Geology and Fuel Resources of the Mesa Verde Area Montezuma and La Plata Counties, Colorado

GEOLOGICAL SURVEY BULLETIN 1072-M

Prepared in cooperation with the National Park Service

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By ALEXANDER A. WANEK

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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GEOLOGY AND FUEL RESOURCES OF THE MESA VERDE AREA, MONTEZUMA AND LA PLATA COUNTIES, COLORADO

By Alexander A. Wanek

ABSTRACT

The Mesa Verde area includes about 520 square miles of the northwestern part of the San Juan Basin in Montezuma and La Plata Counties, Colorado. The area lies within the Colorado Plateaus province and is immediately adjacent to the La Plata Mountains, one of the westernmost ranges in the Rocky Mountain system. Elevations in the area range from about 5,000 to about 8,600 feet above sea level. Mesa Verde is the most conspicuous topographic feature and includes Mesa Verde National Park. The major part of the area lies within the Ute Mountain Indian Reservation and is sparsely populated.

The exposed rocks in the area are of Late Cretaceous age. The Dakota sandstone crops out in the northwestern part of the area, and the overlying Mancos shale of marine origin is exposed widely along the edge of Mesa Verde. The Mesaverde group, consisting of the marine Point Lookout sandstone at the base, the middle coal-bearing Menefee formation, and the marine Cliff House sandstone at the top, overlies the Mancos shale. The Point Lookout sandstone is younger in the northern than in the southern part of the area. It rises stratigraphically northward by intertonguing at its base with the Mancos shale. The Menefee formation is a northeastward-tapering wedge; it intertongues at its base with the top of the Point Lookout sandstone and at its top with the base of the overlying Cliff House sandstone. The marine Cliff House sandstone is older in the northern than in the southern part of the area; it rises stratigraphically to the south by intertonguing at its base with the Menefee formation. The marine Point Lookout and Cliff House sandstones were deposited as a succession of great overlapping lenses; they enclose the wedge of continental coal-bearing sedimentary rocks of the Menefee. Overlying the Cliff House sandstone and separated from it by an erosional surface, are small deposits of unconsolidated gravels of Tertiary(?) age. Several levels of gravel terraces of late Recent origin lie in the Mancos Valley.

The Mesa Verde area lies wholly within the Four Corners platform subdivision of the San Juan Basin. The rocks are gently folded into a shallow syncline that plunges to the south. This structure is flanked on the east by Barker Dome, on the west by the Sleeping Ute Mountain uplift, and on the north by the Dolores Plateau. The rocks are broken by a few normal faults of little displacement.

The coal is of bituminous rank and of good grade, but the beds are lenticular and generally thin, although some are as much as 4 feet thick. Coal beds of commercial importance occur in the lower coal member of the Menefee formation and to a lesser extent in the upper coal member of that formation. Very little coal has been mined commercially in the area.

Gas is produced from the Dakota sandstone in the Point Lookout field; on the adjacent Barker Dome structure it is produced from both the Dakota sandstone and from the Paradox member of the Hermosa formation of Pennsylvanian age. In the subsurface the intertonguing relationship between the Mancos shale and the Point Lookout sandstone may prove an adequate stratigraphic trap for the accumulation of oil and gas. Systematic drilling in the area may show good oil and gas possibilities in the Dakota sandstone and in strata of Pennsylvanian age.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The area described in this report includes about 520 square miles, of which about 95 percent lies in the southeast corner of Montezuma County and 5 percent in the southwest corner of La Plata County. It is rectangular in shape and borders the extreme northwestern part of the San Juan Basin. The north boundary is about lat 37°22′, the south boundary is the Colorado-New Mexico State line, and the east boundary coincides with long 108°20′; the west boundary is U.S. Highway 666. The location of the area of this report and of adjacent areas of other reports is shown in figure 31.

EARLIER INVESTIGATIONS

The general geologic features of the area have been described in reports of earlier investigations. Holmes (1875) made a reconnaissance study of a large part of the San Juan Basin including the area covered by this report. Reports on the geology and economic resources of the La Plata mining area by Cross and others (1899) and Eckel and others (1949) included observations on the stratigraphy along the eastern border of the area. Lee and Knowlton (1917) investigated the rocks of Mesaverde age. Collier (1919) made reconnaissance examinations of the coal field which is south of Mancos and east of Cortez in Montezuma County, Colo. Detailed paleontological studies of Upper Cretaceous and Tertiary formations in the San Juan Basin were made by Reeside (1924). Atwood and Mather (1932) included Mesa Verde in a comprehensive study of the physiography and Quaternary geology of the San Juan Mountains and related areas in the southwestern part of Colorado. Pike (1947) made detailed field studies of the rocks of Mesaverde age from the type locality at Mancos, Colo., to Alamosa Creek, N. Mex. The U.S. Geological Survey has completed coal

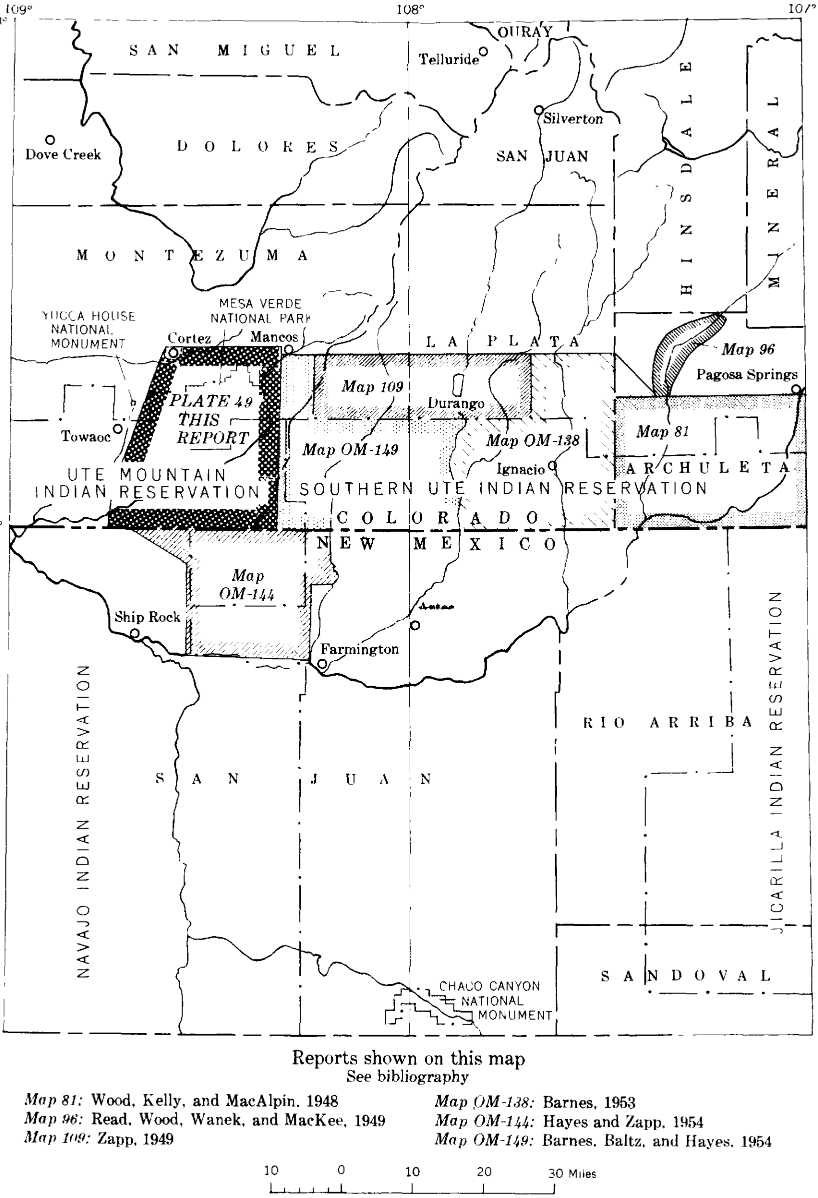

FIGURE 31.—Index map showing area of this report and areas of related reports.

investigations in areas adjacent to the Mesa Verde area (Zapp, 1949; Hayes and Zapp, 1954; Barnes and others, 1954).

FIELDWORK AND ACKNOWLEDGMENTS

The field investigations for this report were undertaken during the summers of 1951 and 1952. Geological mapping was done on aerial photographs at the scale of 1:31,680. The park and reservation boundaries were located on the photographs, and their position as well as that of section corners and land lines was checked against the topographic maps of the U.S. Geological Survey. The base map was modified from the planimetric maps of the Soil Conservation Service. All field data were transferred from the aerial photographs by a radial planimetric plotter or a reflecting projector. Vertical control in the area was obtained from bench marks established by the U.S. Geological Survey in 1910 and 1911.

John D. Hill and James Babcock assisted the author during the fieldwork. The cooperation of R. H. Rose, superintendent of Mesa Verde National Park, and his staff in making available information and park facilities that expedited the field mapping is gratefully acknowledged.

GEOGRAPHY

TOPOGRAPHY

The Mesa Verde area lies in the southeastern part of the Colorado Plateaus province and in general is a high, deeply dissected tableland. Mesa Verde rises nearly 2,000 feet above the gently sloping plain locally known as the Dolores Plateau (pl. 39*A*). In adjacent areas the most prominent topographic features are the rugged La Plata Mountains to the northeast and the Sleeping Ute Mountain to the west. These uplifts are two of the several scattered laccolithic mountains that characterize the plateaus in nearby parts of Colorado, Utah, Arizona, and New Mexico. Thus, from the north rim of Mesa Verde may be seen the Rico, Ute, La Plata, Carrizo, La Sal and, on a clear day, the Henry Mountains, all of which are laccolithic in type.

Mesa Verde is part of a plateau that has been dissected by streams flowing southward and southwestward from the San Juan Mountains to the San Juan River that flows westward to the Colorado River. The surface of Mesa Verde slopes gently southward and ranges in elevation from 6,000 feet near the State line to about 8,600 feet along the north rim.

Mesa Verde is drained by the Mancos River and its tributaries. On the west the mesa is bordered by the Montezuma Valley and on the south and east by the valley and canyon of the Mancos River. The streams that drain the south side of Mesa Verde have eroded headward until in some instances they have reached the north rim of the plateau. When viewed from a distance Mesa Verde appears to be a high and level tableland, but actually it is much dissected. The eroding streams have left narrow strips of upland bordered by steep cliffs that descend into narrow canyons. These interstream

A. DOLORES PLATEAU FROM PARK POINT ON NORTH RIM OF MESA VERDE

Dolores Plateau in background is floored with Dakota sandstone overlain with remnants of Mancos shale. Dissected slopes of Mancos shale rise abruptly to base of overlying cliff-forming Point Lookout sandstone. Laccolithic San Miguel and Rico Mountains are in the distance.

B. LOOKING NORTHEAST ACROSS MESA VERDE FROM SALT CANYON

The much-dissected uplands form narrow "fingers" which make travel difficult. Uplands are surfaced with Cliff House sandstone underlain by the coal-bearing Menefee formation. La Plata Mountains are in the far distance.

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A. CLIFF DWELLING IN MESA VERDE NATIONAL PARK

Square Tower House, a cliff dwelling, is in a great alcove in Cliff House sandstone.

B. LOOKING WEST ACROSS MESA VERDE FROM JOHNSON MESA

Ute 1 well, sec. 8, T. 33 N., R. 14 W., is in foreground. Pediment surface is on flat-dipping beds of Cliff House sandstone. Ute Mountains are in the distance.

areas form "mesa fingers" that trend southward; it is difficult to traverse the area other than along these "mesa fingers" (pl. 39*B*).

The mesas are surfaced by resistant sandstone ledges which rest on a thick softer sequence of rocks. The great alcoves at the heads and along the sides of the canyons are the sites of many ruins of ancient cliff dwellings (Atwood, 1911, p. 95–100).

DRAINAGE AND WATER SUPPLY

The major drainages in the area are the Mancos River and, to a lesser extent, McElmo Creek which flows westward through Montezuma Valley. The discharge of the Mancos River is measured at the gaging station 150 feet upstream from the bridge 12 miles south of Towaoc on U.S. Highway 666. According to measurements made by the U.S. Geological Survey (1951, p. 330–334) the discharge at this gaging station from February to September during the water year 1951 varied from zero on many days to a maximum of 1,160 cubic feet per second (cfs) on September 29, 1951. The average discharge over a period of 22 years (1921–43) was 60.8 cfs. The records of this station show a maximum discharge of 5,300 cfs on October 14, 1941. Water for the irrigation of about 10,000 acres is diverted from the stream above the station.

At the gaging station 4 miles northeast of Mancos on the East Mancos River 800 feet upstream from the junction with the Middle Mancos River, the records for the water year October 1950 to September 1951 show a maximum discharge of 102 cfs recorded on May 28 and a minimum of 0.1 cfs recorded September 25 and 26. The maximum discharge recorded for the period 1938–51 was 642 cfs on May 8, 1941. Above the gaging station, water is diverted from the stream for irrigation.

The gaging station on the West Mancos River is 1½ miles upstream from the confluence with the East Mancos River 3½ miles northeast of Mancos. The records for the water year October 1950 to September 1951 show a maximum discharge of 119 cfs on June 19 and a minimum discharge of 0.1 cfs on April 11–13. A maximum discharge for the period 1910–11 and 1938–51 of 1,080 cfs was recorded on May 13, 1941. Above the station during the water year 1951 about 6,380 acre-feet were diverted to a storage reservoir for irrigation, and 5,970 acre feet were returned to the river.

Montezuma Valley is drained by westward-flowing McElmo Creek. The records for the gaging station located 5 miles southwest of Cortez show for the water year October 1950 to September 1951 a maximum discharge of 653 cfs on September 30, 1951, and a minimum discharge of 3.4 cfs on August 17–19, 1951. The maximum discharge for the periods 1926–29, 1940–43, and 1950–51 was 4,540 cfs on September 22, 1941. The average discharge for this period was 62.3 cfs. Water for the irrigation of about 200 acres was diverted from the stream above the station. The flow in McElmo Creek is mainly return water from the irrigated lands of the Montezuma Valley Irrigation District.

With the exception of the stream in Weber Canyon, the Mancos River is the only perennial stream that drains Mesa Verde. Except during and immediately after periods of precipitation, surface flow is rare in the many canyons in the area. Earth dams have been constructed in the shallow drainages on the mesa surface to store water for cattle during the dry summer months. Springs and seeps are not numerous but do occur in some of the large canyons.

The water supply for Mesa Verde National Park comes from several sources. The initial supply was derived from a deep well which bottomed in sandstone of Jurassic age. This supply was later supplemented by an ingenious catch basin that trapped rainwater and drained it into a large underground reservoir. An additional water supply is obtained from a large surface reservoir northeast of Mancos. The water is piped through large conduits to the base of Mesa Verde and pumped 2,000 feet to the top of the plateau and park headquarters on Chapin Mesa.

The towns of Mancos and Cortez receive their water supply from local reservoirs. Several reservoirs constructed in main drainages on the Dolores Plateau store water for the Montezuma Valley and Mancos Valley Irrigation Districts.

CLIMATE AND VEGETATION

The climate of the Mesa Verde area is semiarid. The average seasonal precipitation as shown by records of weather stations in the area varies from 15.84 inches at Cortez to about 18.73 inches at Mesa Verde Park headquarters. The precipitation on the high tablelands is adequate for dry-farming. The cultivation of crops in the valleys is most successful where additional water is supplied by irrigation. The average monthly and annual precipitation at weather bureau stations in and near the Mesa Verde area is shown in table 1.

The average seasonal temperatures in the area are moderate. The average minimum temperature during January is about 26°F at Fort Lewis, 30 miles east southeast of Cortez. The average maximum temperature for the month of July is about 69°F at Cortez, about 72°F at Mesa Verde Park headquarters, and about 65°F at Fort Lewis. By contrast the extreme temperatures in the month

TABLE 1.—*Average monthly and annual precipitation at Weather Bureau stations in and near the Mesa Verde area*

Station	Length of record (years)	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mancos [1]	6	1.38	1.44	1.99	1.64	1.27	0.95	1.82	1.86	1.50	1.56	1.06	1.18	17.65
Cortez [2]	40	1.10	1.39	1.57	1.36	0.90	0.66	1.52	1.68	1.65	1.52	0.96	1.53	15.84
Mesa Verde National Park headquarters [3]	30	1.58	2.03	1.97	1.36	1.09	0.75	1.76	2.09	1.96	1.49	1.03	1.62	18.73
Fort Lewis [4]	54	1.39	1.78	1.59	1.38	1.08	0.86	2.13	2.22	1.91	1.75	1.02	1.59	18.70
Dolores [5]	22	1.44	1.58	1.89	1.52	1.16	1.06	1.70	1.62	1.60	1.75	1.18	2.07	18.57

[1] 1947–52. [2] 1913–52. [3] 1923–52. [4] 1899–1952.
[5] 1931–52. Dolores is 8 miles north-northeast of Cortez.

of July during the year 1952 were 95°F at Cortez, 93°F at park headquarters, and 87°F at Fort Lewis. During the same year the lowest temperature recorded during the month of November was 15°F at Fort Lewis and 1°F at park headquarters. The lowest temperature recorded during the month of January 1952 was −8°F at Cortez. The average monthly and annual temperatures of the area are shown in table 2.

