Geology of the Red House Cliffs Area, San Juan County, Utah

By Thomas E. Mullens

Trace Elements Investigations Report 445

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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Geology and Mineralogy

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Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE RED HOUSE CLIFFS AREA, SAN JUAN COUNTY, UTAH*

By

Thomas E. Mullens

March 1955

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

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GEOLOGY OF THE RED HOUSE CLIFFS AREA, SAN JUAN COUNTY, UTAH

By Thomas E. Mullens

ABSTRACT

The Red House Cliffs area comprises 296 square miles of canyon and plateau country in southwestern San Juan County, Utah. The rocks that crop out in the area are mostly deposits of terrestrial environment and are of Permian, Triassic, Jurassic, and Quaternary ages. The aggregate thickness of these rocks is about 3,500 feet.

The Permian Cutler formation is the oldest exposed formation and is subdivided into three red bed tongues and two light colored eolian deposited sandstone members. These subdivisions, in ascending order, are: the Halgaito tongue, only partly exposed in the eastern part of the map area in the San Juan River Canyon; the Cedar Mesa sandstone, about 600 feet thick; the Organ Rock tongue, about 350 feet thick; the DeChelly sandstone, about 30 feet thick in the southwestern part of the area and absent due to nondeposition in other exposures of the same stratigraphic interval; and the Hoskinnini tongue, about 110 feet thick in most of the area but only 42 feet where it overlies the DeChelly sandstone.

The Moenkopi formation of Lower and Middle (?) Triassic age conformably overlies the Cutler formation. It ranges from 260 to 340 feet in thickness and is composed of a lower evenly bedded siltstone interval, a middle cross-laminated sandstone interval, and an upper evenly bedded siltstone interval. The Moenkopi is overlain unconformably by the Upper Triassic Shinarump conglomerate, or where the Shinarump is absent, by the Upper Triassic Chinle formation.

The Shinarump conglomerate consists of cross-laminated sandstone and conglomerate irregularly interbedded with mudstone. It is well developed only in the southern part of the map area where it reaches a thickness of 176 feet. In most of the map area the Shinarump is absent or represented only by discontinuous thin lenses; the local absence is due to non-deposition. The Shinarump, where present, conformably underlies the Chinle formation.

The Chinle formation ranges from 784 to 1,018 feet thick and is composed of sandstone, mudstone, variegated claystone, limestone, and calcareous siltstone. Based on dominance of rock types the Chinle can be subdivided into three divisions. These are a lower division of sandstone and mudstone; a middle division of variegated claystone, calcareous siltstone, and limestone; and an upper division of reddish-orange to reddish-brown interbedded siltstone and very fine-grained sandstone. Gradation and intermixing of rock types make the boundaries between divisions of the Chinle indefinite and ill-suited for mapping purposes. The Chinle conformably underlies the Glen Canyon group.

The formations of the Glen Canyon group include the Upper Triassic Wingate sandstone, the Jurassic(?) Kayenta formation, and the Lower Jurassic Navajo sandstone. The Wingate is a massive eolian-deposited sandstone and is about 320 feet thick; the Kayenta consists of irregularly bedded fluviatile deposits and is about 220 feet thick; the Navajo is a massive eolian-deposited sandstone which includes discontinuous lenses of limestone. A complete thickness of the Navajo cannot be obtained in the map area as Quaternary erosion has removed the upper part of the sandstone; the maximum described thickness is about 600 feet.

Quaternary deposits consisting of landslide blocks, terrace deposits, stream alluvium, alluvial fans, and dune sand are wide spread in the map area.

The Red House Cliffs area is on the west and gently dipping flank of the Monument upwarp. Thus, the dominant structure of the area is a gentle westward dip. Locally the westward dip is interrupted by minor north-trending asymmetrical folds. Normal faults are associated with the eastward-dipping limbs of the minor folds, and many joints are well exposed in the sandstone strata.

Interest in the mineral resources of the Red House Cliffs area has centered around uranium, gold, copper, and oil and gas. To the present time, however, no commercially important mineral deposit has been discovered in the area. The Shinarump conglomerate exposed along the San Juan River is a favorable host rock for uranium ore and concealed deposits may be present in some of the Shinarump channels within the map area.

INTRODUCTION

Location and access

The Red House Cliffs area comprises 296 square miles in southwestern San Juan County, Utah (fig. 1). Most of the area is between Red Canyon, a tributary to the Colorado River, and the San Juan River; a part is south of the San Juan River and in the Navajo Indian Reservation. The map area includes the following 7-1/2-minute quadrangles in the Clay Hills 30-minute quadrangle: Clay Hills 1 NW, 2 NE,

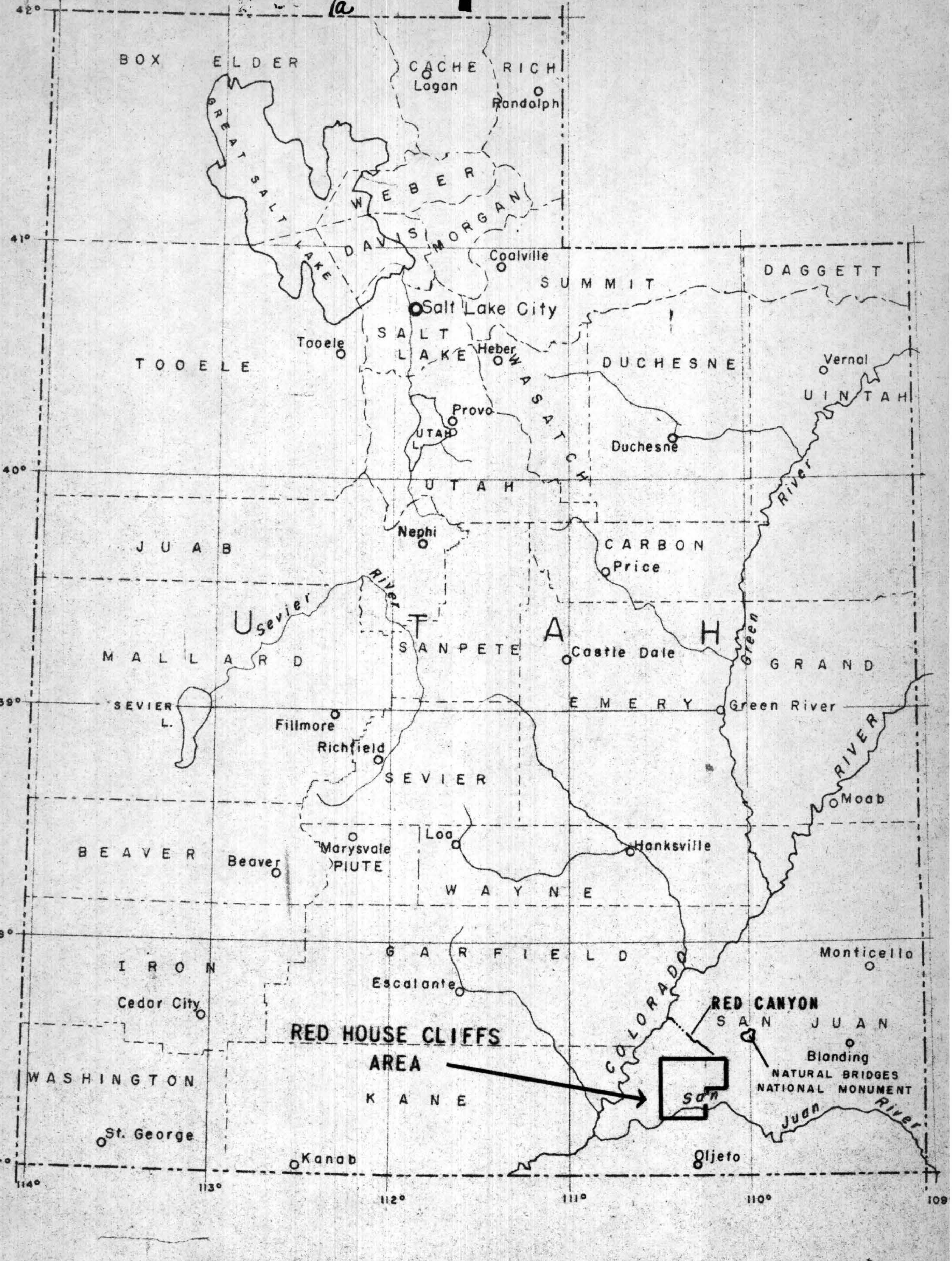


Figure 1. INDEX MAP OF UTAH SHOWING LOCATION OF RED HOUSE CLIFFS AREA, SAN JUAN COUNTY, UTAH

2 NW, 2 SW, and 2 SE. Part of the Red House Cliffs area is in T. 40 S., R. 14 and 15 E., and T. 41 S., R. 13, 14, and 15 E., Salt Lake meridian; the remainder of the area is unsurveyed land.

The part of the Red House Cliffs area north of the San Juan River is reached by a graded dirt road which joins Utah State Highway 95, which is also a graded dirt road, about one-fourth of a mile west of the entrance to Natural Bridges National Monument. The north boundary of the Red House Cliffs area is about 8 miles by road southwest of this junction. Blanding, Utah, the nearest town of supplies, is 48 miles east on Utah Highway 95 from this junction.

The part of the area south of the San Juan River is reached by a dirt road leading north from Oljeto, Utah, a trading post on the Navajo Indian Reservation. The south boundary of the Red House Cliffs area is 20 miles, by unimproved road, north of Oljeto.

Present investigation

Purpose

The present investigation of the Red House Cliffs area is part of the regional geologic mapping program being conducted by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. Primary objectives of the regional mapping program are: 1) to appraise the uranium resources of the main uranium-bearing formations in the Colorado Plateau, 2) to collect and interpret geologic data, and 3) to prepare geologic maps that show the distribution of uranium-bearing formations and geologic setting of uranium deposits.

This investigation of the Red House Cliffs shared the general objectives of the regional mapping program. Although no known uranium ore deposits occur in the area, it includes Triassic rock exposures that may contain significant uranium deposits.

Field work

Field work on which this report is based was done between July and October 1952 and between May and July 1953. Stratigraphic units and geologic structures were mapped and studied. In addition, a search was made for uranium minerals, abnormal radioactivity, and geologic features favorable for uranium deposits.

The stratigraphic units and geologic structures were mapped on stereo-pairs of air photographs (scale 1:31,680) and then transferred to Soil Conversation Service air photograph controlled mosaics (scale 1:31,680). Plane table measurements and checks with Geological Survey topographic maps which join the Red House Cliffs area indicate most points on the controlled mosaics are displaced less than one-tenth of an inch from true position. However, due to relief displacement in the original air pictures or error in constructing the mosaics, some cliffs shown on the mosaics are displaced from true position more than two-tenths of an inch. Thus, the geologic map (fig.4) is short of standard map accuracy.

Stratigraphic units were studied by measuring stratigraphic sections and tracing the units along the outcrop. Composition, grain size and shape, and percentage of cementing material given in the description of the formations is based mainly on megascopic examination.

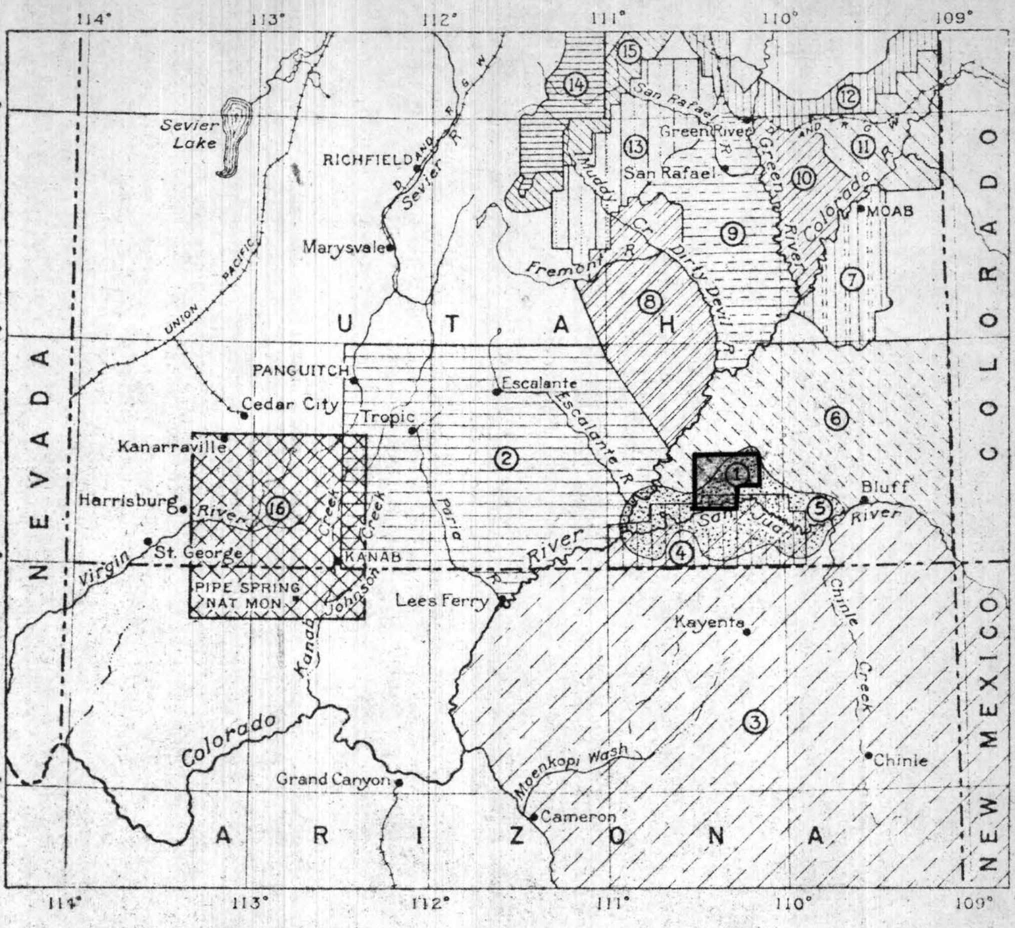
In searching for uranium minerals, abnormal radioactivity, and geologic features favorable for uranium deposits, particular emphasis was placed on the Upper Triassic Shinarump conglomerate and the lower part of the Upper Triassic Chinle formation, as these units are uranium-bearing in nearby areas. A systematic search for these features was made at all exposures of these units. Other formations exposed in the Red House Cliffs area were examined in many places for these features in the course of geologic mapping, but not in such detail as the Shinarump and lower part of the Chinle.

Acknowledgments

Able assistance was rendered in the field by H. A. Hubbard in 1952 and by J. N. Taggart in 1953. The project was under the supervision of J. F. Smith, Jr. who visited the field party several times and gave valuable advice on field methods. The assistance of these men is gratefully acknowledged.

PREVIOUS PUBLICATIONS

Many papers that describe geology, regional correlation of stratigraphic units, and geography of southeastern Utah have been published (fig. 2). Baker (1936, p. 17) compiled an extensive bibliography of literature pertaining to the geology and geography of southeastern Utah, and the complete list is not repeated here. Nevertheless, several papers are directly related to the geology and geography of the area reported here, and they deserve special mention.



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8	PROFESSIONAL PAPER 228	16	PROFESSIONAL PAPER 220

0 100 MILES

Figure 2. MAP SHOWING LOCATION OF RED HOUSE CLIFFS AREA (SHADED AREA) AND AREAS IN ADJOINING REGIONS FOR WHICH REPORTS HAVE BEEN PUBLISHED BY THE U. S. GEOLOGICAL SURVEY

Gregory (1938) described the broad geologic and geographic features of the part of the Red House Cliffs area north of the San Juan River in his geologic and geographic reconnaissance of the San Juan country. Gregory (1917) also included the part of the area south of the San Juan River in his report and map of the Navajo country. Baker (1936) mapped the part of the Red House Cliffs that is south of the San Juan River in his study of the Monument Valley-Navajo Mountain region. Miser (1924 and 1925) described the geology of the San Juan River Canyon from Bluff, Utah, to the mouth of the river, and his map includes a large part of the Red House Cliffs area both north and south of the river.

Regional correlation of some stratigraphic units exposed in the Red House Cliffs area is discussed in detail by Baker, Dane, and Reeside (1936) and Baker and Reeside (1929).

The Red House Cliffs area is on the route of the Mormon settlers who migrated from Escalante, Utah, to Bluff, Utah, in 1879-80. A graphic description of this migration through barren and rugged country is given in a newspaper article by Alter (1921), abstracted by Miser (1924, p. 31-32). Gregory (1938, p. 31-33) and Judd (1924, p. 275-302) have also described the route taken by the Mormon settlers.

GEOGRAPHY

Topographic features

In its general relations the Red House Cliffs area is part of the Canyon Lands section of the Colorado Plateaus Province (Fennenan, 1931, p. 306-312), a section characterized by bare rock surfaces, plateaus, cliffs, and steep walled canyons. These features, characteristic of the section as a whole, are well developed in the Red House Cliffs area which is on the west and gently dipping flank of the Monument upwarp where differential erosion of rocks of unequal resistance has produced a series of westerly sloping plateaus separated by easterly facing escarpments. Both plateaus and escarpments are deeply trenched by the San Juan River Canyon. The map area consists of parts of two of these plateaus, the intervening escarpment and part of the San Juan River Canyon.

General topographic features of the map area are shown diagrammatically on figure 3.

The eastern part of the Red House Cliffs area is a gently undulating surface which slopes gently westward. North of the San Juan River this surface comprises the southwestern edge of Grand Gulch Plateau (Gregory, 1938, p. 11-12), and south of the river the surface comprises the northwestern edge of Douglas Mesa (Baker, 1936, p. 10 and pl. 2). The surface is cut on essentially the same white sandstone stratum, and little difference in topographic expression exists on the opposite sides of the river. Many streams trench the surface, and the San Juan River has cut a vertical-walled west-trending canyon about 600 feet wide near the south part of the map area. This canyon is deepest, about 600 feet, at the east edge of the map area. Westward, owing to the regional dip of the sandstone in which the canyon is cut, the canyon progressively decreases in depth. At Clay Hills Crossing, the top of the sandstone is at water level and the river flows

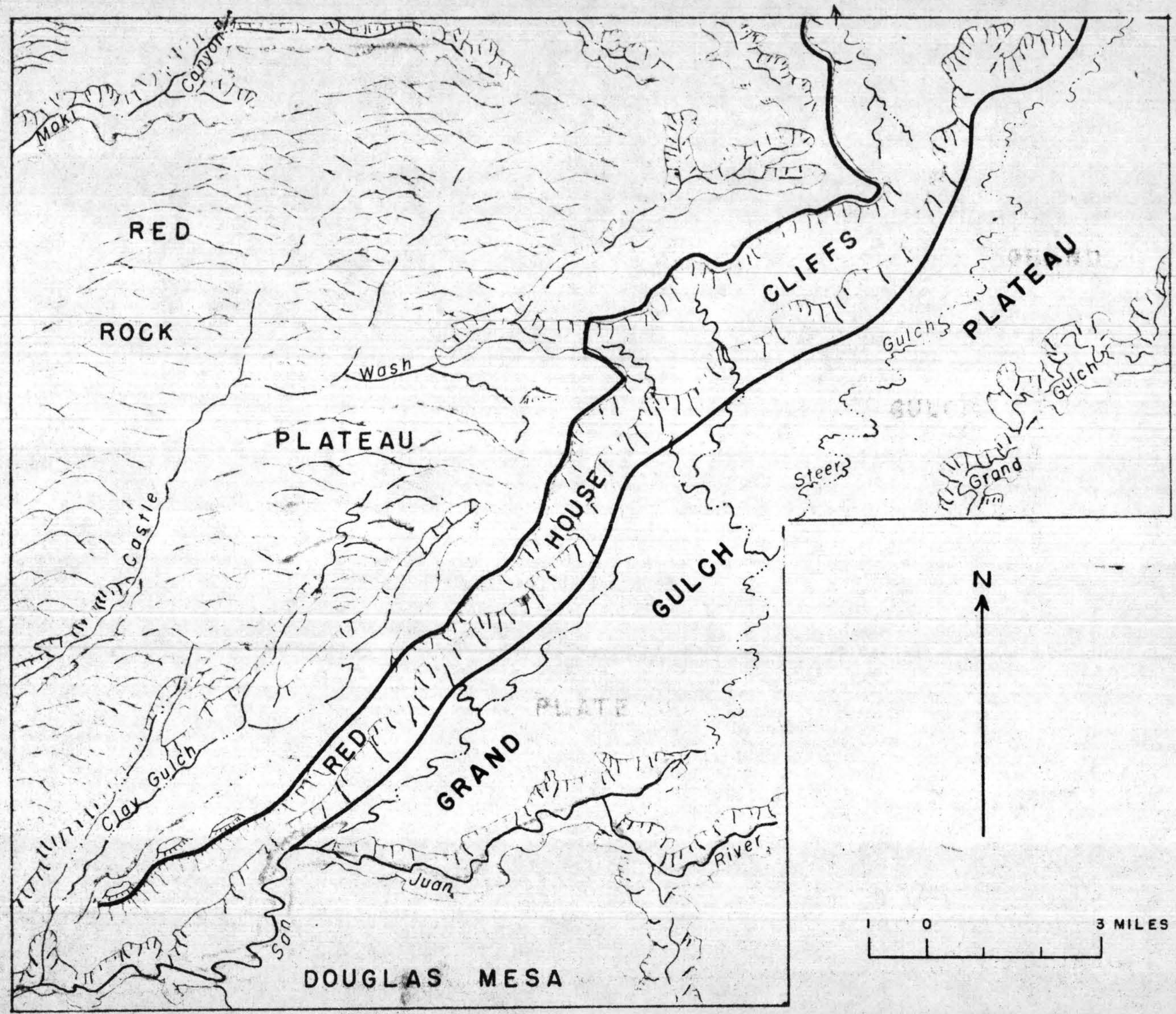

Figure 3. GENERALIZED TOPOGRAPHIC FEATURES OF THE RED HOUSE CLIFFS AREA, SAN JUAN COUNTY, UTAH

in a wide valley. Grand Gulch and Oljeto Wash also flow in vertical-walled canyons 400 to 600 feet deep, but other streams on the surface follow relatively wide and ledgy sloped courses except where they join the San Juan River in narrow vertical-walled canyons. Interstream areas on the Grand Gulch Plateau-Douglas Mesa surface are relatively flat, but locally intricate knobs, rounded domes, and flat-topped buttes of sandstones are developed on the divides.

The Grand Gulch Plateau-Douglas Mesa surface joins the Red House Cliffs escarpment on the west through 60 to 100 feet of ledge-forming beds above the white sandstone. Locally the ledge-forming beds support west-sloping benches one-fourth to 1 mile wide, and in these places the dividing line between the surface and escarpment is not well defined.

Red House Cliffs, named by Gregory (1938, p. 13), form the most conspicuous topographic feature in the map area. These cliffs form a southeast-facing escarpment that trends northeast from the San Juan River to about 8 miles beyond the northeast corner of the map area. The plural "cliffs" is a fitting description, for the escarpment rises about 1,600 feet above Grand Gulch Plateau in two great steps. A lower step comprises a steep slope about 300 feet high capped by a cliff about 100 feet high. The cliff at the top of the lower slope bounds a west-sloping bench that averages about half a mile in width, although the width of the bench ranges from 100 yards to more than a mile. A second step rises from this bench and comprises a steep irregular slope about 900 feet high, at the top of which is a palisade-like cliff about 300 feet high. The upper slope in the escarpment is rubble covered in most places;

but, where the rubble is absent, maroon, gray, green, and purple rocks crop out in the middle of the slope. These pastel colors contrast strongly with the general reddish brown of other rocks exposed in the escarpment and add beauty and color to the otherwise somber landscape.

The upper step of the escarpment has been stripped away by a northwestward-flowing tributary to the Colorado River in the northeast part of the map area. Here the escarpment contains only the lower step and an extensive bench supported by the capping cliff of the lower step. At two other places along the escarpment, Clay Hill Pass and in secs. 4, 8, and 17, T. 40 S., R. 14 E., erosion by southwestward-flowing tributaries to the San Juan River has breached the upper vertical cliff. However, in these two places most of the upper slope is intact.

The San Juan River flows parallel to the base of the Red House Cliffs for a short distance in the southwest part of the map area. At Piute Farms the river turns and flows in a narrow canyon through the escarpment.

The small part of the map area south of this canyon is part of Segi Mesas (Gregory, 1917, pl. 1). Segi Mesas are a much dissected continuation of the Red House Cliffs and the plateau extending west from the capping vertical cliff of the Red House Cliffs south of the San Juan River.

Red Rock Plateau is an extensive surface extending west from the capping cliff of the Red House Cliffs. As defined by Gregory (1938, p. 13-14) the Red Rock Plateau includes 800 square miles and is bounded by the Red House Cliffs, White Canyon, the San Juan River, and the Colorado River. Only the southeast part of Red Rock Plateau, about 150 square miles, is in the map area. Red Rock Plateau is extremely irregular. Many buttes and rounded domes of sandstone rise above the general surface level; and many steep-walled canyons are cut deep in the surface. One of the canyons, Clay Gulch, has separated a large butte from the main mass of the plateau in the south part of the map area.

