Geology of the Cedar Mesa-Boundary Butte Area San Juan County, Utah

GEOLOGICAL SURVEY BULLETIN 1186

Prepared in cooperation with the U.S. Bureau of Indian Affairs

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By ROBERT B. O'SULLIVAN

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GEOLOGY OF THE CEDAR MESA-BOUNDARY BUTTE AREA, SAN JUAN COUNTY, UTAH

By Robert B. O'Sullivan

ABSTRACT

The Cedar Mesa-Boundary Butte area lies within the Colorado Plateau and includes about 650 square miles in southern San Juan County, Utah. Altitudes ranges from 3,890 feet on the westward-flowing San Juan River, the major and only perennial stream, to more than 6,400 feet on Cedar Mesa in the northwest. Bare rocks, high mesas, sheer cliffs, and deep canyons characterize the area. Comb Ridge, a prominent hogback of eastward-dipping rocks, trends north through the middle part of the area and is the most conspicuous topographic feature. The only permanent settlements are Bluff in the east and Mexican Hat in the west, both on the San Juan River.

The area is underlain by Paleozoic rocks as much as 1,650 feet thick that range in age from Cambrian to Pennsylvanian; rocks of Ordovician and Silurian age apparently are not present.

The exposed consolidated sedimentary rocks range in age from Pennsylvanian to Jurassic and aggregate about 6,500 feet in thickness. In the western half of the area, rocks of Pennsylvanian age are exposed in the narrow canyon of the San Juan River. In areas adjacent to the canyon, rocks of Pennsylvanian and Permian age are widely displayed. Eastward near the hogback at Comb Ridge, narrow bands of progressively younger rocks of Permian and Triassic age crop out. Rocks of Triassic (?) and Jurassic age cover most of the eastern half of the area.

The oldest unit exposed in the Cedar Mesa-Boundary Butte area is the Hermosa Formation of Pennsylvanian age. In the subsurface it is 1,300–1,600 feet thick and as much as 1,000 feet crops out locally in the San Juan River Canyon. The Hermosa Formation consists mainly of gray cherty limestone that has some green and gray siltstone and sandstone. The Rico Formation of Pennsylvanian and Permian age conformably overlies the Hermosa and consists of 370–555 feet of red siltstone and interbedded gray sandstone and limestone. In the western part of the area, the McKim limestone of local usage forms the top of the Rico Formation, but eastward near Comb Ridge another limestone about 135 feet higher marks the top of the Rico.

The Cutler Formation of Permian age, about 2,000 feet thick, conformably overlies the Rico Formation and consists of, in ascending order, the Halgaito Tongue, Cedar Mesa Sandstone Member, Organ Rock Tongue, and De Chelly Sandstone Member. The Halgaito and Organ Rock are red-bed tongues. The Cedar Mesa is dominantly a light-colored sandstone in the western part of the area but grades eastward into a unit of gypsum, shale, and limestone containing minor beds of sandstone. The De Chelly thins markedly from about 400 feet in the south to about 50 feet in the north.

The Moenkopi Formation of Early(?), Early, and Middle(?) Triassic age is composed of dark-reddish-brown and buff siltstone and sandstone. It includes a lower member, the Hoskinnini, 20–50 feet thick and an upper unit 60–225 feet thick.

The overlying Chinle Formation of Late Triassic age is 956–1,130 feet thick. It comprises a basal member, the Shinarump, present only in the extreme southern part of the area and an upper part. For descriptive purposes the upper part of the Chinle is divided into four units—unit 1 at the base, pale-blue, brown, and pale-red shale; unit 2, pale-red shale, interbedded limestone, and reddish-orange siltstone; unit 3, two massive cliff-forming reddish-orange sandstones, present at the top of the Chinle Formation throughout most of the area; and unit 4, reddish-orange siltstone lying between the massive sandstones of unit 3 but present only in the southern part of the area. These units were not mapped.

The Glen Canyon Group of Triassic, Triassic(?), and Jurassic age overlies the Chinle Formation. It consists of the massive Wingate Sandstone, 265–340 feet thick, at the base; the thin-to-medium-bedded Kayenta Formation, 35–128 feet thick; and the massive Navajo Sandstone, 200–400 feet thick.

The San Rafael Group of Middle and Late Jurassic age overlies the Glen Canyon Group and consists of four formations. These are, in ascending order: (1) the Carmel Formation, 77–164 feet thick, composed of reddish-brown shale and interbedded sandstone; (2) the Entrada Sandstone, 66–150 feet thick, consisting of reddish-orange and reddish-brown sandstone; (3) the Summerville Formation, 146–162 feet thick, composed of thin-bedded dark-reddish-brown siltstone and shale and white and tan sandstone; and (4) the Bluff Sandstone, 34–338 feet thick.

The Morrison Formation of Late Jurassic age is the youngest consolidated sedimentary deposit exposed and is present chiefly in the northeastern part of the area. It has four members, which are in ascending order: (1) the Salt Wash Member, about 100 feet thick, composed of buff sandstone and grayish-red and green shale; (2) the Recapture Member, 285 feet thick, consisting of reddish-brown shale and buff sandstone; (3) the Westwater Canyon Member, 187 feet thick, composed of grayish-yellow sandstone and green shale; and (4) the Brushy Basin Member, 243 feet thick, consisting of variegated shale containing some sandstone.

Dikes and plugs of minette and volcanic vents containing tuff and agglomerate occur in three general areas. Two igneous features—Alhambra Rock and Boundary Butte—form prominent landmarks.

Deposits of Tertiary or Quaternary age as much as 60 feet thick, consisting of gravel and cobbles in a loose sandy matrix and generally capped by caliche, lie on an old erosion surface at altitudes of 5,000–5,300 feet at several localities in the southern and western parts of the area. Quaternary deposits include windblown sand, alluvium, and terrace gravels.

The area lies within parts of three large structural elements of the Colorado Plateau—the Monument upwarp, Blanding basin, and the Tyende saddle. Comb monocline trending northward through the middle part of the area separates the Monument upwarp to the west from Blanding basin and Tyende saddle to the east. These major structural features are interrupted by several northward and northwestward trending folds. Faulting is relatively unimportant, but one normal fault cuts the Cedar Mesa Sandstone Member of the Cutler Formation along Comb Ridge, and the maximum throw is an estimated 1,500 feet.

The search for mineral deposits within the area has centered around gold, uranium, oil and gas, carbon dioxide, and helium. At the present time (1962) the most important mineral resources are oil and gas.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The Cedar Mesa-Boundary Butte area (fig. 1) is in southern San Juan County in southeastern Utah. The area is bounded by long 109°30′ and 110° by lat 37° and is limited on the north by the line forming the northern boundary of T. 40 S., Rs. 17 through 22 E. (pl. 1). The rectangular area is about 27½ miles wide from east to west and about 23½ miles from north to south and includes about 650 square miles.

All the land south of the San Juan River is on the Navajo Indian Reservation. The only settlements are Bluff in the east and Mexican Hat in the west, both on the San Juan River.

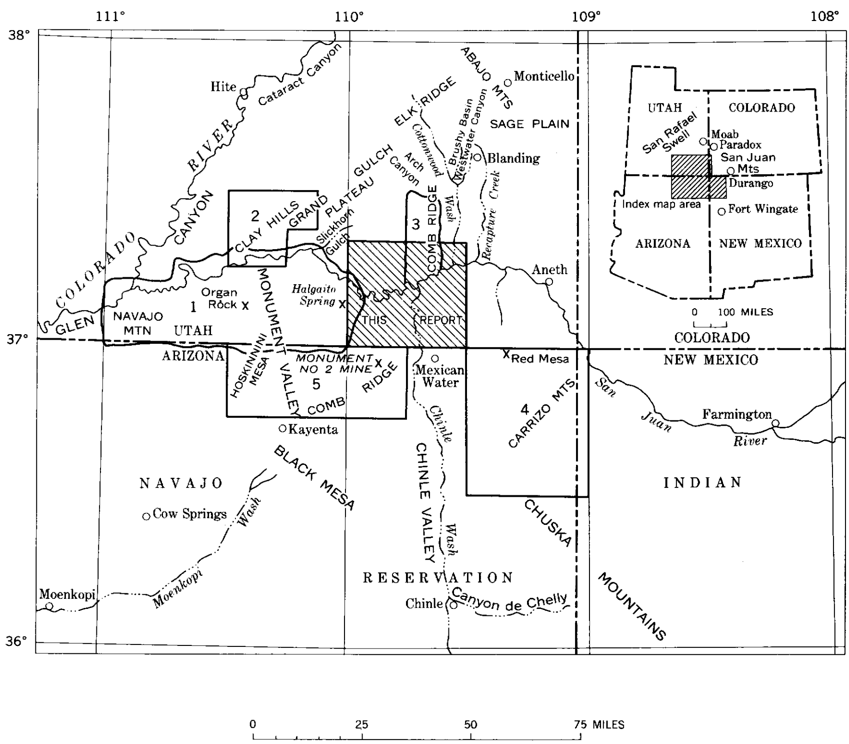

FIGURE 1.—Location of Cedar Mesa-Boundary Butte area. Other areas shown are: 1, Monument Valley-Navajo Mountain region (Baker, 1936); 2, Clay Hills area (Mullens, 1960); 3, Comb Ridge and vicinity (Sears, 1956); 4, Carrizo Mountains area (Strobell, 1956); 5, Monument Valley area, Arizona (Witkind and Thaden, 1963).

PRESENT INVESTIGATION

The present investigation of the Cedar Mesa-Boundary Butte area is part of a regional study of the geology, structure, and stratigraphy of selected parts of the Navajo Indian Reservation primarily designed to evaluate the organic fuel resources of the area. The present report describes the geology of one of the areas studied and also provides information that contributes to the knowledge of the geology of southeast Utah. The work was done on behalf of the U.S. Bureau of Indian Affairs.

The fieldwork on which this report is based was done primarily during the summer of 1958 and 6 weeks in 1960. In 1956 and 1957, short periods of time were spent in the area in conjunction with work in adjacent areas.

The geology was plotted on aerial photographs, furnished by the U.S. Soil Conservation Service, at a scale of 1:31,680. The base map was constructed, by means of slotted metal templates, from aerial photographs at a scale of about 1:60,000 furnished by the Army Map Service. Triangulation stations established by the Geological Survey and the U.S. Coast and Geodetic Survey were used for horizontal control in constructing the base map. The drainage, geology, and culture were transferred to the base map by means of a vertical projector. Section and quarter corners, recovered in the field, were located on the aerial photographs and transferred to the base map. Most of the land net shown on the geologic map (pl. 1), however, was constructed from township plats furnished by the U.S. Bureau of Land Management. Vertical control for the structure contours was obtained from a line of levels established by the U.S. Coast and Geodetic Survey near Utah State Highway 47 and from altitudes at triangulation stations in and near the area.

The geologic map (pl. 1) incorporates with some modifications the work of Sears (1956) along Comb Ridge north of the San Juan River. That part of the map north of 37°15′ and east and west of the region mapped by Sears represents reconnaissance mapping done by the author primarily to supplement geological observations in adjacent areas.

PREVIOUS INVESTIGATIONS

Gregory (1938, p. 2) and Baker (1936, p. 16–17) summarized the investigations prior to 1938 in this part of Utah and adjacent areas. Since 1938 several reports discussed the regional correlation of rocks present in the Cedar Mesa-Boundary Butte area. These reports are given in the bibliography. Other reports describing the areal geology of nearby areas are shown in figure 1.

ACKNOWLEDGMENTS

The author thanks the numerous officials of the Bureau of Indian Affairs for information and other general assistance. R. A. Robison assisted the writer in the field during the summer of 1958, and E. V. Stephens helped in the office compilation of structure contour data. J. A. Thomas determined the calcite-dolomite ratios of 51 samples of carbonate rocks. J. O. Hutchinson prepared the thin sections of microfossils examined by L. G. Henbest.

GEOGRAPHY

The Cedar Mesa-Boundary Butte area is within the Canyon Lands section (Fenneman, 1931, p. 306–317) of the Colorado Plateau province. Sheer cliffs, buttes, mesas, monoclinal ridges, and deep canyons characterize the Canyon Lands. These features are well displayed within the report area, which lies across the eastern flank of the Monument upwarp and parts of the adjacent Blanding basin.

The total relief is greatest near the western edge of the report area where it is about 2,500 feet. The altitude ranges from 3,890 feet on the San Juan River to more than 6,400 feet at the crest of Cedar Mesa. Most of the area falls within an altitude range of 4,050 feet (near Mexican Hat) to 5,400 feet. Three areas depart from this range—part of the San Juan River canyon downstream from Mexican Hat is lower and Raplee Ridge and Grand Gulch Plateau are higher.

Gregory, in two separate reports (1916 and 1938), divided a large region that includes the Cedar Mesa-Boundary Butte area into geographic districts. These districts (fig. 2) are adopted in this report except that the area south of the San Juan River and east of Comb Ridge is all included in the Gothic Mesas district. The districts shown are but parts of larger areas, and fuller descriptions may be found in several reports by Gregory (1916, 1917, 1938).

The main paved road that crosses the Cedar Mesa-Boundary Butte area is Utah State Highway 47. Another paved road, Arizona State Highway 64, crosses northern Arizona, connecting Shiprock, N. Mex., with Kayenta, Ariz., and passes a short distance south of the Utah-Arizona State line. Dirt roads leading from these two paved roads give ready access to most of the report area.

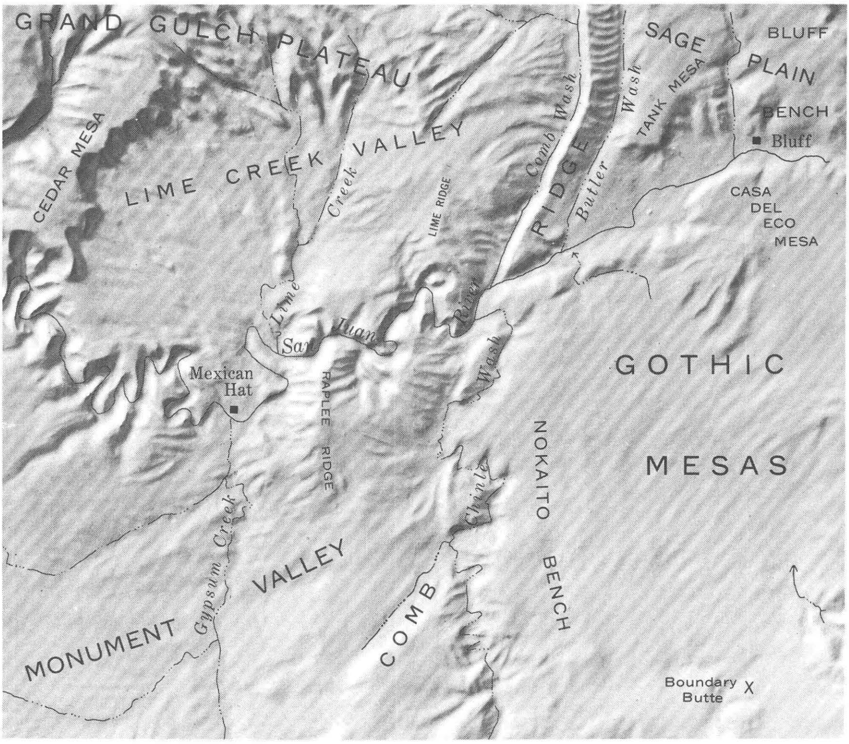

FIGURE 2.—Geographic districts of the Cedar Mesa-Boundary Butte area. A photograph of a part of the Army Map Service plastic relief map of the Cortez Sheet.

ROCK FORMATIONS

Exposed consolidated strata in the mapped area total about 6,500 feet in thickness and range in age from Pennsylvanian to Jurassic. The oldest formation exposed is the Hermosa Formation of Pennsylvanian age, and it crops out along the canyon of the San Juan River in the western part of the area. Successively younger rocks are exposed to the east, and the youngest consolidated sedimentary deposit—the Morrison Formation of Late Jurassic age—is exposed at places in the eastern part of the area. Igneous dikes and plugs of minette and related diatremes or volcanic vents pierce the sedimentary rocks at several places in the report area. Thin remnants of Recent alluvium, terrace gravel, windblown sand, and deposits of late Tertiary or early Quaternary age are present at several places throughout the map area. Sedimentary rocks in the subsurface between the Precambrian and the exposed Hermosa are as much as 1,650 feet thick and range in age from Cambrian to Pennsylvanian. Pennsylvanian and older rocks are prevailingly limestone and dolomite, but the younger rocks are clastics of a dominantly red color, although gray and tan colors are common.

The areal distribution of the rock formations is shown on plate 1. The succession, character, and thickness of the exposed rock formations are summarized in the generalized section given below.

Geologic units exposed in the Cedar Mesa-Boundary Butte area, San Juan County, Utah

System and series		Name		Thickness (feet)	Generalized description
Quaternary					Terrace gravel, alluvium, and sand dunes.
Quaternary or Tertiary				0–60	Tan and brown silty and shaly friable sandstone containing some interbedded conglomerate; commonly contains a caliche cap.
		Unconformity			
Tertiary		Igneous rocks and diatremes			Dikes and plugs of black minette and related diatremes or volcanic vents containing miscellaneous blocks of wallrock and at some places tuff and tuff breccia.
		Unconformity			
Jurassic	Upper Jurassic	Morrison Formation	Brushy Basin Member	100+	Variegated shale containing tan conglomeratic sandstone. Top not exposed in map area.
Jurassic	Upper Jurassic	Morrison Formation	Westwater Canyon Member	187	Grayish-yellow and yellowish-brown sandstone and interbedded light-greenish and light-olive-gray shale.
Jurassic	Upper Jurassic	Morrison Formation	Recapture Member	285	Dark-reddish-brown siltstone and shale with some interbedded buff sandstone.
Jurassic	Upper Jurassic	Morrison Formation	Salt Wash Member	50+	Grayish-orange and white sandstone and interbedded greenish-gray and grayish-red shale and siltstone. Exposed only near Boundary Butte.
Jurassic	Upper Jurassic	San Rafael Group	Bluff Sandstone	35–338	Massive buff sandstone, in part crossbedded.
Jurassic	Upper Jurassic	San Rafael Group	Summerville Formation	142–162	Dark-reddish-brown siltstone and shale with interbedded thin white and tan sandstone.
Jurassic	Upper Jurassic	San Rafael Group	Entrada Sandstone	66–150	Reddish-orange, reddish-brown, and buff sandstone and silty sandstone.
Jurassic	Upper Jurassic / Middle Jurassic	San Rafael Group	Carmel Formation	77–164	Dark-reddish-brown shale and interbedded reddish-orange sandstone.
			Unconformity		
Jurassic / Triassic(?)	Middle Jurassic	Glen Canyon Group	Navajo Sandstone	200–405	Massive grayish-orange and buff crossbedded sandstone, and some thin gray limestone beds.
Triassic(?)	Upper Triassic(?)	Glen Canyon Group	Kayenta Formation	35–128	Reddish-orange, white, and pale-red sandstone with some reddish brown shale.
Triassic	Upper Triassic	Glen Canyon Group	Wingate Sandstone	275–340	Massive reddish-brown and reddish-orange crossbedded sandstone.
Triassic	Upper Triassic	Chinle Formation	Undifferentiated	956–1,133	Unit 4: reddish-orange siltstone, present only in southern part of area. 3: reddish-orange sandstone and massive locally conglomeratic sandstone. 2: pale-red shale and sandstone and interbedded gray and pink limestone and conglomerate. Locally reddish-orange siltstone at top. 1: pale-blue and pale-red shale. Locally brown shale and buff thin sandstone near base.
Triassic	Upper Triassic	Chinle Formation	Shinarump Member	0–50	Buff conglomeratic sandstone. Present in southern part of area and pinches out northward.

Geologic units exposed in the Cedar Mesa-Boundary Butte area, San Juan County, Utah—Continued

System and series		Name		Thickness (feet)	Generalized description
			—Unconformity—		
Triassic(?) and Triassic	Triassic (?), Lower and Middle(?) Triassic	Moenkopi Formation	Upper unit	60–222	Brown even-bedded shaly siltstone and silty sandstone.
			Hoskinnini Member	20–48	Reddish-brown and white sandstone containing disseminated very coarse quartz grains; some thin interbedded siltstone.
			—Unconformity(?)—		
Permian		Cutler Formation	De Chelly Sandstone Member	53–395	Buff and reddish-brown crossbedded sandstone.
			Organ Rock Tongue	613–820	Even-bedded reddish-brown silty sandstone and sandy siltstone.
			Cedar Mesa Sandstone Member	496–870	In the northwest consists of buff massive sandstone and some interbedded reddish-brown siltstone. Along Comb Ridge it grades into variegated siltstone and shale and some buff sandstone, gray limestone, and gypsum.
			Halgaito Tongue	370–442	Reddish-brown siltstone and very fine grained silty sandstone and a few thin lenses of gray limestone.
Permian / Carboniferous	Pennsylvanian	Rico Formation		370–555	Fossiliferous gray cherty sandy limestone and buff limy sandstone in ledge-forming beds as much as 36 feet thick separated by generally thicker sections of reddish-brown siltstone.
Carboniferous	Pennsylvanian	Hermosa Formation		1,000+	Fossiliferous cherty limestone, buff sandstone, gray and greenish-gray siltstone and shale. Locally contains some white gypsum. Base not exposed in map area.

BURIED ROCKS

Rocks older than the Hermosa Formation of Pennsylvanian age are not exposed in the Cedar Mesa-Boundary Butte area. A few wells drilled for oil and gas in and adjacent to the map area, however, have penetrated the entire Pennsylvanian and underlying Paleozoic section. These wells show that below the Hermosa Formation is a sequence of rocks from 1,450 to 1,650 feet thick which includes rocks of Cambrian, Devonian, Mississippian, and Pennsylvanian age. So far as is known, none of the wells have penetrated rocks of the Ordovician or Silurian Systems.

CAMBRIAN ROCKS

Above the Precambrian in the Shell Oil Co. 1 Bluff Unit test well in sec. 32, T. 39 S., R. 23 E., about 9½ miles northeast of the town of Bluff, is 215 feet of pink and red fine- to coarse-grained conglomeratic and arkosic sandstone containing some interbedded dark-red and dark-green micaceous shale. In the Utah Southern Oil Co. 1 Noble test well in sec. 28, T. 40 S., R. 18 E. at Cedar Mesa, a unit of similar lithology is 290 feet thick. This sequence of rocks is here interpreted as a Cambrian unit and is believed to be continuous with the Ignacio

Quartzite exposed in the San Juan Mountains of southwestern Colorado. In the report area, the Ignacio was thought to be of late Middle or Late Cambrian age by Lochman-Balk (1956).

DEVONIAN ROCKS

In the San Juan Mountains of southwest Colorado, the Devonian is represented by the Elbert Formation and Ouray Limestone, both of Late Devonian age. In the subsurface of the Cedar Mesa-Boundary Butte area, Devonian rocks apparently rest on the Cambrian and are considered the correlatives of the Ouray Limestone and Elbert Formation (Bass, 1944, p. 4). The lower contact is drawn above the red arkosic sandstone assigned to the Cambrian, and the upper contact is placed at the highest shale bed or limestone bed containing conspicuous sandy or shaly clastic material. As thus defined, the Devonian rocks range in thickness from 730 to about 900 feet and include four distinctive lithologic units.

At the base is 104–265 feet of white, gray, and green fine- to coarse-grained sandstone containing some red and green micaceous shale. The sandstone is partly dolomitic and commonly glauconitic. The basal contact of this lower unit of Devonian rocks is drawn below the lowest glauconite-bearing sandstone.

The basal sandy glauconitic unit is succeeded by a sequence of pink, dark-gray, dark-brown, and black dolomite containing some green and black shale. Some of the shale is gypsiferous and carbonaceous. This dolomite and black shale unit is the Aneth Formation of Knight and Cooper (1955), and it ranges in thickness from 155 to 265 feet. In the Shell Oil Co. 1 Bluff Unit test well, fossils recovered from cores of this unit are characteristic of the Upper Devonian series (Knight and Cooper, 1955, p. 58).

The next overlying unit ranges from 37 to 120 feet in thickness. It consists of gray very fine to coarse-grained dolomitic and glauconitic sandstone containing interbedded light-colored sandy dolomite and a few green shale beds. This unit forms the McCracken Sandstone Member of the Elbert Formation of Knight and Cooper (1955).

The uppermost unit of Devonian rocks ranges from 245 to 370 feet in thickness. It consists of brown and buff generally sandy dolomite and limestone and a few beds of green and red shale. This uppermost unit contains the Ouray Limestone at the top. According to Knight and Baars (1957, fig. 1), the Ouray Limestone ranges from 35 to 75 feet in thickness within the report area.

Other geologists differ on the assignment of rocks that are here considered to be of Devonian age. At the Utah Southern Oil Co. 1 Noble test well, Lochman-Balk (1956, p. 64) assigned the entire section below the McCracken Sandstone Member and above the Precambrian to the Cambrian. She (Lochman-Balk, 1956, p. 63, fig. 3a) also showed that this section grades and rises stratigraphically eastward into the section below the black shale and dolomite unit present in the Shell Oil Co. 1 Bluff Unit test well. The basal sandy glauconitic unit placed with the Devonian rocks in this report has been assigned by others (Baars, 1958; Bass, 1944; Cooper, 1955; Clair, 1952) to the Cambrian or Devonian.

MISSISSIPPIAN ROCKS

Overlying the Devonian rocks and underlying the Pennsylvanian rocks is 280–460 feet of limestone and dolomite in which sandy or shaly clastic material is either absent or present in very small amounts. The limestone is white and brown and is in part cherty, oolitic, and fossiliferous. The green, brown, and gray dolomite is partly sucrose and vuggy. In adjacent areas of northeastern Arizona, the strata between the Devonian and Pennsylvanian rocks are assigned to the Redwall Limestone of Mississippian age (McKee, 1958, p. 74–77). The sequence of limestone and dolomite in southeastern Utah lying above the Devonian and below the Pennsylvanian appears to be similar to and continuous with the Redwall Limestone.

PENNSYLVANIAN ROCKS

The Hermosa Formation of Pennsylvanian age is exposed at the surface in the Cedar Mesa-Boundary Butte area, but in the subsurface between the Hermosa Formation and the underlying rocks of Mississippian age is the Molas Formation (Bass, 1944, p. 6), another distinctive formation of Pennsylvanian age. The Molas Formation ranges in thickness from 80 to 180 feet and forms an easily recognized unit in the subsurface. It consists of gray, purple, red, and maroon shale containing nodules of chert and limestone and some thin beds of buff and tan limestone. In the Shell Oil Co. 1 Bluff Unit test well, cores of the section below the lower part of the Molas Formation show that red shale and silt of the Molas fill cracks and small cavities in the top part of the underlying Mississippian rocks.

PENNSYLVANIAN SYSTEM

HERMOSA FORMATION

The name Hermosa Formation was applied by Cross and Spencer (1899, p. 8, and 1900, p. 48) to Pennsylvanian rocks in the San Juan Mountains of southwest Colorado. In the Mexican Hat area, Woodruff (1912, p. 81) named rocks considered to be of Pennsylvanian age the Goodridge Formation. Later, Baker and others (1927, p. 791) correlated the Hermosa Formation with the lower part of the Goodridge Formation. Still later, the name Hermosa Formation was extended into the Mexican Hat area and was applied to the lower part of the Goodridge, and the name Goodridge was abandoned (Baker and Reeside, 1929, p. 1415).

The Hermosa Formation is the oldest formation at the surface in the Cedar Mesa-Boundary Butte area but is not completely exposed. The formation crops out in the canyon of the San Juan River (fig. 3) in the western part of the report area but dips below river level near Mexican Hat. It reappears in Raplee and Lime Ridges east of Mexican Hat but again dips below river level near Comb Ridge. Within the report area, the gray slopes and sheer cliffs of the Hermosa Formation form the larger part of the canyon walls.

The Hermosa Formation consists dominantly of fine to very fine crystalline gray limestone. The limestone is laminated to massive and contains nodules of white, brown, gray, and black chert. Dark-gray and grayish-black chert generally is found in the lower part of the Hermosa and lighter colored chert commonly is present in the upper part of the formation. Red chert also occurs in the upper part of the formation and much of it coats fossils. The chert forms rounded or very irregularly shaped nodules disseminated through the beds or concentrated in zones parallel to the bedding. Nodules noted are as large as 20 by 4 inches, but most are 1–5 inches across. At places the chert forms lenticular beds as much as 20 feet long by 2 inches thick.

Interbedded with the limestone are minor amounts of gray, greenish-gray, and purple shale and siltstone. The shale and siltstone are in beds as much as 20 feet thick and commonly form slopes between limestone ledges. A few buff very fine grained sandstone beds are also in the Hermosa Formation.

Gypsum is in the lower part of the Hermosa Formation in Soda basin east of Mexican Hat. There the gypsum forms two beds separated by about 14 feet of dolomite. The lower bed is 37 feet thick and the upper is 6 feet thick. To the west, the gypsum pinches out and is not present at Honaker Trail.

This small outcrop of gypsum and dolomite exposed in Soda basin is equivalent to the Paradox Member of the Hermosa Formation. The Paradox was defined originally as a formation (Baker, 1933, p. 13) but was later reduced to a member of the Hermosa Formation in this area (Bass, 1944, p. 8). At the type locality in Paradox Valley near the town of Paradox, Colo., the member typically consists of beds of gypsum, anhydrite, salt, black shale, fine-grained sandstone, and gray limestone (Baker and others, 1933, p. 965). Although the Paradox Member in Soda basin is only about 55 feet thick, it thickens rapidly in the subsurface to the east and northeast. In the area near Moab, Utah, the Paradox Member is estimated to be 7,000–8,000 feet thick (Hite, 1960, p. 6–10).

The exposed strata of the Hermosa Formation can be divided roughly into three parts on the basis of topographic expression. At the base is a sequence of ledges and slopes that, viewed from a distance, forms one steep ragged slope. The lower part is about 275 feet thick in Soda basin and 250 feet thick at Honaker Trail. Calcite: dolomite ratios were computed from analyses of 24 samples of carbonate rocks from the lower part of the Hermosa Formation in Soda basin. These range from 100 : 0 to 24 : 76 and average 83 : 17. Of the samples, 11 are classified as limestone, 2 as magnesian limestone, 7 as dolomitic limestone, 3 as calcitic dolomite, and 1 as dolomite. The insoluble residues range from 2.6 to 37.8 percent of the sample and average about 17 percent.

The middle part of the Hermosa Formation forms a high sheer prominent cliff that contrasts with the slope formed on the lower part. The cliff consists of hard and soft beds that weather differentially and that give the cliff a jagged and banded or striped appearance. The middle part of the Hermosa is about 230 feet thick in Soda basin and 315 feet thick at Honaker Trail. Wengerd and Matheny (1958, fig. 5) applied the name Horn Point limestone to the upper 90–110 feet of this unit. Nine samples of the middle part of the Hermosa Formation were analyzed by the versenate method. These range from 100: 0 to 88: 12 and average 97: 3 in calcite: dolomite ratio. Of the samples examined, six are limestone, two are magnesian limestone, and one is dolomitic limestone. Insoluble residues range from 2.3 to 10.4 percent of the sample and average 7.3 percent.

Above the middle cliff-forming part of the Hermosa rises another steep ragged slope that continues upward to the top of the formation. This constitutes the upper part and is similar in topographic expression to the lower part of the Hermosa Formation. The upper part is 388 feet thick in Soda basin and 390 feet thick at Honaker Trail. Calcite: dolomite ratios of nine samples were determined by the versenate method. The ratios range from 100 : 0 to 93 : 7 and average 96 : 4 Four samples are classified as limestone and five as magnesian limestone. Insoluble residues range from 6.2 to 15.8 percent of the sample, averaging 10.5 percent.

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.

