Geology of the Circle Cliffs Area, Garfield and Kane Counties, Utah

By E. S. DAVIDSON

GEOLOGICAL SURVEY BULLETIN 1229

Prepared on behalf of the
U.S. Atomic Energy Commission

Stratigraphy, structure, and economic geology of an area at the west edge of the Colorado Plateau

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 67-266

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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GEOLOGY OF THE CIRCLE CLIFFS AREA, GARFIELD AND KANE COUNTIES, UTAH

By E. S. Davidson

ABSTRACT

The Circle Cliffs area is a few tens of miles west of the Henry Mountains, on the west edge of the Colorado Plateau, and is bordered to the west by the High Plateaus of southeastern Utah. The climate is arid to semiarid, and the land is used mainly for cattle grazing. Rugged canyons, mesas, benches, and hogbacks, supported and walled by massive colorful sandstone beds, characterize the topography of the area; the maximum relief is about 4,800 feet.

The rocks in the central part of the area are gently to steeply folded along the northwest-trending axis of the Circle Cliffs anticline. Several thousand feet of stratified rocks were eroded from the anticlinal area during Mesozoic and late Tertiary time, and the oldest rocks now are exposed in the central Circle Cliffs area, along the axis of the anticline, and the youngest rocks on the perimeter of the area. The stratified sedimentary rocks that crop out are Paleozoic, Mesozoic, Tertiary, and Quaternary in age. Some of the Mesozoic sedimentary rocks contain concentrations of uranium minerals, and the study of these rocks and their included uranium deposits was one of the principal objectives of the investigation of the Circle Cliffs area.

Sandstone and mudstone are dominant lithologies in the rock sequence that is about 8,500 feet thick. Slightly more than half of the sequence was deposited in a continental or near-shore continental environment, and the rest was deposited in a marine or littoral marine environment. The Permian rocks are sandstone and dolomite and are chiefly of marine origin. The Triassic and Jurassic rocks are sandstone to mudstone and were deposited partly in continental and partly in marine environments. The Cretaceous rocks are mudstone and sandstone deposited mainly in a marine environment. The Tertiary and Quaternary rocks range from silt to gravel and were deposited entirely in a continental environment.

The sedimentary rocks are folded into an anticline, which is the major structural feature of the area. The anticline trends northwest and dips steeply to the northeast and gently to the southwest. It plunges gently northwest and southeast from the central part of the area. The vertical closure on the central part of the anticline is 1,200 feet, and total displacement of beds is about 9,000 feet. Few faults are present except on the southwest side of the anticline where a minor graben closely parallels the anticlinal axis. The dominant joint sets trend northeast and north to northwest. The anticline probably was formed in middle to late Paleocene time, but the joint systems may be as young as mid-Tertiary.

The uranium deposits are small, and opportunity for discovery of any large deposits seems poor. Most deposits are in the Moenkopi Formation on

the edges of channels filled with sandstone of the Shinarump Member of the Chinle Formation. The criteria favoring minable deposits in the Shinarump are (1) the presence of a channel, (2) the presence of material in the channel sandstone capable of precipitating uranium, (3) a lenticular mudstone-rich sandstone in the channel that has considerable hydraulic continuity with the rest of the unit, and (4) possibly the presence of an overlying cap of relatively impermeable mudstone. Uranium deposits occur in the Salt Wash Sandstone Member of the Morrison Formation near an area where the Salt Wash changes from a massive thick-bedded sandstone to a thin- to thick-bedded lenticular sandstone, but the discovered uranium deposits in the area of change contain only low-grade ore.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The Circle Cliffs area, which is 50 miles southwest of Hanksville, Utah (fig. 1), consists of about 1,660 square miles of rugged canyon-and-mesa land. High cliffs form an oval rim around a central area deeply dissected by streams that head both in the central part and in the northern highlands and flow through gaps in the rimming cliffs. The Henry Mountains rise to the east; to the west are flat-topped Boulder Mountain and the Aquarius Plateau.