Stream valleys on Red Rock Plateau vary greatly in character. The upper part of Castle Wash is a narrow sand covered flat bounded by vertical walls, the middle part is a broad sand covered flat bounded by low rounded sandstone hills, and the lower part is a narrow inner gorge in a broad flat-floored canyon. Moki Canyon, a tributary to the Colorado River, is a steep walled narrow canyon about 600 feet deep and less than half a mile wide. Clay Gulch is about 1-1/2 miles wide and 1,000 feet deep. However, only the upper 300 feet of the canyon that rims Clay Gulch is steep walled; the lower part of the canyon is a relatively gentle rubble covered slope.

Relief

Maximum relief in the Red House Cliffs area is about 2,750 feet. The highest point, about 6,400 feet above sea level, is on Red Rock Plateau 2-1/2 miles southwest of Red House Spring; the lowest point, about 3,650 feet above sea level, is at the water level of the San Juan River in the southwest corner of the map area. These two points are about 22 miles apart. Local relief is greatest from the base to the top of the Red House Cliffs where differences in elevation of 1,600 feet within 2 miles are common.

Climate and vegetation

The climate of the Red House Cliffs area is arid. No records of precipitation are available for the map area, but Bluff, Utah-- about 35 miles east of the area--and Hite, Utah--about 15 miles northwest of the area--usually receive less than 8 inches of precipitation a year (Gregory, 1938, p. 17-18). Most of the precipitation occurs in brief but heavy showers which cover only a few square miles.

The scant precipitation supports very little vegetation. Scattered grass, low bushes, and cactus grow in the lower elevations and some juniper and pinon pine trees grow in the higher elevations on Red Rock Plateau and Grand Gulch Plateau. In addition, a few cottonwood trees grow along the larger drainages such as Castle Wash, Moki Canyon, and Grand Gulch; and salt cedar is abundant along the banks of the San Juan River.

Population and industry

The Red House Cliffs area is not permanently inhabited. An Indian family cultivates a small tract of land of Piute Farms during the spring and summer. The only other regular visitors to the area are ranchers who graze cattle on Red Rock Plateau and Grand Gulch Plateau during the winter and spring.

Accessibility in the area

Few roads are in the Red House Cliffs area. The road that enters near the northeast corner of the map area turns northwest at the Red House Spring and leads to uranium mines in Red Canyon. This is an Atomic

Energy Commission access road, and it was passable to passenger cars in 1954. The road that branches from the access road at Red House Spring leads southwest along the base of the Red House Cliffs. Near the base of Clay Hills Pass the road turns west and continues past the west boundary of the map area. This road was constructed by the Skelly Oil Company in 1951 in order to carry supplies to a well drilled about 4 miles west of the map area. Skelly ceased operations at the well in November 1952, but the road has been maintained and was passable to four-wheel drive vehicles in 1954.

Access by vehicles to most of the map area is limited to the roads. Four-wheel drive vehicles can be driven on some of the interstream areas on Grand Gulch Plateau, but travel by this method is difficult and slow. About three hours are required to drive 12 miles "road" distance from the base of Clay Hills Pass to Clay Hills Crossing. Vehicle travel off the road on Red Rock Plateau is restricted to short stretches along tributaries to Castle Wash; and vehicle travel south on the San Juan River is restricted to creek beds near Piute Farms.

The field party walked to the places that could not be reached by four-wheel drive vehicles. Most places are accessible on foot, although canyons and cliffs necessitate circuitous routes to many places. The main barrier to foot travel is the palisade-like capping cliff of the Red House Cliffs. Access to the main part of Red Rock Plateau is gained only at Clay Hills Pass and in the westernmost tributary of Clay Gulch. Other barriers to travel are Moki Canyon, Grand Gulch, and the San Juan River Canyon cut in the Grand Gulch Plateau-Douglas Mesa surface.

Moki Canyon is unscalable except in the northwest corner of the map area where a sand dune has covered the canyon wall. Grand Gulch can be entered via Dripping Spring Gulch but cannot be crossed in the map area. The San Juan River Canyon cut in the Grand Gulch Plateau-Douglas Mesa surface can be crossed at the fault in sec. 19, T. 40 S., R. 15, E.

The San Juan River is difficult to cross during times of high water, but ordinarily the river is no obstacle to foot travel. During the summer, fall, and winter, few places below Clay Hills Crossing are over 2 feet deep except immediately after rains.

STRATIGRAPHY

Permian, Triassic, and Jurassic rocks aggregating about 3,500 feet in thickness and thin deposits of Quaternary rocks crop out in the Red House Cliffs area. Excepting the Quaternary deposits, the oldest rocks crop out in the eastern part of the area and progressively younger rocks are exposed westward. Most of the formations are continental in origin, and, in the map area, the lithologic characteristics, thickness, and color within the formations are nearly uniform. Red is the dominant color, but most of the Cedar Mesa sandstone member of the Permian Cutler formation is white and the Upper Triassic Chinle formation is strikingly variegated. Diagnostic fossils are absent in all formations, but correlation of Permian and Jurassic stratigraphic units is made with little doubt. Most Permian and Jurassic formations can be traced directly to type areas.

No igneous rocks crop out in the map area.

The areal distribution of the formations is shown on figure 4, and a generalized stratigraphic section is shown on table 1. Measured stratigraphic sections are included in the appendix.

Permian system

Cutler formation

The Cutler formation was named by Cross and Howe (1905, p. 5) for exposures of arkosic conglomerate in southwestern Colorado. Baker and Reeside (1929) extended the name "Cutler formation" to rocks in southeastern Utah where the Cutler formation is comprised of three red-bed tongues and two light-colored sandstone members. These subdivisions of the Cutler formation are, in ascending order, the Halgaito tongue, the Cedar Mesa sandstone member, the Organ Rock tongue, the DeChelly sandstone member, and the Hoskinnini tongue.

The Halgaito tongue is partly exposed in the San Juan River Canyon at the east edge of the map area and the DeChelly sandstone member is exposed only in the canyon in the southwest part of the map area. The other members in the Cutler formation form extensive outcrops in the southeast half of the map area.

Halgaito tongue.--The Halgaito tongue, lowest unit in the Cutler formation, was named for exposures at Halgaito Spring in Monument Valley by Baker and Reeside (1929, p. 1443). The Halgaito crops out in the southeast part of the Red House Cliffs area at the bottom of the San Juan River Canyon. This exposure, which is inaccessible except by boat, was examined only from a distance. About the upper two-thirds of

System	Group	Formation	Member	Thickness (feet)	Description
QUATERNARY					LANDSLIDES, TERRACE GRAVEL, STREAM ALLUVIUM, ALLUVIAL FANS, AND SAND DUNES
UNCONFORMITY					
JURASSIC AND TRIASSIC	GLEN CANYON	NAVAJO SANDSTONE		600+	**CROSS-LAMINATED PALE-RED TO REDDISH-ORANGE MEDIUM-GRAINED SANDSTONE; SCATTERED THIN BEDS OF LIGHT-GRAY TO DARK-GRAY LIMESTONE; TOP OF FORMATION NOT EXPOSED IN MAPPED AREA**
		KAYENTA FORMATION		200-230	CROSS-LAMINATED PALE-RED TO REDDISH-BROWN SANDSTONE AND INTERBEDDED SILTSTONE
		WINGATE SANDSTONE		310-340	CROSS-LAMINATED REDDISH-BROWN TO REDDISH-ORANGE SANDSTONE; CLIFF-FORMING
TRIASSIC		CHINLE FORMATION		784-1018	UPPER ONE-THIRD: EVENLY BEDDED REDDISH-ORANGE FINE-GRAINED SANDSTONE AND SILTSTONE MIDDLE ONE-THIRD: VARIEGATED SILTSTONE AND CLAYSTONE AND LENTICULAR BEDS OF LIGHT-GRAY LIMESTONE LOWER ONE-THIRD: GREENISH-GRAY SANDSTONE AND MAROON AND GREENISH-GRAY MUDSTONE
		SHINARUMP CONGLOMERATE		0-176	LIGHT-GRAY CONGLOMERATIC SANDSTONE; LENTICULAR BEDS, MOTTLED YELLOW AND PURPLE; ABSENT AT MOST PLACES IN MAPPED AREA
	UNCONFORMITY				
		MOENKOPI FORMATION		**260-336**	EVENLY BEDDED BROWN SILTSTONE AND SANDSTONE; ABUNDANT RIPPLE MARKS, WHITE GYPSUM ALONG BEDS AND IN CROSS-CUTTING SEAMS
PERMIAN		CUTLER FORMATION	HOSKINNINI TONGUE	**42-119**	REDDISH-BROWN SILTY VERY-FINE GRAINED SANDSTONE; ABUNDANT FINE TO COARSE WELL-ROUNDED QUARTZ GRAINS, CLIFF-FORMING
			DECHELLY SANDSTONE MEMBER	0-30	CROSS-LAMINATED YELLOWISH-GRAY FINE- TO MEDIUM-GRAINED SANDSTONE. ABSENT IN MOST OF THE MAPPED AREA
			ORGAN ROCK TONGUE	**314-447**	HORIZONTALLY BEDDED REDDISH-BROWN SILTY SANDSTONE; SEVERAL THIN WHITE SANDSTONE BEDS IN UPPER PART
			CEDAR MESA SANDSTONE MEMBER	600	UPPER 60 TO 100 FEET: CROSS-LAMINATED YELLOWISH-GRAY FINE-GRAINED SANDSTONE INTERBEDDED WITH EVENLY BEDDED REDDISH-BROWN SILTSTONE AND SANDSTONE. LOWER 500 FEET: CROSS LAMINATED LIGHT-GRAY FINE-GRAINED SANDSTONE; MANY HORIZONTAL PARTING PLANES
			HALGAITO TONGUE	200+	RED TO CHOCOLATE-BROWN FINE-GRAINED SILTY SANDSTONE AND SHALE; SOME THIN BEDS OF UNFOSSILIFEROUS LIMESTONE ./; BASE OF TONGUE NOT EXPOSED IN MAPPED AREA.

./ DESCRIPTION OF MEMBER FROM BAKER (1936, PL. 5).

Table 1. SEDIMENTARY ROCKS IN THE RED HOUSE CLIFFS AREA, SAN JUAN COUNTY, UTAH

the Halgaito is present at the edge of the mapped area, but progressively less of the member is exposed westward, owing to the regional dip, and about 2 miles down stream it disappears.

Baker (1936, p. 30) describes a section of Halgaito tongue measured in sec. 34, T. 41 S., R. 17 E. There, the Halgaito is 425 feet thick and consists mostly of chocolate brown and purplish red thin-bedded sandstone, and includes some thin beds of grayish unfossiliferous limestone. This section is about 15 miles southeast of the Halgaito exposed in the Red House Cliffs area.

Cedar Mesa sandstone member.--The Cedar Mesa member of the Cutler formation was named by Baker and Reeside (1929, p. 1443) for exposures in the cliffs around Cedar Mesa, a Mesa north and west of Mexican Hat, Utah. The cliffs in this Mesa are the eastern boundary of Grand Gulch Plateau, and they are about 15 miles east of the map area. The Cedar Mesa sandstone crops out in the Grand Gulch Plateau-Douglas Mesa surface and consists of a lower white to grayish-orange massive sandstone and an upper irregularly interbedded reddish siltstone and sandstone unit. Excellent sections of the lower Cedar Mesa sandstone are exposed in the vertical walls of the San Juan River Canyon, Grand Gulch, and Oljeto Wash. The upper unit of Cedar Mesa, 50 to 100 feet in thickness, crops out in ledgy benches along the western edge of the Grand Gulch Plateau-Douglas Mesa surface and is also locally preserved as flat topped hills in the inter-canyon areas on the Grand Gulch Plateau-Douglas Mesa surface.

The thickness of the Cedar Mesa sandstone member cannot be determined accurately in the map area because of the great width of outcrop and the absence of persistent beds. As determined by parallax measurements from air photographs, it is about 600 feet thick where the Organ Rock anticline crosses the San Juan River. The base of the sandstone is not exposed here, but study of the local structure indicates the base is about 25 feet below water level in the canyon. The thickness of the Cedar Mesa sandstone probably varies in different parts of the map area, because of intergrading with the overlying Organ Rock tongue. Probably the same relation holds for the contact with the underlying Halgaito tongue (Baker, 1936, p.32).

The lower part of the Cedar Mesa sandstone is grayish-white to very pale-orange well sorted cross-laminated sandstone. It is composed of subrounded to rounded fine and very fine quartz grains and rare red and black accessory grains weakly cemented by calcium carbonate. Individual sandstone beds range from 8 to 40 feet in thickness and average about 20 feet. The beds of sandstone are cross-laminated with long sweeping laminations of the type attributed to eolian deposition, but each bed is separated from adjacent beds by horizontal parting planes that truncate the cross-laminations in the bed below. Some horizontal parting planes extend for more than a mile before they disappear in a cross-laminated unit, but the average extent is less than half a mile. Immediately above the horizontal parting planes horizontal laminations predominate, but these grade upward into the long sweeping cross-laminations. Locally scour surfaces are associated with the horizontal parting planes in the lower part of the Cedar Mesa sandstones; scours are rare and relief on a scour does not exceed 3 feet. Reddish-brown siltstone in thin films is commonly associated with the parting planes, and a 6-inch bed of dense gray limestone which extended about 500 feet was noted above a parting plane in Grand Gulch. This was the only limestone bed observed in the lower part of the Cedar Mesa sandstone; however, limestone is common in the upper part.

The upper part of the Cedar Mesa sandstone is a transition zone from the light-colored sandstone below to the red beds of the Organ Rock tongue. This transition zone is about 100 feet thick at the San Juan River, and it thins to about 50 feet at the northern boundary of the map area. The zone comprises mainly lenticular beds of sandstone and reddish-brown siltstone, but it includes some 6 inch to 1-foot beds of dense gray limestone and stubby lenses of limestone conglomerate. The sandstone beds range from 1 to 15 feet in thickness, are variably silty, and range from white to pale reddish-brown in color. In general the sandstone is lighter colored, thicker bedded, and contains less silt near the base of the zone than the sandstone near the top. Conversely, reddish-brown siltstone is abundant near the top of the zone and sparse near the base. Some sandstone beds are structureless, some horizontally laminated, and some cross-laminated. Both eolian and fluviatile types of cross-laminations occur in the transition zone, but eolian cross-laminations are found mainly in the lower part of the zone. Scours, some filled with limestone conglomerate, are abundant both within and at the base of the sandstone beds. The maximum relief observed on the scour surface was 7 feet, but the average relief is about 2 feet. Irregular elongate dense gray limestone concretions and some nodular limestone concretions are common in the sandstone in the transition zone.

Limestone conglomerate beds that filled scours in the transition zone are composed of rounded and subrounded limestone pebbles in a silty or sandy limestone matrix; few beds exceed 3 feet in thickness or 100 feet in length. Locally some of the matrix in the conglomerate is replaced with dark-gray or red chert. The maximum observed size of the limestone pebbles was 2 inches, and the average size is about one-half inch.

The well-sorted sand and the cross-laminations in the lower part of the Cedar Mesa suggest this part of the formation was deposited as sand dunes.

The Cedar Mesa sandstone grades into a gypsiferous series of sandstone and red beds about 20 miles east of the map area (Sears, in preparation). These beds are water-laid deposits, and the body of water in which they were deposited possibly transgressed the dune area to the west from time to time. Repeated transgressions by this body of water could possibly account for the horizontal parting planes and the associated siltstone in the lower part of the Cedar Mesa sandstone in the map area. However, the general limited areal extent of the parting planes indicate that they more likely were formed in small shallow lakes not directly connected to the larger body of water to the east.

The upper 50 to 100 feet of the Cedar Mesa sandstone reflects a change of depositional environments. Probably streams overran the sand dunes and formed stream deposits, and in turn the streams were displaced by quiet water. Intermingling of the dune, stream, and quiet-water deposits indicates that the change in depositional environment progressed erratically.

The basal contact of the Cedar Mesa sandstone was not examined in this study. Baker (1936, p. 32) states that the Halgaito tongue-Cedar Mesa sandstone is gradational laterally as well as vertically.

The contact of the Cedar Mesa sandstone with the overlying Organ Rock tongue is conformable with lateral and vertical gradation. Gregory (1938, p. 45) reports an unconformity of unknown significance at the top of the Cedar Mesa sandstone in the San Juan Country, but no evidence for an unconformity was noted in the map area.

No fossils were found in the Cedar Mesa sandstone in the map area. The evidence of Permian age for the Cedar Mesa sandstone is given by Baker (1936, p. 29) and Baker and Reeside (1929, p. 1421-1422). Correlation with the type section in Cedar Mesa is assured as the Cedar Mesa sandstone can be traced without a break in outcrop to the type locality.

Organ Rock tongue.--The Organ Rock tongue of the Cutler formation was named by Baker and Reeside (1929, p. 1443) for exposures at Organ Rock, a slender spire about 10 miles south of the map area in Monument Valley. Within the map area the main outcrop of the Organ Rock tongue is a narrow band along the base of the Red House Cliffs, but this outcrop band widens southeast of Clay Hills Pass across the Organ Rock anticline and Oljeto syncline. The basal part of the Organ Rock tongue crops out south of the San Juan River from Clay Hills Crossing to Piute Farms, and a small isolated exposure of the basal part of the Organ Rock is near the crest of the Organ Rock anticline in sec. 24, T. 40 S., R. 14 E.

The Organ Rock tongue forms both steep slopes and benches in the map area. The upper part of the Organ Rock forms steep ledgy slopes at the base of the Red House Cliffs, and the lower part commonly forms gently sloping benches along the western edge of the Grand Gulch Plateau-Douglas Mesa surface. Many of the benches are covered with Quaternary deposits.

The Organ Rock tongue is thickest, 447 feet, at the southern edge of the map area, and it thins to 314 feet at the northern edge of the map area. The south to north thinning is mostly due to lateral gradation of Organ Rock tongue to Cedar Mesa sandstone, but some of the thinning may be due to lateral gradation with the overlying Hoskinnini tongue near the San Juan River.

The Organ Rock tongue consists mainly of reddish-brown siltstone and silty very fine-grained sandstone. Some limestone-pebble conglomerate beds are disseminated through the Organ Rock, and locally light-gray, highly calcareous, fine-grained sandstone beds as much as 3 feet thick occur in the top 80 feet of the Organ Rock.

The siltstone and sandstone are composed mainly of clear quartz fragments stained red by iron oxide, but abundant interstitial clay and disseminated very fine white mica flakes occur in both the siltstone and sandstone. Both siltstone and sandstone are firmly cemented by calcium carbonate, and both weather to angular fragments about 1 inch in maximum dimension. The limestone-pebble conglomerate beds generally fill small scours at the base of sandstone beds. These conglomerate beds resemble limestone conglomerate beds in the top part of the Cedar Mesa sandstone member except the matrix contains more silt and less calcium carbonate than limestone conglomerate in the Cedar Mesa.

The Organ Rock tongue contains many irregularly spaced pale green mottles, and the lower two-thirds of the Organ Rock contains many fractures bleached pale green. The fractures are apparently randomly spaced and oriented and do not conform to the regional joint pattern. Apparently the pale-green color is due to removal or change of valence of the ferric ion, but the agent, or agents, affecting the ferric ion is not known.

Viewed from a distance, the Organ Rock tongue appears to be evenly bedded in units 3 to 10 feet in thickness; however, in detail the beds are lens-like. Most individual beds in the Organ Rock cannot be traced more than a few hundred yards along the outcrop, but the light-colored beds near the top of the tongue extend 2 to 5 miles along the outcrop. The ledgy character of the Organ Rock slope is due to the sandstone being slightly more resistant than the siltstone.

The reddish color and lenticular nature of the beds suggest a continental origin for the Organ Rock tongue; but these features are not conclusive proof of a continental origin. The Organ Rock tongue probably accumulated in relatively quiet non-marine water. Some current action produced slight scours and lenticular beds, but this current action was relatively unimportant.

The Organ Rock tongue conformably everlies the Cedar Mesa sandstone member and conformably underlies the DeChelly sandstone member and the Hoskinnini tongue where the DeChelly sandstone is absent.

No fossils were found in the Organ Rock tongue in the map area, but fossils which indicate a Permian age are reported south of the map area (Baker, 1936, p. 35). The Organ Rock tongue can be traced without a break in outcrop to the area near Organ Rock, the type section.

<u>DeChelly sandstone member</u>.--The DeChelly sandstone, the upper sandstone member of the Cutler formation, was defined originally by Gregory (1917, p. 31), as exposures of a massive sandstone which forms the walls of Canyon DeChelly in northeastern Arizona. It was included as a member of the Cutler formation by Baker and Reeside (1929, p. 1443). A wedge edge of the DeChelly sandstone crops out in the San Juan River Canyon near the southwest corner of the Red House Cliffs area. North and south of the canyon the DeChelly sandstone is absent due to non-deposition in exposures of the same stratigraphic position in the map area.

The DeChelly sandstone crops out in a rounded to vertical cliff which extends only a few hundred yards along the river. Westward, the DeChelly disappears under younger rocks owing to the regional dip; eastward, the sandstone wedges out between the Organ Rock and Hoskinnini tongues of the Cutler formation.

The maximum thickness of completely exposed DeChelly sandstone in the map area is 30 feet, but the DeChelly may thicken slightly westward as it is 45 feet thick in the next exposure about 5 miles west. Eastward from the maximum of 30 feet the lower 25 feet of the DeChelly wedges out in less than 200 yards. The upper 5 feet grades laterally into the overlying Hoskinnini tongue.

The DeChelly sandstone is a grayish-yellow, cross-laminated sandstone. It is composed of fine to medium well-rounded quartz grains and common very fine-grained black accessory minerals. Many of the quartz grains are frosted and are coated with a thin film of red iron oxide. The sandstone is weakly cemented with calcium carbonate. The thicker part of the DeChelly sandston is cross-laminated with long sweeping cross-laminations; near the wedge edge the DeChelly is horizontally bedded in beds 2 to 6 feet thick, and bedding structures in the individual beds are not distinguishable.

The DeChelly sandstone member is probably a wind-laid deposit and the wedge edge in the map area apparently represents sand dunes near a body of water.

The DeChelly sandstone conformably overlies the Organ Rock tongue. This contact is sharply defined by a change in sedimentary structures and color. However, the change from Organ Rock tongue to DeChelly is in part transitional, for the upper beds of the Organ Rock closely resemble DeChelly sandstone in composition.

The DeChelly sandstone conformably underlies the Hoskinnini tongue. Part of the DeChelly grades laterally into Hoskinnini at the wedge-out, but over the main mass of the DeChelly sandstone the contact is defined by a change in texture and sedimentary structures. The Hoskinnini tongue bevels the cross-laminations in the DeChelly sandstone and some authors (Witkind and others, in preparation; and Harshbarger and others, in preparation) interpret the contact as unconformable. The writer interprets the contact as conformable and as representing a change in depositional environment in which no appreciable break in sedimentation occurred.

No diagnostic fossils are known from the DeChelly sandstone, and it is assigned a Permian age because of its close stratigraphic relationship with the Organ Rock tongue. Baker (1936, p. 37) and Baker and Reeside (1929, p. 1421-1422) cite the evidence for assigning the DeChelly a Permian age.

The outcrop of the DeChelly sandstone in the San Juan River Canyon is isolated from the main mass of the DeChelly sandstone in Monument Valley. The nearest exposed DeChelly sandstone is about 4 miles southeast of the exposure in the canyon, but the correlation is assured on the basis of a distinctive lithologic assemblage and stratigraphic position.

Hoskinnini tongue.--The Hoskinnini tongue of the Cutler formation was named by Baker and Reeside (1929, p. 1443) for exposures in Hoskinnini Mesa near the west side of Monument Valley about 15 miles south of the map area. The Hoskinnini tongue forms a narrow outcrop band along the Red House Cliffs and along the south side of the San Juan River.

The Hoskinnini tongue forms the lower part of the lowest vertical cliff at most places along the Red House Cliffs, but at Clay Hills Pass and north of the San Juan River at Piute Farms the Hoskinnini forms a ledgy slope. Typically the cliff formed by the Hoskinnini is smooth or rounded but locally, many diagonal joints are developed in the cliff and erosion along these joints cause many small arches in the otherwise smooth cliff.

The thickness of the Hoskinnini tongue is nearly constant north of Clay Hills Crossing. It is 119 feet thick at Clay Hills Crossing, 110 feet at Clay Hill Pass, and 108 feet at the north boundary of the area. However, the Hoskinnini tongue is less than 100 feet thick at all places south of Clay Hills Crossing, and it is only 42 feet where it overlies the DeChelly sandstone.

The Hoskinnini tongue is composed mainly of reddish-brown poorly sorted siltstone and very fine-grained sandstone. It is well indurated, but only slightly calcareous. Included in the silty sandstone are abundant larger grains of quartz, chert, and feldspar. The larger grains are subrounded to rounded and range from fine- to coarse-grained. They occur both in laminar concentrations and disseminations throughout the Hoskinnini tongue and, in general, the size and abundance of the larger grains decrease from the base to the top. About 90 percent of the larger grains are clear and iron stained quartz; the remaining 10 percent is composed of about equal proportions of dark colored chert and gray feldspar. In general, the chert and feldspar grains are less rounded than the quartz grains.