[Fossil determinations by L. G. Henbest, Helen Duncan, and E. L. Yochelson]

	Feet
Rico Formation.	
Hermosa Formation:	
86. Silstone and shale interbedded, gray; in beds 4–7 in. thick; siltstone nodular weathering in part, very limy; forms slight ledges; unit as a whole is nonresistant	10.0
85. Siltstone, greenish-gray, upper 3 ft grayish-red, very sandy, very calcareous; weathers into very thin (¼–⅛ in.) beds; contains a 1-ft pale-red limestone bed at 7 ft that forms ledge; unit as a whole forms slope	20.0
84. Sandstone, white, very fine grained, very calcareous, very irregularly bedded; forms ledge	2.2
83. Limestone, light-olive-gray, sandy, thinly (¼–½ in.) and irregularly bedded; weathers yellowish gray; forms slope	11.0
82. Limestone, medium-light-gray, slightly sandy, evenly bedded; weathers yellowish-gray; fossils sparse; in beds 3–6 in. thick	1.4
81. Limestone, gray, coquina; numerous fossils weather out and litter surface; unit forms slope; contains following fossils (USGS loc. 18051–PC):	19.5
Stereostylus sp.	
Lophamplexus? sp.	
Crinoid stems. undet.	
Tabulipora sp. (incrusting form)	
Derbyia crassa (Meek and Hayden)	
Linoproductus sp.	
Juresania nebrascensis (Owen)	
"*Dictyoclostus*" cf. "*D.*" *coloradoensis* (Girty)	
Hustedia mormoni Marcou	
Neospirifer dunbari King	
Composita subtilita (Hall)	
Composita sp.	
Punctospirifer osagensis (Shumard)	
Wellerella cf. *W. osagensis* (Swallow)	
Phillipsia sp. (identified by A. R. Palmer)	
80. Limestone, medium-gray, very fossiliferous; in beds 1–4 in. thick; oolitic in part; forms ledge; contains following fossils:	2.3
Calcitornellid foraminifer	
Endothyrid? foraminifer	
79. Sandstone and siltstone; lower half grayish-red siltstone, sandy and not calcareous; upper half yellowish-gray very fine to fine-grained very calcareous sandstone, containing limestone nodules and stringers of limestone; forms slope	4.5
78. Limestone, pale-red, very sandy; weathers medium tan; forms ledge	1.8
77. Poorly exposed; a ½ ft pale-red limestone at 3 ft forms slight ledge; upper 3 ft pale-red to reddish-brown siltstone; unit forms slope	8.0
76. Limestone, brownish-gray, very sandy; in ⅛-in. beds; forms ledge	3.5
75. Limestone, medium-light-gray; in 2- to 3-in. beds; forms ledge	2.6

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Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

	Feet
Hermosa Formation—Continued	
74. Limestone, medium-light-gray; weathers yellowish gray; forms small ledge	1.0
73. Limestone, light-olive-gray; in beds 2 in.–1 ft thick, bedding planes undulating; forms ledge	15.4
72. Limestone, medium-gray, very fossiliferous; wavy irregular bedding; contains following fossils (USGS loc. 18050–PC):	.5
Batostomella? sp.	
Linoproductus aff. *L. prattenianus* (Norwood and Pratten)	
71. Limestone, medium-dark-gray; weathers light-gray; in beds 3 in.–1 ft. thick; contains sparse dark-gray chert; large (as much as 8 in. across) pale-brown chert nodules in upper 2 ft; forms ledge	16.0
70. Limestone, medium-dark-gray; coquina in part; contains dark-gray chert nodules; contains following fossils (USGS loc. 18049–PC):	5.2
Dictyoclostid brachiopod, undet.	
Composita sp., undet.	
69. Limestone, dark-gray; nodular weathering; contains thin (1–2 in.) stringers of coquina	1.4
68. Limestone, medium-dark-gray; weathers yellowish gray; contains dark-gray chert nodules; fossiliferous in basal 1½ ft; forms ledge; contains following fossils:	8.0
Endothyra sp.	
Echinoderm ossicles, undet.	
Bryozoan fragments, undet.	
67. Limestone, dark-gray; weathers yellowish gray and forms a distinct light-colored band in cliffs; contains following fossils (USGS loc. 18048–PC):	2.1
Lophophyllidium sp.	
Linoproductid? brachiopod, undet.	
Composita subtilita (Hall)	
66. Limestone, light-gray, mottled dark-gray; in part weathers nodular; in beds 6 in.–1 ft thick except upper 2½ ft which is massive; dark- and light-gray chert nodules near middle; forms ledge; contains following fossil (USGS loc. 18047–PC):	7.4
Composita sp., undet.	
65. Siltstone, dark-gray; weathers yellowish gray; forms niche	.4
64. Poorly exposed; upper part a white very fine grained limy sandstone	11.0
63. Limestone, gray; basal 1.6 ft a coquina; middle 1.9 ft a massive cherty limestone; upper 1.3 ft in ¼-in. undulating beds; unit as a whole forms ledge	4.8
62. Poorly exposed; upper 4 ft a coquina; unit forms slope; contains following fossils (USGS loc. 18046–PC):	10.0
Rhombopora sp.	
Neospirifer cf. *N. dunbari* King	

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

Hermosa Formation—Continued *Feet*

61. Limestone, medium-dark-gray; in 6-in. undulating beds; contains following fossils (USGS loc. 18045–PC): 8.7
    - Crinoid stems
    - *Juresania nebrascensis* (Owen)
    - Dictyoclostid brachiopod cf. *Dictyoclostus* (*Antiquitonia*) *hermosanus* (Girty)
    - *Composita subtilita* (Hall)
60. Poorly exposed; appears to be sandy calcareous siltstone and very fine grained sandstone; unit forms slope 12.3
59. Limestone, light-gray; weathers white; contains abundant gray, brown, and white chert; contains following fossils (USGS loc. 18044–PC; f 12536): 10.2
    - *Earlandia perparva* Plummer
    - *Tetrataxis* sp.
    - Millerellid foraminifer
    - *Fusulina* sp. cf. *F. haworthi* (Beede)
    - *Neospirifer dunbari* King
58. Limestone, gray, coquina; poorly exposed; forms slope; contains following fossils (USGS loc. 18043–PC): 5.3
    - *Lophophyllidium* sp.
    - Crinoid stems, undet.
    - *Rhombopora* sp.
    - *Mesolobus mesolobus decipiens* Girty
    - *Neospirifer dunbari* King
    - *Composita* cf. *C. subtilita* (Hall)
    - *Hustedia mormoni* (Marcou)
    - *Punctospirifer kentuckensis* (Shumard)
57. Limestone, gray; a coquina in part; forms ledge; contains following fossils (USGS loc. 18042–PC; f 12535): 1.5
    - *Hyperammina* sp.
    - *Spiroplectammina* sp.
    - *Climacammina* sp.
    - Bradyinid foraminifer
    - *Globivalvulina* sp.
    - *Monotaxis* sp.
    - *Tetrataxis* sp.
    - Millerellid foraminifer
    - *Ozawainella* sp.
    - *Fusulina* aff. *F. knighti* Dunbar and Henbest
    - *Fusulina* aff. *F. lonsdalensis* Dunbar and Henbest
    - Crinoid stems, undet.
    - *Composita subtilita* (Hall)
56. Sandstone, buff, very fine grained, slightly calcareous; contains numerous subround ¼- to ½-in. limestone pebbles; a 2- to 3-in. limestone bed at base; unit forms ledge 5.7
55. Siltstone, grayish-red; poorly exposed; forms slope 9.0

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

	Feet
Hermosa Formation—Continued	
54. Sandstone, pale-yellowish-brown, very fine grained, calcareous; parallel and irregularly bedded in ⅛- to ½-in. beds; upper 1 ft a limestone containing organic remains that are probably algal; unit forms prominent ledge	11.3
53. Limestone and siltstone; lower half light-gray and very light brown sandy limestone, in beds ¼–1 in. thick; upper half pale-red siltstone having thin (less than 6 in.) white very fine grained lenticular sandstone; a 1-ft limestone bed 4 ft below top forms a ledge; unit as a whole forms slope	16.1
52. Limestone, light-gray; contains stylolites; a 6-in. coquina at base; unit forms ledge	8.4
51. Poorly exposed; appears to be olive-gray shale with a fossil zone in the middle; unit forms slope that is littered with fossils; some of fossils may be derived from base of 52; contains following fossils (USGS loc. 18040–PC):	8.0
Crinoid stems, undet.	
Fistulipora sp. (incrusting form)	
Prismopora cf. *P. triangulata* (White)	
Fenestella cf. *F. mimica* (Ulrich)	
Polypora sp.	
Penniretopora sp.	
Rhombopora sp.	
Rhombocladia cf. *R. delicata* Rogers	
"*Dictyoclostus*" cf. "*D.*" *coloradoensis* (Girty)	
Neospirifer dunbari King	
Composita subtilita (Hall)	
Phillipsia? sp. (identified by A. R. Palmer)	
50. Limestone, gray; in beds 6 in.–1 ft thick; upper 3 ft contains abundant light-gray chert that weathers dusky yellowish brown; contains following fossils (USGS loc. f 12534):	7.4
Tolypamminid? foraminifer	
Hyperammina sp.	
Earlandia perparva Plummer	
Spiroplectammina sp.	
Climacammina sp.	
Endothyra sp.	
Bradyina sp.	
Globivalvulina sp.	
Tetrataxis sp.	
Millerellid foraminifer	
Fusulina aff. *F. knighti* Dunbar and Henbest	
Fusulina aff. *F. lonsdalensis* Dunbar and Henbest	
49. Shale, light-olive-gray, slightly silty, noncalcareous; forms slope	4.9
48. Limestone, medium-dark-gray; in beds 6–14 in. thick	10.0
47. Poorly exposed; upper 1 ft is greenish-gray calcareous siltstone; unit forms covered slope	5.0
46. Limestone, medium-gray; weathers very light gray; contains abundant stylolites; forms prominent ledge	11.3

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

Hermosa Formation—Continued	*Feet*
45. Limestone, gray, very shaly; in beds 1 in. thick or massive; forms ledge	4.2
44. Limestone, medium-light-gray; weathers dark yellowish brown; forms ledge	1.3
43. Limestone, gray, very shaly; in beds 1 in. thick or massive; forms ledge	5.7
42. Limestone, medium-light-gray; weathers buff; forms ledge	2.0
41. Limestone, light-gray, shaly; forms niche	1.3
40. Limestone, medium-light-gray; weathers buff; forms ledge; contains following fossils (USGS loc. 18039–PC; f 12532):	3.7
Hyperammina sp.	
Fusulina rockymontana? Roth and Skinner	
Prismopora sp.	
Derbyia crassa (Meek and Hayden)	
Neospirifer dunbari King	
39. Limestone, medium-gray; weathers light gray, in irregular beds 2–3 in. thick; cherty and carbonaceous near top; upper 2 ft is light olive-gray siltstone; unit forms covered slope; contains following fossil (USGS loc. 18038–PC):	14.0
Crurithyris sp.	
38. Limestone, gray; dark-gray chert abundant at top; lower half forms reentrant, upper half forms ledge; contains following fossils (USGS loc. 18036–PC; f 12533):	4.3
Stony algae, undet.	
Nodosinella? sp.	
?*Trepeilopsis grandis* Cushman and Waters	
Plummerinella? sp.	
Spiroplectammina sp.	
Bradyinid sp.	
Monotaxis sp.	
Tetrataxis sp.	
Millerellid foraminifer	
?*Fusulina* aff. *F. lonsdalensis* Dunbar and Henbest	
Chaetetes cf. *C. milleporaceus* Milne-Edwards and Haime	
"*Dictyoclostus*" *coloradoensis* (Girty)	
Composita subtilita (Hall)	
37. Limestone, medium-light-gray; weathers moderate yellowish-brown; some dark-gray chert at top; a 1-ft niche in middle contains limestone nodules as much as 1 in. across in a very fine grained matrix; unit as a whole forms a ledge	6.8
36. Sandstone, light-gray, very fine grained, silty and shaly, very limy; in 1/8- to 1/4-in. beds; forms vertical recessed cliff between overlying and underlying units	4.2
35. Limestone, medium-light-gray, weathers pale yellowish brown; grayish-white cherty zone at top; unit forms ledge	4.4

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

Hermosa Formation—Continued *Feet*

34. Limestone, medium-dark-gray; weathers dark yellowish orange; spheroidal weathering; in beds 6 in.–1 ft thick; contains dark-gray chert nodules; distinctive marker bed; contains following fossils (USGS loc. 18035–PC): 30.8

Rhombotrypella sp.
Polypora sp.

33. Limestone, gray; thoroughly fractured by numerous cracks; in beds 4 in.–2 ft thick; chert very abundant in zones 7–8 ft thick at 70, 169, and 191 ft and at top of unit, otherwise chert sparsely distributed throughout unit; fossils are abundant in zones noted below, otherwise fossils are sparse; unit forms prominent cliff; contains following fossils (USGS loc. 18034–PC; f 12531): 231.0

(from 188 to 192 ft above base)

Nodosinella sp.
Hyperammina sp.
Minammodytes? sp.
Climacammina sp.
Endothyra sp.
Bradyina sp.
Globivalvulina sp.
Tetrataxis sp.
Millerella? sp.
Fusulina cf. *F. leei* Skinner
Caninoid corals, genus undet. (the decorticated fragments seem to represent a form with asexual increase cf. *Barbouria*)
Large gastropods, undet. (possibly euomphalaceans)

(from 167 to 169 ft above base; USGS f 12530):

Earlandia sp.
Climacammina sp.
Endothyra sp.
Bradyina sp.
Monotaxis sp.
Fusulina aff. *F. leei* Skinner

(from 68 to 70 ft above base; USGS f 12529):

Earlandia perparva Plummer, 1930
Climacammina sp.
Endothyra sp.
Bradyina sp.
Wedekindellina euthysepta? (Henbest)
Fusulina sp.
F. leei? Skinner

32. Limestone, gray; forms covered slope 6.0

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

	Feet
Hermosa Formation—Continued	
31. Limestone, light-gray; in beds 11–18 in. thick; contains grayish-black chert; forms ledge; contains following fossils (USGS loc. 18033–PC; f 12528):	10.0
Climacammina sp.	
Endothyra sp.	
Wedekindellina euthysepta (Henbest)	
W. excentrica (Roth and Skinner)	
Dictyoclostus (*Antiquitonia*) *hermosanus* (Girty)	
Neospirifer dunbari King	
30. Covered; forms slope	3.0
29. Limestone, light-gray, cherty; forms ledge	2.8
28. Covered; forms slope	7.0
27. Limestone, light-gray; contains sparse black chert; thoroughly fractured by small cracks; forms ledge	8.0
26. Limestone, light-gray; in beds about 4 in. thick; forms steep slope consisting of a series of ledges 1–2 ft thick	34.0
25. Dolomite, very light gray; silty; a 6-ft bed of gypsum at 7 ft; lower half forms ledge, upper half forms covered slope	30.0
24. Dolomite, buff, very fine grained, sandy, very slightly calcareous, friable; forms slope	7.0
23. Gypsum, white; forms covered slope	37.1
22. Limestone, buff; parallel bedded; in beds ¼–½ in. thick; forms slope	11.5
21. Dolomite, medium-light-gray; in beds 8 in. thick; forms series of ledges	5.0
20. Dolomite, buff, shaly; in beds 22–29 in. thick; forms ledge	7.6
19. Siltstone, dusky-yellow; parallel bedded; in beds ½ in. thick	17.0
18. Limestone and siltstone, interbedded in beds 10 in. thick; medium-gray limestone, weathers very light gray; dusky-yellow siltstone unit contains angular pebbles of limestone and siltstone from ¼ to ½ in. across	5.0
17. Limestone, medium-gray; in beds 4–5 in. thick; generally forms a covered slope; contains following fossils (USGS loc. 18032–PC):	5.0
Ramose bryozoans, undet. molds	
Marginifera muricatina Dunbar and Condra	
16. Limestone, light-gray; weathers dusky yellow; in beds less than ¼ in. thick; forms ledge	3.7
15. Limestone, light-gray; forms ledge; contains following fossils (USGS loc. 18031–PC; f 12527):	2.4
Lophophyllidium sp.	
Tolypamminid foraminifer	
Calcitornellid foraminifer	
Productid spine, undet.	
14. Siltstone, dusky-yellow, micaceous; not calcareous; irregularly bedded; contains 3–4 in. limestone near top	4.0
13. Covered; forms slope	3.0

Section of Hermosa Formation in Soda basin measured in secs. 33 and 34, T. 41 S., R. 19 E.—Continued

Hermosa Formation—Continued	*Feet*
12. Limestone, dark-gray; in beds ½–1 ft thick; undulating bedding; contains following fossils (USGS loc. 18030–PC):	10.5
Composita cf. *C. subtilita* (Hall)	
Crurithyris cf. *C. planoconvexa* (Shumard)	
11. Limestone, light-olive-gray to medium-dark-gray; in beds 1–3 ft thick; bedding irregular and undulating; contains some dark-brown chert; 1 ft coquina at base; also contains some interbedded gray siltstone in beds 3 in–2 ft thick; contains following fossils (USGS loc. 18029–PC):	17.2
Composita sp.	
Neospirifer cf. *N. cameratus* (Morton)	
Crurithyris sp.	
10. Limestone, gray; in beds ½–1½ ft thick; grayish-brown chert in lower 4 ft; forms ledge	6.5
9. Limestone, light olive-gray and interbedded medium-dark-gray siltstone; unit forms a niche	1.8
8. Limestone, medium-gray, massive; weathers dark yellowish brown; forms ledge	2.0
7. Limestone, medium-gray; irregular undulating bedding; unit forms ledge; contains following fossils (USGS loc. f 12526):	4.0
Earlandia perparva Plummer	
Calcitornellid foraminifer	
Plummerinella? sp.	
Endothyra sp.	
Bradyina sp.	
Tetrataxis sp.	
Millerellid? foraminifer	
Wedekindellina ellipsoides Dunbar and Henbest	
W. excentrica (Roth and Skinner)	
6. Limestone, medium-gray; in beds 1 ft thick; upper part contains abundant brownish-black chert; contains following fossil (USGS loc. 18028–PC):	4.1
Composita sp.	
5. Shale, grayish-yellow, silty, not calcareous; forms niche	4.0
4. Limestone, light-olive-gray mottled dark-gray; in beds ½–1 ft thick; forms ledge	2.0
3. Limestone, medium-gray; weathers buff; in beds 1–1½ ft thick; sparse chert; forms ledge	7.7
2. Limestone, medium-gray; in beds 1–1½ ft thick; forms ledge	6.1
1. Siltstone, light-olive-gray, laminated, noncalcareous; form niche	2.5
Total measured thickness of Hermosa Formation	896.3

Base of section at level of San Juan River. This is not total of Hermosa Formation.

The total exposed thickness of the Hermosa Formation ranges from 896 feet in Soda basin to 954 feet at Honaker Trail. Baker (1936, p. 19), reported a thickness of 1,020 feet about 3 miles downstream from Honaker Trail. In the Mexican Hat area, oil tests show that additional Hermosa Formation is present in the subsurface. Thus, the total thickness of the Hermosa in this area is 1,480 feet at the Kingwood Oil Co. 1 Lime Ridge test well (pl. 1) in sec. 28, T. 40, S., R. 20 E. and 1,495 feet at the Utah Southern Oil Co. 1 Noble test well in sec. 28, T. 40 S., R. 18 E. Farther to the east the Hermosa is 1,270 feet thick at the Ohio Oil Co. 1 Navajo test well in sec. 10, T. 43 S., R. 21 E. and 1,630 feet thick in the Carter Oil Co. 2 Navajo-Gothic test well in sec. 36, T. 40 S., R. 21 E.

The exposed Hermosa Formation contains abundant marine fossils of Pennsylvanian age. Fossils collected from the Hermosa in Soda basin are given in the preceding stratigraphic section. These fossils were examined and identified by L. G. Henbest, E. L. Yochelson, Helen Duncan, and A. R. Palmer.

Regarding the larger invertebrates, Duncan and Yochelson (written commun., 1959) stated:

The corals and bryozoans in general are types that commonly occur in the Middle Pennsylvanian of the Midcontinent and Rock Mountain regions. The material collected from beds in the upper part of the section where fusulinids were not found is not well enough preserved or sufficiently distinctive to tell whether strata of post-Des Moines age are present. According to Jeffords, *Lophamplexus* occurs mainly in the Missouri Series in the Midcontinent. A fragment questionably assigned to this genus was found in unit 81, the uppermost collection made.

The brachiopods are more difficult to use in assigning age, because in terms of the Midcontinent area, most of the common species seem to range through rocks from at least as old as Des Moines to as young as Early Permian. A Des Moines age is indicated for unit 17 containing *Marginifera muricatina* and for unit 58 containing *Mesolobus*. No precise age can be given for the younger beds, but none of this information available from the brachiopods is incompatible with a Des Moines age.

The foraminifers obtained from the same section were described by Henbest (written communication, 1959) as follows: Foraminifers from unit 7 to and including the first collection from unit 33 (from 68 to 70 ft above the base of that unit)

are characterized by the presence of advanced species of *Wedekindellina* and *Fusulina*. In the Mid-Continent and the Eastern Interior regions these assemblages lie near but below the middle of the Des Moines Series. These fossils characterize the top part of the marine sequence of the Hermosa at its type area, Animas Valley, San Juan Mountains.

The assemblages of Foraminifera from the middle collection of unit 33 (from 167 to 169 ft above the base of that unit) lack species of *Wedekindellina*, but the species of *Fusulina* do not seem to be younger than those that characterize the middle part of the Des Moines sequence of the central states. I am not sure at this time whether these Mexican Hat species are found in the type Hermosa.

The age significance of the fusulinids in unit 38 is hard to assess. Taken alone, without the aid of any other foraminifers or metazoans, they might be mistaken for species of early Missouri age. * * * Similar, problematic forms seem to lie within the *Fusulina*-zone in the Minturn-Climax area, Colorado, and at possibly two places in Wyoming.

The assemblages in units 50 to unit 59 indicate middle or possibly late Des Moines age.

The age of the fossils contained in unit 68

is not determinable closer than Late Mississippian to Permian inclusive.

On the basis of the fossils collected in Soda basin, the exposed Hermosa Formation for the most part contains rocks of Des Moines age in the Mexican Hat area. The 60–70 feet at the top of the Hermosa, however, apparently contains rocks of Missouri age. A coral questionably assigned to the genus *Lophamplexus* occurs about 50 feet below the top of the Hermosa Formation (in unit 81 of measured section) and indicates the possibility of rocks of Missouri age in that unit. Foraminifers collected in the upper part of the Hermosa in Soda basin are indeterminate as to age. The highest collection (from unit 80 of measured section) about 65 feet below the top of the Hermosa, was examined by Henbest (written communication, 1959), who stated:

This oolitic limestone contains a considerable number of specimens of a calcitornellid species of Foraminifera. Two specimens of an endothyrid(?) were seen. It is not determinable whether these fossils are of Paleozoic or later age.

Both Wengerd and Matheny (1958, fig. 5) and Welsh (1958, p. 155), however, reported *Triticites* sp. indicating rocks of Missouri age at about the same level as unit 80 but at Honaker Trail. Thus, the evidence appears strong that the upper 60–70 feet of the Hermosa Formation contains rocks of Missouri age.

The Mississippian and older Paleozoic rocks record a stable shelf area in southeastern Utah and adjacent parts of Colorado, New Mexico, and Arizona during their deposition. This stable shelf area was folded in Pennsylvanian time to form the Paradox basin (Baker and others, 1933, p. 978–980). The Cedar Mesa-Boundary Butte area is located along the southwest shelf of this basin. The Hermosa Formation in the report area consists dominantly of normal marine sedimentary rocks. Northeast of the report area near the central part of the Paradox basin, the deposition of normal marine rocks was interrupted by the deposition of the Paradox Member of the Hermosa Formation under conditions of high evaporation. Near Moab the Paradox includes as many as 29 separate beds of salt that form the saline facies (Hite, 1960, p. 6–7). The saline facies, an estimated maximum of 7,000 feet thick (Hite, 1960, p. 6), grades vertically and laterally to the southwest (toward the report area) into a penesaline facies of gypsum, dolomite, and black shale. The penesaline facies in turn grades southwestward into normal marine sedimentary rocks.

Part of this lateral gradation from penesaline to normal marine sedimentary rocks takes place within the Cedar Mesa-Boundary Butte area. At Soda basin, east of Mexican Hat, the lateral transition is represented in the lower slope-forming part of the Hermosa Formation. The calcite: dolomite ratios show that the lower part of the Hermosa is more dolomitic than the middle and upper parts. The average ratio determined for the lower part of the Hermosa classifies the rocks as dolomitic limestone, and the only dolomite determined by the versenate method is in the lower part. Where the lower part of the Hermosa is next exposed to the west at Honaker Trail no penesaline beds were noted.

The penesaline facies, in Soda basin, may be represented solely by beds of gypsum and dolomite (units 23, 24, and 25 of measured section), but other carbonate beds in the lower part of the Hermosa Formation probably represent an alternate fluctuation of normal marine and penesaline conditions. Because of the gradation of beds from penesaline to normal marine, it is difficult to draw a sharp border to the Paradox Member.

In Soda basin, the middle and upper parts of the Hermosa Formation record normal marine conditions. The average calcite: dolomite ratios of the middle and upper parts of the Hermosa classify the rocks examined as limestone. Along the San Juan River west of Mexican Hat, all the Hermosa Formation exposed apparently consists entirely of normal marine sedimentary rocks. One bed (unit 39 in measured section), however, may have been deposited under conditions other than normal marine. According to Duncan and Yochelson (written communication, 1959), "The abundance of *Crurithyris* in unit 39 and the absence of other fossils suggest that this collection may be from beds that were deposited under conditions possibly more brackish or hypersaline than those above and below." This is probably a local condition, however, not related to the Paradox Member of the Hermosa.

PENNSYLVANIAN AND PERMIAN SYSTEMS

RICO FORMATION

The Rico Formation conformably overlies the Hermosa Formation and is well exposed along the San Juan River Canyon east and west of Mexican Hat. The major part of the Rico Formation forms steep slopes and ledges in the canyon walls, but the upper 100–130 feet weathers back from the canyon walls and underlies large areas of Lime Creek Valley, Raplee Ridge, and the area west of Alhambra Rock.

The name Rico Formation was first applied by Cross (1899, p. 2) to a sequence of red beds exposed in the San Juan Mountains of southwestern Colorado. The Rico Formation was correlated (Baker and others, 1927, p. 794) with the upper part of the Goodridge Formation and the Supai (?) Formation (now Halgaito Tongue of Cutler Formation) as used by Miser (1924a, p. 121). Later, Baker and Reeside (1929, p. 1416) used the name Rico Formation in the Mexican Hat area rather than Goodridge Formation, which was abandoned. Baker (1936, p. 24–28) described the Rico Formation in greater detail in the adjacent Monument Valley-Navajo Mountain region.

The Rico Formation comprises thick slope-forming siltstone interrupted by eight or nine prominent ledges of limestone or sandstone. The thick siltstone units are prevailingly reddish brown, but individual beds are light gray, purple, and pale red and at places show very pale orange, gray, and purple mottling. Viewed from a distance, all colors except the reddish-brown are masked by slope wash. Individual beds within the siltstone units locally are well cemented by calcium carbonate and form slight ledges. Here and there, thin, less than 1½ feet, lenticular beds or irregular masses of reddish-brown and gray limestone are present. At places, chert and limestone nodules, commonly from 2 to 5 inches across, are found in thin beds in a siltstone matrix or scattered throughout the siltstone units. Locally, limestone nodules as much as 1 foot long by 1 inch thick with the long direction parallel to the bedding occur in the siltstone units. Siltstone units are commonly evenly bedded, but small-scale crossbedding is locally present. In most aspects the reddish-brown siltstone units are very similar to the overlying Halgaito Tongue of the Cutler Formation of Permian age.

Interbedded with the reddish-brown siltstone units are as many as nine prominent ledges of limestone or sandstone that form distinctive marker beds. One limestone, the stratigraphically highest bed of the Rico Formation, crops out only in the Lime Ridge area east of Mexican Hat. The other eight ledges can be traced throughout the Cedar Mesa-Boundary Butte area.

During the oil development in the years 1908–12, five of these ledges were named by drillers, and their position in the stratigraphic section was noted by Woodruff (1912, p. 93). In the area west of Mexican Hat the top of the Rico Formation is marked by a prominent persistent limestone that is widely displayed north and south of the San Juan River. The name McKim limestone, of local usage, has recently been applied to this bed (Wengerd, 1950, p. 778). In the area about 8 miles northeast of Mexican Hat another higher limestone is at the top of the Rico Formation. This limestone forms the surface of most of Lime Ridge and is here referred to as the A limestone. The position and names of these prominent ledges are shown in the following table:

Prominent persistent ledge-forming beds of the Rico Formation

Ledge-forming beds	Thickness (feet)	Thickness (feet) of red beds separating ledge-forming beds	Remarks
A limestone	0–5		Forms top in Lime Ridge area.
		130–136	
McKim limestone	3–20		Forms top on west side of Raplee Ridge and in area west of Mexican Hat.
		24–36	
Baby oil sand	4–13		
		16–40	
Goodridge oil sand	5–23		Exposed at bridge over San Juan River at Mexican Hat.
		24–43	
Unnamed bed	4–19		Forms rim at head of Honaker trail and underlies Goosenecks overlook.
		56–76	
Third oil sand	3–8		
		36–48	
Mendenhall oil sand	19–36		
		50–55	
Unnamed bed	8–27		
		17–48	
Little Loop oil sand	20–28		Forms base.

A bed, unnamed in this report, between the Goodridge oil sand of economic usage and the Third oil sand of economic usage, forms the rim of the canyon at the head of Honaker Trail and underlies the Goosenecks overlook. The name Shafer Limestone has been applied to this bed (Wengerd, 1955, fig. 8; Wengerd and Matheny, 1958, fig. 5). The name Shafer Limestone, however, has also been applied to a bed that marks the top of the Rico Formation over large areas in the Moab, Utah, district (Baker, 1933, p. 25, 26). Baars (1962) reported that the Rico Formation is of different ages in parts of the Moab district and near Mexican Hat. The correlation of the Shafer Limestone from the Moab district to the Mexican Hat area seems uncertain at this time, and the name is not used in this report.

The prominent ledge-forming beds (fig. 3) are fossiliferous and consist of limestone and sandstone. The limestone is gray and generally finely crystalline. At places, beds of coquina as much as 1 foot thick are present in the lower part of the Rico Formation. The limestone commonly is sandy and contains irregular masses of black and reddish-brown chert. The chert also occurs as a reddish-brown coating on many fossils. Generally all the limestone beds weather to a very rough surface.

Calcite: dolomite ratios of seven samples from the prominent ledge-forming beds, six from Soda basin and one from Honaker Trail, were examined by the versenate method, and all are limestones, having a ratio of 100: 0. All samples showed a trace of magnesium. The insoluble residue from the limestone examined is high, ranging from 9 to 32.7 percent, averaging about 24 percent.

The sandstone is white, weathering brown, and at places the smooth face of the sandstone is pitted with numerous small holes. It consists of very fine to fine grains of subrounded quartz. Bedding is generally parallel, but some small-scale low-angle crossbeds are present. The sandstone is generally well cemented by calcium carbonate and at places is coated with a thin rind of rough gray limestone, which appears to be a local weathering feature.

The ledges of interbedded limestone and sandstone locally contain thin lenses of reddish-brown and pale-red siltstone and shale. The prominent ledges range in thickness and composition from place to place. For instance, the Goodridge oil sand exposed at the bridge that carries Utah State Highway 47 across the San Juan River at Mexican Hat and in the area to the west is dominantly a prominent white sandstone. In Soda basin east of Mexican Hat, the Goodridge consists of interbedded limestone and sandstone. The next underlying prominent ledge forms a 20-foot limestone bed at the head of Honaker Trail but in Soda basin is a thin 4-foot bed of white sandstone. About 5 or 6 miles east of Soda basin the same bed thickens again to about 20 feet and consists of white sandstone with a 2-foot limestone at the base. Other ledges show similar variations from place to place, and these variations affect the porosity of the prominent ledges. Where the ledges are porous they are potential reservoirs for oil, and in the Mexican Hat area small amounts of petroleum have been recovered from them.

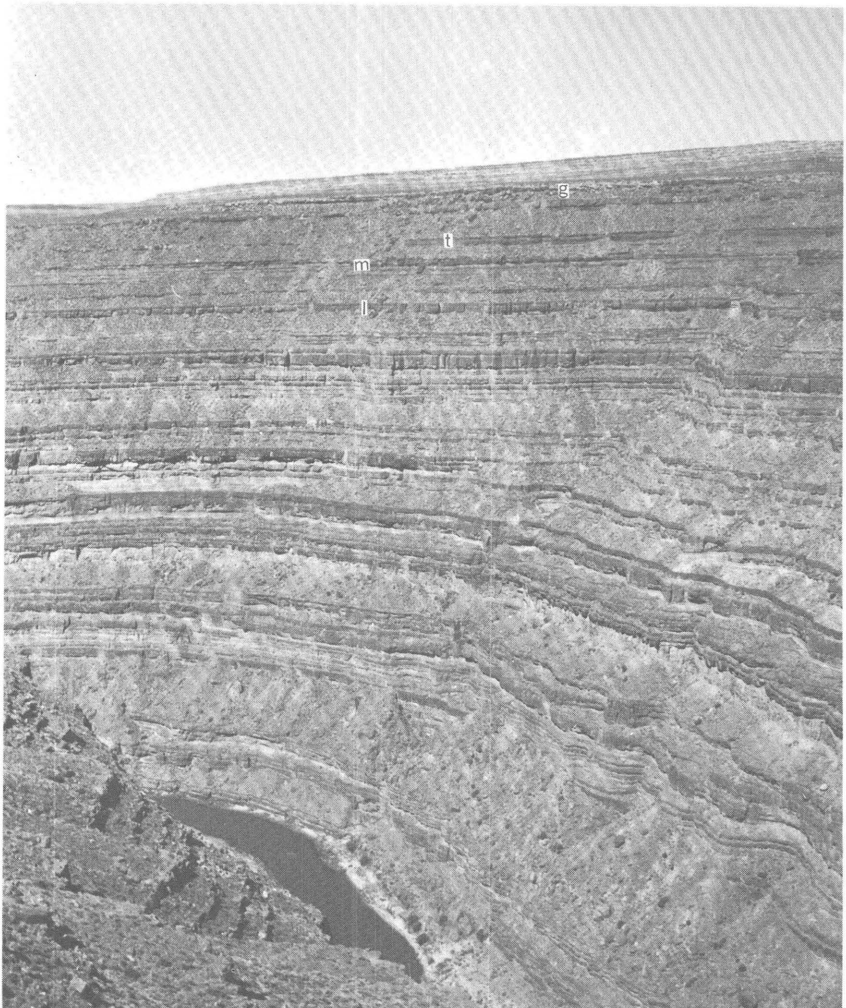

FIGURE 3.—Canyon of the San Juan River near Honaker Trail. Hermosa and Rico Formations form canyon wall. Douglas Mesa lying just west of report area on far skyline. Local ledge-forming economically important beds of Rico Formation include: Little Loop oil sand (l); Mendenhall oil sand (m); Third oil sand (t); and Goodridge oil sand (g).

Section of Rico Formation measured near Goosenecks overlook in secs. 33 and 34, T. 41 S., R. 18 E.

	Feet
Halgaito Tongue of the Cutler Formation.	
Rico Formation:	
17. Limestone, light-gray, thin and crinkly bedded; hackly weathering; forms ledge and bench (McKim limestone)	4.5
16. Siltstone, reddish-brown, calcareous; forms slope	22.0
15. Sandstone, light-gray, very fine grained, very limy; forms weak ledge	1.0
14. Siltstone, reddish-brown; forms slope	5.0
13. Sandstone, reddish-brown, very fine grained and silty, very calcareous; upper 3 ft contains hard interbedded gray limestone and white very fine grained sandstone; unit forms ledge; locally contains abundant echinoid spines (Baby oil sand)	8.0
12. Siltstone, reddish-brown; a 2½-ft pale-red limestone bed forms ledge at 20 ft; unit as a whole forms slope	30.0
11. Sandstone, white, very fine to fine-grained; in part very limy, weathers hackly with pitted surface, fossiliferous; changes thickness rapidly in this area; forms ledge and bench (Goodridge oil sand)	5.5
10. Siltstone, reddish-brown; poorly exposed; forms slope	30.0
9. Limestone, medium-gray, hackly weathering; sandy and having some coarse well-rounded grains; grades downward into a white hard pitted fine-grained sandstone; unit forms the bench at the Goosenecks overlook and the prominent ledge at the head of Honaker Trail	17.0
8. Siltstone, reddish-brown; poorly exposed; forms talus covered slope	65.0
7. Sandstone, white, fine-grained, pitted; forms ledge (Third oil sand)	3.0
6. Siltstone, reddish-brown; contains a 3-in. limestone bed at 20 ft; unit forms slope	45.0
5. Sandstone, white, very fine to fine-grained, calcareous, pitted; locally contains thin beds of reddish-brown siltstone and shale; also contains a 2-ft limestone bed at 4 ft; unit forms prominent ledge (Mendenhall oil sand)	27.8
4. Siltstone, reddish-brown and pale-red; forms slope	52.3
3. Limestone, light-gray, hard; sandy in upper part; forms ledge	9.0
2. Siltstone, reddish-brown; forms slope	25.0
1. Limestone, gray; weathers hackly; forms prominent ledge (Little Loop oil sand)	22.5
Total measured thickness of Rico Formation	372.6
Hermosa Formation.	

As stated previously, the McKim limestone, 4–6 feet thick, forms the top of the Rico Formation west of Mexican Hat. The McKim limestone passes below the level of the San Juan River near Mexican Hat and where it reappears on the west side of Raplee Ridge it is 10 feet thick. Eastward the McKim continues to thicken and at places consists of two limestone beds 5 feet thick separated by 5–8 feet of reddish-brown siltstone. At Lime Ridge the McKim limestone forms a wide bench above the canyon of the San Juan River. Resting on this bench is about 135 feet of red beds capped by another prominent limestone. This higher limestone—the A limestone—forms the top of the Rico Formation in the Lime Ridge area. Utah State Highway 47 crosses the A limestone from a point near Snake Gulch on the east to a point in the northeast part of T. 41 S., R. 19 E., on the west. The A limestone is fossiliferous and was considered the top of the Rico Formation in the area mapped by Sears (1956, p. 180 and pl. 17). The difference in the horizon selected as the contact between the Rico and Cutler in the area east and west of Mexican Hat has been noted by Sears (in Orkild, 1955; and Miller 1955). This difference in the selected top of the Rico Formation, east and west of Mexican Hat, is the result of intertonguing of the upper part of the Rico Formation and the lower part of the Halgaito Tongue of the overlying Cutler Formation. In the area of intertonguing, the top of the Rico Formation rises abruptly about 135 feet to the northeast.

Section of upper part of Rico Formation measured in sec. 17, T. 41 S., R. 20 E.

Halgaito Tongue of Cutler Formation.	
Rico Formation:	*Feet*
8. Limestone, gray, finely crystalline, hard; weathers hackly; forms ledge and surface of most of Lime Ridge; this is the A limestone	2.5
7. Sandstone, pale-red, very fine grained and silty; forms slope	8.0
6. Siltstone, reddish-brown; a 2-ft white fine-grained sandstone at 9½ ft; a 3- to 4-in. limestone caps a resistant ledge at 21 ft; unit as a whole forms a series of ledges and slopes	36.0
5. Siltstone, reddish-brown; forms a gentle slope	28.0
4. Siltstone, reddish-brown, very calcareous; forms a ledge	3.0
3. Siltstone, reddish-brown; forms a gentle slope	26.0
2. Sandstone, reddish-brown, very fine grained and silty, very calcareous; forms ledge	8.5
1. Siltstone, reddish-brown; forms gentle slope	27.5
Total measured thickness	139.5
McKim limestone of Rico Formation.	
Lower part of Rico Formation.	

Although less than 3 feet thick, the A limestone is remarkably resistant and forms the curved surface of most of Lime Ridge. In the Valley of the Gods it pinches out to the southwest along a northwestward-trending line passing roughly along the west fork of Lime Creek. On the east side of Lime Ridge the bed or its lateral equivalent can be traced through to the San Juan River in sec. 28, T. 41 S., R. 20 E.

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The A limestone is very fossiliferous within a quarter of a mile of the pinchout, but the fossils consist mainly of small pieces and fragments. The fossils were examined by E. L. Yochelson (written communication, 1961), who reported:

The abundance of shell fragments and the water-worn condition of many of them implies shallow water and suggests that this may have been a near beach accumulation. There are not enough shell fragments to make the term coquina acceptable, but a similar sort of environment is suggested. The abundance of mollusks and the absence of all other fossil groups except a small fragment of a bryozoan might indicate deviation from normal marine salinity, but this is at best a most tentative suggestion.

In the Valley of the Gods, the A limestone contains ¼–1-inch pebbles of reddish-brown siltstone typical of the Halgaito Tongue of the Cutler Formation. These pebbles are near the extreme southwest limits of the A limestone. Farther to the southwest beyond the limits of the A limestone as shown on the geologic map (pl. 1), a thin limy zone caps isolated outcrops. In this area, too, the lateral equivalents of the A limestone are very gypsiferous, and Lime Creek derives much of the gypsum, seen as white patches along the creek bottom, from this zone.

On the east side of Lime Ridge, from a point about 1½ miles north of the San Juan River, the A limestone can be traced into the northern part of sec. 28, T. 41 S., R. 20 E. Southward to the river the lateral equivalents of the A limestone consist of a zone of discolored purple siltstone, which contains limestone nodules and discontinuous thin lenses of limestone.

In the Cedar Mesa-Boundary Butte area, the Rico Formation thickens eastward. West of Mexican Hat the Rico Formation, from the base of the Little Loop oil sand of economic usage to the top of the McKim limestone, is about 370 feet thick, being 372 feet thick at the Goosenecks overlook, 375 feet thick at Honaker Trail, and 370 feet thick at Cedar Point. East of Mexican Hat the same section thickens, and the Rico Formation is 415 feet thick on the west side of Raplee Ridge. Where the A limestone wedges into the section, the Rico Formation is 555 feet thick.

In the area west of Mexican Hat, Baker (1936, p. 25–26) placed the boundary between the Hermosa and Rico Formations about 100 feet below the Little Loop oil sand. In the Lime Ridge area, Sears (1956, p. 179–180), judging from the thickness of the Rico (about 390 ft) and the description of the basal contact ("just below a conspicuous ledge of tan-weathering sandy limestone * * *"), apparently placed the boundary between the Rico and Hermosa Formations immediately below the Mendenhall oil sand of economic usage. In this report, the base of the Little Loop oil sand (fig. 3) was selected as the contact for two reasons: (1) the Little Loop oil sand is a conspicuous ledge that can be followed with certainty throughout the Cedar Mesa-Boundary Butte area and (2) the section above the Little Loop includes distinctive thick beds of reddish-brown siltstone. Similar reddish-brown beds in the Hermosa below the Little Loop are either absent or not prominent.

Beds assigned to the Rico Formation in this report were considered originally to be of Pennsylvanian age (Woodruff, 1912, p. 83). Later, Baker and others (1927, p. 792) placed the Rico Formation of southeastern Utah in the Permian. Henbest (1948) still later obtained fusulinids of Late Pennsylvanian age from the Rico Formation in the Moab area, and the Rico in southeastern Utah was subsequently assigned to the Pennsylvanian and Permian(?) (Platt, 1955). At the present time the Rico Formation is considered to be Pennsylvanian and Permian.

During this investigation, only a few fossils were collected from the Rico Formation because of the extensive collections made by Woodruff (1912) and Baker (1936). A small collection from the prominent ledge 110 feet below the McKim limestone at Cedar Point were determined by E. L. Yochelson as follows:

Composita sp.
Allorisma cf. *A. terminale* Hall
Myalina (?*Orthomyalina*) sp.
Bellerophontid gastropod, undet.

According to E. L. Yochelson (written commun., 1959): "None of the fossils are diagnostic as to Permian age, but by the same token none contradict this field assignment." Other fossils collected from the Rico Formation, stratigraphically below the McKim limestone, (Baker, 1936, p. 26; Woodruff, 1912, p. 83–85) also apparently are not diagnostic as to the exact age of the Rico Formation.

Fossils collected from the stratigraphically highest limestone of the Rico Formation, the A limestone, in sec. 28, T. 41 S., R. 20 E., were determined by E. L. Yochelson as follows (USGS fossil loc. 19947-PC):

Fenestrate bryozoan fragment, undet.
Permophorus? sp.
Bellerophon, sp.
Ananias? sp.
Paleostylus (*Pseudozygopleura*) sp.

According to E. L. Yochelson (written commun., 1961), the stratigraphic range of these fossils is Pennsylvanian(?). He further stated:

The faunal assemblage is characteristic of the Upper Pennsylvanian. However, all the fossils do occur in the Early Permian, and that age possibility cannot be ruled out until specifically identifiable material is found.

The Halgaito Tongue of the overlying Cutler Formation of Permian age interfingers with the Rico Formation in the Lime Ridge area, and, as a result, the age of the Halgaito has a bearing on the age of the upper part of the Rico Formation. Vertebrate remains collected by Vaughn (1962) in the Mexican Hat area indicate that the Halgaito Tongue probably contains rocks of Wolfcamp age. Other fossils of Permian age are present in the lower part of the Halgaito Tongue in the SW¼ sec. 26, T. 41 S., R. 17 E., a locality that lies just west of the Cedar Mesa-Boundary Butte area. These remains "* * * include a caudal vertebra of a pelycosaur, probably *Ophiacodon* or *Sphenacodon* * * *" (Baker, 1936, p. 30). According to the field notes of L. W. Clark, who worked as an assistant to A. A. Baker (1936) during the mapping of the Monument Valley-Navajo Mountain region, the fossil level is about 125 feet above the McKim limestone. Because the Rico Formation and Halgaito Tongue thicken eastward, the fossil horizon is considered to be at the same stratigraphic level as the A limestone, or somewhat higher.

Recent papers present a conflicting age assignment for the section that includes the upper part of the Rico Formation (to the top of the A limestone) and the basal part of the Halgaito Tongue of the Cutler Formation. Turnbow (1955, p. 66) considered the lower part [Halgaito Tongue] of the Cutler Formation to be of Pennsylvanian age. Wengerd and Matheny (1958, fig. 5) showed the upper part of the Rico Formation and the entire Halgaito Tongue to contain rocks of Virgil(?) age, and Kunkel (1958, p. 164) stated "Possibly part of the Halgaito tongue is also Pennsylvanian in age." Baars (1962, p. 154), however, considered the Rico Formation of this report area to be of Pennsylvanian age and the Halgaito Tongue to contain rocks of Wolfcamp age. Another view was presented by Dunbar (1960, p. 1786), who stated "In the Moab and San Juan River areas the Rico limestones carry Wolfcampian fusulines * * *."

In the light of these divergent views, the boundary between the Pennsylvanian and Permian cannot be placed accurately at this time in the Monument upwarp area. Until further paleontological work clarifies the age of this section, the Rico Formation is considered to be Pennsylvanian and Permian in age.

In the Rico Formation, the fossils found in the ledge-forming beds of limestone and sandstone indicate that marine conditions prevailed during their deposition. The interbedded reddish-brown siltstone, on the other hand, may be of fluviatile origin. According to Baker (1933, p. 29), similar reddish-brown siltstone beds, associated with marine beds, in the Rico Formation near Moab are of fluviatile origin. The reddish-brown siltstone beds are also lithologically similar to the siltstone of the Halgaito Tongue of the overlying Cutler Formation, and the Halgaito for the most part is considered to be of fluviatile origin.

The Rico Formation, apparently including most of the marine limestone and sandstone, extends into Arizona and pinches out on the De Chelly upwarp (Read and Wanek, 1961, pl. 2). In the Cedar Mesa-Boundary Butte area, the Rico Formation seems to have formed in a zone marked by alternate marine and fluviatile conditions. The highest marine bed (the A limestone), unlike the other marine beds, pinches out to the southwest within the report area. This indicates that near the end of Rico deposition the seas were restricted to the northeastern part of the report area.

PERMIAN SYSTEM

CUTLER FORMATION

The Cutler Formation was named by Cross and Howe (1905, p. 5) in the San Juan Mountains of southwestern Colorado. Later, in the Monument Valley area, Baker and Reeside (1929) defined as Cutler the sequence of rocks between the Rico Formation and the overlying Moenkopi Formation. Five members were delineated (Baker and Reeside, 1929, p. 1443); these are, in ascending order, Halgaito Tongue, Cedar Mesa Sandstone Member, Organ Rock Tongue, De Chelly Sandstone Member, and Hoskinnini Tongue. Baker (1936, p. 28–40) described the members of the Cutler Formation in greater detail in the Monument Valley-Navajo Mountain region which lies to the west of the present report area. Stewart (1959, p. 1854) has recently assigned the Hoskinnini Tongue to the overlying Moenkopi Formation of Triassic(?) and Triassic age. In the past, various names have been applied to rocks now called Cutler Formation in this area. The history of this previous usage is described by Baker and Reeside (1929) and by Gregory (1938, p. 37–40).

The Cutler Formation is relatively unfossiliferous, and no fossils were found in the formation during the present investigation. Vaughn (1962), however, has recently collected a small number of vertebrate remains from the Halgaito Tongue in the area near Mexican Hat. Regarding the collection, Vaughn (1962, p. 538) stated "In sum. the Halgaito tongue in the area collected from seems clearly to be of early Permian age, but greater in age than the Clear Fork group of northcentral Texas. * * * it seems probable that the Halgaito tongue in the vicinity of Mexican Hat, Utah is Wolfcampian in age." Baker (1936, p. 30–35) reported vertebrate and plant remains of Permian age from the Halgaito and Organ Rock Tongues in nearby areas. Based on regional correlations and fossils, the Cutler Formation is considered to be of Permian age (Baker and Reeside, 1929).

HALGAITO TONGUE

The Halgaito Tongue of the Cutler Formation was named by Baker and Reeside (1929, p. 1421) for Halgaito Spring just west of the report area on Monument Creek. The Halgaito Tongue includes the sequence of red beds between the Rico Formation and the Cedar Mesa Sandstone Member. Along the southwest flank of Raplee Ridge and along parts of the area near Comb Ridge, it crops out in a narrow band. Elsewhere in Lime Creek and Monument Valleys, the Halgaito is widely displayed. Where protected by the overlying Cedar Mesa Member it weathers to a steep slope (fig. 4) and in some areas forms the pedestals for such features as Mexican Hat Rock, Flag and Bell Buttes, the Rooster, and other monuments in the Valley of the Gods (pl. 1).

The Halgaito Tongue consists of an interbedded sequence of very fine grained silty sandstone and siltstone beds, all a characteristic reddish brown. At places, the beds are micaceous and mottled very pale green or greenish gray. Calcareous well cemented beds alternate with softer beds to form ledges, slopes, and benches. Viewed from a distance, the alternation of hard and soft beds gives the Halgaito a distinctive layered appearance. Thin lenticular unfossiliferous beds of light-gray limestone are widely dispersed throughout the sequence. Measured stratigraphic sections include as many as five such limestone beds, none more than 2 feet thick. A sample of one of these limestone beds examined by the versenate method showed a calcite: dolomite ratio of 100: 0, and it has 31.7 percent insoluble residue. Beds of conglomerate occur at different levels within the Halgaito. The conglomerates consist of subrounded pebbles of siltstone and limestone generally in a silty matrix. A bed of conglomerate at the base of the Halgaito in sec. 21, T. 41 S., R. 19 E. contains pebbles of limestone as much as 4 inches across. Gypsum is present as thin seams, in beds as much as 2 feet thick, or disseminated through the beds as a fine white powder. The gypsum is apparently limited to the area north of the San Juan River, as gypsum was not noted in the Halgaito south of the river.

The Halgaito Tongue above the McKim limestone of the Rico Formation is 393 feet thick at Cedar Point in the western part of the area, 372 feet thick in the lower reaches of Lime Creek in sec. 21, T. 41 S., R. 19 E., and 442 feet thick at Sugarloaf. In the northern part of the Lime Ridge area, the Halgaito thins where the A limestone bed of the Rico Formation wedges into the section. It is an estimated 240 feet thick in the Argo Oil Co. 1 Government Oak test well in sec. 9, T. 40 S., R. 20 E. Southeastward, the Halgaito again thickens above the A limestone, and along Comb Wash near Utah State Highway 47, Sears (1956, p. 181) and Gregory (1938, p. 42) recorded a thickness of 406 and 402 feet, respectively.

Section of Halgaito Tongue measured at Cedar Point in sec. 18, T. 41 S., R. 18 E.

Cedar Mesa Sandstone Member of the Cutler Formation.

Halgaito Tongue:	Feet
18. Siltstone, dark-reddish-brown, very calcareous	10.0
17. Siltstone, dark-reddish-brown; contains seams of gypsum in upper part	5.8
16. Siltstone, lower part pale-reddish-brown; mottled very pale green; upper part very pale green; contains pebbles of limestone and siltstone as much as 1 in. across	3.7
15. Siltstone, pale-reddish-brown; mottled very pale green; upper 2 ft contains thin (1/8 in.) seams of gypsum parallel to bedding	38.4
14. Siltstone, pale-reddish-brown; and conglomerate composed of limestone pebbles as much as 1/4 in. across; beds very lenticular	3.5
13. Siltstone, reddish-brown; contains scattering of limestone pebbles as much as 1 in. across; forms niche	2.5
12. Sandstone, very fine grained, and interbedded reddish-brown siltstone; bedding parallel and irregular; forms a series of ledges and slopes	181.1
11. Sandstone, reddish-brown, very fine grained; forms a ledge	14.0
10. Sandstone, reddish-brown, very fine grained, argillaceous; forms slope	19.0
9. Sandstone, reddish-brown, very fine grained, irregularly bedded; forms ledge	23.0
8. Limestone, light-gray, locally present	.5
7. Sandstone, reddish-brown, very fine grained; parallel beds in 1/4-in. laminae; argillaceous siltstone as much as 3 ft thick at base; entire unit forms slope	16.5
6. Limestone, very light gray; forms a bench on underlying unit	1.0
5. Sandstone, reddish-brown, very fine to fine-grained; forms series of ledges and slopes, irregularly bedded. Gypsum in lower part as seams and disseminated through lower part. Upper 2 ft contains light-brownish-gray limestone pebbles which weather out and litter slopes	27.0
4. Sandstone, reddish-brown, very fine grained; upper 5 ft well cemented and forms cliff, lower part forms slope	15.0
3. Sandstone, reddish-brown, very fine grained, well-cemented; forms ledge	3.0
2. Sandstone, moderate-reddish-brown, parallel-bedded in 1/4-in. laminae; forms series of ledges and slopes	4.0
1. Covered; appears to be reddish-brown sandstone and siltstone; at 18 ft a brownish-gray 3- to 4-in. limestone bed; unit forms gentle slope	25.0
Total thickness of Halgaito Tongue	393.0

Rico Formation.

The base of the Halgaito Tongue is sharp and easily recognized. It is placed at the top of the highest fossiliferous limestone bed of the Rico Formation. As previously mentioned, the highest limestone bed occurs at two different levels within the Cedar Mesa-Boundary Butte area. At Raplee Ridge and in the area to the west, the McKim limestone is at the top of the Rico Formation. In the Lime Ridge area, the A limestone, about 135 feet above the McKim limestone, is at the top of the Rico Formation. The A limestone pinches out to the southwest along a northwestward-trending line which roughly follows the west fork of Lime Creek. As a result, the base of the Halgaito is raised stratigraphically about 135 feet where the A limestone bed wedges into the section.

The Halgaito has yielded several terrestrial vertebrate fossils (Baker, 1936, p. 30; Vaughn, 1962, p. 531), which indicate that much of the Halgaito exposed on the Monument upwarp is of continental origin. According to Vaughn (1962, p. 531), the streams that deposited the Halgaito apparently drained northward, indicating a source to the south in Arizona. Near Grand Gulch Plateau, the exposed Halgaito contains scattered thin beds of gypsum that may be of marine origin, because farther north, near Cataract Canyon (fig. 1), the entire Halgaito grades into marine beds (Baars, 1962, p. 172). On the east side of the Monument upwarp, the Halgaito Tongue also grades into marine beds near Arch Canyon (fig. 1), about 16 miles north of the report area. North of a line roughly connecting Cataract and Arch Canyons open marine waters prevailed in central Utah.

The area east of the site of Comb Ridge was apparently slightly depressed with respect to the Monument upwarp area because the Halgaito in the subsurface includes much gypsum or anhydrite intercalated with red beds. The evaporites, represented by the gypsum or anhydrite, are considered to represent deposition in a restricted arm of the sea that flooded the area from time to time.

The restricted marine deposits of the Halgaito Tongue reflect a further regression of the marine waters in which the Hermosa and Rico Formations were deposited. Near the end of Rico deposition, as noted previously, the marine waters in which the A limestone was deposited covered only part of the Monument upwarp area, being restricted to the area northeast of Mexican Hat. During the deposition of the Halgaito, the marine waters were confined to the area east of the site of Comb Ridge.

CEDAR MESA SANDSTONE MEMBER

The Cedar Mesa Sandstone Member was named by Baker and Reeside (1929, p. 1421) for the flat divide extending southward between Lime Creek and Johns Canyon known as Cedar Mesa. Eastward from Cedar Mesa, the member forms the very prominent sheer cliff (fig. 4) overlooking Lime Creek Valley and caps features such as the Rooster and Setting Hen Butte in the Valley of the Gods. Farther south toward the San Juan River the Cedar Mesa Sandstone Member also forms the caprock of Mexican Hat Rock, Sugarloaf, Bell and Flag Buttes, and other picturesque erosional remnants. Along Comb Ridge the member forms a rather narrow outcrop belt on the steeply inclined east flank of the Raplee and Lime Ridge anticlines. West and southwest of Raplee Ridge, the Cedar Mesa Member floors an intricately dissected area near the southern part of the Mexican Hat syncline.

The Cedar Mesa Sandstone Member consists of two totally unlike facies—a sandstone facies present only in the area near Cedar Mesa and a gypsiferous facies.

As typically exposed on Cedar Mesa, the sandstone facies consists of a sequence that is dominantly sandstone (fig. 4) having minor interbedded siltstone. The sandstone is grayish orange, very pale orange, and yellowish gray and shows at places pale-reddish-brown and very light greenish-gray mottling. It consists of rounded to subangular very fine to medium quartz grains and minor accessory minerals and is generally well cemented by calcium carbonate. The sandstone occurs in thick prominent ledges as much as 125 feet thick that consist of individual beds from 5 to 35 feet thick. Many sandstone beds are cross laminated, and the inclination of the laminae is dominantly eastward (Read and Wanek, 1961, p. 7). Dark-reddish-brown, grayish-red, and pale-reddish-brown siltstone beds from 1 to 13 feet thick are interspersed between the sandstone beds. These siltstone beds at places are calcareous, micaceous, and mottled pale green. Locally there are thin beds of limestone or very fine grained light-colored sandstone. Limestone nodules from ¼ to 1 inch across are in the siltstone beds in the upper part of the Cedar Mesa Sandstone Member. The siltstone beds form reentrants between the resistant cliff-forming sandstone beds. Generally, they do not persist for any great distance and gradually thin laterally to niches between sandstone beds.

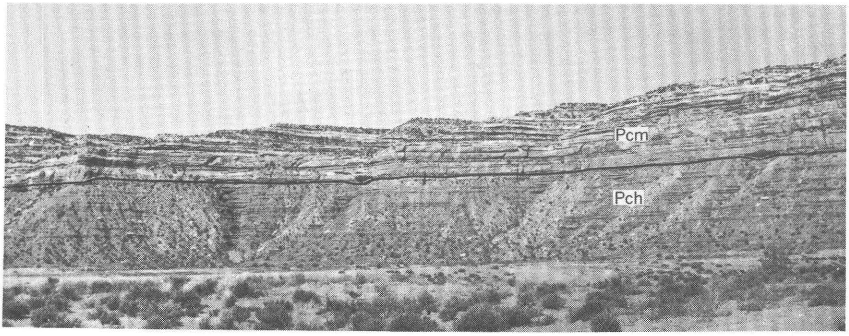

FIGURE 4.—East wall of Cedar Mesa. Halgaito Tongue (Pch) and Cedar Mesa Sandstone Member (Pcm) both of Cutler Formation. Top of Rico Formation forms flat in foreground.

Section of Cedar Mesa Sandstone Member of Cutler Formation measured at Cedar Mesa in secs. 28 and 33, T. 40 S., R. 18 E.

Cedar Mesa Sandstone Member of the Cutler Formation (sandstone facies): Top of measured section at top of Cedar Mesa, not top of Cedar Mesa Sandstone Member.

	Feet
23. Sandstone, grayish-orange, mottled-pale reddish-brown, fine-grained, crossbedded; forms cliff	65.0
22. Siltstone, dark-reddish-brown; scattering of small bits of limestone; contains lens of reddish-orange fine-grained sandstone	7.9
21. Sandstone, grayish-orange, very fine grained; forms cliff	52.0
20. Siltstone, dark-reddish-brown; forms steep reentrant, contains lenses of limestone	13.2
19. Sandstone, grayish-orange, fine-grained; a sandy reddish-brown siltstone bed 1.6 ft thick at 9 ft; forms cliff	31.0
18. Siltstone, dark-reddish-brown; has pale-green streaks; contains grains of limestone as much as ¼ in	3.8
17. Sandstone, grayish-orange, very fine to fine-grained, crossbedded in part; forms cliff	18.0
16. Sandstone, grayish-orange, very fine grained; forms cliff	15.0
15. Sandstone, grayish-orange, very fine grained; forms cliff; upper 3 ft contains irregular lumpy pieces of limestone as much as 1 ft in diameter	20.0
14. Siltstone, pale-reddish-brown; contains numerous tubular and tabular pieces of limestone; forms reentrant	4.5
13. Siltstone, dark-reddish-brown, mottled pale-green, sandy	3.8
12. Sandstone, very pale orange, cross-laminated; contains numerous caves, pits, and holes; forms cliff	32.0
11. Sandstone, grayish-orange; upper 2 ft reddish-brown mottled very light greenish gray; forms reentrant	14.0
10. Siltstone, reddish-brown, mottled pale-green, sandy and calcareous	4.0
9. Sandstone, grayish-orange, mottled and streaked with pale reddish-brown, very fine grained, cross-laminated; forms a ledgy cliff	45.5
8. Siltstone, grayish-red; disappears to south in about 300 ft	1.6
7. Sandstone, yellowish-gray, fine-grained, slightly calcareous, massive, parallel-bedded; forms ledge	5.0
6. Siltstone, pale-reddish-brown, calcareous; forms reentrant	13.0
5. Sandstone, grayish-yellow, very fine to medium-grained; sorting good; calcareous; parts of unit friable; crossbedded and parallel-bedded; forms a ledgy cliff	123.0
4. Siltstone, pale-brown, micaceous, calcareous; in upper 3 ft a pale-green fine-grained sandstone	13.0
3. Sandstone, pale-brown, fine-grained, massive; forms ledge	21.0
2. Sandstone, grayish-red, very fine grained and silty, very hard but not calcareous; thins northward in about 200 ft to a niche	3.0
1. Sandstone, grayish-orange, very fine grained, well-sorted, calcareous; lower 6 ft very pale green; in lower 1½ ft mottled dark reddish brown and pale reddish brown; unit forms cliff	42.0
Total thickness	551.3

Halgaito Tongue of the Cutler Formation.

The sandstone facies of the Cedar Mesa Sandstone Member is preserved only in the northwestern part of the area and in remnants capping erosional features near Mexican Hat. The original total thickness of the sandstone facies in the report area is not known, although 550 feet was measured along Utah State Highway 261. In adjacent parts of the Grand Gulch Plateau, Sears (1956, p. 183) estimated that the sandstone facies is 825 feet thick. Farther north near Elk Ridge, where the upper contact is visible, the Cedar Mesa Sandstone Member is as much as 1,100 feet thick (Lewis and Campbell, 1959). According to Baker (1936, p. 32), the Cedar Mesa is approximately 500 feet thick in the Monument Valley-Navajo Mountain region. Mullens (1960, p. 270) reported a thickness of about 700 feet in the Clay Hills area 15 miles west of Cedar Point. The last three figures cited are all considered to represent thicknesses of the sandstone facies.

Sears (1956) mapped and described a "lower soft" part of the sandstone facies, which is locally present and contrasts markedly with the typical sandstone facies of the Cedar Mesa Sandstone Member. This "lower soft" part at the base of the sandstone facies occurs in parts of Road Canyon in secs. 3 and 4, T. 40 S., R. 20 E. and in other canyons farther north. As described by Sears (1956, p. 183–184), the "lower soft" part, about 130 feet thick, consists of a soft zone of shale and fine-grained sandstone, in part gypsiferous, and several thin beds of gypsum. Three thin beds of limestone are also present and the uppermost limestone contains irregular masses of red chert. The "lower soft" part is not exposed at the base of the Cedar Mesa Sandstone Member in the cliffs overlooking Lime Creek Valley.

A somewhat similar sequence, however, is present along the northwest side of Raplee Ridge at the base of isolated buttes capped by the Cedar Mesa Sandstone Member. At the butte in the northwest part of sec. 21, T. 41 S., R. 19 E., the soft sequence is about 100 feet thick and consists of shale, siltstone, and very fine grained sandstone. One thin bed of limestone is also present locally. These beds are a lighter color than the underlying Halgaito Tongue and here and there are gypsiferous. Red chert occurs at places, and bedding is parallel or massive. This lower softer zone forms a steep slope and is overlain by remnants of cliff-forming grayish-orange crossbedded sandstone in all respects similar to typical Cedar Mesa exposed at the type locality near Cedar Point. At Mexican Hat Rock, the beds of the sandstone facies form the "brim" of the hat and rest on the softer zone. Farther south beyond the San Juan River the typical sandstone facies grades into the gypsiferous facies, and the lower soft part of the Cedar Mesa cannot be separately recognized.

Eastward the sandstone facies of the Cedar Mesa grades into a gypsiferous facies, which is present along Comb Ridge and in the area south of the San Juan River. The zone of transition, about 1 mile wide, was described by Sears (1956, p. 184) as follows:

A larger scale and even more striking departure from the usual lithology of the Cedar Mesa sandstone member is found to the southeast. This is clearly seen within the crude triangle of Cedar Mesa outcrops approximately bounded on the east by the Mormon Trail road, the northwest by the longest branch entering Road Canyon from the southwest, and the south by a line drawn due east from the head of that branch. Within this triangle and in the narrow belt of outcrops southward to the river, the whole Cedar Mesa is a series of very soft pastel-colored rocks that bear virtually no resemblance to the typical series of thick resistant sandstones in the escarpment and canyons to the northwest. Unfortunately, the great lateral change in lithology toward the southeast cannot be followed or studied in detail, bed by bed, because the drainage in relation to the structure (nearly horizontal beds under the upland and steep easterly and southeasterly dips nearer Comb Wash) has served to erode most of the Cedar Mesa within the transition belt. However, that transition belt must be only a mile or so wide and must extend in a northeasterly direction on the northwest side of the crude triangle described above; and the change must occur rapidly toward the southeast within the belt.

Southward from the zone of transition the gypsiferous facies of the Cedar Mesa Sandstone Member is totally unlike the typical exposures of the member near Cedar Point. Near Comb Wash and south of the San Juan River the gypsiferous facies consists dominantly of siltstone and shale and subordinate amounts of sandstone, gypsum, and limestone. The member is soft and weathers to a series of mounds and gentle slopes, although here and there a resistant ledge forms a minor hogback. The general land surface, developed on the gypsiferous facies in this area, is intricately dissected by a veinlike network of streams. The subdued light-pastel colors of the gypsiferous facies contrast sharply (fig. 5) with the dark reddish brown of the overlying and underlying units.

The siltstone and shale are reddish orange, light brown, and light reddish brown and here and there show light-gray or light-green spots and streaks. The sandy and shaly siltstone occurs in beds as much as 60 feet thick and at places contains thin very fine grained sandstone beds. South of the San Juan River the minor sandstone beds are grouped roughly in the lower half of the gypsiferous facies. They are reddish orange, light reddish brown, and buff, and at places are streaked or spotted light green or reddish brown. The sandstone consists of very fine to fine well-sorted subangular to subrounded grains of quartz and minor accessory minerals. At places a few subrounded to rounded grains of limestone are present. The sandstone generally occurs in beds less than 10 feet thick, although locally beds are as much as 26 feet thick. Most of the sandstone beds are soft and friable, but here and there the beds are well cemented by calcium carbonate and form small ridges and ledges. Some sandstone shows no bedding structures, whereas other is parallel bedded or crossbedded. Where parallel bedded, the sandstone is generally laminated in beds ⅛–½ inch thick.

As many as seven limestone beds are in sections south of the San Juan River, and most occur in the lower part of the gypsiferous facies. The limestone is gray, generally sandy, and here and there contains interbedded reddish-brown or light-green siltstone or white gypsum. The laminated limestone beds range in thickness from ½ foot to about 5 feet and contain ⅛–1-inch laminae. Locally, white very fine grained sandstone replaces the limestone laterally. The limestone beds in the lower part of the gypsiferous facies contain masses of a distinctive reddish-brown chert. The thin irregularly shaped chert lying on bedding planes occurs in masses as much as 2½

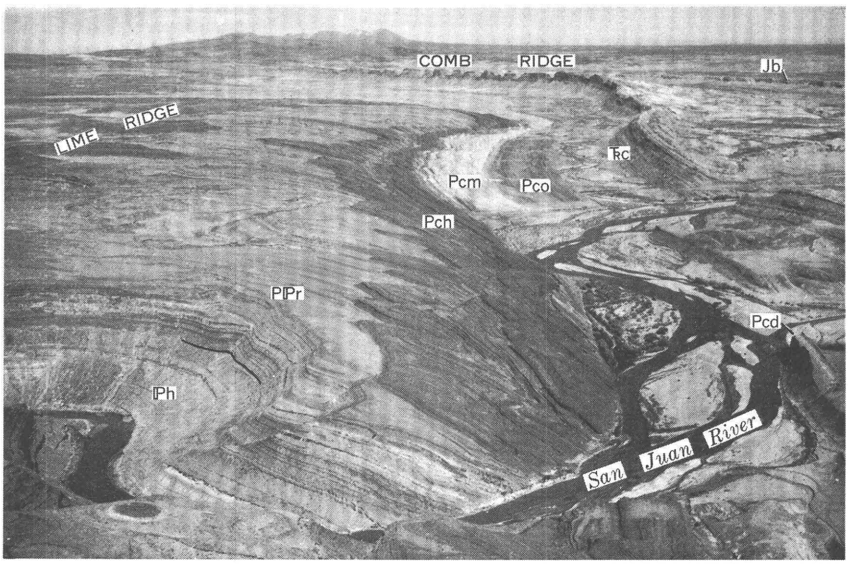

FIGURE 5.—Aerial view northward across San Juan River. Abajo Mountains in far distance with Sage Plain extending to right. Hermosa (Ph) and Rico (P Pr) Formations exposed in canyon of San Juan River at left. Formations of the Glen Canyon Group form Comb Ridge. Halgaito Tongue (Pch), gypsiferous facies of Cedar Mesa Sandstone Member (Pcm), Organ Rock Tongue (Pco), De Chelly Sandstone Member (Pcd), all of the Cutler Formation; Chinle Formation (TRc); and Bluff Sandstone (Jb). Photograph by V. C. Kelley.

feet wide by 4 feet long. Chert is present in the upper part of the gypsiferous facies but is generally white and is not everywhere associated with limestone beds.

As the name implies, gypsum is abundant in the gypsiferous facies of the Cedar Mesa Sandstone Member. It forms beds as much as 5 feet thick, seams that crosscut the sedimentary rocks, and nodules as much as 4 inches across. It is also disseminated throughout some sandstone and siltstone beds as a fine white powder. Impure beds of gypsum as much as 32 feet thick, containing thin lenses and grains of siltstone and shale, are present south of the San Juan River. Sears (1956, p. 186) reported an impure sandy bed of gypsum that is 82 feet thick in the area north of the river.

Section of Cedar Mesa Sandstone Member of Cutler Formation, measured 1½ miles north of south border of mapped area

Organ Rock Tongue of Cutler Formation.	
Cedar Mesa Sandstone Member (gypsiferous facies):	*Feet*
71. Shale, reddish-brown; with a pale-reddish cast; forms slope	16.0
70. Sandstone, reddish-brown, very fine grained, hard; forms ledge	1.5
69. Shale, reddish-brown to reddish-orange; forms slope	9.0
68. Sandstone, reddish-brown, very fine grained; silty at top and bottom, pale-red shale in middle	4.0
67. Covered; forms slope; unit is gypsiferous	42.0
66. Limestone, light-gray; forms ledge	.8
65. Siltstone to very fine grained sandstone, reddish-orange, gypsiferous	25.0
64. Sandstone, reddish-orange, fine-grained, slightly gypsiferous; forms slight ledge	5.0
63. Gypsum, white; containing minor amount of reddish-brown shale	.9
62. Limestone, pale-red, interbedded; reddish-brown shale and gypsum	1.2
61. Gypsum, intermixed with reddish-brown shale	2.0
60. Sandstone, reddish-orange, very fine grained in lower part; pale-red shale with limestone pellets in upper part; entire unit gypsiferous	14.0
59. Siltstone, reddish-orange; contains gypsum fragments all through unit	1.7
58. Poorly exposed slope consisting of gypsum intermixed with reddish-brown shale and limestone pellets; a 3-ft reddish-orange very gypsiferous sandstone in middle forms ledge	15.0
57. Siltstone, like unit 55; forms slope	2.8
56. Sandstone, reddish-orange, very fine grained, very gypsiferous; forms slope	5.0
55. Siltstone, reddish-brown, mottled light-gray; forms slope	1.3
54. Sandstone, reddish-orange, fine-grained, very thinly bedded with gypsum as thin laminae between beds; forms weak ledge	2.5
53. Gypsum, white; intermixed reddish-brown shale	.5
52. Siltsone, reddish-brown	.6

Section of Cedar Mesa Sandstone Member of Cutler Formation, measured 1½ miles north of south border of mapped area—Continued

Cedar Mesa Sandstone Member (gypsiferous facies)—Continued	*Feet*
51. Covered	59.0
50. Limestone, light-gray, thinly bedded; contains minor amount of reddish-brown and reddish-orange shale and some gypsum	5.1
49. Gypsum; contains coarse grains and pebbles of pale-red shale and siltstone	3.2
48. Sandstone, very fine grained, silty, argillaceous, and gypsiferous	1.4
47. Gypsum, white; forms slope	1.5
46. Shale and interbedded very fine grained sandstone, reddish-orange; gypsum present as granules and pebbles	10.0
45. Gypsum, white, sandy, weathers reddish orange; form slope	3.0
44. Sandstone, like unit 39	1.5
43. Gypsum, white	1.0
42. Siltstone and very fine grained sandstone, reddish-orange; bed of gypsum at base; unit forms slope	1.9
41. Siltstone, reddish-brown, irregularly laminated, hard; forms ledge	.9
40. Sandstone, reddish-orange, fine-grained, very gypsiferous; gypsum occurs as pebbles as much as 7 in. across; unit forms slope	2.7
39. Sandstone, reddish-orange, fine-grained; laminated bedding, rare coarse grains of limestone; unit forms ledge	7.0
38. Sandstone, reddish-brown and pale-red, fine-grained, irregularly bedded, hard; contains thin lenses of shale; at top a breccia consisting of fragments of limestone, gypsum, shale, and reddish-brown chert; unit forms ledge	11.0
37. Shale, reddish-brown; contains limestone nodules; forms slope	7.0
36. Sandstone, white, fine-grained; laminated bedding; contains thin reddish-orange siltstone in upper part; forms ledge	4.2
35. Sandstone, light-gray, very fine to fine-grained; irregularly bedded and crossbedded; thin limestone caps unit	5.0
34. Sandstone, like unit 32	4.5
33. Sandstone, white, banded brown and pale-red, very fine grained; irregularly bedded; calcareous; forms ledge	1.5
32. Sandstone, reddish-brown, weathers reddish orange, very fine to fine-grained; basal 1½ ft forms ledge, remainder forms slope	5.0
31. Shale, reddish-brown, mottled light-green; gypsiferous; forms slope	5.0
30. Sandstone, reddish-orange, very fine to fine-grained; laminated bedding; minor amount of interbedded red shale; thin limestone bed caps unit; unit forms ledge	15.0
29. Interbedded siltstone, very fine grained sandstone, and shale, reddish-orange and reddish-brown; forms a slope	18.0
28. Sandstone, reddish-brown, mottled pale-red, very fine grained; thin 2-in. limestone bed at base	2.0
27. Interbedded sandstone like unit 25, and siltstone like unit 26; forms series of ledges and slopes	14.0
26. Siltstone, reddish-orange; contains one very fine grained sandstone bed, 1 ft thick; forms slope	9.0
25. Sandstone, reddish-brown, weathers reddish-orange, very fine grained; laminated and crossbedded; coated at places with gypsum, hard; forms poorly defined ledge	5.0
24. Siltstone, reddish-orange; soft; forms slope	8.0

Section of Cedar Mesa Sandstone Member of Cutler Formation, measured 1½ miles north of south border of mapped area—Continued

Cedar Mesa Sandstone Member (gypsiferous facies)—Continued	*Feet*
23. Sandstone, reddish-orange, very fine grained; hard; forms poorly defined ledge	3.0
22. Siltstone, reddish-brown; reddish-brown chert litters surface; unit forms slope	5.0
21. Sandstone, reddish-orange, fine-grained; parallel- and irregular-bedded; forms weak ledge	12.0
20. Covered; chert litters slope	5.0
19. Sandstone, reddish-orange, very fine grained; parallel-bedded; forms ledge	2.0
18. Shale, mottled reddish-brown and pale-red with light-green spots; gypsum present as granules and small pebbles; forms slope	9.0
17. Siltstone, reddish-orange; bench formed on top; bench littered with calcareous concretions	3.0
16. Covered; forms slope; probably shale	20.0
15. Siltstone, reddish-brown; hard; thin limestone at top; forms ledge	3.0
14. Shale, reddish-brown, silty and very fine sandy; forms slope	5.0
13. Sandstone, white, very fine grained; irregularly bedded; hard; forms ledge. Laterally unit grades into limestone which locally contains masses of chert, one irregular mass of reddish-brown and white chert noted that is 4 ft across by 4–5 in. thick	1.0
12. Interbedded reddish-orange, very fine sandy siltstone and reddish-brown shale; forms slope	5.0
11. Siltstone, reddish-orange, very fine sandy; forms slight ledge	.5
10. Shale, pale-red; forms slope	5.0
9. Sandstone, white, very fine grained; irregularly bedded; forms ledge; unit thickens and thins along outcrop; laterally unit is replaced by limestone which contains masses of chert, one chert mass noted is 2½ ft wide by 4 ft long	1.0
8. Shale, reddish-brown; gypsiferous; forms slope	8.0
7. Sandstone, mottled white, purple, and reddish-brown, very fine grained; irregularly bedded; forms ledge; laterally unit contains thin limestone bed at top which contains masses of reddish-brown chert	.7
6. Shale, reddish-brown; gypsiferous in upper part; a 1 ft siltstone bed forms slight ledge at 4 ft; unit as whole forms slope	6.5
5. Sandstone, white, very fine to fine-grained; hard; irregularly bedded; forms ledge	1.0
4. Shale, reddish-brown; form slope	5.0
3. Siltstone, reddish-brown; laminated ¼-in. bedding; forms ledge	.6
2. Shale, reddish-brown; gypsiferous; forms slope	31.5
1. Limestone, gray; irregularly bedded; forms slight ledge and dip slope	.3
Total thickness of Cedar Mesa Sandstone Member (gypsiferous facies)	496.3

Halgaito Tongue of Cutler Formation.