Access to the interior of the Circle Cliffs area by motor vehicle was limited to three unimproved roads during this study. The most traveled access road, which was built in 1948 by the U.S. Atomic Energy Commission to encourage uranium exploration, enters from the east through Burr Canyon at the location of the old Burr Trail. An old road, used by the Ohio Oil Co. in the early 1920's, enters from Hall Creek Valley via Muley Twist Canyon about 8 miles south of Burr Canyon. This road was impassable during the entire study because of lack of maintenance. Two more access roads were

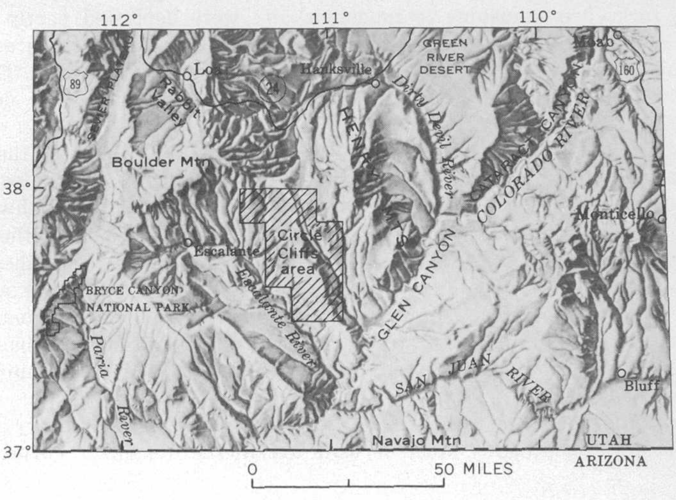

FIGURE 1.—Location of the Circle Cliffs area.

opened in the late 1940's. One enters the Circle Cliffs area from the northwest via the town of Boulder and Long Canyon; the other road, 20–30 miles to the south, forks off a road connecting the town of Escalante and "Hole in the Rock" on the Colorado River and enters the Circle Cliffs area via Harris Wash and Silver Falls Canyon. The Burr Trail and Long Canyon routes generally are passable during all seasons, but the Harris Wash–Silver Falls Canyon route must be used with caution, because in the fall it is frequently washed out by violent flash floods. Most of these access routes were maintained once a year by the Garfield County Highway Department. In the cliff-rimmed interior are many roads—some are in constant use, others are used only once or twice a year, but all are nearly always passable to vehicles having generous road clearance.

GEOGRAPHY AND PHYSIOGRAPHY

The Circle Cliffs area is part of the Canyon Lands section of the Colorado Plateaus physiographic province. Landforms most typical of the area are steep-walled canyons, hogback ridges along Hall and Sandy Creeks, flat windswept sand-covered benches surrounding the cliff-rimmed interior on all sides except the east, and flat-topped mesas in the interior and in the Henry Mountains basin. The maximum relief is about 4,800 feet. The lowest altitude, 4,000 feet, is at Hall Creek in the southeast part of the area, and the highest, 8,800 feet, is in the northwest corner of the map area on the slope of Boulder Mountain.

The climate is semiarid to arid. The average annual precipitation is about 7 inches and occurs as local thundershowers in late summer and as light snow and rain in winter. The first snow usually falls in the middle of November. In mid-December of 1954 as much as 6 inches of snow covered the ground, but generally the snow cover melts quickly and does not hamper travel in the area.

Vegetation consists dominantly of grasses and sage on the alluvium overlying the Kaibab Limestone, sage on the alluvium overlying the Moenkopi Formation, and juniper and piñon in areas of bedrock exposure and on windswept benches. The vegetation is similar to that growing in some parts of the Henry Mountains (Hunt and others, 1953, p. 27–35).

The area has no permanent population, and the land is used for cattle grazing by ranchers living in Boulder and Escalante. Uranium exploration and mining attracted a transient population ranging from about 5 to 50 people during 1954–58.

All drainage in the interior of the Circle Cliffs area is dendritic and almost perfectly adjusted to the bedding attitude of the traversed formations; thus, streams flow in a downdip direction. Canyons in the northwestern part of the area follow the principal northeast-trending joints instead of paralleling the bedding-dip direction and therefore trend 10–20° SW. of the dip direction. Streams draining the western part of the area discharge into the Escalante River, which flows along the southwest flank of the Circle Cliffs anticline to the Colorado River. Most streams in the eastern part of the area flow into Hall Creek, which follows an incised course southeastward along the Waterpocket fold to the Colorado River. The Escalante River is superimposed on the regional structure. The stream in Muley Twist Canyon and Hall Creek may both be superimposed, although they meander principally in the more easily eroded sediments along the strike and can be just as reasonably classified as subsequent streams.