The Hoskinnini tongue contains a unique zone of contorted beds 1 to 4 feet thick ranging from about 12 to 20 feet below the top. North of Clay Hills Pass this zone contains irregular beds of light colored highly calcareous medium-grained sandstone which locally grades into coarsely crystalline limestone. Both the sandstone and limestone contain abundant medium and coarse grains of orange chert. Bedding in this zone is contorted, and some places the contortions are regular and form a sine curve pattern with amplitudes as much as 4 inches. South of Clay Hills Pass to near the outcrop of the DeChelly sandstone the zone becomes gypsiferous and in many places is composed entirely of white granular gypsum. Where the Hoskinnini tongue overlies the DeChelly sandstone the zone contains only calcareous sandstone. This zone can be traced into the "crinkly bed" which is 8 to 11 feet below the top of the Hoskinnini tongue in exposures in Monument Valley described by Baker (1936, p. 39-40).

Bedding structures in the Hoskinnini tongue are not distinct. In general, the Hoskinnini tongue forms a massive cliff broken only by a few discontinuous horizontal parting planes, but close examination of the cliff reveals fine-scale contorted laminations bounded by grayish-red clay films. Probably these are ripple laminations, but they may be extremely small scale cross-laminations. The contortion of the laminations could have been caused by compaction during diagenesis.

The Hoskinnini tongue is a water-laid deposit, but whether the water was marine or not is not known. The lack of sorting indicates that the Hoskinnini sediments were buried rapidly, or that current action was so weak that sorting was not accomplished. The contorted zone near the top of the Hoskinnini tongue probably reflects a stage when a temporary decrease in the supply of detritus allowed an evaporite basin to form. Gypsum extending from Clay Hills Pass to Clay Hills Crossing and limestone and limy sandstone north and south of the gypsum suggest that a central part of the evaporite basin existed between Clay Hills Pass and Clay Hills Crossing. However, the outline of the evaporite basin cannot be determined by the single cross-section exposed along the Red House Cliffs.

Near the wedge edge of the DeChelly sandstone the Hoskinnini tongue is difficult to separate from the underlying Organ Rock tongue. For this reason Baker (1936, pl. 1, p. 39) did not extend the Hoskinnini tongue past the edge of the DeChelly sandstone. However, by detailed examination the Hoskinnini can be separated from the Organ Rock by the distinctive mixed size and the small scale contorted laminations in the

Hoskinnini tongue. North of Clay Hills Crossing the Hoskinnini tongue forms a distinctive rounded cliff that extends many miles north of the map area and can be separated easily from the underlying Organ Rock.

The Hoskinnini tongue conformably overlies the DeChelly sandstone in a small part of the map area, and the upper few feet of the DeChelly sandstone grades laterally into the Hoskinnini tongue at the wedge edge of the DeChelly. In other places the Hoskinnini tongue overlies the Organ Rock tongue with no apparent unconformity that would reflect either erosion or non-deposition of beds equivalent to the DeChelly sandstone. The only evidence of irregularity in the basal Hoskinnini contact is that the Hoskinnini thins from over 100 feet where the DeChelly sandstone is absent to about 40 feet at the wedge of the DeChelly sandstone. This change in thickness may partly represent contemporaneous deposition of the lower part of the Hoskinnini tongue with deposition of part of the DeChelly sandstone.

Some Hoskinnini sediments probably accumulated in water while some DeChelly sediments accumulated in sand dunes at the edge of the water. The strand line was stable in a narrow range for no broad scale alternation of water-laid with wind-laid deposits took place. After a sufficient length of time to allow several tens of feet of Hoskinnini sediments to be deposited off-shore and to allow deposition of DeChelly dunes, the strand line migrated landward. This migration resulted in a beveling of the DeChelly sand dunes and deposition of Hoskinnini sediments over the DeChelly sandstone.

The well-defined unconformity between Permian and Triassic rocks to the west (Gregory and Moore, 1931, p. 45-46) is not present in the map area; here the contact between the Hoskinnini tongue and the Lower Triassic Moenkopi formation is not distinct. In vertical sections the contact is marked by a minor color break, a surface with local irregularities of 1 to 6 inches, and a change in stratification. In less well-exposed sections the contact is difficult to pick with accuracy because of the small differences between the Hoskinnini and the Moenkopi. The writer interprets the contact as conformable. The Moenkopi formation is in part a marine deposit, but the relation of the Moenkopi sea to the body of water in which the Hoskinnini was deposited in not clear. Possibly the water in which the Hoskinnini was deposited was directly connected with the Moenkopi sea.

The Hoskinnini tongue is closely related to the underlying Permian rocks, and it may be closely related to the overlying Triassic rocks. No fossils have been found in the Hoskinnini tongue. It was assigned a Permian age (Baker, 1936, p. 40; and Baker and Reeside, 1929, p. 1421-1422) because it resembles other red bed members of the Cutler formation and in places according to Baker unconformably underlies the Lower Triassic Moenkopi formation. No conclusive evidence as to the age of the Hoskinnini tongue was found in the map area; and the author accepts the Permian age assignment with the reservation that further study may result in a Triassic age assignment for at least part of the Hoskinnini.

The Hoskinnini tongue exposed in the Red House Cliffs area can be traced directly to the type locality at Hoskinnini Mesa.

Triassic system

Lower and Middle(?) Triassic series

Moenkopi formation.--The Lower and Middle(?) Triassic Moenkopi formation was named by Ward (1901, p. 403) for exposures along Moenkopi Wash in northern Arizona. These exposures are about 100 miles southwest of the Red House Cliffs area. In the map area the Moenkopi formation crops out in the Red House Cliffs and along the San Juan River in the southwest part of the area. It forms a lower steep earthy slope, a middle steep ledgy cliff, and an upper steep earthy slope.

The Moenkopi formation is 336 feet thick about 1 mile south of the map area, 291 feet thick at Clay Hills Pass, and 280 feet thick near Red House Spring. These figures indicate a general northeastward thinning, but near the San Juan River the Moenkopi formation is locally only 260 feet thick due to scouring away of the top beds along the erosional surface that separates the Moenkopi from the overlying Upper Triassic rocks. The general northeastward thinning of the Moenkopi formation is apparently due to nondeposition and not related to the erosional surface, as the upper beds in the Moenkopi are persistent except where cut out by scours.

The Moenkopi formation is differentiated from other formations by its distinctive brown color and sedimentary structures. It is composed of micaceous siltstone and fine-and very fine-grained sandstone, and minor amounts of gypsum in beds, seams, and nodules. The siltstone is pale brown and occurs mainly in the basal and upper thirds of the

Moenkopi. It is composed chiefly of quartz particles, but it includes interstitial clay and fine-grained white mica flakes. The siltstone is horizontally laminated, and vertical exposures of the siltstone have a varved appearance. The siltstone is fissile and weathers to thin plates about 1 inch in long dimension. Thin, 1 to 6 inch, beds of very fine-grained sandstone are interbedded at irregular intervals in the siltstone. Many thin sandstone beds in the siltstone intervals and some sandy siltstone beds contain abundant symmetrical and asymmetrical ripple marks which are as much as 4 inches from crest to crest and have linear extents of more than 20 feet. Sandstone beds in the upper siltstone interval are pale green, and this interval weathers to a brown and green banded slope.

Gypsum in the Moenkopi formation is nearly restricted to the siltstone intervals. It occurs in beds as much as 1 foot thick, in seams as much as 1 inch thick which cross-cut the siltstone beds, and in elongate nodules whose long dimensions parallel the general bedding. Gypsum beds are restricted to the lower siltstone interval south of Clay Hills Pass, but the nodules and seams occur in the Moenkopi throughout the map area.

Sandstone is generally concentrated in the middle third of the Moenkopi formation, but near Red House Spring the base of the sandstone zone is only a few feet above the base of the Moenkopi. The sandstone is light brown and fine- to very fine-grained. It is composed of clear subrounded and rounded quartz grains, very fine-grained black accessory minerals, and fine-grained mica flakes; it is variably silty and weakly cemented by calcium carbonate. The sandstone occurs in beds from 2 to 40 feet in thickness which are separated from adjacent sandstone beds by 1 to 8 feet of siltstone. Sedimentary structures in the sandstone beds include asymmetrical and symmetrical ripple marks, horizontal laminations, and ripple and long sweeping low angle (less than 11°) cross-laminations. The individual sandstone beds have flat regular contacts on the underlying siltstone, but the top contact grades into the overlying siltstone through an increase in silt content. Ripple marks, mud cracks, and rain pitted surfaces are common in the sandier part of the transition zone from sandstone to siltstone. Sandstone beds also grade laterally into siltstone beds.

The thin even bedding and ripple marks indicate that most of the Moenkopi formation was deposited in quiet water. The alternation of siltstone and sandstone in the middle part of the Moenkopi formation possibly indicates a shifting of the strand line that allowed an alternation of water-laid and beach deposits. Alternate methods to produce the alternation of sandstone and siltstone would be to maintain a stable strand line and change the source material or change the capacity of streams bringing detritus to the Moenkopi sea. The ripple marks, the mud cracks, and the rain pitted surfaces indicate the Moenkopi formation was deposited in shallow water. No direct proof that this shallow water was marine exists in the map area; however, north and west of the map area the Moenkopi formation contains marine sediments (Gilluly, 1929, p. 86-87; Smith and others, in preparation). In the map area the Moenkopi sediments were probably deposited partly under a shallow extension of the Moenkopi sea and partly under a terrestrial environment that bordered the sea.

The Moenkopi formation conformably overlies the Hoskinnini tongue of the Cutler formation. It is separated from the overlying Upper Triassic Shinarump conglomerate or, where the Shinarump conglomerate is absent, the Upper Triassic Chinle formation, by an erosional unconformity.

No fossils were found in the Moenkopi formation exposed in the map area. The Lower Triassic age has been established by marine fossils collected in southwestern Utah by Reeside and Bassler (1922, p. 67-68) and in the San Rafael Swell in east-central Utah by Gilluly (1929, p. 86-87).

The Moenkopi formation exposed in the map area cannot be traced by continuous outcrops to the type locality in Moenkopi Wash, but the distinctive sedimentary structures, the brown color, and the composition of the Moenkopi formation leave little doubt in the correlation.

Upper Triassic series

Shinarump conglomerate.--The name "Shinarump conglomerate" was first used in print by Gilbert (1875, p. 176) and Howell (1875, p. 247-248) in two articles published in the same volume. Neither defined the Shinarump conglomerate; and Howell, (1875, p. 270-273) indicates the name was suggested by J. W. Powell. Powell (1876, p. 458) defined a Shinarump group which included a middle conglomerate that capped the Shinarump cliffs in southwestern Utah, but Gilbert (1877, p. 6) in his study of the Henry Mountains used the name "Shinarump conglomerate" to designate only the conglomerate that caps the Shinarump cliffs. These cliffs are about 120 miles west of the Red House Cliffs area.

Shinarump conglomerate rims the San Juan Canyon in the southwest part of the map area, but near Clay Hills Crossing the main mass of the Shinarump conglomerate pinches out. North of Clay Hills Crossing the Shinarump conglomerate is represented only by discontinuous lenses.

The thickness of the Shinarump conglomerate varies irregularly. Part of the irregularity in thickness is due to scouring at the base, part is due to lateral gradation of Shinarump conglomerate to Chinle sandstone at the top, and part is due to the general thinning of the

Shinarump to a wedge-out near Clay Hills Crossing. A maximum thickness of 176.6 feet was measured about 200 yards south of the map area in section 2, T. 41 S., R. 13 E. This thickness included Shinarump sediments that filled a 40 foot deep scour cut into the Moenkopi formation. The maximum observed thickness on the north side of the river is 108 feet, and this includes a 50 foot thick scour cut into the Moenkopi formation. In general, the Shinarump which rims the innner gorge of the San Juan River Canyon is 20 to 50 feet in thickness where no basal scours are involved.

The basal scours are important economically as most uranium deposits in the Shinarump conglomerate occur in sediments which fill scours cut into the Moenkopi formation. The position of the basal scours is shown on figure 4, although no known uranium ore deposits occur in them. They range from 5 to 50 feet in depth, and from 25 to 500 feet in width.

The Shinarump conglomerate is composed of greenish- to yellowish-gray sandstone irregularly interbedded with lenses of dark-colored conglomerate and greenish-gray mudstone. The sandstone is fine- to coarse-grained, poorly sorted, and composed largely of clear quartz, but it includes minor amounts of red and orange chert grains, feldspar grains, and fine-grained black accessory minerals. It is weakly cemented by calcium carbonate. The sandstone is irregularly stained by yellowish-brown iron oxide and black desert varnish. The conglomerate is composed of fragments of quartzite, chert, quartz, and silicified limestone ranging in size from granule to cobble. Granules are most abundant numerically, but probably most volume is occupied by pebbles; cobbles are relatively rare. Average pebble size is about three-fourths of an inch; the largest cobble observed was 4 inches. Granules are mainly angular quartz; pebbles and cobbles are subrounded to rounded and are composed of quartzite, chert, quartz, and silicified limestone in decreasing order of abundance. Some pebbles and cobbles of quartzite and chert are disseminated in the sandstone. The mudstone consists of very fine-grained sand, silt, and clay. It is not fissile, and it is only slightly calcareous.

The sandstone, conglomerate, and mudstone are irregularly interbedded. In general, lenses of conglomerate are abundant in the basal scours cut into the Moenkopi formation and also at the base of the Shinarump where no scours occur. Mudstone is abundant in the basal scours and near the top of the Shinarump. Quantitatively, the Shinarump comprises about 70 percent sandstone, 20 percent mudstone, and 10 percent conglomerate.

Plant remains, preserved as carbonaceous material and by replacement with silica and calcium carbonate, are abundant in the Shinarump conglomerate. They are most abundant in the basal scours and in the basal 3 feet of the Shinarump where no scours occur. Carbonaceous material occurs as logs as much as 10 feet long and 2 feet in diameter, as coal beds as much as 4 inches thick, and in poorly preserved leaves and stems. The coal beds and the leaves and stems are nearly restricted to the lenses of mudstone. Plant remains replaced by silica and calcium carbonate are common in the conglomerate lenses and disseminated in the sandstone. Most replaced plant material occurs as small fragments 2 to 10 inches long and 1 to 3 inches in diameter, but replaced logs 10 feet long and 2 feet in diameter are not uncommon.

The lenses of Shinarump conglomerate north of Clay Hills Crossing in gross appearance are unlike the Shinarump conglomerate exposed south and west of Clay Hills Crossing. These lenses are composed of angular to subrounded quartz and quartzite pebbles one-fourth to 3 inches in diameter, some chert pebbles, and angular fragments of the Moenkopi formation as much as 12 inches in diameter, all in a matrix of poorly sorted silty quartz sandstone. Carbonaceous material is absent, and silicified plant remains are uncommon in these lenses. The lenses are stained yellow and purple by iron and manganese minerals, sedimentary structures are not well preserved, and these lenses do not contain discrete beds of mudstone. The largest lens is about 20 feet thick and extends about 2 miles; the other lenses are less than 8 feet thick and extend less than 1 mile. Probably these lenses are not continuous with the main mass of the Shinarump conglomerate; they were mapped as Shinarump because they are conglomerates at the base of the Chinle formation.

The lens-type bedding and the scour and fill-type cross-bedding indicate the Shinarump conglomerate was deposited by shifting streams. In the map area most of the cross-laminations dip northwestward and most of the scours trend northwestward; therefore, it is presumed that the streams that deposited the Shinarump conglomerate flowed northwestward.

The nature of the streams that deposited the Shinarump conglomerate is problematical. The relatively thin conglomerate has been traced over much of southern Utah and northern Arizona and nowhere does it differ greatly from exposures along the San Juan River. To reconcile this great areal extent with the small thickness and persistent lithologic character, Stokes (1950, p. 91-92) has considered the Shinarump to be a vast pediment deposit.

The pinchout of the Shinarump conglomerate west of Clay Hills Crossing possibly reflects the northern extent of a persistent drainage pattern of Shinarump streams. Shinarump conglomerate north of Clay Hills Crossing occurs only as discontinuous lenses, and apparently these lenses do not reflect areas of stabilized drainage. This northern limit of stabilized drainage possibly reflects movement of the Monument upwarp during Upper Triassic time. However, the lack of outcrop east and southeast and presumably upstream in the Shinarump drainage pattern precludes a solution to this problem in the map area.

The lower contact of the Shinarump conglomerate is an erosional unconformity. Irregularly spaced scours as deep as 50 feet are cut into the underlying Moenkopi formation, but between scours the relief on the unconformity is generally less than 1 foot. Near the San Juan River the contact is sharp with little or no apparent weathering or reworking in the Moenkopi formation, but under the lenses of Shinarump north of Clay Hills Crossing the contact is less well defined. Here, the lower few feet of the Shinarump immediately above the contact consists of reworked Moenkopi. These few feet contain pebbles which were brought in by the streams re-working the upper few feet of the Moenkopi.

The upper contact of the Shinarump conglomerate is gradational both laterally and vertically into the Chinle formation. In places the contact is defined as a mudstone on sandstone, but in other places the contact is between sandstone and sandstone. Shinarump sandstone is differentiated from Chinle sandstone mainly on the basis of bedding characteristics. Where sandstone in the lower part of the Chinle overlies the Shinarump conglomerate, the Chinle sandstone is characterized by contorted bedding which is not present in the sandstone of the Shinarump.

No identifiable fossils were found in the Shinarump conglomerate in the map area. The formation is assigned an Upper Triassic age chiefly because of its close stratigraphic relation with overlying Chinle formation (Gregory, 1950, p. 66).

The formation cannot be traced by unbroken outcrop from the map area to the type locality which is about 120 miles west of the map area. Because of the close stratigraphic relation of the conglomerate to the overlying Chinle formation at the Shinarump Cliffs, geologists regarded any conglomerate at the base of the Chinle formation as Shinarump conglomerate. However, recent work by members of the Geological Survey (Stewart and others, in preparation) has shown that the conglomerate at the base of the Chinle formation in the vicinity of the junction of the Colorado and Green Rivers does not correlate with the Shinarump conglomerate of the type area. They restrict the term "Shinarump conglomerate" to a conglomerate at the base of the Chinle formation south of a line trending northwest through Blanding, Utah.

This conglomerate is believed to be continuous with the conglomerate that caps Shinarump Cliffs. Thus the Shinarump conglomerate exposed in the Red House Cliffs area is believed to correlate with the conglomerate at Shinarump Cliffs.

Chinle formation.--The Chinle formation was named by Gregory (1917, p. 42-43) for exposures in Chinle Valley of northeastern Arizona which is about 75 miles southeast of the Red House Cliffs area.

In the map area the entire thickness of the Chinle formation is exposed along the upper slope of the Red House Cliffs from the south rim of Red Canyon to the San Juan River. The Chinle is also exposed in Clay Gulch, Castle Wash, and Moki Canyon, but not in complete thickness, as none of these drainages has cut into Shinarump or Moenkopi beds. The basal part of the Chinle is exposed south of the San Juan River in the southwestern corner of the map area.

The Chinle formation normally crops out in a steep slope at the base of the vertical Wingate sandstone cliff, but it forms a relatively wide valley in Clay Gulch, and sandstones near the base of the Chinle form benches in the southwestern corner of the map area. The Chinle slopes are mantled with landslide and talus which conceal the underlying bed rock in most of the map area. Completely exposed sections of the Chinle formation occur only in three places; in the cliffs above Red House Spring, at Clay Hills Pass, and in sections 17, T. 40 S., R. 14 E. The basal part of the Chinle is exposed in most places along the cliffs, and the upper part of the Chinle is exposed in Castle Wash and Moki Canyon. Exposures of Chinle rocks add color and beauty to the landscape, for the pastel colors in the lower two-thirds of the formation contrast strongly with the generally reddish rocks exposed in the area.

The Chinle formation is 792 feet thick above the Red House Spring, 784 feet at Clay Hills Pass, 819 feet in section 17, T. 40 S., R. 14 E., and 1,018 feet about half a mile south of the map area in the southwest corner of section 2, T. 41 S., R. 13 E.

The Chinle formation is the most heterogeneous of the formations exposed in the map area. It is composed mainly of reddish-orange to reddish-brown siltstone and sandstone; variegated claystone and mudstone; gray to light-greenish sandstone; pale red calcareous claystone; gray limestone; and gray mudstone and limestone-pellet conglomerate. Based on predominance of types of rocks, the Chinle formation can be divided into three divisions: a lower division characterized by sandstone and mudstone, a middle division characterized by claystone, calcareous siltstone, and limestone, and an upper division characterized by siltstone and sandstone. Gradation and intermixing of rock types and intertonguing between divisions make these boundaries indefinite and ill-suited for mapping purposes. Although the divisions are not well-defined units, each will be described in some detail because of their bearing on the depositional environment of the Chinle formation.

The lower division consists mainly of sandstone and mudstone but includes a few beds of mudstone and limestone-pellet conglomerate, claystone, and chert. This division ranges from about 240 to 350 feet in thickness. Gray, light greenish gray, and maroon are the most common colors in the lower division. The color zones appear distinct and sharply defined from a distance, but close examination shows that the colors are transitional. Color zones roughly follow beds; but a color zone may project into another color zone with no change in rock type, or a color zone may be continuous across a change in rock type. In general, the sandstone is gray or greenish gray; the mudstone may be either greenish gray or maroon.

Sandstone in the lower division is composed of clear quartz and abundant dark minerals which include mica flakes. Locally the dark minerals comprise more than 30 percent of the sandstone, but the general composition of sand sized particles in about 90 percent quartz and 10 percent other minerals. Interstitial silt and clay are present in varying amounts. Some sandstone beds contain little clay, other sandstone beds contain abundant clay; and some clean sandstone grade laterally and vertically into mudstone. Generally the sandstone is weakly cemented and friable, but some is firmly cemented with calcite or silica. Where firmly cemented, the sandstone beds form resistant ledges or support relatively large benches. Sandstone occurs in beds ranging from a few inches to more than 30 feet thick; and the shape of the individual beds ranges from tabular to lens-shaped. Lens-shaped beds appear to be due to sandstone filling stream channels, and the width of these lens-shaped beds ranges from a few feet to more than half a mile. The scour into underlying beds generally ranges from a few inches to 5 feet, but in section 4, T. 40. S., R. 14 E., a channel was scoured 25 feet into the underlying beds.

Because of the friable nature of the sandstone, primary bedding structures generally are not well exposed. However, several types of structures occur in the sandstone. Some sandstone contains no visible laminations, some is cross-laminated, some is horizontally-laminated, and some is ripple-laminated. Ripple laminations and most cross-laminations are of the type generally attributed to stream deposition; however, some cross-laminations continue from the top to bottom of sandstone beds as much as 20 feet in thickness. This cross-lamination may be related to a deltaic type deposition.

Local accumulations of silicified wood are scattered in the sandstone in the lower division of the Chinle formation. These accumulations may contain logs as much as 20 feet long, but most pockets contain only fragments of wood about 2 feet long or less. Except in these local pockets, wood fragments are rare in the lower part of the Chinle. In addition to silica replaced logs, coalified logs and fronds were noticed in a muddy sandstone near the base of the Chinle formation in Clay Gulch, and small bits of carbonaceous material are disseminated in many of the sandstone beds.

The term "mudstone" aptly applies to the mixture of clay, silt, and sand interbedded with the sandstone in the lower part of the Chinle formation. Pure claystone beds are locally present, but mudstone consisting of silt, very fine sand grains, and interstitial clay is the dominant type of rock. Mica flakes and small blebs of swelling clay are common in the mudstone. Colors in the mudstone are dominantly maroon and light greenish gray, but shades of purple, orange, and pink are present. The colors locally cross-cut beds with no apparent regard for rock types. Chemical cement is uncommon in the mudstone and where present consists of calcite or gypsum.

Some horizontal laminations were observed in the mudstone, but massive bedding with no visible laminations is characteristic of most of the mudstone.

Thin beds of gray or red chert occur locally at the base of the Chinle. These beds of chert are lenticular and apparently are due to silica replacement of material that filled small channels cut in the top of the Moenkopi formation. In addition to the chert beds, chert concretions are common in the lower 20 feet of the Chinle formation. The chert concretions range from one-half to 5 inches in diameter, are mostly round, and have a dull, nearly black metallic luster on weathered surfaces. Fresh surfaces of the chert concretions are dark gray and have a vitreous luster, but streak or powder to a red hematitic color. These concretions occur in the lower 20 feet of the Chinle, but they are most abundant where they collect on the bench supported by the middle part of the Moenkopi formation.

The middle division of the Chinle formation consists mainly of claystone, calcareous siltstone, and thin beds of limestone. Sandstone similar to sandstone in the lower division is sparsely distributed in the lower part of the middle division. This division ranges from 215 to 375 feet in thickness in most of the map area. However, in the extreme south part of the map area the thickness of the limestone-siltstone interval exceeds 500 feet, as the upper division of the Chinle grades into an interbedded sequence of limestone and siltstone which cannot be easily separated from the limestone and siltstone of the middle division.

In general, the middle division contains mainly variegated claystone and siltstone at the base and grades upward by a gradual increase in calcium carbonate content to interbedded siltstone and impure clayey limestone at the top. The gradation in composition is accompanied by gradation in color from variegated at the base to dominantly pale at the top. The gradations in composition and color are gross features and locally pale red calcareous siltstone or greenish-gray limestones are locally present near the base of the middle division.

The claystone is probably bentonitic, as it weathers to a frothy surfaced slope typical of claystones that contain swelling clays. Allen (1930, p. 280-285) has shown that similar rocks in the Chinle formation of northern Arizona contain montmorillonite, the chief constituent of bentonite, as the dominant mineral.