TABLE 2.—*Average monthly and annual temperatures*

Station	Length of record (years)	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Fort Lewis [1]	46	21.6	25.9	20.3	41.8	50.0	58.4	64.7	61.3	55.7	45.3	33.6	27.0	42.1
Cortez [2]	40	26.2	31.3	38.0	45.9	54.3	63.1	69.3	67.7	60.2	49.5	36.1	28.6	47.5
Mesa Verde National Park headquarters [3]	30	29.2	33.5	38.6	47.8	56.8	67.3	72.4	70.5	62.7	51.9	39.6	31.5	50.2

[1] 1907–52. [2] 1913–52. [3] 1923–52.

The characteristic summer precipitation of the area is from sudden and violent thunderstorms accompanied by locally heavy rain and frequently by hail. The first frost usually occurs early in October in the valleys and later in areas of high elevation.

The native vegetation is adapted to semiarid conditions. The differences in elevations, however, appear to divide the flora into zones that range from arid to semiarid. The vegetation of the lowlands consists of various species of cactus, sagebrush, cottonwood, greasewood, and an introduced genus, tamarisk. Piñon and juniper cover the higher slopes of the canyons sparsely but grow abundantly on the surfaces of the mesas. There is a moderate cover of grass on the tablelands and heavy growths of scrub oak along the north rim of Mesa Verde. Piñon and yellow pine occur in moderate stands in the highest parts of the plateaus and in the heads of some of the larger canyons.

SETTLEMENT AND TRANSPORTATION

The town of Mancos, a supply point for the ranchers and farmers in Mancos Valley and the adjacent areas, is just east of the northeast corner of the mapped area. It contains only a small resident population but lies in the midst of a thickly populated farming and ranching area. The population of Mancos was 785 in 1950, according to the Census Bureau.

The present major industries in the area are ranching and farming, although in the early part of the century Mancos was a center of metal-mining activity in the nearby La Plata Mountains. The valley lies in the fruit-growing belt of northwestern New Mexico and southwestern Colorado. Today the mining and lumbering industries have declined but some small logging operations are conducted in the La Plata Mountains.

Until 1951, when it was abandoned, a narrow gauge branch of the Rio Grande Southern Railway connected Mancos with the city of Durango and also with the settlement of Dolores. U.S. Highway 160 connects Mancos with the towns of Hesperus and Durango to the east, and with Cortez and Salt Lake City, Utah, to the west. Cortez, the county seat of Montezuma County, is an important trading center in the western part of the area. The 1950 population of Cortez was 2,680. An airline maintains scheduled air service to Cortez. U.S. Highway 666 connects Cortez with the towns of Shiprock and Gallup, N. Mex. Many unimproved roads radiate from Cortez and Mancos to small settlements in the area.

The Indian settlement of Towaoc, in the northwest part of T. 34 N., R. 17 W., south of the Ute Line, is a subagency of the Consolidated Ute Indian Agency; it has a school that is maintained by the Bureau of Indian Affairs. Towaoc can be reached by improved road from U.S. Highway 666. Several trading posts along this highway are independent supply points for the Ute Indians.

About 8 miles west of Mancos a paved road connects the headquarters of Mesa Verde National Park with U.S. Highway 160. It ascends the precipitous north rim of Mesa Verde and affords a fine panorama of the country to the north.

Mesa Verde National Park was established by an Act of Congress on June 29, 1906. The size of the park was increased in the years 1913, 1931, and 1932 to include additional scenic and historical areas along Mancos River. At present Mesa Verde National Park covers 90 square miles of canyon and tablelands that contain many ruins of ancient Indian cliff dwellings. The ruins are situated in alcoves between two great sandstone layers along precipitous canyon walls or in the boxlike heads of canyons. The most remarkable ruins are in the southern part of the park, but there are others almost equally spectacular in the more inaccessible western part (pl. 40*A*). Well-paved roads which traverse Chapin Mesa afford the visitor excellent views of many ruins. Horse trails give access to the cliff dwellings in the more remote areas of the park.

An improved road, the Ute trail, traverses Mancos Canyon from U.S. Highway 666 east to Johnson Mesa where it joins unimproved roads that lead southward to the Barker Creek gas field or northward toward Mancos. In most parts of the area these roads are the primary arteries for transportation in the canyon country. The more remote areas are accessible only by horse trails.

GEOLOGY

GENERAL FEATURES

The exposed sedimentary rocks in the area are Late Cretaceous in age and are about 3,600 feet thick (table 3). The rocks consist of sandstone, siltstone, shale, and coal that were deposited in marine, brackish, or fresh water. Locally these rocks are intruded by small irregular igneous bodies and by dikes. The stratigraphic sequence is conformable from the Dakota sandstone, the oldest exposed formation, to the Cliff House sandstone, the youngest exposed unit. Locally the Cliff House sandstone is unconformably overlain by small bodies of cemented gravels. The mesa surface appears to be a part of a late Tertiary(?) pediment (Atwood and Mather, 1932, p. 91) that rises northeastward toward the La Plata Mountains. The close relationship of the mesa to the La Plata and San Juan

TABLE 3.—*Generalized section of outcropping sedimentary rocks in the Mesa Verde area*

Age	Formation	Thickness (feet)	Character
Upper Cretaceous	Cliff House sandstone	400±	Pale to dark yellowish-orange massive cliff-forming crossbedded marine sandstone; intertongues toward base with Menefee formation and includes locally a lower tongue, a middle tongue (Barker Dome tongue), and an upper tongue. Top eroded.
	Menefee formation	340–800	Gray to grayish-orange lenticular crossbedded sandstone and gray to brownish-gray and black carbonaceous shale and coal beds; includes locally an upper coal member, a middle barren member, and a lower coal member; intertongues toward top with Cliff House sandstone and toward base with massive sandstone member of Point Lookout sandstone.
	Point Lookout sandstone	400±	Pale to yellowish-orange massive cliff-forming crossbedded marine sandstone; consists of an upper massive sandstone member 230–340 feet thick and at the base an alternating sandstone and shale member 60–140 feet thick which intertongues with upper massive sandstone member at top and Mancos shale at base.
	Mancos shale	2,000	Soft dark-gray to black marine shale containing thin lenses and concretions of sandy yellowish-orange limestone; intertongues at top with sandstone and shale member of Point Lookout sandstone.
	Dakota sandstone	134+	Grayish to yellowish-orange crossbedded sandstone interbedded with siltstone and carbonaceous shale and lenticular coal; conglomeratic toward base. Base not exposed.

Mountains is indicated by the gravel deposits and a scattering of well-worn pebbles which, from their composition, must have been derived from these areas of uplift.

The major structural features of the area resulted from the Laramide orogeny and subsequent folding and tilting movements. Mesa Verde lies in a shallow southward-plunging synclinal fold that is marginal to the northwest part of the San Juan Basin. On the west the beds are inclined away from the bordering Sleeping Ute Mountain uplift; on the east they dip gently from the La Plata Mountains and Barker Dome, and to the north the beds dip away from the Dolores Plateau. The strata flatten in the southern part of the area, but southeast of the area the dips increase sharply along the hogback or structural rim of the basin.

The lithologic character and thickness of the formations exposed in the area are summarized in table 3.

SEDIMENTARY ROCKS

UNEXPOSED ROCKS

Sedimentary rocks older than the Dakota sandstone are not exposed in the area, but rocks ranging in age from Pennsylvanian to Late Cretaceous crop out in the La Plata Mountains. In the San Juan Mountains a sequence of rocks ranging in age from Cambrian to Tertiary are present.

Data of unexposed sedimentary rocks older than the Dakota sandstone was obtained from the logs of oil, gas, and water wells drilled in the area. A well drilled at Mesa Verde Park Headquarters bottomed at 4,200 feet in sandstone of Jurassic age. Ute 1, drilled by the Tidewater Associated Oil Co. on Johnson Mesa, penetrated 9,508 feet of sedimentary rocks ranging in age from Pennsylvanian to Late Cretaceous (pl. 40*B*). The well depths to the tops of the formations are indicated in the following log.

Summary of log of the Tidewater Associated Oil Ute 1 well, sec. 8, T. 33 N., R. 14 W.

	Depth (feet)
Point Lookout sandstone	832
Mancos shale	1, 185
Greenhorn limestone member equivalent(?)	3, 095
Dakota sandstone	3, 220
Morrison formation	3, 320
Todilto limestone	4, 330
Entrada sandstone	4, 350
Chinle formation	4, 830
Shinarump member	5, 590
Moenkopi formation	5, 665
Cutler formation	5, 710
Hermosa formation	7, 435
Paradox member	8, 706

In the Rico Mountains, Cross and Ransome (1905) measured a sequence of sedimentary rocks which range in age from Late Cambrian to Late Cretaceous. In the La Plata Mountains the exposed sedimentary rocks range from the Hermosa formation of Pennsylvanian age to the Mancos shale of Late Cretaceous age (Eckel and others, 1949, p. 7–52). The stratigraphic sections described by Eckel in this district differ considerably from that given by Cross (Cross and others, 1899). The Rico and Cutler formations had not been differentiated by Cross in his fieldwork, and he grouped them with the Dolores now considered Late Triassic age. In the earlier investigations the Hermosa formation was not recognized in exposures on the La Plata River and Hermosa Creek. The La Plata sandstone, originally defined by Cross (1905) is now subdivided into three formations. A composite section of the sedimentary rocks was measured by Eckel and others (1949, p. 9) in the La Plata district and along the Animas River. This section is briefly described in table 4.

Sedimentary rocks younger than the Cliff House sandstone do not occur in the Mesa Verde area although such younger rocks were probably present prior to erosion. A thick sequence of strata of Late Cretaceous, Paleocene, and Eocene age overlies the Cliff House sandstone in the Durango area. Zapp (1949) and Barnes and others (1954) give detailed descriptions of these rocks. It seems likely that the maximum thickness of sedimentary rocks that once probably overlay the Cliff House sandstone in the area was as much as 5,400 feet.

CRETACEOUS SYSTEM, UPPER CRETACEOUS SERIES

DAKOTA SANDSTONE

The oldest formation exposed in the area mapped is the Dakota sandstone. It crops out in the northwest and forms the surface of most of the Dolores Plateau.

The lithologic character and thickness of the formation is variable. A partial section of Dakota sandstone was measured in sec. 28, T. 36 N., R. 15 W. At this locality the formation crops out in a ledge-forming sequence of rocks that consists of an upper ledge of grayish- to yellowish-orange crossbedded medium-grained quartzose sandstone overlying a softer sequence of siltstone and ferruginous fine-grained sandstone intercalated with carbonaceous shale. The base of the Dakota sandstone is not exposed. The carbonaceous shale contains lenticular beds of impure coal of bituminous rank. The coal was being mined for local use at the time of the fieldwork for this report. The lower part of the formation which is partially exposed consists of medium- to coarse-grained light-gray sandstone

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TABLE 4.—*Sedimentary rocks of the La Plata district, Colorado*[1]

Age	Formation names in current use by Geological Survey	Member	Name in local use	Name used in U.S.G.S. Geol. Atlas, Folio 60[2]	Thickness (feet)	Character
Upper Cretaceous	Mancos shale		Mancos shale	Mancos shale	1, 200	Dark-gray to black soft carbonaceous shale with thin lenses and concretions of impure limestone. Only the lower part is exposed within La Plata district.
	Dakota sandstone		Dakota sandstone	Dakota sandstone	100–150	Gray or brown sandstone with variable conglomerate at or near base. Carbonaceous shale partings and coal at several horizons. Forms cliffs. Should be favorable to ore, but little occurs in the mineralized area.
Upper Jurassic	Morrison formation		McElmo formation	McElmo formation	400–625	Yellowish-brown to gray friable, fine-grained sandstone, alternating with variegated shales, with one or more lenses of conglomerate near top. Largely altered to dense light-colored quartzite and hornfels in central part of district. Generally unfavorable to ore deposits.
	Junction Creek sandstone		Upper La Plata sandstone	La Plata sandstone	160–500	White massive friable sandstone, distinctly crossbedded. Altered to hard white to brown quartzite in central part of district. Contains much ore in several places.
	Wanakah formation	Marl and Bilk Creek sandstone	Middle La Plata shale		25–125	Pink to red sandy marls alternating with lenses of friable white to light-colored sandstone. Similar to Morrison formation where metamorphosed. Generally unfavorable to ore deposits.
		Pony Express limestone	La Plata limestone		0–25	Medium-gray to black massive unfossiliferous limestone. Locally replaced by pyrite or by telluride minerals. Largely altered to contact metamorphic minerals in central part of district. Locally contains much ore.
	Entrada sandstone — Unconformity —		Lower La Plata sandstone		100–265	Similar to Junction Creek sandstone.
Jurassic(?) and Upper Triassic	Dolores formation		Dolores formation; red beds	Dolores formation	500–750	Salmon-pink to bright-red mudstones and fine-grained sandstones. Several beds and lenses of limestone-shingle conglomerate and of light-gray slabby sandstone at or near base. Where metamorphosed it has same character as shale of Morrison formation. Limestone conglomerate beds altered to contact-metamorphic minerals in places. Generally unfavorable to ore deposits.
Permian	Cutler formation		Cutler formation; red beds		1, 500–2, 200	Alternating dull-red arkosic sandstone, conglomerate, limy shale, and mudstone. Similar to Morrison where metamorphosed. Nodules of limestone, unaltered in places but elsewhere altered to garnet, epidote, etc. Favorable to ore deposits where rocks are silicified.

Pennsylvanian	Rico formation		Rico formation [red beds]	Not recognized: included with Dolores in mapping	100–300	Dull-red shale, sandstone, and thin beds of sandy fossiliferous limestones. Similar to Morrison where metamorphosed. Locally contains ore deposits.
	Hermosa formation		Hermosa formation		2,800+	Alternating green to gray and occasionally dull-red arkosic sandstone, shale, fossiliferous limestone, and gypsum. Only the upper 500 feet is exposed within La Plata district. Favorability to ore deposits not known.
	Molas formation				0–75(?)	Red limy shale. May not be present beneath La Plata district.
	— Unconformity —					
Mississippian	Leadville limestone				60(?)	Fossiliferous massive to laminated limestone.
Upper Devonian	Ouray limestone				75(?)	Fossiliferous limestone, sandy limestone, and quartzite.
	Elbert formation				0–130(?)	Shale, limestone, and sandstone.
	— Unconformity —					
Upper Cambrian	Ignacio quartzite				50–100(?)	Massive to thin-bedded quartzite with some conglomerate at base.
	— Unconformity —					

[1] From Eckel and others (1949).
[2] Cross and others (1899).

with intercalated conglomerate lenses that contain abundant black and gray chert pebbles.

To the west near McElmo Canyon, the Dakota sandstone crops out in massive hard ledges and contains very little carbonaceous material. In the Mesa Verde area the formation ranges from 125 to 150 feet in thickness and is represented by sandstone, siltstone, carbonaceous shale, and coal. In the Durango area the Dakota sandstone is about 213 feet thick (Zapp, 1949) and consists of hard gray to buff sandstone and conglomeratic sandstone with subordinate amounts of interbedded shale, carbonaceous shale, and coal. At some localities in the San Juan Basin the Dakota sandstone is several hundred feet thick, and at other places it is only a few feet thick (Pike, 1947, p. 7–8). In T. 36 N., R. 15 W., it contains abundant carbonaceous matter and a coal bed 2.8 feet thick; a few miles to the west very little coal is present.

The original sediments of the formation were evidently deposited in flood-plain, swamp, and lagoonal environments. The upper part of the Dakota sandstone in places appears transitional with the overlying Mancos shale; it was possibly deposited as beach sand.

The Dakota sandstone is the basal formation of the Upper Cretaceous series and lies unconformably upon the Morrison formation of Late Jurassic age.

Partial section of Dakota sandstone measured in sec. 28, T. 36 N., R. 15 W.

