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

GEOLOGICAL SURVEY BULLETIN 1021-E



# A CONTRIBUTION TO GENERAL GEOLOGY

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

By Julian D. Sears

#### 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

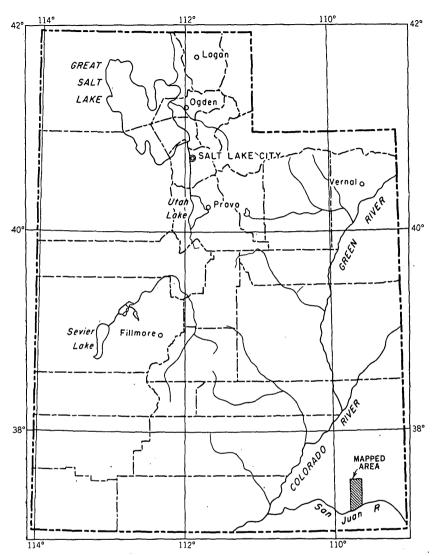


FIGURE 40.-Index map showing location of the area described in this report.

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

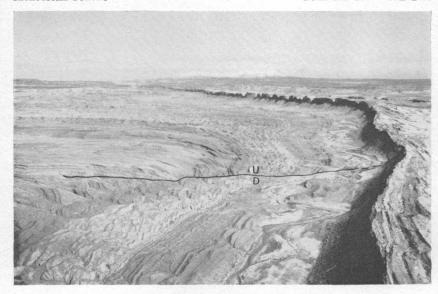
The project was planned and carried out under immediate supervision of the writer assisted by R. Dewey Sample. For the first 8 weeks the staff members assigned to the party were Gerald W. Fuller, Mineral Deposits Branch; Chabot Kilburn, Fuels Branch; Sergius H. Mamay, Paleontology and Stratigraphy Branch; 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 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 canvons 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

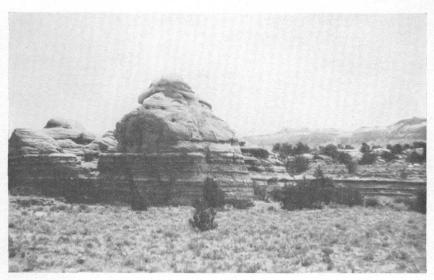
View up Comb Wash northward from San Juan River. Limestone at top of Rico formation in left foreground, ringed by successively younger formations. Comb Ridge at right. Photograph by J. R. Balsley.



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.



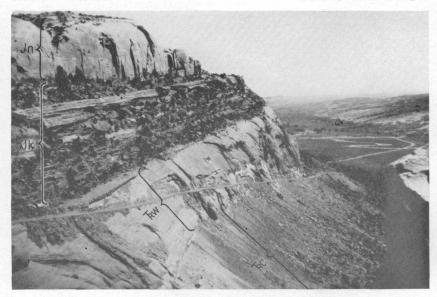
A. THICK-BEDDED SANDSTONES REGIONALLY TYPICAL OF CEDAR MESA SANDSTONE MEMBER
This member of the Cutler formation upholds nearly level top of Grand Gulch Plateau and is exposed in
deep canyon cut into slope of eastward-dipping beds in Comb monocline. View westward from top of
Comb Ridge near road from 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.



 $\varLambda.$  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

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 Kaventa formation. Thus the west face of the ridge, towering to a constant height of about 800 feet above the adjacent Comb Wash (see pl. 18A), 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. 20A.)

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. 18A.)

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 leafvein 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, 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. 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. 20A), 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		Thick- ness (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 cross-bedded.
			Summerville forma- tion	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 sand- stones 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±	Gravish-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土	Alternating sandstone, siltstone, and limestone, buff, tan, gray, white, and light red; essentially flat bedded; medium to thin bedded.
Triassic sytem	UpperTriassic series	Glen Canyon group (lower part)	Wingate sandstone	275±	Massive, cliff-making light-orange-red or brick-red to reddish-buff sand- stone, 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

				<u> </u>
Systems and series	Group, fo	ormation, and member	Thick- ness (feet)	Character of rocks
	Outler 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.
Permian system		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 mud- stones, with a few thin beds of gray limestone and white to buff sand- stone.
Pennsylvanian and Permian (?) systems	R	ico formation	390±	Hard gray limestone and massive sand- stone in beds up to 20 feet thick, interspersed with thicker zones of prevailingly red softer sandstones and thin-bedded mudstones.
Penn- syl- vanian 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. 18A.)

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 thinbedded 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. 18B.) 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. O 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
	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 red-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: