Geology of Comb Ridge and Vicinity North of San Juan River San Juan County, Utah

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GEOLOGY OF COMB RIDGE AND VICINITY NORTH OF SAN JUAN RIVER, SAN JUAN COUNTY, UTAH

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ABSTRACT

The area described, in San Juan County, Utah, is approximately 7 miles wide and extends from the San Juan River northward for about 20 miles. It includes the northern part of Comb Ridge and a narrow belt on each side.

Altitudes range from 4,170 feet on San Juan River at the southwest to 6,000 feet on Grand Gulch Plateau at the northwest, where its eastern rim forms a high escarpment. Comb Ridge, a conspicuous hogback of eastward-dipping rocks extending through the area and far to the southwest, is the most striking topographic feature and a nearly impassable barrier.

San Juan River is the major drainage course and the only perennial stream. It cuts across Comb Ridge, follows the strike in softer beds for 2 miles, and then flows in a deep, tortuous canyon through steeply dipping hard rocks. Comb and Butler Washes are the two principal tributaries, flowing in strike valleys. These streams and their numerous branches show close adjustment to the nature and structure of the formations over which they run.

This remote area is about 140 miles by road from the railroad to the north and about 215 miles from that to the south. No one is now living within its boundaries. The nearest communities are Blanding and Bluff to the east and Mexican Hat to the west. Only one main road, the newly improved State Highway 47, reaches the area, and it crosses the southern part. A new, similar rock-surfaced road extending from Blanding to the Natural Bridges comes within a few miles of the area's northern edge. The only other roads within the area are of dirt; after the abnormal rains and floods in the summer of 1953 they were nearly unusable.

The exposed sedimentary formations range in age from Pennsylvanian to Recent and aggregate 5,000 feet or more in thickness. The oldest rocks—the upper part of the Hermosa and the lower part of the Rico—are exposed in the deep canyon of San Juan River. Hard upper limestones of the Rico form the surface of a structural uplift and topographic upland near the river. Successively younger formations crop out toward the east, the youngest being the Bluff sandstone of Late Jurassic age, which forms a westward-facing escarpment along the east margin of the area. Most of the formations show approximately the same appearance and thickness that is characteristic of them over a wide region. A few show more variation or unusual features. The Cedar Mesa sandstone member of the Cutler formation, usually made up chiefly of a thick series of massive gray to buff sandstones, has a soft zone about 130 feet thick at its base in the northern part of the area. Farther south, the entire

member, 830 feet thick, grades laterally within a short distance into a soft facies of very nonresistant sandstone, much light-colored clay, and many beds of gypsum. The De Chelly sandstone member and the Hoskinnini tongue, both of the Cutler formation, together form only a thin zone in the southern part of the area and seem to wedge out northward in its central part. The formations of the San Rafael group, though maintaining a constant thickness, show marked lithologic changes from south to north in Butler Wash. In this group the Carmel formation changes from mostly soft reddish sandstones and mudstones to a unit composed chiefly of gray to buff sandstones with a soft reddish band in the middle. The upper part of the Entrada sandstone, which at the south is a zone of soft thin-bedded brick-red shaly sandstones, becomes northward a massive red sandstone. The Summerville formation is composed of grayish-brown or tan thin-bedded sandstones, sandy siltstones, and some minor shaly beds at the south; northward the upper part changes to a distinct reddish brown, becomes less thin bedded, and includes several thin grayish-white sandstones.

Alluvium, slope wash, windblown sand, and terrace gravels seen at many places within the area are omitted from the map.

Igneous rock was noted only in one small lamprophyre dike near San Juan River.

The area is in the eastern part of the broad regional Monument upwarp, and its principal structural feature is the great Comb monocline, which forms the eastern flank of that upwarp. In the northwest corner, on Grand Gulch Plateau, the area includes a relatively few square miles of the nearly horizontal beds that make up the broad top of the upwarp. The northeast end of one of the subordinate anticlines that complicate the Monument upwarp is exposed in the southwest corner, where the structure is clearly revealed by the shape of the surface eroded on the thin but very resistant uppermost limestone of the Rico formation.

A large fault, in part single, in part compound, is in the southern part of the area. With downthrow on the south, to a maximum of perhaps 200 feet, it begins in the Rico formation, extends northeast across the younger formations exposed in Comb Wash, and dies out before reaching Comb Ridge.

Two small faults on the northeast nose of the subordinate anticline mentioned above show minor overthrusting toward the southwest and suggest that, after uplift, the anticline may have subsided slightly and caused some lateral compression.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The area (see fig. 40) described in this report is in the southern part of San Juan County, Utah. It is a northward-trending belt nearly 7 miles wide and 21 miles in maximum length and covers about 130 square miles. On the east it is bounded by longitude 109°37′30″ W. and on the west by 109°45′ and extends from the San Juan River on the south to latitude 37°30′ N. It thus covers about two and a quarter 7½-minute quadrangles: the Bluff 1 NW and Bluff 1 SW quadrangles and the northern part of the Bluff 4 NW quadrangle.

PURPOSES OF THE INVESTIGATION

Though of considerable stratigraphic and structural interest, the area had previously been studied only by reconnaissance and mapped

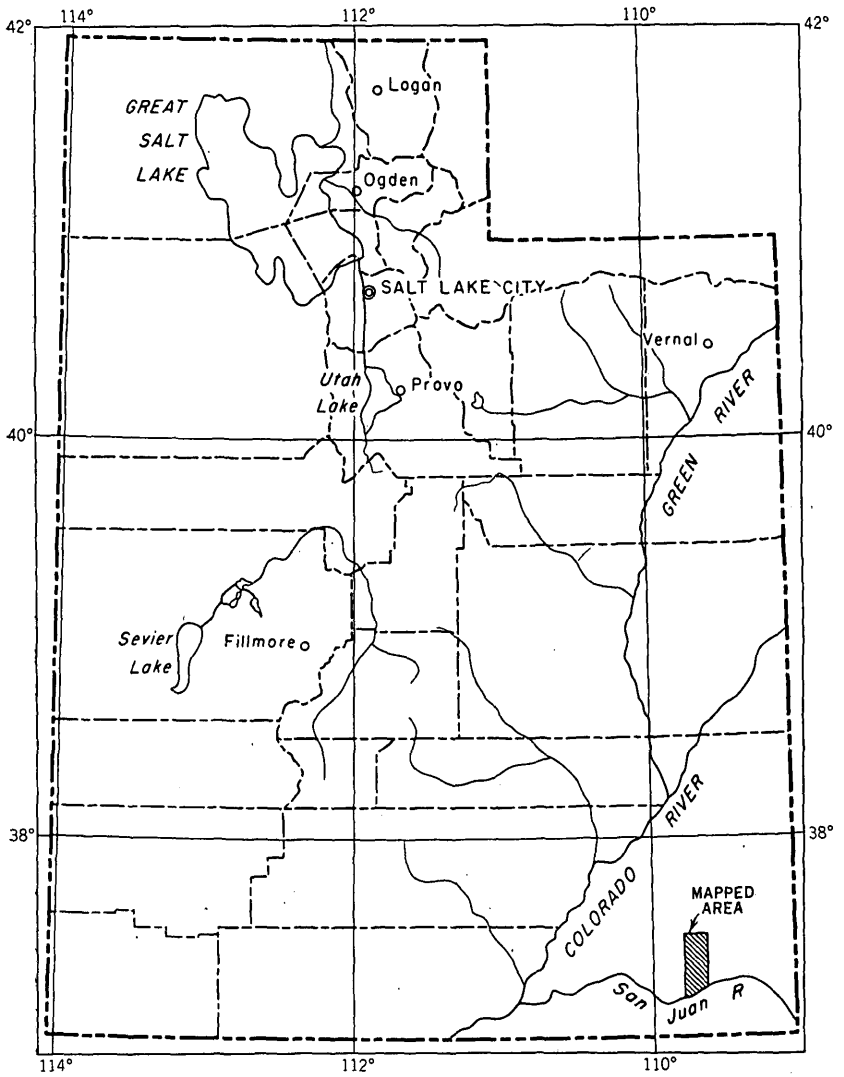


FIGURE 40.—Index map showing location of the area described in this report.

only on small scales. Added details and larger scale mapping were needed because of the marked variations in stratigraphy and the abrupt structural changes. Furthermore, the project was designed to supply a certain amount of instruction and practice in field investigation and in techniques of mapping stratigraphy and structure by means of planetable and air photographs to selected groups of younger members of the U. S. Geological Survey—well-trained geologists and paleontologists whose experience had been principally in other specialized lines.

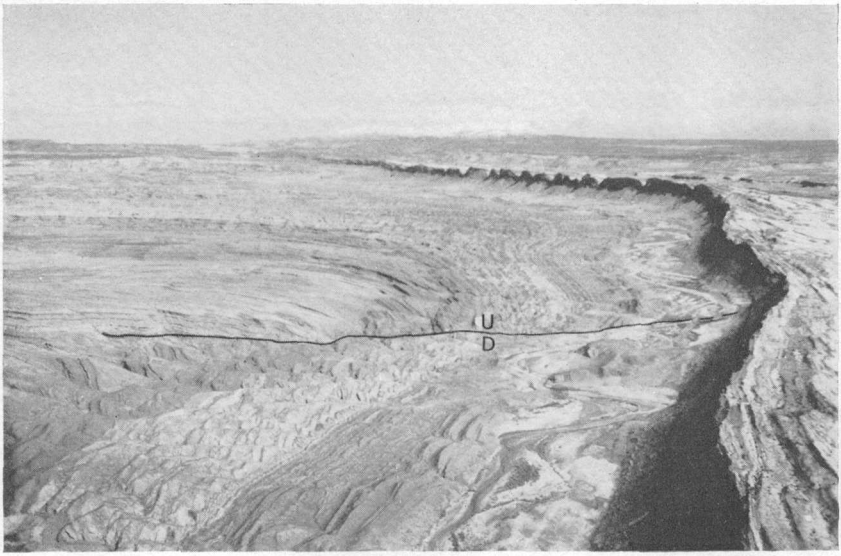
PERSONNEL

The project was planned and carried out under immediate supervision of the writer assisted by R. Dewey Sample. For the first 8 weeks the staff members assigned to the party were Gerald W. Fuller, Mineral Deposits Branch; Chabot Kilburn, Fuels Branch; Sergius H. Mamay, Paleontology and Stratigraphy Branch; and Warren L. Peterson, Engineering Geology Branch. For the ensuing 6 weeks the members assigned were Mendell M. Bell, Mineral Deposits Branch; Max H. Bergendahl, General Geology Branch; Mario A. Conti, Military Geology Branch; and Ellis L. Yochelson, Paleontology and Stratigraphy Branch. Throughout the season, Robert A. Madden served as field assistant and aided in stadia traverses and other mapping as well as in miscellaneous camp duties.

FIELDWORK

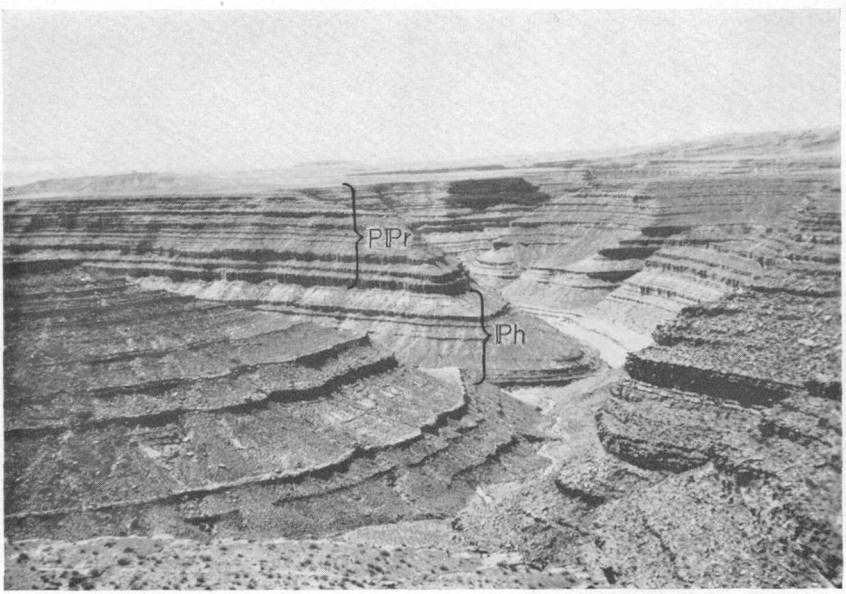
The investigation on which this report is based was carried out in the field from early June to mid-September 1953. For most of the season the party maintained a base camp in Comb Wash. Transportation by jeeps and light trucks to points where foot traverses started was impeded by an abnormal series of heavy rains, which caused the dirt roads to become virtually impassable and even brought temporary closing of the two main rock-surfaced roads.