The gypsiferous facies of the Cedar Mesa Sandstone Member is 830 feet thick near Comb Wash where Utah State Highway 47 crosses the outcrop (Sears, 1956, p. 187). About 3½ miles south of the San Juan River the gypsiferous facies is 870 feet thick. Southward the gypsiferous facies thins and is about 500 feet thick 1½ miles north of the south border of the area. According to Witkind and Thaden (1963, p. 10), the Cedar Mesa Sandstone Member (here considered the gypsiferous facies) is approximately 315 feet thick in the Monument Valley area to the south.

Where the sandstone facies is present, the contact between the Cedar Mesa and the Halgaito is marked by a sharp change in lithology, topographic expression, and color. From Cedar Point eastward to T. 40 S., R. 20 E., the contact is placed at the abrupt change from the slopes of the underlying dark-reddish-brown Halgaito Tongue to the thick light-colored cliff-forming Cedar Mesa Sandstone Member. The contact is further emphasized by the change from the siltstone of the Halgaito to the sandstone of the Cedar Mesa.

Where the gypsiferous facies of the Cedar Mesa Sandstone Member is present the contact is even and sharp. Generally a very thin limestone is at the base of the Cedar Mesa, and the top part of the Halgaito is bleached white or gray. Locally a conglomerate consisting of pebbles of siltstone and limestone as much as 2 inches across is at the base. Above this the basal part of the Cedar Mesa, about 70 or 80 feet thick, consists of light-colored gypsiferous shale and siltstone beds and local thin beds of gray or white sandstone and limestone that contain masses of distinctive reddish-brown chert.

The Cedar Mesa Sandstone Member represents deposition in two different environments. The gypsiferous facies was deposited in a slight downwarp or basin that formed east of the site of Comb Ridge during deposition of the Halgaito Tongue. This basin was flooded from time to time by an arm of the sea and the gypsum or anhydrite contained in the gypsiferous facies of the Cedar Mesa was deposited under conditions of high evaporation. Evaporites in the Cedar Mesa, unlike the evaporites in the Halgaito, were deposited on part of the Monument upwarp area. A line separating the sandstone and gypsiferous facies trends southwest from T. 40 S., R. 20 E., across the site of Raplee Ridge and passes to the south of Mexican Hat, indicating that marine waters, within the report area, invaded the southeast part of the Monument upwarp. In Lime Creek Valley and Grand Gulch Plateau, the "lower soft" part of the Cedar Mesa, at the base of the sandstone facies, was also probably deposited in marine waters.

The lateral gradation of the sandstone facies into the gypsiferous facies supports a concept of a marginal marine or shore environment

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for the deposition of the sandstone facies. The horizontal bedding planes associated with the thin interbeds of reddish-brown siltstone suggest that marine waters from the restricted arm of the sea transgressed the sandstone facies from time to time. Parts of the sandstone facies contain great sweeping crossbeds and may reflect beach and sand dunes accumulated back from the basin of evaporation. Crossbeds of the sandstone facies dip to the southeast and east (Read and Wanek, 1961, p. 6–7), and the sandstone facies thickens to the north and northwest. A possible source to the northwest has been suggested by Baker and Reeside (1929, p. 1447).

ORGAN ROCK TONGUE

Conformably overlying the Cedar Mesa Sandstone Member is a sequence of red beds similar to the Halgaito Tongue at the base of the Cutler Formation. The unit was named the Organ Rock Tongue by Baker and Reeside (1929, p. 1422) for a slender spire carved in the member and located about 20 miles to the west of the report area.

In the Cedar Mesa-Boundary Butte area the Organ Rock Tongue forms a curved relatively narrow belt of outcrop (fig. 5) from the north edge to the south edge of the map area. It is somewhat less resistant than the overlying De Chelly Sandstone Member and weathers to a slight depression. Here and there a thin resistant ledge projects above the depression as a ridge. Viewed from a distance the dark-reddish-brown outcrops of the Organ Rock Tongue are easily distinguished from the light-colored underlying Cedar Mesa Sandstone and overlying De Chelly Sandstone Members of the Cutler Formation.

The Organ Rock Tongue is very similar to the Halgaito Tongue. It consists dominantly of dark-reddish-brown siltstone and sandy siltstone having subordinate amounts of very fine grained and silty sandstone. Some beds, particularly the sandstone, are well cemented by calcium carbonate and form ledges, whereas others are weakly cemented and form slopes, all of which gives the Organ Rock a horizontally banded appearance. Numerous light-green or light-gray circular spots as much as about half an inch across and irregular elongate mottles, generally parallel to the bedding, occur all through the sequence. Bedding for the most part is obscure or massive, but some laminated bedding is present. Thin beds of conglomerate, consisting of pebbles of limestone and siltstone as much as 1 inch across in a silty matrix, are present at places near the base of the tongue. Also in the basal part of the Organ Rock Tongue are one or more very thin beds of pale-red very hard limy siltstone. These thin beds are fairly persistent and are laminated. One of these beds near the base is thoroughly fractured by joints normal to the bedding.

The top part of the Organ Rock Tongue contains a sequence of light-colored sandstone beds that lithologically resemble the overlying massive De Chelly Sandstone Member. This sandstone is fine grained and somewhat silty and is separated into several layers by reddish-brown siltstone beds. Vertically the sequence forms a transitional unit from the top of the Organ Rock into the overlying De Chelly. Laterally the sequence represents interfingering between the two members. At one place near the southern part of the Cedar Mesa-Boundary Butte area, a 35-foot bed of reddish-brown siltstone typical of the Organ Rock underlies the massive light-colored De Chelly and is in turn underlain by a massive sandstone bed that resembles the De Chelly. Farther south the siltstone bed thins and disappears as the upper part of the Organ Rock Tongue grades laterally into the lower part of the De Chelly and the underlying massive sandstone joins the main body of De Chelly. In the area south of the San Juan River the zone of transition between the Organ Rock and De Chelly ranges in thickness from 40 to 65 feet.

Section of Organ Rock Tongue of Cutler Formation measured about 4 miles north of Moses Rock

De Chelly Sandstone Member of Cutler Formation.	
Organ Rock Tongue:	*Feet*
22. Siltstone, reddish-brown, calcareous; very fine sand in places; micaceous; makes sequence of weak ledges; upper one-third consists of several beds of pale-reddish brown very fine grained sandstone where Organ Rock grades into overlying De Chelly; unit forms slope	130.0
21. Sandstone, reddish-brown, very fine grained; forms prominent ledge	12.0
20. Siltstone, reddish-brown; forms slope	22.0
19. Sandstone, reddish-brown; contains calcareous nodules; forms ledge	1.5
18. Siltstone, reddish-brown; forms slope	23.0
17. Sandstone, very fine grained and silty; forms ledge	1.0
16. Siltstone, reddish-brown; forms slope	4.5
15. Sandstone, reddish-brown, very fine to fine-grained and silty, hard; forms ledge	2.0
14. Siltstone and very fine grained sandstone, reddish-brown, mottled light-green; calcareous; micaceous; unit parallel banded due to alteration of soft and hard zones; forms slope	277.0
13. Siltstone and very fine grained and silty sandstone, reddish-brown; sandstone forms ledges from 1 to 5 ft thick	65.0
12. Siltstone, reddish-brown; forms slope	27.0
11. Sandstone, reddish-brown, very fine grained and silty, hard; forms ledge	2.5
10. Siltstone, reddish-brown; forms slope	11.0
9. Siltstone, reddish-brown, hard, calcareous; contains very fine sand; forms ledge	1.0

Section of Organ Rock Tongue of Cutler Formation measured about 4 miles north of Moses Rock—Continued

Organ Rock Tongue—Continued	*Feet*
8. Siltstone, reddish-brown; forms slope	5.0
7. Sandstone, reddish-brown, spotted and banded white, very fine to fine-grained and silty; forms ledge	2.0
6. Siltstone, like unit 4	13.0
5. Siltstone, pale-red, banded white, laminated, very calcareous; forms ledge	1.0
4. Siltstone and very fine grained sandstone, reddish-brown, argillaceous; in part calcareous; micaceous; forms banded slope due to interbedded hard and soft zones	51.6
3. Sandstone, reddish-brown, fine- to coarse-grained and conglomeratic; conglomerate consists of subangular limestone pebbles ¼–½ in. across; unit forms ledge	2.0
2. Siltstone, reddish-brown, mottled light-green; limestone pellet conglomerate 1 ft thick at 4 ft; unit forms slope	11.4
1. Siltstone, pale-red, very calcareous; thoroughly fractured by joints normal to bedding; forms a slight ledge	.2
Total thickness of Organ Rock Tongue	665.7
Cedar Mesa Sandstone Member of Cutler Formation.	

The Organ Rock Tongue ranges widely in thickness. In the area between Utah State Highway 47 and Road Canyon, the tongue ranges in thickness from 642 to 820 feet (Sears, 1956, p. 190). On the south bank of the San Juan River the Organ Rock is 594 feet thick. At points 2¼ and 3½ miles south of the San Juan River the tongue is, respectively, 613 and 665 feet thick. About 4 miles south of the Cedar Mesa-Boundary Butte area near Monument No. 2 mine, the Organ Rock Tongue is 670 feet thick (Witkind and Thaden, 1963, p. 11).

From the north edge of the Cedar Mesa-Boundary Butte area south to the San Juan River, the base of the Organ Rock Tongue is drawn above a conspicuous persistent light-gray limy sandstone or sandy limestone (Sears, 1956, p. 187–188). To the north, Sears (1956, p. 188) found small-scale intertonguing between the Cedar Mesa Sandstone Member and Organ Rock Tongue. South of the San Juan River, light-gray limestone and sandstone at the top of the Cedar Mesa do not persist for any great distance. In this area, the contact is placed below a conspicuous very thin pale-red hard and limy siltstone. Generally, at the base of the Organ Rock Tongue at least two such pale-red siltstone beds are present, and these beds at places are laminated and thoroughly fractured. The pale-red siltstone beds are separated by 45–65 feet of beds that at some places resemble Organ Rock and at other places resemble the Cedar Mesa. The contact is arbitrarily placed at the base of the stratigraphically lower bed and may not be at the same horizon at all localities. The contact with the

Cedar Mesa Sandstone Member is considered to be intertonguing, as the Organ Rock Tongue maintains roughly the same thickness southward from the San Juan River between a thinning underlying Cedar Mesa and a thickening overlying De Chelly.

The red color, lithology, and lenticular nature suggest a continental, possibly fluviatile, origin for the Organ Rock Tongue. Intertonguing with the gypsiferous facies of the Cedar Mesa indicates that part of the Organ Rock may be marine or marginal marine. Regionally, the Organ Rock grades eastward into coarse arkose and this reflects a source in that direction (Baker and Reeside, 1929, p. 1446). The deposition of the Organ Rock marks the end of the basin of evaporation in the eastern part of the report area that existed during the deposition of the Cedar Mesa Sandstone Member and the Halgaito Tongue.

DE CHELLY SANDSTONE MEMBER

The name De Chelly Sandstone was applied by Gregory (1917, p. 32–33) to a thick massive sandstone exposed at Canyon De Chelly near Chinle, Ariz., about 60 miles south of the Cedar Mesa-Boundary Butte area. In the Monument Valley area, Gregory (1915, p. 102) recognized as De Chelly part of a unit formerly called the Oljeto Sandstone Member of the Moenkopi Formation by Woodruff (1912, p. 87). Baker and Reeside (1929) later classified the De Chelly as a member of the Cutler Formation in this area.

Throughout most of the Cedar Mesa-Boundary Butte area the De Chelly crops out in a narrow smooth ridge. The outcrop widens in the southern part of the area but is largely concealed by windblown sand. Where exposed, the De Chelly forms a prominent west-facing cliff, but the upper surface is irregular, rounded, and hummocky.

The De Chelly Sandstone Member is light tan and pale reddish brown. Southwest of Moses Rock where the belt of outcrop widens, the sandstone is prevailing buff or almost white showing local thin bands that are reddish brown. The sandstone consists of very fine to fine subangular to subrounded quartz grains and minor amounts of white and black accessory minerals. The De Chelly is weakly cemented and consequently is friable. Near the southern part of the area the basal 5 feet of the De Chelly is parallel bedded and contains minor amounts of gypsum in thin seams along bedding planes. The sandstone is massive and shows conspicuous crossbedding (fig. 6) which dips dominantly to the southwest (Read and Wanek, 1961, pl. 1).

The De Chelly Sandstone Member thins rapidly northward. South of the report area the member is 550 feet thick near Monument No. 2 mine (Witkind and Thaden, 1963, p. 13). The De Chelly is 395 feet thick near the south border of the report area, 225 feet thick about 4 miles north of Moses Rock, and 183 feet thick just south of the San Juan River. Sears (1956, p. 192) reported a thickness of 53 feet about 2½ miles north of Snake Gulch. The De Chelly continues to thin northward and pinches out, beyond the report area, at a point about 2 miles north of Road Canyon (Sears, 1956, p. 192).

The lower contact of the De Chelly Sandstone Member with the Organ Rock Tongue is arbitrary. Progressively upward, the top part of the Organ Rock contains increasing amounts of sandstone similar to the De Chelly. The contact is considered gradational and interfingering and in this study has been placed arbitrarily at the level where the sandstone forms a continuous massive sequence.

Within the Cedar Mesa-Boundary Butte area, the prominent sweeping crossbeds suggest an eolian origin for the De Chelly Sandstone Member. The crossbeds dip southwest (Read and Wanek, 1961, pl. 1) and the De Chelly thickens to the south. There is a difference of opinion about the nature and origin of the De Chelly. Mullens (1960, p. 274) stated that in the Clay Hills area it "is probably a wind-laid deposit and the wedge edge in the area mapped apparently was deposited in sand dunes near a body of water." According to Strobell (1958, p. 69), the De Chelly "probably represents bar, beach, and dune deposits related to the Permian seas that lay to the west and south and reworked the red clastics contributed from the east." Baker and Reeside (1929, p. 1447) considered the De Chelly to be in part water laid as well as wind laid and that it was derived from the northwest. Baars (1962, p. 194) believed that the De Chelly originated from the coarse Cutler arkose in southwestern Colorado and that the De Chelly was distributed westward by the prevailing winds from the northeast.

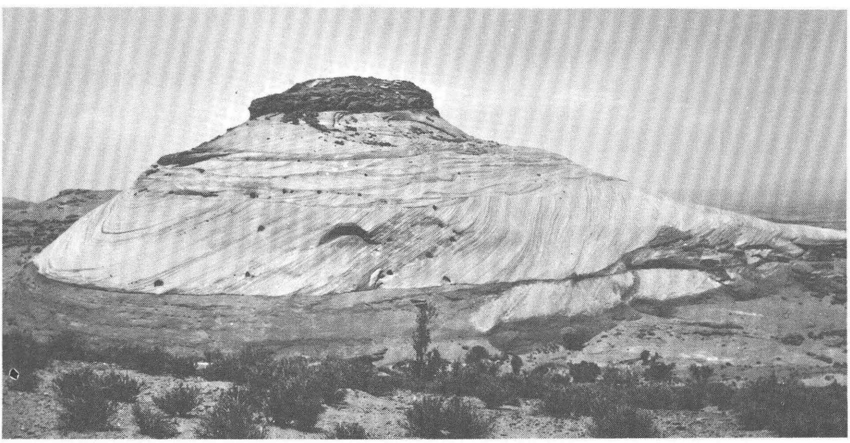

FIGURE 6.—Crossbedded De Chelly Sandstone Member of Cutler Formation, near Utah-Arizona State line, capped by contorted Hoskinnini Member of Moenkopi Formation. Hill is about 200 feet high.

TRIASSIC(?) AND TRIASSIC SYSTEM

MOENKOPI FORMATION

Ward (1901, p. 403–404) applied the name Moencopie [now spelled Moenkopi (Gregory, 1917, p. 23)] beds to a sequence of rocks lying between the Kaibab Limestone and what was formerly called the Shinarump Conglomerate along Moenkopi Wash, Ariz. The Moenkopi Formation was extended into the Monument Valley area by several workers but applied to different parts of the stratigraphic section. Baker and Reeside (1929, p. 1440–1444) summarized this early usage of Moenkopi Formation in the Monument Valley area. They (Baker and Reeside, 1929, p. 1416) recognized as Moenkopi the sequence of rocks lying between the Shinarump Conglomerate and the Cutler Formation.

A thin unit of red beds at the top of the Cutler Formation was named the Hoskinnini Tongue of the Cutler Formation by Baker and Reeside (1929, p. 1422). The name was derived from Hoskinnini Mesa, which lies about 20 miles west of the Cedar Mesa-Boundary Butte area. At the type locality the Hoskinnini Tongue overlies the De Chelly Sandstone Member of the Cutler Formation. Northward, near the Clay Hills area, the De Chelly wedges out, and the Hoskinnini Tongue rests on the Organ Rock Tongue of the Cutler Formation. Baker (1936, p. 39) considered the Hoskinnini to be inseparable from the Organ Rock where the De Chelly Sandstone Member is absent and for this reason included the Hoskinnini with the Cutler Formation. During later detailed work by Mullens (1960, p. 277), it was found that the Hoskinnini could be differentiated from the underlying Organ Rock. Stewart (1959, p. 1853) correlated the Hoskinnini over wide areas of Utah and found that whereas the basal contact is sharp, the upper contact with the Moenkopi Formation is gradational. He also found (Stewart, 1959, p. 1864) that the Hoskinnini is lithologically identical to parts of the Moenkopi Formation elsewhere in Utah. For these reasons, Stewart (1959) assigned the Hoskinnini as a member of the Moenkopi Formation.

The Hoskinnini is present throughout the Cedar Mesa-Boundary Butte area as the lower member of the Moenkopi Formation. Overlying the Hoskinnini is a sequence of rocks that previously constituted the entire Moenkopi Formation in the Monument Valley area (Baker, 1936, p. 40–44) but in this report is referred to as the upper unit.

Throughout the area the Moenkopi Formation overlies the De Chelly Standstone Member of the Cutler Formation. The Moenkopi Formation forms a narrow continuous band (pl. 1) from the north edge of the map area to the vicinity of Moses Rock. From this point southward for several miles the main belt of outcrop of the Moenkopi is completely obscured by windblown sand. At the extreme south edge of the map area the Moenkopi Formation is again exposed in a very small outcrop beneath a ledge of the Shinarump Member of the Chinle Formation. About 4 miles north of this last outcrop, a thin erosional remnant of the Hoskinnini Member is preserved on the west side of a small mesa.

Throughout most of the area the harder, more resistant Hoskinnini Member forms a dip slope on the De Chelly. The upper unit of the Moenkopi is softer and weathers to lower levels down the east-facing dip slope of the Hoskinnini Member. The upper unit is, for the most part, obscured by alluvium, windblown sand, and slope wash.

HOSKINNINI MEMBER

The Hoskinnini Member consists of dark-reddish-brown, grayish-red, moderate-reddish-orange, and very light gray sandstone having minor amounts of siltstone. The lighter and darker colored sandstone beds are interspersed, and the Hoskinnini has a banded appearance. The sandstone beds are very fine to medium grained and contain coarse to very coarse grains of subrounded to rounded chert and quartz. The coarse grains are disseminated all through the Hoskinnini and are diagnostic of the member. Locally the sandstone beds are mottled—in the darker colored beds the mottling is very light gray or light green, but in the lighter colored beds the mottling is reddish brown. Bedding is generally obscure but at places small-scale contorted or wavy bedding occurs, and there the Hoskinnini has a ropy or gnarly appearance. Here and there the Hoskinnini contains thin beds of dark-reddish-brown sandy and argillaceous siltstone, which are generally less than 3 feet thick.

The Hoskinnini Member has a rather uniform thickness throughout the Cedar Mesa-Boundary Butte area. At the south edge of the map area it is 36 feet thick, and 1½ miles south of Mule Ear it is 48 feet thick. North of the San Juan River the Hoskinnini Member is 20–30 feet thick (Sears, 1956, p. 193).

UPPER UNIT

The upper unit of the Moenkopi Formation conformably overlies the Hoskinnini Member. It comprises a sequence of interbedded prevailingly dark-reddish-brown siltstone and sandstone having lesser amounts of grayish-red and pale- to dark-reddish-brown shale. The siltstone beds are thin and evenly bedded, and the outcrops have a finely ruled appearance. At places the siltstone contains white or very light green spots or bands. Sandstone beds are very fine to medium grained and consist of subangular to subrounded quartz grains having minor amounts of mica and other accessory minerals. At places the sandstone beds are white or light brown and contain abundant ripple marks, which are characteristic of the upper unit.

The upper unit of the Moenkopi Formation is about 60 feet thick at the south edge of the map area and thickens progressively northward. About 7 miles north of the San Juan River the upper unit is 222 feet thick (Sears, 1956, p. 193).

Section of Moenkopi Formation at southern edge of mapped area

	Feet
Shinarump Member of the Chinle Formation.	
Moenkopi Formation:	
Upper unit:	
9. Siltstone and fine-grained sandstone, grayish-red; unit in part banded white; upper 5 ft bleached greenish yellow; unit forms a rubble-covered slope	37.0
8. Sandstone, grayish-red, silty and very fine grained sandy; contains a scattering of coarse to very coarse rounded quartz grains, upper part contains ¼-in. chips of shale; unit forms weak ledge	6.0
7. Shale, dark-reddish-brown, very sightly silty; forms poorly exposed slope	16.5
Hoskinnini Member:	
6. Sandstone, white, very fine to coarse-grained, very hard and calcareous; weathers brown; parallel bedded; forms ledge	.7
5. Sandstone and siltstone interbedded; lower part pale red, upper part dark reddish brown; lower part very fine grained sandy and argillaceous; middle part medium grained; upper part siltstone; unit forms slope	6.2
4. Sandstone, reddish-brown, mottled white, medium-grained; bedding irregular; contains calcite crystals as much as 3 in. across; unit forms ledge	1.0
3. Sandstone, dark-reddish-brown, mottled white and very light-green, medium-grained; a scattering of very coarse grains; bedding obscure; weather to slope	4.8
2. Sandstone, white, medium-grained, calcareous; forms ledge	1.2
1. Sandstone, dark-reddish-brown, fine- to medium-grained; numerous coarse rounded quartz grains disseminated through unit; bedding very irregular and gnarly; unit weathers to a steep irregular slope	22.5
Total thickness of Moenkopi Formation	95.9
De Chelly Sandstone Member of the Cutler Formation.	

The entire Moenkopi Formation thickens northward from about 96 feet at the south border to 146 feet about 1 mile south of Mule Ear. The entire Moenkopi as used in this report is nearly 250 feet thick about 7 miles north of the San Juan River (Sears, 1956, p. 191–193).

The lower contact of the Moenkopi Formation with the underlying De Chelly Sandstone Member of the Cutler (fig. 6) is a disconformable sharp wavy surface of slight relief. There is an abrupt change in lithology from the finer grained well-sorted crossbedded De Chelly

Sandstone Member to the hard irregularly bedded Hoskinnini Member, which contains coarse to very coarse grains of quartz and chert.

The upper unit of the Moenkopi is not fossiliferous in the Cedar Mesa-Boundary Butte area but is fossiliferous in other areas of Utah. The fossils indicate an Early and Middle(?) Triassic age for the upper unit. No fossils have been found in the Hoskinnini, either in the report area or in other areas where it is exposed. Previously the Hoskinnini was considered to be of Permian age (Baker, 1936, p. 40). Baker and Reeside (1929, p. 1424) also recognized an unconformity at the top of the Hoskinnini that they believed marked the boundary between Permian and Triassic rocks. Stewart (1959, p. 1854), however, did not recognize such an unconformity nor was one observed by the writer in the Cedar Mesa-Boundary Butte area or by others (Witkind and Thaden, 1963, p. 17; Mullens, 1960, p. 278) elsewhere in the Monument Valley area. As a result, the Moenkopi Formation, where the Hoskinnini Member is present, is of Triassic(?) and Early and Middle(?) Triassic age (Stewart, 1959, p. 1854).

The Cutler Formation in southeast Utah is only of Early Permian age and the entire Late Permian is missing (Dunbar, 1960, pl. 1). If the Hoskinnini is indeed of Triassic age then the basal contact with the Cutler marks the boundary between Permian and Triassic rocks and represents a significant hiatus. In the eastern and southern parts of Monument Valley, stratigraphic evidence indicates that the Hoskinnini is more closely related to the Moenkopi than to the Cutler Formation. In the report area, the contact of the Hoskinnini and the upper unit of the Moenkopi is arbitrary and gradational. At places it consists of a zone as much as 20 feet thick that contains an alternation of lithology typical of the Hoskinnini interbedded with lithology typical of the upper unit. In the Monument Valley area of Arizona, Witkind and Thaden (1963, p. 20) also reported that this same contact is gradational. In addition, Witkind and Thaden (1963, p. 16) noted that the Hoskinnini includes small blocks of the De Chelly Sandstone Member indicating that the De Chelly was consolidated before deposition of the Hoskinnini.

The stratigraphy and history of the Moenkopi Formation are described in detail by McKee (1954). The Moenkopi Formation in southwestern Utah contains marine beds and is as much as 2,150 feet thick (McKee, 1954 (p. 6–15). It thins eastward across southern Utah to a pinchout near the Colorado-Utah State line. In northeastern Arizona the Moenkopi pinches out on the old Defiance positive area, as reflected by the absence of the Moenkopi in the subsurface near Boundary Butte in the southeastern part of the report area. On the outcrop, ripple marks and thin bedding indicate deposition in water, but other features such as mudcracks and raindrop impressions elsewhere in Monument Valley (Baker, 1936, p. 44) suggest that the Moenkopi was exposed to subaerial conditions at times. A study of crossbeds (Poole, 1961, fig. 199.1) shows that streams that deposited some of the Moenkopi flowed generally westward in this part of Utah. Much of the Moenkopi, within the report area, probably accumulated under terrestrial conditions, but marine waters from the west may have inundated the area from time to time.

The distinctive contorted bedding of the Hoskinnini Member may be due to subaqueous sliding of unconsolidated water-saturated sediments and probably reflects deposition in a body of water. The gypsum in the Clay Hills area to the west (Mullens, 1960, p. 276–277) indicates that evaporitic conditions prevailed locally. The Hoskinnini Member apparently is confined principally to the Monument upwarp area (Stewart, 1959, fig. 1). This limited distribution of the Hoskinnini suggests that the body of water may have been a lake.

TRIASSIC SYSTEM

CHINLE FORMATION

The distinctive Chinle Formation occurs as a continuous, but relatively narrow, northward-trending belt of outcrop near the central part of the mapped area. The upper part of the Chinle throughout most of the area forms steep slopes near the base of the west-facing escarpment of Comb Ridge. The steep slopes are littered with blocks of sandstone that have fallen from the overlying cliffs of Comb Ridge. The lower part of the Chinle Formation forms a depression at the base of Comb Ridge. Talus, alluvium, and slope wash, not all of which are shown on the geologic map (pl. 1), largely conceal the lower part.

The Chinle Formation was named by Gregory (1917, p. 42) for exposures along Chinle Valley of northeastern Arizona about 25 miles south of the Cedar Mesa-Boundary Butte area. Within the report area the Chinle Formation is divided into two parts, the Shinarump Member at the base, which is only in the southern part of the area, and the undifferentiated Chinle Formation, which occurs throughout the outcrop belt.

SHINARUMP MEMBER

The Shinarump Member was originally named the Shinarump Conglomerate, a formation, in a report describing the geology of southwestern Utah (Gilbert, 1875, p. 176; Howell, 1875, p. 247–248). The Shinarump Conglomerate in the Navajo Indian Reservation was described by Gregory (1913; 1917, p. 37–41). Recently, Stewart (1957, p. 442) reduced the Shinarump to member rank and assigned it to the Chinle Formation.

The Shinarump Member is present in a small area extending northward for a distance of about 1½ miles from the south border. In this area, the Shinarump forms a prominent ledge and dip slope at the base of the Chinle Formation. The member consists of buff very fine to coarse-grained and crossbedded sandstone. A conglomerate consisting of chert, quartz, and quartzite pebbles in a fine- to coarse-grained sandstone matrix is in the lower 5 feet. Above this the Shinarump Member is rarely conglomeratic. Chunks of petrified wood as much as 3 feet long are scattered throughout the member.

The top of the Shinarump Member is concealed, but on the basis of exposures in a prospect pit and on the dip slope, the Shinarump Member near the southern border is estimated to be 45–50 feet thick. According to Witkind (1956, p. 103), the Shinarump in the Monument Valley area immediately to the south is generally about 75 feet thick and locally thickens to 150 feet in channels.

The base of the Shinarump Member can be seen at only one place—at the extreme southern edge of the map area. There the basal contact with the underlying Moenkopi Formation is unconformable and an erosional surface of slight relief. Elsewhere in the Monument Valley area, the lower contact of the Shinarump is described as a surface of erosion marked at places by channels 5–200 feet deep and 15–2,300 feet wide that cut into the underlying Moenkopi Formation (Witkind, 1956, p. 114; Lewis and Trimble, 1959, p. 111). The upper contact of the Shinarump Member with the overlying parts of the Chinle is not visible in the report area. Witkind (1956, p. 103) reported that the contact is gradational and that locally the Shinarump Member intertongues with the next higher part of the Chinle Formation.

The base of the Chinle Formation is concealed for a distance of about 3½ miles northward from the exposures of the Shinarump Member in the southern part of the area. Where the base of the Chinle is next visible, the Shinarump Member is not present. North of this point there occur locally near the base of the Chinle widely separated lenticular beds of buff fine- to coarse-grained sandstone, which contain a few widely distributed pebbles as much as one-fourth inch across. These beds are 5–10 feet thick and are as much as several hundred feet long. All are underlain by 2–5 feet of generally light-greenish-gray and pale-blue shale. At places there are two such sparsely conglomeratic sandstone beds, one near the base, the other as much as 30 feet higher. The lower bed may be equivalent to the Shinarump exposed at the south end of the area. However, as these sandstone beds are lenticular and do not persist for any great distance, they are included with the undifferentiated Chinle Formation.

UNDIFFERENTIATED CHINLE FORMATION

Above the Moenkopi Formation or Shinarump Member, where present, is a heterogeneous mixture of variegated shale, reddish-orange, pale-red, and brown siltstone and sandstone, and gray and greenish-gray limestone. This sequence of rocks constitutes the undifferentiated Chinle Formation and may be divided into four units which in ascending order are: unit 1, characterized by pale-blue and gray shale;[1] unit 2, characterized by a pale-red shale having minor ledges of limestone and sandstone and containing varying amounts of reddish-orange siltstone in the upper part; unit 3, two prominent massive ledges of reddish-orange sandstone; and unit 4, reddish-orange siltstone present only in the southern part of the area.

Unit 1 of the undifferentiated Chinle Formation (fig. 7) is generally poorly exposed throughout much of the area but is completely exposed in a small area about 2½ miles north of Moses Rock. There, unit 1 consists mainly of pale-blue, light-greenish-gray, and pale-red shale having minor drab beds of brown and gray shale. The shale is generally silty and calcareous and locally gypsum is present as flakes or as a fine white powder. One thin lenticular light-gray limestone bed was noted near the middle of unit 1. Here and there near the base are beds of reddish-brown shale and siltstone and lenticular sandstone. These sandstone beds near the base of unit 1 are described with the Shinarump Member. The basal contact of unit 1 with the underlying Moenkopi Formation is unconformable. The contact is covered throughout most of the area but where exposed is a wavy surface of slight relief. At one point 2½ miles north of Moses Rock, however, there is about 35 feet of relief where the base of the Chinle cuts down across the Moenkopi Formation in a distance of about 400 feet. Unit 1 in the area 2½ miles north of Moses Rock is about 470 feet thick.

Unit 2 consists mainly of pale-red shale, which contrasts sharply with the darker blue and gray of unit 1. The shale is generally silty and calcareous and much of it is spotted light greenish gray. Interspersed with the shale are several ledge-forming beds of sandstone, siltstone, and limestone. At a point 2½ miles north of Moses Rock, unit 2 contains five such ledges. The ledges are nonpersistent and lenticular however, and as a result the number and arrangement of the ledges varies from place to place. The brown and pale-red crossbedded sandstone beds are fine to coarse grained and at places conglomeratic. Pebbles of limestone and shale where present are as much as 4 inches across but generally are less than half an inch across. The

[1] The term "shale" used throughout this report refers to rocks that, in the field, appear to be finer grained than siltstone. The shale commonly is sandy and silty and not necessarily fissile.