Water flows all year in the southern reaches of Hall Creek. In the western and southwestern parts of the map area, the Escalante River and Deer Creek flow all year. Steep Creek, also in the western part of the area, flows intermittently. Additional water is supplied by springs that issue at the base of the Wingate Sandstone and flow as much as 40 gpm (gallons per minute), and springs at the base of the Shinarump Member of the Chinle Formation that flow 1–2 gpm.

PREVIOUS WORK

M. E. Thompson and his party of the Powell Survey traversed the west and north sides of the Circle Cliffs area in 1872. Gilbert (1874) traversed nearby regions in 1872 as a member of the Wheeler Survey. Thompson surveyed the area in 1874–75 (Gregory and Moore, 1931, p. 7–9). In 1873 Howell (1875) studied the stratigraphy between the Aquarius Plateau and the Henry Mountains, and in 1875–76 Gilbert (1877) mapped the Henry Mountains and parts of the Waterpocket fold. Gregory and Moore (1931) studied the geology of the Kaiparowits region in 1915–27. Moore mapped the geology of the Circle Cliffs area in considerable detail in 1921–22 as part of that study. Hunt remapped the Henry Mountains in 1935 and included parts of the Circle Cliffs area (Hunt and others, 1953). Steed (1954) published results of mapping and stratigraphic work in the Circle Cliffs area done in connection with the drilling of a second oil-test well near Wagon Box Mesa in 1954. Steed's work is published in a guidebook of the geology of the High Plateaus, which contains many papers regarding the geology of the region. Reports dealing primarily with stratigraphic problems in the Circle Cliffs and surrounding areas are those by Dake (1919, 1920), Moore (1922), Longwell, Miser, Moore, Bryan, and Paige (1923), Baker, Dane, and Reeside (1936), McKee (1938, 1954a, b), Craig and others (1955), Stewart (1957), and Stewart, Williams, Albee, and Raup (1959).

PURPOSE AND SCOPE

This report is based on work done on behalf of the U.S. Atomic Energy Commission to determine the mineral potential, primarily that of uranium, and to discover causes of localization of uranium ore in the Circle Cliffs area. Detailed geologic maps, prospect examinations, and analyses of prospect and outcrop rock samples were made to provide a sound geologic basis for the conclusions presented in this report. All prospects were examined, and some of the more promising ones were mapped in detail. The results of all the work are included in this report.

FIELD METHODS

Fieldwork was started in July 1954 and was completed in October 1957. Mapping parties were based at trailer camps in several parts of the area. When the area around a camp was mapped, generally about 60–100 square miles, the camp was moved to a new site. In this way areas of difficult access were rendered fairly accessible.

Travel in the Circle Cliffs is no longer as arduous as it was in 1872 when members of Powell's survey first examined the area. Roads suitable for pickup trucks and four-wheel-drive vehicles are abundant and occasionally are maintained. Some roads, or trails, are very rough, or are otherwise difficult for travel. Horses were used briefly in the southern part of the map area; Silver Falls, Big Bown, Little Bown, and the other benches in the southern part are accessible from only a few places, and at those places only on foot or horseback.

Topographic base maps (1953 edition) at a scale of 1 inch to 2,000 feet and a contour interval of 40 feet were used in field mapping. Field-inspection methods were used in most of the area to plot rock-unit features on the maps.

Geologic contacts in inaccessible areas were transferred to topographic maps from aerial photographs, mainly by the use of a Kale plotter. Contacts gained this way may be accurately mapped, but the consistency achieved was not always uniform. The southern part of the area, where formations of the Glen Canyon Group are the principal outcrop, was mapped photogrammetrically using the very accurate Kelsh plotter.

The base of the Wingate Sandstone cliff was located accurately by turning vertical angles on it from points of known altitude and position, using a transit, explorer's alidade, or a hand level. The approximate distance to the cliff was measured on the topographic map, and the altitude of the base was computed trigonometrically.