Recent large-scale air photographs were used, by means of portable stereoscopes, in laying out the work and studying the geology; on them the formational boundaries were drawn and other geologic data were noted. Most of the actual mapping, however, was done by planetable and telescopic alidade. Significant points were located on both the photographs and the planetable sheets, and boundaries between those points were sketched from the photographs on the sheets. A triangulation network for horizontal control was established for the whole area. Vertical control was set up by determining the elevation of triangulation points by vertical angles, starting from a bench mark near the "Mormon Trail" road half a mile north of State Highway 47. Insofar as possible, instrument stations and other points were located by triangulation. However, in much of the area—in the deep canyons with unscalable walls, in the lower part of Comb Wash, and on the rounded limestone upland west of the wash—triangulation was not feasible, and it was necessary to resort to more time-consuming stadia traverses. Even such traverses could not be made in the deep canyons cutting Grand Gulch Plateau because of the growing danger from recurring flash floods; for those canyons the geology that had been studied and recorded on the air photographs was transferred to a controlled photographic mosaic of the area and used in compiling the final map.



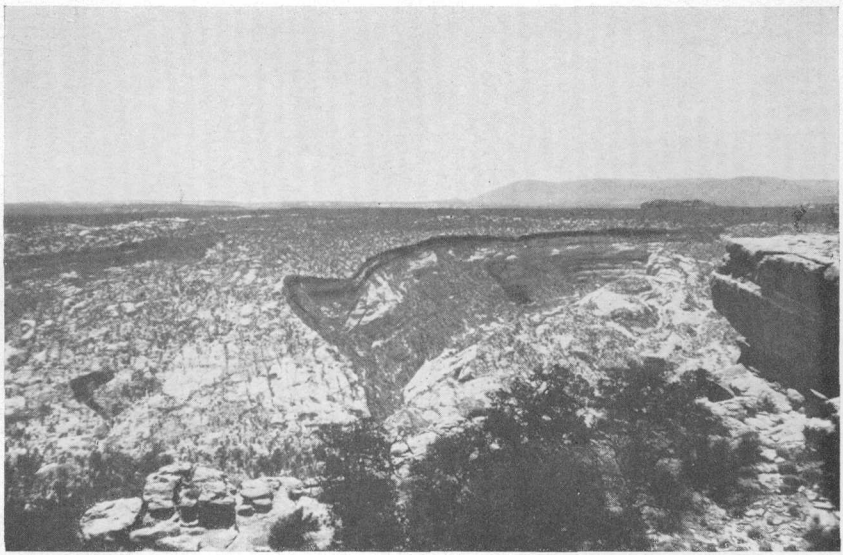
A. LARGE NORMAL FAULT CROSSING COMB WASH

View up Comb Wash northward from San Juan River. Limestone at top of Rico formation in left foreground, ringed by successively younger formations. Comb Ridge at right. Photograph by J. R. Balsley.



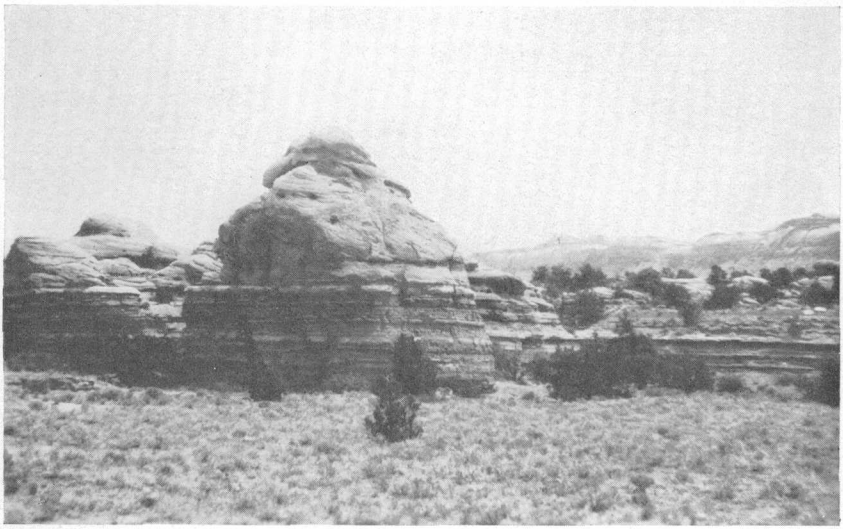
B. HERMOSA AND RICO FORMATIONS IN SAN JUAN RIVER CANYON

Rim of canyon and bench behind it are formed by limestone about 132 feet below top of Rico.



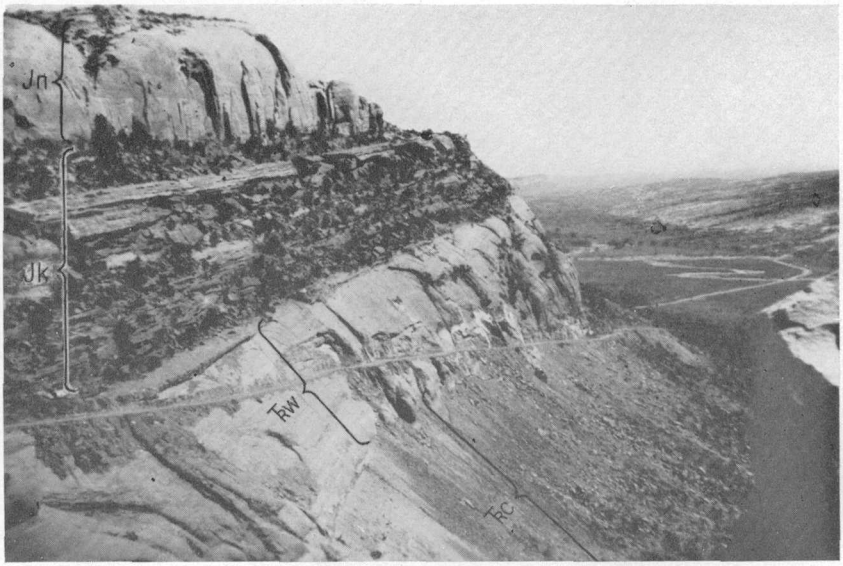
A. THICK-BEDDED SANDSTONES REGIONALLY TYPICAL OF CEDAR MESA SANDSTONE MEMBER

This member of the Cutler formation upholds nearly level top of Grand Gulch Plateau and is exposed in deep canyon cut into slope of eastward-dipping beds in Comb monocline. View westward from top of Comb Ridge near road from Blanding to the Natural Bridges. Elk Ridge in distance at right.



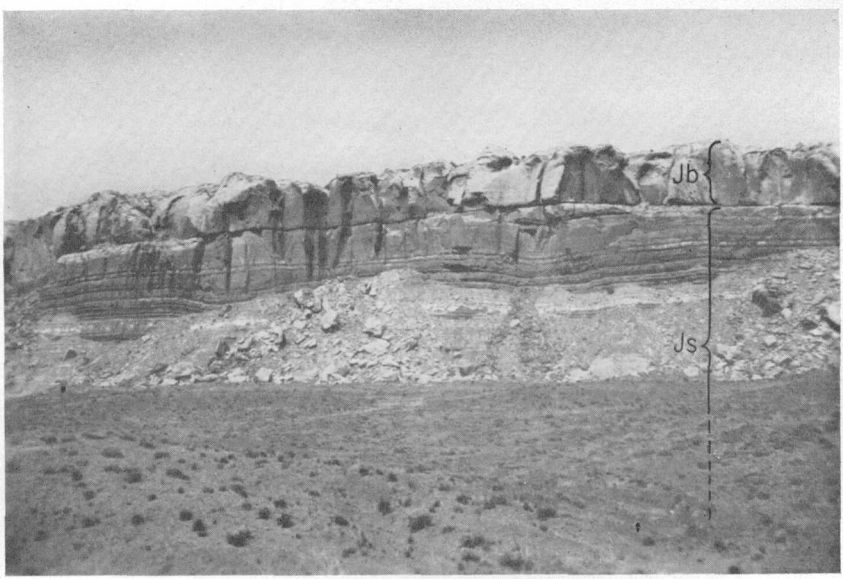
B. LOCAL FACIES OF CEDAR MESA SANDSTONE MEMBER WITH HARD UPPER PART AND SOFT THIN-BEDDED LOWER PART

This facies is found in northern half of mapped area. Contact crosses middle of "haystack" at left center. About 20 feet below this, a thin bench-forming limestone causes the flat surface in foreground.



A. NAVAJO SANDSTONE, KAYENTA FORMATION, WINGATE SANDSTONE, AND CHINLE FORMATION ON WEST SIDE OF COMB RIDGE

View southward. Low road from Blanding to the Natural Bridges descends the dugway, crosses Comb Wash near the Perkins Ranch, and climbs the dip slope of Cedar Mesa sandstone member at extreme right.



B. SAGS IN SUMMERVILLE FORMATION, OVERLAIN BY BLUFF SANDSTONE

On east side of Butler Wash, 4 miles north of State Highway 47. Locally, a thick sandstone at top of Summerville closely resembles the Bluff sandstone.

During the course of the fieldwork, about a score of section and quarter corner pipes established by the Bureau of Land Management were observed and located by triangulation. Most of the area, however, is unsurveyed or only partly surveyed. The corners found are mostly on a range-line survey along the west side of Tps. 38 and 39 S., R. 21 E.; two of them are within a partial interior survey in T. 38 S., R. 21 E.; and a few are in the southern part of T. 40 S., R. 20 E.

The results of the season's fieldwork are brought together in a general geologic map of the field (pl. 17).

ACKNOWLEDGMENTS

The writer is grateful to numerous officials, merchants, and other residents in Blanding, Bluff, and Mexican Hat for the helpful information and other assistance they gave to the party during its fieldwork.

Lawrence C. Craig and Thomas E. Mullens, of the U. S. Geological Survey, visited the party during the season, shared their broad knowledge of the regional geology, and supplied an unpublished section they measured in the area in 1951.

William R. Hemphill, of the U. S. Geological Survey, contributed substantial assistance by making numerous measurements and calculations, from air photographs by means of a stereometer, of strikes and dips and of formation thicknesses on Comb Ridge and in Butler Wash.

GEOGRAPHY AND PHYSIOGRAPHY

GENERAL STATEMENT

The area of Comb Ridge and vicinity, north of the San Juan River, mapped in the summer of 1953, is but a small part of a region called by Gregory (1938) "the San Juan country." The reader is referred to his report, not only for the regional geologic and geographic setting for the smaller area but also for many details of geography and physiography that cannot be discussed in the present brief report and for an account of the human history of the region—its prehistoric and later Indian dwellers and its exploration and settlement.

SURFACE FEATURES AND DRAINAGE

Total relief within the mapped area is approximately 1,800 feet, the altitude ranging from about 4,170 feet on San Juan River at the southwest corner to about 6,000 feet on Grand Gulch Plateau at the northwest corner.

Comb Ridge is the most striking topographic feature. This great hogback of eastward-dipping rocks begins southeast of Elk Ridge about 8 miles north of the mapped area and extends southward and southwestward more than 80 miles to a point beyond Kayenta in

Arizona. Its eastern slope is a hummocky surface eroded on the Navajo sandstone in a belt from a third of a mile to a mile or more in width. Its western face is much more abrupt; above a steep slope of clays and sandstones of the Chinle formation, rises a well-nigh vertical cliff, at most places several hundred feet high, of massive Wingate sandstone and the lower sandstones of the Kayenta formation. Thus the west face of the ridge, towering to a constant height of about 800 feet above the adjacent Comb Wash (see pl. 18*A*), forms an almost impassable barrier. At only one place within the mapped area can it be crossed with vehicles—where a dugway has been blasted out on the north side of a reentrant to carry State Highway 47. South of that road, there are places where, because of jointing in the Wingate sandstone, the ridge can with difficulty be climbed on foot; but in the more than 16 miles between the highway and the north edge of the mapped area its westward-facing cliff probably is unscalable. Several miles still farther north, near the Perkins Ranch in Comb Wash, another reentrant on the west side of the ridge was used in the spring of 1953 to construct a dugway for a new road between Blanding and the Natural Bridges National Monument. (See pl. 20*A*.)

Another conspicuous, though somewhat less striking, topographic feature is the high escarpment that extends northeastward across the northwest corner of the area. This is the eastern margin of the wide upland known as Grand Gulch Plateau, which rises to an altitude several hundred feet greater than that of the northern part of Comb Ridge. The plateau is underlain by a thick series of nearly horizontal heavy sandstones, and the high escarpment and the walls of the deep canyons that are cut back into it are unscalable at most places. Where the escarpment crosses the west edge of the mapped area, however, the old "Mormon Trail" road zigzags to the top of the plateau.

The third prominent upland within the area is in the southwest corner, where by uplift and erosion the hard gray limestone at the top of the Rico formation is exposed as a domelike surface. After passing Comb Wash, State Highway 47 climbs and crosses this upland on its way southwest into the valley of Lime Creek and to the bridge over the river at Mexican Hat.