The clayey limestone in the middle division of the Chinle formation occurs in beds 6 inches to 16 feet in thickness; it ranges from pale red to greenish gray, and from only slightly clayey limestone to extremely clayey and silty limestone. The top and bottom contacts of all limestone beds in this division are gradational with calcareous siltstone and some of the limestone grades laterally into calcareous siltstone. Locally the limestone contains small gastro-pods identified as <u>Triasamnicula assiminoides</u> Yen by J. B. Reeside, Jr. This gastropod is believed to be a fresh water form.

Most of the middle division is horizontally bedded in beds 6 inches to 10 feet in thickness. The scattered sandstone beds are cross-bedded, and they occur as small lenses that apparently represent filled channels of small streams.

The upper division of the Chinle formation is as much as 190 feet thick and consists mainly of reddish-orange interbedded siltstone and very fine-grained sandstone. Dense gray limestone and limestone-pellet conglomerate beds are sparsely distributed in the upper division, and locally the upper 10 to 40 feet of the upper division consists of a pale-red medium- to coarse-grained sandstone.

The reddish-orange siltstone and sandstone consist mainly of iron-stained quartz grains with minor amounts of red and black accessory minerals. Most of the beds are mixtures of very fine-grained sand and silt, and lateral and vertical gradations between sandstone and siltstone are common. The sandstone and siltstone occur in horizontal beds from 1 foot to several feet thick and individual beds are structureless.

Pale-red sandstone locally present in the upper part of the division consists of medium to coarse angular to subrounded clear quartz grains. Red mudstone pellets and thin seams of reddish-brown mudstone and coarse white mica flakes are common in the sandstone which occurs in lenticular beds and is cross-laminated with the type of cross-laminations attributed to stream deposition.

The limestone-pellet conglomerate in the upper division occurs in lenticular beds and apparently represents filling of stream channels. The pellets consist of granule to pebble sized silty limestone, and they occur in a poorly sorted matrix of clay, silt, and sand sized angular grains. These limestone-pellet conglomerate beds locally contain reptilian teeth and bone fragments.

The upper division of the Chinle formation grades southwestward into an interbedded limestone and calcareous sandy siltstone sequence which cannot be separated from the middle division of the Chinle in the southwest corner of the map area.

The sedimentary structures and the fossils contained in the Chinle rocks indicate these rocks accumulated in a terrestrial environment. The lower division is dominantly of fluviatile origin. The lenticular sands represent filling of stream channels and the mudstone probably accumulated on floodplains bordering the streams. The claystone, limestone, and calcareous siltstone in the middle division apparently accumulated in a lacustrine environment. The lenticular sandstone beds scattered here and there in the middle division and the intertonguing of the lower and middle divisions clearly indicate the transitional nature of the dominantly fluviatile environment of the lower division to the dominantly lacustrine environment of the middle division. The gentle lensing and gradation of rock types in the middle division probably indicate many shallow lakes on a generally low plain, instead of a single large lake. Most of the upper division of the Chinle probably accumulated in a dominantly lacustrine environment, which represents a continuation of the environment of the middle division. However, the change in texture and composition of sediments in the upper division represents a gradual change in type of sediments supplied to the lakes. The coarse-grained sandstone locally present in the upper part of the upper division possibly represents an eastern edge of a predominantly stream deposited unit in the upper Chinle of the Zion Canyon region (Gregory, 1950, p. 67).

The source of the Chinle sediments is not known at the present time. Williams and others (in preparation) indicate many of the sands in the Chinle formation were derived from southeast of the Red House Cliffs area, possibly in central New Mexico. Much of the mudstone and clay in the lower two divisions of the Chinle is bentonitic, and probably the bentonite was derived from ash falls. However, no pure beds of bentonite were noted in the Red House Cliffs area. This would indicate that most of the volcanic ash was carried in by streams, and only a small part or none of the ash fell in the map area. No bentonite material is present in the upper division; therefore, it is assumed that volcanic activity had ceased or source areas of Chinle sediments had so shifted that volcanic ash was not deposited in the upper part of the Chinle formation.

In the original description and definition of the Chinle formation Gregory (1917, p. 42-43) separated the formation into four divisions. These divisions, in descending order, are: Division A, characterized by red, brown, or pink calcareous shales and sandstones; Division B, characterized by gray, pink, and purple limestone interbedded with light- to dark-red shale; Division C. characterized by variegated shales and marls with rare calcareous sandstone; and Division D, characterized by dark-red, light-red, and chocolate-colored shales (70 percent) and shaly sandstone (30 percent). Later workers have assigned member status to these divisions. These members are: Church Rock member, equivalent to Division A (Witkind and others, in preparation); Owl Rock member, equivalent to Division B (Witkind and others, in preparation); Petrified Forest member, equivalent to Division C (Gregory, 1950. p. 67); and the Monitor Butte member, equivalent to Division D (Witkind and others, in preparation).

These various members are all represented in gross features in the three-fold division of the Chinle formation in the Red House Cliffs area. The lower sandstone and mudstone division contains the Monitor Butte member. The lower division is thicker than the Monitor Butte member, however, as sandstone extends considerably up into rocks equivalent to the Petrified Forest member farther south. The middle division in the map area is equivalent to most of the Petrified Forest member and the Owl Rock member. South of the map area the boundary between the Petrified Forest and Owl Rock member is generally placed at the lowest limestone bed in the Owl Rock member. This boundary is not applicable in the map area as limestone is sporadically distributed in the entire middle division. The upper division in the map area correlates in general with the Church Rock member. However, in the map area, the presence of limestone in the upper division indicates gradation of Church Rock and Owl Rock members and precludes an exact correlation of the upper division with the Church Rock member.

The greater thickness and the increased limestone content in the Chinle formation in the southern part of the map area may indicate Triassic age movement of various structural elements along the Monument upwarp. The Chinle in this area is near the trough of the Nokai syncline (Baker, 1936, p. 67-68), which lies about 2 miles west of the map area. This syncline separates the Organ Rock anticline (fig. 4) and the Balanced Rock anticline (Baker, 1936, p. 69-70) which is about 3 miles west of the southwestern corner of the map. The increased thickness and limestone content of the Chinle near the trough of the Nokai syncline can be explained by postulating movement of these structural elements during Triassic time. The basin formed by the Nokai syncline of Triassic age would have received more sediments than adjoining areas. It possibly may have contained more standing water in which limestone could accumulate than adjoining areas.

The evidence for the Upper Triassic age of the Chinle formation was recently summarized by Gregory (1950, p. 71-72). In general, this evidence consists of saurian and plant remains abundantly present in the Chinle formation in northern Arizona and southern Utah. Both saurian and plant remains are present in the Chinle in the map area, but the remains are fragmentary and receive no special attention in this study.

The Chinle formation conformably overlies the Shinarump conglomerate with lateral and vertical gradation of beds. Where the Shinarump conglomerate is absent, the Chinle formation is separated from the underlying Moenkopi formation by a marked erosional unconformity.

The Chinle formation conformably underlies the Upper Triassic Wingate sandstone. This contact is marked by a sharp change in sedimentary structures and in topographic form. However, the conformable relationship of the Chinle and Wingate is attested to by the even character of the contact and the close resemblance in texture and composition of uppermost Chinle beds to Wingate sandstone.

Triassic and Jurassic system

Glen Canyon group

The name "Glen Canyon group" was adopted for the series of rocks which rim the Glen Canyon of the Colorado River. The group, as defined by Gilluly and Reeside (1928, p. 69) and Gregory and Moore (1931, p. 61) included in ascending order the Wingate sandstone, the Todilto(?) formation, and the Navajo sandstone. No diagnostic fossils were found in the Glen Canyon group, and, because of its stratigraphic position between Upper Triassic rocks and Middle Jurassic rocks, the group was assigned a Jurassic(?) age by these authors. Later work revealed that the Todilto formation of northwestern New Mexico was younger than the middle formation in the Glen Canyon group and the middle formation was redefined as the Kayenta formation (Baker and others, 1936, p. 5).

Recent work by Harshberger and others (in preparation) on Jurassic stratigraphy of the Navajo Indian Reservation has revealed an intertonguing relation between the Wingate sandstone, the basal formation in the Glen Canyon group, and rocks previously mapped as Chinle formation. This relation has resulted in a new definition of the Glen Canyon group. The group now contains in ascending order: the Wingate sandstone of Triassic age, the Moenave formation of Triassic(?) age, the Kayenta formation of Jurassic(?) age, and the Navajo sandstone of Jurassic age (Harshbarger and others, in preparation).

The Wingate sandstone, the Kayenta formation, and the Navajo sandstone crop out extensively on Red Rock Plateau, but the Moenave formation does not extend into the Red House Cliffs area.

Wingate sandstone.--The name "Wingate sandstone" was applied by Dutton (1885, p. 136-137) to rocks that form a steep cliff near Ft. Wingate in northwest New Mexico. This name was subsequently applied to a massive cliff-forming sandstone which crops out extensively in southeast Utah and northeast Arizona; nevertheless, detailed study by Baker and others (1947, p. 1664-1668) proved the two cliff-forming units were not correlative. But, because the name "Wingate sandstone" was firmly established in geologic literature pertaining to southeast Utah, the name was retained in southeast Utah and the type locality was abandoned. Thus no type section of the Wingate sandstone exists except as it is defined as part of the Glen Canyon group.

In the map area the Wingate sandstone forms the dark desert-varnished palisade-like upper cliff in the Red House Cliffs and similar cliffs that rim Clay Gulch, upper Castle Wash, and Moki Canyon. The sandstone is not particularly resistant to erosion, and it owes its cliff-forming characteristics to its stratigraphic position. It overlies relatively non-resistant beds in the Chinle formation and underlies relatively resistant beds in the Kayenta formation. The underlying Chinle rocks allow erosion to undercut the massive homogeneous Wingate sandstone, but the overlying Kayenta rocks protect the upper part. Thus, most of the Wingate is removed by slabbing off large blocks of sandstone along joints, and the cliff remains vertical. In other places in Red Rock Plateau the overlying Kayenta formation has been stripped back or the Chinle rocks are not exposed, and in these places the Wingate outcrop is characterized by smooth, rounded, light colored slopes which steepen and form steep slopes at the top and bottom of the exposure. In many places the steep lower and upper slopes exceed 10 feet in height, and they form effective barriers to crossing exposures of Wingate sandstone.

The thickness of the Wingate sandstone ranges from 310 to 340 feet in the map area and averages about 320 feet. The range in thickness is due partly to irregularity in the boundary between the Wingate sandstone and the overlying Kayenta formation. Both upper and lower boundaries of the Wingate sandstone are selected primarily on changes in sedimentary structures. The lower boundary forms a parting plane that can be traced for several miles whereas the upper contact forms a parting that generally extends less than a mile before it disappears either in Wingate or in Kayenta sediments. The vertical variation in the upper contact does not exceed 15 feet in any one jump in contact, but over several miles of outcrop the total variation may exceed 30 feet. No systematic variation in the contact between the Wingate sandstone and the Kayenta formation was observed in the map area.

The Wingate sandstone is reddish brown to pale reddish orange on freshly broken surfaces; but the rounded slopes of Wingate sandstone are moderate orange pink, and the vertical cliffs are reddish brown to black due to desert varnish. The Wingate is almost uniformly a fine-grained sandstone, although the basal few feet of sandstone commonly contain abundant medium-sized well rounded quartz grains. One thin bed of limestone was observed near the base. The sandstone is composed of subrounded to rounded clear and iron-stained quartz with common very fine-grained black accessory minerals. It is weakly to firmly cemented with calcium carbonate. Well-rounded medium-sized quartz grains, both clear and iron stained, are disseminated in and concentrated along cross-laminations in the basal 10 feet of the sandstone. Individual sandstone beds are cross-laminated by the long, sweeping laminations attributed to eolian deposition and are separated from adjacent sandstone beds by horizontal parting planes. The parting planes truncate cross-laminations in the bed below, but cross-laminations in the bed above are tangential to the parting planes. Thickness between parting planes ranges from 5 feet to 80 feet and averages about 40 feet.

A limestone bed four-fifths of a foot thick crops out 19 feet above the base of the Wingate sandstone near Green Water Spring.

The uniform character of the sandstone and the long sweeping cross-laminations suggest that the Wingate sandstone is a wind-laid deposit. Most of these cross-laminations dip southeast and presumably indicate that the wind blew southeast. The horizontal parting planes suggest that from time to time a body of water beveled the wind-laid sand, and at least one body of water existed long enough for a thin bed of limestone to accumulate. These parting planes generally extend less than 1 mile along strike before they disappear into a cross-laminated unit, and they apparently represent small discrete lakes instead of a large body of water which periodically transgressed the Wingate sand dunes.

The Wingate sandstone conformably overlies the Chinle formation and conformably underlies the Kayenta formation.

No fossils were found in the Wingate sandstone in the map area. The Triassic age of the Wingate has been established by Harshbarger and others (in preparation) by the stratigraphic relations of the Wingate and the Upper Triassic Chinle formation.

No type locality of the Wingate sandstone now exists; however, the Wingate can be traced without a break in outcrop to the Glen Canyon group, which is about 15 miles west of the map area.

Kayenta formation.--The name Kayenta formation was adopted for a series of irregularly bedded rocks previously called "Todilto(?) formation" when detailed work proved that the Todilto limestone in northwestern New Mexico was much younger than the Todilto(?) formation in southeastern Utah (Baker and others, 1936, p. 5). The type locality of the Keyenta formation is about 1 mile north of Kayenta, Ariz., and about 30 miles south of the Red House Cliffs area.

The Kayenta formation crops out on Red Rock Plateau where the lower part of the formation forms extensive benches and the upper part forms steep ledgy slopes which merge with the steep rounded slopes of the overlying Navajo sandstone. The thickness of the Kayenta ranges from 200 to 230 feet in the map area.

The Kayenta formation is composed of irregularly bedded sandstone, which is locally conglomeratic, and some interbedded mudstone. The sandstone is poorly sorted, very fine- to coarse-grained and is composed mainly of subrounded to angular clear quartz grains with red and black accessory minerals, although locally it includes abundant white mica flakes and claystone fragments. It is cemented with calcium carbonate. Most of the sandstone is pale red but reddish-brown and white sandstone is common. Sandstone beds occur as lenses a few inches to 30 feet in thickness and a few feet to several hundred feet long. Most lenses are cross-laminated with the channel- and fill-type laminations attributed to stream deposition, but some of the longer lenses are horizontally laminated or contain long sweeping cross-laminations with a 2 to 5 degree dip. The sandstone with the stream type cross-laminations commonly scours a few inches to several feet into the underlying bed, and many of these scours contain conglomerate composed of quartz granules, mudstone fragments, and minor amounts of limestone pellets. The mudstone fragments are as much as 2 inches in diameter and range from well rounded to extremely angular. Many of the more angular mudstone fragments resemble part of tightly curved mudstone curls found on dry lake surfaces.

The interbedded mudstone is a poorly sorted mixture of sand and silt-sized quartz particles and clay. It is commonly reddish brown to pale red, but greenish-gray mudstone occurs below some of the scour surfaces. Mudstone beds as much as 25 feet thick and several miles long occur in the Kayenta formation; however lens-like mudstone beds 1 inch to 4 feet thick and 10 to 300 feet long interbedded with the sandstone are most common.

The lenticular and irregularly bedded sediments in the Kayenta formation indicate the sediments were deposited in water. This water probably was in shifting streams and associated floodplains. However, the small part of the Kayenta formation that contains long low angle cross-laminations may have been deposited in shallow lakes. No fossils were found in the Kayenta formation in the map area but Unios (Baker and others, 1936, p. 5). found in the Kayenta formation in other places in southeastern Utah indicates the formation was deposited in fresh water.

The basal bed of the Kayenta formation locally channels into the underlying Wingate sandstone as much as 6 feet, which indicates some erosion of Wingate sandstone prior to deposition of Kayenta sediments. However, in other places the basal bed in the Kayenta formation may be traced along strike through gradual changes from a cross-laminated stream deposited bed to a structureless bed and finally to a wind-deposited bed that cannot be separated from the Wingate. This contact apparently represents a change from an eolian to fluviatile environment, but it apparently does not represent a time break in sedimentation.

The contact of the Kayenta formation with the overlying Navajo sandstone is similar to the lower contact, but in the upper contact the change in environment is from fluviatile to eolian.

No diagnostic fossils have been found in the Kayenta formation, and it has been assigned a Jurassic(?) age because it overlies Upper Triassic rocks and underlies Jurassic rocks. Correlation of the Kayenta formation in the map area to the type locality is made with assurance as the rocks can be traced directly.

Navajo sandstone.--The Navajo sandstone was defined originally by Gregory (1917, p. 53) without a specific type locality other than the "Navajo country" but years later Gregory (1950, p. 73) indicated a more specific type locality as surrounding Navajo Mountain which is about 25 miles southwest of the Red House Cliffs area.

The Navajo sandstone crops out extensively in the west part of the map area where it forms buttes and gently rounded domes rising above the bench formed by the Kayenta formation.

Complete thicknesses of the Navajo sandstone cannot be determined in the map area, as the top of the sandstone has been removed by Cenozoic erosion. Gregory (1938, p. 56) reports the Navajo is 880 feet thick on the south side of Wilson Mesa which is about 15 miles southwest of the map area. The maximum preserved thickness in the map area is about 600 feet.

The Navajo sandstone contains long sweeping cross-laminations and is composed mainly of medium-sized rounded to subrounded quartz grains and rare red and black accessory minerals. A few beds of limestone are interbedded with the sandstone.

The sandstone is very pale orange and moderate reddish orange and is weakly cemented with calcium carbonate. Most individual sand grains are clear or frosted, but a number are covered with a thin film of iron oxide. The sandstone is cross-laminated with high angle tangential laminations of the type generally attributed to wind deposition. Horizontal bedding planes in the sandstone are rare; along some of them thin beds of limestone occur.

The limestone in the Navajo sandstone ranges from light gray to nearly black and from massive to thin bedded. Most of the limestone contains abundant clear quartz grains, and near the top and bottom of the beds enough quartz grains occur to classify it as sandy limestone.

The limestone occurs in lens-like beds as much as 1 mile long and as much as 10 feet thick, and each limestone bed is associated with a horizontal bedding plane in the generally cross-laminated sandstone. In most cases the horizontal bedding plane extends several hundred yards past the edge of the limestone lens before it disappears into cross-laminated sandstone.

The long, sweeping high angle cross-laminations and the well sorted sand in the Navajo sandstone are indicative of eolian deposition. The majority of the cross-laminations dip southeast, and presumably this indicates the sandstone was deposited by winds blowing southeast. The scattered limestone beds are believed to have been deposited in local lakes that existed in the general dune area.

No fossils were found in the Navajo sandstone in the map area, and no diagnostic fossils have been found in any exposures of Navajo sandstone. The Navajo is assigned a Jurassic age (Harshbarger and others, in preparation) as it underlies fossiliferous Middle and Upper Jurassic beds and overlies beds that lack diagnostic fossils but which in turn overlies beds which contain late Triassic fossils.

The Navajo sandstone exposed on Red Rock Plateau can be traced directly to the type locality of the Navajo sandstone around Navajo Mountain.

Quaternary system

Quaternary deposits comprising landslide blocks, terrace gravels, stream alluvium, alluvial fans, and sand dunes are widespread in the Red House Cliffs area. All these deposits lie unconformably on older rocks.

The deposition of landslide blocks, terrace gravels, stream alluvium, alluvial fans, and sand dunes apparently has continued simultaneously. Thus, among groups of deposits no difference in age of the Quaternary deposits exists. On the other hand, individual deposits in a group can, in some places, be dated relative to other deposits in the group; and individual deposits in one group can, in a few places, be dated relative to individual deposits in another group. As examples of dating among individual deposits in a group: some terrace gravels are older than other terrace gravel, and some landslide blocks are older than other landslide blocks. As examples of dating individual deposits among groups: some terrace gravels are younger than some landslide blocks, and some dunes are younger than some alluvium.

Landslide blocks

All landslide blocks in the map area are related to outcrops of the Chinle formation. The Chinle crops out in a steep slope, and the claystone and clayey siltstone in the lower part of the formation furnish excellent planes of slippage when they are saturated with water. This allows large blocks of upper Chinle and Wingate sandstone to slide down towards the bench formed by the middle part of the Moenkopi formation or by the Shinarump conglomerate. Landslide blocks are common along the Red House Cliffs and Clay Gulch where most of the Chinle is exposed; but few landslide blocks occur in Castle Wash and Moki Canyon where only the top part of the Chinle is exposed.

All landslide blocks in the map area are more or less covered with rubble composed of large angular boulders of limestone and sandstone. Many of the sandstone boulders are derived from slabbing-off of the overlying Wingate sandstone and are not related to a landslide. It was impossible, in most places, to determine which part of the boulder rubble was talus derived directly from the Wingate sandstone, and which part was derived from weathering of the landslide blocks that contained Wingate sandstone. The units shown as landslide deposits on figure 4, therefore, contain an unknown amount of material better classified as talus.

Two end types of landslide deposits and all gradations between the two types can be differentiated in the map area. The end types consist of: 1) toreva blocks (Reiche, 1937, p. 538-548), landslide blocks that preserve the original bedding of the Chinle formation, and 2) landslide blocks in which all traces of the original bedding of the Chinle formation are obliterated.

In general, toreva blocks are most abundant high on the upper slope of the Red House Cliffs, but some occur on the middle bench and lower slope. In these blocks the original bedding of the Chinle formation dips into the Red House Cliffs as much as 50°, but in most cases the dip ranges from 3° to 8°. The largest toreva block in the map area is about half a mile long and is about 1 mile northeast of Clay Hills Pass. Other toreva blocks are mainly less than 100 yards long, but whether the smaller blocks represent discrete slides or whether they represent differential movement along much larger blocks was not determined. These smaller toreva blocks form a nearly continuous but minor bench below the cliff formed by the Wingate sandstone along the Red House Cliffs and in Clay Gulch.

The minor bench developed on the toreva blocks is locally as much as 400 feet wide and is generally about 150 feet below the base of the Wingate sandstone. The bench dips from 1° to 5° into the Cliffs, and it is supported by sandstone from the upper part of the Chinle formation and lower part of the Wingate sandstone. The sandstone is resistant to erosion, and it protects the upper part of the toreva block while claystone and siltstone in the lower part of the block are rapidly eroded.

The second type of landslide, the type in which all traces of the original bedding has been obliterated, consists of a heterogeneous mixture of angular blocks of sandstone and limestone in a poorly sorted mudstone matrix. This type of landslide is probably caused by repeated movement of toreva blocks; and the type is more common on the middle bench and lower slope of the Red House Cliffs than on the upper slope.

The second type of landslide weathers to rough boulder covered irregular hills. Most of these landslides have been badly eroded and are no longer connected to their source in the Chinle slope. These badly eroded landslides form hills as the boulder rubble is more resistant to erosion than the undisturbed bedrock on which they rest.

Most landslide blocks are probably related to a time or times when the climate in southeastern Utah was more humid. Apparently no landslides have occurred in the last few years, for the bench formed on landslide blocks near the top of the upper slope is fairly well covered with juniper trees. This indicates that the current climatic conditions do not furnish enough water to saturate the Chinle formation and cause landslides. Some landslide blocks near the San Juan River may be related to saturation by water from the river, however, and these blocks would not necessarily indicate a more humid climate in the map area.

Terrace gravel

Terrace gravel occurs at several places south of Clay Hills Crossing. All the terrace gravels are shown in a single category on figure 4; however, at least four, and possibly five, distinct terrace levels are represented. The highest terrace is represented by a small remnant of gravel near the axis of the Organ Rock anticline and about 600 feet above the present level of the San Juan River. The lowest terrace is between Clay Hills Crossing and Piute Farms and is about 10 feet above water level. The intermediate terrace levels are from 25 to 450 feet above present water level, and these levels contain the bulk of the terrace material in the map area.

Regardless of the height above the present river level the size and composition of the gravel in the terrace deposits are remarkably uniform. The gravels are composed mainly of quartzite, limestone, a dark fine-grained igneous rock, and milky quartz in about this order of abundance. Sandstone and coarse-grained igneous rocks occur in all gravels but are relatively rare. All rocks in the gravels are foreign to the map area.

Several sizes range from about one-eighth inch to 14 inches and average about 2 inches. All gravels have rounded edges. Most gravels over 4 inches in long dimension have disc or elongate elipsoidal shapes; only gravels less than 4 inches in long dimension tended to approach a spherical shape. No correlation between composition and size or degree of roundness was observed.

Most of the terrace deposits contain abundant poorly sorted sand as a matrix; and some terrace deposits contain large lenses of poorly sorted sand in which gravels are lacking. As a general rule the terrace deposits are poorly cemented, but locally the deposits are firmly cemented with calcium carbonate in the form of caliche.

Baker (1936, p. 78-80) suggests that these terrace deposits were related to temporary base levels caused by resistant bed rock units downstream. Probably this is true for some of the terrace deposits; on the other hand, some of terrace deposits may be related to damming of the river by landslide blocks. About 100 yards west of the map area terrace gravels occur on a landslide block about 100 feet above present level. It is possible that this landslide may have dammed the river and formed a temporary base level which caused deposition of terrace gravel. Many such temporary base levels could have been formed by landslides as the Chinle formation was exposed at progressively lower altitudes down dip, but at the same relative distance above the San Juan River as the Red House Cliffs escarpment retreated westward. Therefore, accurate correlation of any single terrace level to a base level caused by a resistant bed rock unit exposed downstream would be difficult.