	Feet
Sandstone, yellowish-orange to dark yellowish-orange, medium-grained, crossbedded, medium-bedded	10. 0
Sandstone, silty, dark yellowish-orange, irregularly bedded, thin-bedded, calcareous	17. 0
Siltstone, dark yellowish-orange; intercalated with thin flaggy sandstone beds	36. 0
Sandstone, hard, fine-grained, even-bedded, thin-bedded, ferruginous	6. 5
Shale, dark-gray, calcareous	4. 0
Sandstone, grayish-orange, fine-grained, thin-bedded, carbonaceous	2. 0
Shale, grayish-brown, carbonaceous	1. 0
Coal, silty	2. 8
Shale, grayish-brown, carbonaceous	3. 0
Sandstone, light-gray, fine-grained, crossbedded, thin-bedded; contains carbonaceous stringers	15. 0
Sandstone, intercalated with thin beds of siltstone and shale; very poorly exposed	25. 0
Sandstone, conglomeratic, light-gray to grayish-orange, coarse-grained, crossbedded; contains quartzite and chert pebbles	>12. 0
Total exposed Dakota sandstone	>134. 3

MANCOS SHALE

The Mancos shale was named by Cross (Cross and Purington, 1899) from exposures in the Mancos Valley near the town of Mancos, Colo. Cross measured a section of the Mancos shale about 1,200 feet thick in the La Plata area (Cross and others, 1899); Pike (1947, p. 42–43) measured a thickness of 2,191 feet of the Mancos shale in the vicinity of Point Lookout at the north rim of Mesa Verde. In the same area the present author measured a section of the Mancos shale about 2,000 feet thick. The discrepancy in thickness at this locality is due to the arbitrary choice of the boundary at the base of the Point Lookout sandstone. Pike (p. 42) included in his Mancos shale section all rocks from the top of the Dakota sandstone to the base of the massive sandstone of the Point Lookout, whereas the author considered the base of the transition interval of the Point Lookout sandstone as the top of the Mancos shale.

The Mancos shale conformably overlies the Dakota sandstone. It crops out in a wide belt along the escarpment of Mesa Verde, forming steep, intricately dissected slopes which rise to the base of the overlying cliff-forming sandstone beds of the Mesaverde group. Where this resistant cap rock has been removed by erosion, as on the Dolores Plateau, the Mancos shale forms low ridges or gently sloping hills (pl. 39*A*).

The upper part of the Mancos shale is generally sandy and light olive gray; it contains many thin arenaceous limestone lenses and concretions. The lower part of the Mancos shale is predominantly brownish gray to olive gray and olive black and is very calcareous and gypsiferous; it contains abundant limestone concretions near the base. This sequence of shale contains numerous selenite seams along bedding planes and joints. At its top the Mancos shale includes interbeds of sandstone and shale that are transitional to the overlying Point Lookout sandstone.

About 100 feet above the top of the Dakota sandstone, a zone of interbedded thin platy limestone and limy shale nearly 50 feet thick (pl. 41*A*) contains abundant specimens of *Inoceramus labiatus*. It is probably the equivalent of the Greenhorn limestone member of the Mancos shale in the eastern part of the San Juan Basin. About 550 feet above the base of the Mancos shale several fossiliferous sandstone beds form a distinct lithologic unit. The sandstone is calcareous, yellowish brown, medium bedded, and intercalated with thin intervals of dark brownish-black shale. The unit is an excellent marker in the Mancos and forms a prominent cuesta wherever exposed along the rim of Mesa Verde. Pike (1947, p. 18–23) suggests that this unit might be correlated with the Ferron sandstone member of the Mancos shale in central Utah which occurs about 650 feet above the base of the Mancos and carries the same fauna. He refers to this horizon as "The zone of *Prionocyclus wyomingensis* and *Scaphites warreni*." Newberry (1876) traced this same zone over large areas in New Mexico. The part in northern New Mexico is correlated with the Juana Lopez sandstone member of Rankin (1944).

The age of the Mancos shale as described by Cross from exposures at the type locality was recognized as including all of Colorado and a part of Montana time. Pike (1947, p. 23) found the base of the Montana group equivalents to be near the middle of the Mancos shale at Mesa Verde or about 1100 feet below the top of the Mancos shale.

The base of the Montana group equivalents is about 435 feet below the top of the Mancos shale on the San Juan River (Reeside, 1924). Hunt (1936, p. 45) believed that in the southeastern part of the San Juan Basin this horizon comes within the upper part of the Satan tongue of the Mancos shale. In the Chuska Mountains the base of the Montana equivalents coincides approximately with the Mancos-Mesaverde contact (Pike, 1947, p. 24). Pike attributed this northward divergence of lithologic and faunal boundaries to a stratigraphic rise of the Point Lookout sandstone and the northward thinning of older faunal zones and the thickening of younger zones in the same direction. The author, in measuring a line of sections along the margins of Mesa Verde, ascertained a northward stratigraphic rise of more than 200 feet in the base of the Point Lookout sandstone. Pike (p. 24) considered the top of the Mancos in this area to be as young as the middle part of the Pierre shale. At Point Lookout he approximated the thickness of faunal zones measured downward from the base of the massive Point Lookout sandstone to the base of the Mancos shale. The Pierre shale equivalents and Eagle sandstone equivalents were 475 feet thick, the Telegraph Creek formation equivalents were 700 feet thick, the Niobrara equivalents were 400 feet thick, the Carlile equivalents were 500 feet thick, and the Greenhorn and Graneros equivalents were about 125 feet thick.

Section of Mancos shale measured at Point Lookout

[Shown on plate 49]

Sandstone and shale member of the Point Lookout sandstone.	
Mancos shale:	*Feet*
Shale, silty; includes occasional discontinuous sandstone beds	57.0
Shale, olive-gray; contains sandy concretions	44.0
Shale, dark olive-gray; includes siltstone lenses	96.0
Shale, dark-gray; contains occasional sandy concretions	56.0
Shale, grayish-black, calcareous	68.0
Shale, dark-gray; contains abundant limy concretions	43.0
Shale, olive-gray; contains thin lenses of calcareous sandstone	51.0
Sandstone, yellowish-gray, very fine grained; interbedded with shale	62.0
Sandstone, light-brown, very fine grained, thin-bedded, calcareous	6.5

Mancos shale—Continued	*Feet*
Shale, dark-gray; intercalated with thin sandstone lenses	30. 0
Limestone, medium-gray, aphanitic, granular	1. 5
Shale, dark-gray; intercalated with thin sandstone lenses	123. 0
Limestone, medium-gray	2. 0
Shale, dark-gray, silty	112. 0
Limestone, medium-gray	1. 5
Shale, dark-gray, sandy; intercalated with occasional limestone concretions	66. 0
Shale, olive-gray with sporadic thin sandstone beds	63. 0
Limestone, dark-gray	2. 0
Shale, grayish-black; contains abundant selenite crystals along bedding planes	47. 0
Limestone, dark-gray	1. 0
Shale, dark-gray, soft	90. 0
Limestone, dark-gray	1. 0
Shale, brownish-gray, soft	32. 0
Shale, grayish-yellow, silty	2. 0
Limestone, olive-gray, shaly	1. 0
Shale, olive-gray; contains selenite crystals	2. 0
Limestone, dark-gray	1. 0
Shale, olive-gray	7. 0
Limestone, arenaceous	1. 0
Shale, dark-gray	11. 0
Limestone, dark-gray	1. 0
Shale, brownish-gray, sandy	24. 0
Limestone, light-olive-gray; contains fragments *Inoceramus* sp	1. 0
Shale, brownish-gray, sandy	25. 0
Limestone, brownish-gray; contains fragments *Inoceramus* sp	. 5
Shale, brownish-gray, gypsiferous	53. 0
Shale, olive-gray, hard; contains white specks on weathered surface, abundant fragments of large *Inoceramus* specimens and *Ostrea congesta*	94. 0
Shale, olive-gray, sandy, gypsiferous	2. 0
Shale, light-brown, abundant fragments *Inoceramus* sp	14. 0
Shale, dark-gray; contains seams of selenite in bedding planes	21. 0
Shale, brownish-black; weathers with many white specks	18. 0
Shale, light olive-gray	23. 0
Shale, olive-gray, sandy, gypsiferous	26. 0
Shale, olive-black, calcareous	16. 0
Shale, brownish-black, sandy; contains occasional large septaria concretions	9. 0
Shale, olive-black; contains abundant septaria concretions	36. 0
Sandstone, yellowish-brown, thin-bedded, ferruginous; contains abundant fossils, sp. *Prionocyclus wyomingensis* and *Scaphites warreni*	1. 5
Shale interbedded with thin sandstone, calcareous, fossiliferous	5. 0
Shale, brownish-gray sandy	33. 0
Sandstone, yellowish-brown, fine-grained, calcareous, very fossiliferous	1. 0
Shale, brownish-gray, sandy	23. 0
Sandstone, yellowish-brown, ferruginous, fossiliferous	2. 0
Shale, brownish-black	41. 0
Shale, dark-gray; contains large limy concretions	156. 0
Shale, olive-gray, soft	68. 0
Shale, dark olive-gray, very gypsiferous	91. 0

Mancos shale—Continued	*Feet*
Shale, dark-gray, calcareous	39. 0
Limestone, dark-gray, platy, thin-bedded, intercalated with thin limy shale beds; contains abundant *Inoceramus labiatus*	18. 0
Shale, dark-gray; intercalated with thin nodular limestone beds	24. 0
Shale, brownish-black, with large sandy concretions	51. 0
Total Mancos shale	1, 997. 5

Dakota sandstone.

MESAVERDE GROUP

GENERAL FEATURES

Rocks of the Mesaverde group crop out conspicuously along the tablelands of Mesa Verde (pl. 41*B*). They form the surface of the high plateau and appear as an unbroken escarpment along the north and west rims. The interior of this tableland is deeply dissected by the drainage of the Mancos River. The excellent exposures of the rocks enabled the author to make detailed stratigraphic studies of the formations.

Holmes (1875, p. 237–276) originally used the name Mesaverde to include the sequence of sandstone beds that cap Mesa Verde in Montezuma County, Colo. These rocks, which conformably overlie the Mancos shale, range from 1,200 to 1,500 feet in thickness at this locality. Holmes subdivided the sequence to include a massive sandstone at the base which he called the "Lower escarpment," a middle coal-bearing unit, and a massive sandstone at the top which he called the "Upper escarpment" (pl. 42*A*). Collier (1919, p. 245) recognized these rocks as three distinct formations and referred to them as the Mesaverde group. The "Lower escarpment" of Holmes was named the Point Lookout sandstone, the middle coal-bearing measure was named the Menefee formation, and the "Upper escarpment" of Holmes was named the Cliff House sandstone. These three divisions may not be recognized everywhere but the name Mesaverde as a formation or group has been applied to sandstones and coal-bearing measures in the Upper Cretaceous series over large areas of the Rocky Mountains and the Southwest.

The relationship of the Mancos shale to the Mesaverde group is generally that of large-scale intertonguing caused by repeated oscillations of the shore line. Everywhere in the area a transition interval or zone of intertonguing occurs between the top of the Mancos shale and the base of the massive Point Lookout sandstone (pls. 42*B* and 43*A*). The relationship is best observed along the west side of Mesa Verde where the rim appears to be capped by a single unit of sandstone. Closer examination shows that within the massive sandstone individual bedding planes are replaced downward by thin shale partings of the transition zone. The shale partings thicken at the expense of the intercalated sandstone tongues which finally wedge out into the main body of the Mancos shale. The Point Lookout sandstone rises stratigraphically in a northward direction as a result of the continuous lensing out at the base of thin sandstone tongues into the Mancos shale (pl. 43*B*). In consequence, the base of the Point Lookout sandstone is younger at the type locality than at places on the San Juan River or at other points farther south in the San Juan Basin.

POINT LOOKOUT SANDSTONE

The basal formation of the Mesaverde group, the Point Lookout sandstone, conformably overlies the Mancos shale. As defined by Cross (Cross and others, 1899) the base of the formation is a thin crossbedded quartzose sandstone, 6 inches thick, that overlies the Mancos shale. It is here recognized that the base of the Point Lookout sandstone is transitional and rises northward by successive intertonguing with the Mancos shale. The lower part of the Point Lookout sandstone includes a sequence of interbedded sandstone and shale, which in this report has been informally termed the sandstone and shale member of the Point Lookout sandstone; it underlies the upper cliff-forming part of the formation, which is here termed the massive sandstone member of the Point Lookout sandstone. A comparable nomenclature for the subdivisions of the formation was also used in the investigations of Zapp (1949) and Barnes and others (1954).

The sandstone and shale member consists of intercalated thin- to medium-bedded yellowish-gray fine-grained cross-laminated sandstone and sandy gypsiferous dark olive-gray fossiliferous shale. The proportion of sandstone to shale increases upward to the massive sandstone member of the Point Lookout. In the Mesa Verde area the thickness of the sandstone and shale member ranges from 80 to 125 feet. Zapp (1949) and Barnes and others (1954) report that the thickness of the lower member reaches as much as 250 feet in the areas of their investigations. The variations in thickness of this unit in different localities are proportional to the amount of interfingering between the massive sandstone member and the sandstone and shale member. Plate 43*A* illustrates this relationship. The gradational nature of the contact between the Point Lookout sandstone and the underlying Mancos shale is clearly shown.

The massive sandstone member of the Point Lookout forms the "Lower escarpment" of Holmes (1875, p. 244). It crops out in vertical cliffs (pl. 39*A*) along the rim of Mesa Verde. The Point Lookout sandstone is not exposed in the central or the southeastern part of the area. This sequence of strata consists of thick to massive beds of light-gray to yellowish-gray crossbedded fine- to medium-grained sandstone. Locally, beneath overlying coal beds of the Menefee formation, the upper beds of the sandstone are leached very light gray. The sandstone forms alcoves in the box heads of numerous reentrants; it frequently also forms overhanging cliff faces.

The base of the massive sandstone member intertongues with the top of the sandstone and shale member. The excellent exposures along the west rim illustrate this relationship very well. At different localities in the area shale tongues separate wedges of sandstone from the massive sandstone member. The sandstone wedges thin toward the north (basinward) and grade laterally and vertically into the strata of the sandstone and shale member. The thickness of this member increases in localities of intertonguing. Barnes and others (1954) refer to a similar relationship at the north end of Weber Mountain where the lower part of the massive sandstone member intertongues downward with the transitional member and thins to the northeast (pl. 43*B*). Some evidence of this intertonguing can be observed at Point Lookout in secs. 5 and 8, T. 25 N., R. 14 W., where a shale unit wedges out to the south into massive sandstone. The massive sandstone member appears bipartite and the lower part of this unit contains many shale partings.

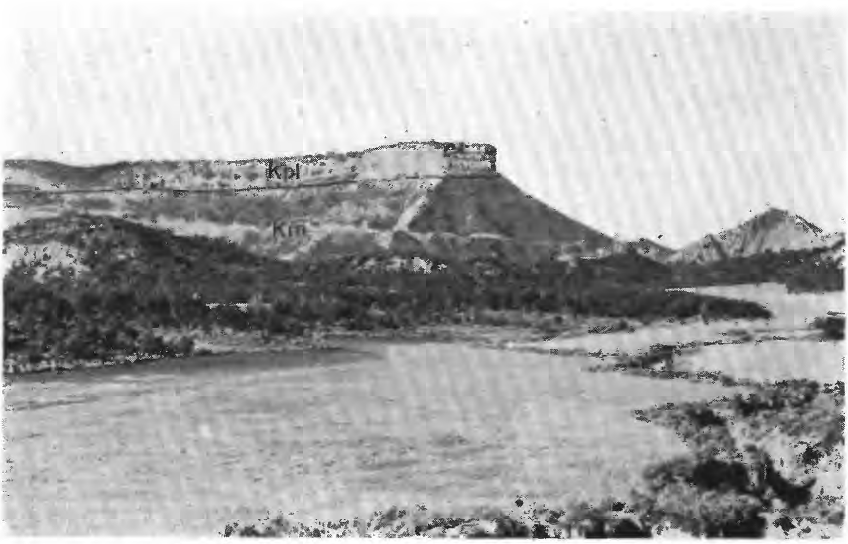
The sea retreated to the northeast, and the strand line appears to strike northwestward across the area. Successive tongues at the base of the Point Lookout result in a continuous transition interval and a stratigraphic rise of the sandstone northeastward. What appears to be a single massive sandstone stratum 200 to 250 feet thick is, in consequence, a series of lapping sandstone lenses. The loss of the strata at the base is compensated by addition to the sandstone mass at the top.

The nature of the contact between the Point Lookout sandstone and the Menefee formation at several localities definitely indicates intertonguing relationships. In Mancos Canyon along the east boundary of Mesa Verde National Park the thick marine sandstones of the Point Lookout are split by coal beds and carbonaceous shale of the Menefee formation. The marine strata interfinger northward with nonmarine sandstone lentils, carbonaceous shale, and coal beds. Similar relationships were noted near the Todd mine and in the West Fork of Ute Canyon. These tongues are not delineated on the map (pl. 49) but are shown in the graphic sections.