The San Juan River, which forms the southern boundary of the mapped area, is the major drainage course and the only perennial stream. Near and downstream from Bluff the river occupies an open valley cut in nearly horizontal rocks, but as the easterly dips of the beds become steeper the valley grows narrower. After passing in a fairly wide and low gap through Comb Ridge, the river turns south and follows the general strike of the softer beds in the Cutler formation for some 2 miles. At that point it swings to the northwest and cuts boldly into the steep dip of the hard Rico and Hermosa formations, in a deep, tortuous canyon—the beginning of a series of spectacular

entrenched meanders, the best known and most visited of which are the "Goosenecks" downstream from Mexican Hat. Some 2 miles below its upper end the canyon has its right wall breached by the edge of a striking, deeply entrenched, and almost oval oxbow that marks a cut-off canyon loop occupied by the river when flowing at a higher level. The bottom of this oxbow is now marked by two small dry stream beds, which join near their lower ends and drain into the present canyon by a high "dry waterfall."

The two principal tributaries within the mapped area are Comb Wash and Butler Wash. Comb Wash and its upper branches head on the south flank of Elk Ridge; Butler Wash heads somewhat farther south. Both streams flow south and southwest, closely flanking Comb Ridge on its west and east sides, respectively, to their junction with the San Juan River. The locations and patterns of both streams reflect the relative hardness and structure of the underlying and adjacent formations. Both streams closely follow the strike; and as their valleys were being slowly lowered in the softer rocks, both streams probably migrated laterally eastward down the dip slopes of the underlying more resistant Cedar Mesa sandstone member and the Navajo sandstone respectively.

In its upper reaches Comb Wash flows south in a fairly wide shallow channel cut in earlier valley fill; its meanders are of moderate size, and its low alluvial banks are flanked by deposits of windblown sand and slope wash. Downstream, where the strike is more to the southwest and the dips are much steeper, the valley and the belt of alluvium are much narrower, and the exposures of bedrock are better. (See pl. 18*A*.)

Butler Wash is similar in some ways and different in others. In its upper reaches it, too, flows in an alluvium-filled valley; but its meanders are much smaller and more twisted, and its channel is narrower and deeper. Downstream, beginning where the strike swings to the southwest (just as does the narrowing of Comb Wash valley), the alluvium abruptly ceases; and the wash flows in a narrow canyon cut in the Navajo sandstone.

The many side streams entering Comb and Butler Washes also clearly show the effect of the varied geology and topography of the area and present many interesting physiographic problems that deserve more detailed study than could be devoted to them in the course of the fieldwork. Those tributaries entering Comb Wash on the east are numerous; but being confined to the narrow slope of clay at the foot of the west side of Comb Ridge, they are short and shallow. Those on the west are much larger and more conspicuous. They are also much more varied, falling into three principal types. In the northern part of the area, where the thick Cedar Mesa sandstone member is very hard and resistant, the streams flow in deep, formidable canyons.

Farther south, between the lower reaches of Road Canyon and Snake Gulch, the Cedar Mesa is much softer and less resistant, and the principal streams and their innumerable branches make an intricate leaf-vein pattern. Still farther south the streams have cut deeply into the southeastward-dipping hard limestones and sandstones of the Rico formation. Some of these streams show anomalies in their lower courses in that, where they cut across the steeply dipping hard layers in the Halgaito and Cedar Mesa, they flow northeast instead of southeast toward Comb Wash as would be expected. These anomalies are thought to be due to the softening effect of northeastward-trending fractures and incipient faults in those beds, parallel to the large fault shown on the map.

The side drainage of Butler Wash is of more usual types. The many roughly parallel streams flowing down the east slope of Comb Ridge are conspicuous because of the rounded trenches they have eroded in the dip slope of the Navajo sandstone; but they are of physiographic interest particularly because a number of them, upon reaching the foot of that slope, do not enter Butler Wash directly but first turn south and run for considerable distances before entering the main stream.

Comb and Butler Washes and their branches are all intermittent streams, usually flowing only in prompt response to rainfall. A single heavy, though local, storm may send a flash flood many feet deep down a side canyon. When this flood pours into the main stream it widens out but still may fill the channel bank to bank with a muddy stream several feet deep persisting for perhaps half a day.

CLIMATE AND VEGETATION

The area lies within a semiarid region and with its relatively high altitudes has the characteristic scanty rainfall (averaging perhaps 8 or 10 inches a year) and large daily and yearly range of temperatures (from a winter minimum below zero to a summer maximum of well above 100 degrees). Readings are not taken within the area itself; the nearest Weather Bureau stations are at Blanding, Bluff, and Mexican Hat, a few miles northeast, east, and southwest of its limits, respectively; and the approximate figures given above are based on the available records from those three stations over the past decade. Most of the rain falls in brief local showers, some of which are very heavy. Only a minor part of the precipitation is absorbed to become ground water. In a few of the canyons, there are small water seepages, but most of them are only large enough to cause wet patches for a short distance downstream and few merit the name of "spring." To the writer's knowledge, the largest spring within the area was the long-known and frequently used "Navajo spring," below the old dugway on the west side of Comb Ridge. This spring was

damaged and largely covered by the rocks that tumbled down the steep slope during the rebuilding of State Highway 47 in the spring of 1953 and would require considerable work to make it again usable.

Timber in the area is limited chiefly to the numerous junipers on Grand Gulch Plateau and a fair number of cottonwoods in the upper part of Comb Wash. Elsewhere, a few scattered cottonwoods are found in lower Comb Wash and in Butler Wash, and sparse piñon pines and junipers are seen on some of the sandstone ledges. Tamarisks grow along the edge of Comb Wash valley at a few places. In general, however, the vegetation of the area includes only sagebrush, greasewood, prickly pears, and other low-growing plants typical of a semiarid region. Forage plants are sufficient in both Comb and Butler Washes to supply a moderate amount of winter grazing for cattle.

SUPPLY POINTS AND TRAVEL ROUTES

There are no towns or villages in the mapped area—indeed, so far as known to the writer not one person is now living within its borders. Until 1951 or 1952 a few Indian families lived in hogans in the upper part of Butler Wash; but at that time they were required by court decision to move to the reservation south of the river.

The nearest communities are Bluff, an early Mormon settlement on the river a few miles east, and Mexican Hat some 15 miles to the southwest. More varied supplies and facilities are available in Blanding, a town of some 1,200 population about 30 miles by State Highway 47 from the southeast corner of the area. For other services and supplies recourse is had to the more distant towns such as Monticello, Moab, and Cortez or to Grand Junction, Colo., some 250 miles distant by road.

The only main road crossing the area is State Highway 47, usually referred to locally by the briefer term "U–47." It begins at Monticello, where it connects with paved U. S. Highway 160, which extends northward 88 miles through Moab to Crescent Junction, located on U. S. Highways 6 and 50 and the Denver & Rio Grande Western Railroad, and extends eastward and southeastward 60 miles to Cortez, Colo. From Monticello, State Highway 47 runs south through Blanding and Bluff, thence west and crosses the southern part of the mapped area. Still farther southwest it crosses the San Juan River by a bridge at Mexican Hat and reaches Monument Valley, where it connects with Arizona roads leading via Kayenta and Cameron to Flagstaff on The Atchison, Topeka, and Santa Fe Railway. By these roads the mapped area is about 140 and 215 miles, respectively, from the railroads to the north and south. Despite the remoteness of the area, however, State Highway 47 brings to it a rather surprising amount of tourist as well as other traffic. In the spring of

1953 that part of State Highway 47 between Blanding and Mexican Hat was improved. It was relocated in places, widened to permit continuous 2-way traffic, and surfaced throughout with crushed rock. Particular improvements were the construction of a bridge over Butler Wash, eliminating the descent into its deep rock-cut canyon; the construction of a new dugway with much gentler grade down the west side of Comb Ridge; and just west of Comb Wash, bypassing of the former twisting route up Snake Gulch. In the fall of 1953 that part of the road from Monticello to Blanding was surfaced with "black top," and a new bridge was being built over the river at Mexican Hat.

Another main road extends east and west several miles north of the northern edge of the mapped area. This new road, also surfaced with crushed rock, was completed in the spring of 1953. It leaves State Highway 47 at a point about 3 miles south of Blanding, runs roughly west to the Natural Bridges National Monument, and connects with the road down White Canyon to the Colorado River ferry at Hite. This road is much lower than, and an alternative for, the old road from Blanding to the Bridges, which, because of its altitude of more than 8,500 feet near the Bear's Ears is blocked by snow or made impassable by mud during much of the year. The new road descends Comb Ridge by a steep dugway down its west side (see pl. 20*A*), crosses Comb Wash just upstream from the Perkins Ranch, climbs the dip slope of sandstone to the top of Grand Gulch Plateau, and goes west some 15 miles to join the Bear's Ears road a few miles east of the Bridges.

Between these 2 main roads extend 3 dirt roads through or across the mapped area. The first and most important of these was the old "Mormon Trail" road. This leaves State Highway 47 and runs north on the west side of Comb Wash for about 5 miles, crosses Road Canyon, and turns northwest for a few miles, where it climbs to the top of Grand Gulch Plateau. Some 25 miles farther northwest it joins the 2 roads between Blanding and the Bridges—the new low road and the older high road by way of the Bear's Ears. In the past the "Mormon Trail" road was much used by travelers to and from the Bridges and White Canyon, because it served both as a short cut from or to the south on State Highway 47 and as a substitute for the Bear's Ears road, when impassable, for those going from or to Blanding and the north.

Just south of Road Canyon a road branches from the "Mormon Trail" road, crosses to the east side of Comb Wash, and runs north some 15 miles to the Perkins Ranch just outside of the mapped area.

The third road leaves State Highway 47 and goes up the east side of Butler Wash to a point just north of the mapped area, then turns

northeast out of the wash, climbs over a divide, and drops into Cottonwood Wash where it joins the new low road from Blanding to the Bridges. That part of the road in Butler Wash is in general passable only by vehicles with 4-wheel drive, even in dry weather; and after storms it becomes virtually impassable.

Indeed, all 3 of these dirt roads suffered so badly from the heavy rains and floods in July and August 1953, with washed-out culverts, deep rutting, cave-ins, and boulder cover, that some doubt was expressed about their repair and further maintenance, especially in view of the fact that the new low road from Blanding to the Bridges now gives the necessary alternative for the Bear's Ears road and also shorter and better access to the Perkins Ranch.

STRATIGRAPHY

GENERAL SECTION

Within the area described in this report are exposed beds aggregating 5,000 feet or more in thickness and ranging in age from Pennsylvanian to Recent. The oldest rocks—the Hermosa formation, of Pennsylvanian age—are seen in the deep canyon of the San Juan River. The next overlying formation—the Rico, of Pennsylvanian and Permian(?) age—is exposed in the same canyon walls, and its hard upper limestone layers form the surface of the uplift in the southwest part of the area. Because of the easterly dips in the Comb monocline, bands of successively younger formations are found toward the east; the youngest named formation within the area—the Bluff sandstone, of Late Jurassic age—lying nearly horizontal forms a westward-facing escarpment along the east margin of the mapped area. Recent alluvium, terrace gravels, slope wash, and windblown sand were noted at a number of places within the area, particularly along the upper part of San Juan River and in the valleys of Comb and Butler Washes; but these were not studied in detail and are not shown on the geologic map because in places they would too fully obscure the bedrock.

The stratigraphy is in part complicated by marked lateral variations of several formations and members in both lithology and thickness, as brought out in the descriptions of those units. The regional setting and broader relations of these strata, as well as many pertinent details about them, have been presented by Gregory (1938). Many helpful details are furnished also by Baker (1936) for the Monument Valley–Navajo Mountain region, which approaches within 10 miles of the southwest corner of the area described herein.

The areal distribution of the formations is shown on plate 17. Their succession and character are summarized in the following general section.

General section of sedimentary rocks exposed in mapped area

Systems and series		Group, formation, and member		Thickness (feet)	Character of rocks
Quaternary					Alluvium of clay and conglomeratic lenses in Comb and Butler Washes; slope wash of clay and of sandstone boulders on east side of Comb Wash; windblown sand on west side of Comb Wash and elsewhere; terrace gravel near mouth of Comb Wash and on San Juan River.
Jurassic system	Upper Jurassic series	San Rafael group (upper part)	Bluff sandstone	100+	Grayish-brown, thick, massive, resistant sandstone, in part crossbedded.
			Summerville formation	146–162	Grayish-brown or tan thin-bedded sandstones, sandy siltstones, and minor shaly beds. Northward, upper part becomes reddish brown, includes several thin grayish-white sandstones, and is less thin bedded.
			Entrada sandstone	150	Lower unit, medium-bedded gray to buff sandstones. Upper part, soft thin-bedded brick-red shaly sandstones to south, more massive red sandstone to north.
	Middle and Upper Jurassic series	San Rafael group (lower part)	Carmel formation	108–114	Soft, thin-bedded red sandstones and mudstones, with a few thin gray sandstones, in southern part. Gray to tan, thicker, more massive sandstones, with a softer reddish zone at middle, in northern part.
	Lower Jurassic series	Glen Canyon group (upper part)	Navajo sandstone	341±	Grayish-white sandstone, in part weathering light buff; a few softer reddish sandstones in lower part. Large-scale tangential crossbedding.
Jurassic(?) system		Glen Canyon group (middle part)	Kayenta formation	126±	Alternating sandstone, siltstone, and limestone, buff, tan, gray, white, and light red; essentially flat bedded; medium to thin bedded.
Triassic system	Upper Triassic series	Glen Canyon group (lower part)	Wingate sandstone	275±	Massive, cliff-making light-orange-red or brick-red to reddish-buff sandstone, crossbedded on large scale.
		Chinle formation		956	Variegated shale and clay; brown-gray and orange-red sandstones; thin limestones.
	Lower and Middle(?) Triassic series	Moenkopi formation		140(?)–222	Chocolate-brown and brownish-red thin-bedded sandstone and siltstone; ripple marked at numerous horizons.