Stream alluvium

Stream alluvium in patches large enough to show on the geologic map (fig. 4) occurs along the San Juan River near Piute Farms, in two places in Castle Wash, and in upper Clay Gulch. Other streams in the area flow mainly in narrow bedrock channels and have not cut floodplains on which alluvium can be deposited. The alluvium varies greatly in composition and detail in the places shown on the map. In Castle Wash and Clay Gulch the alluvium forms a relatively wide and even floor in steep walled canyons, and the present streams are incised as much as 40 feet in the alluvial fill. Along the San Juan River near Piute Farms the alluvium coincides with the present floodplain of the river.

Alluvium in Castle Wash is light colored, consists mainly of poorly consolidated irregularly bedded sand, was derived mainly from sandstone in the Glen Canyon group, and is locally more than 40 feet thick. The alluvium is covered by a thin veneer of wind-blown sand, and in the wider part of Castle Wash west of Moki anticline is concealed by wind-blown sand as much as 40 feet thick.

Alluvium in Castle Wash forms a relatively even and little dissected floor in a steep-walled canyon. The present stream is incised in this floor, locally as much as 40 feet below the top of the alluvium. Hunt and others (1954, p. 205-209) determined that the most recent arroyo cutting cycle for streams in southeastern Utah began shortly after 1880. Presumably, then, the present stream in Castle Wash began its downcutting about the same date. Since downcutting began, the alluvial flat has probably changed from a well-watered meadow to the present-day sandy waste land. (See Hunt and others, 1954, p. 205-209 for effects of arroyo cutting in southeastern Utah).

Alluvium in Clay Gulch consists of light-brown evenly-bedded mudstone which grades into poorly sorted conglomerate downstream. Most of the alluvium in Clay Gulch was derived from the Chinle formation, but the conglomeratic alluvium consists of slightly reworked landslide material.

The evenly bedded character of part of the alluvium in Clay Gulch may indicate this alluvium was deposited in a lake instead of a true floodplain. A past lacustrine environment in upper Clay Gulch is entirely plausible, as the lower part of the channel of Clay Gulch is in a narrow deep canyon cut in the lower part of the Chinle formation and surrounded by landslide material. Probably some of the landslides have dammed Clay Gulch in the past and caused a lake in upper Clay Gulch.

Alluvium at Piute Farms is on the present-day floodplain of the San Juan River. This alluvium consists mainly of poorly consolidated sand, but it includes a few lenses of granule gravel. No evidence is present to indicate the thickness of the alluvium near Piute Farms. Miser (1924, p. 67-71) estimates that the maximum thickness of alluvium along the San Juan River Canyon is about 80 feet.

Alluvial fans

Alluvial fans occur at several places along the base of the Red House Cliffs. These fans consist of fanglomerate spread over small pediments locally developed at the base of the cliffs. Only a few of the fans coalesce, and most fans have been cut off from a source of sediments.

The fanglomerate is coarsely stratified and is composed mainly of angular fragments or sandstone and some limestone in a poorly sorted sand and silt matrix. The fragments are as much as 2 feet in long dimension, but most are only 1 or 2 inches across.

The thickness of the fanglomerate deposited on the pediment surfaces is as much as 60 feet in the large compound alluvial fan southeast of Clay Hills Pass. In other alluvial fans shown on the map, however, the fanglomerate is much thinner, and locally the fanglomerate is only a 1 or 2 foot veneer on the pediment surfaces.

Dune sand

Hummocky sand covered flats and low rounded sand hills cover relatively large areas on Red Rock Plateau and small parts of the Grand Gulch Plateau-Douglas Mesa surface. The sand covering the hummocky flats and the sand in the rounded hills is apparently wind deposited, and it is included with a relatively minor amount of shifting sand as "dune sand" on figure 4.

Dune sand on Red Rock Plateau is derived mainly from the Navajo sandstone and occurs chiefly on Navajo sandstone floored benches and shallow valleys and on alluvial fill in Castle Wash. This dune sand is a few feet to 20 feet thick on the hummocky flats. Locally, however, in the rounded hills the sand increases to about 80 feet in thickness. Sand in the hummocky flats and the rounded hills is fairly well stabilized by sparse vegetation.

Dune sand on the Grand Gulch Plateau-Douglas Mesa surface is derived mainly from the Cedar Mesa sandstone. It occurs chiefly in hummocky flats developed here and there on benches floored by the Cedar Mesa sandstone, on the toes of alluvial fans, and on terrace deposits. The thickness of sand in these flats generally ranges from 2 to 10 feet.

Shifting sand dunes are relatively abundant in the map area, but they cover relatively little area and are not important in total volume. Many of the shifting dunes occupy small basins in bare rock and are too small to show on the geologic map. Larger shifting dunes occur on the leeward side of the hummocky flats. The largest single area covered by shifting sand is on the south side of Moki Canyon where sand derived from a relatively stabilized dune area has spilled over the Canyon rim. This dune reaches to the bottom of Moki Canyon, and it is the only place where the canyon can be entered in the map area.

STRUCTURE

The Red House Cliffs area is on the west flank of the Monument upwarp, a large elongate dome which extends from near Kayenta, Ariz., to near the junction of the Colorado and Green Rivers in southeastern Utah.

Monument upwarp is an symmetrical fold with a steeply dipping east limb and a gently dipping west limb; thus, the dominant structure of the Red House Cliffs area is a gentle westward dip. In two places the regional dip is interrupted by minor north-trending asymmetrical folds. Normal faults are associated with the eastward dipping limbs of the minor folds, and many joints associated both with the Monument upwarp and the small folds are well exposed in the sandstone strata.

Folds

Oljeto syncline

The Oljeto syncline is the easternmost of the minor folds in the map area. This syncline was named the "Moonlight syncline" (Miser, 1924, p. 134) for Moonlight Creek which flows northward approximately along the axis of the syncline on the south side of the San Juan River. Baker (1936, p. 66, and pl. 1), however, used the named "Oljeto," the Navajo word for "moonlight," for both the creek and the syncline.

The Oljeto syncline trends north across the map area. It extends northward only a mile or so past the map area, but it extends southward at least 20 miles (Baker, 1936, p. 67) and is best developed south of the map area. The axis of the syncline is sinuous and lies about 2 miles west of the 110° 15' meridian. The eastern limb of the syncline rises gently to the crest of the Monument upwarp which is about 15 miles east. The western limb is shorter and rises to the crest of the Organ Rock anticline about 1 mile west of the axis of the syncline. Although the two limbs of the syncline are unequal in length, the western limb dips more steeply only near the north side of the San Juan River. Here the western limb dips 3° to 5° and the eastern limb dips only about 2°.

The axis of the Oljeto syncline is concealed by Quaternary deposits southeast of Clay Hills Pass for about 3 miles. South of the Quaternary cover the axis of the syncline is not faulted, but north of the cover the axis coincides with a north-trending fault.

The Cedar Mesa sandstone member of the Cutler formation is the surface rock across the syncline in the southern part of the map area. Younger rocks crop out in the syncline where it crosses Red House Cliffs and the Red Rock Plateau.

Organ Rock anticline

The axis of the Organ Rock anticline is about 1 mile west of and parallel to the Oljeto syncline. The fold was named from Organ Rock (Miser, 1924, p. 134) which is near the crest of the fold about 10 miles south of the map area. The fold extends north of the map area an unknown distance and south of the map area for at least 21 miles (Baker, 1936, p. 17). As with the Oljeto syncline, the Organ Rock anticline is best developed south of the map area. The structural relief between the Organ Rock anticline and Oljeto syncline is about 200 feet at the south boundary of the map area and about 1,400 feet a few miles south at the Utah-Arizona state line (Baker, 1936, p. 68). In the map area the anticline plunges gently to the north and has a maximum plunge of 2° about 1 mile north of section 6, T. 40 S., R, 15 E. No closed domes occur along this anticline in the map area.

The east limb of the Organ Rock anticline dips 2° to 5° toward the axis of the Oljeto syncline about a mile away. The west limb dips about 2° westward to the Moki anticline and Balanced Rock anticline which are 3 to 12 miles away.

In general, the upper part of the massive Cedar Mesa sandstone member floors the dip slopes developed on the anticline in the Grand Gulch Plateau-Douglas Mesa surface, but a small remnant of the Organ Rock tongue is preserved near the crest of the anticline about one-half of a mile south of the San Juan River. The Organ Rock and all younger rocks in the map area crop out along the crest of the anticlines where it crosses Red House Cliffs and Red Rock Plateau.

Moki anticline

A poorly defined anticline and syncline trend northeastward from about 5 miles north of the southwest corner of the map area. This anticline crosses the north boundary of the map area about 8 miles east of the northwest corner and extends an unknown distance northward. The structure was shown in part by Gregory (1938, pl. 1), but not named. It is here named the Moki anticline from exposures in Moki Canyon about 3 miles north of the map area where the anticline is best developed. The anticline plunges very gently to the south and gradually flattens near the southwest corner of the map area. The Glen Canyon group forms the surface over most of anticline, and, as persistent beds are absent in the Glen Canyon group, the exact configuration of the anticline cannot be determined.

The east limb has a maximum dip of about 3° and is less than 1 mile long. The axis of the poorly defined syncline east of Moki anticline is not shown on the geologic map (fig. 4), but the axis generally is slightly east of the fault zone east of the crest of the Moki anticline. The east limb of this syncline extends to the crest of Organ Rock anticline. The west limb of the Moki anticline has a maximum dip of about 2° and extends past the west boundary of the map area. The maximum structural relief between the crest of the Moki anticline and the slight syncline on the east is less than 100 feet in the map area. And, in places along the anticline the beds are structurally lower at the crest of the anticline than in the trough of the syncline because the beds west of the synclinal axis are downthrown along a series of faults.

The Glen Canyon group forms the surface rock along much of the Moki anticline, but the Chinle formation is exposed where a tributary to Moki Canyon has cut a canyon normal to the trend of the anticline near the north edge of the map area.

If the regional dip of the map area is considered, the Moki anticline and part of the Organ Rock anticline are better classified as small eastward-dipping monoclines. Dip of the west flank of Moki anticline corresponds to the regional dip; the dip of the east flank of the syncline east of Moki anticline also corresponds to the regional dip. A similar pattern holds for most of the Organ Rock anticline. Thus, both folds would become small eastward-dipping monoclines if the regional dip were removed.

Faults

Several normal faults occur in the map area. All the faults dip steeply, most are downthrown on the west side, and most are in two fault zones associated with the east flanks of the minor anti-clines superimposed on the west flank of the Monument upwarp. The maximum displacement along any of the faults is slightly over 200 feet, and in most places the displacement is less than 100 feet.

Faults along the east flank of the Organ Rock anticline form an en echelon pattern in the southeast part of the map area. Displacement along the faults in the en echelon zone is as much as 100 feet on the northernmost fault, but most faults in this zone have displacements of only a few feet. North across Red House Cliffs and Red Rock Plateau a long continuous fault is along the continuation of the zone of en echelon faults. This continuous fault is vertical, is downthrown on the west side, and has a displacement of about 80 feet. Locally short faults with displacements of a few feet parallel the larger fault.

For the most part faults along the east side of Moki anticline form an en echelon pattern, but they form a horsetail pattern near the north boundary of the map area. The faults are all downthrown on the west side and have displacements ranging from a few inches to 200 feet. The maximum observed displacement along this fault zone was 235 feet measured across two faults just north of Castle Wash. Near the north boundary of the map area the faults have displacements of less than 50 feet.

Faults not associated with the east side of the minor anticlines have displacements of only a few feet and apparently represent displacement along faults parallel to the dominant joint set.

Joints

Two sets of joints are well exposed in the sandstone formations exposed in the Red House Cliffs area. The most prominent set trends about N. 40° E. in the southeast part of the area and changes to trend about N. 15° E. in the north and west parts of the mapped area. The second set of joints trends nearly east and is best developed in the northwest part of the area. All joints are vertical or nearly vertical. Major joint sets in the Moenkopi formation and Organ Rock tongue of the Cutler formation conform to the regional joint pattern, but these joints are not well exposed.

Age of deformation

The age of the folding and faulting in the map area is considered to be either latest Cretaceous or earliest Tertiary. Evidence for this particular age of deformation is lacking in the map area, but Baker (1936, p. 74-75), Gregory (1917, p. 80-81), and Hunt and others (1954, p. 201) cite evidence which indicated a latest Cretaceous or earliest Tertiary age for the formation of the Monument upwarp. The small folds superimposed on the Monument upwarp, in the map area, show the same trend and cross sections as the Monument upwarp, and they are inferred to be of the same age.

Within the map area the age of deformation cannot be determined closer than post early Jurassic and pre-Quaternary. The youngest "bed rock" unit, the early Jurassic sandstone, has been involved in folding and faulting; the Quaternary mantle which rests unconformably on the "bed rock" has not been involved.

The stratigraphic relationship of both the Shinarump conglomerate and the Chinle formation to the structural elements possibly indicates a slight movement of the Monument upwarp during Triassic time.

MINERAL RESOURCES

Interest in the mineral resources of the Red House Cliffs area centers around five possible products: uranium, gold, copper, oil and gas, and gravel. However, to the present time no commercially important mineral deposit has been discovered within the area.

Uranium

A primary purpose of this investigation was to appraise the uranium resources of the Red House Cliffs area. As no uranium minerals or places with abnormally high radioactivity were found in the area, any appraisal of the uranium resources must be based on the habits of uranium deposits in similar geologic settings.

Uranium deposits on the Colorado Plateau have a wide stratigraphic range, but significant uranium deposits have been found only in a few stratigraphic zones. These zones include the Shinarump conglomerate, the lower part of the Chinle formation, the Jurassic Morrison formation, and the Cretaceous Dakota and Mesaverde formations. Deposits in these zones all are of similar habits: they are associated with stream-deposited sandstone which contains abundant carbonaceous material.

Among the formations exposed in the Red House Cliffs area only the lower parts of the Chinle formation and the Shinarump conglomerate contain stream-deposited sandstone which contains carbonaceous material. Thus, these stratigraphic zones were thought most likely to contain uranium minerals, and particular attention was given these zones during this investigation. The Shinarump conglomerate and the lower part of the Chinle formation were examined systematically for uranium minerals and geologic features thought to be favorable for the accumulation of uranium minerals at all accessible outcrops. No systematic search for uranium minerals was made in the other formations, although these formations were examined in many places in the course of geologic mapping.

Uranium ore associated with copper minerals occurs at several places in the Shinarump conglomerate in exposures 3 miles north of the Red House Cliffs area, and uranium ore associated with copper and vanadium minerals occurs at the Whirlwind mine in the Shinarump conglomerate about 200 yards south of the map area in section 2, T. 41 S., R. 13 E. However, no uranium minerals or abnormally high radioactivity were observed in the Shinarump conglomerate exposed within the Red House Cliffs area.

Although no uranium minerals were observed, this does not indicate that uranium ore deposits are absent in the Shinarump conglomerate within the map area. To the present time, little is known about the origin and the manner of deposition of the uranium ore in the Shinarump conglomerate, but several empirical guides to uranium deposits in the Shinarump conglomerate have been established. According to Finch (1953) these guides are: (1) most ore deposits occur in Shinarump sediments that filled channels cut into the Moenkopi formation, (2) most ore deposits are associated with abundantly carbonaceous and irregularly bedded sediments, and (3) most ore deposits are associated with a regional margin of deposition of the Shinarump conglomerate. The Shinarump conglomerate exposed along the San Juan River is, on the basis of the empirical guides listed, a favorable host rock for uranium ore. Thus, concealed uranium deposits may be present in some of the Shinarump channels within the map area. However, exploration for concealed deposits will be relatively expensive for the Shinarump conglomerate in the map area is deeply covered in most places.

The lower part of the Chinle formation is uranium-bearing in Lisbon Valley, Utah; San Rafael Swell, Utah, near the junction of the Colorado and Green Rivers, Utah; and near Cameron, Arizona. The lower part of the Chinle formation in the Red House Cliffs area contains many stream deposited sandstone beds, and many of the beds contain carbonaceous material. Nevertheless, no uranium minerals or places of abnormal radioactivity were observed in the Red House Cliffs area.

Th lack of known uranium minerals in the lower part of the Chinle formation, the relatively great distances to places where the lower Chinle is uranium-bearing, and the lack of knowledge about habits and origin of ore in the lower part of the Chinle formation preclude an appraisal of the uranium potential of the lower part of the Chinle in the map area.

Gold

Placer gold in extremely fine flakes is widely distributed in the gravel terraces and bars along the San Juan River, but apparently not in sufficient concentrations to justify mining. Gregory (1917, p. 139-140) states that in 1891 and 1892 reports of rich gold deposits along the river caused a gold rush, and that a reported 1,200 men were searching for gold along the river by 1892. Prospecting and development work continued until about 1912, but the small amounts of gold recovered did not justify commercial operations (Gregory, op. cit.).

Since 1912 few attempts have been made to recover gold from the San Juan River, and in 1952 and 1953 there were no gold prospectors in the area.

Copper

Malachite, a copper carbonate, is disseminated through an irregular patch of about 15 square feet in a small lens of Shinarump conglomerate exposed about 3 miles northeast of Clay Hills Pass. This occurrence, which is not of economic value, was the only occurrence of copper observed in the map area.

Oil and gas

Prospects for producing oil and gas in the Red House Cliffs area are poor. Structural conditions are relatively unfavorable, rocks that crop out within the area are not oil-bearing, and rocks that underlie the area apparently have little potential as sources of oil and gas.

The dominant structural feature of the area is the gentle westward dip from the crest of the Monument upwarp. This large scale feature is considered unfavorable for the accumulation of oil and gas because it has no closure within the map area.

Superimposed on the flank of the upwarp are two north trending anticlines. One, the Organ Rock anticline, is not closed in the map area, but 11 miles south of the map area it has about 150 feet of closure (Baker, 1936, p. 96). The second anticlinal structure, the Moki anticline, is vaguely defined by gently eastward dips immediately west of the westernmost fault zone. The lack of key beds in the Glen Canyon group which caps this anticline prohibits determining exactly the structural configuration. It possibly has more than 50 feet of closure a few miles north of the map area (Trites and Thaden, in preparation).

Except for part of the Moenkopi formation, the rocks which crop out in the map area are of continental origin and show no indications of oil, and are not believed to offer any possibility of oil production in the map area. The Lower and Middle(?) Triassic Moenkopi formation contains oil in several places in southern Utah. It produces oil in southwestern Utah (Gregory, 1950, p. 190); and it is impregnated with oil in Circle Cliffs (Gregory and Moore, 1931, p. 154) and in the San Rafael Swell (Gilluly, 1929, p. 128). However, no indications that the Moenkopi formation would produce oil or serve as a source of oil were noted in the map area.

Shallow wells drilled a few miles east of the map area near Mexican Hat, Utah, have produced small amounts of oil from the Pennsylvanian Hermosa formation and Permian Rico formation (Baker, 1936, p. 87-89; Miser, 1925, p. 150-155). These formations undoubtedly continue westward and underlie the map area; and probably the formations have about the same lithologic characteristics in the map area as near Mexican Hat. Nevertheless, attempts to extend the Mexican Hat oil field to the west have been unsuccessful (Baker, 1936, p. 88-91).

Deep wells drilled within 45 miles of the map area--the Shell Oil Company Bluff Unit no. 1, about 45 miles east; the California Company Muley Creek unit no. 1, about 25 miles northwest; the Skelly Oil Company Nokai Dome unit 1-A, about 4 miles west; and the Sinclair Oil and Gas Company Navajo no. 1, about 35 miles southwest--indicate the map area is underlain by Pennsylvanian, Mississippian, Devonian Ordovician, and Cambrian rocks. Some of these rocks are petroliferous, but none of the wells listed were considered producing wells. Presumably the same stratigraphic conditions would prevail in Red House Cliffs area, and no producing wells from older Paleozoic rocks would be expected in the Red House Cliffs area.

Gravel

A large amount of gravel suitable for construction purposes occurs in the terraces along the San Juan River. This gravel is not now of economic value; nevertheless, the gravel has potential economic value because of its geographic location.

The potential economic value of the gravel depends on the construction of the Glen Canyon Dam on the Colorado River; the lake formed behind this dam will extend up the San Juan River to Clay Hills Crossing. As Clay Hills Crossing will be the most accessible part of the lake along the San Juan River, the area of the Crossing may become a focal point for recreational facilities, and nearby gravels will be a source of material for roads and buildings.

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APPENDIX

REPRESENTATIVE STRATIGRAPHIC SECTIONS MEASURED IN OR NEAR THE RED HOUSE CLIFFS AREA

Section of Kayenta formation and Wingate sandstone measured on north side of Castle Wash about half a mile north of Green Water Spring. Section measured by T. E. Mullens and H. A. Hubbard.

Thickness (feet)

Navajo sandstone:

17. Sandstone, pale red; horizontally bedded in basal 1 ft., grades upward to eolien type cross-laminated reddish-orange fine-grained sandstone. Navajo sandstone not measured. . . . . ----

16. Contact between Kayenta formation and Navajo sandstone. No apparent unconformity, but abrupt change in lithologic and bedding characteristics. The contact seems to represent continued deposition but a change from one depositional environment to another. Within the Red House Cliffs area there is intertonguing rocks with "Navajo"-type bedding and Kayenta rocks . . . . ----

15. Sandstone, pale red: fine-to medium-grained; composed of clear subangular quartz grains with common black and red accessory minerals and white mica flecks, some lenticular beds contain abundant reddish-brown mudstone and clay blebs; weak carbonate cement; fluviatile type bedding, basal scour surface of individual beds; local concentrations of greyish-purple sandstone with abundant white mica at base of deeper scours. Unit forms ledgy slope with small benches developed on lenticular beds. 54.0 212.6

14. Sandstone, pale red; very fine-grained; composed of clear subrounded quartz grains with common red and black accessory minerals; horizontally laminated; unit forms rounded ledge. Locally scoured up to 6 ft. by unit 15 . . . . 5.2 158.6

13. Calcareous sandstone, light gray and moderate pink; very fine-grained; composed of clear well-rounded quartz grains in a dense limestone matrix; horizontally bedded from 1/2 to 4 in. thick. Unit 13 grades upward to unit 14 by subtraction of lime. . . 4.7 153.4

12. Sandstone, grayish orange to moderate reddish orange; very fine-grained, well-sorted; composed of clear and iron-stained quartz grains with abundant black accessory mineral; weak carbonate cement; bedding structures not visible, unit forms two horizontal ledges. Unit contains abundant irregular-shaped calcareous concretions up to 6 in. in length. Unit 12 grades upward to unit 13 . . 10.7 148.7

11. Siltstone, moderate reddish brown; very fine-grained, sandy, contains abundant very fine white mica flakes; weak carbonate cement; forms earthy slope. Unit contains a 2-1/2 ft. white fine-grained sandstone 5 ft. above base. Sandstone bed very lenticular, does not extend over 50 ft. along strike. Noted in section because of spotty oil stains in sandstone. Top of unit a 3 ft. lenticular pale-red sandstone with abundant nodules of carbonate covered sandstone. Unit 11 grades into sandstone like unit 10 along strike. 25.0 138.0

10. Sandstone, white; fine-grained, well-sorted; composed of clear angular to subrounded quartz grains with abundant dull white accessory mineral (possibly altered feldspar) and common orange and black accessory grains; firm noncarbonate cement; lenticular bed, fluviatile-type cross-laminations; unit forms minor ledge in line of section. 2.0 113.0

9. Sandstone, pale red; fine- to medium-grained, poorly sorted; composed of angular to subrounded clear quartz grains, common black accessory mineral and rare green accessory grains; unit is composed of many lenticular beds, each varying slightly in cementation, porosity, and mudstone bleb content from adjacent beds. Locally individual beds contain enough mudstone and clay blebs to be termed conglomerate. About 8 ft. above base of unit is a limestone concretion zone which locally becomes a sandy limestone bed 1 ft. in thickness. Directly above the limestone zone is a 1 to 2 ft. lenticular bed of fissile silty sandstone that contains abundant white mica flakes. Unit is compositely bedded, horizontal and fluviatile-type cross-laminations are present; unit forms steep ledgy slope with local development of small benches on lenticular beds. 85.5 111.0

		Thickness (feet)	
8.	Sandstone, pale red; fine- and very fine-grained, poorly sorted, silty; composed of clear quartz with common black accessory mineral and rare white mica flakes; firm to weak carbonate cement; lenticular fluviatile type beds in part, unit mostly covered by talus. Top of unit a 1 ft. bed of dark reddish-brown clay-bleb conglomerate in a pale red sandstone matrix	18.3	25.5
7.	Sandstone, pale red; dominantly medium-grained, poorly sorted, contains abundant fine and very fine grains; composed of subangular quartz with common black accessory mineral, rare white mica flakes, and abundant blebs of dark reddish-brown claystone and mudstone; blebs average about 1/4 in. in diameter; largest observed 1 in.; lenticular bed, basal scour surface, fluviatile type cross-laminations; some cross-beds are well-shaped festoons up to 20 ft. across, but most cross-beds 1 to 2 ft. in thickness and 4 to 8 ft. long; units form irregular ledge at top to rounded Wingate cliff.	7.2	7.2
6.	Contact, Wingate sandstone-Kayenta formation. Scour surface and abrupt change in lithologic and bedding characteristics. Local relief on scour surface up to 6 ft. Deeper scours filled with reworked Wingate sandstone and added reddish-brown and pale red mudstone blebs up to 2 in. in diameter. Scour surface probably does not represent a time break in sedimentation; instead it probably represents an encroachment of Kayenta fluviatile deposition on eolian Wingate sandstone. Along strike the basal ledge of Kayenta sandstone loses its fluviatile characteristics and merges into a structureless rounded weathering part of the Wingate sandstone	----	----

Thickness (feet)

Top of Wingate sandstone:

5. Sandstone, moderate reddish orange and pale reddish brown; fine-grained, well-sorted; composed of clear rounded and subrounded quartz grains with common iron-stained quartz grains and common black accessory mineral and rare stringers and disseminations of well-rounded medium quartz grains; weak calcareous cement; composite bedding, long sweeping cross-laminations between lenticular horizontal parting planes, horizontal planes from 8 to 30 ft. apart; local small scale cross-laminations, smaller units from 2 to 6 ft. thick and 4 to 20 ft. in length; unit weathers to rounded cliffs in general with some development of benches on horizontal planes and local flaggy weathering of cross-laminations 289.0 308.8

4. Limestone, light gray, locally grayish pink; dense noncrystalline; thin bedded from 1 in. beds to a massive 9 ft. bed; locally very sandy with fine subrounded clear quartz grains; unit forms a narrow gray band in sandstone cliff. A limestone bed in the Wingate is unique. At Clay Hills Pass limestone beds such as this unit are in the Chinle formation and it is possible that units 3 and 4 should be included in the Chinle formation. 0.9 19.8

		Thickness (feet)	
3.	Sandstone, pale reddish brown; very fine-grained; composed of clear and iron-stained subrounded quartz with abundant black accessory mineral and disseminated medium subrounded clear quartz grains; firm nonclacareous cement; cross-bedded in units from 2 to 6 ft. thick and from 4 to 10 ft. in length; composite type laminations; unit forms vertical smooth cliff	18.9	18.9
2.	Contact, Wingate-Chinle. No apparent unconformity but an abrupt change in lithology and bedding characteristics.	----	----

Chinle formation:

1.	Sandstone, dark reddish brown; poorly sorted, dominantly very fine-grained, but contains abundant silty and common fine grains; composed of clear and iron-stained subrounded quartz with abundant black accessory mineral and common white mica flakes; well indurated, calcareous cement; hackly weathering; forms earthy slope; unit poorly exposed in boulder and sand dune covered slope at base of Wingate. Chinle formation not measured.	----	----

Section of Chinle formation measured on the north face of the extreme southeast side of the cliff which rims Red Canyon. Section measured by T. E. Mullens and H. A. Hubbard.