The Point Lookout sandstone is a marine deposit laid down by a retreating sea. Deposition was a process of continual upward and outward building of the beach sands and of forcing back of

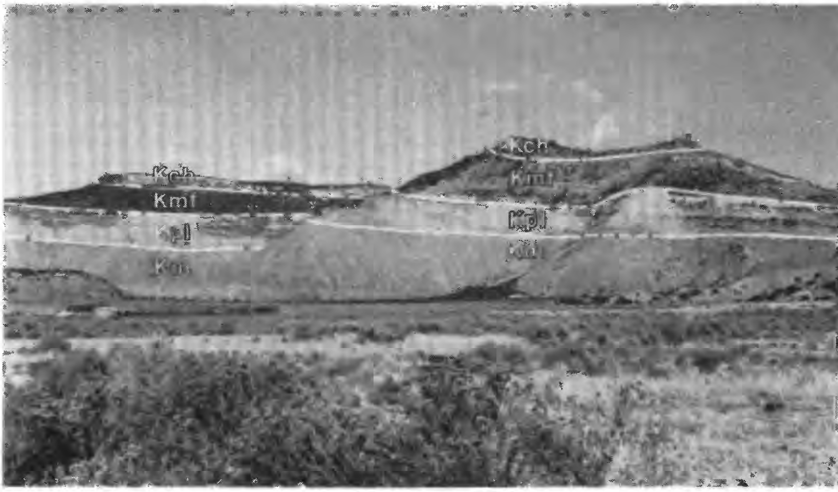
A. PROBABLE EQUIVALENT OF GREENHORN LIMESTONE MEMBER OF MANCOS SHALE

Thin platy limestone and limy shale contain *Inoceramus labiatus*. U. S. Highway 160, sec. 25, T. 36 N., R. 15 W.



B. POINT LOOKOUT, MESA VERDE NATIONAL PARK

Point Lookout sandstone (Kpl) forms prominent cliffs underlain by soft Mancos shale (Km). The Government road is cut in Mancos shale.



A. NORTH RIM OF MESA VERDE FROM CORTEZ AIRPORT

Rocks of Mesaverde group are underlain by Mancos shale (Km). Kpl, Point Lookout sandstone; Kmf, Menefee formation; Kch, Cliff House sandstone. Cuesta in left foreground is capped with thin fossiliferous sandstone beds in Mancos shale.

B. MANCOS CANYON EAST OF U.S. HIGHWAY 666

Steep slopes of Mancos shale (Km) are overlain by rocks of Mesaverde group. Kpl, Point Lookout sandstone; Kmf, Menefee formation; Kch, Cliff House sandstone. Lower part of Point Lookout sandstone is split by thin shale tongues.

the sea. The mass of regressive sandstone is preceded by the thin sandstone tongues of the sandstone and shale member (transition zone) and is followed by deposits of a swamp environment.

The formation is of Late Cretaceous age. Because of invertebrates found in it, Cross and Purington (1899) and Pike (1947, p. 21–23) correlated it with the Pierre shale of the Montana group. The author collected, at one locality near the Mesa Verde mine, a fauna which included *Baculites* cf. *B. ovatus*, *Inoceramus* sp., and casts of *Halymenites major*. Very few fossils were found in the Point Lookout sandstone elsewhere in the area.

Section of Point Lookout sandstone measured in sec. 30, T. 35 N., R. 13 W.

	Feet
Menefee formation.	
Point Lookout sandstone:	
Massive sandstone member:	
Sandstone grayish-orange to light-gray, thin- to medium-bedded, cross-laminated, fine-grained, well-sorted; contains occasional *Halymenites;* forms rounded ledges	31. 0
Sandstone intercalated with minor carbonaceous shale, pale yellowish-orange, thin-bedded, cross-laminated, fine-grained; forms benches	11. 0
Sandstone, pale yellowish-orange, medium- to thick-bedded, cross-laminated, fine-grained; contains occasional *Inoceramus* fragments; weathers into rounded cliffs with alcoves	94. 0
Sandstone with interbedded silty shales, yellowish-gray, thin-bedded, fossiliferous; forms bench	16. 0
Sandstone intercalated with thin shale, grayish-orange, thin- to thick-bedded, cross-laminated, fine-grained; contains abundant casts *Halymenites;* forms vertical cliffs. Unit interfingers northward with the basal member of the Point Lookout	83. 0
Total massive sandstone member	235. 0
Sandstone and shale member:	
Sandstone yellowish-gray, thin-bedded, very fine grained, calcareous; interbedded with shale and siltstone beds; forms irregular slope; poorly exposed	>56. 0
Total sandstone and shale member	>56. 0
Mancos shale.	

Section of Point Lookout sandstone measured in secs. 35 and 36, T. 34 N., R. 36

	Feet
Menefee formation.	
Point Lookout sandstone:	
Massive sandstone member:	
Sandstone, very pale orange, thick-bedded, cross-laminated, fine- to medium-grained, contains ironstone concretions in upper part; weathers in vertical cliffs	42. 0
Sandstone, grayish-orange, thick-bedded to massive, cross-laminated, very fine grained, abundant ironstone concretions; contains occasional *Halymenites* and *Inoceramus*	71. 0

	Feet
Point Lookout sandstone—Continued	
Massive sandstone member—Continued	
Sandstone with shaly partings, pale yellowish-brown to grayish-orange, medium- to thick-bedded, cross-laminated, very fine grained; weathers into cliffs with alcoves	83. 0
Sandstone interbedded with minor thin shale beds, pale yellowish-brown, thin- to medium-bedded, cross-laminated, fine-grained; occasional fossil impressions; forms vertical cliffs	87. 0
Total massive sandstone member	283. 0
Sandstone and shale member:	
Sandstone, pale yellowish-brown to light olive-gray, thin- to medium-bedded, cross-laminated, fine-grained; interbedded with shale and siltstone beds; contains fossil impressions; weathers in irregular slopes. The sandstone beds increase in proportion upward from base of unit	>94. 0
Total sandstone and shale member	>94. 0
Mancos shale.	

MENEFEE FORMATION

The Menefee formation, the middle, coal-bearing formation of the Mesaverde group, conformably overlies the Point Lookout sandstone. It crops out in precipitous slopes along the escarpment of Mesa Verde and is continuously exposed in the canyons within the area.

The formation is a northeastward-tapering wedge ranging in thickness from about 340 feet in the northern part of the mapped area to about 800 feet along the Colorado-New Mexico State line. It is a thick sequence of massive lenticular sandstone beds with interbeds of siltstone, shale, and coal. Individual sandstone beds (pl. 44*A*) are not continuous over any great distance; along the outcrop they appear to grade laterally into siltstone or shale. However, zones of sandstone can be traced over large areas. The variability of the Menefee formation and the correlations of the sandstone units are shown in the lines of stratigraphic sections (pl. 50).

Near Mancos, Colo., the Menefee is about 340 feet thick (pl. 44*B*). It is composed of a sequence of cliff-forming sandstone beds separated by sandy clay shale and coal beds. The sandstone is thick bedded to massive, fine to medium grained, and light gray to grayish orange. The beds are cross laminated and crop out in rounded cliffs and ledges. The predominant mineral is quartz with minor amounts of ferromagnesian minerals and weathered feldspar. The quartz grains are variably cemented with argillaceous materials, calcium carbonate, or ferruginous matter. Abundant ironstone concretions occur in the sandstone or in the intervening thick shale. Clay shale in the Menefee is predominantly dark gray or grayish brown and contains a high percentage of arenaceous material. The carbonaceous shale is dark brown and generally is closely associated with coal. Commercial coal beds located in the lower 50 to 80 feet of the Menefee formation vary in number, thickness, and extent throughout the Mesa Verde area.

Collier (1919, p. 298–302) subdivided the Menefee into three zones or coal groups. The lowest zone is the Spencer or coal group A. It contains one to four beds of relatively pure coal which have been mined commercially. Coal group B, a higher zone, includes a number of thin beds of impure coal in the 140 feet of section overlying the Spencer coal group. The highest zone, group C, consists of a sequence of lenticular coal beds and thick carbonaceous shale in the upper part of the Menefee underlying the Cliff House sandstone. These zones, in a general way, can be traced southward along Mancos Canyon and can be correlated with the subdivisions of the formation informally applied by others to the Menefee. Hayes and Zapp (1954) subdivided the Menefee south of the mapped area into the lower coal member, the middle barren member, and the upper coal member. This nomenclature is acceptable for these rocks in the Mesa Verde area adjacent to that covered by the investigations of Hayes and Zapp (1954).

Coal group A of Collier (p. 298) in general correlates with the lower coal member of Hayes and Zapp. These correlations are based on the stratigraphic position of the units above the Point Lookout sandstone which, between the State line and the area near Mancos, rises about 150 feet by small scale interfingering. In consequence, coal beds in group A in the north are younger than the coal beds in the lower coal member in the south. Barnes and others (1954) report similar relations between the Menefee and Point Lookout formations at Menefee Mountain.

The middle barren member consists of 300 to 500 feet of massive cliff-forming cross-laminated light-gray concretionary sandstone intercalated with thick beds of irregularly bedded siltstone and silty shale. Very little coal is present in this member. It thins northeastward and can be traced into coal groups B and lower C of Collier in the vicinity of Mancos, Colo.

The upper part of the Menefee formation, or the upper coal member, is composed of dark carbonaceous clay shale, bone coal, and lenticular coal beds that are interbedded with thin sandstone beds and siltstone. The base of the unit interfingers with the top of the underlying barren member, and the coal beds rapidly pinch out southward into the sandstone beds of the barren member. Large-scale intertonguing also occurs between the strata of the Menefee formation and the overlying Cliff House sandstone. Along Mancos Canyon in localities 15, 16, and 17 (pl. 49), the top of the Menefee rises stratigraphically more than 400 feet by successive intertonguing with the base of the overlying Cliff House sandstone. Sedimentary rocks typical of the Menefee formation can be traced northward in the Cliff House sandstone over large areas, whereas southward thick wedges of marine sandstone rapidly grade in short distances into sediments typical of the Menefee by interfingering. These tongues are shown on the geologic map (pl. 49) and in the graphic sections (pl. 50). In localities where the formations intertongue thick sequences of carbonaceous shale and bone coal are usually present.

Locally, disconformities occur between the Menefee and the Cliff House formations. Where such relations exist the coal beds may have been partly or entirely removed by erosion. In the lower part of the Mancos Canyon and some of the canyons tributary to it, the strata of the upper coal member have been burned, and the adjacent shale as well as the more impure parts of the coal beds is clinkered. At these localities the Menefee forms brilliantly colored cliffs.

The Menefee formation is of nonmarine origin. The sedimentary structures of the rocks and the association of coal beds indicate a probable deposition in river flood plain and coastal swamp environments.

Section of the Menefee formation measured in secs. 34 and 35, T. 35 N., R. 14 W.

Cliff House sandstone.	
Menefee formation:	*Feet*
Clay shale, dark-gray; contains thin carbonaceous seams	1. 0
Bone coal	. 7
Coal	. 4
Shale, carbonaceous, reddish-brown	5. 2
Sandstone, grayish-yellow, thick-bedded, cross-laminated	8. 0
Coal	. 8
Shale, dark-gray, contains thin coal seams	2. 5
Bone coal	. 4
Coal	. 3
Bone coal	. 3
Shale, dark-gray; contains carbonaceous stringers and thin coal	5. 0
Siltstone interbedded with grayish-brown carbonaceous shale	7. 5
Coal	. 6
Shale, dark-gray	1. 0
Siltstone interbedded with yellowish-gray shale	3. 0
Sandstone, light-gray, thin-bedded, cross-laminated; contains ironstone concretions	6. 0
Siltstone, yellowish-gray, with carbonaceous seams near the center	12. 0
Shale, carbonaceous	2. 0
Siltstone, shaly, yellowish-gray; contains much carbonaceous material	15. 0
Sandstone, yellowish-gray, massive, cross-laminated; ironstone beds near top and base	33. 0
Shale, dark-gray, silty; interbedded with thin carbonaceous shale and bone coal	8. 7
Sandstone, yellowish-gray, medium-bedded, cross-laminated; contains abundant ironstone concretions	5. 0

Menefee formation—Continued	Feet
Shale, yellowish-gray, silty	7.0
Coal	.9
Shale, dark-gray; intercalated with bone coal	1.5
Shale, silty, with interbeds of siltstone	5.0
Coal	.2
Bone coal	.5
Siltstone, shaly; contains abundant ironstone concretions	24.0
Shale, dark-gray, carbonaceous	1.8
Sandstone, yellowish-gray, thick-bedded, cross-laminated; contains ironstone concretions	30.0
Shale, dark-gray	6.5
Coal	1.0
Bone coal	1.2
Shale, black, carbonaceous	.7
Shale, dark-gray; interbedded with thin fine-grained sandstone	7.5
Bone coal	1.6
Siltstone, shaly, yellowish-gray	5.0
Shale, coaly	.4
Siltstone, with shale interbeds	14.0
Shale, dark-gray, carbonaceous; contains coal seams	1.8
Siltstone, dark-gray	16.0
Sandstone, yellowish-gray, medium-bedded, cross-laminated	15.0
Siltstone, dark-gray	10.0
Shale, dark-gray; contains coaly seams and ironstone beds	1.5
Siltstone, yellowish-gray, and interbedded silty shale	5.0
Shale, carbonaceous, with bone coal and interbedded thin coal	2.1
Siltstone, yellowish-gray, cross-laminated	10.0
Sandstone, grayish-orange, thick-bedded, cross-laminated; contains ironstone concretions; weathers into ledges with alcoves	19.0
Coal	1.2
Bone coal	.4
Coal	.9
Bone coal	.7
Siltstone and interbedded silty shale, with ironstone lenses	1.7
Sandstone, grayish-orange, massive, cross-laminated, fine-grained; ironstone bed at top; weathers into alcoved cliffs	20.0
Shale, dark-gray, silty	12.0
Coal	.5
Bone coal	1.0
Shale, black, carbonaceous	.7
Sandstone, yellowish-gray, medium-bedded, cross-laminated, very fine-grained (tongue of the Point Lookout sandstone)	5.0
Shale, carbonaceous, silty	2.7
Coal	1.0
Shale, silty; interbedded with carbonaceous shale and bone coal	5.4
Sandstone, grayish-orange, thick-bedded, cross-laminated, very fine-grained; contains casts of *Halymenites*; weathers in alcoved cliffs (tongue of the Point Lookout sandstone)	23.0
Siltstone and silty shale, yellowish-gray	14.0
Shale, carbonaceous	2.0
Siltstone; contains thin carbonaceous stringers	1.5
Total thickness of Menefee	401.3

Point Lookout sandstone.

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Section of Cliff House and Menefee formations measured in sec. 20, T. 33 N., R. 15 W.

	Feet
Cliff House sandstone:	
Sandstone, yellowish-orange to yellowish-brown, thick-bedded, cross-laminated, fine-grained, fossiliferous; forms cliffs (tongue of the Menefee formation)	50. 0
Siltstone interbedded with silty shale and thin coal beds	22. 0
Sandstone, yellowish-orange to grayish-orange, massive, cross-laminated, fine-grained, calcareous; forms cliffs	100. 0
Sandstone, thin-bedded; intercalated with carbonaceous shale (tongue of the Menefee formation)	14. 0
Sandstone, yellowish-orange, thick-bedded, cross-laminated; intercalated with carbonaceous shale partings	45. 0
Menefee formation:	
Shale, grayish-brown, carbonaceous	5. 0
Bone coal, sulfurous	2. 2
Shale, grayish-brown, carbonaceous	11. 0
Coal	. 5
Bone shale, coaly	3. 0
Shale, grayish-brown, carbonaceous	28. 0
Sandstone, yellowish-brown, thin-bedded	3. 0
Shale, grayish-brown, carbonaceous, gypsiferous	5. 5
Shale, bone	1. 0
Shale, dark-gray, carbonaceous	8. 0
Sandstone interbedded with thin shale beds	11. 0
Shale, grayish-brown, carbonaceous	1. 5
Bone coal, sulfurous	2. 0
Shale, dark-gray, carbonaceous	5. 0
Coal	. 8
Shale, carbonaceous	3. 0
Bone coal	. 8
Shale, dark-gray, carbonaceous	8. 0
Sandstone, yellowish-brown, calcareous	8. 0
Shale, dark-gray, carbonaceous, with interbeds of bony coal	28. 0
Coal	1. 1
Shale, dark-gray, carbonaceous; contains bone coal	4. 5
Coal	. 7
Shale with coaly bone	3. 7
Shale, dark-gray, carbonaceous	11. 0
Bone coal	. 8
Shale, yellowish-gray, silty	5. 5
Sandstone, grayish-orange, concretionary	5. 5
Shale, yellowish-gray, silty	11. 0
Sandstone, thin-bedded; intercalated with thin shale beds	28. 0
Shale, yellowish-gray, silty	22. 0
Sandstone, light-gray, thin-bedded	6. 0
Shale, yellowish-gray, silty; interbedded with thin sandstone beds	75. 0
Sandstone, grayish-orange, thick-bedded, cross-laminated; forms cliffs	20. 0
Shale, yellowish-gray, silty	10. 0
Sandstone, silty; contains abundant ironstone concretions	12. 0
Shale, dark-gray, carbonaceous; contains thin beds of bone	18. 0
Sandstone, grayish-orange, silty; weathers into ledges with alcoves	8. 0
Shale, yellowish-gray, silty; contains ironstone concretions	5. 5
Sandstone, yellowish-brown, medium-bedded, cross-laminated	8. 0

	Feet
Menefee formation—Continued	
Shale, silty; interbedded with yellowish-brown siltstone	22. 0
Sandstone, grayish-orange, thin-bedded	6. 0
Shale, silty, yellowish-gray; contains ironstone concretions	17. 0
Base not exposed.	
Total thickness of exposed formations	667. 6

Section of Menefee formation measured in sec. 19, T. 32 N., R. 16 W.