General section of sedimentary rocks exposed in mapped area—Continued

Systems and series	Group, formation, and member		Thickness (feet)	Character of rocks
Permian system	Cutler formation	Hoskinnini tongue	0–30±	Alternating thin layers of orange-red, brownish-red, chocolate-brown, and grayish-white sandstone.
		De Chelly sandstone member	0–135	Red-brown sandstone, crossbedded in upper part, more massive in lower part.
		Organ Rock tongue	560(?)–820	Brownish- to orange-red rather thin-bedded fine-grained sandstones and sandy mudstones that weather into rounded surfaces and thin slabs. Grayish-green mottling in patches and stringers is common.
		Cedar Mesa sandstone member	830	Thick-bedded, massive gray and buff sandstones with some thinner layers and lenses of gray, buff, and reddish sandstone and clay, in northern part; locally, basal 130 feet is softer, with thin beds of variegated clay, sandstone, gypsum, and limestone. Toward south, whole member grades into soft facies, of pastel-colored clays, friable sandstones, and gypsum.
		Halgaito tongue	406	Hard and soft thin-bedded brownish-red sandstones, siltstones, and mudstones, with a few thin beds of gray limestone and white to buff sandstone.
Pennsylvanian and Permian(?) systems	Rico formation		390±	Hard gray limestone and massive sandstone in beds up to 20 feet thick, interspersed with thicker zones of prevailingly red softer sandstones and thin-bedded mudstones.
Pennsylvanian system	Hermosa formation		330+	Gray, cherty, very siliceous limestones, interbedded with gray shale.

PENNSYLVANIAN SYSTEM

HERMOSA FORMATION

Above river level in the canyon of San Juan River in the southwest part of the mapped area is exposed some 330 feet of beds identified as belonging to the Hermosa formation. They consist chiefly of gray cherty very siliceous limestones, interbedded with gray shale. The limestones contain some fossils, principally brachiopods and echinoid spines. The exposed Hermosa occupies roughly the lower half of the canyon wall and has the general appearance of a gray slope interrupted by harder, ledge-making layers. Its upper contact was selected as the top of a light-blue-gray sandy shale zone 15 to 20 feet thick (the upper of two such light-toned bands) just below a conspicuous ledge of tan-weathering sandy limestone about 25 feet thick. (See pl. 18*A*.)

The beds thus exposed represent only the uppermost and minor part of the Hermosa of this region, for Baker (1936, p. 19) records an incomplete thickness of 1,020 feet farther down the river, 3 miles northwest of the Honaker Trail.

PENNSYLVANIAN AND PERMIAN(?) SYSTEMS

RICO FORMATION

Lying above the Hermosa formation with apparently full conformity is the Rico formation, now classed by the Geological Survey as of Pennsylvanian and Permian(?) age. Based upon several elevation readings by Bell and Yochelson, it is estimated in this area to be about 390 feet thick. It includes numerous hard gray limestones and massive sandstones up to 10 or even 20 feet thick, interspersed with thicker zones of softer and prevailingly red sandstones and thin-bedded mudstones. At its top is a thin dense blue-gray limestone with local zones of fragmental crinoid remains. This limestone is so resistant that it forms the surface of most of the domelike anticlinal upland in the southwest part of the area. Nearer the river, however, this limestone and the subjacent 130 feet of beds have been eroded, and the next resistant gray limestone (characterized by included, irregular masses of red chert) forms a wide bench and the rim of the canyon. (See pl. 18*B*.) In the walls of the canyon, the Rico contrasts markedly with the underlying gray slope of the Hermosa, for it has a generally red tone and a greater number of thick ledge-forming beds that give a step-and-slope profile to the upper canyon walls. As previously stated, its contact with the Hermosa was selected as the base of a tan-weathering ledge of sandy limestone some 25 feet thick.

The uppermost 133 feet of the Rico in this vicinity was recorded by Yochelson as follows:

Section of upper part of Rico formation measured just north of entrenched oxbow in southwest corner of mapped area

	Feet
Limestone, fine-grained, light-gray, massive, resistant; uppermost layer of Rico, forms surface of upland	2.5
Sandstone, shaly, weathering dark red	5.5
Sandstone, upper part massive, ledge-forming, weathering light tan; lower part thin bedded, shaly, weathering dark red	13.0
Limestone, sandy to shaly, weathering gray	1.0
Sandstone, mostly thin-bedded, shaly, weathering dark red; includes 5 or 6 more resistant layers each 2 to 3 feet thick	111.0
Total	133.0

Limestone, fine-grained, gray, with included irregular masses of red chert; resistant, weathers to rough surface; forms a prominent bench and the rim of San Juan River canyon.

PERMIAN SYSTEM

CUTLER FORMATION

In his report on the Monument Valley–Navajo Mountain region, Baker (1936, p. 28) states, "All the strata between the top of the Rico formation and the base of the Moenkopi formation, of Lower Triassic age, are included in the Cutler formation. * * * The Cutler formation is divided into five distinct units, which, from oldest to youngest, are the Halgaito tongue, Cedar Mesa sandstone member, Organ Rock tongue, De Chelly sandstone member, and Hoskinnini tongue." Gregory (1938, p. 41) brought this usage of the Cutler formation and its five subdivisions northward across the San Juan River into the San Juan country, and it is appropriate and applicable for the area discussed in the present report.

HALGAITO TONGUE

Lying upon the Rico formation with no evident break is the basal unit of the Cutler formation, the Halgaito tongue. In the southwest sector of the mapped area, the Halgaito makes a prominent, rather bright-red zone above and curving around the arched gray-limestone surface of the Rico. Farther north, varying amounts of its upper part are seen in the several branches of Road Canyon, Fish Creek, and Dry Wash, but the lower part and the underlying Rico are not exposed.

In this area the Halgaito tongue is made up chiefly of hard and soft thin-bedded sandstone in layers from a foot to 10 feet thick, interspersed with thin-bedded siltstones and mudstones, of a general reddish tone. A few scattered thin beds of gray limestone and white to buff sandstone were noted. Some 10 feet above the base is a red sandstone several feet thick whose upper surface weathers into separate rounded blocks; where mounds or "islands" capped with this layer remain on the gray-limestone upper surface of the Rico the bed viewed from a little distance has the appearance of a low manmade stone wall of piled-up small boulders. As a whole, the alternating hard and soft thin-bedded material in the Halgaito gives to its outcrops a distinct layered effect. Yochelson noted that near the river the unit contains somewhat thicker and more resistant ledges of sandstone than it does near State Highway 47. He also recorded that south of the highway a few local lenses of conglomerate were observed.

In the small canyon half a mile south of Snake Gulch, near State Highway 47, the Halgaito was found to be 406 feet thick, as measured by Bell and Yochelson in the following section:

Section of Halgaito tongue measured in canyon half a mile south of Snake Gulch

Cedar Mesa sandstone member of the Cutler formation.

Halgaito tongue of the Cutler formation:	Feet
10. Sandstone, platy, red, poorly exposed	10.5
9. Gypsum in beds 1 to 2 feet thick, interbedded with gypsiferous shale	8.0
8. Largely covered; gypsiferous sandy shale in upper part, and some fine-grained platy calcareous sandstone in lower part	41.0
7. Sandstone, fine-grained, somewhat platy; white to red, weathering brick red	6.0
6. Sandstone, very calcareous, or limestone, very sandy; fine-grained, platy; brown with purplish cast, weathering red brown	1.5
5. Sandstone, fine- to medium-grained, brick-red, in 1- to 6-foot layers, interbedded with more friable layers. Lower quarter of zone has massive and softer beds of about equal thickness; upper three-quarters averages 10 to 15 feet of soft sandstones between ledges	140.0
4. Shale, sandy, dark-red, interbedded with sandier dark-tan layers weathering red. A 2-foot ledge of sandstone in lower third of zone, and a prominent 5- to 6-foot sandstone ledge slightly above middle of the zone	190.6
3. Sandstone, fine-grained, light-gray, weathering gray with bluish cast	.2
2. Sandstone, very fine-grained, blue-gray, weathering tan	1.2
1. Shale, weathering red; mostly covered	7.0
Total	406.0

Rico formation.

This thickness of 406 feet checks closely with the 402 feet nearby at Navajo Springs as recorded by Gregory (1938, p. 42). On the same page Gregory gives 203 feet as the thickness in Fish Creek Canyon, and two paragraphs later says, "In Fish Creek Canyon strata assigned to the Halgaito are about half the thickness of those 10 miles farther south and are weathered at the top." For this and several other recorded reasons, he suggests the possibility of erosion and an unconformity at the top of the Halgaito. On the next page (1938, p. 43) he suggests a "northward thinning and final disappearance of the Halgaito." This suggestion has since been confirmed by studies of other geologists to the north and northwest; but his cited thickness of 203 feet in Fish Creek Canyon could scarcely be considered evidence of that thinning in view of the fact stated earlier that the base of the tongue is not there exposed.

CEDAR MESA SANDSTONE MEMBER

The sharp color change between the red Halgaito tongue and the predominantly light-hued strata of the overlying Cedar Mesa sandstone member makes the belts of outcrop of the two units readily visible and separable where seen from vantage points. Furthermore, in that part of the mapped area where the Cedar Mesa consists chiefly of

thick, massive sandstones, the separation is emphasized by the change from the sloping surface of the less resistant Halgaito to the abrupt ledges and cliffs of the Cedar Mesa.

Gregory's suggestion (1938, p. 42, 43) that there was erosion at the top of the Halgaito tongue and at least minor unconformity between it and the Cedar Mesa is given some support within the mapped area by the presence locally of a thin limestone-pebble conglomerate at the base of the Cedar Mesa, as noted in 1953 by Fuller near Snake Gulch and by Yochelson near Comb Wash between State Highway 47 and the river. Gregory points out, however, that the conditions he describes may be due to lateral gradation between the intertonguing Halgaito and Cedar Mesa, as they were considered by Baker and Reeside (1929).

The Cedar Mesa sandstone member was named by Baker and Reeside (1929, p. 1443) from an upland north of the San Juan River and north and west of Lime Creek known as Cedar Mesa, which is part of the broader Grand Gulch Plateau. Strikingly exposed in the mesa walls the Cedar Mesa member consists of many hundreds of feet of light-colored sandstone in beds 10 to 50 feet or more in thickness, with some thinner layers and lenses of softer sandstone and clay, some of which are red. The member can be followed far to the north and northwest under Grand Gulch Plateau (see pl. 19*A*) and to and beyond Elk Ridge, the Natural Bridges, and White Canyon, with essentially similar thickness and lithology.

Along the east margin of Grand Gulch Plateau, where its southeastward-facing escarpment extends across the northwest corner of the mapped area discussed in this report, about 725 feet of the Cedar Mesa member remains (as calculated from elevation readings); and about 100 feet of its uppermost beds are estimated to have been eroded. The upper, major part of the member consists chiefly of the usual sequence of thick, massive, somewhat crossbedded white to buff sandstones, so resistant that the walls of the upland and of the deep canyons cutting it are unscalable at most places. The basal, minor part of the Cedar Mesa member, averaging about 130 feet thick immediately above the Halgaito, shows a markedly different and unusual lithology. It is much less resistant than the upper part and of a generally grayer tone, so that viewed from a distance its soft rounded slopes below the ledge-forming sandstones appear to be carved from a zone of gray clay with a few harder layers. Examined more closely, it was found to contain not only gray, reddish, and purplish shale or clay but also a number of soft fine-grained friable sandstones, some of them gypsiferous; several thin beds of gypsum; and three thin beds of gray limestone. The uppermost limestone, occurring at an average distance of some 20 feet below the top of the zone, contains many small irregu-

lar masses of red chert; it is sufficiently resistant to hold up benches and dip slopes. (See pl. 19*B*.) The other two limestones are less conspicuous. The middle limestone, which is absent at places, was found to contain scattered fossils (apparently most of them pelecypods) that, however, were unfortunately too fragmentary and poorly preserved for identification or for use in determining the age of the beds.