Stratigraphic sections were measured as time and circumstances permitted, some by U.S. Geological Survey personnel not directly associated with the Circle Cliffs project. In general, the bedding terminology used in the sections and in the rest of the report follows that suggested by McKee and Weir (1953).

ACKNOWLEDGMENTS

Geologists who assisted in mapping the area are Lorence C. Collins, in the summer of 1954; David A. Brew, in the fall of 1954 and the summer of 1955; Louis D. Carswell, in 1955–56; R. A. Cadigan for 2 months in 1956; and Glen A. Miller in 1956 and 1957. In 1957, Paul P. Orkild did most of the Kelsh plotting of the southern part of the area. Brew, Carswell, and Miller assisted in compiling field data in the winter months following the field seasons.

I was capably assisted in the fieldwork by John Ringle and John Avent, in 1954; Kent Kane and Richard Gilman, in 1955; Gilbert Thomas and Donald Schultz, in 1956; and Bill Long and Albert Specht, in 1957. Sam Pyeatt, John Moreland, Charles Sparks, Alva Newman, and William Bruggemeyer brought supplies and repeatedly moved the trailer camps. Max Behumin of Boulder, Utah, conducted a pack trip in the northwestern part of the area.

The work was done under the supervision of A. L. Brokaw, D. G. Wyant, and L. C. Craig, for whose help and advice I am grateful.

STRATIGRAPHY

Sedimentary rocks exposed in the map area total 8,500 feet in thickness. The oldest rocks that crop out are Permian and probably are best correlated with the Cutler Formation, well known from its outcrop in the Henry Mountains region to the east. The youngest rock unit, except Tertiary and Quaternary alluvial and colluvial deposits, is the mesa-capping Mesaverde Formation of Late Cretaceous age.

Rocks of continental, littoral, and marine origins are present. Sandstone of continental fluvial and eolian origin composes part of the White Rim Sandstone Member of the Cutler Formation, the Wingate, Navajo, Entrada, and Dakota Sandstones, and the Morrison Formation. Sandstone and siltstone of marine or littoral origin compose part of the White Rim Sandstone Member, the Moenkopi, Carmel, Summerville, and Mesaverde Formations, the Entrada and Dakota Sandstones, and the Mancos Shale. Dolomite deposits of marine origin compose the Kaibab Limestone and the Sinbad Limestone Member of the Moenkopi Formation.

Tertiary and Quaternary rocks in the area may be divided generally into alluvial and colluvial deposits. The mapped alluvial deposits are fan deposits in the northern part of the area, bouldery deposits and pediment deposits near Boulder Mountain, windblown sand, and stream alluvium. The mapped colluvial deposits are talus cones and landslide deposits. The landslide deposits include large rotated blocks (some of which are Toreva blocks), mudflows, and other types of landslide material.

The total thickness of the sedimentary rocks overlying the basement rock is not known from direct evidence, such as outcrops or oil tests. Two oil-test wells, both unsuccessful producers, were drilled in the Circle Cliffs area at almost the same location (pl. 1, sheet 1). The Ohio Oil Co. Government 1, drilled in 1921 (Gregory and Moore, 1931, p. 156–157), spudded near the top of the Kaibab Limestone half a mile west of Wagon Box Mesa and was completed at a total depth of 3,212 feet. The N. B. Hunt Government 1, drilled in 1953–54, spudded in the lower part of the Moenkopi Formation near the north end of Wagon Box Mesa and penetrated 5,628 feet of Triassic, Permian, Pennsylvanian, Mississippian, Devonian, and Cambrian rocks (Steed, 1954, fig. 1, p. 100–101). A few miles east of the mapped area, the California Co. Muley Creek 1, a test of the Muley Creek anticline, penetrated Jurassic to Devonian rocks.

The following generalized section briefly describes all exposed sedimentary rocks in the Circle Cliffs area.