	Feet
Cliff House sandstone.	
Menefee formation:	
Shale, dark-gray to grayish-brown, carbonaceous	4. 0
Sandstone, grayish-orange, thick-bedded, cross-laminated	17. 0
Shale, dark-gray, carbonaceous	2. 5
Sandstone, massive, cross-laminated, fine-grained	27. 0
Shale, yellowish-gray; interbedded with minor thin sandstone beds and lenticular coal beds 6 to 9 inches thick	44. 0
Sandstone, thin-bedded; intercalated with carbonaceous shale	11. 0
Shale, dark-gray, carbonaceous, contains some bone	22. 0
Sandstone, grayish-orange, thick-bedded, cross-laminated; contains ironstone concretions	27. 0
Coal and bone shale; changes along strike to coaly bone	6. 0
Shale, silty, carbonaceous	17. 0
Sandstone, grayish-orange, thin-bedded, fine-grained, carbonaceous	6. 5
Shale, dark-gray; intercalated with thick beds of carbonaceous shale and bone coal	38. 0
Sandstone, thin-bedded; contains thin coal lenses	8. 0
Shale, yellowish-gray, silty; contains thick carbonaceous shale beds and minor lenses of bone coal	50. 0
Sandstone, grayish-orange, massive, cross-laminated, fine-medium-grained; contains ironstone concretions	38. 0
Shale, yellowish-gray, silty; interbedded with thin sandstone beds	16. 5
Sandstone, yellowish-gray, medium-bedded, cross-laminated; contains ironstone concretions	11. 0
Shale, silty; contains carbonaceous shale lenses and abundant ironstone concretions	28. 0
Sandstone, yellowish-gray,shaly, thin-bedded	7. 5
Shale, yellowish-gray, carbonaceous; contains thin coals	28. 0
Sandstone, grayish-orange, massive, cross-laminated, silty; weathers into ledges with alcoves	22. 0
Shale, silty, carbonaceous	14. 0
Sandstone, grayish-orange, medium-bedded, cross-laminated	6. 0
Shale, dark-gray; contains lenses of bone and abundant ironstone concretions	24. 0
Sandstone, silty, thin-bedded	5. 5
Shale, silty, yellowish-gray; contains abundant ironstone concretions	11. 0
Sandstone yellowish-gray, silty, cross-laminated	7. 0
Shale intercalated with thin siltstone beds and coal lenses	22. 0
Sandstone, yellowish-gray, massive, cross-laminated, medium-grained; contains silty partings	30. 0
Shale, grayish-brown, carbonaceous; contains thin coal beds	5. 5
Sandstone, yellowish-gray, silty, thin-bedded	4. 0
Shale, silty; contains abundant ironstone concretions	11. 0

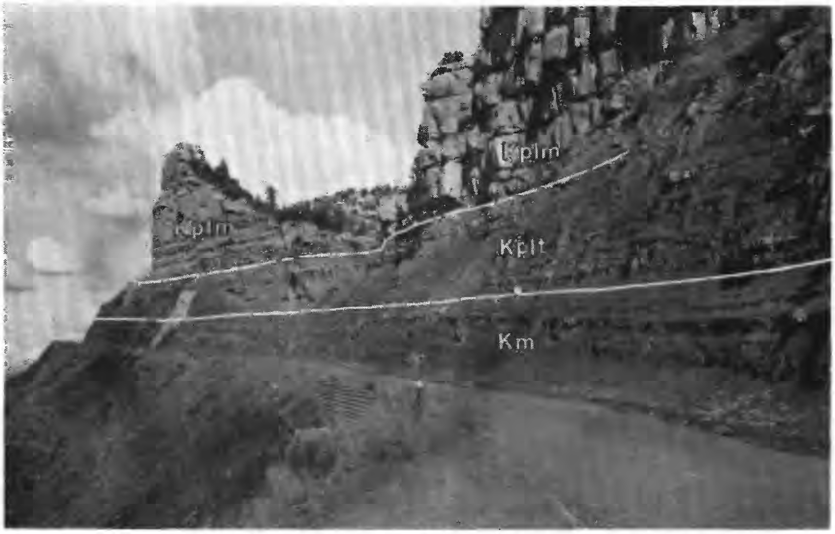
Menefee formation—Continued	Feet
Shale, silty; interbedded with thin sandstone and siltstone beds; many concretions	19. 0
Sandstone, grayish-orange, massive, cross-laminated, medium-grained; ironstone bed near the top	27. 0
Shale, yellowish-gray; intercalated with thin sandstone beds	22. 0
Shale, silty; interbedded with carbonaceous shale and thin coal	28. 0
Sandstone, yellowish-orange, thin-bedded, ferruginous	2. 5
Siltstone, thin-bedded; intercalated with carbonaceous shale and iron stone beds	10. 5
Coal	1. 0
Shale, yellowish gray, silty	3. 0
Sandstone, grayish-orange, thin-bedded, cross-laminated	3. 0
Shale, dark-gray, silty; contains thin interbeds of carbonaceous shale and coal seams	7. 0
Sandstone, shaly, thin-bedded	2. 5
Shale, dark-gray, silty; intercalated with carbonaceous shale and thin coal beds 4 to 11 inches thick	21. 0
Shale, grayish-brown, carbonaceous; contains some bone	1. 5
Siltstone interbedded with sandstone beds and silty gray shale	20. 0
Sandstone, grayish-orange, cross-laminated; many plant impressions	5. 5
Shale, dark-gray, carbonaceous	2. 0
Coal	1. 4
Shale, carbonaceous	. 4
Siltstone, thin-bedded; intercalated with thin sandstone and shale	6. 0
Coal	1. 0
Siltstone, yellowish-gray; interbedded with carbonaceous shale; contains many ironstone concretions	8. 0
Total Menefee formation	763. 3
Point Lookout sandstone.	

CLIFF HOUSE SANDSTONE

The upper formation of the Mesaverde group, the Cliff House sandstone, forms the "Upper escarpment" of Holmes (1875, p. 244) in the Mesa Verde area. It does not present the same character everywhere. The formation constitutes the surface of mesas and in the northern part of the area is too friable to form the prominent cliffs prevalent in the southern and western part. The total thickness in the Mesa Verde area was not determined because the upper strata of the formation have been removed by erosion.

The Cliff House sandstone conformably overlies the Menefee formation. At many localities large scale intertonguing occurs between these strata (pl. 45*A*). Locally, however, the contact is disconformable. The Cliff House sandstone is of marine origin and was deposited nearshore in a transgressing sea.

Near Mancos (pl. 44*B*) the formation is shaly and is eroded into steep slopes above the underlying bench-forming Menefee formation. It varies from 100 to 350 feet in thickness and consists of



A. KNIFE EDGE ON GOVERNMENT ROAD IN MESA VERDE

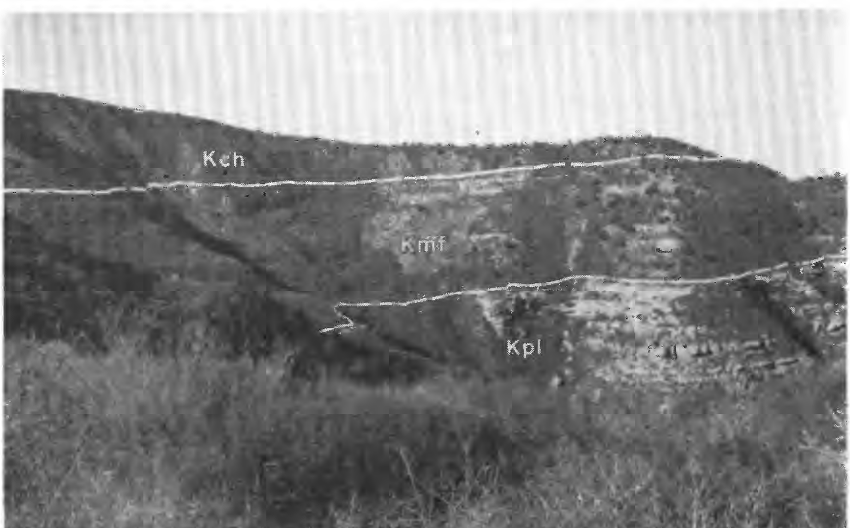
Road cut in soft Mancos shale. Cribbing and concrete aprons prevent landsliding at critical points. Note gradational nature of contact of Point Lookout sandstone and Mancos shale. Km, Mancos shale; Kplt, sandstone and shale member of Point Lookout sandstone; Kplm massive sandstone member of Point Lookout sandstone.

B. NORTH END OF WEBER MOUNTAIN

Point Lookout sandstone exposed in cliffs of Weber Mountain and in Menefee Mountain in left background. Note breakup of lower part of massive sandstone member (Kplm) in Weber Mountain and intertonguing relation with sandstone and shale member (Kplt) in Menefee Mountain. Km, Mancos shale; Kmf, Menefee formation; Kch, Cliff House sandstone.

A. SANDSTONE IN MENEFEE FORMATION, SEC. 18, T. 35 N., R. 14 W.

Exposure of lenticular Menefee sandstone (Kmf) in road cut on government road. Hill on left is capped with shale and thin sandstone beds of the Cliff House sandstone (Kch).

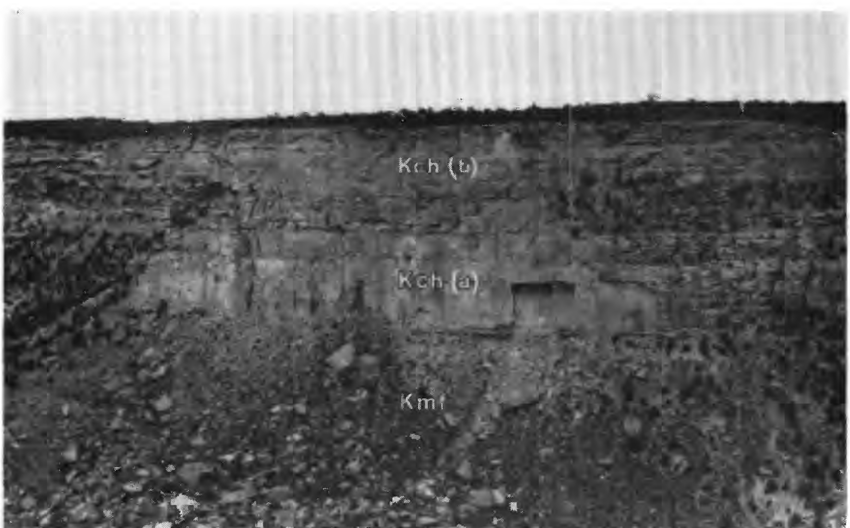


B. THE MESAVERDE GROUP BELOW PARK POINT

Note silty character of Cliff House sandstone (Kch) and thin interval of Menefee strata (Kmf). Kpl, Point Lookout sandstone.

A. MANCOS CANYON FROM GRAVEL PIT ON CHAPIN MESA, SEC. 10, T. 34 N., R. 15 W.

Note stratigraphic rise of Menefee formation (Kmf) by successive intertonguing with overlying Cliff House sandstone. Kch(a), lower tongue of Cliff House sandstone; Kch(b), Barker Dome tongue of Cliff House sandstone; Kch, Cliff House sandstone, undifferentiated; Ti, large igneous body; QTg, pediment gravels.

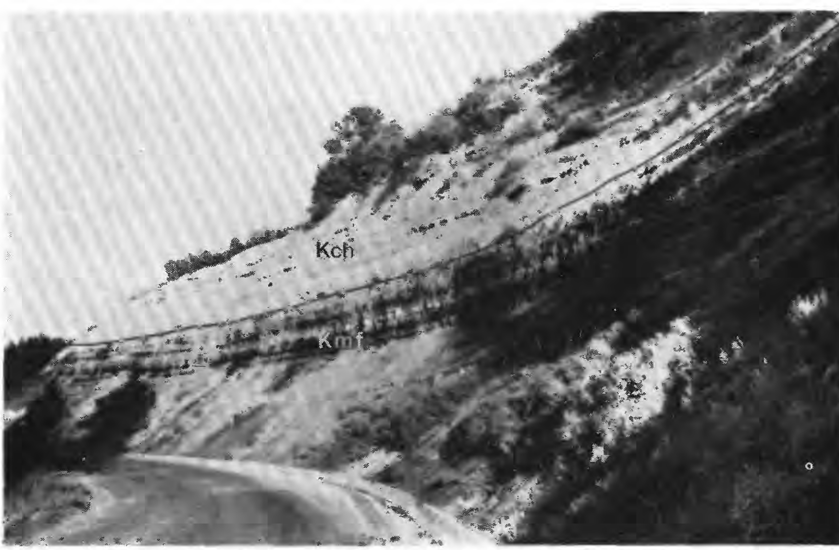


B. ECHO CLIFF, MESA VERDE NATIONAL PARK

Exposure of Cliff House sandstone showing the massive sandstone separated by characteristic bench. Note extensive colluvium and landslide blocks. Kch(a), lower tongue of Cliff House sandstone; Kch(b). Barker Dome tongue of Cliff House sandstone; Kmf, Menefee formation.

A. SPRUCE TREE HOUSE, MESA VERDE NATIONAL PARK

The cliff dwellings are situated in a large alcove on bench between Barker Dome tongue and lower tongue of Cliff House sandstone.



B. CONTACT BETWEEN MENEFEE FORMATION AND CLIFF HOUSE SANDSTONE IN ROAD CUT, SEC. 24, T. 35 N., R. 15 W.

The contact is placed immediately above thin coal beds of Menefee formation (Kmf). Note silty character of Cliff House sandstone (Kch).

thin to thick beds of fine-grained yellowish-gray to yellowish-brown sandstone intercalated with thick beds of yellowish-gray fossiliferous shale. The shale interfingers with the sandstone beds and wedges out toward the south. This relationship strongly suggests deposition under an oscillating shoreline so that beach sands interfingered basinward with the finer clastics of off-shore deposits.

Southward along Mancos Canyon this sequence of sandstone and shale can be differentiated into several units. The lower part of the formation becomes increasingly arenaceous and thick bedded and crops out in irregular cliffs. The upper part contains a greater proportion of sandstone near the top but is somewhat shaly toward the base. The sandstone is thin bedded, calcareous, and very fossiliferous. The strata contain abundant specimens of *Inoceramus* and casts of *Halymenites*. Near the junction of Horse Canyon with the canyon of the Mancos River, the upper and lower parts of the formation coalesce to form two massive ledges of sandstone separated by a shaly parting. A maximum thickness of about 400 feet of Cliff House sandstone is conspicuously exposed in Echo Cliff, Mesa Verde National Park (pl. 45*B*). The sandstone is grayish orange to pale yellowish brown, very fine to fine grained, thick bedded to massive, and cross laminated in large scale. The cross laminae are truncated by horizontal bedding planes 10 to 30 feet apart. The sandstone beds weather into niches and alcoves along the bedding planes. They are composed predominantly of well-rounded quartz grains variably cemented with calcium carbonate and argillaceous material.

The partings between the sandstone beds generally are a sequence of thin- to medium-bedded sandstone intercalated with thin beds of silty shale, carbonaceous shale, and thin coal lenses; they weather into benches between vertical cliffs of massive sandstone. The base of the upper cliff has niches and alcoves along the parting. Many ruins of ancient cliff dwellings are situated in the alcoves (pl. 46*A*).

The lithologic change in the Cliff House sandstone from a friable sequence of rocks to a prominent cliff-forming cap rock can be readily traced along the canyons bordering Chapin Mesa. A northwest trend can be established for the old shore line by the relationship of the rocks. The same transition of lithology in the Cliff House formation can also be observed along the north rim of Mesa Verde. It is evident that the Cretaceous seas transgressed to the southwest. The variable character of the Cliff House sandstone is the result of deposition under different environments. The massive sandstone accumulated as beach sands in near-shore areas and interfingered basinward with the finer clastics of the off-shore zone.

The upper massive sandstone in the central part of the area is conformably overlain by a sequence of interbedded sandstone and shale. Southward along the mesas this unit, which forms regular slopes above the sandstone cliffs, grades upward into a cliff of sandstone, the third and highest unit mapped in the Cliff House sandstone.

The great sandstone lenses of the Cliff House are separated by thin shale partings which thicken toward the south into tongues of coal-bearing strata and finally coalesce with the main body of the Menefee formation. Such relations are shown on the map and in the graphic sections at localities 6, 8, 15, 16, and 17. At these localities the base of the Cliff House sandstone rises stratigraphically southward by large-scale intertonguing between the strata of the two formations (pl. 45*A*). The wedges of the Menefee formation thicken in the same direction.