This interesting and striking contrast between the "lower soft" and "upper hard" parts of the Cedar Mesa (apparently not noticed by previous workers during their reconnaissance in the area) is well exposed in the valleys of Mule Canyon, Dry Wash, Fish Creek, and nearby smaller streams. The sharp contact between them, above a series of thin beds of sandstone and below a massive, ledge-forming buff sandstone, makes a clear horizon marker. (See pl. 19*B*.) It was therefore mapped in the field, a number of elevation readings being taken on it for structure-contour purposes (pl. 17). Farther south, in the northern two forks of Road Canyon, the distinction is still visible; and the contact was mapped, though with less certainty because the lower part is much more sandy. Still farther south, in the other two main forks of Road Canyon and along the Cedar Mesa cliffs above the Halgaito, the lower part is again a series of ledge-forming sandstones like the upper part, and tracing of the contact was no longer feasible.

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.

This unusual facies of the Cedar Mesa sandstone member, the softness of which has resulted in a land surface cut by an intricate leaf-

vein pattern of small streams (not shown on the map, because of its small scale), has aroused the interest of geologists earlier visiting the area. Probably the first to notice it was Woodruff (1912, p. 86), who described it briefly. Gregory (1938, p. 44) gives the following graphic description—

> Along lower Comb Wash the Cedar Mesa member, as represented elsewhere, is scarcely recognizable. The dominant resistant sandstones give way to weak strata and, in consequence, the usual cliffs are replaced by slopes and mounds of crumbling rock. * * * the Cedar Mesa here includes not only beds of white sandstone but also red-pink gypsiferous shales, brown shaly sandstones, conglomeratic and even-bedded dense limestones, chert, and much gypsum. Though the section includes beds of typical tan-colored Cedar Mesa sandstone, the thickest measures only 22 feet. Most of them are sheets a few inches to a few feet thick that appear as if inserted between layers of shale, of shale and gypsum, and of limestone and dark-red thin sandstones. Some of them taper to extinction; others grade laterally into thin beds or thick beds that differ from the type only in color; still others grade along the strike and down the dip into gypsiferous or arenaceous shales with or without change in color.

Most of the sandstones in this facies of the Cedar Mesa are so soft and friable that from a distance of a few hundred feet their existence is scarcely suspected. They were studied more closely by Bell and Yochelson, who measured the following section of the member in the small canyon half a mile south of Snake Gulch, near State Highway 47. (This is an upward continuation of the section, the Halgaito part of which is recorded on p. 182.)

Section of Cedar Mesa sandstone member measured in canyon half a mile south of Snake Gulch

Organ Rock tongue of the Cutler formation.

Cedar Mesa sandstone member of the Cutler formation:	Feet
60. Limestone, sandy, medium-grained, pale-green to lavender, weathering dark gray in lower half, almost white at top; laminated near base	1.0
59. Shale, dark- to brick-red, weathering into small blocks and chips	27.0
58. Poorly exposed; probably mostly soft reddish sandstone	28.0
57. Sandstone, medium-grained, brownish-red, weathering light red; crossbedded at low angle	1.2
56. Shale, weathering dark purple to brick red and into small blocks; thin layer of more consolidated claystone 6 feet above base	9.0
55. Limestone, fine-grained, light-greenish-gray, weathering light gray; in two beds separated by 0.2 foot dark red shale	1.2
54. Sandstone, very friable, weathering brick red; very poorly exposed	9.0
53. Sandstone, fine-grained, white, weathering tan; lower 0.5 foot, platy; upper 1.7 feet, a ledge former weathering into large blocks	2.2
52. Sandstone, friable, soft, weathering dark to brick red	1.1
51. Sandstone, medium-grained, white, weathering gray brown	1.5

Section of Cedar Mesa sandstone member measured in canyon half a mile south of Snake Gulch—Continued

Cedar Mesa sandstone member of the Cutler formation—Continued	*Feet*
50. Sandstone, fine-grained, chocolate-brown, weathering very dark red brown; less resistant than beds above and below	1.5
49. Sandstone, medium-grained, white, weathering gray brown; a ledge former; weathered surface shows fine laminae	2.4
48. Sandstone, soft, white, weathering dark red; upper 2 feet more shaly	10.1
47. Limestone, slightly sandy, fine-grained, very light-gray, weathering gray with dark-red streaks	.8
46. Sandstone, platy, weathering purple	1.5
45. Sandstone, medium-grained, white, weathering gray brown; a ledge former	2.0
44. Shale, sandy, weathering red to purple, upper foot weathering white	7.0
43. Sandstone, platy, fine-grained, very light-gray, weathering nearly white	.8
42. Sandstone, gypsiferous, weathering red	18.4
41. Limestone, fine-grained, dark-gray, weathering dark gray, blocky	.7
40. Limestone and chert, thin, at bottom; overlain by gypsiferous beds like No. 38; distinguished from No. 39 chiefly by color	82.3
39. Shale, gypsiferous, and gypsum; like No. 38, but weathering somewhat darker red without pinkish cast; bed of white gypsum at base	109.6
38. Gypsum, some very sandy, weathering with pinkish cast; somewhat sandier and darker red at top	82.3
37. Limestone, in two beds separated by gypsiferous shale, lower bed weathering light blue gray, upper bed, dark gray	1.0
36. Gypsum, weathering pink; locally with a foot of white gypsum at base	32.7
35. Sandstone, gypsiferous, and gypsum, weathering red faintly tinted with pink or orange; upper 4 feet, slightly more resistant, darker red sandstone	81.4
34. Limestone, very thin-bedded, medium-grained, lavender, weathering gray to purple	1.8
33. Gypsum, sandy, white, weathering red	9.0
32. Limestone, fine-grained, light-gray	.3
31. Sandstone, gypsiferous, platy, weathering with pinkish cast; top marked by 1-foot gypsum bed above 2 feet of purple shale	36.4
30. Sandstone, moderately resistant, slabby to platy, weathering purplish near base, brick red in middle, gray to white above	6.0
29. Shale, sandy, gypsiferous, and gypsum	37.9
28. Limestone, fine-grained, dark-purplish-gray, weathering light blue gray	.5
27. Sandstone, fine-grained, purplish-brown, weathering very dark red; more calcareous upward	4.0
26. Limestone, thin-bedded, fine-grained, dark-gray, weathering blue gray; some white chert	1.0
25. Shale, gypsiferous, and sandstone, weathering red with pinkish to orange cast	15.9
24. Limestone, very sandy, fine-grained, dark-brown, weathering brownish gray, rubbly	1.0

Section of Cedar Mesa sandstone member measured in canyon half a mile south of Snake Gulch—Continued

	Feet
Cedar Mesa sandstone member of the Cutler formation—Continued	
23. Sandstone, fine-grained, dark-brown, weathering brick red; in beds a quarter to a half inch thick; crossbedded at low angle; soft, but somewhat more resistant than No. 22	53.3
22. Poorly exposed. Lower 3 feet, sandstone, platy, weathering brick red; upper part, gypsiferous shale and sandstone, weathering brownish red	48.6
21. Sandstone, medium-grained, light-buff to tan, weathering light brown with orange cast; locally a ledge former	8.0
20. Sandstone, soft, platy, crossbedded at low angle, weathering dark red	27.1
19. Poorly exposed. Interbedded thin limestones, weathering white, and shale, weathering purplish	4.5
18. Limestone, very sandy, medium-grained, light-blue-gray, weathering brown	2.0
17. Sandstone, white, and gypsum; very soft; poorly exposed	4.5
16. Sandstone, fine-grained, white, weathering white to red with orange cast	1.3
15. Limestone, very sandy, medium-grained, blue-gray, weathering dark gray; at top a 0.1-foot layer of sandy limestone conglomerate; changes laterally into sandstone of No. 14	.8
14. Sandstone, fine-grained, very light-gray, weathering blue gray; splintery	5.5
13. Sandstone, medium-grained, dark-brown, weathering brownish red; crossbedded at low angle; locally indurated, but mostly weathering soft, platy; top of No. 13 is a 1-foot massive sandstone over 2 feet of shale	13.9
12. Sandstone, very gypsiferous, medium- to fine-grained, friable, weathering pinkish red; platy; upper half includes several thin sandstone layers, weathering white	29.2
11. Limestone, medium-grained, dark-purplish-gray, weathering dark gray, in 2 beds, the lower 0.4 foot thick and separated by 0.4 foot of purplish-weathering shale	1.8
Total	830.0
Halgaito tongue of the Cutler formation.	

The thickness of 830 feet measured in the foregoing section is consistent with the thickness of 825 feet (calculated from elevation readings for the lower part and estimated for the eroded upper strata) already given for the member in the northwest corner of the mapped area.

The top of the Cedar Mesa was somewhat arbitrarily drawn above the highest white layer below the uniformly red mass of Organ Rock strata, even though this places in the upper part of the Cedar Mesa several tens of feet of beds some of which resemble those of the Organ Rock tongue in color and lithology. This white layer, though only from 6 inches to 2 feet thick, is quite persistent and conspicuous among

the darker beds. It is a light-gray limy sandstone or sandy limestone, weathering white on its upper surface, which is platy and somewhat crinkled. At places it breaks into thin slabs an eighth to a half inch thick. It is underlain by nonresistant red to brownish-red siltstone with greenish mottling, suggestive of material in the Organ Rock.

At no place in the area was there noted any evidence of erosion or unconformity at the top of the Cedar Mesa, described by Gregory (1938, p. 45) for the region, although he refers to the opinion of Baker and Reeside (1929) that the Cedar Mesa is "an integral part of the Cutler formation, conformable with red beds above and below." On the contrary, where the contact crosses Sweet Springs Draw, the uppermost thin white layer, there about 2 feet thick, was observed by Mamay to thin eastward and pinch out within about 20 feet, the underlying red siltstones thus merging with those of the overlying Organ Rock.

ORGAN ROCK TONGUE

Just as the prevailingly light-colored strata of the Cedar Mesa overlie the thick red zone of the Halgaito, so they are in turn overlain by another sequence of red beds, the Organ Rock tongue of the Cutler formation. The small-scale intertonguing between Cedar Mesa and Organ Rock that was noted at Sweet Springs Draw is described in the preceding paragraph. At no place within the mapped area was there seen any example of marked erosional or depositional irregularities of the contact such as had previously been observed by the writer in White Canyon. Thus the area contributed no further evidence bearing on the possible unconformity between Cedar Mesa and Organ Rock discussed by Gregory (1938, p. 45, 46).

The Organ Rock tongue is rather uniform, both vertically and laterally, in lithology as well as in its brownish-red or orange-red color. The unit is not very resistant, and for the most part weathers into slopes broken by steplike thin harder ledges. It is composed chiefly of sandy mudstone and fine-grained sandstone in rather thin continuous beds that weather into rounded surfaces, thin slabs, and angular chunks. Much of the material is calcareous. Grayish-green mottling in small patches, spots, and stringers is common throughout the unit.

The following section of the Organ Rock tongue and the overlying uppermost beds of the Cutler formation was measured by Bell and Yochelson in the small canyon half a mile south of Snake Gulch, near State Highway 47. (This is an upward continuation of the section, the Halgaito part of which is recorded on page 182 and the Cedar Mesa part on pages 185–187.)

Section of Organ Rock tongue and the overlying uppermost beds of the Cutler formation measured in canyon half a mile south of Snake Gulch

Moenkopi formation.

	Feet
Hoskinnini tongue of the Cutler formation:	
70. Sandstone, thin-bedded, somewhat wavy or crumpled; alternating dark-brick-red and light-gray-white lensing layers; nonmicaceous; sand grains very irregular in size, mostly well rounded, poorly cemented with iron oxide	20.0
De Chelly sandstone member of the Cutler formation:	
69. Sandstone, massive, crossbedded throughout; near top, crossbedding in festoons; fine-grained, red-brown to tan; grains somewhat larger than any noted below; some grains very dark, probably heavy minerals	20.0
68. Mostly sandstone, fine-grained, red-brown, well-cemented; broken by several layers or lenses a foot thick of silty, finely bedded sandstone; massive except for the silty layers, and weathers in the gulch as a solid sandstone mass with smooth rounded ledges; at top a 15-inch shale layer separates massive sandstone below from overlying red-brown crossbedded sandstone. (In the field, Bell favored including No. 68 in the Organ Rock; the writer has placed it in the De Chelly as seemingly more logical.)	115.0
Total De Chelly sandstone member	135.0
Organ Rock tongue of the Cutler formation:	
67. Sandstone, red-brown, in layers that differ in hardness so as to develop a series of minor ridges about 2 feet thick and about 12 feet apart; for most of unit, bedding planes marked by thin, 1- to 2-inch layers of light-gray sandy clay which give striped appearance to outcrop; near top of unit, striping more closely spaced, bedding appears varved; in uppermost 4 feet 40 percent of rock light colored	133.0
66. Sandstone 8 to 10 feet thick at top, fine-grained, brown; iron oxide cement, some small mica chips; separated into 4 layers by 12-inch to 14-inch lenses of silty sandstone, somewhat fissile; soft, but forms a low ridge. Rest of unit is like No. 64	89.0
65. Sandstone 6 feet thick at top, fine-grained, red-brown, only a little mottling; soft, but forms a low ridge. Rest of unit is like No. 64	60.0
64. Sandstone 5 feet thick at top, separated into 2 layers by 6 inches of finely banded soft sandstone; red-brown; each sandstone layer shows light-gray mottling in its upper part; forms a low ridge. Most of the unit is sandstone, silty, fine-grained, thin-bedded, red-brown, with gray-white clay balls and chips along bedding planes and within the more massive sandstones; soft and does not form ridges	227.0
63. Mostly sandstone, red-brown, soft, weathering to small chips. At top, a 2-foot sandstone, red-brown with some minor light-gray blotches, fine-grained, somewhat fissile, weathering platy. About 10 feet lower, a 3-foot sandstone, fine-grained, smooth-weathering, with light-gray blotches as much as 6 inches in diameter; forms a low ridge	43.0

Section of Organ Rock tongue and the overlying uppermost beds of the Cutler formation measured in canyon half a mile south of Snake Gulch—Continued

	Feet
Hoskinnini tongue of the Cutler formation—Continued	
62. Sandstone 2 feet thick at top, red-brown, with iron oxide cement; makes a low ridge. Most of unit fine-grained brown-red silt-cemented sandstone with some light-greenish-gray mottling along bedding planes	18.0
61. Sandstone 2 to 3 feet thick at top, very fine-grained, silt-cemented, red to red-brown, mottled in part by circular and oval spots of light greenish gray, irregularly distributed, from ½ to 3 inches in diameter. About 40 feet lower, a 2-foot sandstone, dark-chocolate, fine-grained, slightly micaceous, with iron oxide cement. At base, 2 feet of reddish-tan siltstone followed by 2 feet of purplish siltstone. Most of interval light- to medium-red and brownish-red siltstone, sandy, thin bedded, generally soft, weathering platy	72.0
Total Organ Rock tongue	642.0
Cedar Mesa sandstone member of Cutler formation.	