	Thickness (feet)	
Wingate sandstone:		
34. Sandstone, moderate reddish brown, very fine-grained, common to rare red and black accessory minerals; well indurated, only slightly calcareous. Wingate not measured	----	----
33. Contact between Wingate sandstone and Chinle formation. Contact apparently conformable. Change in bedding and grain size but no channeling observed. Wingate sandstone has both ripple mark and mud crack fillings on basal surface	----	----
Chinle formation:		
32. Siltstone, dark reddish brown, sandy; well indurated, noncalcareous cement; hackly to concretionary weathering. Unit forms slight undercut below Wingate sandstone	4.5	795.3
31. Siltstone to very fine-grained sandstone like unit 27	63.9	790.8
30. Limestone, greenish gray, dense, noncrystalline, relatively pure; lenticular bed. Contains scattered chert concretions.	1.1	726.9

		Thickness (feet)	
29.	Siltstone to very fine-grained sandstone like unit 27	15.4	725.8
28.	Sandstone, moderate reddish orange, very fine-grained, well-sorted; composed of clear quartz with common black and rare red accessory minerals; firm calcareous cement; unit one massive bed with horizontal laminations; unit forms distinctive ledge at base, platy slope at top	17.8	710.4
27.	Siltstone to very fine-grained sandstone, moderate reddish orange, very fine quartz grains, rare rounded medium quartz grains; well indurated, calcareous cement; bedding structures not exposed, but probably horizontal as horizontal ledges crop out in upper part of steep slope. Ledges 18 in. to 2 ft.	85.4	692.6
26.	Sandstone, pale red, fine to very fine-grained, poorly sorted, composed of clear quartz with abundant black and dark green accessory minerals, common green and white mica, abundant interstitial clay; weak calcareous cement; bedding structures masked; unit forms steep slope.	23.8	607.2

Thickness (feet)

Top of middle division:

25. Mudstone to silty sandstone, moderate orange pink to moderate reddish orange, abundant greenish-gray mottling; composed of clay, silt, and very fine clear quartz grains; well indurated, calcareous cement; crudely horizontally bedded; hackly to rounded weathering; "cleaner" and more calcareous beds form rounded to angular ledges; unit forms a prominent ledge in line of section. Calcite and chert concretions common in more limy beds. Top 12 ft. of unit a poorly developed limestone-pellet conglomerate. Local concentration of coarse angular quartz grains and rare pieces of pale red chert up to 1 in. in the top 12 ft. of the unit 42.5 583.4

24. Claystone, moderate reddish orange to pale reddish brown; well indurated, firm calcareous cement. Unit poorly exposed. 81.1 540.9

23. Sandstone, pale red; fine-grained, poorly sorted; composed of subangular to subrounded clear quartz with abundant black and green accessory minerals, rare white mica, common interstitial clay, firm calcareous cement; lenticular bed, basal scour surface, thin (1/8 in.) gentle dipping cross-laminations; unit forms minor ledge in line of section 1.6 459.8

		Thickness (feet)	
22.	Limestone-pellet conglomerate, light gray; clay matrix; rounded limestone pebbles average 3/4 in., largest 1-1/2 in., unit poorly consolidated, forms very weak minor ledge	0.8	458.2
21.	Claystone, like top of unit 19.	12.6	457.4
20.	Clayey limestone grading upward to very limy claystone, pale red purple; basal 18 ft. fair limestone, top part a hackly claystone; unit forms distinctive ledge in line of section. Chert and abundant sand grains and green mottling concretions in limestone. Small gastropods collected from limestone	7.1	444.8
19.	Claystone, grayish red to pale red purple in lower 12 ft., moderate reddish orange to top, greenish-gray mottling; well indurated, firm calcareous cement; bedding masked by hard frothy cover; unit forms steep slope	37.8	437.7
18.	Clayey limestone, pale red purple; dense, non-crystalline, contains common fine quartz grains; variable clayey to a limy claystone. Unit in 2 beds separated by a 1 ft. clayey zone. Unit forms distinctive ledge. Abundant chert concretions and green mottling in limestone	4.8	399.9

		Thickness (feet)	
17.	Claystone, moderate reddish orange, greenish-gray mottling; well indurated, calcareous, cement. Forms steep frothy slope. Upper 1 ft. of unit altered to pale red purple	40.5	395.1
16.	Mudstone, pale red to pale red purple; composition like unit 15 with more silt and clay. Unit forms steep slope	66.0	354.6
15.	Sandstone, pale red purple, pale red, and grayish-orange pink; very fine- to medium-grained; poorly sorted; composed of clear angular to subrounded quartz, abundant black and green accessory minerals, abundant interstitial clay, abundant green and white mica, and rare red accessory mineral; firm to weak calcareous cement; lenticular bed, stream-type cross-laminations, some channeling within unit, scour basal surface; weathers to friable rounded ledge with irregular spaced, more resistant smaller ledges. A 2 ft. limestone-pellet conglomerate present 27 ft. above base of unit. . .	37.6	288.6
14.	Mudstone, moderate reddish orange and yellowish orange; locally fine-grained sandstone; well indurated, calcareous cement; bedding structures mashed by frothy slope. Unit contains some beds of limestone nodules. Unit weathers moderate reddish orange at top and base, pale yellowish orange in middle.	47.0	251.0

Thickness (feet)

13. Mudstone, moderate reddish brown; composed of clay, silt, and very fine to fine-quartz grains, contains abundant white mica; well indurated, noncalcereous cement; bedding structures masked; forms steep frothy slope 7.3 204.0

12. Sandstone, pale red; very fine- to fine-grained, poorly sorted, composed of clear quartz with abundant black and green accessory minerals, abundant white mica, abundant interstitial clay, and common red accessory mineral; friable, weak calcareous cement; bedding, complex, a mixture of horizontal and gentle dipping cross-laminations, some beds weather as short lenses; unit forms steep sandy slope. A 4 ft. bed of limestone conglomerate like unit 8 present 12 in. above base 31.4 196.7

11. Claystone, dark reddish brown, weathers dusky red; slightly silty; well indurated, noncalcareous cement; unit contains some nodular limestone concretions; unit forms steep frothy slope. 44.2 165.3

		Thickness (feet)	
10.	Sandstone, medium light gray; very fine-grained, well sorted, composed of clear quartz with abundant black and green and rare red accessory minerals; firm calcareous cement; irregular beds, gentle cross-laminations 1/8 to 1/2 in. thick, local channels within the ledge; platy weathering along cross-laminations; unit forms irregular platy ledge . . .	15.9	121.1
9.	Sandstone, light greenish gray; medium- to coarse-grained, poorly sorted, composed of clear quartz with abundant green and black accessory minerals, abundant interstitial clay, and rare red accessory mineral; weak calcareous cement, unit slightly friable; bedding structures indistinct, local traces of stream type cross-laminations; unit forms rounded ledge	3.2	105.2
8.	Limestone-pellet conglomerate, greenish gray; rounded limestone and clay pebbles in a matrix of medium to coarse clear quartz grains and coarse dark grains; well indurated, calcite cement; pebbles up to 1-1/2 in. in diameter, but average less than 1/2 in.; lenticular bed; locally becomes more sandy or more conglomeratic along strike. In line of section unit 8 is split into two distinct limestone conglomerate ledges by a tongue of sand like unit 7.	5.0	102.0

		Thickness (feet)	
7.	Sandstone, light greenish gray; very fine-grained, well sorted, composed of clear quartz with rare red and black accessory minerals; firm calcareous cement; tabular bed with horizontal laminations 1/8 to 1/4 in. thick; unit forms distinctive ledge in line of section but apparently not present along strike	3.8	97.0
6.	Limestone conglomerate, light gray with spots of medium dark gray; well indurated, calcite and silt matrix; limestone pebbles subrounded, average size 3/4 to 1 in., largest observed 2-1/2 in.; bedding indistinct, scour surface at base and locally the upper 1 ft. of unit are altered to greenish gray. Unit locally contains small lenses of coarse-grained quartz sand	3.0	93.2
5.	Mudstone, dark reddish brown; composed mainly of silty clay with rare very fine quartz grains; well indurated, noncalcareous cement; hackly fracture deep frothy weathering; unit forms steep dusky red slope. . . .	64.7	90.2
4.	Mudstone, grayish blue; composition same as unit 3; unit forms lenticular grayish blue band	7.0	25.5

Thickness (feet)

3. Mudstone, grayish red; composed of sand grains, silt, and clay; sand grains of clear angular to subrounded quartz up to medium-grained; accessory minerals are brown and white mica and unknown black mineral; unit well indurated, noncalcareous cement. Bedding structure masked, unit shows many lateral changes. Along strike unit changes color to grayish purple and pale yellowish orange and develops a local basal conglomerate which can be termed Shinarump conglomerate. This conglomerate is pale red purple with mottles of dusky yellow. It is composed of fine to pebble size quartz fragments and slightly siltier along strike. Quartz fragments mainly subangular. Unit friable, to firmly cemented, bedding structures masked, but conglomerate is highly lenticular and a scour surface at base. Conglomerate has high iron content chert concretions up to 3 in. in diameter. Thickness of conglomerate up to 5 ft. 18.5 18.5

Thickness
(feet)

2. Abrupt change in composition, color and bedding characteristics. Also local channeling up to 3 ft. Contact marked in most places by a concentration of light colored quartzite and quartz pebbles. These pebbles are subrounded and average 1-1/2 in. to 2 in. in diameter, the largest observed was 3-1/2 in. Chert and silicified limestone pebbles are present, but rare at the contact . . . . ---- ----

Moenkopi formation:

1. Siltstone, pale reddish brown, mottled and banded grayish yellow green; slightly very fine-grained sandy; well indurated, slight calcareous cement; horizontal beds 1 in. to 1 ft. thick, light colored beds up to 2 in. thick form bends about 1 to 2 ft. apart; hackly to slightly fissile weathering; unit forms steep slope. Moenkopi formation not measured. . . . . ---- ----

Section of Chinle formation at Clay Hills Pass. The section was measured south of the road and up the south fork of the stream bed. Section measured by T. E. Mullens and H. A. Hubbard.

Thickness (feet)

Wingate sandstone:

32. Sandstone, moderate pink to moderate reddish orange; fine- to very fine-grained; poorly sorted, silty and contains abundant medium grains; composed of subrounded clear quartz except that larger grains are iron-stained. Wingate sandstone not measured . . . . ---- ----

31. Contact between Wingate sandstone and Chinle formation. Contact apparently conformable. Locally the basal surface of the Wingate sandstone is ripple marked and shows mud crack impressions. . . . . ---- ----

Chinle formation:

30. Covered. Along strike (across to north side of pass) this interval is the same as unit 28, however along line of section the covered interval is probably a very fine- to fine-grained reddish-brown sandstone. . . 19.4 784.5

29. Sandstone, pale red; fine- to coarse-grained, poorly sorted, composed of angular to subrounded clear quartz with abundant silt and clay blebs; firm calcareous cement; lenticular beds, scour type cross-laminations, beds up to 6 ft. thick; unit forms ledgy to vertical slope. 36.5 765.1

		Thickness (feet)	
28.	Sandstone, pale red; very fine- to fine-grained, poorly sorted, silty; composed of clear and iron-stained quartz grains, firm calcareous cement; lenticular beds, faint traces of stream type laminations. Unit forms steep ledgy slope. Locally unit contains mica and reddish-brown clay blebs. Top of unit poorly exposed along line of section. . .	39.6	728.6
27.	Sandstone, moderate reddish orange; very fine-grained, abundant silt; firmly calcareous cement; horizontal beds 2 to 5 ft. thick, no laminations; heckly weathering; unit forms steep ledgy slope. Along strike unit forms vertical cliff. Flat at Clay Hills Pass is about 20 ft. below top of unit 27	40.5	689.0
26.	Sandstone, moderate reddish orange; very fine-grained, very silty; composed of clear and iron-stained quartz grains, calcareous cement; horizontal beds 1 to 1-1/2 ft., laminations not observed; unit forms steep slope. Unit becomes more massive toward top	35.0	648.5

	Thickness (feet)	
Top of middle division:		
25. Claystone and siltstone, light brown contains abundant fine clear quartz grains; highly calcareous, well indurated; hackly weathering; bedding structures masked; unit forms steep slope which merges with the moderate to light reddish-orange color of unit 26. Abundant light green mottling, mottling increases upward	70.0	613.5
24. Limestone, greenish gray; dense, lithographic, contains abundant fine to medium sand grains and clay inclusions; bedding indistinct in line of section. This unit forms a distinctive ledge along strike	3.0	543.5
23. Claystone, light reddish brown to moderate yellowish orange; slightly sandy; bedding structures masked; hackly weathering, forms steep slope; unit poorly exposed in line of sections	86.0	540.5
22. Limestone pellet conglomerate, like unit 15	1.7	454.5
21. Sandstone, moderate reddish brown; very fine-grained, abundant silt and clay matrix; composed of clear and iron-stained quartz; weak calcareous cement; bedding structures masked; unit forms steep slope	11.4	452.8

Thickness (feet)

20. Limy claystone, grayish red. Unit in 5 ledges along line of section. Each ledge about 1 ft. thick, separated by about 1 ft. of claystone like unit 19. Unit forms a distinct ledge in area 8.2 441.4

19. Claystone, moderate orange pink; scattered fine and very fine quartz grains; calcareous cement; bedding structures masked, unit forms slope. 36.0 433.2

18. Limestone, light gray; dense; conchoidal fracture; contains abundant pale red-purple chert concretions. Unit is in two indistinct beds, each bed weathers into irregular blocks up to 1 ft. in length. Unit forms distinct ledge in area 4.4 397.2

17. Claystone, greyish purple in lower half, moderate reddish orange in upper part; upper half weathers moderate orange pink; contains common very fine to fine clear grains; calcareous cement; slightly fissile, bedding structures masked; unit forms steep slope 72.0 392.8

16. Sandstone, like unit 11. Unit 16 contains lenticular beds of limestone pellet conglomerate such as unit 15. One limestone pellet conglomerate near the top is 8 ft. thick but extends less than 150 ft. along strike 36.1 320.8

		Thickness (feet)	
15.	Limestone pellet conglomerate, grayish red; limestone pellets up to 1/2 in. long in a matrix of fine to coarse clear quartz grains and clay; quartz grains angular to rounded; matrix contains common black mica. Locally the lime cement has been removed from this unit and the "limestone" pellets weather to gray clay. Unit is lenticular, and has low angle scour type cross-laminations	2.8	284.7
14.	Claystone, moderate reddish orange, mottled dusky yellow; forms moderate orange pink slope; common fine clear quartz grains; firm calcareous cement; bedding structures masked; hackly weathering	41.5	281.9
13.	Sandstone, pale reddish brown with abundant very light gray mottling; fine- to medium-grained, poorly sorted; composed of angular to subrounded quartz grains, common black accessory minerals, rare red chert grains, and abundant silt and clay; weak calcareous cement; bedding structures masked; unit forms distinct thin light-gray band.	0.3	240.4
12.	Mudstone, dark reddish brown; composed of silt and fine and very fine quartz grains; weak calcareous cement; bedding structures masked; unit forms moderate red slope	4.0	240.1

		Thickness (feet)	
11.	Sandstone, grayish red and light gray; medium- to coarse-grained, poorly sorted; composed of angular to subrounded quartz grains and abundant green mineral, abundant interstitial clay, black accessory mineral, clear mica, and common fine red chert grains; friable, slightly calcareous; bedding structures poorly exposed, some traces of stream type cross-laminations. Unit forms steep rounded grayish slope	31.4	236.1
10.	Claystone, dark reddish brown to grayish red local mottles and streaks of greenish gray. Unit contains thin lenticular beds of fine-grained very calcareous sandstone, thin stringers of nodular limestone and calcite concretions. Bedding masked; forms steep frothy slope	52.0	204.7
9.	Sandstone, pale green; fine- to medium-grained; poorly sorted; composed of clear quartz, with at least 50 percent black and green minerals and interstitial clay; grains angular to rounded; friable, calcareous cement; bedding generally masked, local exposures show stream type cross-laminations; unit forms steep green slope. Unit contains fossil wood, largest log observed 14 in. by 8 ft. Gradational contact with unit 10.	76.5	152.7

		Thickness (feet)	
8.	Mudstone, grayish yellow green; unit consists of clay, silt and fine- to very fine sand grains; weak noncalcareous cement; contains gypsum concretions which locally alter the unit to dark gray and grayish orange in color. Bedding masked, frothy weathering; forms greenish slope. Along strike this unit contains some lenticular beds of sandstone. Locally aragonite float is abundant on slope. Unit interfingers with dark reddish claystone along strike	17.5	76.2
7.	Claystone, variegated; colors include dark yellowish orange near base, grayish purple to grayish blue in middle, and dark reddish brown at top; unit contains common very fine to fine clear quartz grains; unit forms steep frothy slope.	33.3	58.7
6.	Claystone, grayish purple with local dark grayish-orange mottling; well indurated, noncalcareous cement; local concentrations of iron oxide (limonite and hematite). Frothy weathering; forms steep slope. . . .	8.1	25.4
5.	Sandstone, light gray; very fine to medium-grained, abundant silt; composed of angular to subrounded quartz grains; firm cement, very calcareous, local calcareous nodules. Unit forms thin gray band in steep slope	0.3	17.3

		Thickness (feet)	
4.	Claystone, grayish purple; contains rare clear quartz sand grains; unit well indurated, noncalcareous cement; bedding indistinct; hard surface, hackly weathering; unit forms steep grayish-purple slope	6.0	17.0
3.	Mudstone, grayish red and light gray with irregular spots of dark reddish brown. Unit is an unsorted mixture of clay, silt, sand, and larger sized particles. Sand and granule sized particles are predominantly clear quartz, angular to subrounded. Larger pebbles are present locally as stringers and also disseminated throughout unit. Larger pebbles mainly reddish-brown quartz and quartzite, common milky to clear quartz, and rare reddish cherts. Pebbles are angular to well rounded. Local concentrations of iron oxide near the Moenkopi-Chinle contact. Also local stringers and lenses of sandy conglomerate. Composition same as for larger sized particles. Entire unit well indurated with very slight calcareous cement. Unit forms steep gray slope	11.0	11.0

Thickness (feet)

2. Contact between Chinle formation and Moenkopi formation. Contact is an erosional unconformity marked by an abrupt change in lithologic characteristics and local channeling of Chinle rocks into Moenkopi. Greatest channel depth 2 ft. Shinarump conglomerate absent in line of section . . . . ---- ----

Moenkopi formation:

1. Siltstone, dark reddish brown, banded and mottled wibh streaks of pale yellowish green; contains abundant very fine quartz grains; well indurated, slightly calcareous cememt. Horizontal beds 1 in. to 1 ft. thick, bedding accentuated by bands of pale yellowish green; hackly fracture; unit forms steep rounded slope. Moenkopi formation not measured. . . . . ---- ----

Section of Chinle formation measured on the point at the south side of the head of Clay Gulch. Section measured by T. E. Mullens and J. H. Stewart.

	Thickness (feet)	
Wingate sandstone:		
28. Sandstone, moderate reddish orange; very fine-grained with abundant stringers or medium, well-rounded and iron-stained quartz grains near base of unit. Wingate sandstone not measured	----	----
27. Contact between Chinle formation and Wingate sandstone. No apparent unconformity, but a slight waviness at basal surface of Wingate sandstone . . .	----	----
Chinle formation:		
26. Sandstone, pale reddish brown; very fine-grained, silty; composed of clear quartz, common white mica flakes, other accessory minerals masked; firm calcareous cement; tabular bed and horizontally laminated; platy weathering, forms steep talus covered slope	13.6	818.6
25. Sandstone; same as unit 23 but only 25 percent of unit is limestone-pebble conglomerate	14.2	805.0
24. Covered.	16.8	790.8

Thickness (feet)

23. Sandstone, pale red and minor very light gray; poorly sorted, very fine- to coarse-grained, locally silty; composed of clear and milky angular and subangular quartz, abundant black and green accessory minerals, and common white mica flakes. Along line of section this unit is about 50 percent limestone-pellet conglomerate, pellets up to 1 ft. and average 1 in. in diameter. Pellet conglomerates also contain common granule size and abundant milky quartz grains up to very coarse-grained. Unit forms minor ledge in earthy slope 62.9 774.0

22. Limestone-pellet conglomerate, pale red and light greenish gray; contains subrounded limestone pebbles up to 2 in. in diameter and abundant milky and clear quartz, subrounded to rounded, from very fine- to very coarse-grained. Unit forms whitish ledge. 5.0 711.1

21. Poorly exposed, probably like unit 14. Weathers to gentle earthy slope. 1.2 ft. bed of limestone-pellet conglomerate 7 ft. above base; conglomerate in general finer grained than other limestone-pellet conglomerates; largest pellet 3/8 in. in diameter. Trough type cross-bedding and lamination. Very blocky weathering and forms steep ledgy slope. 34.8 706.1

Unit	Description	Thickness (feet)	
20.	Like unit 14. Common very fine-grained mica flakes noted. Upper 12.7 ft. limier and forms ledge . .	21.8	671.3
19.	Limestone, grayish orange pink, pale red and light greenish gray; very silty; greenish portions contain abundant very fine quartz grains; massive basal portion; thin bedded and flaggy weathering in upper half; flaggy portion contains abundant "worm borings" and possibly plant impressions.	14.1	649.5
18.	Like unit 14 except for 1 ft. limy ledge at 34.8 ft. above base of unit.	39.4	635.4
17.	Sandstone, limy, conglomeratic; light greenish gray; sandstone composed of very fine to coarse subangular to well-rounded quartz grains, fine calcareous cement; conglomerate of limestone pellets from very coarse-grained to 1/4 in. in diameter, clay pellets up to 1 in. in diameter	3.2	596.0
16.	Sandy siltstone like unit 14.	52.2	592.8
15.	Limestone, pale red mottled light greenish gray, unit very silty and very fine-grained sandy; gradational with lower and upper unit; forms highly fractured ledge in line of section.	9.4	540.6

		Thickness (feet)	
14.	Sandy siltstone, pale reddish brown, subangular to subrounded clear and iron-stained quartz grains abundant, well-indurated calcareous cement, thin to 4 in. beds of light greenish-gray (5GY8/1) limestone nodules and calcareous bed common in lower 2/3 of unit. Abundant light greenish-gray (5GY8/1) spots	52.2	531.2
13.	Mudstone, pale red and pale reddish brown; composed of equal proportions of clay, silt, and very fine quartz grains; contains abundant very fine mica flakes; calcareous cement and top 5 ft. contains nodules of light greenish-gray very fine-grained highly calcareous sandstone	39.6	479.0
12.	Sandstone like unit 10 except that locally bands of pale red and light greenish gray from 3/8 to 2 in. occur along lamination planes	13.6	439.4
11.	Claystone, slightly very fine-grained sandy, pale red in lower half and moderate orange pink in upper half; pale red slightly more calcareous than orange pink; unit well indurated and forms steep frothy slope. .	40.6	425.8
10.	Calcareous siltstone, pale red; locally contains abundant fine to very coarse- well-rounded quartz and limestone grains. Locally unit also becomes relatively pure dense limestone. Unit forms prominent band in slope. Gradational with units above and below	7.0	385.2

		Thickness (feet)	
9.	Claystone, pale red with abundant pale-green mottling in spots and streaks; well-indurated, calcareous; unit forms steep frothy slope	39.3	378.2
8.	Sandstone, pale red; fine- to very fine-grained, poorly sorted, silty, composed of subangular clear quartz with abundant black and white mica and green and black accessory minerals; calcareous cement, firm to friable; basal scour surface, trough type cross-lamination, lenticular unit. Forms minor ledge in line of section.	10.2	338.9
7.	Siltstone, slightly very fine-grained sandy, variegated dusky yellow (5Y6/4), moderate pink brown (5R7/4), grayish red (5R4/2), dark reddish brown (10R3/4), well-indurated, calcareous cement, weathers to moderate orange pink (10R6/6) with a basal moderate yellow (5Y10/6), contains a 29.8 ft. sandstone unit at 56.3 ft. above base of unit	86.1	328.7
6.	Sandstone, moderate pink; medium-grained; composed of angular clear quartz and milky quartz, white and pink feldspar, and abundant black and white mica and yellow accessory minerals; friable; cross-bedded; individual beds weather to form ledges in gentle rounded slope. Locally contains lenses of grayish-red sandstone more firmly cemented	24.7	242.6

Thickness (feet)

5. Sandstone, like greenish sandstone and pale red in unit 4 except grains are larger (fine- to medium-grained) and sandstone black mica flakes up to 2 mm. This sandstone contains short lenses of medium gray limestone pellet conglomerate; conglomerate locally contains aggregates of small pellets and large nodules up to 2 in. in diameter. Largest limestone bed is 2 ft. thick and extends less than 200 ft. along strike. Cross-bedded with trough type bed with low angle lamination. Locally cross-beds range in length from a few feet to 200 ft. and in thickness from a few feet to the total thickness of the unit. Unit forms a nearly vertical cliff, but slightly rounded at the top and grades into unit at the top. Basal scour surface 24.1 217.9

Thickness
(feet)

4. Claystone and sandstone. Claystone, grayish red; well indurated, noncalcareous cement. Sandstone, light greenish gray and pale red. Greenish sandstone is very fine-to medium-grained, poorly sorted, slightly silty and composed of angular clear quartz and black, green and red and pink accessory minerals. Accessory minerals make up at least 25 percent of greenish sandstone. Grayish red sandstone is very fine- to fine-grained, poorly sorted, silty and clayey, and composed of clear quartz and abundant white mica, other accessory minerals masked. Within unit greenish sandstone and red claystone are predominant. Reddish sandstone are found only at contact of greenish sandstone and claystone. Original bedding structures concealed, however contemporaneous deformation with deposition in unit is apparent. Large blocks of unit have slumped to where bedding is at least 30° away from true bedding planes. Unit weathers to steep frothy covered slope or to rounded hills where not protected by overlying unit. Some pale-red limestone in slope but none found in place 181.4 193.8

	Thickness (feet)	
3. Sandstone, light gray; very fine-grained; poorly sorted, silty and contains well-rounded fine to medium-fine quartz grains; composed of clear quartz; well indurated, noncalcareous cement; mottled dark yellowish orange and very dusky purple; mottling probably due to iron and manganese. Scoured lower surface up to 1 ft. Other bedding features obscured. Unit forms white ledge	6.0	12.4
2. Siltstone, dark reddish brown, pale red, pale purple, light greenish gray, and very light gray; well indurated, noncalcareous cement. Unit highly fractured. Color mixture gives general light greenish appearance. Reddish-brown siltstone greatly resembles reddish-brown siltstone in Moenkopi formation immediately below contact. Purplish stains possibly due to manganese	6.4	6.4
1. Contact between Moenkopi formation and Chinle formation. Contact is an erosional unconformity; local scours up to a foot	----	----
Moenkopi formation:		
Moenkopi formation not measured or described. . . .	----	----

Section of Chinle formation and Shinarump conglomerate measured south of the Whirlwind mine in section 2, R. 13 E., T. 41 S. Sections measured by L. C. Craig and P. J. Katich in June 1951. Section slightly modified by T. E. Mullens.

Thickness (feet)

Wingate sandstone:

27. Sandstone, moderate reddish orange to moderate orange pink; very fine-grained, abundant concentrations of subangular to subrounded grains on lamination planes; composed of subangular clear quartz with common amber, black and white accessory minerals; inclined to compound cross-laminations. Forms vertical desert varnished cliff . . . . Not measured

26. Contact between Wingate sandstone and Chinle formation. Contact not well exposed but is based on color and texture change. . . . . ---- ----

Chinle formation:

25. Sandstone, conglomerate at base, medium reddish orange, pale red, and pale yellowish orange; fine- to medium-grained; composed of subangular to subrounded clear quartz common black accessory minerals; moderately calcareous, moderately cemented; festoon cross-lamination, gently dipping lamination (less than 10°). At base is prominent but local intraformational conglomerate containing cobbles and pebbles of underlying limestone 38.0 1018.3

Thickness (feet)

Top of middle division:

24. Limestone (90%) and minor siltstone and claystone; limestone, light greenish gray to very light gray, dense to very fine-grained, in platy to slabby to massive ledges; sandstone and claystone form interbeds up to 1 ft. thick, sandstone and claystone are pale red; bedding planes in limestone show siltstone and claystone mud-cracks, horizontally laminated to ripple-laminated 39.4 980.3

23. Silty very fine-grained sandstone, moderate reddish orange, up to very fine-grained size; hackly weathering, structureless; unit forms prominent red ledge in lower part and red slope above 15.8 940.9

22. Claystone (80%) and limestone (20%); claystone grayish red, mottled and streaked light greenish gray, probably silty, hackly weathering, forms very steep slope; limestone pale red and light greenish gray, forms sequence of prominent hackly to slabby ledges 6 in. to 3 ft. thick, prominent ledgy unit below upper red unit. Not accessible along line of section 87.8 925.1

		Thickness (feet)	
21.	Claystone (99%) plus limestone (1%), unit not inspected because of dangerous slope. Claystone, grayish red, mottled and streaked light greenish gray, very thin discontinuous limestone ledges less than 6 in. thick, claystone probably quite sandy; unit forms steep slope	99.2	837.3
20.	Sandstone, pale red, weathering a purplish cast; medium- to fine-grained; composed of subangular to subrounded clear quartz, common to abundant orange, black, and uncommon green accessory minerals; abundant interstitial clay; stream type cross-laminations; forms friable ledge.	10.0	738.1
19.	Claystone, grayish red and pale red; slightly sandy up to fine grain size, highly calcareous; hackly weathering, forms minor cliff.	8.4	728.1
18.	Limestone, pale red, mottled light greenish gray; dense to very fine-grained, brecciated appearance, no fossils observed.	0.8	719.7
17.	Claystone, sandy to clayey sandstone, dark reddish brown below to pale reddish brown and moderate reddish orange above; sand up to fine grain size, moderately calcareous; forms steep slope; hackly to earthy weathering	97.2	718.9

		Thickness (feet)	
16.	Sandstone and claystone, pale red and light greenish gray, variably composed; sand up to medium grain size; composed of subangular clear quartz, common orange, black, and green accessory minerals, sandstone shows fine cross-laminations in indistinct beds. Unit locally forms minor ledge	5.5	621.7
15.	Limestone, pale red; very fine-grained to dense, forms local minor ledge; contains scattered pelecypods. . .	1.0	616.2
14.	Sandstone, very clayey to claystone, pale red; medium-grained; composed of clear subangular to subrounded quartz with common to abundant orange, black, and green accessory minerals; structureless; very friable, forms hard surfaced steep slopes. Above 22 ft. is predominantly claystone, variably silty to sandy, hackly weathering. Thin, moderate reddish-orange clay bed 8 ft. thick at top of unit	128.2	615.2
13.	Claystone, grayish red with light greenish-gray mottles, sandy up to medium-grain size, hard frothy weathering, forms gentle to steep slopes, contains concretionary rubble of light to medium grey dense to fine-grained limestone	25.0	487.0
12.	Covered interval. Slump blocks of Wingate sandstone on bench.	61.4	462.0

		Thickness (feet)	
11.	Heterogeneous unit. Sandstone, siltstone, and minor claystone; sandstone pale red, pale reddish brown, moderate red, pale red (color banded in ascending order); sandstone ranges from very fine- to coarse-grained, poorly sorted; composed of subangular to subrounded clear quartz, very common to abundant orange and black accessory minerals, abundant clay matrix. Thin limestone rubble conglomerate at base in grayish band; limestone, pale red, mottled light greenish gray, very fine-grained, partly dolomitic (?), limestone beds up to 5 ft. thick at top of unit	75.6	400.6
10.	Claystone, grayish red, light greenish-gray mottling, much greenish-gray mottling in lower part; slightly silty, hackly weathering; unit forms steep slope; unit rather indistinct and some slumping included. .	81.0	325.0
9.	Claystone, variably pure to slightly silty to very fine-grained, sandy, yellowish gray, pale olive to pale green; hackly to deep frothy weathering; contains bands of red locally; in part unit badly slumped; weathers to a steep hard slope.	97.2	244.0
8.	Interval covered, sparse exposures of variegated shale.	49.6	146.8

		Thickness (feet)	
7.	Claystone (80%) and sandstone (20%), interbedded; claystone pale olive, silty to slightly fine-grained sandy, earthy weathering, forms poorly exposed slope. Sandstone, brownish gray, fine-grained, weathering dark brown; highly calcareous; slabby (2 to 3 ft. thick) ripple-laminated ledges showing great distortion. Laterally along strike near section Shinarump-type sandstone builds up as high as top of this member sandstone but shows no contortion	97.2	97.2
	Total of Chinle formation.	1018.3	
6.	Contact between Chinle formation and Shinarump conglomerate. Contact conformable with local gradation and intertonguing of Chinle and Shinarump rocks . .	----	----
Shinarump conglomerate:			
5.	Sandstone, slightly quartzitic, light greenish gray to pale yellowish brown, weathering very pale orange to grayish orange; fine- to medium-grained, rare coarser grains; composed of subangular to subrounded clear quartz, rare black and orange accessory minerals; stream-type cross-lamination; plant fragments and layers with pebbles up to 1 in. in diameter in middle of unit; occasional granules of quartz and dull white chert	94.8	176.6
4.	Claystone, dusky yellow to yellowish gray; flaky to platy weathering, interval poorly exposed	4.9	81.8

Thickness (feet)

3. Sandstone, conglomeratic, pale yellowish orange to yellowish gray; medium-grained and coarse; composed of subangular to subrounded clear quartz, rare black accessory minerals; pebbles mostly white quartz, rose to pink quartz, white chert, and dark chert, pebbles less than 1 in., mostly 1/2 to 1/4 in., pebbles disseminated in sand matrix as well as concentrated in in lenses. Stream-type laminations, beds 1 to 10 ft. thick, channels common. Channel locally cuts 25 ft. lower into Moenkopi along outcrop than here. Unit forms massive ledge. Common plant fragments and intraformational clay pebbles at base. Channeling contact cuts out 40 ft. of Moenkopi within 300 ft. along outcrop 76.9 76.9

Total of Shinarump conglomerate. 176.6

2. Contact between Shinarump conglomerate and Moenkopi formation. Contact an erosional unconformity and marked by scours and abrupt change in lithologic characteristics . . . . ---- ----

Moenkopi formation:

1. Claystone and siltstone, interbedded, grayish red, mottled light greenish gray; claystone silty and micaceous; parallel sets less than 6 in. of parallel laminations. Top 4 in. altered light greenish gray . . . . Not measured

Section of Shinarump conglomerate measured about 2 miles southwest of Red House Spring. Section measured by T. E. Mullens.

	Thickness (feet)	
Chinle formation:		
5. Mudstone, variegated Chinle formation, not measured or described	----	----
4. Contact between Chinle formation and Shinarump conglomerate. Contact gradational vertically and laterally.	----	----
Shinarump conglomerate 1/:		
3. Conglomerate, light gray but mottled grayish purple and dusky yellow; matrix composed of fine to very coarse subangular clear quartz, interstitial clay, and rare black accessory mineral; larger sized fragments consist of clear and rose quartz, quartzite, chert and rare unidentified black mineral; larger fragments range from granule to pebble and angular to subrounded; largest pebble observed 2 in. in diameter, average pebble size 1/4 to 1/2 in.; lenticular bed, basal scour surface with relief up to 4 ft. Purple and yellow mottling possibly due to a combination of iron and manganese oxides. The basal foot or so of the Shinarump conglomerate consists of altered and reworked Moenkopi rocks. Unit forms a prominent light colored ledge in line of section	12.0	12.0

1/ The Shinarump conglomerate in this section corresponds closely in stratigraphic and lithologic characteristics to the "purple-white" bed generally considered as part of the Chinle formation (Finch, 1953).

Thickness (feet)

2. Contact between Shinarump conglomerate and Moenkopi formation. Contact an erosional unconformity with local scours as deep as 4 ft. Contact marked by abrupt change in lithologic characteristics . . . . ---- ----

Moenkopi formation:

1. Siltstone, moderate reddish brown; evenly bedded and slightly fissile. Moenkopi formation not measured ---- ----

Section of Shinarump conglomerate, Moenkopi formation, and Hoskinnini tongue of the Cutler formation, measured up major southeast drainage at Clay Hills Pass. Section measured by T. E. Mullens and H. A. Hubbard.

	Thickness (feet)	
Chinle formation:		
Not measured or described in this section, but base of Chinle section at Clay Hills Pass started about 300 yds. northwest of this point	----	----
19. Contact between Chinle formation and Shinarump conglomerate. Contact conformable with local gradation and intertonguing of Chinle and Shinarump beds.	----	----
Shinarump conglomerate:		
18. Conglomeratic sandstone, light gray and mottled grayish purple, dusky purple, and dusky yellow; composed of fine to very coarse angular to well-rounded clear quartz and red chert grains in a silicified clay matrix and common black accessory minerals; firm siliceous cement; bedding structures not visible, lenticular bed. Unit contains disseminated pebbles; pebbles consist of translucent reddish-orange quartz and quartzite, clear quartz, and gray and red chert in decreasing order of abundance; pebbles well-rounded to angular and average about 1/2 in. in diameter. Mottling of unit probably due to iron and manganese stains. Unit forms local prominent ledge that extends about 300 yds. along outcrop.	3.0	3.0

Thickness (feet)

17. Contact between Shinarump conglomerate and Moenkopi formation. Contact marked by an abrupt change in lithologic characteristics at an erosional unconformity. Shinarump beds locally fill scours up to 3 ft. deep in the uppermost Moenkopi . . . . ---- ----

Moenkopi formation:

16. Siltstone, moderate brown to dark reddish brown; contains common very fine white mica flakes and quartz grains; slight carbonate cement; fissile to hackly weathering. Unit contains two beds similar to unit 15, one 6 ft. above the base and the other 46 ft. above the base, the higher one caps small points. Also many pale-green very fine-grained sandstone beds occur in unit. The sandstone beds occur in 1 to 3 in. thick and from 8 in. to 10 ft. apart. These pale-green sandstone beds give the unit a banded appearance. Unit forms steep bare slope. 118.5 291.0

15. Sandstone, light gray; very fine-grained; composed of clear quartz and abundant dark and white mica and black accessory mineral; firm calcareous cement; tabular bed, ripple laminations and some cusp-type ripples 6 in. long; flaggy weathering; unit forms irregular thin ledges, but is distinctive because of the gray flagstones 1.1 172.5

Thickness (feet)

14. Siltstone, pale brown to moderate reddish brown; unit poorly exposed 20.9 171.4

13. Sandstone, gypsiferous, pale brown, fine- to very fine-grained, poorly sorted; composed of clear and iron-stained quartz and eommon dark and white mica and black accessory mineral; weak calcareous cement, slightly friable, flat based bed, cross-laminated in lower part, horizontally laminated in upper part; grade upward into next highest unit. Caps long points at Clay Hills Pass 8.6 150.5

12. Siltstone and sandstone interbedded; siltstone, dark brown, slightly fissile,; sandstone, light brown, very fine-grained. Abundant dark and white mica in both siltstone and sandstone; sandstone is gypsiferous and siltstone contains abundant veinlets and nodules of gypsum. Unit horizontally bedded in 8 in. to 2 ft. beds. Unit forms vertical cliff to steep earthy slope 34.6 141.9

	Description	Thickness (feet)	
11.	Sandstone, light brown; fine-grained and slightly silty; composed of subrounded quartz, abundant black accessory mineral, and common dark and white mica; firm to weak cement, part gypsum and part carbonate cement; lower 15 ft. cross-laminated, upper 15 ft. is structureless; along outcrop upper 15 ft. grades to siltstone; unit has flat base. Along line of section this unit forms most prominent ledge in the Moenkopi	30.9	107.3
10.	Siltstone, like unit 8 except that unit 10 forms vertical cliff under sandstone ledge	33.0	76.4
9.	Sandstone, gypsiferous, white; fine- to very fine-grained, composed of clear rounded quartz and common black accessory mineral; friable, gypsiferous cement; tabular bed, stream type cross-laminations; unit forms minor ledge in basal shale slope of Moenkopi . . .	6.5	43.4
8.	Siltstone, moderate brown; contains abundant very fine quartz grains and local veinlets and beds of white gypsum; weak carbonate cement; horizontally bedded in beds 1/2 to 2 ft; some beds slightly fissile. This unit contains several 1 to 2 in. beds of grayish sandstone and greenish-gray claystone beds which give unit a banded appearance.	36.9	36.9

		Thickness (feet)	
7.	Contact between Moenkopi formation and Hoskinnini tongue of the Cutler formation. Contact apparently conformable and marked by slight change in lithologic characteristics	----	----

Hoskini tongue of the Cutler formation:

6.	Silty sandstone; pale reddish brown; predominantly very fine-grained and silt but contains fine and medium clear and iron-stained quartz grains; firm to weak carbonate cement; horizontally bedded, but individual beds contain contorted fine scale laminations; basal 6 ft. form a vertical cliff, upper 8 ft. form a ledgy slope which merges with the overlying Moenkopi slope.	14.7	109.8
5.	Mudstone, grayish red with abundant greenish-gray mottling in spots and streaks; composed of clay, silt, and very fine to medium sand grains; larger grains are rounded clear and iron-stained quartz; firm calcareous cement; bedding structures obscured; hackly weathering	2.1	95.1

	Thickness (feet)	
4. Sandstone, light greenish gray; very fine- to medium coarse-grained; composed of subangular to rounded clear quartz and common gray chert and feldspar grains and rare very fine-grained black accessory mineral; firm calcareous cement; contorted wavy bed and contorted thin laminations. Locally the sandstone grades into pure white gypsum and contortions may be due to crystallization of gypsum. Unit forms distinctive whitish zone in Hoskinnini cliff	1.0	93.0
3. Sandstone, pale reddish brown; poorly sorted, dominantly very fine-grained but extremely silty and contains disseminations and stringers of fine to coarse grains; composed of clear and iron-stained quartz and a few of the larger grains are gray chert and gray feldspar; slight decrease in size and relative abundance of larger grains towards top of unit; well indurated, but only slightly calcareous; abundant contorted ripple laminations which contain grayish-red clay films. Unit weathers to a vertical or steep ledgy cliff, ledges rounded and from 2 to 10 ft. thick.	92.0	92.0

Thickness (feet)

2. Contact between the Hoskinnini and Organ Rock tongue of the Cutler formation. Contact conformable and Hoskinnini is separated from Organ Rock only by larger grains which occur disseminated and as stringers in the Hoskinnini tongue . . . . ---- ----

Organ Rock tongue of the Cutler formation:

1. Sandstone, moderate reddish brown; very fine-grained. Organ Rock tongue not measured. . . . . ---- ----

Section of the Moenkopi formation and Hoskinnini tongue of the Cutler formation measured in secs. 3 and 4, T. 40 S., R. 14 E. Section measured by T. E. Mullens.

		Thickness (feet)	
Chinle formation:			
15.	Chinle formation not measured or described	----	----
14.	Contact between Chinle formation and Moenkopi formation. Contact an erosional unconformity. No scours present, but abrupt change in lithology and color and some fragments of Moenkopi siltstone included in the basal Chinle formation. Shinarump conglomerate not present	----	----
Moenkopi formation:			
13.	Siltstone, dark reddish brown, but weathers pale reddish brown. Unit contains numerous bands and streaks of pale-green mottling. Some siltstone beds have a concretionary type of weathering due to a higher sand content. Unit forms a steep rounded slope at base of Chinle formation.	93.7	336.0
12.	Siltstone, light brown; fissile; slightly calcareous cement; interbeds of light-gray very calcareous fine-grained sandstone, white gypsum, and greenish silty sandstone beds. Siltstone beds from 1 in. to 2 ft., other beds from 1 to 6 in. Unit forms strikingly horizontally-banded gentle slope	49.5	242.3

		Thickness (feet)	
11.	Sandstone, light brown to pale red; fine- to very fine-grained; poorly sorted, silty and common medium grains; composed of clear quartz with abundant cement; rare gypsum stringers up to 1/4 in. in thickness; lenticular beds, local scours up to 2 ft. in depth, local lenses of brown siltstone 3 ft. thick and up to 15 ft. long included in units. Some scour type laminations in basal 35 ft., upper 9 ft. has ripple laminations. This unit forms long bench in Moenkopi outcrop. Locally this unit contains dark brown rounded and angular clay blebs up to 5/8 in. in long diameter	44.0	192.8
10.	Sandstone, like unit 8.	43.0	148.8
9.	Sandstone, light brown; very fine-grained; poorly sorted, silty; composed of clear and iron-stained quartz grains and common black accessory minerals; weak gypsiferous cement; bedding structures not visible; basal contact flat. Unit forms rounded to vertical ledge. Along strike unit develops siltstone partings and upper part of unit is not easily recognizable	21.6	105.8

		Thickness (feet)	
8.	Sandstone, light brown; very fine-grained; poorly sorted, silty; slight calcareous cement; horizontal beds, ripple laminations; interbeds of pale-brown siltstone, greenish silty sandstone and white nodular gypsum. Unit forms horizontally banded vertical cliff	42.0	84.2
7.	Sandstone, very pale green; very fine- to fine-grained; poorly sorted; composed of clear subrounded to subangular clear quartz grains and abundant green and common black accessory minerals; friable, gypsiferous cement; lenticular bed; develops siltstone partings and disappears along strike; some scour type cross-laminations	4.5	42.2
6.	Siltstone, light grayish brown; clayey, abundant very fine quartz grains; slight calcareous cement. Thin (1 in. to 2 ft.) tabular beds with horizontal laminations, siltstone interbedded with white gypsum and moderate reddish-brown gypsiferous silty sandstone. Gypsum in beds up to 1 ft. thick. Unit contains abundant gypsum stringers. Siltstone is slightly fissile. Unit forms horizontally-banded vertical unit	37.3	37.7
5.	Gypsum, white, fine-grained; base of unit wavy. . .	0.4	0.4

Thickness (feet)

Cutler formation:

Hoskinnini tongue:

4. Sandstone, moderate reddish brown; very fine- to fine-grained; poorly sorted, silty, weak calcareous cement; composed of clear and iron-stained subrounded quartz grains and black accessory mineral and gypsum grains and small blebs; gypsum also present in 1/10 to 1/8 in. seams and stringers. Bedding generally obscured by slump, but some indications of ripple laminations. A 2 in. very light-green sandstone bed present 10 ft. above base of unit. Unit forms steep slope and weathers to small platy fragments 23.0 117.9

3. Gypsum, white; fine to coarsely crystalline; variable impure along strike. Locally contains abundant very fine to fine clear quartz grains and greenish-gray clay impurities. Tabular bed, basal surface slightly wavy. 1.9 94.9

Thickness (feet)

2. Silty sandstone, light brown, very fine-grained intermixed with abundant silt; composed of clear quartz, abundant subrounded to well-rounded fine to coarse grains, common black accessory minerals; and abundant white mica flecks; well-indurated, noncalcareous cement; larger grains are mainly clear and iron-stained quartz, common black and rare red grains; bedding slightly contorted, finely laminated ripple-type laminations. Spheroidal-type weathering, individual spheres up to 8 ft. in diameter; unit forms knobby vertical cliff . . 93.0 93.0

1. Contact between Hoskinnini and Organ Rock tongues of the Cutler formation. Contact apparently conformable and selected at lowest occurrence of coarser grains . . ---- ----

Organ Rock tongue of the Cutler formation:

1. Organ Rock not measured or described. . . . . ---- ----

Section of Hoskinnini and Organ Rock tongues of the Cutler formation, measured about 3-1/2 miles east of Clay Hills Pass. Section is about midway between Red House Spring and Clay Hills Pass. Measured by T. E. Mullens and H. A. Hubbard.