The lowest sandstone unit, informally named the lower tongue of the Cliff House sandstone, interfingers with the underlying upper coal member of the Menefee formation between localities 17 and 16 and in a very short distance completely grades into Menefee lithology. Similarly the higher overlying sandstone, the Barker Dome tongue, intertongues with the Menefee formation between localities 15 and 14. This unit is of great extent and can be correlated with the tongue at the type locality at Barker Creek mapped by Hayes and Zapp (1954). The highest sandstone mapped, informally named the upper tongue of the Cliff House sandstone, caps the mesas near the Colorado-New Mexico State line.

The coal-bearing strata of the Menefee formation is clinkered in the areas of intertonguing, and locally the burned areas extend upward into the lower beds of the Cliff House sandstone. The areas of oxidation appear to parallel the trend of the old shorelines. The strata in the zones of intertonguing contain thick intervals of carbonaceous shale and bone coal, as well as some pyritized material. The vividly colored cliffs along Mancos Canyon between Ute and Johnson Canyons lie within the zone of intertonguing.

The Cliff House sandstone was deposited in successive great sandstone lenses in a transgressing sea. The lithologic changes in these units are due to the variation of conditions which prevailed during their deposition. The shoreline probably advanced southwestward steadily but with minor reversals. In exposures along the government road on the north rim, the contact between the Menefee and Cliff House formations appears transitional. Many thin tongues of sandstone of Cliff House lithology interfinger with the coal beds of the Menefee (pl. 46*B*).

When the rate of subsidence exceeded the rate of deposition, the sea advanced rapidly without disturbing the deposits over which it transgressed. Occasionally the advance was slowed and some of the deposits were eroded and swept seaward. When the supply of sediments increased, the shoreline became more stable, and a large amount of detritus was deposited along the margin of the basin. The shoreline oscillated in minor movements as the supply of detritus exceeded subsidence or subsidence exceeded supply. The result of this interrelationship is a sequence of intertonguing marine and nonmarine sediments. When the rate of supply was far greater than the rate of subsidence, the shoreline regressed basinward and coal-bearing nonmarine sediments were deposited over the marine sediments. This cycle of deposition, repeated many times, probably produced the sequence of overlapping sandstone lenses observed and mapped in the Mesaverde.

Section of the Cliff House sandstone measured in sec. 5, T. 34 N., R. 13 W.

	Feet
Cliff House sandstone:	
Sandstone, dark yellowish-orange, fine-grained, medium- to thick-bedded, cross-laminated, ferruginous; contains interbeds of pale yellowish-brown siltstone and shale; very fossiliferous with *Inoceramus* and *Halymenites;* weathers into irregular slopes	>175. 0
Sandstone, pale yellowish-orange, very fine grained, thin- to medium-bedded; occasional intercalated shale beds; abundant fossils; weathers into regular slope	132. 0
Sandstone, grayish-orange to dark yellowish-orange, thin-bedded, very fine grained; contains interbeds of shale	37. 0
Total Cliff House sandstone	>344. 0
Menefee formation.	

Section of Cliff House sandstone measured in sec. 18, T. 34 N., R. 15 W.

	Feet
Cliff House sandstone:	
Sandstone, ferruginous, dark yellowish-brown, thin-bedded, calcareous; contains interbeds of fossiliferous gray shale	>25. 0
Sandstone, pale yellowish-orange, thick-bedded to massive, cross-laminated, fine-grained, silty; contains well-rounded quartz grains; weathers into vertical cliffs, with alcove at base	110. 0
Sandstone interbedded with minor gray shale and thin coal beds, dark yellowish-orange, thin- to medium-bedded, cross-laminated; forms bench between upper and lower sandstone cliffs	55. 0
Sandstone, yellowish-gray to light-gray, massive, cross-laminated, fine- to medium-grained; contains weathered feldspar near base; forms lower sandstone cliff	138. 0
Sandstone, interbedded with thick tongues of carbonaceous shale and thin coal beds	51. 0
Total Cliff House sandstone	>379. 0
Menefee formation.	

Section of Cliff House sandstone measured in sec. 18, T. 34 N., R. 15 W.

	Feet
High level gravels.	
Cliff House sandstone:	
Sandstone, yellowish-orange to yellowish-brown, thick-bedded, cross-laminated, silty; contains abundant casts *Halymenites;* forms cliff at base and slope near top	>100.0
Siltstone interbedded with carbonaceous shale and thin beds of coal; forms benches	22.0
Sandstone, yellowish-orange to grayish-orange, fine-grained, calcareous, thick-bedded to massive, cross-laminated; forms cliffs	100.0
Sandstone, thin-bedded; intercalated with thin beds of carbonaceous shale and bone; forms benches	14.0
Sandstone, yellowish-orange, thick-bedded, cross-laminated, medium-grained; abundant weathered feldspar; unit intercalated with thin beds of carboniferous shale; forms irregular cliff	45.0
Base not exposed.	
Total exposed Cliff House sandstone	>281.0

TERTIARY(?) SYSTEM

PEDIMENT GRAVELS

The mesas in the map area are topped by and erosional surface of late Tertiary or Quaternary age. At several localities they are overlain by remnants of gravel deposits ranging in thickness from a few feet to about 60 feet. These deposits appear waterlaid and include polished pebbles and cobbles of jasper and quartzite. Among the coarse detritus there are also many kinds of igneous rock which could have been derived from the intrusive bodies of the La Plata Mountains. Scattered nearly everywhere over the upland surface are pebbles and cobbles of materials associated with the gravel deposits.

There are several remnants of unconsolidated gravel deposits at the south end of Chapin Mesa in secs. 2, 10, 16, 20, 21, T. 33 N., R. 15 W. Atwood and Mather (1932, p. 91) referred to these remnants as boulder deposits washed out from the mountains soon after the San Juan peneplain was uplifted and the streams rejuvenated; they correlated them with the Bridgetimber gravels of Bridge Timber Mountain southwest of Durango. One such deposit was of sufficient extent and thickness to serve as road material for the National Park Service. The deposits disconformably overlie the Cliff House sandstone. The nature of the disconformity can be observed at the east side of Moccasin Mesa, sec. 2, T. 33 N., R. 15 W. There the surface underlying the gravels is cut by channels about 20 feet deep.

At the north end of Big Mesa, T. 34 N., R. 14 W., north of the Ute Line, there is a deposit of gravels correlative with the gravel remnants on Chapin Mesa. The deposit is several feet thick at this place but decreases rapidly to a thin mantle elsewhere over the mesa. A large deposit of gravel about 60 feet thick caps the hill on which the triangulation station Ruin is established just west of the head of Barker Creek canyon. Other remnants of gravels along the Ute trail in T. 33 N., R. 14 W., were also mapped. These deposits now constitute a long low ridge which forms the divide between the watersheds of the Mancos River and Barker Creek and the boundary between La Plata and Montezuma Counties.

QUATERNARY SYSTEM

TERRACE GRAVELS

A former position of the valley floor is preserved along the east and north edges of Mesa Verde. The shoulder, usually visible in the Mancos shale 800 to 1,000 feet below the surface of the mesa, is a remnant of an old land surface that can be traced along Mancos Canyon as far south as its junction with Weber Canyon (pl. 47*A*). It also can be traced northward along Weber Canyon to the north end of Menefee Mountain. This surface is the highest gravel-covered terrace in the area; it represents an epoch of erosion which left its record over large parts of adjacent areas. Cross (Cross and others, 1899) correlated this surface with that of the gravel-capped mesa between the East Mancos River and Cherry Creek, with the divide below 8,500 feet on the opposite side of the La Plata River, and with the gravel terraces on both sides of the river near Hesperus. Atwood and Mather (1932, p. 112) correlated this old land surface with the gravel-covered top of Florida Mesa southeast of Durango. They named these gravel deposits at the type locality the Florida gravel. The only gravels on the high terraces observed in the area are a scattering of igneous cobbles and boulders. Their lithologic character is similar to that of the outcropping intrusive rocks in the La Plata Mountains.

Below the high terrace, several other gravel surfaces occur above the present valley floor. The next highest terrace can be seen along the head of Weber Canyon just south of the town of Mancos, along the north end of Weber Mountain, and along U.S. Highway 160 at Mud Creek.

A lower terrace along West Mancos River is the gravel-covered surface which extends just above the floor of Mancos Valley from the town of Mancos to the junction of Mud Creek and the West Mancos River. These terraces are well preserved and consist largely of subrounded boulders and cobbles of igneous and sedimentary materials mixed with gravels and silts. The low-lying boulder deposits strongly suggest outwash material from moraines high in the rock basins of the La Plata Mountains. Atwood and Mather (1932, p. 129) mapped remnants of terminal moraines at the head of the West Mancos River which they believed were deposited by ice of the Durango and Wisconsin glacial stages. Below the outwash-gravel terraces the river flows in a channel in late Recent alluvium in the Mancos Valley. At the town of Mancos and downstream from there, the river flows in a trough in boulder deposits which floor the valley.

COLLUVIUM

Colluvial deposits cover the slopes and floors of the majority of the canyons in the area. The deposits are aggregates of rock detritus, talus, and avalanche material as well as soil of colluvial origin. The detritus consists of material ranging in size from silt through coarse gravel to large blocks and boulders derived from nearby sources.

Much of the colluvium is of Recent origin and is still in the process of forming. On the north face of Mesa Verde, narrow remnants of colluvium cap dissected ridges of Mancos shale. In areas where the underlying formation is only partly covered, the colluvial deposits are not mapped. The thickness of the colluvium varies from place to place. In the debris-choked canyons it may be 20 to 30 feet thick, whereas elsewhere it may be only a few feet thick.

Along the north rim of Mesa Verde a thin mantle of colluvium covers the steep slopes of Mancos shale. The Government road traverses the slopes in a series of switchbacks to the top of the mesa. The recent road-cuts in the slope have hastened erosion by accelerating landsliding of debris over fresh oversteepened cutbanks. During periods of precipitation the moisture lubricates the bedding and joint planes in the exposed shale and, in consequence, much material slides downward, imperiling traffic on the road. Great effort is spent in stabilizing these active areas (pl. 47*B*). A park road crew continually repairs stretches of the road. A new road has been surveyed from the head of Morfield Canyon to Prater Canyon. The road will pass through a long tunnel cut in the Point Lookout sandstone and will bypass the active area below Point Lookout.

LANDSLIDE MATERIAL

Large landslide areas are not common. Most landsliding occurs when large blocks of massive sandstone overlying softer sequences of shale slump downward as they are loosened by erosion (pl. 45*B*). These slump or landslide blocks are very recent and can be seen in many localities. There is a large landslide block of Point Lookout sandstone on the sharp point west of the Todd mine.

ALLUVIUM

Narrow bands of alluvium are present intermittently along the floors of the large canyons, especially near their junction with the Mancos Canyon. The largest deposit of alluvium occurs along the Mancos River in the upper and lower parts of the canyon where the land is valuable for agriculture. In some places the alluviated areas are terraces that are much higher than the present stream bed. Generally the alluvium consists of silt, sand, clay, and some gravel. Near Mancos where the river flows through gravel terraces there is a predominance of pebbles and cobbles.

IGNEOUS ROCKS

Several small bodies of igneous rocks are intruded into the sedimentary strata along Mancos Canyon and in Wetherill Mesa. These intrusives, locally called "blowouts," apparently did not disturb the position of adjacent rocks to any great extent. The igneous plugs and connecting dikes show a northeastward trend.

The composition of the several igneous bodies generally is identical mineralogically. They have been identified megascopically as minette, a basaltic rock which contains abundant biotite flakes and olivine crystals. These intrusive rocks appear similar in composition to the many small bodies of igneous rocks along the western side of the San Juan Basin. Many of these rocks are characterized by a high potash and low silica content. The period of emplacement of the igneous bodies appears analogous to that of similar intrusives in the San Juan Basin. Williams (1936) judged the age of these intrusives to be Pliocene.

The large igneous body which intrudes strata of the Mesaverde group in secs. 15 and 22, T. 33 N., R. 15 W., contains abundant sedimentary rock debris. Some of the material in the intrusive rocks appears to be tuff breccias traversed by dikes of minette. The sedimentary strata on the east side are slumped downward into the intrusive body (pl. 45*A*). There is some suggestion of subsidence after emplacement of the igneous rock. The dikes are more resistant to weathering and crop out in jagged spurs. Two large dikes which trend southward from this intrusion coalesce near the State line and can be traced into the San Juan Basin in the direction of the Shiprock area. The dikes appear to intrude strata up to the base of the massive Cliff House sandstone.

In sec. 24, T. 35 N., R. 14 W., a large igneous plug intrudes the sedimentary strata as high as the base of the Point Lookout sandstone (pl. 47*A*). A thin contact aureole surrounds the plug, and the country rock shows evidence of metamorphism. A large dike trends southwestward from the central mass but is exposed only for a short distance owing to heavy soil cover. A system of dikes may connect all the igneous bodies in the area.

Another intrusive body (pl. 48*A*) is present along Mancos Canyon in sec. 11, T. 33 N., R. 15 W. The strata are little disturbed but appear to dome slightly near the apex of the intrusion. Abundant fragments of country rock occur in the periphery of the igneous plug. The massive sandstone beds of the Menefee formation are truncated and abut against the flank of the cone-shaped weathered igneous mass. The coal shows very little metamorphism.

Near the south end of Wetherill Mesa in sec. 6, T. 33 N., R. 15 W., a large igneous plug is intruded into the base of the massive Cliff House sandstone. The plug is composed of minette sheathed with a zone of altered country rock. The host rock is vitrified and contains inclusions of the igneous body. The flat-lying strata rise very steeply along the flanks of the igneous body.

The dikes examined in the area are shown on the geologic map, plate 49. Their composition is similar to the igneous bodies. One dike just west of Mesa Verde Park headquarters penetrated the entire exposed section of the Cliff House sandstone. If other dikes occur in the mapped area, the heavy soil cover conceals their outcrop.

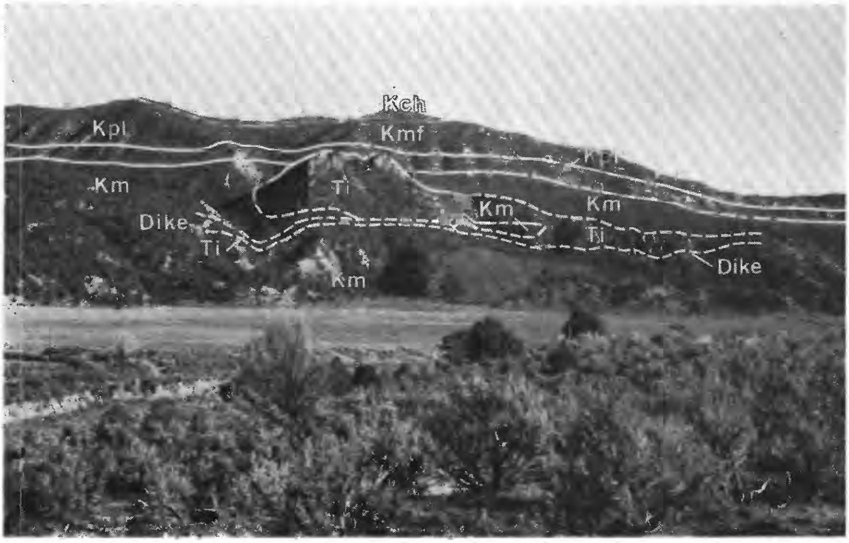
At all localities where the plugs occur, the sedimentary rock is completely eroded from the apparent summit of the intrusive body. Collier (1919, p. 297–298) considered the "blowouts" as the necks of short-lived volcanoes. The writer interprets most of the intrusive rocks as small stocks which stoped their way into the overlying strata. No material similar to the weathered plugs could be found on the surface of the mesas, even in the immediate vicinity of the plugs. These igneous rocks were emplaced later than the laccoliths of the Sleeping Ute and La Plata Mountains (Callaghan, 1950).

The La Plata Mountains northeast of Mancos contain a variety of porphyritic rocks intermediate between diorite and monzonite. Equi-granular syenite, monzonite, and diorite are intruded into sedimentary rocks as young as Mancos shale (Eckel and others, 1949, p. 32). The Sleeping Ute Mountain southwest of Cortez, Colo., is described as a stock (Coffin, 1921) and the rock identified as an andesite porphyry. An early mid-Tertiary age for the emplacement of these intrusions is suggested by analogy with other eruptive areas in New Mexico and Colorado (Callaghan, 1950, p. 119).