Within the mapped area the thickness of the Organ Rock tongue seems to differ widely, as measurements and calculations of it range from 560 to 820 feet. The section recorded above shows that (with unit 68 being included in the De Chelly sandstone member) the thickness is 642 feet. This is consistent with the 650 feet calculated from structure and elevation readings half a mile to the south. Calculations from similar readings farther north (several of which are open to question because of poor exposures) give 710 feet, 720 feet, and 780 feet, respectively, half a mile, 1½ miles, and 2½ miles north of Snake Gulch; 820 feet near the mouth of Road Canyon, 660 feet a mile north of that point, and about 560 feet near the mouth of Sweet Springs Draw and midway between the mouths of Fish Creek and Dry Wash.

At a point near the mouth of Sweet Springs Draw and extending northward for about a mile, Mamay observed outcrops (noncontinuous, because of alluvial cover) of a sandstone which he and the writer at first thought to be the De Chelly. Later they found it to be near the middle of the Organ Rock tongue and overlain as well as underlain by beds characteristic of that unit, although lithologically it differs from those beds and resembles the De Chelly. It differs from the usual Organ Rock beds by the absence of the typical grayish-green mottling, by its rather sandy texture as contrasted with the usual more silty texture, and by its distinct crossbedding. The sandstone was observed to reach a thickness of 20 feet. At places the lower part fills distinct channels, and it contains conglomeratic lenses near its base. It is more resistant than the typical Organ Rock beds below; hence, where exposed, the contact is clearly defined. The temporary confusion of this sandstone with the De Chelly was even easier because

the latter thins northward and seems to pinch out just before reaching this locality.

The uppermost beds of the Organ Rock tongue and the contact with the overlying De Chelly sandstone member differ somewhat from place to place within the mapped area. In the northern part of the area, where exposures in the midst of the alluvium of Comb Wash are poor, the De Chelly and Hoskinnini appear to be absent, and the Organ Rock seems to be followed directly by the Moenkopi formation. For the belt from Road Canyon northward for some 2 miles, Mamay recorded that in the few exposures the Organ Rock–De Chelly contact is clearly defined; the upper beds of the Organ Rock show the typical coloring, mottling, texture, and mode of weathering, and they are overlain by a massive poorly bedded medium-grained red sandstone with very irregular weathering features. To the south, between Road Canyon and Snake Gulch, Fuller recorded at several points a "gradational contact between crossbedded massive De Chelly and flat-bedded fissile Organ Rock." In that vicinity L. C. Craig, in a section measured by him and T. E. Mullens in 1951, identified as the De Chelly a partly massive and partly crossbedded sandstone zone 53 feet thick and recorded that it is underlain by a 37-foot "transition interval between De Chelly sandstone member and Organ Rock tongue." This transition interval he described as follows—

> Sandstone, interbedded moderate reddish brown and dark reddish brown, abundant pale green mottling in streaks, bands, and ½- to 1-inch spots, very fine to fine grained, angular to sub-angular, non- to slightly calcareous, firmly cemented, composed of clear and amber-stained quartz, uncommon black accessory minerals, very fine white mica; parallel bedded, faint sub-parallel laminations; weathers to ledgy cliff; darker colored parts less resistant.

Still farther south, in the section measured by Bell and Yochelson half a mile south of Snake Gulch (see p. 189), doubt was felt as to whether the Organ Rock–De Chelly contact should be drawn below or above unit 68. That a difficulty in selecting this contact is not limited to this small area is emphasized by Baker (1936, p. 36), who in writing about the Monument Valley region says, "The determination of a precise boundary between the De Chelly sandstone and the underlying red beds of the Organ Rock tongue is usually impossible."

DE CHELLY SANDSTONE MEMBER

In northeastern Arizona and in adjacent areas in southeastern Utah, the De Chelly sandstone member is a thick prominent cliff-making unit. It is known to thin greatly toward the northwest and north. Baker (1936, p. 36) measured 375 feet in Wide Butte at Monument Pass but found it is "90 feet on the San Juan River near the mouth of Nokai Creek * * * and is absent near the San Juan River in the vicinity of Clay Hill Crossing." He adds, "the De Chelly sandstone

is about 500 feet thick in Comb Ridge, near the Arizona–Utah State line, but it is only about 100 feet thick a few miles to the north, near the mouth of Comb Wash." Another measurement, in geographical location and thickness intermediate between the last two quoted from Baker, was made by Craig (written communication, 1953) in a section by him and others in 1951 "about 2 miles south of place where San Juan River crosses Comb Ridge"; there he determined the De Chelly to be 294 feet thick and underlain by a 66-foot "De Chelly–Organ Rock transition interval."

Northward from the San Juan River, in the lower reaches of Comb Wash, the thinning De Chelly member becomes less and less conspicuous. Though it is more massive and somewhat more resistant than the units above and below, it forms only a low rounded ridge. Northward from State Highway 47 it is still lower, more moundlike, and less conspicuous; and from the mouth of Road Canyon northward for 2 miles only 3 small isolated outcrops of it were seen. At this last point it seemed to have thinned almost to disappearance, and it was mapped as wedging out beyond that point. In the northern quadrangle of the mapped area, where the strata near Comb Wash are very largely covered by alluvium, slope wash, and windblown sand, no conclusive evidence was found of any De Chelly or overlying Hoskinnini between the Organ Rock and the Moenkopi.

Peterson noted at two places—one opposite the mouth of Dry Wash and the other a mile and a half to the north—below small outcrops of the Moenkopi, patches of a medium-grained sandstone containing coarse grains, which he suggested might possibly be remnants of the De Chelly.

As shown in the section measured by Bell and Yochelson half a mile south of Snake Gulch (see p. 189), the upper part of the De Chelly (unit 69) is 20 feet thick and the lower part (unit 68, which Bell suggested be included in the Organ Rock) is 115 feet thick, a total of 135 feet. Three miles north, where Craig and Mullens in 1951 measured a section (referred to above in the discussion of the Organ Rock), they found the De Chelly sandstone member to be 53 feet thick and noted that it is crossbedded in its middle half and more massive in its upper and lower quarters.

Because of the narrowness of their bands of outcrop and the scale of the mapping, the De Chelly sandstone member and the Hoskinnini tongue are undifferentiated on the map. (See pl. 17.)

HOSKINNINI TONGUE

The Hoskinnini tongue was named by Baker and Reeside (1929, p. 1443) "for the relatively thin red-bed unit above the De Chelly sandstone and beneath the Moenkopi, the name being derived from the exposures on the north face of Hoskinnini Mesa, several miles west

of Oljeto trading post on Moonlight Wash." Among many details about the unit in that region later reported by Baker (1936, p. 38, 39), the following are pertinent to the present discussion—

> The Hoskinnini tongue * * * is the highest of the three red-bed tongues of the Cutler formation. It * * * is composed of red beds similar to those of the Organ Rock and Halgaito tongues of the Cutler formation. It * * * where present is less than 100 feet thick. * * * Where the De Chelly sandstone wedges out * * * the Hoskinnini is inseparable from the Organ Rock tongue.

Within the mapped area north of the San Juan River, the Hoskinnini is a very minor unit, even thinner and less conspicuous than it is in Monument Valley. Above the massive and crossbedded red De Chelly sandstone member is a zone some 20 to 30 feet thick of alternating thin layers of orange-red, brownish-red, chocolate-brown, and grayish-white sandstones having a banded or striped appearance. This zone was interpreted to represent the Hoskinnini tongue. Its contact with the De Chelly is rather sharp, but contact with the overlying Moenkopi is less certain and was placed somewhat arbitrarily at the horizon where the banded beds of several hues give way to more generally chocolate-brown thin platy beds of sandstone that bear ripple marks at many places.

North of the point where the De Chelly is shown as pinching out, no trace of the Hoskinnini was noted; and it, too, is mapped as pinching out before it reaches the northernmost quadrangle. However, in that northern part of the mapped area, the exposures are so sparse and poor that it may be present but indistinguishable from the underlying Organ Rock.

As stated above, because of the narrowness of their bands of outcrop and the scale of mapping, the De Chelly sandstone member and Hoskinnini tongue were mapped together.

TRIASSIC SYSTEM

LOWER AND MIDDLE(?) TRIASSIC SERIES

MOENKOPI FORMATION

In general, the Moenkopi formation is readily distinguishable from the red beds of the Cutler units below by its prevailingly more chocolate-brown color, its thin platy bedding, and the presence of ripple marks at a number of horizons, particularly on the more sandy layers. Viewed more closely, it is seen to be more micaceous and somewhat coarser grained. It is composed chiefly of fine- to medium-grained somewhat calcareous sandstone and siltstone or shale. Here and there it shows whitish and greenish-gray spots and a few thin white layers.

The section measured by Craig and Mullens about 2½ miles north of Snake Gulch shows a thickness of 222 feet for the Moenkopi. From that point northward in Comb Wash, the exposures are so poor that

no satisfactory measurements could be made; hence, the thickness of 222 feet is assumed to persist. The same section shows 32 feet for the Hoskinnini and 53 feet for the De Chelly, making a total of 307 feet for the 3 units. Southward from the vicinity of the section, the Moenkopi appears to thin at about the rate of thickening of the De Chelly–Hoskinnini zone; and therefore, for the purpose of preparing structure contours, the combined thickness of the 3 units, 307 feet, was assumed to continue unchanged south to the river.

Within the mapped area no convincing evidence was noted of the unconformities that elsewhere have been found to exist at the base and top of the Moenkopi.

UPPER TRIASSIC SERIES

CHINLE FORMATION

The Chinle formation crops out in a continuous belt from the north edge to the south edge of the mapped area. Its upper, major part is fairly well exposed in the slope flanking the west side of Comb Ridge. Its lower, minor part is largely concealed by the talus and slope wash from the ridge and by the alluvium of Comb Wash.

In his report on the Navajo country, Gregory (1917, p. 42) subdivided the Chinle formation into four units called A, B, C, and D in descending order. In 1951, Witkind (1954, in preparation) found that in Comb Ridge and adjacent areas in Monument Valley, Ariz., these four units are rather distinctive, and therefore he names and separates them on his map. Within the mapped area of the present report, approximate representatives of these four units can be observed. However, because they are not clearly distinctive, because their lower part is so poorly exposed, and because with the small scale of the map it is undesirable to further divide the already narrow belt, the Chinle is mapped as a single formation. Its character in this area and the surrounding San Juan country is well described by Gregory (1938, p. 49, 50) as follows—

> * * * the Chinle formation * * * presents at all exposures much the same lithology and erosion forms. Its outstanding features are fossil wood, a peculiar limestone conglomerate, and series of richly colored variegated shales—gray, red, pink, lavender, yellow, green—that weather in the manner of marls. In the San Juan country, as in regions immediately adjoining, measured sections of the Chinle show four rough subdivisions—(1) at the base, brown and gray sandstones that weather into steps and benches; (2) variegated sandy and calcareous shales or "marls" that weather as mammillary mounds and immature mesas with typical badland expression; (3) light-red, dark-red, and mottled shales and massive or conglomeratic limestone in alternating beds, weathering as a stepped slope on which the resistant limestone forms the top of long, narrow benches and small mesas; (4) red and brown sandstone and sandy shale, weathering as a cliff that, continued upward, includes the Wingate sandstone. Although these subdivisions are generally recognizable and the beds that compose them

combine to give the Chinle an appearance unlike that of the formations above and below, the variation in composition, texture, color, and order of deposition is extreme. In no two sections are the relative amounts of sandstone, limestone, and shale or the position of these strata in the series the same. Most beds are lenses that within short distances along the strike are replaced by rock of other kinds.