Generalized stratigraphic section of sedimentary rocks exposed in the Circle Cliffs area

System	Series	Group, formation, and member			Thickness (ft)	Lithology
Quaternary, Tertiary(?), and Tertiary		Alluvial and colluvial deposits				Gravel, sand, silt, and bouldery deposits.
		Unconformity				
Cretaceous	Upper Cretaceous	Mesaverde Formation			400	Light-brown cliff-forming sandstone and gray mudstone interbeds; intertongues with Masuk Member of Mancos Shale.
Cretaceous	Upper Cretaceous	Mancos Shale	Masuk Member		700–900	Gray silty mudstone and light-gray sandstone interbeds that increase in quantity upward.
Cretaceous	Upper Cretaceous	Mancos Shale	Emery Sandstone Member		120–300	White crossbedded lenticular sandstone, coaly mudstone, light-yellow fine-grained even-bedded sandstone; intertongues with Blue Gate Shale Member.
Cretaceous	Upper Cretaceous	Mancos Shale	Blue Gate Shale Member		1,200–1,500	Bluish-gray finely laminated mudstone, some bentonitic clay, shaly sandstone, and limestone beds.
Cretaceous	Upper Cretaceous	Mancos Shale	Ferron Sandstone Member		200–350	Brown fine-grained ripple-laminated sandstone, white crossbedded sandstone, and gray mudstone interbeds; uppermost part contains coal beds; intertongues with Tununk Shale Member of Mancos Shale.
Cretaceous	Upper Cretaceous	Mancos Shale	Tununk Shale Member		550–650	Dark-gray mudstone to slightly fissile shale; gradational with Dakota Sandstone.
Cretaceous	Upper Cretaceous and Lower(?) Cretaceous	Dakota Sandstone			100–150	Yellowish-brown to gray mudstone and yellowish-brown fossiliferous sandstone; few coaly mudstone beds; white sandstone and coaly mudstone in lower part.
		Unconformity				
Jurassic	Uppper Jurassic	Morrison Formation	Brushy Basin Shale Member		<100–300	Variegated mudstone and claystone, minor sandstone and conglomerate.
Jurassic	Uppper Jurassic	Morrison Formation	Salt Wash Sandstone Member		300–450	White medium-grained sandstone and reddish- to greenish-gray mudstone; lenticular to tabular bedding.
Jurassic	Uppper Jurassic	San Rafael Group	Summerville Formation		50–190	Red to brown ribbed siltstone, mudstone; brown to white fine-grained sandstone.
Jurassic	Uppper Jurassic	San Rafael Group	Curtis(?) Formation		0–5	White discontinuous calcareous sandstone to sandy limestone.
			Unconformity			
Jurassic	Uppper Jurassic	San Rafael Group	Entrada Sandstone	Upper sandy member	170–250	White and brown thin-bedded sandstone to brown massive cliff-forming sandstone.
Jurassic	Uppper Jurassic	San Rafael Group	Entrada Sandstone	Medial silty member	320–360	Reddish-brown siltstone, very fine grained sandstone, and mudstone.
Jurassic	Uppper Jurassic	San Rafael Group	Entrada Sandstone	Lower sandy member	210–365	Brown massive very fine grained to fine-grained sandstone with large-scale crossbeds.
Jurassic	Upper Jurassic and Middle Jurassic	San Rafael Group	Carmel Formation		200–300	Upper unit: red gypsiferous soft earthy siltstone; gypsum beds decrease in quantity to south. Lower unit: bright-red siltstone and minor sandstone and yellowish-gray to pink limestone interbeds.

Generalized stratigraphic section of sedimentary rocks exposed in the Circle Cliffs area
—Continued