STRUCTURE

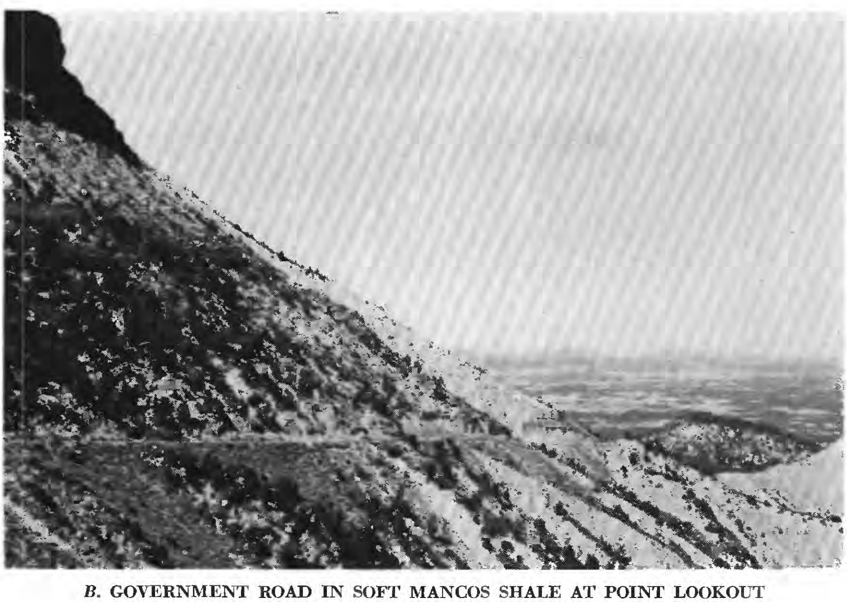
Mesa Verde occupies part of the northwest corner of the San Juan Basin. It lies entirely within the structural platform of the Four Corners area, one of a number of relatively low, flat, and broad structural divides that separate the central part of the San Juan Basin from the adjoining uplifted areas.

As shown by the contour lines on the geologic map (pl. 49), the major geologic structure of the Mesa Verde area is a wide shallow



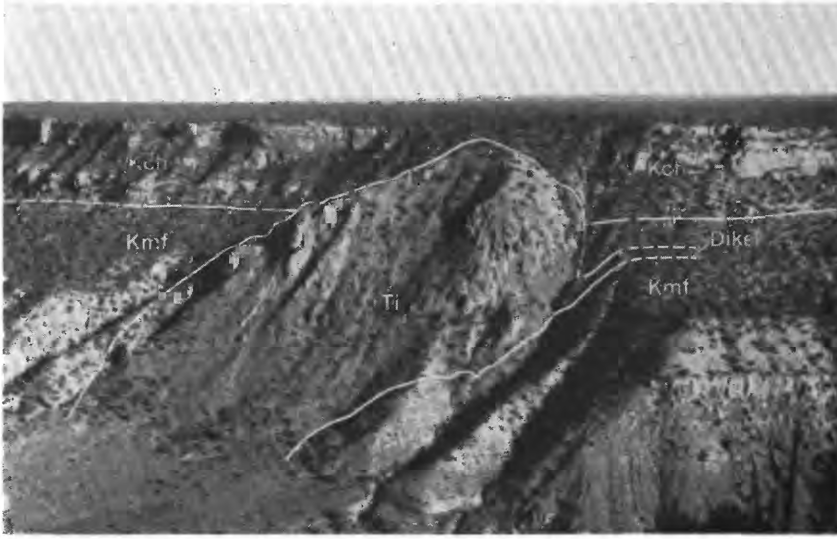
A. "BLOW OUT" IN NORTH END OF WEBER MOUNTAIN, SEC. 24, T. 35 N., R. 14 W.

Large igneous plug (Ti) and dike (Ti) intrude Mancos shale (Km). High level terrace cut on Mancos shale. Kpl, Point Lookout sandstone; Kmf, Menefee formation; Kch, Cliff House sandstone.



B. GOVERNMENT ROAD IN SOFT MANCOS SHALE AT POINT LOOKOUT

Colluvium deposits cover slopes below Point Lookout sandstone.



A. **IGNEOUS PLUG IN MANCOS CANYON**

Igneous body (Ti) is intruded into Cliff House sandstone (Kch) in sec. 11, T. 33 N., R. 15 W. Strata are little disturbed. Kmf, Menefee formation.

***B.* UPPER END OF PRATER CANYON FROM GOVERNMENT ROAD, SEC. 18, T. 35 N., R. 14 W.**

Prominent cliff in right background is Point Lookout sandstone. The Point Lookout sandstone is bipartite and forms alcoves. Dip of strata is toward road. Valley is floored with Mancos shale. Present drainage has eroded headward to north rim of Mesa Verde.

syncline which plunges to the south. It is characterized on the north by gentle southward dips away from the structural high of the La Plata Mountains. The strata are almost flat lying toward the south. To the east the beds rise gradually on the west flank of Barker Dome, an elongate structure which trends northeastward. On the west the strata dip southeastward away from the structural high of the Sleeping Ute Mountain. Immediately south of the mapped area the west flank of the syncline is deflected eastward around the north-plunging flexure of the Chimney Rock dome.

When viewed from Park Point on the north rim, the Mesa Verde area appears to be an enclosed basin. The surface of the uplands which are underlain by the resistant Cliff House sandstone slopes almost to the dip of the underlying strata. In consequence the surface appears to mirror the approximate geologic structure of the area. The maximum topographic relief taken from control points on the surface of the Cliff House sandstone is about 2,200 feet, whereas the maximum structural relief taken from control points on the top of the Point Lookout sandstone is about 2,300 feet.

Locally there are slight reversals of the synclinal structure, especially near intrusions where the strata are slightly arched. In the northwest part of the area the beds dip away from the Cortez anticline, an elongate structure that trends northeastward. The Dakota sandstone outcrop trends parallel to the axis of this structure. Another minor flexure in T. 36 N., R. 14 W., lies immediately to the east of the Cortez anticline. The reversal of the strata is observed in the road cut on U.S. Highway 160 about 4 miles east of the park entrance.

Few faults occur in the mapped area. In sec. 13 and 14, T. 35 N., R. 15 W., a normal fault which trends to the east can be traced across several promontories below Park Point. The displacement is about 50 feet, and coal beds of the Menefee formation north of the fault are downthrown against the Point Lookout sandstone. Another area of faulting is along the rim in the northwest part of Mesa Verde where several small normal faults trend southeastward and coalesce. The beds of the massive member of the Point Lookout sandstone are downfaulted on the north against the sandstone and shale member of the same formation. The total displacement of the faults is about 100 feet. A well-marked scarp delineates the trace of the fault zone for some distance from the rim of Mesa Verde. Several miles farther south a small normal fault occurs in the rim of the mesa. It is downthrown on the south and strikes to the east. The displacement is about 40 feet. In the upper part of Grass Canyon in T. 32 N., R. 14 W., a small normal fault occurs in the Menefee formation. It is downthrown on the west, with a displacement of about 50 feet, and trends generally toward the northeast. The fault decreases in throw northward and in about a mile passes into a small fold.

AGE OF DEFORMATION

Within the area there is little direct evidence on the age of deformation. The Cliff House sandstone of Montana age is the youngest formation involved in the folding. In consequence the earliest date of the orogeny would be in post-Montana time. In the area immediately to the east younger formations are exposed which give more precise dating of the deformation. Zapp (1949), on the basis of stratigraphic evidence, believed that crustal deformation, reflected in the coarse detritus of the Animas formation including the McDermott member which he classed as a separate formation, began near the close of the Cretaceous period and probably extended into the early part of the Tertiary period. The structural features of the Durango area were formed early in the Tertiary period but have not been precisely dated. The steep dips in the basal beds of the Animas formation may indicate that most of the folding took place after early Animas time. Barnes and others (1954) arrived at similar conclusions and judged this evidence adequate for the dating of the deformation in the Red Mesa area.

Cross (Cross and Ransome, 1905) concluded that the laccolithic mountain uplifts such as the La Plata, the Rico, and the West Elk Mountains are of early Tertiary age. He considered a part of the volcanic series of the San Juan Mountains to have been erupted at the period of laccolithic intrusions. Another laccolith, the El Late or Sleeping Ute Mountain, on the basis of corresponding evidence, is also dated early Tertiary. Callaghan (1950) suggested an early mid-Tertiary age for these uplifts by analogy with other intrusive areas in New Mexico and Colorado.

The dikes and small igneous bodies present in Mesa Verde are analogous to the small bodies of igneous rock present along the western side of the San Juan Basin between the Four Corners area and Gallup. They have been studied in detail by Williams (1936, p. 111–172) and dated Pliocene in age.

It is probable that the deformation and the faulting in the area was contemporaneous with the uplift of the La Plata and Sleeping Ute Mountains. Kelley (1950, p. 130) believes that the present structural elements of the San Juan Basin, which include the domal uplifts, the platforms, and the monoclines or "hogbacks," were largely formed by middle Tertiary time.

GEOLOGIC HISTORY

DEPOSITION

The depositional history of Upper Cretaceous rocks and the interrelationship between the formations in the San Juan Basin have been studied in detail. The major events of the Late Cretaceous history have been discussed by Sears and others (1941), Pike (1947), Zapp (1949), and Barnes and others (1954). The present author will limit discussion of this section to the geologic history of the exposed rocks of the Mesa Verde area.

The large-scale intertonguing of the marine and continental sedimentary rocks, as herein described, was caused by repeated movements of the shoreline. The lithology and stratigraphic relations of these rocks are directly related to transgressions and regressions of Late Cretaceous seas across a wide shallow basin. The conditions of deposition characteristic of fluvial, paludal, estuarine, littoral, and neritic origin are all represented in the sedimentary rocks of the Mancos and the Mesaverde.

At the time of deposition a shallow marine basin to the northeast was bordered on the southwest by swamps. The uplands that supplied the detritus probably lay to the west and southwest.

In the Mesa Verde area the earliest Late Cretaceous deposition is represented by sandstone, conglomerate, shale, and coal beds of the Dakota sandstone. During the accumulation of these deposits, the strand line advanced across the area to a point far to the southwest. The marine sediments that were deposited following the transgression of the sea were chiefly mud and impure limestone of the Mancos shale. The area remained submerged for a long time allowing the accumulation of deposits of fine-grained sediments that are now represented by the great thickness of Mancos shale.

The withdrawal of the sea to the northeast is recorded by the large-scale intertonguing between the Mancos shale and the basal strata of the Mesaverde group. The repeated oscillation of the strand line is recognized by Sears and others (1941) and Pike (1947, p. 15) as a phenomenon that may take place in a sinking basin of deposition with variations in the rate of sinking and the rate of supply of detritus to the basin. Sears does not consider it necessary to postulate an uplift of the basin of deposition to explain the regression of an epicontinental sea. A large increase in the rate of accumulation of sediments would indicate an elevation of a source area, but that area could be so far removed as to leave the site of deposition unaffected.

During early Montana time the shoreline retreated, with occasional reversals, across the area to a point far to the northeast. It was during this withdrawal that the Point Lookout sandstone accumulated as a sequence of overlapping lenticular beach deposits. The sandy shales of the uppermost part of the Mancos represent the offshore muds that accumulated during this retreat; the lower part of the Menefee formation comprises swamp and river deposits laid down behind the retreating shoreline.

Field data suggests that the area of deposition continued to subside, and that the strand line regressed because of accumulation of sediments along the margin of the basin either through the increase in the rate of deposition or decrease in the rate of subsidence, or both. In this area the process appears to have been one of continual upward and outward building of the beach sands and the resulting regression of the sea. The Point Lookout sandstone is underlain by thin sandstone tongues of the transition zone and overlain by deposits of the swamp environment. This relationship is well defined along the west side of Mesa Verde where the stratigraphic basinward rise of the massive regressive marine sandstone can be traced along the rim. The Point Lookout sandstone rises northward by the constant lensing out of sandstone tongues at the base of the formation. Several of these tongues occur between localities 13 and 5 and are shown on the geologic map (pl. 49). The sea must have retreated slowly over a broad shelf area to provide such uniform conditions of sedimentation.

As the shoreline moved northeastward into the former epicontinental sea, the swamps followed. It seems likely that meandering rivers frequently changed their course and spread fluvial sands and muds over earlier swamp deposits and beach sands. These sediments compose the middle barren member of the Menefee formation. As the whole area was gradually depressed, the swamps were continually built upward and progressively northeastward onto the former sea floor.

During middle Montana time the sea advanced southwestward across the area. The Cliff House sandstone is a transgressive sandstone laid down before this marine invasion. The oscillation of the strand line due to variations in the rate of subsidence and accumulation resulted in much intertonguing between marine and nonmarine deposits and also between marine deposits. The rate of subsidence at times was relatively rapid, and the sea advanced without seriously disturbing the deposits over which it transgressed. At other times the rates of subsidence and accumulation were balanced, and in a nearly stable shoreline resulted. During this period of stability intertonguing occurred between the marine beach sands and the coal-forming swamp deposits. Along Mancos Canyon thicknesses of coaly shale merge laterally into marine sandstone within short distances. In consequence the base of the Cliff House sandstone rises rapidly stratigraphically in very short distances. Minor regressions of the sea caused the overlap of nonmarine sediments over marine sediments. These regressions clearly define the northwestward trend of the shoreline and mark its successive positions in the area during Cliff House time. The massive lenticular marine deposits (pls. 49 and 50) are successive overlapping beach deposits which intertongue landward with the more typically continental deposits of the Menefee formation and intertongue basinward with the finer clastic material of the overlying marine Lewis shale. The lithology and interrelationship of the sandstone lenses in the Cliff House can be traced along Mancos Canyon as well as in other canyons in the Mesa Verde.

The sequence of events during the remainder of Late Cretaceous time cannot be observed in the Mesa Verde area; the rocks younger than the Cliff House sandstone have been removed by erosion. However, this record is well preserved in the Durango area, and Zapp (1947) and Barnes and others (1954) give detailed accounts of the stratigraphy of that and adjacent areas.

EROSION

Mesa Verde is the western part of a great plateau that has been dissected by streams flowing southward from the La Plata and San Juan Mountains. Cliffs descend abruptly from the plateau rim 1,000 to 2,000 feet to the lowlands. Mesa Verde is intricately dissected by steep-walled canyons into narrow and ragged uplands. The slope of the surface of the uplands conforms to the dip of the resistant sandstone beds which underlie it. Viewed from Park Point on the north rim, the surface slopes southward into a bowl-shaped amphitheater from an elevation of about 8,600 feet in the north to about 6,000 feet in the southern part of the area. If the canyons and lowlands were filled to the rim of the uplands, a uniform surface would exist that would rise gently toward the La Plata Mountains with a gradient of about 150 feet to the mile.

Scattered over the surface of the mesas are water-worn pebbles and cobbles and locally a veneer of gravels which must have been transported from distant sources. Atwood and Mather (1932) believed these gravels to be remnants of stream deposits made on the widespread San Juan peneplain. These deposits containing boulders, cobbles, and gravels of granite, schist, banded slate, quartz, and greenstone are characteristic of the central part of the San Juan Mountains where the Precambrian is exposed. Scattered among these boulders are also cobbles of quartzitic sandstones, several types of basic fine-grained igneous rocks, and diorites, monzonites, and porphyries which probably were derived from the adjacent La Plata Mountains.

In mid-Tertiary time the sites of the La Plata and the Sleeping Ute Mountain were intruded and uplifted by magmas that correspond in age to at least a part of the volcanic rocks of the San Juan Mountains. Upon these uplifts, radial streams developed which rapidly removed the Tertiary cover and deeply eroded the Cretaceous formations. Erosion was so extensive that the uncovering of the intrusive rocks was accomplished during the cycle which culminated in the formation of the San Juan erosional surface. The presence of the gravel remnants which contain rocks similar in lithologic character to the intrusive core of the La Plata and possibly of the Sleeping Ute Mountain supports this hypothesis. At the end of this cycle of erosion the higher peaks of the mountain areas stood as monadnocks above the low-lying plain. The high gravel-covered upland areas flanking the present rugged summits are remnants of this erosional surface.

Atwood and Mather (1932, p. 92) believed that there was a general crustal elevation of the San Juan region subsequent to the deposition of the Bridgetimber gravel and at the end of the cycle of erosion, during which the San Juan surface was developed. The streams in the uplift areas were rejuvenated; they carried many large boulders and cobbles together with sand and gravel to the lowlands and deposited them in alluvial fans. The streams flowing to the south and west were also rejuvenated in their lower courses as a result of the regional uplift. They eroded headward, cut canyons into the plateaus, and dissected the alluvial fans. The Bridgetimber gravel marks the beginning of a new cycle of erosion in the area and is the result of a temporary period of deposition along the margin of the range. The age of the gravels may be late Pliocene or early Pleistocene.

The uplift that ended the San Juan cycle of erosion elevated the central part of the mountain ranges as much as several thousand feet above the surrounding marginal areas. In consequence, the streams cut downward to greater depth in the central part of the uplift than the outlying areas to reach the new base level. Along the margin of the uplift areas the rejuvenated streams quickly incised the old erosion surface and cut their canyons to the new base level. As soon as the grade of the master streams was adjusted, lateral planation began and the Mancos and La Plata Rivers and their tributaries carved broad valleys. This former valley position can be seen in the well-marked shoulder in the Mancos shale about 800 to 1,000 feet below the rim of Mesa Verde. It can be traced along Mancos and Weber Canyons in general along the entire north front of the mesa westward to the Sleeping Ute Mountain and over the entire San Juan region (Atwood and Mather, 1932).