At no place within the mapped area did the writer and his associates find any unquestionable remnants of the Shinarump conglomerate, which at most places over a wide region lies, with some intertonguing, at the base of the Chinle formation and unconformably above the Moenkopi. Here and there gray to tan sandstone lenses occur up to several hundred feet in length and 10 feet or more in thickness, some showing a little faint cross lamination, some coarser grains, and a few widely scattered pebbles up to a quarter of an inch in diameter. As these lenses are so near the base of the Chinle, they were at first assumed to represent the Shinarump. However, on closer inspection and some digging, they were found to be underlain by several to 10 feet of light-greenish clay or whitish to lavender calcareous mudstone of Chinle type, above characteristic chocolate- or reddish-brown thin-bedded Moenkopi. It was therefore concluded that these lenses are in the Chinle and that the Shinarump conglomerate is almost if not wholly absent within the mapped area. The nature of the contact is such that it yielded no clear evidence as to whether the top of the Moenkopi was eroded before further deposition, but an unconformity between Moenkopi and Chinle formations seems probable.

In the section measured by Craig and Mullens about 2½ miles north of Snake Gulch, the thickness of the Chinle was found to be 956 feet. That thickness is assumed to be constant throughout the mapped area, and the party in the summer of 1953 undertook no further measurements.

GLEN CANYON GROUP (LOWER PART)

The Glen Canyon group, consisting of the Wingate sandstone at the bottom, the Kayenta formation, and the Navajo sandstone above, is very prominent over a wide region in southern Utah and northern Arizona; and a wealth of detail about it is contained in many published reports, including those by Gregory (1938) and Baker (1936). Because the three formations are so well known and because of the difficulty of reaching most parts of them within the mapped area, the party made no detailed study of them in the summer of 1953.

The U. S. Geological Survey formerly considered the whole Glen Canyon group to be of Jurassic(?) age. It now places the lower part, the Wingate sandstone, in the Upper Triassic; the middle part, the Kayenta formation, in the Jurassic(?); and the upper part, the Navajo sandstone, in the Lower Jurassic.

WINGATE SANDSTONE

As in most parts of the Colorado Plateau, the Wingate sandstone is one of the most conspicuous formations. On the west side of Comb Ridge it forms a nearly vertical cliff, at most places from 250 to 300 feet high. (See Surface features and drainage.)

The formation is an essentially single, homogeneous mass of light-orange-red or brick-red to reddish-buff sandstone. (See pl. 20*A*.) Its crossbedding is on a large scale but is not obvious in the rather smooth or vertically jointed cliff face. It is composed chiefly of fine rounded quartz grains.

The lower limit of the formation in this area is placed at the base of the sheer massive cliff. Below this is a zone a few feet thick of softer sandstone beds that make a small continuous break or slope logically separating the Wingate from the several thick red ledge- or cliff-forming sandstones in the upper part of the Chinle.

At most places the top of the sheer cliff plainly marks the top of the Wingate and the transition to the overlying resistant but thinner-bedded material of several kinds that makes up the Kayenta.

As thus defined, the Wingate sandstone has a rather uniform thickness of about 275 feet throughout the mapped area. This thickness was calculated from a large number of pairs of altitude readings on the top and base of the unit; most of these pairs gave thicknesses quite close to this averaged figure.

JURASSIC(?) SYSTEM

GLEN CANYON GROUP (MIDDLE PART)

KAYENTA FORMATION

In contrast to the underlying and overlying more massive, crossbedded Wingate and Navajo sandstones, the Kayenta formation in this area, as in most parts of the Colorado Plateau, stands out across country as a zone of thinner and flatter bedded alternating sandstone, siltstone, and lenticular limestone, of buff, tan, gray, and light-red tones. At only a few scattered localities, where it is protected by small high remnants of basal Navajo sandstone, is the full thickness of the Kayenta formation preserved in the west face of Comb Ridge. (See pl. 20*A*.) Generally the upper part of the Kayenta and the lower part of the Navajo are eroded to lower levels down the east slope of the ridge. The lower part of the Kayenta seems to be much more resistant, however, and weathers as thick ledges that at many places are nearly vertically flush with the sheer Wingate cliff below, form the upper segment of the steep west wall of Comb Ridge, and hold up the highest parts of its serrated crest.

Although when viewed as a whole, the Kayenta is strikingly different from the Wingate and the Navajo below and above; when seen at closer range, its exact boundaries in much of the area cannot be selected with confidence. This is particularly true for its upper boundary, as one or more thick white to buff sandstones of Navajo-like appearance are found in the upper part of the Kayenta, and one or two reddish zones occur in the lower part of the mostly white or gray Navajo, causing confusion where only small parts of the two formations are in sight.

By calculations based on air photographs, W. R. Hemphill, of the Photogeology Section, U. S. Geological Survey, found the thickness of the Kayenta at 6 places in the northern quadrangle of the mapped area to average 126 feet. This thickness accords reasonably well with the average figure obtained by the writer from two sets of elevation readings on the top and base of the formation.

JURASSIC SYSTEM

LOWER JURASSIC SERIES

GLEN CANYON GROUP (UPPER PART)

NAVAJO SANDSTONE

The Navajo sandstone forms the major part of the east slope of Comb Ridge, being exposed in a belt ranging generally from a third of a mile to a mile or more in width. At a very few places small remnants of the lower part of the Navajo are preserved above the full thickness of the Kayenta in the west wall of Comb Ridge. (See pl. 20*A*.) Generally, however, the Navajo and the upper part of the Kayenta are eroded eastward down dip. This gives the Kayenta-Navajo boundary on the map (see pl. 17) an unusual saw-edged pattern, in which the "teeth" or noses of Navajo between the closely spaced drainage lines point uphill westward. Many of these noses stand at high altitudes, and some of them are higher than the top of the west wall where it is held up by sandstone ledges in the Kayenta.

The eastward-sloping surface of the Navajo is not a dip slope. On the contrary, successively higher horizons are crossed downhill until the upper boundary is reached near Butler Wash. South of State Highway 47 the dip near the wash is nearly horizontal, and the belt of Navajo widens to reach the river.

As is usual with the Navajo sandstone in the Colorado Plateau, its surface is very irregular, rounded, and hummocky. The sandstone is quite friable—in fact, it breaks down into much loose sand that at many places drifts to fill hollows and form dunes. Large-scale tangential crossbedding is so conspicuous that only at a few places, where views are extensive, can there be seen breaks between materials of

differing color and lithology that appear to represent parallel bedding.

In this area the Navajo is prevailingly grayish white, in part weathering to tan or buff. It contains one or more zones of softer sandstone of a reddish hue. Nowhere does it show the general light orange red that characterizes the formation in many parts of the region. Its light tone in this area brings it into strong contrast with the red or other darker hued strata below and above and makes doubly striking the long-range views of Comb Ridge from the east—for example, from the road between Blanding and Bluff.

Because of its extensive crossbedding and paucity of true bedding planes, its width of outcrop, and the great difference in dips between the steep basal beds high on Comb Ridge and the gently dipping uppermost beds near Butler Wash, trustworthy field measurements of its thickness in this area are scarcely feasible. For the same reasons, calculations of the thickness from air photographs are difficult to make and can be considered only approximate. Such calculations made by Hemphill at 6 places within the northern quadrangle of the mapped area average 341 feet, which, though recognized as not precise, indicates the magnitude of the true thickness.

MIDDLE AND UPPER JURASSIC SERIES

SAN RAFAEL GROUP (LOWER PART)

CARMEL FORMATION

The Carmel formation is a relatively thin zone of soft rocks, lying on the slightly irregular surface of the Navajo sandstone and forming a slope capped by the protecting ledge of the basal sandstone of the Entrada sandstone.

Its nature and thickness in the lower part of Butler Wash are shown by the following section, measured half a mile north of State Highway 47 by Conti and the writer.

Section of Carmel formation measured on east side of Butler Wash half a mile north of State Highway 47

	Feet
Entrada sandstone.	
Carmel formation:	
Mudstone, red, soft, weathering to clay	5.5
Sandstone, red	4.0
Mudstone, red, soft, weathering to clay	4.5
Sandstone, red, blocky	3.0
Mudstone, red, soft, weathering to clay	5.5
Sandstone, red, rounded or knobby	3.0
Mudstone, red, soft, weathering to clay	2.0
Sandstone, red, knobby	2.0
Clay, red, and a few very thin layers of red sandstone	14.0
Sandstone, red, weathering rounded or knobby	2.0

Section of Carmel formation measured on east side of Butler Wash half a mile north of State Highway 47—Continued

Carmel formation—Continued	Feet
Clay, red, and a few very thin layers of red sandstone	18.5
Sandstone, gray, in two layers	3.0
Clay, red, and thin sandy layers	4.0
Sandstone, grayish below, pinkish above	5.0
Clay, red	3.0
Sandstone, gray	.5
Clay, red	4.0
Sandstone, gray	.5
Clay, red	2.5
Sandstone, thin-bedded, red	.5
Mostly sandy red clay	8.0
Sandstone, fine-grained, gray, soft, friable	1.5
Partly concealed; mostly red clay and some soft reddish sandy mudstones	11.5
Total	108.0

Navajo sandstone.

Northward in Butler Wash the thickness of the Carmel formation remains nearly constant. The composition gradually changes, however; the unit becomes more and more sandy and lighter in color, until it is made up chiefly of gray to buff sandstones with a notably reddish soft band in the middle. Despite these changes, the Carmel is still readily separable from the gray-white crossbedded Navajo below and the darker buff, more resistant basal sandstone of the Entrada above. Its nature and thickness in the northern area are recorded in the following section measured by Bergendahl and the writer.

Section of Carmel formation measured on west side of Butler Wash 2 miles south of northern boundary of mapped area

Entrada sandstone.

Carmel formation:	Feet
Mostly buff clay, with several thin soft gray to buff sandstones, thickest about 5 feet	38.0
Sandstone, gray	2.0
Conspicuously red zone; mostly red clay and thin platy red sandstones; about 4 feet above base, a 0.5-foot buff sandstone; about at middle, a 1-foot gray to buff sandstone	24.0
Sandstone, buff, massive; laterally lower part changes to interbedded red clay and buff sandstone layers	25.0
Sandstone, gray to buff; somewhat less resistant than thick sandstone next above	10.0
Poorly exposed; lower part, buff sandy clay; middle, buff sandstone; upper part, buff sandy clay, some faintly reddish	15.0
Total	114.0

Navajo sandstone.

Bergendahl inspected the Carmel formation and related strata about 4 miles north of the mapped area, where the upper end of Butler Wash is crossed by the new "low" road between Blanding and the Natural Bridges. The Navajo is as usual white to light-gray massive and crossbedded sandstone. The Carmel appears to be of approximately the same thickness and appearance as in the section just given. It is composed of mostly buff massive sandstones that at places form ledges up to 15 or 20 feet high, but includes some thinner beds (up to 3 or 4 feet) of red mudstone weathering to clay. The mudstones and some of the thin, platy sandstones are wavy or crinkled at places.

UPPER JURASSIC SERIES

SAN RAFAEL GROUP (UPPER PART)

ENTRADA SANDSTONE

The Entrada sandstone crops out in a narrow band up to half a mile wide in Butler Wash valley from State Highway 47 northward for more than 16 miles to the northern edge of the mapped area.

The upper and lower parts of the formation differ markedly from each other in lithology. Furthermore, though the lower unit is fairly constant throughout its length, the upper unit changes considerably from south to north.

The lower unit, making up roughly a third of the formation, is composed chiefly of medium-bedded gray to buff sandstones, of which the lower are the more resistant ledge-formers and the upper are the more friable. Near State Highway 47 the basal sandstones form a low bench. Half a mile to the north the more resistant lower sandstones form a steep ledge or rim above the slope of soft Carmel rocks. This rather pronounced escarpment, near and on the east side of Butler Wash, continues unbroken northward for about 3 miles and with gaps for another 2½ miles. The upper sandstones of this lower unit are somewhat thinner bedded and softer and are found either as irregular remnants above the escarpment or eroded back to soft steplike slopes to the east. In this southern part of the area, the upper unit of the Entrada is made up of soft thin-bedded brick-red shaly sandstones that lie in a poorly exposed zone between the lower light-hued unit and the overlying tan thin-bedded strata assigned to the Summerville formation.