System	Series	Group, formation, and member			Thickness (ft)	Lithology
Jurassic and Triassic(?)		Glen Canyon Group	Navajo Sandstone		950–1,400	White massive cliff-forming sandstone with large-scale crossbeds.
Triassic(?)	Upper Triassic(?)	Glen Canyon Group	Kayenta Formation		250–400	Reddish-brown thin- to thick-bedded sandstone and siltstone; some mud-chip conglomerate, calcareous sandstone, and light-yellow limestone beds.
Triassic	Upper Triassic	Glen Canyon Group	Wingate Sandstone		230–350	Light-brownish-orange cliff-forming very fine-grained to fine-grained sandstone; large-scale crossbeds.
		—Unconformity—				
Triassic	Upper Triassic	Chinle Formation	Church Rock Member		0–25	Brown massive fine- to medium-grained sandstone.
Triassic	Upper Triassic	Chinle Formation	Owl Rock Member		150–250	Red, brown, and greenish-gray sandstone and mudstone; greenish-gray thin lenticular limestone beds.
Triassic	Upper Triassic	Chinle Formation	Petrified Forest Member		150–350	Variegated bentonitic mudstone and sandstone.
Triassic	Upper Triassic	Chinle Formation	Monitor Butte Member		100–200	Green and minor grayish-red bentonitic mudstone; gray to light-brown ripple-laminated fine-grained micaceous sandstone.
Triassic	Upper Triassic	Chinle Formation	Shinarump Member		0–250	White medium-grained thin to thick crossbedded sandstone; interbedded white thin-bedded sandstone, greenish-gray mudstone, and light-yellow very thick bedded sandstone; contains carbonaceous and charcoaly material.
		Unconformity				
Triassic	Upper Triassic	Chinle Formation	Mottled-siltstone unit		0–50	Mottled red and white siltstone with medium sand-size quartz fragments; hackly vertical fracture; well cemented; locally includes at base a mottled red and white fine-grained sandstone.
		—Unconformity—				
Triassic	Middle(?) Triassic and Lower Triassic	Moenkopi Formation	Upper ledge-forming unit		0–45	Reddish-brown mudstone and yellowish- to greenish-gray sandstone, dolomite, and dolomitic sandstone interbeds; forms ledgy slope and cliff.
Triassic	Middle(?) Triassic and Lower Triassic	Moenkopi Formation	Slope-forming unit		0–250	Reddish-brown siltstone and minor thin sandstone beds; slope forming.
Triassic	Middle(?) Triassic and Lower Triassic	Moenkopi Formation	Lower ledge-forming unit		200–245	Reddish-brown ledge- and bench-forming interlayered sandstone and siltstone; light yellow to dark gray on weathered surface where saturated with oil or asphalt.
Triassic	Lower Triassic	Moenkopi Formation	Sinbad Limestone Member		0–120	Brownish- to yellowish-orange oolitic fossiliferous dolomite and conglomeratic dolomitic sandstone.
		—Unconformity—				
Triassic	Lower Triassic	Moenkopi Formation	Basal unit		0–25	White to light-gray fine-grained dolomitic sandstone to sandy dolomite; abundant fragments of white chert; local abundant bedded white chert.
		—Unconformity—				
Permian		Kaibab Limestone			0–60	Light-yellow thin-bedded dolomite; contains specks of green glauconite and collophane.
Permian		Cutler Formation	White Rim Sandstone Member	Upper unit	65–155	White thin- to thick-bedded dolomitic sandstone and minor sandy dolomite interbeds.
Permian		Cutler Formation	White Rim Sandstone Member	Lower unit	108+	White very thickly crossbedded fine-grained sandstone; medium- to large-scale crossbeds; base not exposed.

PERMIAN SYSTEM

Rocks of Permian age crop out only in deep canyons in the interior of the Circle Cliffs area, and they consist of, in ascending order, a white sandstone with large-scale crossbeds, a tabular stratified dolomitic sandstone—both of which probably are equivalent to the White Rim Sandstone Member of the Cutler Formation—and the Kaibab Limestone. The total thickness of Permian rocks, as known from the N. B. Hunt oil-test well, is about 2,300 feet.

Facies changes, origin, and correlation of Permian and older Paleozoic rocks of the Kaiparowits region were summarized by Heylmun (1958).