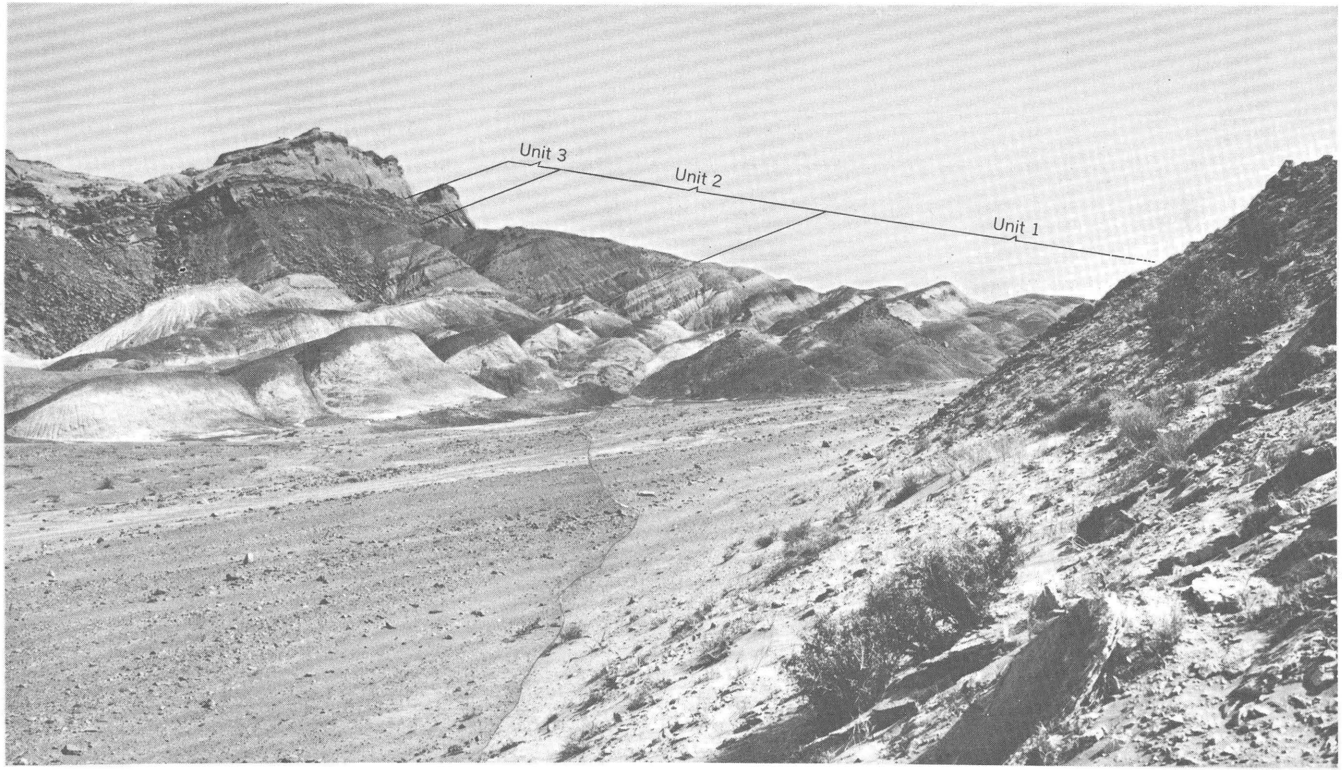

FIGURE 7.—Three units of the Chinle Formation about 2½ miles north of Moses Rock. Wingate Sandstone on skyline to left at crest of Comb Ridge.

sandstone occurs in beds 1–10 feet thick. The beds of limestone are light greenish gray to light gray and at places are mottled pale red. The limestone occurs in beds that range from less than 1 foot to 8 feet in thickness. At places the limestone occurs in a conglomerate of granule to pebble size that is contained in a matrix of silt, sand, and shale. The limestone conglomerate occurs as individual units or interbedded with sandstone. North of Moses Rock the upper part of unit 2 contains reddish-orange siltstone beds that generally form a continuous sequence upward to the base of unit 3. The sandy siltstone forms a banded slope due to the alternation of hard and soft layers. Locally, beds of pale-red and brown shale similar to the main part of unit 2 are interbedded with the siltstone. This zone of reddish-orange siltstone is 65 feet thick about 1½ miles north of Moses Rock and thickens to 130 feet 2½ miles north of Moses Rock. Northward this siltstone zone thickens and thins erratically and is about 90 feet thick 2 miles north of the San Juan River. A continuous sequence of reddish-orange siltstone is absent at the top of unit 2 in the area south of Moses Rock. There are ledges of reddish-orange siltstone as much as 5 feet thick, but the upper part of unit 2 is dominantly pale-red shale having minor interbedded ledges of siltstone, sandstone, and limestone. South of Moses Rock the upper part of unit 2 shows evidence of intraformational disturbance. At places, beds at the top are distorted and crinkled and at other places units thin along the outcrop below unit 3. The base of unit 2 is concealed throughout most of the area, but where visible is placed at the lowest prominent ledge of sandstone or limestone. Because the ledges of limestone or sandstone are not persistent and because pale-red shale typical of the main part of unit 2 occurs in the upper part of unit 1, the contact is very arbitrary. In the area 2½ miles north of Moses Rock, unit 2 is 544 feet thick.

Unit 3 is present throughout the area and consists of two prominent and distinct cliff-forming sandstone beds referred to here as the lower and upper ledges. The lower ledge is reddish orange, crossbedded in part, generally fine grained, and commonly stained with a black manganese coating. Locally in the area south of Moses Rock, the lower ledge is conglomeratic, containing cobbles of sandstone and limestone as much as half a foot across. At places the lower ledge consists of four beds, which thicken and thin along the outcrop. At other places the lower ledge forms one massive sandstone bed. Two miles north of the San Juan River the lower ledge is 63 feet thick. It is 92 feet thick 2½ miles north of Moses Rock and 53 feet thick about 1 miles south of Moses Rock. The lower ledge thins southward to a thickness of 5 feet at the Arizona-Utah State line and apparently disappears a short distance to the south. The upper ledge of unit 3 is also present throughout the area. It consists of pale-red very fine to fine-grained quartz sandstone that is generally crossbedded. The upper ledge is 62 feet thick about 2 miles north of the San Juan River. It is about 30 feet thick in the area 2½ miles north of Moses Rock. Like the lower ledge, it thins southward and is only 11 feet thick at the Arizona-Utah State line and apparently disappears a short distance to the south. The base of unit 3 is placed at the base of the lower ledge, a contact marked by a sharp topographic break from the slope-forming upper part of unit 2 to the cliff-forming lower ledge.

Unit 4 is present only in the southern part of the area. At the Arizona-Utah State line, unit 4 is 180 feet thick and lies between the upper and lower ledges of unit 3. Unit 4 consists mainly of reddish-orange siltstone, which at places is spotted light grayish green. The unit forms a slope interrupted by ledges as much as 4 feet thick. Unit 4 is similar to the reddish-orange siltstone in the upper part of unit 2 but is everywhere separated from unit 2 by the lower ledge of unit 3. Northward, unit 4 thins between the upper and lower ledges of unit 3 and is 77 feet and 27 feet thick 3 miles and 1 mile south of Moses Rock, respectively. Unit 4 is not recognized separately at Moses Rock.

Section of Chinle Formation measured 2½ miles north of Moses Rock

Wingate Sandstone.	
Chinle Formation:	
Unit 3:	*Feet*
19. Sandstone (upper ledge), pale-red, very fine to fine-grained; crossbedded in part; forms prominent ledge	28.0
18. Sandstone (lower ledge), reddish-orange, very fine grained; a 5-ft soft zone at 40 ft forms a niche; unit forms a prominent cliff	92.0
Unit 2:	
17. Siltstone, reddish-orange, shaly and arenaceous; unit forms irregular ledgy and rubble-covered slope	130.0
16. Shale, pale-red; forms slope	7.0
15. Siltstone, pale-red; contains very coarse grains of limestone; unit hard and calcareous; forms ledge	1.5
14. Shale, pale-red, calcareous; contains a reddish-orange siltstone bed at 141 ft; unit forms a steep rubble-covered slope	155.0
13. Limestone, light-greenish-gray, mottled pale-red, massive; forms ledge	1.0
12. Shale, pale-red, spotted light greenish-gray; forms slope	12.0
11. Conglomerate, pale-red, mottled very light green; consists of siltstone and sandstone pebbles interbedded with very fine grained sandstone and siltstone; lower 5 ft contains coarse-grained limestone and interbedded reddish-orange siltstone and pale-red shale; unit thins southward and forms a slight ledge	25.0

Section of Chinle Formation measured 2½ miles north of Moses Rock—Continued

	Feet
Chinle Formation—Continued	
Unit 2—Continued	
10. Shale, pale-red, silty, calcareous; unit forms a rubble-covered slope	108.0
9. Sandstone, pale-red, fine- to medium-grained, argillaceous; in beds 3 in.–2 ft thick, laminated and crossbedded; unit forms prominent cliff which thins rapidly southward to 1 or 2 ft thick	18.0
8. Shale, pale-red, calcareous; forms slope	85.0
7. Limestone, light-gray, very fine grained, locally contains pebbles as much as ¼ in. across of shale or limestone; forms ledge	1.5
Unit 1:	
6. Shale, pale-blue in lower one-third, reddish-orange and pink in upper two-thirds, slightly silty, several thin sandstone beds form discontinuous ledges in lower part; unit forms slope	143.0
5. Shale, pale-red and reddish-orange; forms slope	59.2
4. Shale, pale-blue, very slightly silty and calcareous; forms slope	11.0
3. Shale, variegated in bands of pale blue, pale red, light greenish gray; minor drab intervals of brown and medium gray, slightly silty; contains logs at places; at 199 ft a thin light-gray limestone forms a dipslope; unit as a whole forms a series of cuestas	248.0
2. Sandstone, very light yellow, fine-grained; locally coarse grained with rare pebbles up to ½ in.; pebbles are white and red quartzite; bedding parallel and crossbedded; unit is lenticular pinching out north and south; forms a prominent cuesta	5.0
1. Shale, greenish; forms slope	3.0
Total thickness of Chinle Formation	1,133.2
Moenkopi Formation.	

Gregory (1917, p. 42–43) originally recognized four lettered divisions (which did not include the Shinarump Member) in his Chinle Formation. In the Monument Valley area of Arizona, "Division A," the youngest, consists dominantly of reddish-orange siltstone and is now called Church Rock Member (Stewart, 1957, p. 459). "Division B" is characterized by limestone and interbedded pale-red shale and constitutes the Owl Rock Member (Stewart, 1957, p. 458). The name Petrified Forest Member (Gregory, 1950, p. 67) is applied to "Division C," which consists of variegated siltstone and shale. "Division D," at the base or Gregory's Chinle Formation, consists predominantly of crossbedded conglomeratic sandstone and interbedded dark-gray shale and is the Monitor Butte Member (Stewart, 1957, p. 452).

In the Cedar Mesa-Boundary Butte area, unit 1 contains equivalents

746–745 O—65——5

of the Monitor Butte and Petrified Forest Members. Unit 2 at the Arizona-Utah State line is equivalent to the Owl Rock Member. The reddish-orange siltstone in the upper part of unit 2 north of Moses Rock has been correlated with the Church Rock Member (Stewart, 1957). In this report, however, unit 2 is considered equivalent to the Owl Rock. The Church Rock Member at the Arizona-Utah State line is entirely equivalent to unit 4, which thins and disappears south of Moses Rock.

The Chinle Formation undivided is 1,133 feet thick in the area 2½ miles north of Moses Rock. It thins northward and is 956 feet thick north of the San Juan River (Sears, 1956, p. 195).

The Chinle Formation is considered of Late Triassic age. Fossils were found at two localities in limestone conglomerate beds of unit 2. The fossils consist of bone fragments identified as skeletal material of Late Triassic phytosaurs by G. E. Lewis (written commun., 1960). Gregory (1950, p. 71–72) reviewed other evidence for the Late Triassic age of the Chinle Formation.

Regional studies by McKee and others (1959) showed that the Chinle Formation accumulated in a basin covering large parts of Arizona, Utah, and New Mexico. All the flora and fauna recovered from the Chinle Formation on the Colorado Plateau are of fresh-water origin, and the formation is therefore of continental origin. Deposition was probably on a relatively flat and low surface. Many of the lenticular poorly sorted sandstone beds, including all of the Shinarump Member, were deposited in streams, whereas the shale that composes much of the Chinle accumulated in a flood-plain environment. The limestone ledges of unit 2 probably represent deposition in lakes of limited extent.

Streams depositing the Chinle Formation in and near the Cedar Mesa-Boundary Butte area generally flowed to the north and west (Poole, 1961, p. C141). The Chinle Formation becomes coarser grained to the east, toward the Precambrian rocks of southwestern Colorado, and to the south, toward the ancient Mogollon Highland, and a source in those directions is indicated.

TRIASSIC, TRIASSIC(?), AND JURASSIC SYSTEMS

GLEN CANYON GROUP

Overlying the Chinle Formation in large parts of Utah and Arizona are two thick massive cliff-forming sandstones separated by a zone of thinner bedded sandstone. The name Glen Canyon Group, derived from Glen Canyon on the Colorado River where these rocks form the canyon walls, was applied to this sequence of rocks by Baker and others (1927, p. 802). The Glen Canyon Group, as originally defined, consisted in ascending order of Wingate Sandstone, Todilto(?) Formation, and Navajo Sandstone and was described more fully by Gilluly and Reeside (1928, p. 68–73) and by Gregory and Moore (1931, p. 60–68). The name Kayenta Formation (Baker and others, 1931) subsequently replaced Todilto(?) Formation when stratigraphic studies showed that the Todilto Limestone of northwestern New Mexico was younger than the middle unit of the Glen Canyon Group (Baker and others, 1936, p. 5).

Later studies of the Glen Canyon Group (Harshbarger and others, 1957) resulted in the introduction of a new unit, the Moenave Formation, above the Wingate Sandstone. The Moenave Formation is closely related to the Kayenta Formation (Harshbarger and others, 1957, p. 13–17) but does not extend into the Cedar Mesa-Boundary Butte area.

Fossils are uncommon everywhere in the Glen Canyon Group, and none were found in the report area. Small collections of fossils from adjacent areas are listed and discussed by Harshbarger, Repenning, and Irwin (1957, p. 25–31) and by Lewis, Irwin, and Wilson (1961, p. 1437–1440).

Recently the formations of the Glen Canyon Group have undergone several age reassignments. These are discussed by Baker, Dane, and Reeside (1936, p. 55–58), Averitt and others (1955) and Harshbarger, Repenning, and Irwin (1957, p. 25–32). The most recent age assignments are discussed in a report by Lewis, Irwin, and Wilson (1961) and the formations of the Glen Canyon Group now have the following assignments:

Navajo Sandstone	Triassic(?) and Jurassic
Kayenta Formation	Late Triassic(?)
Moenave Formation	Late Triassic(?)
Wingate Sandstone	Late Triassic

Lewis, Irwin, and Wilson (1961, p. 1440) further stated:

> We would have suggested reassignments of the Kayenta and Moenave Formations and also the lower part of the Navajo Sandstone to the Triassic without query, except that: (1) the formations are unfossiliferous in most areas; (2) there are still some differences of opinion regarding the age of some of the fossils.

WINGATE SANDSTONE

Dutton (1885, p. 136–137) applied the name Wingate to a prominent sandstone forming a cliff above the Chinle Formation north of Fort Wingate, N. Mex. The name Wingate was then extended to a cliff-forming sandstone overlying the Chinle in parts of Arizona and Utah. Subsequent work suggested that the sandstone exposed at Fort Wingate was younger than the Wingate Sandstone of Utah and Arizona, and Dutton's type locality was abandoned (Baker and others, 1947, p.

1666–1668). More recent stratigraphic studies, however, show that the Wingate Sandstone of Arizona and Utah is present in the lower half of the cliff at Fort Wingate (Harshbarger and others, 1957, p. 8).

In the report area, the Wingate Sandstone forms sheer cliffs, facing west along Comb Ridge. At places erosion has etched the Wingate into spires and pinnacles such as Moses Rock and Mule Ear, but generally along Comb Ridge the Wingate forms a smooth-faced (fig. 8) nearly vertical cliff. The sandstone tends to weather out along vertical joints, and the huge blocks loosened from the cliff face litter the underlying Chinle Formation. In the southern and southeastern parts of the area, the Wingate Sandstone is exposed in sheer cliffs along Chinle and Gothic Washes. At places, alcoves are developed near the base of the cliff of Wingate. The large cliff dwelling shown in figure 8 (Poncho House) is along one of these alcoves. A few small shelters are also contained in these alcoves along Gothic Wash.

Throughout the report area the Wingate Sandstone is a rather uniform moderate reddish orange to light brown, but at places the sandstone is black on weathered surfaces due to desert varnish. The sandstone is very fine to fine grained and is composed of well-sorted subround to round clear and iron-stained quartz grains. Dark accessory minerals are common. Large-scale crossbedding is characteristic of the Wingate Sandstone. Locally the basal few feet are parallel bedded and contain a small number of coarse grains.

The Wingate Sandstone is about 340 feet thick in the area just north of Moses Rock. According to Sears (1956, p. 196), the Wingate is about 275 feet thick north of the San Juan River, and Witkind and Thaden (1963, p. 35) reported it to be 210 feet thick in the area immediately south of the Arizona-Utah State line.

The lower contact is placed above the upper pale red ledge of unit 3 in the underlying Chinle Formation. Generally the base of the Wingate is sharp and even, but at places is a wavy surface with less than half a foot of relief. In the Monument Valley area, this contact between the Chinle Formation and Wingate Sandstone is considered to be conformable (Baker, 1936, p. 50; Mullens, 1960, p. 290; Witkind and Thaden, 1963, p. 35).

The sweeping crossbeds and uniform lithology suggest that the Wingate Sandstone is an eolian deposit. Regional evidence from heavy minerals, particle-size analyses, the character of animal tracks, and the nature of intertonguing with fluviatile deposits that further supports an eolian interpretation is discussed by Harshbarger, Repenning, and Irwin (1957, p. 11–12). In nearby areas of southeastern Utah, irregularly bedded deposits (Baker, 1936, p. 50) and a lens of limestone

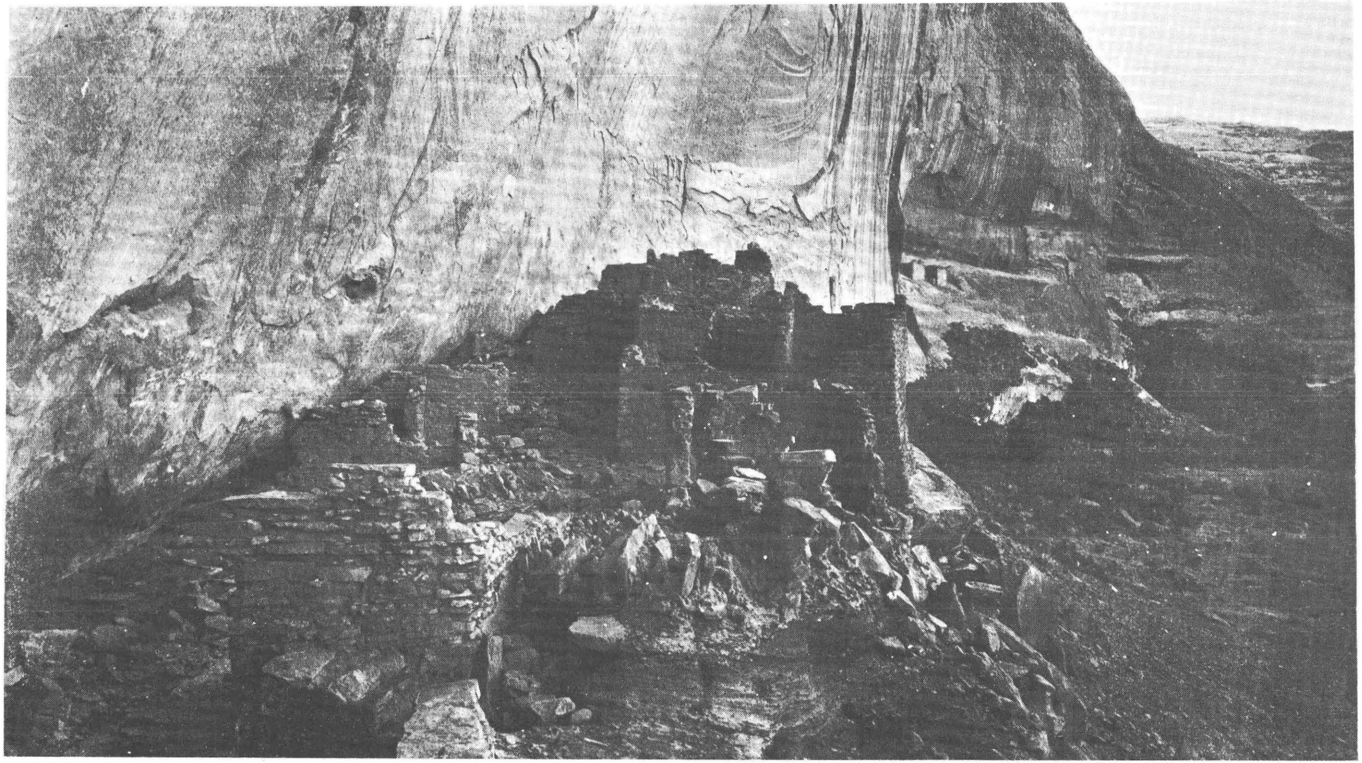

FIGURE 8.—Towering smooth-faced wall of Wingate Sandstone along Chinle Wash and Comb Ridge. Alcoves, some containing cliff dwellings such as this one (Poncho House), are common at the base. Photographed by W. H. Jackson in 1875. (Photograph courtesy of Peabody Museum, Harvard University.)

(Mullens, 1960, p. 292) in the basal part of the Wingate indicate that fluviatile or lacustrine conditions continued at some localities in the Monument Valley area for a short time after the start of Wingate deposition. The crossbeds of the Wingate dip southeast and, according to Poole (in McKee and others, 1959, p. 24), indicate that great quantities of sand were transported by the wind from northwest to southeast across parts of southeast Utah and northeast Arizona.

KAYENTA FORMATION

The name Kayenta Formation was first used by Baker, Dane, and McKnight (1931), and subsequently the unit was described in greater detail by Baker (1933, p. 44–46) and by Baker, Dane, and Reeside (1936). The type locality is along Comb Ridge about 1 mile north of Kayenta, Ariz., 25 miles south of the Cedar Mesa-Boundary Butte area.

The Kayenta Formation is well exposed along Comb Ridge and Chinle Wash in a relatively narrow band. At places, where the Kayenta lies flat, the lower part forms a bench above the Wingate Sandstone, but more commonly the Kayenta occurs as a slight reentrant separating the massive underlying Wingate from the overlying Navajo Sandstone. It is also present in the area 2–3 miles east of Boundary Butte, where it forms extensive dip slopes above the Wingate. Viewed from a distance, the Kayenta stands out as a zone of ledges that are thinner and irregularly bedded and are pale-red tinged with a purple cast that contrasts markedly with the adjacent formations. The Kayenta Formation, at places, supports prominent clusters of plants, which mark the site of springs.

The Kayenta consists mainly of sandstone and minor amounts of interbedded siltstone and shale. The sandstone beds are very fine to coarse grained and at places are conglomeratic. The conglomerate generally consists of sandstone, clay, and chert pebbles as much as 1 inch across dispersed in a sandstone matrix. Here and there irregularly shaped dark-tan and light-gray calcareous nodules as much as 9 inches across are scattered through the beds. The sandstone beds are as much as 15 feet thick and are lenticular and have parallel bedding or small-scale crossbedding. Sandstone beds are pale red, white, tan, reddish orange, and brownish orange. Dark-reddish-brown silty shale and siltstone form beds that generally are less than half a foot thick but at places are as much as 5 feet thick.

Section of Kayenta Formation measured 2 miles north of Utah-Arizona State line on large stream trending southwest from Chinle Wash

Navajo Sandstone.	
Kayenta Formation:	*Feet*
13. Siltstone and sandstone; reddish-brown siltstone; white fine-grained sandstone; unit forms niche	0.5
12. Sandstone, grayish-orange, fine-grained, parallel- and cross-bedded; weathers brown; forms ledge	15.0
11. Shale, dark-reddish-brown, slightly silty; near top seamed with white very fine grained ¼-to-½-in.-thick sandstone dikes; unit forms slope	7.0
10. Sandstone, white, very fine to fine-grained, parallel-bedded, hard; forms notable ledge in this area	11.5
9. Sandstone, white, fine-grained, parallel- and irregularly-bedded; lower half contains sandy limestone nodules; upper half contains medium to coarse grains; forms rounded to steep outcrop	11.5
8. Sandstone, white, fine-grained, crossbedded; medium to coarse grains concentrated along cross lamination; forms rounded slick rim	5.0
7. Sandstone, white, fine-grained; crossbedded and parallel-bedded; contains limestone nodules in lower half; forms rounded slick rim	15.0
6. Sandstone, pale-red, very fine grained, crossbedded; thin calcareous and arenaceous dikes cut unit; contains limestone nodules; upper half of unit is locally conglomeratic having sandstone pebbles as much as ¾ in. across; unit forms slick rim	7.5
5. Sandstone, brownish-orange, very fine grained; lower half parallel bedded and contains numerous rounded coarse grains of quartz and chert; upper half crossbedded	4.5
4. Sandstone, pale-red, fine-grained; contains sandy limestone nodules; bedding irregular	2.0
3. Sandstone, pale-red, very fine to coarse-grained; conglomeratic in lower 2 ft., having sandstone pebbles as much as 1 in. across; bedding irregular; forms sloping bench	6.0
2. Sandstone, like unit 1 except crossbedded; forms ledge	4.0
1. Sandstone, brownish-orange, very fine grained; resembles underlying Wingate Sandstone except bedding is parallel; forms rounded slick rim	11.0
Total thickness of Kayenta Formation	100.5
Wingate Sandstone.	

According to Sears (1956, p. 197), the Kayenta Formation is 126 feet thick in the area north of the San Juan River. About 4 miles south of the river it is 128 feet thick, and near the Arizona-Utah State line along Chinle Wash it is 100 feet thick. The Kayenta thins eastward and is 35 feet thick in the area about 2 miles east of Boundary Butte.

Although the irregularly bedded Kayenta Formation contrasts markedly with the Wingate Sandstone, the contact between the two formations is difficult to place except by close examination. At places, beds at the base of the Kayenta resemble the sandstone in the underlying Wingate, but the lower contact is placed below all the lenticular beds that show parallel-bedded or small-scale crossbeds and above the large-scale crossbeds of the Wingate Sandstone. The lower contact at most places appears to be a surface of erosion with relief of 1–3 feet.

According to Harshbarger, Repenning, and Irwin (1957, p. 18), the basal contact of the Kayenta at the type locality is erosional. At one locality, in the nearby Carrizo Mountains area, Strobell (1956) noted that boulders of Wingate Sandstone occur in the base of the Kayenta Formation. Elsewhere, in the Monument Valley area of Utah, Mullens (1960, p. 294) and Baker (1936, p. 51) reported that the contact between the Kayenta and Wingate at some places is erosional, whereas at other places it is arbitrary. According to Witkind and Thaden (1963, p. 36), this same contact in the Monument Valley area of Arizona is gradational and transitional and no break between the formations is apparent.

The generally coarser grains as compared to adjacent formations, the irregular and lenticular bedding, and the nature of the crossbeds suggest that the Kayenta Formation is a fluviatile deposit. Invertebrate fossils found in the Kayenta are all fresh-water forms (Harshbarger and others, 1957, p. 19). A regional study of the orientation of the crossbeds indicates that the Kayenta Formation was deposited by streams that flowed generally to the west from a positive area in southwestern Colorado and northwestern New Mexico (Poole, 1961, p. C141).

NAVAJO SANDSTONE

The Navajo Sandstone was named and described by Gregory (1917, p. 57–59) and is the uppermost formation of the Glen Canyon Group. The name of the formation is derived from the Navajo country in general, where it is so widely displayed.

The Navajo Sandstone is exposed extensively east of Comb Ridge in a belt of outcrop that is about 1 mile wide in the north and as much as 9 miles wide in the southern part of the area. It forms the principal surface rock of the irregular, rolling, and hummocky Nokaito Bench. Where Chinle Wash has cut through the Glen Canyon Group, the Navajo Sandstone forms the upper canyon walls. North of the San Juan River, spires and knobs of the Navajo Sandstone form part of the serrated crest of Comb Ridge. The Navajo Sandstone weathers readily to loose sand, which is accumulated by the prevailing southwest wind into scattered dunes throughout most of the outcrop area.

The Navajo Sandstone exposed in the report area is grayish orange and generally weathers buff or tan. It is composed of very fine to fine-grained well-sorted subround generally clear quartz grains and minor amounts of accessory minerals. The Navajo Sandstone is conspicuously and extensively marked by high-angle and large-scale crossbeds. The dip of the crossbeds was not measured in the report area, but in the areas to the south, Hodgson (1961, p. 12) found the dip to be dominantly eastward.

Here and there in the upper part of the Navajo Sandstone are thin beds of light-gray limestone. The limestone beds are as much as 2–3 feet thick and locally at the base contain some thin lenses of dark reddish-brown siltstone and shale. A sample from one of these limestones shows a calcite-dolomite ratio of 100:0, a trace of magnesium, and less than 6 percent insoluble residue. The limestone beds, where exposed, have a circular or more commonly an elongate pattern in plan view and may be as much as 4,000 feet long. At places these lenticular limestone beds form a protective cap on mesas and flat-topped ridges that are as much as 100 feet high.

The Navajo Sandstone is 405 feet thick on the west side of Chinle Wash about 1½ miles north of the southern border. It is 200 feet thick in the area about 3 miles east of Boundary Butte (Strobell, 1956). On the basis of calculations made from aerial photographs, Sears (1956, p. 198) reported an average approximate thickness of 341 feet for the Navajo north of the San Juan River.

The basal contact is generally sharp and is placed where the bedded deposits of the Kayenta Formation give way to the massive cross-bedded deposits of the Navajo. Generally, too, the Navajo Sandstone is finer grained overall than the Kayenta. Locally, however, the Navajo intertongues with the underlying Kayenta Formation. At one place near the mouth of Chinle Wash the contact between the formations is lowered abruptly about 40 feet by this intertonguing.

The Navajo Sandstone is characterized by great sweeping crossbeds and a uniform lithology and like the Wingate Sandstone is believed to be of eolian origin. Baker, Dane, and Reeside (1936, p. 51–52) cited additional evidence to support this concept. The crossbeds dip to the east and suggest that the prevailing winds blew to the east Thin beds of limestone in the Navajo are thought to represent deposition in ephemeral lakes. The limestone appears to be in the upper part of the formation and may reflect a climatic change to wetter conditions at the end of Glen Canyon deposition.

JURASSIC SYSTEM

SAN RAFAEL GROUP

A report on the stratigraph of the Moab region, Utah (Baker and others, 1927, p. 787) contains the first published reference to the San

Rafael Group. The group was described in detail by Gilluly and Reeside (1928, p. 73–80) and derives the name from the San Rafael Swell of central Utah. In the San Rafael Swell, the group consists, in ascending order, of the Carmel Formation, the Entrada Sandstone, and the Curtis and Summerville Formations. The Curtis Formation is not present in the Cedar Mesa-Boundary Butte area, but an additional unit, the Bluff Sandstone, is at the top of the San Rafael Group.

The San Rafael Group is unfossiliferous in the report area, but parts of the group, particularly the Carmel and Curtis Formations, are fossiliferous elsewhere on the Colorado Plateau. The fossil evidence indicates that the entire San Rafael Group is of Middle Jurassic (lower part of Carmel Formation) and Late Jurassic age.

CARMEL FORMATION

The Carmel Formation was named by Gregory and Moore (1931, p. 72–76) for exposures near Mount Carmel in Kane County, Utah. The Carmel Formation near the type locality contains fossiliferous limestone and interbedded gypsum, sandstone, and shale. In the report area, limestone is absent, and the formation consists entirely of interbedded sandstone and shale.

In the Cedar Mesa-Boundary Butte area, the Carmel Formation lies unconformably on the Navajo Sandstone and forms an irregular slope beneath the overlying cliff- or bench-forming Entrada Sandstone. The Carmel is exposed along Butler and Gothic Washes, and erosional remnants are present along the San Juan River and along the southern border. The Carmel Formation is well exposed at a few places near the San Juan River and near Boundary Butte. Elsewhere, large parts of the formation are completely obscured by recent dune sand and alluvium.

The Carmel Formation consists of interbedded shale and sandstone. The shale commonly forms slopes (fig. 9) interrupted by sandstone ledges. Shale beds compose the bulk of the Carmel Formation. The shale is dark reddish brown, micaceous, and at places is silty or sandy. The shale occurs in beds as much as 11 feet thick, but the beds generally range from 1 to 5 feet in thickness. Sandstone beds are reddish orange or yellowish gray and consist of fine- to medium-grained poorly sorted quartz grains. The sandstone generally is argillaceous and well cemented by calcium carbonate. Here and there the sandstone is crossbedded but generally is massive or gnarly bedded. Sandstone beds generally are about 1–3 feet thick, but some, especially in the upper part of the Carmel Formation, are as much as 10 feet thick. In the lower part of the Carmel Formation there are polygonal-shaped features parallel to the bedding and as much as 7 feet

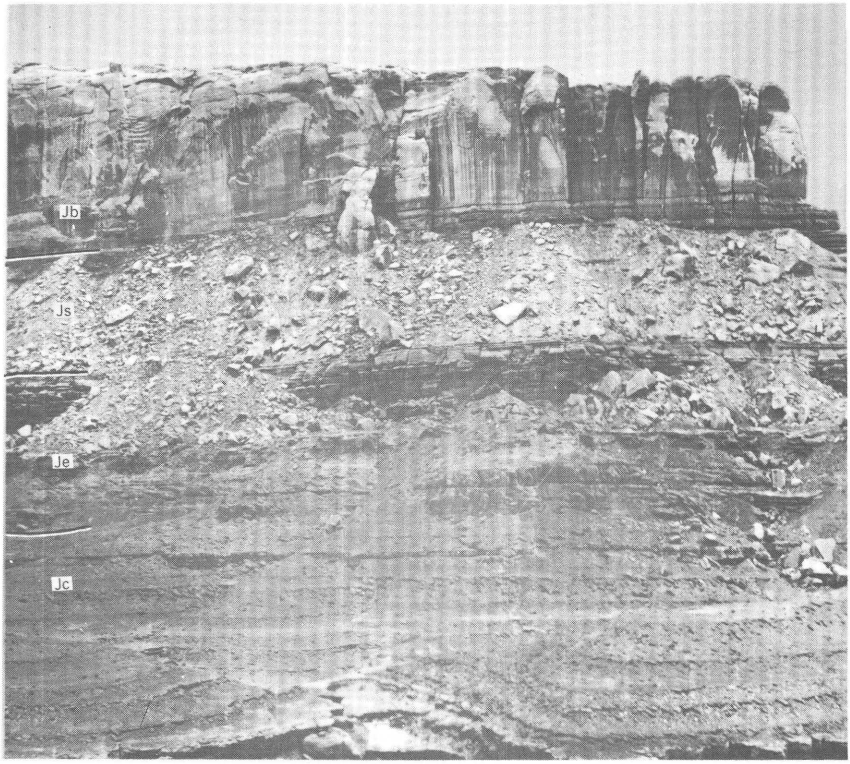

FIGURE 9.—West wall of Casa del Eco Mesa. On south side of San Juan River in sec. 3, T. 41 S., R. 21 E. Carmel Formation (Jc); Entrada Sandstone (Je); Summerville Formation (Js); and Bluff Sandstone (Jb).

across. The sides of the polygons consist of sandstone and where exposed form ribs around a center from which softer material has been removed by recent erosion. These features are considered to be casts of large mudcracks, which were formed at the top of a shale bed and later filled with sand.

Section of Carmel Formation measured near Boundary Butte in secs. 24, 25, and 26, T. 43 S., R. 21 E.

Entrada Sandstone.	
Carmel Formation:	*Feet*
27. Shale, dark-reddish-brown, silty; forms slope	4.0
26. Sandstone, like unit 10	1.0
25. Shale, like unit 15	8.3
24. Sandstone, reddish-orange, fine-grained, hard; forms ledge	1.0
23. Shale, dark-reddish-brown, very fine grained, silty; reddish-orange sandstone interbedded in upper 2 ft.; forms slope	5.0
22. Sandstone, reddish-orange, very fine grained, hard; forms ledge	.6

Section of Carmel Formation measured near Boundary Butte in secs. 24, 25, and 26, T. 43 S., R. 21 E.—Continued

	Feet
Carmel Formation—Continued	
21. Shale, like unit 15	3.0
20. Sandstone, white, fine-grained, crossbedded, well-cemented; forms ledge	.7
19. Shale, like unit 15; thin siltstone interbedded in upper 2 ft	5.0
18. Sandstone, like unit 10	1.0
17. Shale, like unit 15	1.5
16. Sandstone, white, fine-grained, crossbedded; forms slight ledge	.4
15. Shale, dark-reddish-brown; forms slope	3.4
14. Sandstone, reddish-orange, fine-grained; a scattering of medium grains, irregularly bedded	2.6
13. Covered; probably shale	.4
12. Sandstone, reddish-orange, fine-grained; a scattering of medium grains; forms ledge	.5
11. Shale, dark-reddish-brown; forms slope	4.0
10. Sandstone, moderate-reddish-orange, medium-grained, hard; forms ledge	1.0
9. Poorly exposed; lower 3 ft. contains white fine-grained sandstone and a scattering of medium grains; remainder of unit appears to be dark-reddish- brown shale; unit forms long slope	11.0
8. Sandstone, reddish-orange, fine- to medium-grained, hard; weathers dark brown; forms ledge	1.0
7. Shale, dark-reddish-brown, poorly exposed; a thin fine- to medium-grained sandstone near base; forms slope	5.0
6. Sandstone, white and reddish-orange, fine-grained; a scattering of medium hard calcareous grains; forms ledge	1.5
5. Shale, dark-reddish-brown; contains a 6-inch-thick white fine-grained sandstone in middle which has a scattering of medium grains	3.3
4. Sandstone, like unit 2, but contains more medium grains	1.0
3. Shale and siltstone, interbedded, dark reddish-brown; forms slope	5.0
2. Sandstone, reddish-orange, mottled in white bands, fine- to medium-grained, poorly sorted, hard, irregularly bedded; forms ledge	1.0
1. Poorly exposed; appears to be very fine grained, reddish-brown sandstone, soft; forms slope	5.0
Total thickness of Carmel Formation	77.2
Navajo Sandstone.	

