassic?) of Moenkopi formation on Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 8, p. 1852–1868.

Stewart, J. H., and others, 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geol. Survey Bull. 1046–Q, p. 487–576.

Stieff, L. R., and Stern, T. W., 1952, Identification and lead-uranium ages of massive uraninites from the Shinarump conglomerate, Utah: Science, new ser., v. 115, p. 706–708.

——— 1953, Isotopic composition of lead in lead minerals from the Colorado Plateaus [abs.]: Geol. Soc. America Bull., v. 64, no. 12, pt. 2, p. 1478–1479.

Stokes, W. L., 1947, Primary lineation in fluvial sandstones a criterion of current direction: Jour. Geology, v. 55, p. 52–54.

——— 1948, Geology of the Utah-Colorado salt dome region with emphasis on Gypsum Valley, Colorado: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 3, 50 p.

Trites, A. F., Jr., and Chew, R. T., III, 1955, Geology of the Happy Jack mine, White Canyon area, San Juan County, Utah: U.S. Geol. Survey Bull. 1009–H, p. 235–248.

Trites, A. F., Jr., and Hadd, G. A., 1958, Geology of the Jomac mine, White Canyon area, Utah: U.S. Geol. Survey Bull. 1046–H, p. 165–181.

Trites, A. F., Jr., Chew, R. T., III, and Lovering, T. G., 1959, Mineralogy of the uranium deposit at the Happy Jack mine, San Juan County, Utah, *in* Garrels, R. M., and Larsen, E. S., 3d, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, pt. 16, p. 185–195.

Webber, B. N., 1929, Marcasite in the contact metamorphic ore deposits of the Twin Buttes district, Pima County, Ariz.: Econ. Geology, v. 24, p. 304–310.

Weeks, A. D., 1951, Red and gray clay underlying ore-bearing sandstone of the Morrison formation in western Colorado: U.S. Geol. Survey TEM–251, issued by the U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

Weeks, A. D., and Thompson, M. E., 1954, Identification and occurrence of uranium and vanadium minerals from the Colorado Plateau: U.S. Geol. Survey Bull. 1009–B, p. 13–62.

Wengerd, S. A., and Strickland, J. W., 1954, Pennsylvanian stratigraphy of Paradox salt basin, Four Corners region, Colorado and Utah: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2157–2199.

Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona, *with a section on* Serpentine at Garnet Ridge, by H. E. Malde and R. E. Thaden: U.S. Geol. Survey Bull. 1103.

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