CUTLER FORMATION

The name Cutler Formation was given by Cross and Howe (1905) to a series of red beds near Ouray, Colo., that overlies the Rico Formation and is unconformably overlain by the Dolores Formation. The Cutler has been traced into the Henry Mountains region, where it is overlain by the Moenkopi Formation and underlain by the Rico (Baker and Reeside, 1929; Hunt and others, 1953, p. 37–40). Three members of the Cutler crop out in the eastern part of the Henry Mountains region. These are, in ascending order, the Cedar Mesa Sandstone Member, the Organ Rock Tongue, and the White Rim Sandstone Member. Hunt followed Gilluly and Reeside (1928, p. 63) and Gregory and Moore (1931, p. 40) in assigning a correlative sandstone in the western part of the Henry Mountains region to the Coconino Sandstone. The Coconino was named by Darton (1910, p. 21, 27) from exposures of crossbedded sandstone in the Grand Canyon region, where the sandstone is overlain by the Kaibab Limestone and underlain by rocks of Pennsylvanian age. The crossbedded sandstones of the Circle Cliffs and Capitol Reef areas and the San Rafael Swell, occupying similar stratigraphic positions, were correlated with the Coconino of the Grand Canyon area. This correlation has been questioned (McKee, 1954b; Stewart and others, 1959, p. 494) because the formation does not crop out continuously between the Circle Cliffs and the Grand Canyon areas, because bore holes are few, and because the Coconino progressively thins northward to a pinchout near the Arizona-Utah State line.

I suggest that the name Coconino Sandstone be dropped in favor of Cutler Formation in the Circle Cliffs area. This usage follows that of Steed (1954, p. 100–101) and Heylmun (1958, p. 1792). Steed correlated subsurface red beds in the central part of the Circle Cliffs "Coconino" with the Organ Rock Tongue of the Cutler Formation. These red beds occupy a stratigraphic position similar to that of the Organ Rock Tongue and are markedly dissimilar to the overlying and underlying quartzose sandstones, in that they are slightly arkosic and micaceous. Parts of the Coconino and Cutler are probably time equivalents, but the name Cutler is more appropriate for the sandstone beds underlying the Kaibab Limestone in the Circle Cliffs area.

The White Rim Sandstone Member of the Cutler, as herein defined and as shown on plate 1, consists of two units in the Circle Cliffs area. Both units are sandstone, and their total thickness is about 500 feet in the N. B. Hunt Government 1 well near the north end of Wagon Box Mesa.

The lower unit, of which a maximum of 108 feet is exposed in a tributary to Muley Twist Canyon, is white quartzose sandstone that is cross-stratified on a medium to large scale. The sandstone is very friable and only slightly calcareous. It is composed of well-sorted very fine to fine subangular and angular grains of frosted quartz sand with very minor amounts of plagioclase, microcline, muscovite, chert, tourmaline, and zircon(?). The contact between the lower and upper units of the White Rim is sharp and easily identified in the eastern part of the Circle Cliffs area; but in White Canyon, where almost 80 feet of the lower unit should be exposed, it intertongues with the upper unit so that a contact between the two cannot be picked. The crossbedded nature of the lower unit indicates eolian deposition, probably at the edge of a Kaibab sea; the crossbeds dip generally south, indicating that the prevailing wind at the time of deposition was from the north.

The upper unit of the White Rim Sandstone Member is horizontally stratified thin- to thick-bedded dolomitic sandstone with a few sandy dolomite beds. The total thickness of this unit increases from 66 feet in the easternmost stratigraphic section (section 2) to 154 feet in White Canyon (section 1). This increase almost certainly is gained through intertonguing with the underlying crossbedded sandstone. The upper contact is sharp and conformable; the uppermost bed is almost everywhere a very poorly sorted very fine grained to medium-grained dolomitic sandstone about 5 feet thick, and is overlain by dolomite of the Kaibab Limestone containing 5 percent or less of quartz grains.

The upper unit was included in the Kaibab Limestone by Gregory and Moore (1931), McKee (1938), and Steed (1954). In the geologic map and stratigraphic sections accompanying this report, the upper unit is included in the White Rim Sandstone Member because it intertongues with that unit and because it is dominantly a sandstone, not a carbonate rock; thus, lithologically, it is more similar to the White Rim than to the Kaibab. The contact between the upper unit

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and the Kaibab is sharp, occupies the same stratigraphic position throughout the Circle Cliffs area, and can be identified with a fair degree of certainty from a reasonable distance. The lower contact, as explained above, cannot be identified as easily.