In the lower part of Butler Wash, half a mile north of Utah State Highway 47, the Carmel Formation is 108 feet thick (Sears, 1956, p. 199). It is 86 feet thick (Strobell, 1956) on the south side of the San Juan River near Bluff and 77 feet thick at Boundary Butte. The Carmel Formation is thickest, 164 feet, in and near sec. 16, T. 42 S., R. 22 E.

The contact between the Navajo Sandstone and the Carmel Formation is an unconformity marked by an abrupt change in lithology.

The finer grained crossbedded Navajo Sandstone is truncated and overlain by shale and coarser grained ledge-forming sandstone beds of the Carmel Formation. Here and there the top part of the Navajo Sandstone contains chert pebbles as much as half an inch across. Locally there is slight wavy relief of not more than 1 or 2 feet at the contact. Regionally the relief developed on the top of the Navajo Sandstone is more pronounced as indicated by the variable thickness of the Carmel Formation. This relief reaches an extreme near Red Mesa, about 5 miles east of the report area, where the Carmel is absent and the overlying Entrada Sandstone rests on a local high in the Navajo Sandstone (Strobell, 1956). The unconformable contact between the Carmel and Navajo does not necessarily represent a long hiatus, for in southwest Utah the Carmel and Navajo intertongue (Lewis and others, 1961, p. 1439), indicating continual deposition between the formations in some areas.

According to Baker, Dane, and Reeside (1936, p. 45–46 and fig. 11), the Carmel Formation is thickest in southwestern and central Utah and in those areas contains fossiliferous marine rocks. The Carmel thins and grades into a red nonfossiliferous facies in southeast Utah and northeast Arizona. The Cedar Mesa-Boundary Butte area lies within the red nonfossiliferous facies, which probably represents deposition in a lagoonal or estuarine environment marginal to the sea (Harshbarger and others, 1957, p. 44).

ENTRADA SANDSTONE

Conformably overlying the Carmel Formation is the Entrada Sandstone, which was named and defined by Gilluly and Reeside (1928, p. 76–78). The name of the formation is derived from Entrada Point in the San Rafael Swell, Utah.

The Entrada Sandstone is well exposed along Butler Wash and at places near the San Juan River. It is also well exposed near Boundary Butte and in parts of T. 42 S., R. 22 E. For long distances along Gothic Wash, the Entrada generally is completely obscured by windblown sand. Where well exposed, the Entrada Sandstone forms a cliff and bench above the irregular slope formed on the underlying Carmel Formation.

The Entrada Sandstone is a prevailingly reddish-orange to moderate reddish-brown sandstone. At places the sandstone contains small—about a quarter of an inch across—white or light greenish-gray spots and is streaked with white beds or bands parallel to bedding planes. The sandstone is composed of very fine to fine-grained subround to subangular quartz. Here and there are a scattering of medium to coarse grains of white chert and clear or frosted well-rounded quartz. Sandstone beds are massive and parallel bedded, and some crossbedded units are present, especially in the southern part of the area. The middle part of the Entrada Sandstone generally is silty, well cemented, and tends to weather into rounded spheroidal forms called stone babies, pillows, or hoodoos. This middle hoodoo zone occurs throughout the Cedar Mesa-Boundary Butte area and permits division of the Entrada Sandstone into three members—upper and lower members separated by a middle hoodoo member.

The lower member of the Entrada Sandstone forms a prominent ledge and consists of medium-bedded sandstone. At most places a prominent bench is developed on the lower member. The lower member contains chert and calcite, which, near Tohonadla Springs, occur as disk-shaped masses as much as 1 foot across. These masses of chert and calcite are widely dispersed and where the lower member forms a sheer cliff are not readily apparent. Where a prominent bench is developed on the lower member, as along Butler Wash, near Tohonadla Springs, and near Boundary Butte, chert and calcite crystals are accumulated by weathering and litter the outcrop. Conspicuous white generally crossbedded sandstone beds about 1–3 feet thick are at most localities. One white sandstone bed is at the top of the lower member at all localities. At other places, white sandstone beds may be at the base or near the middle of the lower member. Except for the white sandstone beds, the lower member is reddish brown or reddish orange. Beginning at a point about 4 miles north of Utah State Highway 47, however, the lower member grades into a prominent white ledge-forming sandstone, which constitutes the lower member northward along Butler Wash. The lower member is 44–48 feet thick near the San Juan River, 42 feet thick near Tohonadla Springs, and 26–30 feet thick near Boundary Butte.

The middle hoodoo member is hard, well cemented, and forms a prominent cliff. Though commonly a moderate reddish brown to reddish orange, the middle member is locally a distinct brick red. The calcareous middle hoodoo member is a very fine grained sandstone that contains a considerable amount of silt and clay. There are locally widely scattered small amounts of fine- to coarse-grained quartz and chert grains. The rounded spheroidal forms that characterize the middle member are conspicuous from the northern border as far south as Tohonadla Springs. Near Boundary Butte the hoodoos, though clearly recognizable, are not as well developed as farther north. The middle hoodoo member is 55–63 feet thick near the San Juan River, 37 feet thick near Tohonadla Springs, and 22–23 feet thick near Boundary Butte.

The upper member of the Entrada Sandstone is a fine- to medium-grained sandstone that forms a smooth ledge above the middle hoodoo member. At Boundary Butte and near Tohonadla Springs the upper member consists of white sandstone beds ½–3 feet thick at the base and top, separated by a reddish-brown or reddish-orange sandstone bed that is 6–20 feet thick. The white sandstone beds at places are crossbedded. In sec. 9, T. 41 S., R. 21 E., the upper member consists of two beds. The lower white-banded reddish-orange sandstone is 11 feet thick, whereas the upper one is reddish orange and about 9 feet thick. About half a mile north of Utah State Highway 47, near Butler Wash, the upper sandstone member is reddish brown, banded light gray. North of the San Juan River the upper member of the Entrada Sandstone is 12 feet thick; south of the river it is 10–20 feet thick.

According to Sears (1956, p. 201), the entire Entrada Sandstone along Butler Wash has a uniform thickness of about 150 feet. One mile south of the San Juan River the Entrada is 123 feet thick. The Entrada Sandstone thins southward and ranges from 66 to 85 feet in thickness in the area near Tohonadla Springs and Boundary Butte. The following two sections—one measured near Bluff, the other near Boundary Butte—show this southward thinning as well as the character of the three persistent members of the Entrada Sandstone described in this report.

Section of Entrada Sandstone measured in sec. 9, T. 41 S., R. 21 E.

Summerville Formation.	
Entrada Sandstone:	
Upper member:	*Feet*
8. Sandstone, reddish-orange, fine-grained; forms rounded ledge	8.8
7. Sandstone, white, banded reddish orange, fine-grained; parallel-bedded except a 2-ft thick medium-grained crossbedded sandstone at 4 ft; unit forms ledge	11.0
Middle hoodoo member:	
6. Sandstone, reddish-orange, very fine grained, silty; scattering of fine to medium grains; unit weathers into rounded spheroidal hoodoos; forms cliff	55.5
Lower member:	
5. Sandstone, reddish-orange, very fine to fine-grained, massive-bedded; a white calcareous sandstone bed at top forms a prominent marker zone; unit forms cliff	32.0
4. Siltstone, darke-reddish-brown, sandy and shaly; forms niche	.9
3. Sandstone, reddish-orange, fine-grained, parallel-bedded; forms ledge	9.0
2. Siltstone, like unit no. 4	.1
1. Sandstone, like unit no. 3	6.0
Total thickness of Entrada Sandstone	123.3
Carmel Formation.	

Section of Entrada Sandstone in sec. 26, T. 43 S., R. 21 E.

	Feet
Summerville Formation.	
Entrada Sandstone:	
Upper member:	
7. Sandstone, reddish-orange in lower part, white in upper part, very fine to fine-grained, irregularly bedded; forms ledge	0.7
6. Sandstone, reddish-orange, fine-grained, well-sorted, parallel- and irregular-bedded	15.0
5. Sandstone, white, fine-grained, well-sorted, parallel-bedded and crossbedded, hard; forms bench on unit 4	1.0
Middle hoodoo member:	
4. Sandstone, reddish-orange, very fine to fine-grained, silty, parallel-bedded; tends to weather to rounded forms but hoodoos are not well developed	22.0
Lower member:	
3. Sandstone, banded white and reddish-brown, very fine to fine-grained; no bedding apparent	1.5
2. Sandstone, reddish-orange and reddish-brown, fine-grained; scattering of medium grains; crossbedded and irregularly bedded	18.3
1. Sandstone, reddish-orange, fine-grained, well-cemented; scattering of medium grains; bedding obscure; forms ledge	7.8
Total thickness of Entrada Sandstone	66.3
Navajo Sandstone.	

The lower contact of the Entrada Sandstone with the Carmel Formation is conformable and sharp. It is placed above the highest characteristic dark-reddish-brown shale bed of the Carmel Formation. Sandstone beds in the upper part of the Carmel Formation strongly resemble the Entrada Sandstone and suggest continual deposition between the two formations.

In central Utah, the Entrada Sandstone is more than 1,800 feet thick and probably is a normal marine deposit (Wright and Dickey, 1958 (p. 174–176). In the Cedar Mesa-Boundary Butte area the Entrada is much thinner and represents deposition in areas marginal to the marine basin farther north. The clean well-sorted sands of the upper and lower members contain many horizontal bedding planes and for the most part are believed to represent deposition in shallow water. Locally, small areas in the lower member are characterized by sweeping crossbeds and may reflect eolian deposition where the member was exposed temporarily to subaerial conditions. The middle member of the Entrada within the report area is similar to the dominant lithology of the Entrada of central Utah and may have been deposited during an invasion of the deeper marine waters.

SUMMERVILLE FORMATION

Above the Entrada Sandstone rises the crinkled and banded Summerville Formation. Gilluly and Reeside (1928, p. 79–80) named the Summerville Formation for exposures at Summerville Point in the San Rafael Swell, Utah.

The Summerville is well exposed in steep slopes and cliffs at places near Bluff and Boundary Butte. Along Butler Wash the lower part of the formation is generally covered, and the upper part is well exposed. In the area along Gothic Wash the exposures vary, at some places the Summerville is completely obscured, but at other places, as north of Tohonadla Springs, the formation forms well-exposed cliffs. In general, along Gothic Wash the formation is somewhat better exposed than the underlying parts of the San Rafael Group.

The Summerville consists of interbedded sandstone, shaly siltstone, and thin minor shale beds. The sandstone beds are tan, grayish orange or buff and range in thickness from 1 to 8 feet. The very fine to fine-grained and silty sandstone beds locally contain a scattering of medium grains and generally are parallel or irregularly bedded but locally are crossbedded. The reddish-brown shale and siltstone beds occur mainly as thin niches between the hard calcareous sandstone beds. The Summerville Formation weathers to a characteristic banded cliff formed by the alternation of light- and dark-colored beds.

Throughout the area, parts of the Summerville are intricately contorted or crinkled (fig. 10) as a result of intraformational deformation. At places along Butler Wash the entire Summerville is contorted (Sears, 1956, p. 201). From Bluff southward, the lower part of the Summerville Formation, resting on the Entrada Sandstone, is contorted, whereas the upper part is evenly bedded. The contorted zone at the base of the Summerville is about 85 feet thick in the area between Bluff and Tohonadla Springs. Near Boundary Butte it is 71 feet thick.

Section of Summerville Formation in secs. 25 and 26, T. 43 S., R. 21 E.

Bluff Sandstone.	
Summerville Formation:	*Feet*
20. Sandstone and shale, interbedded, grayish-orange, reddish-brown; sandstone fine grained and has scattering of medium grains; unit poorly exposed	8.5
19. Sandstone, buff, fine-grained; scarce medium-grains, parallel bedded; forms lenticular knobby ledges	7.5
18. Shale, brown, arenaceous; two 5-in. thick sandstone beds, one near base and one near top	5.0
17. Sandstone, white, fine- to medium-grained, crossbedded; forms ledge	3.0

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Section of Summerville Formation in secs. 25 and 26, T. 43 S., R. 21 E.—Continued

	Feet
Summerville Formation—Continued	
16. Sandstone, white, mottled brown, fine-grained; forms ledge	3.2
15. Shale, brown, arenaceous; forms niche	.7
14. Sandstone, brown, fine-grained, parallel-bedded, hard; forms ledge	2.6
13. Sandstone and shale, like unit 3	4.2
12. Sandstone, white, fine-grained, hard; weathers brown; forms ledge	1.5
11. Shale, dark-reddish-brown, arenaceous; forms niche	.6
10. Sandstone, white, fine-grained, friable; weathers brown; thin lenses of shale near top	2.9
9. Sandstone, banded white and brown; conatins shale partings at top and bottom	4.0
8. Sandstone, white, fine-grained; weathers brown; basal 1 ft. covered and may be shale; whole unit is soft and forms slope	2.5
7. Sandstone, light-tan, fine-grained, parallel- and irregular-bedded; forms ledge	1.2
6. Sandstone, banded white and brown, fine-grained, friable, parallel-bedded	4.7
5. Sandstone and shale, like unit 3	16.9
4. Sandstone, white, very fine grained, hard; weathers brown; forms ledge	2.2
3. Sandstone, buff, fine-grained, hard; in 6-in. thick beds separated by pale-brown shaly partings; weathers to rounded form; unit forms cliff unit is contorted	14.0
2. Sandstone, white, fine-grained, hard; forms ledge; unit is contorted	2.0
1. Shale and sandstone, irregularly mixed; reddish-orange in lower half- light-brown in upper half; contains blocks of reddish-orange, fine-grained sandstone in lower part; unit is contorted	55.0
Total thickness of Summerville Formation	142.2

According to Sears (1956, p. 202), the Summerville Formation along Butler Wash ranges in thickness from 146 to 162 feet, averaging 152 feet. South of the San Juan River, the Summerville Formation is 148 feet thick just south of Bluff, 159 feet near Tohonadla Springs, and 142 feet near Boundary Butte.

The basal contact of the Summerville Formation with the Entrada Sandstone is sharp and apparently conformable. At all exposures a white or reddish-orange clean sandstone bed is at the top of the Entrada Sandstone. The basal beds of the Summerville are crinkled and contain dark-reddish-brown siltstone and shale, which contrast markedly with the underlying Entrada Sandstone.

The generally flat, even and thin bedding of the Summerville Formation suggests deposition in quiet waters. The crumpled, distorted beds at the base of the Summerville are believed to represent movement of water-saturated sediments prior to consolidation (Harsh-

FIGURE 10.—San Rafael Group at Boundary Butte. Boundary Butte igneous feature forms spires at left. Entrada Sandstone (Je); Summerville Formation (Js); and Bluff Sandstone (Jb). Note crinkled lower part of Summerville Formation.

barger and others, 1957, p. 41). Regionally, the Summerville intertongues to the north in central Utah with the marine Curtis Formation (Baker and others, 1936, p. 54). Within the report area the Summerville represents deposition, probably in an estuarine or lagoonal environment, in an area marginal to the Curtis sea.

BLUFF SANDSTONE

The Bluff Sandstone was named by Gregory (1938, p. 58) for the excellent exposures near the town of Bluff, where the sandstone forms prominent cliffs (fig. 9) above the Summerville Formation. Gregory treated the Bluff Sandstone as the basal member of the Morrison Formation. Previously, the Bluff had been similarly assigned to the Morrison by Baker, Dane, and Reeside (1936, p. 15). Later, Craig, Holmes, Cadigan, and others (1955, p. 133) recognized the Bluff as a tongue of the Cow Springs Sandstone (Harshbarger and others, 1951, p. 97), a formation whose type locality lies about 50 miles southwest of Bluff in Arizona. Craig, Holmes, Cadigan, and others (1955, p. 133) further found that the Bluff Sandstone is related to both the underlying Summerville Formation and overlying Morrison Formation. Northward, the Bluff tongues and grades into the Summerville Formation, and southward in northeastern Arizona it intertongues with the Morrison Formation. At present the Bluff Sandstone is considered a separate and the uppermost formation of the San Rafael Group (Sears, 1956, p. 202; Harshbarger and others, 1957, p. 42).

In the northern part of the report area, the thick Bluff Sandstone forms prominent cliffs (fig. 9) that for the most part are virtually unscalable. Near Bluff these bold cliffs sharply outline Tank and Casa del Eco Mesas and Bluff Bench. Along Gothic Wash on the southwest side of Casa del Eco Mesa the cliffs are somewhat less prominent and at places are interrupted and concealed by patches of windblown sand which slope gently downward from the mesa top to the valley floor. The Bluff Sandstone also forms the rolling hummocky surface, largely veneered by windblown sand, over much of Casa del Eco and Tank Mesas and Bluff Bench.

The Bluff Sandstone occurs also in the southern part of the report area near Boundary Butte. There it is much thinner and less prominent (fig. 10) than it is near Bluff, but it forms a distinctive small white cliff at the top of the Summerville Formation.

Near Bluff, the thick massive resistant Bluff Sandstone is yellowish gray to very light gray and weathers tan or buff. Although cliff forming, the Bluff Sandstone is quite friable. It is composed of well-sorted very fine to fine-grained subrounded to rounded grains of quartz and has minor amounts of feldspar, varicolored chert, and dark accessory minerals. Well-rounded medium to coarse grains are scattered throughout the formation or concentrated along laminae. The Bluff Sandstone in the northern part of the area is for the most part crossbedded and has large-scale and high-angle crossbeds. The crossbeds dip in two main directions—one about due east and the other about N. 45° E. (Craig and Cadigan, 1958, p. 185). As much as 60 feet of the lower part of the formation near Bluff commonly consists of a series of beds that have both parallel beds and crossbeds. At places the lower and upper parts of the Bluff Sandstone contain thin lenticular lenses of reddish-brown siltstone.

The Bluff Sandstone is 338 feet thick in sec. 35, T. 40 S., R. 21 E.; it is 276 feet in sec. 24, T. 41 S., R. 21 E., and it is 180 feet thick in sec. 10, T. 42 S., R. 22 E.

The Bluff Sandstone continues to thin southward and is only about 35 feet thick in the area near Boundary Butte. In this area the Bluff is a fine- to medium-grained white sandstone. The lower 23 feet is parallel bedded, whereas the upper 12 feet is crossbedded.

The basal contact is placed where the banded slopes of the underlying Summerville Formation give way to the sheer massive cliff of the Bluff Sandstone. The contact is commonly marked by a thin reddish-brown siltstone that forms a niche. Elsewhere, there is a marked contrast in grain size from the silty and argillaceous beds of the Summerville to the fine- to coarse-grained Bluff Sandstone.

The Bluff Sandstone is characterized by great sweeping crossbeds that are thought to be indicative of eolian deposition. The crossbeds dip to the east and northeast and suggest that the wind blew in that direction. Parallel-bedded deposits near the base of the Bluff probably represent deposition in water. The Bluff Sandstone thins in all directions from a maximum thickness near the town of Bluff. This suggests that the Bluff Sandstone for the most part is a local accumulation of dune sand.

MORRISON FORMATION

Cross (1894, p. 2) first applied the name Morrison Formation to rocks exposed near the town of Morrison in eastern Colorado. Later, in east-central Utah, the Morrison Formation with the Salt Wash Sandstone Member at the base was recognized by Baker and others (1927, p. 806). In parts of San Juan County, Utah, Gregory (1938, p. 58–60) subdivided the Morrison into four members, which were, in ascending order, the Bluff Sandstone Member, Recapture Shale Member, Westwater Canyon Sandstone Member, and Brushy Basin Shale Member. As previously noted, the Bluff Sandstone is now considered a separate formation of the San Rafael Group. Stokes (1944, p. 963–964) subsequently recognized that the Salt Wash Sandstone Member was the lower part of Gregory's Recapture Shale Member.

The Morrison Formation consists of white and yellow lenticular sandstone, which generally forms ledges and benches, and reddish-brown and green shale, which forms slopes. Windblown sand locally conceals much of the Morrison. Within the Cedar Mesa-Boundary Butte area, most of the Morrison has been removed by erosion. The thickest section, which includes only the lower part of the Brushy Basin Member, is exposed in the extreme northeastern part of the area. Elsewhere, Morrison remnants cap mesas near Bluff and Boundary Butte.

Fossils are scarce in the Morrison Formation and none were found during the present investigation. The Late Jurassic age of the Morrison Formation is generally accepted although the exact age of its upper limits is questionable (Imlay, 1952, p. 953). A comprehensive discussion of the age assignment of the Morrison Formation is contained in a report by Baker, Dane, and Reeside (1936, p. 58–63).

According to Craig, Holmes, Cadigan, and others (1955), the lithology, bedding structure, fossils, and regional stratigraphy indicate that the Morrison Formation is dominantly a stream and flood-plain deposit having minor lacustrine deposits. Northeastward-flowing streams, from southwest of the report area, deposited the Salt Wash and Brushy Basin Members. The Recapture and Westwater Canyon Members were deposited by northward-flowing streams from a highland probably in west-central New Mexico.

SALT WASH MEMBER

The Salt Wash Member, named by Lupton (1914, p. 127), occurs only in a small area near Boundary Butte. It consists dominantly of crossbedded lenticular sandstone beds having minor amounts of interbedded shale. The sandstone beds are white and grayish orange, generally weathering light brown. The sandstone consists of poorly sorted very fine to medium subangular to subrounded grains of quartz and minor amounts of chert, feldspar, and dark accessory minerals. Pebbles and small pellets of greenish-gray shale are common throughout the sandstone units. The beds generally are well cemented and tend to form ledges. Low-angle small-scale crossbedding is characteristic.

Light-greenish-gray and grayish-red shale beds are present in amounts that probably do not exceed 10–20 percent of the Salt Wash Member. The shale is silty and sandy and occurs in beds generally less than 5 feet thick.

A complete section of the Salt Wash Member is not exposed within the report area, but 3 miles south of Boundary Butte the member is about 100 feet thick. The Salt Wash is not present on Casa del Eco and Tank Mesas and Bluff Bench. The absence of the Salt Wash in these areas may be due to the greater thickness of the underlying Bluff Sandstone, for Craig and Cadigan (1958, p. 187) noted: "* * * in general, as the Bluff thickens the Salt Wash thins."

Near Boundary Butte there is an abrupt change in lithology, bedding, and topographic expression from the Bluff Sandstone to the Salt Wash Member. The lower contact is marked either by a thin grayish-red shale or by the lowest lenticular channeling sandstone. The Salt Wash also weathers to a steep ragged slope of ledges and benches. The upper contact with the Recapture Member, in adjacent areas, is arbitrary and gradational (Strobell, 1956).

RECAPTURE MEMBER

The Recapture Member was named by Gregory (1938, p. 58). The name is derived from Recapture Creek, which enters the San Juan River about 5 miles above Bluff. In the area near Bluff on Casa del Eco and Tank Mesas, 30–70 feet of Recapture is present as remnants that rest directly on the Bluff Sandstone. A complete section of Recapture occurs in the northeastern part of the map area on Bluff Bench but the basal part of the member is obscured by windblown sand.

The Recapture Member, however, is completely exposed about 2 miles to the east at Recapture Creek. There, at the type locality, the Recapture Member is 285 feet thick and consists of interbedded sandstone and shale. The very light tan and grayish-orange-pink sandstone beds are very fine to medium grained. Pebbles as much as half an inch across occur in one bed in the lower part of the member. The sandstone beds are poorly cemented and tend to be friable. The interbedded shale is grayish red and pale red, arenaceous, and silty and locally contains very thin very fine to fine-grained sandstone beds. At one locality on Recapture Creek the Recapture Member contains about 60 percent shale. Although the amount of shale varies considerably from place to place, the Recapture Member contains a greater proportion of shale than the Salt Wash Member.

Where the Recapture Member rests on the Bluff Sandstone, the basal contact is a wavy surface of erosion. The greatest relief noted at the contact is 27 feet in a channel on the west side of Casa del Eco Mesa. The contact in the Cedar Mesa-Boundary Butte area is generally sharp, especially where dark-colored shale of the Recapture lie on the Bluff Sandstone.

Viewed from a distance, the dark-colored Recapture Member contrasts conspicuously with the lighter colored Bluff Sandstone and overlying Westwater Canyon Member. The friable sandstone and the interbedded shale are not resistant and weather to a characteristic rough slope.

WESTWATER CANYON MEMBER

The Westwater Canyon Member (Gregory, 1938, p. 59) is named for Westwater Canyon, a tributary to Cottonwood Wash, about 12 miles north of the report area. The member, exposed in the extreme northeast corner of the Cedar Mesa-Boundary Butte area, forms a characteristic yellow cliff between the Recapture Member and the overlying Brushy Basin Member.

The Westwater Canyon Member consists of yellowish-brown, grayish-yellow, and buff sandstone, and minor amounts of interbedded shale. The sandstone, generally crossbedded, is fine to medium grained, poorly sorted, and locally, coarse grained and conglomeratic. The interbedded greenish-gray and olive-green shale generally is silty and sandy.

Near the mouth of Recapture Creek, the Westwater Canyon Member is 187 feet thick. The lower contact with the Recapture Member is arbitrary and is placed at the top of the highest grayish-red or pale-red shale bed.

BRUSHY BASIN MEMBER

The Brushy Basin Member (Gregory, 1938, p. 59) derives its name from a locality about 15 miles north of the report area. The member is present in a very small area in sec. 4, T. 40 S., R. 22 E. It is composed dominantly of slope-forming variegated shale containing minor thin sandstone and siltstone beds that commonly form ledges. The top of the Brushy Basin is not exposed in the report area, but on Recapture Creek the member is 243 feet thick. The lower contact is arbitrarily placed at the top of the highest cliff-forming sandstone of the Westwater Canyon Member.

INTRUSIVE ROCKS OF TERTIARY AGE

Intrusive rocks occur in three general areas within the Cedar Mesa-Boundary Butte area—near Mexican Hat, along Comb Ridge, and at and near Boundary Butte. There is no direct evidence for the age of these intrusive bodies, but Williams (1936, p. 148) considered all the volcanic activity in the Navajo country to be of middle and late Pliocene age.

As used in this report, intrusive rocks include igneous dikes, related plugs, and several diatremes formed by volcanic explosions. The intrusive rocks were examined only briefly as a comprehensive and detailed study of the intrusive rocks of the Navajo country is being prepared by other geologists (Shoemaker, 1956, p. 180). In general, the dike rock is lamprophyric, but the diatremes contain agglomerate of sedimentary and igneous rocks, generally cemented by tuff. The dikes and related plugs are described first.

Alhambra Rock (pl. 1) is a conspicuous landmark rising above the surface of the Rico Formation west and southwest of Mexican Hat. The jagged prominence is but part of several northward-trending dikes, whose outcrop length is 4 miles. These dikes are from 2 to 20 feet wide and at places are parallelel by other short thin dikes. At Alhambra Rock the dike widens to about 100 feet, and there the igneous rock contains numerous rounded and angular pebbles and boulders of sandstone, siltstone, and limestone derived from the country rock. The included fragments of country rock generally range in size from 1 to 6 inches, but some are as much as 4 feet across. Angular fragments of granite are also present at Alhambra Rock (Williams, 1936, p. 133). The igneous rock, according to E. S. Larsen (in Woodruff, 1912, p. 90–91), is an augite minette consisting of abundant phenocrysts of biotite and augite and a very few phenocrysts of orthoclase and sodic plagioclase. The phenocrysts are enclosed in a groundmass of orthoclase, diopside, biotite, and opacite.

A little less than 5 miles southeast of Alhambra Rock at the south end of Raplee Ridge, several small disconnected outcrops of igneous rock intrude the Cedar Mesa Sandstone Member of the Cutler Formation. Five small igneous outcrops lie along a line that trends about N. 20° E. The igneous rocks are exposed over a distance of about 800 feet, and the largest body, at the north end, measures about 100 feet wide by 250 feet long. This northern outcrop of igneous rock contains pebbles and cobbles of siltstone, limestone, and gneiss as much as 3 feet across. Because of the linear trend, these outcrops are considered to be apophyses of a dike that is in the process of being uncovered. The rock is a minette having a light-gray aphanitic groundmass that contains a scattering of small dark minerals. In thin section, biotite, augite, and calcite as much as 1.5 mm across are set in a poikilitic groundmass of orthoclase containing microlites of labradorite.

About 150 feet to the west of the dike is a circular area about 120 feet in diameter. A low ridge about 30 feet wide, consisting of rocks of the Cedar Mesa bleached white or very light tan, circumscribes the area. In the center of this circular area is a small outcrop of igneous rock about 5 feet wide by 30 feet long. The extensive bleaching of the strata is unusual and suggests that this small outcrop of igneous rock may represent the top of a small plug that, like the dike to the east, is in the process of being uncovered.

Bell Butte dike, north of the San Juan River, extends for a distance of about 2 miles through secs. 7, 18, and 19, T. 41 S., R. 19 E. and sec. 12, T. 41 S., R. 18 E. Generally, the dike does not rise more than 4 feet above the ground and for long distances is level with the ground.

Where examined, the dike is 7 feet wide and has altered the wallrock for only 1 or 2 inches. The dike is an augite minette similar to Alhambra Rock. According to E. S. Larsen (in Woodruff, 1912, p. 91), it differs from Alhambra Rock in that it contains aegirite, secondary calcite, analcite, and a birefracting zeolite. The aegirite occurs as borders around the augite phenocrysts or as a complete replacement of the augite. It also occurs as crystals piercing the calcite and analcite.

Sears (1956) mapped and described a dike in the area north of the San Juan River. This dike is a few feet wide and less than a quarter of a mile long and trends northwest through secs. 20 and 29, T. 41 S., R. 20 E. According to Charles Milton (in Sears, 1956, p. 203), "The rock is a lamprophyre * * *. In thin section pale-brown biotite and colorless pyroxene, both fresh and euhedral, are abundant in a crystalline dark groundmass too fine grained to be decipherable mineralogically."

In the southeast part of the area, near Boundary Butte, a system of dikes trends northward for about 9 miles. Dikes also extend to the south beyond the south border of the map area for several miles. The dikes are greenish-gray porphyritic minette containing small phenocrysts of biotite and augite. At places the dikes contain a few small rounded pebbles of granite and sandstone as much as 3 inches across.

Associated with these dikes are three plugs consisting of minette and fragments of sedimentary rock and granite. The plugs are circular in plan and form conspicuous conical-shaped hills. The plug in sec. 36, T. 42 S., R. 21 E. consists dominantly of quartzite (an estimated 85 percent) which is apparently metamorphosed sandstone derived from the Glen Canyon Group. Included with the quartzite are blocks and dikes of minette. The two other plugs, one in sec. 24, T. 43 S., R. 21 E., the other in sec. 31, T. 43 S., R. 22 E., consist of an estimated 90–95 percent minette lightly charged with rounded fragments of sandstone, shale, and granite which are generally less than 1 foot across.

In the Cedar Mesa-Boundary Butte area, there are, in addition to the igneous dikes and plugs, several volcanic vents or diatremes drilled through the country rock by volcanic explosions. The diatremes are filled with agglomerate of rounded and angular fragments of sedimentary and crystalline rocks. At some of these diatremes the agglomerate is set in a matrix of tuff seamed by dikes of igneous rock. In the area just to the east and south of Raplee Ridge are three diatremes (pl. 1) alined along the trend of Comb Ridge. Another cluster of diatremes is present at Boundary Butte.

Boundary Butte is a well-known landmark near the Arizona-Utah State line and is the southernmost and highest of five diatremes arranged along a line that trends north. The main Boundary Butte diatreme forms a rude tower and consists of greenish-gray tuff, tuff-breccia, and agglomerate of sedimentary and igneous rocks, all of which are seamed by dikes of minette. The diatremes to the north, not as conspicuous as the main Boundary Butte vent, contain about equal amounts of volcanic rock and country rock. Four diatremes are connected by zones of disturbed country rock and by dikes. The northern diatreme is the smallest and is not connected to the others at the surface. A short distance to the east a curved dike of minette forms an arc that almost surrounds the eastern half of this northern diatreme.

The Mule Ear and Moses Rock diatremes along Comb Ridge have been described by Shoemaker and Moore (1956). The Mule Ear diatreme, named for a nearby sharp peak on Comb Ridge, lies about 1½ miles south of the San Juan River. As described by Shoemaker and Moore (1956, p. 199), it consists of a central zone of several pipe-like masses of serpentine tuff containing a few fragments of basement rock surrounded by large blocks of country rock derived stratigraphically from above and below the present level of the Mule Ear vent. These large blocks of sedimentary rock fill the remainder of the diatreme and are associated with only minor amounts of serpentine tuff.

About 4 miles southwest of the Mule Ear diatreme is a fishhook-shaped feature about 3 miles long called the Moses Rock diatreme. Where the diatreme trends to the southeast it forms a low dark ridge from 200 to 500 feet wide. At first glance it resembles a gravel deposit and contains numerous rounded pebbles that range in diameter from 6 inches to 4 feet in a loose matrix of serpentine and pulverized country rock. Farther north where the diatreme trends to the northeast, it consists dominantly of a jumble of large tilted blocks of country rock. One thin dike of igneous rock and some asbestos was found in this part of the vent. At one locality at the northeast end of the vent, a huge fossiliferous block of the Hermosa Formation, measuring 150 by 20 by 15 feet, was noted. From the extreme northeast end of the diatreme a dike of greenish-yellow rock, probably serpentine, trends roughly north for about 1½ miles.

Less than 2 miles to the southwest is a kidney-bean-shaped feature, called the Cane Valley diatreme, that resembles the northeastern part of the Mule Ear vent. The diatreme abruptly interrupts the prevailing dip and strike of the Organ Rock Tongue of the Cutler Formation. Within the vent are numerous tilted blocks of country rock striking and dipping in a variety of ways. The blocks include light-colored gypsiferous shale and sandstone (an estimated 10 percent) obviously derived from the underlying Cedar Mesa Sandstone Member of the Cutler Formation. No igneous rocks of any kind were noted in the vent.

The first geologist to visit the Moses Rock diatreme referred to the feature as "drift" more than "100 feet thick" with the "general appearance * * * of a glacial deposit" (Sterrett, 1909, p. 825). Subsequently, the Mule Ear diatreme was described by Woodruff (1912, p. 89) as "a small area covered by debris which is believed to be of glacial origin," whereas the Moses Rock vent was mapped and described as a fault with a maximum displacement of 200 feet (Woodruff, 1912, p. 92–93 and pl. VIII). Gregory (1915) later concluded that these features were intrusive and probably had an igneous origin.

Whether or not igneous material is visible in these vents, all the diatremes probably had much the same origin. According to Williams (1936, p. 171), they were formed by explosions which "* * * were essentially phreatic in type resulting principally from the tension of water vapor."

According to Shoemaker and Moore (1956, p. 200), the reaction "* * * causing most, if not all, explosive volcanism appears to be the rapid to violent boiling of an aqueous solution or exsolution of a gaseous phase from a magma * * *." The vent- or neck-forming explosions must have been of a low temperature, for there is very little metamorphism, bleaching, or alteration of either the wallrock or the debris contained within the vents or necks.

The diatremes probably started along short fractures. As further elaborated by Shoemaker and Moore (1956, p. 201–202):

> Once the fracture is opened the gas may move along it at high velocity. * * * fragments of rock plucked from the walls of the fracture would become entrained converting the simple gas phase to a gas-solid fluidized system * * * . The intricate mixing, rounding, and polishing of the debris * * * strongly indicate fluidization. The first stages of widening of the vent are probably accomplished mainly by simple abrasion of the high velocity fluidized system on the walls of the fracture.
>
> As the vent widens a secondary process comes into play. Due to a pressure drop across the wall of the vent the wall will tend to spall inward. * * * Depending on the velocity and density of the fluidized system, large blocks spalled from the walls of the vent may tend to rise or sink.