The process of mountain dissection was interrupted by a period of glaciation, the first of three that are recognized in the San Juan region. The Cerro glacial stage (Atwood and Mather, 1932, p. 83) resulted in the ice sculpturing of the La Plata and the San Juan Mountains. Cirques were formed at the heads of valleys of the master streams, and masses of glacial debris clogged the streams. This material was transported out of the mountains and deposited upon the wide valley floors. Remnants of this gravel veneer can be found on the high-level terraces along the major streams. This gravel is correlated with similar material on Florida Mesa southeast of Durango, which Atwood and Mather (1932, p. 112) named the Florida gravel. In the Mesa Verde area only a scattering of boulders can be found on the high terraces. Larger remnants were noted by Cross (Cross and others, 1899) on the gravel-covered mesa between the East Mancos River and Cherry Creek and on the highest terraces along the La Plata River.

The Florida cycle ended with the renewal of domal uplift of the San Juan region. The uplift, as before, was more pronounced in the central part of the mountains than along the margin. As a result of this crustal deformation, the erosive power of streams was again increased, and deep canyons were incised in the floor of the valleys formed during the Florida cycle. The present form of the canyons is the result of this canyon cycle of erosion.

Soon after the beginning of the canyon cycle of erosion the San Juan region was subjected to two periods of glaciation, the Durango and the Wisconsin glacial stages. The end results of these glacial episodes were the carving of cirques in the heads of valleys and the deposition of morainal debris in the lower courses of the valleys. The streams transported this material from the mountains and covered the valley bottoms with thick deposits of gravels. Such deposits can be seen in the lower gravel terraces in the vicinity of the town of Mancos.

At present the canyon cycle of erosion is still in the youthful stage. In the Mesa Verde area the Mancos River, like other master streams in the San Juan region, is actively engaged in valley deepening and widening.

STREAM ADJUSTMENTS

A condition of stream adjustment is seen in the relation of the Middle and West Mancos Rivers to the Weber Canyon drainage. During the Florida cycle of erosion the Middle Mancos River must have flowed through Weber Canyon. Evidence of this former drainage is the well-marked high-level terrace that can be traced from the head of Weber Canyon to its junction with the canyon of the Mancos River. This terrace can also be followed up Mancos

Canyon and East Canyon, a tributary of Weber Canyon. Near the junction of the Middle and West Mancos Rivers there are many gravel terraces and gravel-covered mesas rising steplike above the valley bottom. The highest of these terraces is veneered with Florida gravel and the lowest with fluvial-glacial gravel similar to that on the lower terraces in the head of Weber Canyon. The higher former-valley level can be projected to coincide with the high terrace in Weber and Mancos Canyons. It is possible that the West and Middle Mancos Rivers flowed through separate canyons, below their present confluence, during the Florida and canyon cycles of erosion. When masses of detritus choked the stream channel after the glacial epochs, the West Mancos River was able to divert the Middle Mancos from its course. At that time the divide separating the streams must have been low. The West Mancos drained a larger area and eventually its headward-eroding tributaries captured the drainage of the Middle Mancos River. The present stream that is eroding the gravel terraces at the head of Weber Canyon is entirely inadequate for the broad valley in which it flows. Cross (Cross and others, 1899) refers to a similar condition where the East Mancos River has been diverted from East Canyon by the piracy of the Middle Mancos River.

The broad Montezuma Valley, which borders the north and west margins of Mesa Verde, is drained in the north by McElmo Creek and in the south by Navajo Springs Creek. Continuous terraces along the edge of the valley indicate that at one time only a single stream existed. The diversion of the main drainage probably occurred late in the canyon cycle of erosion. The tributaries of McElmo Creek, eroding rapidly headward along the fractured strata immediately north of Sleeping Ute Mountain, tapped the upper drainage of the Montezuma Valley and diverted it westward. A low divide crosses the former valley just north of the Yucca House National Monument. McElmo Creek has now cut its channel deep into the valley floor.

Prater and Morfield Canyons may have been cut during the Florida cycle of erosion. The floors of the valley heads correspond in altitude to the high-level terraces that mark the slopes on the Mancos shale along the rim. The present drainage is deepening the former valleys by headward erosion. Erosion along the north rim of Mesa Verde has beheaded the upper valleys of Prater and Morfield Canyons (pl. 48*B*).

FUEL RESOURCES

COAL

In the Mesa Verde area coal is present in the Dakota sandstone and in the Menefee formation. Coal in the Dakota sandstone is very impure and of bituminous rank. At the time of this investigation, coal of the Dakota was being mined only for local consumption. Coal of minable thickness in the Mancos area is contained in the Menefee, the middle formation of the Mesaverde group.

The Menefee formation has coal with commercial possibilities only in its upper and lower parts. Toward the south the coal zones diverge and the barren interval becomes thicker and increasingly sandy. In the northern part of the area the zones converge and the barren interval becomes thinner.

The important coal beds occur in the lower part of the formation. These coal beds are lenticular, extend for several miles, and have a maximum observed thickness of 4 feet. The coal is high volatile C bituminous and of about the same rank as the better coals of southeastern Illinois, western Kentucky, Ohio, and southeastern Kansas (Collier, 1919, p. 303). It usually has a bright luster and, in many localities, contains abundant fossil resin. The coal is brittle and breaks in roughly cubical blocks. Analyses of coal samples taken in the Mesa Verde area are shown in table 5.

Exploitation of the coal has been confined to two or three small mines in the area south of Cortez, Colo. No mines were in operation at the time of this investigation. Mesa Verde National Park covers a considerable part of the coal field, but adequate reserves of commercial coal exist in the remaining part of the area. Estimated reserves of minable coal in the area mapped are listed in table 6.

The coal beds in the lower part of the Menefee formation correspond in position to the Spencer coal group (Collier, 1919) which lies immediately above the Point Lookout sandstone and includes about 60 feet of beds. The lenticularity and extent of the coal beds are due to the conditions under which they were deposited.

The coal beds of the middle barren interval are very thin, discontinuous, and impure. They are generally associated with siltstone and sandstone beds; locally they are cut by unconformities.

The upper group of coal beds are below the base of the Cliff House sandstone. These beds are very lenticular and are variable in thickness, with an observed maximum thickness of 6 feet. They are associated with thick sequences of dark carbonaceous shale espe-

TABLE 5.—*Analyses of coals in the Mesa Verde area*

[From U.S.Bureau of Mines (1937). Kind: A, mine sample collected by Bureau of Mines; B, mine sample collected by Geological Survey. Condition; 1, as received; 2, moisture free; 3, moisture and ash free.]

Locality: In relation to Cortez, Montezuma County	Mine	Kind	Condition	Laboratory No.	Proximate (percent)				Ultimate (percent)					Air-drying loss, (percent)	Heating values	
					Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen		Calories	Btu
6 mi. SE	Todd	A	1	16476	11.0	40.3	42.2	6.5	0.8	------	------	------	------	3.7	6,461	11,630
	Todd	A	1	16477	13.1	39.6	39.2	7.6	.7	------	------	------	------	5.1	6,194	11,150
	Todd	A	1	16478	12.1	39.7	41.2	7.0	.7	5.9	63.4	1.4	21.6	4.4	6,311	11,360
	Todd	B	1	20267	12.1	37.7	44.1	6.1	.6	6.0	64.4	1.4	21.5	8.7	6,328	11,390
			2		------	42.9	50.2	6.9	.7	5.3	73.3	1.6	12.2	------	7,200	12,960
			3		------	46.1	53.9	------	.7	5.7	78.7	1.7	13.2	------	7,739	13,930
10 mi. SE	Jackson	A	1	16472	12.2	41.3	40.4	6.1	0.4	------	------	------	------	4.1	6,311	11,360
	Jackson	A	1	16473	12.3	42.2	40.5	5.0	.5	------	------	------	------	3.8	6,400	11,520
	Jackson	A	1	16474	13.8	40.7	39.9	5.6	.5	------	------	------	------	4.9	6,178	11,120
	Jackson	A	1	16475	12.8	41.3	40.2	5.7	.5	6.1	63.5	1.3	27.9	4.3	6,311	11,360
			2		------	47.4	46.1	6.5	.6	5.4	72.8	1.6	13.2	------	7,233	13,020
			3		------	50.7	49.3	------	.6	5.7	77.8	1.7	14.2	------	7,733	13,920
10 mi. SW	Cushman	B	1	A45506	11.6	38.8	42.7	6.9	0.6	6.4	64.0	1.4	20.7	7.0	6,378	11,480
			2		------	43.8	48.4	7.8	.7	5.7	72.4	1.6	11.8	------	7,217	12,990
			3		------	47.6	52.4	------	.7	6.2	78.5	1.7	12.9	------	7,828	14,090

TABLE 6.—*Estimated original bituminous coal reserves of the Menefee formation in the Mesa Verde area*

[All coal is under 1,000 feet of overburden]

County, township, and range	Reserves, in thousands of short tons, in beds of thickness shown												Estimated recoverable reserves (assuming 50 percent recovery)
	Measured and indicated				Inferred				All categories				
	14–28 inches	28–42 inches	More than 42 inches	Total	14–28 inches	28–42 inches	More than 42 inches	Total	14–28 inches	28–42 inches	More than 42 inches	Total	
La Plata County:													
T. 32 N., R. 14 W.	4,944		20,412	25,356	47,628			47,628	52,572		20,412	72,984	36,492
Montezuma County:													
T. 32 N., R. 14 W.	2,304			2,304	57,872			57,872	60,176			60,176	30,088
T. 32 N., R. 15 W.	45,126	20,196		65,322	285,454			285,454	330,580	20,196		350,776	175,388
T. 32 N., R. 16 W.	48,744	14,760	23,004	86,508	297,792	53,424	18,738	369,954	346,536	68,184	41,742	456,462	228,231
T. 32 N., R. 17 W.					27,666	27,774		55,440	27,666	27,774		55,440	27,720
T. 33 N., R. 14 W.	6,408			6,408	129,996			129,996	136,404			136,404	68,202
T. 33 N., R. 15 W.	50,706	10,476		61,182	355,564	27,030		382,594	406,270	37,506		443,776	221,888
T. 33 N., R. 16 W.	97,848	6,004		103,852	477,438	39,384		516,822	575,286	45,388		620,674	310,337
T. 33 N., R. 17 W.	20,866			20,866	37,746			37,746	58,612			58,612	29,306
S. T. 34 N., R. 14 W.	56,908		23,580	80,488	345,538		87,210	432,748	402,446		110,790	513,236	256,618
S. T. 34 N., R. 15 W.	3,974	2,340		6,314	91,158	35,766	12,960	139,884	95,132	38,106	12,960	146,198	73,099
S. T. 34 N., R. 16 W.	5,202			5,202	69,242			69,242	74,444			74,444	37,222
S. T. 34 N., R. 17 W.	26,568			26,568	56,358			56,358	82,926			82,926	41,463
N. T. 34 N., R. 14 W.							2,286	2,286			2,286	2,286	1,143
N. T. 34 N., R. 16 W.					211,122	50,886		262,008	211,122	50,886		262,008	131,004
T. 35 N., R. 14 W.	9,138			9,138	3,348		1,962	5,310	12,486		1,962	14,448	7,224
T. 35 N., R. 16 W.	34,794	20,322		55,116	115,362	58,017		173,379	150,156	78,339		228,495	114,247
Grand total	413,530	74,098	66,996	554,624	2,609,284	292,281	123,156	3,024.721	3,022,814	366,379	190,152	3,579,345	1,789,672

cially in localities where intertonguing occurs between the strata of the Cliff House sandstone and the Menefee formation. In many areas along lower Mancos Canyon this group of coal beds has been completely burned, and the associated sedimentary beds are clinkered. Oxidation associated with the burning often occurs well into the lower strata of the Cliff House sandstone.

The lines of coal sections (pl. 51) illustrate the thickness and correlation of the coal beds in the Mesa Verde coal field. The stratigraphic relationship of the coal-bearing Menefee formation to the other formations in the Mesaverde group indicate that it is a northeastward-tapering wedge of nonmarine sedimentary rocks enclosed by the marine Point Lookout sandstone and marine Cliff House sandstone. Zapp (1949) stated that the Menefee thins and grades into sedimentary rocks of marine lithology northeast of Durango.

OIL AND GAS

Exploration for oil and gas in the Mesa Verde area has been carried on intermittently for many years, and gas has been found in the Dakota sandstone (Colorado School of Mines, 1946, p. 279–280). A small gas field, the Point Lookout field in T. 36 N., R. 14 W., was discovered in 1930. It produces 200,000 cubic feet of gas per day from the Dakota. Shows of oil were encountered in the Mancos shale in other well tests, but no oil fields have been discovered at the time of this writing (1958). There are no anticlines with large structural closure within the Mesaverde outcrop. The Barker Dome, which lies immediately to the southeast of the area, is a large gas-producing field. The production of gas is from the Dakota sandstone and the Paradox member of the Hermosa formation of Pennsylvanian age.

The marine Cliff House sandstone and the Point Lookout sandstone of the Mesaverde group and the Paradox of Pennsylvanian age are also important gas producers in the San Juan Basin. In the Mesa Verde area the Mesaverde group is at the surface, and any gas potential has been destroyed by erosion. Commercial exploration should be directed toward possible shallow gas in the Dakota sandstone or deep tests of the rocks of Pennsylvanian age. These horizons, influenced by either structural or stratigraphic traps, or both, are proven reservoir rocks in areas immediately adjacent to Mesa Verde. It is very possible that systematic drilling in the area may show good oil and gas possibilities in the Dakota sandstone and in the strata of Pennsylvanian age. The logs of selected wells are shown in table 7.

TABLE 7.—*Logs of selected wells, Montezuma County, Colo.*

Well	Location	Depth (feet)	Year	Remarks
Tidewater Associated Oil Ute 1.	Sec. 8, T. 33 N., R. 14 W.	9,508	1951	Abandoned. Top Pennsylvanian at 7,435 ft. No show oil or gas. Drilled on structural platform.
E. G. Goldsworthy Porter 2.	Sec. 1, T. 34 N., R. 17 W.	4,075	1949	Drilled in Mancos. Abandoned.
Coltar-Coon Syndicate Oil Hall 1.	Sec. 9. T. 35 N., R. 13 W.	1,464	1928	Dakota shows oil with water at 1,230 ft. Oil and gas shows at 1,070–90 ft, 1,119–23 ft, 1,150–52 ft, and 1,377–82 ft. Water sand at 1,295–1, 302 ft, 1,337–46 ft, and 1,457–64 ft. Abandoned.
Ed Wiley Robin 1	Sec. 4, T. 35 N., R. 14 W.	406	1933	Drilled in Mancos. Abandoned.
M. T. Anderson Day 2	Sec. 11, T. 35 N., R. 14 W.	950	1948	Drilled in Mancos. Bottomed in Morrison.
M. T. Anderson and Randsdall Fee 1.	Sec. 14, T. 35 N., R. 14 W.	1,334	1948	Surfaced in Mancos.
G. H. Talcot et al 1	Sec. 7, T. 35 N., R. 16 W.	594	1931	Surfaced in Dakota.
Mesa Verde Ranch Haller 2.	Sec. 33, T. 36 N., R. 14 W.	720	1930	Top Dakota at 700 ft; 200,000 cu ft gas per day. Sand 693–720 ft; 90,000 cu ft gas per day. Elev. 6,600 ft.
Mesa Verde Ranch Haller 3.	Sec. 33, T. 36 N., R. 14 W.	900	1930	Top Dakota at 712 ft. 52 ft saturated sand. Salt water in Morrison. White sand at 723–748 ft. Elev. 6,849 ft.
Fred Haller Carr 2	Sec. 33, T. 36 N., R. 14 W.	745	1931	Water in Dakota. Abandoned.
Fred Haller Stephens 1	Sec. 33, T. 36 N., R. 14 W.	745	1931	Top Dakota at 745 ft; 75,000 cu ft gas per day.
Fred Haller Haller 4	Sec. 34, T. 36 N., R. 14 W.	585	1931	No water or gas. Abandoned. Elev. 6,500 ft.
Montezuma Oil and Gas 1.	Sec. 8, T. 36 N., R. 14 W.	700	1925	Abandoned at 700 ft in Mancos. Some gas. Show oil.
Fred Haller Haller 1	Sec. 29, T. 36 N., R. 14 W.	1,130	1930	Dakota at 740 ft showed wet sweet gas. 250 cu ft to 200,000 cu ft gas at 180 lbs rock pressure.
McElmo Oil West 1	Sec. 31, T. 36 N., R. 17 W.	5,285	1940	Abandoned. Top Pennsylvanian at 3,105–? ft. 1,200 cu ft oil from lime at 3,131 ft. Oil at 3,830 ft. Salt at 4,350 ft.
Dunning and Lane 1	Sec. 35, T. 36 N., R. 14 W.	920	1940	Abandoned.

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