Between points, respectively 6 and 8½ miles north of State Highway 47, the Entrada sandstone is almost wholly concealed by the alluvium of Butler Wash. In that concealed stretch, its lower boundary crosses the wash; and from the latter point almost to the north edge of the mapped area, the boundary is west of the wash, its lower, most resistant sandstones again making a conspicuous westward-facing escarpment above the Carmel and their upper surface making a promi-

nent dip slope eastward. Bergendahl records that within this northern stretch of Butler Wash the upper unit of the Entrada "is a massive red sandstone which is in contact with the Summerville. The thin-bedded unit, conspicuous in the south, is not visible in the north; however, it may be present as a middle unit, buried in alluvium. The actual facies change cannot be seen, owing to the discontinuity of outcrop."

The Entrada sandstone has a uniform thickness of about 150 feet in Butler Wash.

SUMMERVILLE FORMATION

In the southern part of Butler Wash, north of State Highway 47, the Summerville formation is composed of grayish-brown or tan thin-bedded sandstones, sandy siltstones, and some minor shaly beds. Its lowest part is poorly exposed; its middle and upper parts, though rather soft and nonresistant to weathering, form a slope and above that a banded cliff protected by the massive rim of Bluff sandstone. In general, the thin layers are parallel and horizontally bedded; but at places they are somewhat crumpled, and at others they turn upward for a few feet and are truncated by later beds, even in some instances by the Bluff sandstone. At one locality, on the east side of Butler Wash about 4 miles north of the highway, the beds exposed in the bottom of the cliff show two conspicuous sags (see pl. 20*B*) within a hundred feet of each other; these are interpreted to have been caused by slumping during deposition while the material was unconsolidated. These sags affect several beds; but higher in the cliff both sags are seen to have been fully filled in and leveled across, each at a different horizon, so that the next bedding plane above shows no bend.

In this vicinity some of the upper thin-bedded sandstones coalesce for considerable distances into a single thick, massive, ledge-forming sandstone that looks just like the Bluff sandstone. Generally it is separated from the Bluff by a few feet of the thinner beds; but at one place this zone of thin beds wedges out, and the two thick sandstones merge into an unbroken cliff. This intertonguing, in marked contrast to the more usual type of boundary between the two formations, suggests a close relationship in age and depositional history between the Summerville and Bluff in this area.

Beginning near the boundary between the middle and the northern quadrangles of the mapped area, within a short distance the upper part of the Summerville changes from grayish brown to a distinct reddish brown or brownish red and includes several thin layers of grayish-white sandstone. It also becomes less thin bedded toward the north.

As calculated by the writer from a number of pairs of altitude readings taken by Conti, the thickness of the Summerville formation

in Butler Wash ranges from 146 to 162 feet and averages 152 feet. This average is almost identical with the average of a number of readings obtained by Hemphill from air photographs.

BLUFF SANDSTONE

The youngest named formation in the mapped area is the Bluff sandstone, a grayish-brown thick massive resistant sandstone, in part crossbedded. It upholds the high bench east of Butler Wash, and its lower part forms the west rim of that bench as a prominent unscalable escarpment on the east side of the wash (see pl. 20*B*) from near State Highway 47 northward for some 6 miles, where the dwindling escarpment still is more than 70 feet high. Farther northward its topographic expression is less bold, and its outcrop is interrupted by alluvium in the numerous stream valleys that drain westward into Butler Wash.

The formation was not measured or studied in detail within the mapped area; but a brief description of it a few miles to the east, at and near the village of Bluff from which it is named, is given by Gregory (1938, p. 58).

The Bluff sandstone was formerly classed as a member of the Morrison formation; but because of present uncertainties as to its stratigraphic relations, it is now treated as a separate formation. East of the upper reaches of Butler Wash, it is overlain by a thick series of sandstones and clays fully accepted as Morrison.

QUATERNARY SYSTEM

In Comb Wash and in Butler Wash northward from a point 2 miles north of State Highway 47, the bottom lands are made up of alluvial fill of clay and very sandy clay with lenses of coarse grit and pebbles. In Comb Wash the belt of alluvium is flanked on the east by clayey slope wash and large and small sandstone boulders eroded from Comb Ridge and on the west by mounds of windblown sand presumably derived from the Cedar Mesa.

Yochelson noted that in the lower reaches of Comb Wash, south of State Highway 47, two low-lying terraces are well developed. Their surfaces are covered with gravel and cobbles up to 6 inches in diameter; most of the material is chert and limestone, and few boulders are of sandstone. At one locality the upper surface of the lower terrace deposits has been cemented.

The alluvium and other deposits here described largely mask the older formations for long stretches and make the outcrops of their boundaries difficult to find and identify. The concealing material is therefore omitted from the map (pl. 17), and the approximate position of the older boundaries is drawn with dashed lines so as to bring out the bedrock geology more clearly.

IGNEOUS ROCK

The only igneous rock observed within the mapped area is a small dike noted by Bell just north of the San Juan River canyon in the southwest corner. This dike, a few feet wide and less than a quarter of a mile long, extends northwest and protrudes through the limestone bench in the Rico. A specimen taken by Bell was examined by Charles Milton, of the U. S. Geological Survey, who reports as follows:

> The rock is a lamprophyre, with the usual bronze biotite flakes in a fine-grained but holocrystalline gray-green mafic groundmass. With a hand lens pale-green diopsidic pyroxene may also be seen; there are also numerous whitish small vesicles filled with clayey and calcitic material. This drops out in the process of making the thin section (unless special precautions are taken), so that in the thin section there are only holes representing the vesicle fillings.
>
> 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.

STRUCTURE

METHODS OF REPRESENTING STRUCTURE

The present attitude or structure of the sedimentary rocks in this area is shown on the geologic map (pl. 17) by strike and dip symbols, two cross sections, and contour lines drawn through points of equal altitude above sea level on a selected stratigraphic horizon. For all that part of the area west of the wall of Wingate sandstone in Comb Ridge, the top of the Rico formation was selected as the horizon for contouring. In the eastern part of the area, the base of the Wingate sandstone was chosen as the key horizon.

In the southwest corner of the area, where by uplift and erosion the top of the Rico is exposed at the surface, many altitude readings were taken on it by planetable and triangulation or stadia traverses, and these readings gave accurate figures directly usable for contouring. Similar readings on the top of the Halgaito tongue of the Cutler and the "lower soft" part of the Cedar Mesa in the northern part of the area were recalculated to altitudes of the Rico by subtracting the stratigraphic thickness of the upper units adjusted at each place for the degree of dip; the results are considered reliable. Altitudes of the Rico formation calculated from readings on still higher contacts (from the top of the Cedar Mesa up to the top of the Chinle) are progressively less accurate the higher each contact is in the geologic column, for there are variations in and questions about the stratigraphic thickness of several of the formations and members, and also there is possibility that the forces causing the uplift and steep easterly dips squeezed and thinned some of the softer zones. Therefore, for those parts of the area where the dips are steeper and the strata from Organ Rock to Chinle are at the surface, the contour lines are less

accurately placed but give an approximate picture of the structure. For this reason and because the Rico is so deeply buried under and east of Comb Ridge, it was deemed preferable to use the base of the Wingate sandstone as the key horizon for contouring in the eastern part of the area.

FOLDS

As described and partly mapped by Gregory (1938, p. 85–86, pl. 1), the Monument upwarp is one of the dominant structural features of the San Juan country. This broad fold has a north-south length of some 110 miles and a width, eastward from the Colorado River, of 40 to 60 miles. Gregory says: "in general the Monument upwarp is characterized by a broad, nearly flat top, gentle westward slope, steep eastward slope * * *." Its "steep eastward slope" is the Comb monocline, so named because the more resistant of its sharply dipping beds form the conspicuous hogback aptly called Comb Ridge.

Gregory points out further that the Monument upwarp is modified by a number of lesser anticlines and synclines. Only one of these subordinate folds is of concern to the present report. It is described by Gregory as follows—

> The fold defined in published reports as the Raplee anticline is an elongated dome sharply bounded on the east and west by monoclines. Beginning near the mouth of Comb Wash, the beds of Rico limestone that form the cap rock of the anticline rise abruptly westward from beneath higher beds with dips of 15° to 40°, flatten to less than 3° across the crest, then bend sharply downward and disappear beneath beds of the Cutler formation in the Mexican Hat syncline. As a structural and topographic unit the anticline is 15 miles long and 4 to 6 miles wide * * *. As mapped by Woodruff, its top is not a continuous structural ridge. Instrumental surveys show low anticlines with ends that overlap.

Gregory indicates this compound minor folding on his map by showing two parallel axes, the pair being labeled "Raplee anticlines."

The area discussed in the present report is in the eastern part of the Monument upwarp, and its main structural features can be readily fitted into the broader structural pattern described by Gregory and summarized above. From the contour lines and the strike and dip symbols on the geologic map (pl. 17), the steep eastward-dipping Comb monocline can be at once recognized in a belt extending from the north to the south boundary of the area. Westward from the monocline the dips become progressively less steep, and in the northwest part of the mapped area, in and behind the escarpment rimming the Grand Gulch Plateau, the capping sandstones of the Cedar Mesa member have the nearly horizontal bedding that characterizes the broad central part of the Monument upwarp. In the southwest part of the mapped area is the steep eastern limb and a small part of the crest of the compound fold mapped by Gregory as the "Raplee anticlines," to which his description quoted in the preceding paragraph is applicable. Small flexures on this fold are shown by the slightly

undulating surface of the top limestone of the Rico and are particularly evident near where State Highway 47 crosses the west edge of the map.

FAULTS

The only faulting of considerable magnitude found within the mapped area is that observed and studied by Bell and Yochelson in the west slope of Comb Wash valley south of State Highway 47. (See pl. 18*A*.) At places there is a single fault; at others there are two side by side, which approach and merge, or elsewhere are connected by small cross faults. (Owing to the small scale of the map, the fault as drawn is slightly generalized from the conditions noted in the field.) 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. The fault heads directly toward the small reentrant in the west wall of Comb Ridge that was utilized for the dugway to carry the State road and toward Navajo Spring near the bottom of the reentrant, but it seems to die out before reaching them, as no trace of either break or bending could be found in the massive Wingate sandstone or the several sandstone ledges in the upper part of the Chinle at that locality. However, it seems reasonable to suggest that both the erosion of the reentrant and the existence of the spring reflect some weakening or even undetected shattering of the otherwise hard, resistant strata by the same earth force that to the west brought the more obvious fault and movement.

Of a different and unrelated type are two small faults noted by Fuller some 2 miles to the north. These lie close to but on opposite sides of State Highway 47 about a quarter of a mile north of the point where the road crosses Snake Gulch, in the stretch where it runs in the lower Halgaito tongue before turning southwest and climbing the Rico slope. Both are overthrust faults, trending north-northwest and traceable for a few hundred feet. In both faults the overthrust side is on the northeast, and the throw reaches a maximum of perhaps 15 feet. The southwest fault, very near the road, runs along and cuts back and forth across the "normal" line of outcrop of the Rico–Halgaito contact. This is at the foot of the prominent dip slope on the hard, uppermost gray limestone of the Rico. On the hanging wall that limestone is repeated in outcrop by being shoved southwest over the dip-slope bed. Its lower surface, dipping northeast, is scored by

large grooves or slickensides. Along the strike the fault cuts obliquely for a small distance into the Halgaito, and there is duplication also of a thin buff sandstone near the base of that member. The second fault is northeast of and a little farther from the road and cuts across the southwestward-pointing rounded promontory of lower Cedar Mesa beds that surround the small inlier of Halgaito. As the beds are softer, the details are less sharp, but the general pattern of overthrust toward the southwest on a steep plane is clear.

These two faults, though too small to be shown on the general map, are of interest because they suggest that, after uplift, the anticlinal nose pointing toward this spot subsided slightly; and the resulting lateral compression caused a small buckling and an overthrusting inward from the flanks. This hypothesis finds support from a third feature found nearby. Southwest of the road in this vicinity, about a hundred yards up the dip slope on the Rico and approximately parallel to its boundary with the Halgaito, is a peripheral narrow belt of flattening, almost to reversal, of the prevailing northeasterly dip. This belt of modified dip shows clearly in the hard surface of the uppermost limestone of the Rico; viewed from the road, it gives the impression of an old rounded, continuous mound of earth tossed out on the downhill side of a ditch dug around the curve of a hill at a constant level. A diagrammatic cross section of this belt of flattened dips and the two overthrust faults is given in figure 41.

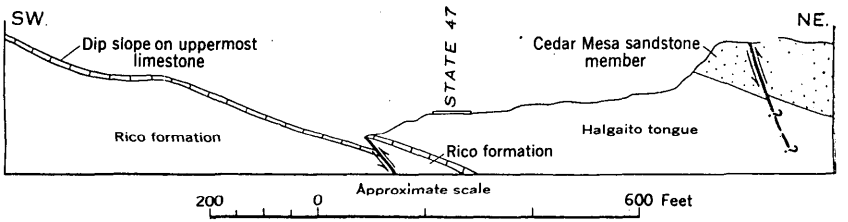


FIGURE 41.—Diagrammatic cross section of two small overthrust faults and of a flattening of dip near State Highway 47 in the southern part of the mapped area. (The section from end to end represents a distance of about 1,600 feet; the structural details are disproportionately enlarged to emphasize them.)

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INDEX