This explanation of an aqueous explosion is supported by a report of a volcanic eruption on March 28, 1957, near the center of Iwo-Jima Island in the western Pacific Ocean. As described by Foster and Corwin (1957).

> The eruption of steam, volcanic sand, and volcanic sandstone and conglomerate blocks began suddenly at 11:55 a.m. local time, continued for 65 minutes, and ended abruptly. Coarse ejecta were thrown as high as 150 feet; dust and steam

rose to heights of 200 to 300 feet. No juvenile material was ejected. An elliptical crater 90 to 110 feet in diameter and 45 feet deep resulted. * * * The eruption resulted from the sudden release of an underground accumulation of steam under high pressure beneath fill adjacent to an abandoned air field.

SEDIMENTARY DEPOSITS OF TERTIARY OR QUATERNARY AGE

Baker (1936, p. 61–62) described a small deposit of gravel in the northeastern part of T. 43 S., R. 17 E. The gravel deposit lies about 1 mile west of the map area and floors the remnants of an old erosion surface. According to Baker (1936, p. 62), the altitude at the northeastern end of this deposit is 5,300 feet.

Similar deposits, shown on the geologic map (pl. 1) as Tertiary or Quaternary sedimentary deposits, are found within the Cedar Mesa-Boundary Butte area. These deposits are south of the San Juan River and west of Alhambra Rock and at other scattered localities in the southern part of the map area. The deposits are as much as 60 feet thick and consist of loose sand, silt, and clay containing lenses of pebbles and cobbles. Caliche caps the deposits at many places.

In sec. 11, T. 42 S., R. 17 E., about a quarter of a mile west of the report area, the deposits are 30 feet thick. At the base is a conglomerate bed 3½ feet thick that contains angular limestone and sandstone cobbles and pebbles as much as 8 inches across. Overlying the conglomerate is a friable mixture of clay and silt containing few pebbles. This overlying sequence is tan but in places shows white bands. The sequence is capped by a caliche bed throughout most of the area west of Alhambra Rock. From 30 feet thick the deposits thin rapidly to less than 6 feet and the lower conglomerate is not everywhere present. Over most of the area west of Alhambra Rock the deposits are less than 2 feet thick and consist mainly of a caliche cap which contains at places small pebbles. The altitude of this deposit ranges from about 5,200 to 5,300 feet.

On a small mesa about 4½ miles southwest of Moses Rock, equivalent deposits are 4–5 feet thick and consist of friable fine-grained sand and nodules of caliche. A hard resistant bed of caliche 6 inches to 2 feet thick caps the deposits. The deposit lies on a slightly undulating surface that generally is at an altitude of 5,000 feet.

Farther east between Chinle Wash and the crest of Comb Ridge, three remnants of Tertiary or Quaternary rocks are found at an altitude of about 5,200 feet. The small deposit near Comb Ridge contains small pebbles (about ¼ in. across) of sandstone, chert, petrified wood, and igneous rocks. The caliche cap of this deposit has a pronounced dip to the east. The deposits near Chinle Wash are at least 20 feet thick and consist of pebbles, cobbles, and boulders in a sandy matrix, locally having a thin veneer of caliche. The largest boulder noted is 3½ by 3 by 1½ feet. Some sandstone cobbles in the deposit were probably derived from the Navajo Sandstone, but others apparently were derived from Cretaceous rocks exposed on Black Mesa about 40 miles to the south. Several quartzite cobbles were possibly derived from the Dakota Sandstone of Cretaceous age which is exposed in adjacent areas to the east. Some pebbles of igneous rocks consisting of porphyries and lamprophyres are also present. This deposit is about 600 feet above the floor of Chinle Wash.

Near Boundary Butte the Tertiary or Quaternary deposits are extensively covered by windblown sand. In the northwest part of sec. 34. T. 43 S., R 21, E., however, the sedimentary deposits are as much as 60 feet thick and consist of loose sandy silt and shale, which contain 3- and 5-foot conglomerate beds at depths of 22 and 50 feet, respectively. A caliche bed forms a cap on the deposits in most areas. The Conglomerate beds consist of pebbles, cobbles, and boulders of chert and quartzite as much as 1 foot across in a sandy matrix. Most of the conglomerate is probably derived from the Dakota Sandstone which crops out in nearby areas. The deposits thin from a maxium thickness rapidly in all directions and over most of the area are represented by a thin 1- to 2-foot bed of caliche. The altitude of the eastern end of the deposits is 5,200 feet, but the deposits slope gently westward to an altitude of about 5,100 feet.

The Tertiary or Quaternary sedimentary deposits are all similar in lithology and all lie at roughly the same altitude—from 5,000 to 5,300 feet. The deposits are associated with a surface formed prior to the present rapid downcutting of the San Juan River. Baker (1936, p. 77) applied the name Rainbow Stage to this former level of the San Juan River, and he (1936, p. 61) believed the deposits on this old surface might possibly be of late Tertiary age but noted that fossil evidence to fix the age was lacking. During this investigation, lamprophyric rocks were noted in the deposit just west of Chinle Wash. Igneous rocks of this type were supposedly intruded in adjacent areas of Arizona in the middle or late Pliocene (Williams, 1936, p. 148). Because the deposits at places contain lamprophyric rocks they could not be older than the igneous intrusion and in this report are considered to be of very late Tertiary or early Quaternary age.

SEDIMENTARY DEPOSITS OF QUATERNARY AGE

Quaternary deposits in the Cedar Mesa-Boundary Butte area consist of gravel deposited on several terraces along the San Juan River and along Chinle and Comb Washes, windblown sand in parts of Chinle Wash and on the uplands east of Comb Ridge, and recent alluvium along the major streams and washes. The Quaternary deposits were not studied in detail and were mapped only where they are widespread or extensively cover the bedrock.

Several levels of terrace gravel occur along the San Juan River above the mouth of Chinle Wash. The terrace gravels along this part of the river are not differentiated on the geologic map (pl. 1), but at least five different levels are present. The highest gravel deposit is about 700 feet above the San Juan River. Remnants of this highest gravel occur in the SE¼ sec. 9, T. 41 S., R. 21 E. and the SW¼ sec. 18, T. 40 S., R. 22 E. The lowest terrace in the area near Bluff is about 10 feet above river level. Several terrace levels are present from 50 to 350 feet above the river. The gravel is composed of some locally derived sedimentary rocks and abundant igneous rocks that are commonly found in the nearby Ute, Carrizo, and Abajo Mountains. Other igneous and metamorphic rocks, particularly quartzite, are probably derived from the San Juan Mountains of southwestern Colorado.

Near Mexican Hat, the San Juan River emerges from a deep canyon cut through Raplee Ridge and for a distance of about 9 miles flows through a low-lying area before entering another deep canyon below Mexican Hat. In this area, there are at least four levels of terrace gravels, but all cover small areas and are not shown on the geologic map (pl. 1). Parts of the town of Mexican Hat are built on the most extensive terrace in this area, which is about 125 feet above river level.

In the areas east and west of Mexican Hat, where the San Juan River flows through steep-walled narrow canyons, terraces were not likely to form, and none were noted during the present investigation. The terraces are found at places where the San Juan River flows through relatively open areas. They also are found upstream from places where the river has cut a narrow, deep canyon through hard rock. Hence, the gravel may represent deposition during a pause in downcutting, while the river excavated the narrow canyon through harder rock.

Terrace gravel was also noted along tributaries to the San Juan River including Chinle and Comb Washes. The terrace gravel occurs at two or more levels but all cover only small areas. The terrace gravel on the tributaries was not studied and is not shown on the geologic map (pl. 1).

In the Cedar Mesa-Boundary Butte area, stream alluvium consists of fine sand, silt, and clay having some lenses of coarse sand and pebbles. In the deep canyons of the San Juan River the alluvium also includes an abundance of large boulders that have fallen from the canyon walls. Above Chinle Wash, the alluvium forms a wide level flat along the San Juan River. Near Bluff, Gregory (1938, p. 102) reported that a well penetrated 32 feet of alluvium above bedrock, and this figure probably represents the thickness of alluvium along the river above Comb Ridge. Below Chinle Wash the San Juan River flows through a narrow, deep canyon except for the stretch near Mexican Hat, and the alluvium for the most part underlies the riverbed. For the stretch of river below Chinle Wash and within the report area, Miser (1924, p. 58–71) reported that the alluvium is generally not more than 20 feet thick and apparently is absent at places.

Alluvium floors some tributaries to the San Juan River but is shown only where it underlies fairly large areas and forms a conspicuous feature of the landscape. In the tributaries in the western part of the area alluvium is thin or absent. Along Chinle Wash, large areas of alluvium lie west of Comb Ridge, and this alluvium has been trenched in recent times to a depth of 40 feet. In the deep canyons cut through the Glen Canyon Group along Chinle Wash, the alluvium at places clings to the canyon walls, and bedrock is exposed below the alluvium.

Windblown sand obscures large areas of bedrock in parts of Chinle Wash and along Gothic Wash. The sand also covers large areas of Casa del Eco and Tank Mesa and Bluff Bench. The windblown sand ranges in thickness from a few feet to about 40 feet. Most of the sand is probably derived from the disintegration of the Glen Canyon Group. Along Comb Ridge, dune sand spills down from the uplands to the valley below. Large blocks of sandstone detached from the Glen Canyon Group along Comb Ridge move down into the lowlands and disintegrate and contribute additional sand to the dunes. In the high areas north and south of Bluff, the weathering of the underlying Bluff Sandstone may contribute some sand to the dunes, but much of it is also probably derived from the Glen Canyon Group. Along Gothic Wash, for instance, the prevailing southwest winds have blown sand up out of the valley to the higher lands to the northeast.

STRUCTURE

The Cedar Mesa-Boundary Butte area embraces parts of three structural elements of the Colorado Plateau. These elements include part of the east flank of the Monument upwarp; the southwest part of the Blanding basin, and the northwest part of the Tyende saddle (Kelley, 1955, fig. 5). The Monument upwarp is a broad northward-trending uplift about 35 miles wide and 100 miles long extending from near the junction of the Green and Colorado Rivers to near Kayenta, Ariz. The upwarp is asymmetrical and has a gently dipping west limb and a steeply dipping east limb. The belt of steep dips that marks the eastern border of the Monument upwarp is the Comb monocline. The broad Monument upwarp is interrupted by numerous folds, several of which lie within the report area. East of Comb Ridge, the Blanding basin, a shallow downwarp about 50 miles across, underlies a part of the northeastern part of the map area. From Comb Ridge the surface rocks have a gentle regional inclination to the east or northeast. The southeastern part of the report area is included within the Tyende saddle. The Tyende saddle is a broad intermediate structural feature connecting four major structural features—the Monument upwarp on the northwest, the De Chelly upwarp on the southeast, the Blanding basin on the northeast, and the Black Mesa basin on the southwest. The boundary between the Blanding basin and Tyende saddle is indefinite, but in this report the two folds in the southeastern part of the area are included in the Tyende saddle.

The structure of the sedimentary rocks in the Cedar Mesa-Boundary Butte area is shown on the geologic map (pl. 1) by structure contours and by a cross section. For the area roughly west of Chinle and Comb Washes the top of the McKim limestone of the Rico Formation is the key horizon. In the eastern part of the area the top of the Navajo Sandstone is the contoured horizon. The contour lines connect points of equal altitude above sea level and are most accurate where the contoured horizon is at the surface. The altitude of known geologic horizons was determined for most of the area by plane table and alidade. The altitude of points on horizons other than the selected horizon was then reduced to the selected horizon by adding or subtracting the intervening stratigraphic interval.

The contours shown on the geologic map (pl. 1) incorporate, with some modification, the published work of four other geologists. The contours on the Halgaito anticline were determined by Baker (1936, pl. 1). In the Comb Wash area the contours shown by Sears (1956, pl. 17) on the top of the A limestone bed of the Rico Formation were changed to the top of the McKim limestone. The contours on the Chinle Wash and Boundary Butte anticlines were adapted from Turner (1958, p. 269) and Spragg (1952, p. 105), respectively.

FOLDS

COMB MONOCLINE

The largest structural feature in the Cedar Mesa-Boundary Butte area is the sinuous Comb monocline which trends generally northward. This sharp flexure can be traced from near Kayenta, Ariz., northward to near the Abajo Mountains, a distance of about 90 miles. The Comb monocline forms the steep border between the Monument upwarp on the west and the Blanding basin and Tyende saddle on the east.

The steepest dips on the monocline are near the San Juan River. Sears (1956, pl. 17) showed dips as high as 57° less than 1 mile north

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of the San Juan River. In the area just south of the river, beds of the Cedar Mesa Sandstone Member of the Cutler Formation dip as high as 81°. Just north of the Mule Ear diatreme, beds near the contact of the Cedar Mesa Sandstone Member and Organ Rock Tongue of the Cutler Formation are vertical.

Dips along the Comb monocline decrease both northward and southward from the San Juan River. Near Road Canyon at the northern border of the report area, dips on the monocline range from 21° to 28° (Sears, 1956, pl. 17). At the south border of the report area the beds dip about 12° to the east.

HALGAITO ANTICLINE

Baker (1936, p. 65–66) named and described the Halgaito anticline which is located along the west border of the report area. The Halgaito anticline is an elongate relatively flat-topped feature trending northward. Near the San Juan River the west flank of the anticline dips gently to the west at about 1°–3½°, but between sec. 2 and sec. 26, T. 42 S., R. 17 E., the west flank dips as much as 24° (Baker, 1936, p. 66). The broad crest of the anticline is interrupted by three small domes. The center of the northern dome is in the eastern part of sec. 14, T. 41 S., R. 17 E., just west of the report area, and the center of the southern dome is near the center of the common section line between secs. 13 and 14, T. 42 S., R. 17 E. Another small dome is located about 1½miles to the east of the southern dome. These three small structural features all rise to about the same altitude. The east flank of the anticline dips 1°–6° to the axis of the Mexican Hat syncline about 9 miles to the east. Closure on the anticline is about 100 feet, but the structural relief from the center of the Mexican Hat syncline to the crest of the Halgaito anticline is somewhat more than 1,600 feet. The Rico Formation primarily forms the surface rocks at the crest of the anticline. The San Juan River, however, cuts a deep canyon through the northern part of the anticline and exposes more than 1,000 feet of the Hermosa Formation.

CEDAR MESA ANTICLINE

The axis of an anticline that trends to the south enters the report area in sec. 3, T. 40 S., R. 18 E. Farther to the south the axis swings to the southwest and merges with the axis of the Halgaito anticline at the small dome in sec. 14, T. 41 S., R. 17 E. The Cedar Mesa anticline, within the map area, is poorly defined and has low dips of only 1° or 2° on the flanks. The anticline is on the crest of the Monument upwarp and was named the Mitten Butte anticline by Gregory (1938, p. 86–88). As pointed out by Baker (1936, p. 65), however, the axis lies several miles east of Mitten Butte, and Baker renamed the southern part of this feature the Halgaito anticline. The name Cedar Mesa anticline is applied to that part of the structure lying between the San Juan River and Elk Ridge, the latter being about 35 miles north of the river. The exact configuration of the Cedar Mesa anticline north of the report area is unknown. According to Gregory (1938, p. 88), near the San Juan River the Cedar Mesa "* * * anticline is essentially the summit of the Monument upwarp, but toward the north it seems to merge into other features and may be genetically related to the anticlines on Elk Ridge."

RAPLEE-LIME RIDGE ANTICLINES

A large prominent fold, crossed by the San Juan River, is between Mexican Hat and Comb Ridge near the central part of the area. The fold is a bifurcated anticline; the name Raplee anticline is applied to the western axis and Lime Ridge anticline to the eastern axis. The Raplee anticline is about 9 miles long and trends northward. The anticline is asymmetrical, the steepest dips being on the west flank. Closure on the Raplee anticline is about 500 feet. From the crest of the anticline the beds dip about 5° SE. for about 3 miles. Farther to the southeast the beds dip more steeply along the Comb monocline. From the axis of the Raplee anticline, near the San Juan River, the beds dip gently to the northeast about 1° or 2°. The northeast inclination of the beds is terminated by a curved shallow syncline extending a little east of north from about the SW¼ sec. 25, T. 41 S., R. 19 E., to the NW¼ sec. 18, T. 41 S, R. 20 E. From there the syncline curves abruptly to the west around the northern edge of the Raplee anticline. Eastward from this syncline the beds rise to the crest of the Lime Ridge anticline.

A very important aeromagnetic high coincides closely with the Raplee anticline (Case and Joesting, 1961, fig. 393.1). This high is thought to reflect a discrete body of highly magnetic and dense rock in, but at the top of, the Precambrian (J. E. Case, 1962, oral communication). The nearest well that penetrates the Precambrian, the Utah Southern Oil Co. 1 Canyon (sec. 27, T. 41 S., R. 19 E.), found mica schist, but this well is believed to lie just north of the rock body causing the aeromagnetic high.

The Lime Ridge anticline begins as an anticlinal nose trending northeast from the crest of the Raplee anticline. Farther to the northeast the Lime Ridge anticline continues as a relatively flat-topped fold whose axis may be traced for a distance of about 9 miles. As noted by Sears (1956, p. 204–205), the anticline terminates in an area of several low-amplitude flexures where Utah State Highway 47 crosses

Lime Ridge. The Lime Ridge anticline is asymmetrical, for the east limb is continuous with the belt of steep dips that mark the Comb monocline. Closure on the Lime Ridge anticline is about 250 feet.

About 2 miles south of the Raplee anticline is an anticlinal nose that is probably a southward continuation of the Raplee anticline. The surface expression of this nose is primarily in the De Chelly Sandstone Member of the Cutler Formation. The De Chelly Member lies flat beneath the cap of Quaternary and Tertiary deposits, which are present about 4½ miles southwest of Moses Rock. A small outlier of the Moenkopi Formation at the west side of this Quaternary and Tertiary cap dips slightly to the west. The axis of the anticline is about 3 miles long and trends to the northeast, but near the cap of Quaternary and Tertiary deposits the axis swings to the north. The beds in the area north and south of the anticlinal nose have a regional inclination to the east along Comb monocline. A short syncline to the west, toward Gypsum Creek, separates the anticlinal nose from this general eastward inclination.

GYPSUM CREEK ANTICLINE

In the southern part of the area, Gypsum Creek crosses the gently plunging northerly trending axis of an anticline which enters the map area from the south. This is the Gypsum Creek anticline, the larger part of which lies to the south of the report area. As described by Witkind and Thaden (1963, p. 63), the anticline has an 8-mile-long axis that forms an arc concave to the west. The anticline is asymmetrical and has dips of 7° on the east flank and 3° on the west flank. In the report area, dips on the east flank locally are as much as 13°. The axis of the anticline plunges gently northward at about 1°. Closure on the anticline in the area to the south is about 400 feet (Witkind and Thaden, 1963, p. 64).

MEXICAN HAT SYNCLINE

The Mexican Hat syncline lies between the Raplee-Lime Ridge anticlines to the east and the Halgaito-Cedar Mesa anticlines to the west. The Mexican Hat syncline is asymmetrical and has steep dips, as much as 25°, to the east and lesser dips, as much as 6°, to the west. The axis of the syncline is somewhat sinuous and may be traced for a distance of 16 miles in a north-south direction. The syncline is shallow and closure is not much more than 100 feet. The structural relief from the trough of the syncline to the crest of the Raplee anticline, however, is more than 1,800 feet in a distance of about 1 mile. The youngest rocks preserved in the syncline are remnants of the Cedar Mesa Sandstone Member of the Cutler Formation, which cap picturesque erosion forms such as Flag Butte and Mexican Hat Rock.

CHINLE WASH ANTICLINE

The Chinle Wash anticline is a northwestward-trending structure lying principally in T. 43 S., R. 21 E. The structure is symmetrical, and dips on the flanks of the anticline do not exceed 2°. The closure on the anticline is about 200 feet.

From Comb Ridge, the beds dip to the east. A slight reversal in the dominant direction of dip is suggested by the broad expanse of Navajo Sandstone exposed in this area. The anticline was mapped by tracing limestone beds within the Navajo Sandstone (Turner, 1958), and the contours shown on the geologic map (pl. 1), as previously stated, are adapted from a map prepared by Turner.

BOUNDARY BUTTE ANTICLINE

The anticlinal nose in T. 43 S., R. 22 E. represents the northwestern part of the Boundary Butte anticline. East of the report area the axis of the Boundary Butte anticline has been traced about 12 miles to the southeast. The axis of the anticline trends northwest, but near sec. 16, T. 43 S., R. 22 E. it turns abruptly to the north. The anticline is asymmetrical, and where the axis trends northwest the steepest dips are on the southwest limb. Closure at the surface is about 400 feet (Spragg, 1952, p. 104). The contours shown on the geologic map (pl. 1) are adapted from Spragg (1952, p. 105).

The Boundary Butte anticline corresponds in general both with an important aeromagnetic high and a large positive gravity anamoly (Case and Joesting, 1961, figs. 393.1 and 393.2; Plouff, 1958, p. 26). The geophysical data suggest that the anticline coincides roughly with a body of dense and highly magnetic rock in, but at the top of, the Precambrian. The nature of the basement rock underlying the Boundary Butte anticline is unknown, for no wells have penetrated the Precambrian.

FAULTS

The sedimentary rocks in the Cedar Mesa-Boundary Butte area have been displaced by a few faults. Most of these are associated with the Raplee-Lime Ridge anticlines and the Comb monocline. A few short faults are also found in the canyon along the San Juan River but are inaccessible except by boat and were not studied during this investigation. These inaccessible faults at the Goosenecks of the San Juan River and near Cedar Point were described by Miser (1924b, p. 138). Both normal and reverse faults are in the canyon, but the throw on any one fault does not exceed 3½ feet.

The largest fault occurs in the area near Comb Ridge and south of the San Juan River. It can be traced from the river along Comb monocline to a point about 3 miles to the south. The trace of the fault is generally confined to the Cedar Mesa Sandstone Member of the Cutler Formation, but for some distance it forms the fault contact between the Cedar Mesa and the Halgaito Tongue of the Cutler. Locally, just north of Mule Ear, the trace forms a fault contact between the Cedar Mesa and the Organ Rock Tongue of the Cutler.

Where best exposed, just south of the Mule Ear diatreme, the fault dips 85° east. The fault is normal and the east side is downthrown. The maximum throw on the fault is an estimated 1,500 feet. To the north, between the San Juan River and the Mule Ear diatreme, the fault appears to branch into two or more parallel faults, but the abundant gypsum in the Cedar Mesa Sandstone Member weathers out forming a tough coating on the beds, and the relations are concealed. The extent of the faulting in this northern area is indicated by an abrupt change in exposed thickness of the Cedar Mesa. At one locality just north of the Mule Ear diatreme, the Cedar Mesa totals about 100 feet in thickness; the remainder of the member, 700 feet or so, has been cut out by faulting. To the south the throw on the fault becomes progressively smaller, and about 3 miles south of the San Juan River the Cedar Mesa Sandstone Member is in normal contact with the Halgaito Tongue. To the north the fault passes under the alluvium of the San Juan River and does not reappear north of the river. The slight offset in the outcrop of the De Chelly Sandstone Member of the Cutler Formation across Chinle Wash, near the junction with the San Juan River, suggests that the northern part of the fault curves to the east. It may underlie the alluvium at the mouth of Chinle Wash, but the throw must decrease rapidly for no offset of the younger beds is apparent to the east in Comb Ridge. The fault beneath the alluvium undoubtedly weakened the sedimentary rocks and may account both for the abrupt southward swing of the San Juan River downstream from the point where it crosses Comb Ridge and for the abrupt westward swing of Chinle Wash across Comb Ridge.

In the area mapped by Sears (1956) north of the San Juan River, a fault occurs in secs. 2 and 3, T. 41 S., R. 20 E. This fault was described by Sears (1956, p. 205) as follows:

> The faulting is normal but dips steeply. Downthrow is on the south side and is greatest near the contact between the Rico and Halgaito, where it exceeds 100 feet and perhaps is as much as 200. The fault is made conspicuous by the substantial lateral offset of the gray limestones of the Rico, the red sandstones of the Halgaito, and the light-colored beds of the Cedar Mesa, all of which, dipping steeply to the southeast, make many small ridges. Eastward, the throw on the fault becomes progressively smaller, and the contacts of the upper formations appear not to be offset.

Farther north in sec. 26, T. 40 S., R. 20 E., Sears (1956, p. 205–206) described two other small faults that are near Utah State Highway 47 but are too small to be shown on the geologic map (pl. 1). The two faults trend north-northwest and can be traced for a few hundred feet. Both are reverse faults and have a maximum throw of about 15 feet.

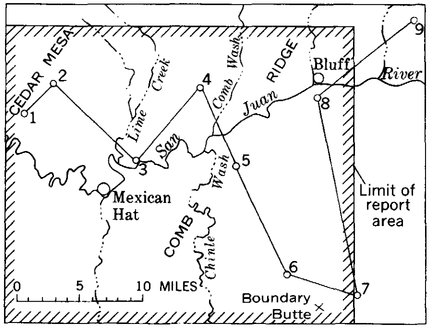
Three normal faults that trend eastward displace the rocks at the north end of the Raplee anticline. The faults lie principally in the north parts of secs. 13 and 14, T. 41 S., R. 19 E., and range in length from 3,000 feet to about 2 miles. The faults are vertical and the north sides are downthrown. The maximum throw on each fault probably does not exceed 6 feet.

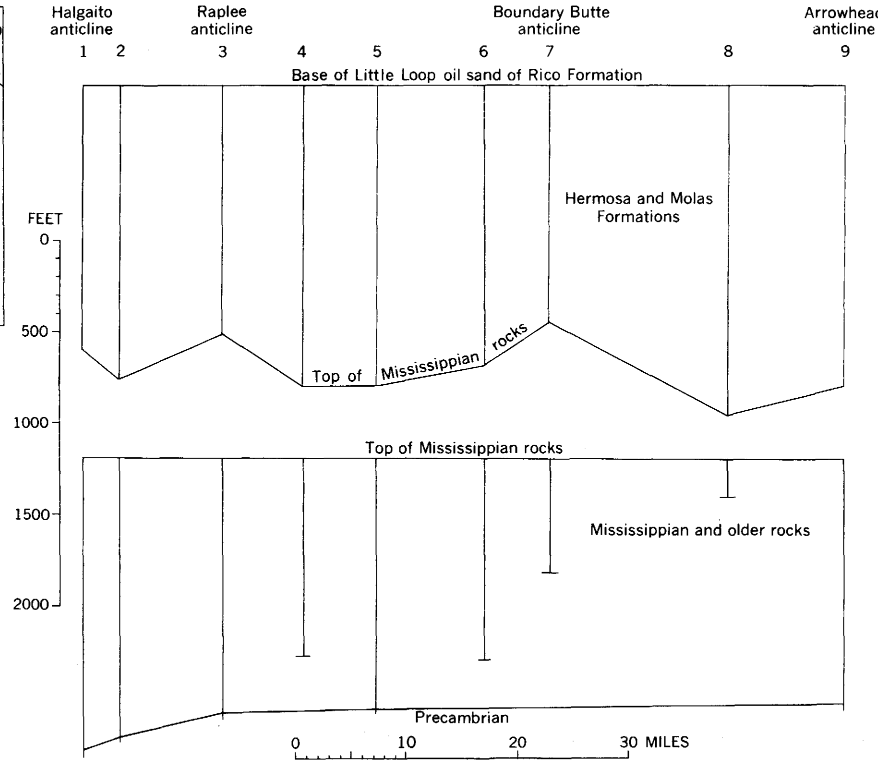
Three faults that trend eastward are chiefly in the SW¼ sec. 7, T. 41 S., R. 20 E., but only two are shown on the geologic map (pl. 1) because of their limited extent. These faults are normal and are nearly vertical. The north sides are downthrown, and the throw is 3 feet on the southern fault, 12 feet on the middle fault, and 5 feet on the northern fault.

AGE OF DEFORMATION

The age of the faulting as well as of the folding shown by the structure contours on the geologic map (pl. 1) cannot be established accurately within the Cedar Mesa-Boundary Butte area other than as post-Jurassic and pre-late Tertiary or early Quaternary. The youngest consolidated rock unit involved in the deformation is Jurassic in age; the high-level gravels of Tertiary and Quaternary age have not been involved. The exposed rocks within the Cedar Mesa-Boundary Butte area are virtually parallel, but local and regional stratigraphic evidence indicates that parts of the area may have undergone periods of warping in the late Paleozoic and the Mesozoic.

Based on the scanty available information, the lower Paleozoic rocks thin gradually eastward (fig. 11) across the report area and reflect none of the prominent structural features present today. In Pennsylvanian time a northwestward-trending trough lying to the east of the report area received as much as 8,000 feet of sediments. The Cedar Mesa-Boundary Butte area was along the southwestern shelf area of this trough. The Pennsylvanian strata (fig. 11) thin over certain features, which suggests differential uplift of these structures during Pennsylvanian time. The thickness variations appear to be large on the diagram because of vertical exaggeration but actually are relatively small. The combined Hermosa and Molas Formations thin about 500 feet between wells 8 and 7, but the distance is about 16 miles and this amounts to about 30 feet per mile. The thinning of the strata, slight though it is, however, coincides with present structural features as labeled on figure 11. This thinning suggests that these structural features began to form in Pennsylvanian time.





LIST OF WELLS SHOWN ON MAP AND SECTIONS

1 Texaco Inc., Johns Canyon 1, sec. 6, T. 41 S., R. 18 E.
2 Utah Southern Oil Co., Noble 1, sec. 28, T. 40 S., R. 18 E.
3 Utah Southern Oil Co., Canyon 1, sec. 27, T. 41 S., R. 19 E., and surface section.
4 Pan American Petroleum Corp., Lime Ridge 1, sec. 28, T. 40 S., R. 20 E.
5 Texaco Inc., Navajo 1 "V", sec. 36, T. 41 S., R. 20 E.
6 Ohio Oil Co., Navajo 1, sec. 10, T. 43 S., R. 21 E.
7 Western Natural Gas, and others, English Tribal 1, sec. 29, T. 43 S., R. 22 E.
8 Carter Oil Co., Navajo Gothic 2, sec. 36, T. 40 S., R. 21 E.
9 Shell Oil Co., Bluff 1, sec. 32, T. 39 S., R. 23 E.

All well data modified from lithologic well logs purchased from American Stratigraphic Co., Denver, Colo., and mechanical logs, except for No. 3, which is a drillers log

FIGURE 11.—Thickness of pre-Rico Formation sedimentary rocks in and near the Cedar Mesa-Boundary Butte area.

In the nearby Carrizo Mountains area, of northeastern Arizona, similar variations in thickness over structural features has been noted and, according to Strobell (1958, p. 73), "* * * much of the structural configuration now visible is inherited from a tectonic pattern established in Pennsylvanian or even earlier time." In addition to the smaller structural features, the old Defiance positive area apparently influenced the deposition of Mesozoic formations, several of which thin or pinch out in the Carrizo Mountains area (Strobell, 1958, fig. 3). Within the Cedar Mesa-Boundary Butte area, the absence of the Moenkopi in the subsurface near Boundary Butte is believed to be due to this factor.

Sometime after the deposition of the Hermosa Formation, the sea that covered southeast Utah during most of Paleozoic time gradually withdrew eastward. Near the end of Rico time, the sea in which the A limestone was deposited reached only to the area northeast of Mexican Hat and east of the site of Comb Ridge. As the sea withdrew, it became more saline and during early Cutler time evaporites were deposited.

While the retreating sea covered parts of the Cedar Mesa-Boundary Butte area, other parts were at or slightly above sea level as indicated by the distribution of subaerial deposits. Fluviatile or terrestrial deposits were laid down either in the western half of the area (end of Rico and all of Halgaito time) or in the northwestern part of the area (Cedar Mesa time).

Probably the eastward withdrawal of the sea, as well as the striking lithologic changes, was due to irregular warping of the Cedar Mesa-Boundary Butte area. As a result of this irregular warping, parts of the area were depressed and filled with marine or restricted marine deposits whereas other parts were slightly elevated and were the site of fluviatile or terrestrial deposition.

The northward pinchout of two units in the southern part of the Monument upwarp area may reflect doming or a slight topographic high during their deposition. One of these units, the Shinarump Member of the Chinle Formation, thins and disappears near the Arizona-Utah State line and, according to Finch (1959, p. 133), the pinchout "* * * may be due to a slight topographic high caused by a structure ancestral to the Monument upwarp that controlled deposition of the Shinarump Member." The other unit, the De Chelly Sandstone Member of the Cutler Formation, disappears about 2 miles north of Road Canyon. Yet both the De Chelly and Shinarump are in the subsurface east of Comb Ridge. The absence of these two units over parts of the Monument upwarp suggests that their northern limits may have been influenced by continued tectonic warping.

In the report area, the record of any post-Triassic movement of the Monument upwarp area was largely removed by erosion. Regional evidence cited by Baker (1936, p. 74–75) and Hunt (1956, p. 73) indicates that the principal deformation of the Colorado Plateau is Late Cretaceous or early Tertiary. The writer believes that during the principal deformation the present limits of the Monument upwarp as well as other structural features of the report area were fixed.

ECONOMIC GEOLOGY

In the Cedar Mesa-Boundary Butte area, interest in possible mineral resources has centered around gold, uranium, oil and gas, carbon dioxide, and helium. At the present time (1962), the most important mineral resources are oil and gas.

GOLD

In 1879, E. L. Goodridge made the first known traverse of the San Juan and Animas Rivers from near Durango, Colo., to the junction with the Colorado River. During this traverse, he noted extremely fine placer gold at several places along the river but gave discouraging reports about the quantity and cost of recovery (Gregory, 1938, p. 108). After Bluff was founded in 1880, settlers panned some gold from the river near the town of Bluff. Then, in 1891, rumors of rich gold deposits in the canyon of the San Juan River led to the "Bluff excitement" of 1892–93, when a reported 1,200 men stampeded to this part of Utah searching for gold. The entire stretch of the San Juan River within the report area was prospected, and Honaker Trail was built to reach the deep canyon near Cedar Point. According to Miser (1924, p. 21–22), the largest amount of gold was obtained from the Nephi claim about 4 miles below Honaker Trail where $3,000 worth was recovered in 30 days.

The gold operations proved to be unprofitable, and prospecting was generally suspended about 1912. Few attempts have been made to recover gold since, and no prospectors were noted during the years 1958 and 1960. The gold along the San Juan River is further discussed by Gregory (1917, p. 139–140; 1938, p. 108) and Miser (1924, p. 21–22).

URANIUM

In Monument Valley south of the report area, important uranium deposits are found in the Shinarump Member of the Chinle Formation. At the extreme southern edge of the mapped area, the Shinarump Member contains several prospect pits, but the production, if any, is not known. The Shinarump Member pinches out a short distance north of the prospect pits and is not present at the base of the Chinle Formation throughout most of the area.

The Salt Wash Member of the Morrison Formation produces uranium along Butler and Cottonwood Washes north of the limits of the map and from the Carrizo Mountains southeast of Boundary Butte. The Salt Wash Member is at the base of the Morrison Formation in only one small area near Boundary Butte, however, and no uranium deposits have been found there.

OIL AND GAS

Oil seeps from the Hermosa and Rico Formations along the San Juan River below Mexican Hat led to the original interest in the oil and gas possibilities of the Cedar Mesa-Boundary Butte area. These oil seeps were described by Woodruff (1912, p. 97–98), Miser (1924a, p. 140–141), and Baker (1936, p. 87). E. L. Goodridge noted these oil seeps during his traverse (Gregory, 1911, p. 21) of the San Juan River in 1879, but not until about 28 years later was the first well drilled.

A total of 207 wells were completed within the report area from 1908 to 1961 inclusive. The drilling activity has been concentrated mainly into four periods: 1908–12; 1922–28; 1944–47; and 1954 to the present (1962). The history of the exploration prior to 1930 was described in detail by Woodruff (1912), Miser (1924b), Baker (1936), and Miser (in Gregory, 1938).

During the first period of activity, many wells were drilled near Mexican Hat and adjacent areas of Lime Creek Valley. Early well records are incomplete and inaccurate, but based on available information a total of 98 wells were completed before 1920. Most, if not all, were drilled in the years 1908–12. Only 10 wells drilled before 1920 exceeded 600 feet in depth, and many were mere pits dug as assessment work to hold claims.