		Thickness (feet)	
Moenkopi formation:			
	Moenkopi not measured or described	----	----
11.	Contact between Moenkopi formation and Hoskinnini tongue of the Cutler formation. Contact apparently conformable and marked only by a slight change in composition and bedding characteristics.	----	----
Hoskinnini tongue of the Cutler formation:			
10.	Silty sandstone, pale reddish brown; composed of clear and iron-stained quartz, common white mica, and common black accessory mineral; contains common to rare fine, medium, and coarse rounded clear and iron-stained quartz and gray chert and feldspar grains; larger grains disseminated and in stringers; unit well indurated but only slightly calcareous; contains contorted ripple laminations bounded by grayish-red clay films; unit forms two rounded ledges separated by a 1 ft. dark reddish brown silty sandstone.	18.1	101.6

		Thickness (feet)	
9.	Sandstone, light greenish gray; medium-grained; composed of clear rounded quartz grains, common red chert grains, and rare very fine-grained black accessory mineral; firm calcareous cement and locally unit grades to a coarse-grained white limestone which contains medium and coarse rounded quartz grains; bedding structures contorted, some give wave-shaped contortions as much as 8 in. in amplitude; unit forms a distinct whitish band in Hoskinnini cliff	3.8	83.5
8.	Silty sandstone, pale reddish brown; composed chiefly of very fine-grained clear and iron-stained quartz, rare to common white mica flakes, rare black accessory minerals, and abundant fine to coarse subrounded to well-rounded clear quartz and gray chert and feldspar grains. About 90 percent of the larger grains are clear quartz, the remainder divided equally between chert and feldspar. Larger grains in laminar concentrations and disseminations; they decrease slightly in size and abundance from base to top of unit. Unit well-indurated, but contains only traces of carbonate cement. Bedding structures contorted and appear to be fine scale ripple laminations bounded by grayish red clay films. Unit forms nearly vertical smooth cliff with local patches of solution pit weathering	79.7	79.7

Thickness (feet)

7. Contact between the Hoskinnini and Organ Rock tongues of the Cutler formation. Contact apparently conformable and marked by an appearance of larger grains as disseminations and laminar concentrations and contorted and fine scale bedding . . . . ---- ----

Organ Rock tongue of the Cutler formation:

6. Sandstone, pale to moderate reddish brown; very fine-grained; silty, composed of iron-stained quartz, common white mica flakes, and rare black accessory mineral; well indurated but only slight carbonate cement; horizontally-bedded in beds 6 in. to 2 ft. thick with 1 to 6 in. very clayey and silty sandstone partings; hackly to rounded concretionary weathering; unit forms steep ledgy slope. Unit contains several beds like unit 5 which give a white banded appearance to slope. 86.0 327.5

5. Sandstone, yellowish gray; very fine-grained, well-sorted; composed of clear quartz, common red, green, and black accessory minerals, and rare white mica flakes; firm carbonate cement; unit forms lowest prominent light-colored ledge in Organ Rock tongue. 1.5 241.5

		Thickness (feet)	
4.	Sandstone and mudstone, dark reddish brown; sandstone, very fine-grained and slightly silty; mudstone, a mixture of very fine-grained sand, silt, and clay. Unit horizontally bedded in 1 to 10 ft. beds; forms ledgy slope, sandstone forms ledges, mudstone forms steep slopes. Unit contains numerous randomly oriented fractures bleached greenish gray in upper half	230.0	240.0
3.	Sandstone, moderate reddish brown; very fine-grained; poorly sorted, silty; composed of clear and iron-stained quartz and common white mica flakes, unit supports a 100-yd. wide bench in line of section	10.0	10.0
2.	Contact between the Organ Rock tongue and Cedar Mesa sandstone member of the Cutler formation. Contact placed at top of highest light-colored bed in the transition zone between the Cedar Mesa sandstone and Organ Rock tongue. Contact conformable with local gradation	----	----
Cedar Mesa sandstone member of the Cutler formation:			
1.	Sandstone, light brown. Cedar Mesa not measured or described.	----	----

<u>Section of the Hoskinnini and Organ Rock tongues of the Cutler formation measured about 2 miles northeast of Red House Spring. Section measured by T. E. and M. C. Mullens.</u>

	Thickness (feet)	
Moenkopi formation:		
Moenkopi formation not measured or described.		
12. Contact between Hoskinnini tongue and Moenkopi formation. No apparent unconformity at contact, but a slight change in lithologic characteristics. Moenkopi beds contain more mica, are ripple-marked, and are slightly fissile	----	----
Hoskinnini tongue:		
11. Sandstone, like unit 8 except that coarser grains are relatively rare and do not exceed medium in size	20.0	108.0
10. Sandstone, moderate reddish brown, contains scattered greenish-gray mottles; very fine-grained; poorly sorted, silty, scattered fine and medium grains; composed of clear and iron stained quartz grains; firm calcareous cement; hackly weathering.	3.9	88.0
9. Sandstone, white, very calcareous; mainly very fine-grained; but contains small lenses and disseminations of coarser grains; composed of quartz and accessory red chert; fine calcareous cement; contorted bedding, bedding wavy, but no scour at base, some waves up to 6 in. in amplitude; unit forms a thin white to gray band	1.1	84.1

Thickness (feet)

8. Sandstone and siltstone, moderate reddish brown; composed of clear and iron stained quartz with common black accessory minerals; abundant white mica, very rare red accessory mineral and abundant fine to very coarse quartz and chert grains; the larger grains are predominantly subrounded to rounded clear and iron stained quartz with minor subangular to subrounded gray chert grains; firm carbonate cement; bedding structures in unit not visible. Spheroidal-type weathering, individual spheres as much as 8 ft. in diameter. Unit forms lower part of prominent vertical cliff. This unit separated from Organ Rock on basis of weathering and abundant larger grains 83.0 83.0

Organ Rock tongue:

7. Siltstone, like unit 5 except it contains abundant very fine to fine iron-stained quartz grains; unit forms very ledgy slope, ledges 2 ft. to 8 ft. in height and angular to concretionary in shape. Ledges separated by lenticular partings of reddish-brown silty claystone. a 1 ft. zone like unit 6 at top of unit and a 2 ft. zone like unit 6, 5 ft. from top of unit 46.0 314.2

		Thickness (feet)	
6.	Sandstone, yellowish gray; very fine-grained, well-sorted; composed of clear quartz, common green and black accessory minerals, and common white mica flecks; firm calcareous cement	1.0	268.2
5.	Siltstone, moderate reddish brown; variably very fine-grained sandy and contains rare very fine mica flecks; well indurated, calcareous cement; horizontally bedded, individual beds inconspicuous except for several pale yellowish-green very fine-grained sandstone beds. Unit contains pale yellowish-green joint discolorations up to 2 in. in width but no preferred orientation noted. Unit separated from underlying unit by finer grain size and subtle color change . .	142.0	267.2
4.	Sandstone, dark reddish brown to moderate reddish brown, some greenish-gray mottling in streaks and spots; very fine-grained, variably silty; composed of clear and iron-stained quartz, common white mica flakes, and rare red and black accessory minerals; well indurated, slight to abundant calcareous cement; no bedding structures visible; hackly to platy weathering; unit forms steep slope with sandier zones making minor ledges. Break in topographic slope from slight benches to steeper slope 60 ft. above base of unit	95.0	125.2

	Thickness (feet)	
3. Sandstone, pale reddish brown; very fine- to fine-grained, poorly sorted, silty; composed of clear and iron stained subangular to well-rounded quartz grains, larger grains better rounded, rare red and black accessory minerals and white mica flecks; firm calcareous cement; tabular bed, no bedding structures visible; unit forms rounded ledge and caps minor points	2.0	30.2
2. Siltstone, dark reddish brown; contains abundant very fine quartz grains; well indurated, noncalcareous cement; bedding structures masked; hackly weathering; unit forms long gentle slope.	28.2	28.2
Contact between Organ Rock tongue and Cedar Mesa sandstone:		
Contact gradational vertically and laterally. . . .	----	----
Cedar Mesa sandstone member:		
1. Sandstone, very pale orange, weathers moderate orange pink; very fine- to medium-grained, poorly sorted; composed of angular to well rounded clear quartz with rare red and white accessory minerals, larger grains well rounded; firm calcareous cement; bedding structures masked; unit forms narrow bench.		
Cedar Mesa sandstone not measured	----	----

Thickness (feet)

Section of DeChelly sandstone member of the Cutler formation measured about 1/2 mile north of the north boundary of sec. 3, T. 41 S., R. 12 E. Section measured by T. E. Mullens and J. N. Taggart.

		Thickness (feet)	
Hoskinnini tongue of the Cutler formation:			
	Hoskinnini tongue not measured or described . . .	----	----
3.	Contact between the Hoskinnini tongue and the DeChelly sandstone member of the Cutler formation. Contact marked by a sharp break in color, change in bedding characteristics, and change in grain size	----	----
DeChelly sandstone member of the Cutler formation:			
2.	Sandstone, yellowish gray; fine- to medium-grained; composed of clear and iron-stained rounded quartz and common black accessory minerals; weak carbonate cement; unit cross-laminated with eolian type cross-laminations; basal 18 ft. form vertical ledge, upper 12 ft. form rounded ledge. East along outcrop the basal part of the DeChelly wedges out; the upper 5 to 10 ft. probably grade laterally into Hoskinnini tongue.	30.0	30.0
1.	Contact between the DeChelly sandstone member and Organ Rock tongue of the Cutler formation. Contact marked by change in bedding characteristics and a slight increase in grain size	----	----
Organ Rock tongue of the Cutler formation:			
	Organ Rock not measured or described.	----	----

Section of Organ Rock tongue of the Cutler formation and upper part (transitional unit to Organ Rock tongue) of the Cedar Mesa sandstone member of the Cutler formation, measured near west boundary of sec. 20, T. 40 S., R. 14 E. Section measured by J. H. Stewart and G. A. Williams. Section slightly modified by T. E. Mullens.

Thickness (feet)

Cutler formation:

Hoskinnini tongue of the Cutler formation:

11. Contact between Hoskinnini and Organ Rock tongues of the Cutler formation. Contact apparently conformable and placed at the base of the first unit containing disseminated larger grains . . . . ---- ----

Organ Rock tongue of the Cutler formation:

10. Siltstone, pale reddish brown; contains abundant very fine grains and locally grades into very fine-grained sandstone, argillaceous in parts; common mica; firmly cemented, calcareous and argillaceous cement; tabular unit of thin to very thick horizontal beds; weathers to form a steep slope and locally a vertical cliff. Thin beds of light greenish-gray siltstone occur at 13.5 ft., 29.5 ft., and about every 10 ft. above 221.4 ft. above base of unit. Rare thin bleached zone along fractures that cut bedding. Channel about ±20 ft. wide and 4 ft. deep noted at 210.0 ft. above base of unit. 354.5 394.4

Thickness (feet)

9. Siltstone (85%) and sandstone (15%). Siltstone, pale reddish brown and grayish red; contains abundant very fine grains and common mica; poorly sorted; firmly cemented, calcareous; stratification poorly developed but probably horizontally laminated and bedded; shaly splitting. Sandstone, pale reddish brown; fine- to medium-grained; composed of subrounded iron-stained quartz and rare black accessory minerals; firmly cemented, calcareous; thin to thick horizontal beds; flaggy to slabby splitting. Sandstone interbedded with siltstone. Unit as whole tabular; prominent sandstone ledge from 37.8 to 39.9 ft. above base of unit weathers to form gentle slope with common minor ledges 39.9 39.9

8. Contact between Organ Rock tongue and Cedar Mesa sandstone member of the Cutler formation. Contact is conformable and is placed at the top of the highest light-colored bed . . . . ---- ----

Thickness
(feet)

Cedar Mesa sandstone member of the Cutler formation:

Transitional interval between Organ Rock tongue and Cedar Mesa sandstone:

7. Sandstone, yellowish gray and pale reddish brown; fine-grained, fair-sorted; composed of subrounded clear quartz and rare black accessory minerals; firmly cemented, calcareous; tabular unit of medium scale cross-laminae in thin to thick horizontal beds; slabby to massive splitting; weathers to form ledges and prominent benches. Unit contains common grayish red, fine-grained, micaceous sandstone beds which are largely covered by rubble slopes. Color of sandstone varies along outcrop. Top 10.8 ft. weathers back into broad slope in interval that is probably highly argillaceous. Aphanitic limestone from 27.0 to 27.7 ft. forms prominent bench within unit 26.4 98.1

6. Sandstone, pale reddish brown and grayish red; fine-grained, argillaceous in parts; poorly to fair-sorted; abundant mica in parts; firmly cemented, calcareous; tabular unit of medium scale cross-laminae in thin to thick horizontal beds; flaggy to slabby splitting; argillaceous and nonargillaceous parts interstratified. 9.8 71.7

Thickness (feet)

5, Sandstone and argillaceous sandstone interstratified. Sandstone, predominantly light brown and minor very pale orange; fine- to medium-grained fair-sorted; composed of subangular clear quartz and rare orange and black accessory minerals; poorly to firmly cemented, calcareous; tabular unit, stratification poorly exposed but probably mostly medium scale, high angle cross-laminae; flaggy to massive splitting; weathers to form ledges and prominent benches. Rare irregular masses of limestone. Argillaceous sandstone, pale reddish brown and grayish red, very fine- to fine-grained, poorly sorted; abundant mica; firmly cemented, calcareous and argillaceous. Color and composition of beds vary along outcrop. Light-brown sandstone from 0.0 to 3.3 ft. above base of unit, 13.7 to 19.7 ft., 30.2 to 32.4 ft., 33.6 to 37.7 ft., and 38.2 to 42.4 ft. Very pale-orange sandstone from 8.8 to 13.7., and 19.7 to 29.7 ft. Argillaceous sandstone from 3.3 to 8.8 ft., 29.7 to 30.2 ft., 32.4 to 33.6 ft., and 37.7 to 38.2 ft. . . 42.4 61.9

		Thickness (feet)	
4.	Sandstone, yellowish gray; fine to medium-grained, fair-sorted; composed of subangular clear quartz and rare orange and black accessory minerals, rare limonite stains; poorly cemented, calcareous; tabular unit of medium-scale high angle cross-laminae; massive splitting; weathers to form rounded ledge	14.3	19.5
3.	Sandstone, dark reddish brown; fine-grained, fair-sorted; composed of subrounded clear quartz and rare black accessory minerals, argillaceous; firmly cememted, argillaceous; lenticular unit of low angle cross-laminae in thin to very thick horizontal beds; slabby to massive splitting; weathers to form prominent re-entrant in massive sandstone cliffs. Contains rare limestone masses.	5.2	5.2
2.	Contact between the upper part of the Cedar Mesa (transitional unit) and lower part of the Cedar Mesa (massive sandstone unit) placed at the base of the lowest red bed	----	----

Thickness (feet)

1. Sandstone, yellowish gray; fine- to medium-grained, fair-sorted; composed of subrounded clear quartz and rare orange, green, and black accessory minerals, common limonite spots; poorly cemented, calcareous; tabular unit of large scale cross-laminae; massive splitting; weathers to form vertical cliff. Rare irregular masses of limestone. Base of unit not exposed . . . .

CONTENTS

PART II

URANIUM RESOURCES OF THE RED HOUSE CLIFFS AREA, SAN JUAN COUNTY, UTAH

By Thomas E. Mullens

ABSTRACT

The Red House Cliffs area comprises 296 square miles of canyon and plateau country in southwestern San Juan County, Utah. The rocks that crop out in the area are mostly deposits of terrestrial environment and are of Permian, Triassic, Jurassic and Quaternary age.

No uranium minerals or places of abnormally high radioactivity are known in the Red House Cliffs area; however, empirical guides and geologic similarities of the Red House Cliffs area to the Monument Valley area indicate that 9,000 to 18,000 tons of ore containing an average of 0.15 to 0.20 percent U_3O_8 could be reasonably expected in the Shinarump conglomerate in the Red House Cliffs area. This appraisal is made on the basis that only 15 square miles of the area is underlain by favorable Shinarump.

A slight shift in the trend of the line separating favorable from unfavorable Shinarump could increase the potential of the Red House Cliffs area a hundredfold. This increase would be due to more ground being underlain by Shinarump and also a connection with more favorable Shinarump in the White Canyon area.

INTRODUCTION

Location and access

The Red House Cliffs area comprises 296 square miles in southwestern San Juan County, Utah (fig. 1). The area includes the following 7-1/2 minute quadrangles in the Clay Hills 30-minute quadrangle: Clay Hills 1 NW, 2 NE, 2 NW, 2 SW, and 2 SE. Part of the Red House Cliffs area is in T. 40 S., R. 14 and 15 E., and T. 41 S., R. 13, 14, and 15 E., Salt Lake base; the remainder of the area is unsurveyed land. The part south of the San Juan River is in the Navajo Indian Reservation.

The part of the Red House Cliffs area north of the San Juan River is reached by a graded dirt road which joins Utah State Highway 95, also a graded dirt road, about one-fourth of a mile west of the entrance to Natural Bridges National Monument. The north boundary of the Red House Cliffs area is about 8 miles by road south of this junction. Blanding, Utah, the nearest source of supplies, is 48 miles east on Utah 95 from this junction.

The part of the area south of the San Juan River is reached by an unimproved dirt road leading north from Oljeto, Utah, a trading post on the Navajo Indian Reservation. The south boundary of the Red House Cliffs area is 20 miles by road north of Oljeto.

Purpose

This investigation of the Red House Cliffs area is part of a regional geologic mapping program conducted by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. Primary objectives of the regional mapping program are: 1) to appraise the uranium resources of the main uranium-bearing formations in the Colorado Plateau, 2) to collect and interpret geologic data, and 3) to prepare geologic maps that show the distribution of uranium-bearing formations and geologic setting of uranium deposits.

The investigation of the Red House Cliffs shared the general objectives of the regional mapping program. Part II of the report presents conclusions on the uranium resources of the area.

GEOLOGY

The Red House Cliffs area comprises 296 square miles of canyon and plateau country in southwestern San Juan County, Utah. The rocks that crop out in the area are mostly deposits of terrestrial environment and are of Permian, Triassic, Jurassic, and Quaternary ages. The aggregate thickness of these rocks is about 3,500 feet. The distribution of the rocks is shown on figure 4.

The oldest formation exposed in the area is the Permian Cutler formation which is subdivided into three red bed tongues and two light-colored eolian-deposited sandstone members. These subdivisions, in ascending order are: the Halgaito tongue, the Cedar Mesa sandstone, the Organ Rock tongue, the DeChelly sandstone, and the Hoskinnini tongue.

The Moenkopi formation of Lower and Middle (?) Triassic age overlies the Cutler formation conformity. It ranges from 260 to 340 feet in thickness and is composed of a lower evenly bedded siltstone interval, middle cross-laminated sandstone intervals, and an upper evenly bedded siltstone interval. The Moenkopi is overlain unconformably by the Upper Triassic Shinarump conglomerate, or where the Shinarump is absent, by the Upper Triassic Chinle formation.

The Shinarump conglomerate consists of cross-laminated sandstone and conglomerate irregularly interbedded with mudstone, and it contains abundant carbonaceous material. The Shinarump conglomerate is well-developed only in the southwest part of the map area; northeast of a line trending northwest through Clay Hills Crossing the Shinarump is represented only by discontinuous lenses. The lenses of Shinarump conglomerate exposed northeast of Clay Hills Crossing consist of quartz, quartzite pebbles, and chert pebbles in a poorly sorted silty quartz sandstone matrix. Carbonaceous material is absent in these lenses. The Shinarump is separated from the Moenkopi formation by an erosional unconformity, and in several places in the southwest corner of the Red House Cliffs area this unconformity is marked by scours cut into the Moenkopi and filled with Shinarump sediments. These scours are important economically as they contain most of the known urnaium deposits in the Shinarump. The location of the basal scours exposed in the Red House Cliffs area is shown on figure 4, although no known uranium deposits occur in them. These scours range from 5 to 50 feet deep and 25 to 500 feet wide.

The Chinle formation ranges from 784 to 1,018 feet thick and is composed of sandstone, mudstone, variegated claystone, limestone, and calcareous siltstone. Based on dominance of rock types the Chinle can be subdivided into three divisions. These are a lower division of sandstone and mudstone; a middle division of variegated claystone, calcareous siltstone, and limestone; and an upper division of reddish-orange to reddish-brown interbedded siltstone and very fine-grained sandstone. Gradation and intermixing of rock types make the boundaries between divisions of the Chinle indefinite and ill-suited for mapping purposes. The Chinle conformably underlies the Glen Canyon group.

The formations of the Glen Canyon group include the Upper Triassic Wingate sandstone, the Jurassic (?) Kayenta formation, and the Lower Jurassic Navajo sandstone. The Wingate is a massive crossbedded sandstone; the Kayenta consists of irregularly bedded sandstone and siltstone; and the Navajo is a massive crossbedded sandstone which includes discontinuous lenses of limestone.

Quaternary deposits consisting of landslide blocks, terrace gravels, stream alluvium, alluvial fans, and dune sands are widespread in the map area. These deposits all lie unconformably on older rocks.

The Red House Cliffs area lies on the west and gently dipping flank of the Monument upwarp. Thus, the dominant structure of the area is a gentle westward dip. Locally the westward dip is interrupted by minor north-trending asymmetrical folds. Normal faults are associated with the eastward dipping limbs of the minor folds; and many joints are well exposed in the sandstone strata.

URANIUM RESOURCES

A primary purpose of this investigation was to appraise the uranium resources of the Red House Cliffs area. As no uranium minerals or places with abnormally high radioactivity were found in the area, appraisal of the uranium resources must be on the basis of habits of uranium deposits in similar geologic setting.

Uranium deposits on the Colorado Plateau have a wide stratigraphic range, but significant uranium deposits have been found only in a few stratigraphic zones. These zones include the Triassic Shinarump conglomerate and lower part of the Chinle formation, the Jurassic Morrison formation, and the Cretaceous Dakota and Mesaverde formations. Deposits in these formations all have similar habit; they are associated with stream-deposited sandstone which contains abundant carbonaceous material.

Among the formations exposed in the Red House Cliffs area only the Shinarump conglomerate and the lower part of the Chinle formation contain stream-deposited sandstone which contains carbonaceous material. Thus, these stratigarphic zones were thought most likely to contain uranium minerals and particular attention was given these zones during this investigation. All accessible outcrops of the Shinarump conglomerate and the lower part of the Chinle formation were examined systematically for uranium minerals and geologic features thought to be favorable for the accumulation of uranium minerals. Only the potential of these two zones will be discussed. No systematic search for uranium minerals was made in the other formations, although these formations were examined in many places in the course of geologic mapping.

Uranium ore associated with copper minerals occurs at several places in the Shinarump conglomerate in exposures 3 miles north of the Red House Cliffs area; and uranium ore associated with copper and vanadium minerals occurs at the Whirlwind mine in the Shinarump conglomerate about 200 yards south of the area in section 2, T. 41 S., R. 13 E. However, no uranium minerals or abnormally high radioactivity were observed in the Shinarump conglomerate exposed within the Red House Cliffs area.

Although no uranium minerals were observed, this does not indicate that uranium ore deposits are absent in the map area. To the present time, little is known about the origin and the manner of deposition of the uranium ore in the Shinarump conglomerate, but several empirical guides to uranium deposits in the Shinarump conglomerate have been established. According to Finch (1953) these guides to Shinarump ore deposits are: 1) most ore deposits occur in channels cut into the Moenkopi formation, 2) most ore deposits are associated with abundantly carbonaceous and irregularly bedded sediments, and 3) most ore deposits are associated with a regional margin of deposition of the Shinarump conglomerate. The Shinarump conglomerate exposed along the San Juan River is, on the basis of the empirical guides listed, a favorable host rock for uranium ore. Thus concealed uranium deposits may be present in some of the Shinarump channels (fig. 4) within the map area.

Empirical guides and geologic similarities with the Monument Valley area (Lewis and Trimble, report in preparation) to which the Red House Cliffs area must be compared for appraisal indicate that 3 to 6 deposits roughly comparable to the Whirlwind mine (3,000 tons at an average grade of 0.15 to 0.20 percent U_3O_8) could be reasonably expected to occur in the Shinarump conglomerate in the map area.

This appraisal is made on the basis that 1) the Shinarump lenses northeast of Clay Hills Crossing are unfavorable for uranium deposits as they contain no carbonaceous material, and 2) that the line separating favorable Shinarump from unfavorable Shinarump trends northwest through Clay Hills Crossing. This trend would allow about 15 square miles in the southwest corner of the map area to be underlain by favorable Shinarump. A greater potential, possibly by a factor of 100, must be assigned to the Shinarump in the map area if the line separating favorable from unfavorable Shinarump trends north or northeast through Clay Hills Crossing.

The greater potential, if the trend is north or northeast, is due to two factors. First, a north or northeast trend would allow about 150 square miles instead of 15 to be underlain by favorable Shinarump. Second, and more important, a north or northeast trend to the favorable Shinarump would allow a connection with the favorable Shinarump in Red Canyon to the north (Trites and others, in preparation). This would mean that at least some of the map area is underlain by Shinarump favorable for uranium deposits around 50,000 tons in size and 0.35 percent in contained U_3O_8.

The lack of known uranium minerals in the lower part of the Chinle formation in the map area, the relatively great distances to places where the lower Chinle is uranium-bearing, and the lack of knowledge about habits and origin of ore in the lower part of the Chinle formation preclude an appraisal of the uranium potential of the lower part of the Chinle in the map area; however, the author believes that the Chinle has little potential in the map area.

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