Early results were discouraging, and activity in the area virtually stopped until the 1922–28 period. At that time, 11 wells were drilled, some near Mexican Hat, but others within the report area tested the Cedar Mesa, Halgaito, Raplee, and Boundary Butte anticlines. A nearby well also tested the Gypsum Creek anticline. The wells drilled during the years 1922–28 were generally deeper than the earlier wells, and two test wells drilled by the Utah Southern Oil Co., the 1 Noble and 1 Canyon, penetrated the Precambrian.

After a period of comparatively little activity there was a third flurry of exploration in the years 1943–48. At this time, 20 shallow wells were drilled in Lime Creek Valley near Mexican Hat. The deepest well reached a depth of 1,580 feet.

From 1954 to 1961, inclusive, a total of 66 wells were drilled in the report area. Most of these wells were drilled east of Comb Ridge. This recent increased drilling activity has resulted in the discovery of numerous oil and gas fields, some within the report area but more in adjacent parts of southeast Utah and northeast Arizona.

As of 1962, six oil and gas producing fields have been discovered within the Cedar Mesa-Boundary Butte area. All but the Mexican Hat field lie east of Comb Ridge.

MEXICAN HAT FIELD

The Mexican Hat field covers secs. 25 and 36 T. 41 S., R. 18 E., secs. 30, 31, 32, T. 41 S., R. 19 E., secs. 1 and 12, T. 42 S., R. 18 E., secs. 5, 6, 7, T. 42 S., R. 19 E. Woodruff (1912, p. 98) described the initial discovery of oil as follows:

> Though oil springs must have been seen by prospectors and traders who operated along San Juan River, they seem to have received only casual notice until 1882, when E. L. Goodridge made the first location of a claim. No drilling was done, however, until the fall of 1907, when the first well, Crossing No. 1, was begun. This well encountered oil March 4, 1908, at a depth of 225 feet. It was a gusher, throwing oil to a height of 70 feet above the floor of the derrick and led to considerable excitement.

The Mexican Hat field lies on the west flank of the Mexican Hat syncline. Almost all the oil is produced from the Rico Formation. According to Wengerd (1955, p. 156), production in the Mexican Hat field to about the year 1950 was approximately 54,000 barrels of oil which, except for 500 barrels, was produced from the Rico Formation.

In the Rico Formation the oil is restricted to the marine beds of limestone and sandstone that form prominent ledges on the outcrop. Three of these beds produce most of the oil and include the following with their estimated cumulative production (Wengerd, 1955, p. 156):

	Barrels
Goodridge oil sand	10, 000
Mendenhall oil sand	25, 000
Little Loop oil sand	18, 000

Most of the oil in the Mexican Hat field has been found in the NW. cor. T. 42 S., R. 19 E., in secs. 5, 6, 7, and 8. The petroleum in the oil sands appears to have accumulated in pools of small extent. The Conway Drilling Co. 1 well in sec. 7, T. 42 S., R. 19 E., for instance, produced about 1,000 barrels of oil and then began producing water. Other wells have a similar history. At some places, wells that have produced a small amount of petroleum are located but a short distance from dry holes. This suggests that porosity and permeability must have been important factors in the accumulation of the oil.

On the outcrop, the ledge-forming oil sands vary considerably in thickness and lithology from place to place. The beds grade laterally from a friable sandstone to a calcareous well-cemented sandstone to a sandy limestone and at some localities this change takes place rapidly. The variation in lithology, in turn, affects the porosity and permeability of the oil sands in the Mexican Hat field.

Most of the oil wells in the Mexican Hat field are clustered in two places—the west half of section 6 and the east half of section 7 and adjacent parts of section 8. The cluster of wells roughly coincides with changes or flexing in the dominant eastward inclination of the Rico Formation. The flexing may delineate a trend of increased porosity and permeability of the reservoir rocks due to fracturing along this change in dip. Wengerd (1955, p. 158) suggested that the relatively large production of oil from the Bluff Oil Co. 1 Mexican Hat in sec. 6, T. 42 S., R. 19 E. may be due to this fracturing. It is possible that fracturing has occurred at other places along the change in dip and may be the controlling factor in the production of oil in the Mexican Hat field.

Other geologists (Gregory, 1911; Woodruff, 1912; Miser, 1924a; Baker, 1936) believed that the Mexican Hat field is an example of a synclinal accumulation of oil. As explained by Woodruff (1912, p. 97), the water has been drained from the strata by the deep-cut canyon of the San Juan River and "* * * the strata near the canyons are dry above the river and therefore the oil is not held under the crest of the anticline, as in humid regions, but has sought lower levels in the syncline." Wengerd (1955, p. 154, 163), on the other hand, disagreed with this concept of a synclinal oil field and suggested that the oil accumulation may be related to the structural terrace on the west flank of the Mexican Hat syncline. He further postulated that this structural terrace "* * * may have existed as a closed anticline with an unknown, but suggested northeasterly trend prior to the folding which created the prominent north-trending Cedar Mesa-Mexican Hat-Raplee structures."

FIELDS EAST OF COMB RIDGE

Five important fields are located east of Comb Ridge, and, except for Boundary Butte, all have been discovered since 1955.

The Boundary Butte field lies partly within the report area and covers secs. 8, 9, 10, 15, 16, 17, 21, 22, 23, and 27, T. 43 S., R. 22 E. The Boundary Butte anticline was tested by five wells from 1923 through 1930. All but the Wyoming Associated Oil Corp. 1 F. A. Kemp lie just to the east of the report area. A well started by the Southwest Oil Co. in sec. 22, T. 43 S., R. 22 E., was later taken over by the Continental Oil Co. and completed in 1929 as the 1 Navajo at a depth of 5,612 feet. According to Sheffer (1958, p. 262), a small amount of oil was found in the Shinarump and a reported 15 million cubic feet of gas per day was found in the Hermosa Formation. The remoteness of the area when the test was drilled and a lack of market, however, prevented the use of this well.

Western Natural Gas Co. completed several wells before 1950, just east of the report area on the Boundary Butte anticline. These wells produce oil from the Shinarump Member of the Chinle Formation and oil and gas from the Hermosa Formation. The cumulative production of oil to January 1961 was 67,503 barrels from the Shinarump Member of the Chinle and 16,179 barrels from the Hermosa Formation (Fisher, in Preston, 1961). All the wells that produce from the Shinarump Member, however, lie east of the report area.

The Chinle Wash field includes secs. 4, 5, 8, and 9, T. 43 S., R. 21 E. The discovery well completed in 1957 is the U.S. Smelting, Refining, and Mining Co. 1–9 Ohio-Navajo in sec. 9, T. 43 S., R. 21 E. Gas is produced from strata at two different depths in the Hermosa Formation.

The Akah field includes secs. 28 and 33, T. 42 S., R. 22 E. The discovery well completed in 1955 is the Shell Oil Co. 1 North Boundary Butte in sec. 33. Oil and gas are produced from the Hermosa Formation. The total cumulative production to January 1961 was 247,000 barrels of oil (Seeley, in Preston, 1961).

The Tohonadla field covers secs. 34, 35, and 36, T. 41 S., R. 21 E., and secs. 1 and 2, T. 42 S. R. 21 E. The discovery well is the Shell Oil Co. 1 Tohonadla completed in 1957 in sec. 35, T. 41 S., R. 21 E. Oil and gas from this field are produced from the Hermosa Formation. The total production of oil to January 1961 was 600,794 barrels (Elias, in Preston, 1961).

The Bluff Bench field includes secs. 20 and 21, T. 40 S., R. 22 E. The discovery well is the Carter Oil Co. 4 Bluff Bench completed in 1957. The production, from the Hermosa Formation, to January 1961 was 11,238 barrels (Phipps, in Preston, 1961).

FUTURE OIL AND GAS POSSIBILITIES

Except for some Triassic production at Boundary Butte, all the fields east of Comb Ridge produce from the Paradox Member of the Hermosa Formation. The Paradox Member underlies the eastern half of the report area and crops out in Soda basin on the San Juan River. The southwestern limit of the Paradox Member lies along a southeastward-trending line passing through the Mexican Hat area and near Moses Rock (the zero gypsum-anhydrite line of Wengerd and

Strickland, 1954, fig. 12). Southwest of this line the Paradox grades into normal marine sedimentary rock and cannot be separately recognized. Hence, the Paradox within the Cedar Mesa-Boundary Butte area lies near the limits of deposition of the member and represents a marginal facies. Normal marine and penesaline to hypersaline conditions alternated, and this resulted in a complex assemblage of sediments deposited in a variety of environments.

The fields described above produce from one or more distinct zones within the Paradox Member. According to Carter (1958, p. 145), these zones "* * * are cyclic deposits characterized by horizontal and vertical gradation from normal marine carbonates into penesaline carbonates and evaporites. Nearly all of the production is from shelf carbonates deposited in a normal marine environment. * * * Porosity—and production—is closely related to organic layers and mounds." Cores of one of these organic mounds examined by Elias (1962, p. 265) are composed of *Ivanovia*, an alga, which grew as algal masses or banks on lagoonal shoals.

Up to the year 1962, all the oil and gas in the Cedar Mesa-Boundary Butte area had been produced from the Shinarump Member of the Chinle Formation and the Rico and Hermosa Formations. The first well to obtain pre-Pennsylvanian production was completed in May 1962. This well, the Texaco Inc. Navajo 1–AE in sec. 19, T. 43 S., R. 21 E., had an initial production of 47 barrels of oil per day from the Mississippian. The well, however, also produced 105 barrels of water per day and apparently was not economical. In September 1962, the well was plugged back, worked over, and produced 98 barrels of oil per day from the Paradox Member of the Hermosa.

Undoubtedly, future deeper drilling will reveal additional reserves of oil and gas. Mississippian and Devonian rocks produce significant quantities of oil and gas in nearby parts of northeastern Arizona and other areas of southeastern Utah. Of the wells drilled within the report area as of June 1962, only 22 have penetrated pre-Pennsylvanian rocks, and only 11 have penetrated part or all of the Devonian rocks. Hence, the Mississippian and Devonian rocks have not been adequately tested and are an important target for future exploration.

In the area west of Comb Ridge, all the anticlines have been tested. At the Kingwood Oil Co. 1 Lime Ridge test well, on the Lime Ridge anticline, gas is present in the Paradox Member of the Hermosa. Farther to the southwest the Paradox grades into the normal marine limestone facies of the Hermosa Formation. Hence, the important zone that produces the oil and gas in the fields east of Comb Ridge is not present over most of the area to the west. The only notable production west of Comb Ridge is primarily from the Rico Formation near Mexican Hat, on the west limb of the Mexican Hat syncline. Additional small quantities of oil might be found in the same structural position but south of the San Juan River in an area untested by exploratory drilling.

HELIUM AND CARBON DIOXIDE

Helium and carbon dioxide occur in several wells in the Cedar Mesa-Boundary Butte area. Samples of gas from some wells within the report area analyzed by the U.S. Bureau of Mines are reported by Anderson and Hinson (1951, p. 120) and Boone (1958, p. 100), and the following percentage figures are from those two reports.

Gas from wells on the Boundary Butte structure show varying concentrations of helium and carbon dioxide. At the Western Natural Gas Co. 7 English in sec. 16, T. 43 S., R. 22 E., gas from the Hermosa Formation analyzed 0.68 percent helium and 6.1 percent carbon dioxide. Other wells on the Boundary Butte anticline, but east of the report area, contain as much as 1.42 percent helium and 9.7 percent carbon dioxide.

To the north at the Akah field in T. 42 S., R. 22 E., two wells drilled by the Shell Oil Co. contain some concentration of helium and carbon dioxide. These two wells, the 1 North Boundary Butte in sec. 33 and the 43–28 North Boundary Butte in sec. 28, show a concentration of helium that ranges from 0.23 to 1.16 percent from the Hermosa and Rico Formations. Gas from Devonian rocks in the 43–28 North Boundary Butte analyzed 1.58 percent helium and 56.8 percent carbon dioxide.

At the Raplee anticline near Mexican Hat, the Utah Southern Oil Co. 1 Canyon had an initial estimated capacity of 40 million cubic feet of gas a day. This gas apparently was derived from Devonian rocks and contained 0.7 percent helium and 97.3 percent carbon dioxide.

Carbon dioxide is known also to have been found in two other wells within the mapped area. The Al Hill 1 State well in sec. 32, T. 40 S., R. 20 E., had a reported initial production of 5 million cubic feet of carbon dioxide a day. The Carter Oil Co. 2 Navajo-Gothic in sec. 36, T. 40 S., R. 21 E., also found appreciable quantities of carbon dioxide in Mississippian rocks.

At the present time (1962), there is no great demand for carbon dioxide, but new uses or new demands may increase the importance of this gas. Helium, on the other hand, is needed in ever-increasing amounts, and as future demands increase, the helium within the report area probably will constitute an important mineral resource.

RECORD OF WELLS DRILLED

As of September 1962, a total of 210 wells had been drilled for oil and gas within the Cedar Mesa-Boundary Butte area. The following list shows all the wells drilled and was compiled from Baker (1936), Gregory (1911), Hansen and Scoville (1955), Miser (1924a), and Woodruff (1912). Other sources of information include completion cards compiled by Petroleum Information, Denver, Colo., and records of the U.S. Geological Survey. The status of wells plotted on the map (pl. 1) is as originally reported. The subsequent status of the wells, if known, is shown in the record of wells drilled.

Record of wells drilled

Wells drilled are as of September 1962. The letters used and their meanings are as follows: A, abandoned; POW, producing oil well; POGW, producing oil and gas well; PGW, producing gas well; SD, shut down or abandoned; ------------, no record; SO, show of oil; SG, show of gas; SOG, show of oil and gas; BOPD, barrels of oil per day; CFGPD, cubic feet of gas per day. Numbers in parentheses refer to corresponding location number on map and total depth is not known

Section	Operator	Well	Status	Total depth (feet)	Year completed	Oldest rocks penetrated	Remarks
			T. 40 S., R. 17 E.				
25	Norwood Oil Co.	Galloway 1	A	1,938	1911	Hermosa Formation	SO and strong flow of gas from Goodridge oil sand. SOG at 600 and 1,170 ft in Hermosa.
25	Mutual Oil Co.	Galloway 2	A	225	1912	Rico Formation	SO in Goodridge oil sand, small amount of oil was bailed.
			T. 40 S., R. 18 E.				
24	------------	------------	A	150	Pre-1920	Rico Formation	
28	Utah Southern Oil Co.	J. E. Noble 1	A	3,633	1927	Precambrian	
33	Barney Cockburn	Halbersteben 1	A	560	1946	Hermosa Formation	
33	------------	Finley 3	A	50	Pre-1920	Rico Formation	
33	------------	Finley 2	A	40	Pre-1920	do	
34	------------	Finley 1	A	50	Pre-1920	do	
35	California Co.	Red Butte	A	60	1909	do	SO reported in Baby oil sand.
36	------------	------------	A	(1)	Pre-1920	------------	
36	------------	------------	A	300	1920	Rico Formation	
			T. 40 S., R. 19 E.				
11	San Francisco-San Juan Oil Co.	Oil City 5	A	595	1910	Rico(?) Formation	SG. In 1910 well was full of oil, and was plugged.
13	do	Oil City 8	A	126	1908	Rico Formation	Small flow of oil from Baby oil sand.
13	do	Oil City 6	A	165	1910	do	Oil reported from Baby Oil sand.
13	do	Oil City 7	A	140	1910	do	Oil reported from Baby oil sand.
13	Francis M. Raymond	Federal 1	A	2,456	1958	Mississippian	SO in Hermosa.
14	San Francisco-San Juan Oil Co.	Oil City	A	145	1908	Rico Formation	
16	------------	1	A	12	1909	do	
19	------------	1	A	600	Pre-1920	Hermosa Formation	
19	------------	1	A	20	Pre-1920	Rico Formation	
23	San Francisco-San Juan Oil Co.	Oil City 9	A	50	Pre-1920	do	
23	do	Oil City 1	A	150	1910	do	

29	Gilbraltar Oil Co	1	A	500	1910	Hermosa Formation	
30		1	A	80	Pre-1920	Rico Formation	
30		1	A	400	1908	Hermosa Formation	
31		1	A	100	1909	Rico Formation	
32	Monumental Oil Co	Red Butte	A	50	1909	do	SO in Baby oil sand.
33	Navajo Oil Co	1	A	1,200	1909	Hermosa Formation	SO reported.

T. 40 S., R. 20 E.

9	Argo Oil Co., and others	Government Oak 1	A	3,552	1957	Devonian	SG in Hermosa.
26	Anderson-Allen	Government 1	A	880	1955	Hermosa Formation	
28	Kingwood Oil Co	Lime Ridge 1	SD	3,357	1959	Devonian	Initial production of 1,450,000 CFGPD from Hermosa. First completed and abandoned in 1957 by Pan American Petroleum Corp. In 1959 worked over and completed as a producer.
32	Al Hill, and others	State 1	A	3,214	1950	do	Initial production of 5 million cu ft of carbon dioxide. Abandoned for lack of market.

T. 40 S., R. 21 E.

1		1	A	200	1910	Jurassic	
8	Humble Oil & Refining Co.	Government-Fehr & Lyon 3.	A	5,471	1960	Hermosa Formation	SOG in Hermosa.
12	do	Bluff Bench 12	POW	5,751	1960	do	Initial production 47 bbl of oil and water from Hermosa.
14	E. R. Perkins	Rolling Mesa 1	A	5,418	1961	do	SG in Hermosa.
27	Tennessee Gas & Oil Co	Rolling Mesa 4	A	6,368	1960	Mississippian	SOG in Hermosa and SG in Mississippian.
31	Carter Oil Co	Government-Fehr & Lyon 2.	A	6,345	1959	do	SOG in Hermosa.
33	do	Government-Fehr & Lyon 1.	A	6,283	1959	do	Initially produced 25 BOPD and water from Hermosa. Well later abandoned.
36	do	Navajo-Gothic 2	A	6,780	1956	do	SOG in Hermosa and SO in Mississippian. Carbon dioxide gas in Mississippian, tested initially at rate of 116,000 cu ft. This decreased to 41,000 cu ft rate at end of test.

T. 40 S., R. 22 E.

4	Carter Oil Co	Bluff Bench 6	A	6,080	1958	Hermosa Formation	
17	do	Bluff Bench 5	A	5,862	1958	do	
20	do	Bluff Bench 4	POW	5,633	1957	do	Discovery well for Bluff Bench field. Initial production 250 BOPD and water from Hermosa.
21	do	Bluff Bench 8	POW	5,585	1958	do	Initial production 264 BOPD from Hermosa.
21	Sand Oil Co	Mark 1	A	5,757	1961	do	SOG in Hermosa.
33	Carter Oil Co	Navajo 39–1	A	5,729	1958	do	Do.

Record of wells drilled—Continued

Section	Operator	Well	Status	Total depth (feet)	Year completed	Oldest rocks penetrated	Remarks
T. 41 S., R. 17 E.							
36	Utah Petroleum Corp	Francis Clark 1	A	1,707	1927	Hermosa Formation	
T. 41 S., R. 18 E.							
1	Service Oil Co	Columbus-Rexall 1	A	3,005	1957	Devonian	
1		Ashenhurst 2	A	20	Pre-1920	Rico Formation	
1		1	A	300	Pre-1920	do	
1		1	A	50	1910	do	
1		2	A	(1)	Pre-1920		
2			A	20	Pre-1920	Rico Formation	
2	Pinnacle Oil Co	1	A	520	1909	Hermosa Formation	SOG in Mendenhall oil sand; completed as a water well.
3			A	10	Pre-1920	Rico Formation	
4		1	A	10	Pre-1920	do	
4		Olympic 1	A	150	Pre-1920	do	
6	Texaco, Inc	Johns Canyon Unit 1	A	4,469	1962	Precambrian	
9	Fulton, McKim & Hadlock.	Government 1	A	143	1950	Rico Formation	Crooked hole, rig skidded 10 ft west and 1-A drilled.
9	do	Government 1-A	A	1,646	1950	Hermosa Formation	SO in Hermosa.
12	Pacific San Juan Co	1	A	60	1911	Rico Formation	SO in Goodridge oil sand.
12	London-San Juan Oil Co.	1	A	520	1909	Hermosa Formation	
12	do	2	A	450	1909	do	
13	do	4	A	(2)	1923		
15	Aztec Oil Co	1	A	1,350	1912	Hermosa Formation	Some oil bailed from well.
16			A	30	Pre-1920	Rico Formation	
16			A	150	Pre-1920	do	
17			A	150	Pre-1920	do	
20			A	150	Pre-1920	do	
22		Humboldt	A	30	Pre-1920	do	
22	San Juan-Dolores Co	1	A	80	Pre-1920	do	
22	Palo Pinto Oil Co	1	A	900	1910	Hermosa Formation	
22	do	2	A	500	Pre-1920	do	
23	San Juan Oil Co	Chicago 1	A	213	1912	Rico Formation	SG in Goodridge oil sand.
24			A	50	1909	do	
24			A	10	Pre-1920	do	

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24			A	10	Pre-1920	do	
24			A	10	Pre-1920	do	
25	MacFulton Drilling Co.	1	A	1,025	1947	Hermosa Formation	
25	London-San Juan Oil Co.	3	A	356	1909	Rico Formation	SO in Mendenhall oil sand.
26	Gooseneck Oil Co.	1	A	(3)	Pre-1920		Rig in place and ready to drill in 1910.
28			A	150	Pre-1920	Rico Formation	
28		1	A	150	Pre-1920	do	
29		1	A	150	Pre-1920	do	
36	Yates-McLane	1	A	260	1910	do	SO in Goodridge oil sand.
36		Producers	SD	800	Pre-1920	Hermosa Formation	Gas from this well was piped to Mexican Hat and used in lighting. Some oil also was found.

T. 41 S., R. 19 E.

5	Redwood Oil Co.	Elithia	A	50	1909	Rico Formation	
6	do	Bitter Springs 1	A	200	1909	do	SO in Goodridge oil sand.
6	do	Bitter Springs 2	A	160	1909	do	SO at 160 ft.
6	do	Bitter Springs 3	A	10	1912	do	
7	F. H. King and others	1	A	50	1909	do	
7			A	25	1909	do	
8	San Francisco-San Juan Oil Co.	1	A	450	1908	do	SO in Baby and Goodridge oil sands.
8	do	2	A	(1)	Pre-1920		
10	Jackson & McKee	1	A	100	1909	Rico Formation	SO in Rico.
15	Oil Co. of San Juan	Golden Gate 1	A	500	1909	Hermosa Formation	SO in Baby oil sand.
16	Barney Cockburn	1	A	354	1946	Rico Formation	
17	Pioneer Development Co.	Conejos 1	A	215	1908	do	SO in Goodridge oil sand.
17	Spokane Oil Co.	McMoran 1	A	200	1908	do	SOG in Goodridge oil sand.
18	Lime Creek Oil Co.	1	A	20	1909	do	
19	San Francisco-San Juan Oil Co.	1	A	400	Pre-1920	do	
20			A	10	Pre-1920	Cutler Formation	
20	San Francisco-San Juan Oil Co.	1	A	500	1910	Hermosa Formation	
27	Utah Southern Oil Co.	Canyon 1	A	1,870	1928	Precambrian	Initial production 15-20 BOPD from Hermosa; (SO in Mississippian, 40,000,000 CFGPD from the Devonian(?). Gas analyzed 97.3 percent carbon dioxide and 0.07 percent helium.
30	Barney Cockburn	1	A	1,580	1946	Hermosa Formation	SO in Rico and Hermosa.
30	Connecticut Oil Co.	1	A	26	1909	Rico Formation	
30			A	70	Pre-1920	do	
31	A. C. Ellis	2	A	1,130	1925	Hermosa Formation	
31	do	1	A	100	1925	Rico Formation	
31			A	(2)	Pre-1920		
31			A	(3)	Pre-1920		
31	Lone Cone Oil Co.	1	A	700	Pre-1911	Hermosa Formation	SO in Hermosa.
31		Townsite	A	210	1912	Rico Formation	SO in Goodridge oil sand.

Record of wells drilled—Continued

Section	Operator	Well	Status	Total depth (feet)	Year completed	Oldest rocks penetrated	Remarks
				T. 41 S., R. 20 E.			
8	General Petroleum Corp.	F-22-8	A	2,096	1958	Molas Formation	SOG in Hermosa.
25	Texaco, Inc.	Navajo "V" 2	A	5,176	1960	Hermosa Formation	Do.
36	do	Navajo "V" 1	POW	8,016	1959	Precambrian	Produced 14 BOPD and water from Hermosa.
				T. 41 S., R. 21 E.			
4	Champlin Oil & Refining Co.	Navajo 35-1	A	6,505	1959	Mississippian	SOG in Hermosa.
14	Superior Oil Co.	Navajo 11-14	A	5,884	1961	Hermosa Formation	
24	Carter Oil Co.	Navajo 21-1	POW	5,645	1959	do	Initial production 23 BOPD from Hermosa.
25	Shell Oil Co.	Tohonadla 41-25	POGW	6,114	1958	do	Initial production 104 BOPD and 110,000 CFGPD from Hermosa.
28	Miami Petroleum Co., Inc.	Navajo "B"-1	POW	5,830	1960	do	Initial production 233 BOPD from Hermosa.
35	Shell Oil Co.	Tohonadla 32-35	POGW	5,791	1958	do	Initial production 84 BOPD and 41,000 CFGPD from Hermosa.
35	do	Tohonadla 41-35	POW	6,010	1958	do	Initial production 192 BOPD from Hermosa.
35	do	Tohonadla 12-35	POW	5,797	1958	do	Initial production 29 BOPD from Hermosa.
35	do	Tohonadla 1	POGW	6,345	1957	Devonian	Discovery well for Tohonadla field. Initial production 1,450 BOPD and 1,200,000 CFGPD from Hermosa.
35	do	Tohonadla 23-35	POW	5,764	1958	Hermosa Formation	Initial production 2,150 BOPD from Hermosa.
35	do	Tohonadla 43-35	POGW	5,910	1958	do	Initial production 1,188 BOPD and 796,000 CFGPD from Hermosa.
				T. 41 S., R. 22 E.			
7	Carter Oil Co.	Navajo 30-1	A	7,098	1958	Mississippian	Recovered some nonflammable gas from Mississippian.
9	do	Navajo 40-1	SD	5,885	1958	Hermosa Formation	Swabbed 24 BOPD and water from Hermosa.
19	Miami Petroleum Co., Inc.	Navajo "C" 1	A	5,781	1960	do	SOG from Hermosa.
28	Carter Oil Co.	Navajo 42-1	A	6,336	1958	Molas Formation	
33	do	Navajo 1	A	6,467	1955	do	SOG from Hermosa.

T. 42 S., R. 17 E.

23	Monumental Oil Co.	K. L. Jones and others 1	A	756	1923	Hermosa Formation	

T. 42 S., R. 18 E.

1	Arcola Oil Co.	1	A	25	1911	Rico Formation	
1		1	A	400	1909	Hermosa Formation	
19	Monumental Oil Co.	1	A	1,140	1923	do	
19	do	2	A	1,622	1924	do	

T. 42 S., R. 19 E.

5	R. L. Raplee	1	A	900	1912	Hermosa Formation	About half a barrel of oil from Baby oil sand.
5	Monumental Oil Co.	Jackson 1	A	635	1909	do	SO in Goodridge and Little Loop oil sands.
5	Mexican Hat Oil Co.	2	A	300	1944	Rico Formation	SO in Goodridge oil sand.
5	Southside Oil Co.	1	A	600	1910	Hermosa Formation	Do.
5	Western Investment Co.	1	SD	500	1909	Rico Formation	Initial production an estimated 10 bbl of oil from Baby oil sand.
5	Anderson Oil & Development Co.	Hudson 1	SD	1,222	1909	Hermosa Formation	In 1920 oil was standing 100 ft from top of well and small amounts were bailed for use in oilfield.
6	Western Investment Co.	Bryce 1	SD	500	1910	do	Bailed 2-3 BOPD from Baby oil sand.
6	Arcola Oil Co.	3	A	210	1910	Rico Formation	SO in Goodridge oil sand.
6	Greenfire Uranium Corp.	5 E.G.	A	600	1955	Hermosa Formation	No record of exact location.
6			A	10	1910	Rico Formation	
6	Mexican Hat Oil Ventures.	Redbed 1	A	256	1958	do	
6	Arcola Oil Co.	Utah Southern 1	SD	713	1930	Hermosa Formation	SO in Little Loop oil sand. Well is reported to have produced a small amount of oil.
6	Western Investment Co.	Bryce 2	SD	517	1909	do	Initial production 20 bbl of oil. Well produced an estimated 8,000 bbl of oil from the Mendenhall oil sand.
6	Arcola Oil Co.	4	A	50	1909	Rico Formation	SO in Goodridge oil sand.
6		Producers 1	A	800	1910	Hermosa Formation	SOG in Hermosa.
6	F. S. Munson	1	SD	360	1948	Rico Formation	Pumped 10 BOPD from Little Loop oil sand.
6	Allen-Wooley	1	A	740	1944	Hermosa Formation	SO in Rico.
6	do	2	SD	335	1947	Rico Formation	Initial production 25 BO from Rico.
6	do	3	SD	440	1948	Hermosa Formation	Initial production 10 BOPD from Little Loop oil sand.
6	do	5	SD	1,130	1931	do	Drilled to 263 ft and produced 400 bbl of oil from Mendenhall oil sand then began producing water. Drilled to 512 ft in 1932 but no increase in production. Cleaned out to 512 ft in 1947 and produced 10 BOPD. Drilled to 1,130 ft in 1948 but only SOG at lower depths.
6	Bluff Oil Co.	Mexican Hat 1	SD	362	1922	Rico Formation	Initial production 200 bbl of oil from Little Loop oil sand.
6	do	2	A	630	1925	Hermosa Formation	

Record of wells drilled—Continued

Section	Operator	Well	Status	Total depth (feet)	Year completed	Oldest rocks penetrated	Remarks
			T. 42 S., R. 19 E.—Continued				
6	Oil Company of San Juan.	Burlap 1	SD	284	1909	Rico Formation	Initial production 3½ bbl of oil from Baby oil sand.
6	Urado Development Co.	1	A	271	1945	do	SO in Rico.
6	do	2	A	257	1945	do	
6	do	3	A	645	1945	Hermosa Formation	
6	do	4	A	269	1945	Rico Formation	
7	do	Monticello 1	A	273	1945	do	SO in Rico.
7	Barney Cockburn	2	SD	241	1946	Rico Formation	Initial production 1½ bbl of oil from Rico probably from Goodridge oil sand.
7		Goodridge 1	A	100	Pre-1920	do	
7	San Juan Oil & Refining Co.	1	SD	215	1944	do	Estimated 50 bbl of oil from Rico probably from Goodridge oil sand.
7	Mexican Hat Oil Co.	1	SD	205	1944	do	Pumped 48 BOPD from Goodridge oil sand.
7	W. E. Nevills	6	SD	194	1933	do	Initial production 4 BOPD from Rico.
7	Oil Company of San Juan.	Crossing 1	SD	226	1908	do	Discovery well for Mexican Hat field. Produced 3 BOPD from Goodridge oil sand.
7	W. E. Nevills	7	SD	565	1955	do	SO in Rico. Well drilled deeper to 565 ft in 1955 and produced 1 BOPD from Goodridge oil sand.
7	Conway Drilling Co.	1	A	295	1953	do	Initial production 12 BOPD. Produced about 1,000 bbl of oil then went to water.
7	do	2	A	204	1934	do	
7	do	3	A	265	1955	do	Initial production 4½ BOPD. Well later worked over and produced only water.
8	Pacific-San Juan Oil Co.	High Grade 6	A	600	Pre-1920	Hermosa Formation	SO in Mendenhall oil sand.
8	Barney Cockburn	1	SD	296	1945	Rico Formation	Pumped 35 BOPD from Goodridge oil sand.
8	do	3	SD	296	1946	do	Initial production 2 BOPD from Rico.
8	do	4	SD	306	1946	do	Initial production 5 BOPD from Rico.
8	do	5	A	21	1946	do	Lost surface casing in gravel and abandoned location.
8	do	6	A	633	1946	Hermosa Formation	SO in Rico.
8	Monticello Oil Co.	Goodridge 4	A	263	1909	Rico Formation	Initial production 20 bbls of oil from Goodridge oil sand.
15	Associated Oil Co.	1	A	10	1925	do	Large pit dug and steel rig erected but drilling apparently never started.
			T. 42 S., R. 20 E.				
10	Sinclair Oil & Gas Co.	San Juan-Navajo 172-1	A	6,151	1961	Mississippian	SO in Hermosa.
34	Shell Oil Co.	Dzaneez 1	A	5,558	1961	Molas Formation	Do.

T. 42 S., R. 21 E.

1	Carter Oil Co	Navajo 23-2	A	6,010	1959	Molas Formation	SOG in Hermosa.
1	Miami Petroleum Co., Inc.	Navajo "A"-1	A	5,970	1960	do	Do.
2	Carter Oil Co	Navajo 23-1	POW	5,950	1957	Hermosa Formation	Swabbed 120 BOPD and water from Hermosa.
2	do	Navajo 23-3	A	5,935	1959	do	SOG in Hermosa.
3	Davis Oil Co	Navajo-Tohonadla 1	A	5,962	1958	Molas Formation	Do.
4	Monsanto Chemical Co.	Ahkeah 1	A	5,683	1962	Hermosa Formation	Do.
10	E. B. LaRue, Jr	Navajo 1	A	6,189	1959	Mississippian	SO in Hermosa.
33	Ohio Oil Co	Chinle Wash 1-33	A	5,350	1959	Hermosa Formation	Do.

T. 42 S., R. 22 E.

7	Shell Oil Co	Tohonadla 2	A	6,099	1957	Molas Formation	SOG in Hermosa.
16	do	North Boundary Butte 2.	A	5,925	1960	Hermosa Formation	
28	do	North Boundary Butte 43-28.	POW	5,586	1956	Molas Formation	Initial production 223 BOPD; two samples of gas from Hermosa analyzed as much as 0.13 percent helium and 0.58 to 14.9 percent carbon dioxide.
33	do	North Boundary Butte 1.	POGW	5,975	1955	Devonian	Discovery well for Akah field. Initial production 117 BOPD and 1,565,000 CFGPD; two samples of gas, one from the Hermosa the other from the Rico, analyzed from 0.23 to 1.16 percent helium and as much as 19.3 percent carbon dioxide. Gas from Devonian analyzed 1.58 percent helium and 56.8 percent carbon dioxide.

T. 43 S., R. 20 E.

6	Pan American Petroleum Corp.	Navajo 161-1	A	4,245	1958	Molas Formation	Show of carbon dioxide gas in Hermosa.

T. 43 S., R. 21 E.

4	U.S. Smelting, Refining & Mining Co.	Ohio-Navajo 1-4	PGW	5,181	1958	Hermosa Formation	Initial production 18,925,000 CFGPD from Hermosa.
5	do	Ohio-Navajo 1-5	A	5,772	1957	Molas Formation	SOG in Hermosa.
9	do	Ohio-Navajo 1-9	PGW	5,706	1957	do	Discovery well for Chinle Wash field. Initial production 9,735,000 CFGPD from Hermosa.
10	Ohio Oil Co	Navajo 1	A	6,944	1954	Cambrian	SOG in Hermosa.
19	Texaco, Inc	Navajo 1-AE	POW	6,218	1962	Devonian	Initial production 47 BOPD and water from Mississippian. Later plugged back and produced 98 BOPD from the Hermosa.
23	Davis Oil Co	Chinle Wash 1	A	6,385	1961	Mississippian	

Record of wells drilled—Continued

Section	Operator	Well	Status	Total depth (feet)	Year completed	Oldest rocks penetrated	Remarks
T. 43 S., R. 22 E.							
4	Sinclair Oil & Gas Co.	Navajo 2	A	5,220	1960	Hermosa Formation	SOG in Hermosa.
6	Sunray Mid-Continent Oil Co.	Utah-Navajo 1	A	5,830	1957	Molas Formation	SO in Hermosa.
16	Western Natural Gas Co.	English 9	POW	5,020	1957	do	Initial production 27 BOPD from Hermosa.
16	do	English 7	SD	5,409	1956	Mississippian	Initial production 16 BOPD and water from Hermosa; gas from Hermosa analyzed 0.68 percent helium and 6.1 percent carbon dioxide.
16	Wyoming Assoc. Oil Corp.	F. A. Kemp 1	A	505	1924	Triassic	
20	Sunray Mid-Continent Oil Co.	Utah-Navajo "A"-1	A	5,641	1958	Molas Formation	SO in Hermosa.

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