The sandstone beds of the upper unit are light yellow to grayish white and are friable to well cemented. The major constituent is quartz, which is accompanied by lesser amounts of dolomite cement and traces of feldspar, muscovite, chert, pyrite, and various opaque and nonopaque heavy minerals. Locally, some beds contain 1–5 percent of heavy minerals. The sand grains are subrounded to rounded and dominantly very fine to fine. A few beds are composed of silt, and others contain coarse grains, but on the whole the sandstone is well sorted. The dolomite beds are pale yellow to yellowish brown and are generally fossiliferous. They show traces of oolitic structure, now largely destroyed by dolomitization. A sample of the uppermost dolomite bed measured near North Fork Creek (strat. section 4) was analyzed by Wayne Mountjoy, of the U.S. Geological Survey, who reported (written commun., 1956) a 1.57 calcium : magnesium ratio in the soluble carbonate; X-ray diffractograms completed by A. J. Gude 3d (written commun., 1965) showed that the sample comprised about 70 percent dolomite, 20 percent quartz, and 10 percent calcite. The dolomite beds contain as much as 10 percent quartz grains and as much as 1 percent pyrite crystals, some altered to hematite. Locally, quartz geodes lined with crystals of calcite and quartz are abundant, and some of the geodes may be filled or partly filled with asphaltic material.

Fossils in the dolomite beds are fragments or molds of gastropods and pelecypods, bryozoans, crinoid stems, brachiopods, scarce trilobites, and sparse molds of sponge spicules. In places some of the fossil fragments are replaced by collophane.

All fossils reported from the Kaibab Limestone by McKee (1938, p. 212) were collected from the upper unit, and every Kaibab lot reported by Gregory and Moore (1931, p. 42–43), except the upper collection of lot 4382, is from this unit. Fossils collected during the present study were identified by E. L. Yochelson, of the U.S. Geological Survey, who reported (written commun., 1956): "incomplete trilobite pygidium, cf. *Ditomopyge* or *Delaria*, and *Permophorus* sp., probably not *P. albequus*" from the upper 10 feet; "*Permophorus* sp. (large; common); fragments of gastropods, indeterminate (two genera)" from the uppermost dolomite layer about 8–15 feet below the top of the unit; "myalinid pelecypod, pectinoid pelecypod, *Permophorus* sp., and ?*Schizodus* sp." from sandstone below the uppermost prominent dolomite bed about 15–25 feet below the top of the unit. The fossils are of marine origin but are not diagnostic in determining the age of the unit, according to Yochelson.

The presence of marine fossils, the westward thickening and accompanying intertonguing with the underlying crossbedded sandstone, and the lithologic characteristics all lead to the conclusion that the upper unit of the White Rim is a transgressive marine deposit formed as Permian seas encroached to the east. In the western area of its outcrop the formation seems to contain more carbonate than in other areas; a few miles west of the Circle Cliffs area it probably is indistinguishable from the overlying Kaibab Limestone.

KAIBAB LIMESTONE

The Kaibab Limestone (Darton, 1910, p. 21–30), originally named the Aubrey Limestone by Gilbert (1875, p. 176–185, 187), is a thin-bedded light-yellow dolomite in the Circle Cliffs area. It is about 45 feet thick in most of the area and has a maximum thickness of about 60 feet, in White Canyon.

The Kaibab is absent in the southern and southeastern areas of Permian outcrop owing to erosion in Late Permian to Early Triassic time. It is missing also in the California Co. Muley Creek 1 (Alexander and Clark, 1954) on the crest of the Muley Creek anticline and in outcrop areas to the east in the Henry Mountains region. The formation thickens 10–15 feet, probably in the upper half, from the eastern to the western parts of the Circle Cliffs area. This trend of thickening is probably due to gradually less severe post-Kaibab erosion to the west.

The lithology of the Kaibab is virtually the same throughout the Circle Cliffs area. The formation is a thin-bedded very fine-grained to fine-grained oolitic porous dolomite. Most of the oolitic structure is poorly displayed, probably because of dolomitization. The formation as a whole is very light yellow, but beds range from white to brown. A few ¼–⅜-inch layers of green glauconitic feldspathic sandstone separate massive beds of dolomite. Three samples of the Kaibab, collected from widely separated locations, were analyzed by Wayne Mountjoy, who reported (written commun., 1956) that calcium : magnesium ratios in the carbonate mineral ranged from 1.27 to 1.44. X-ray diffractograms of the same samples made by A. J. Gude 3d (written commun., 1965) showed that the carbonate was dolomite. Pyrite cubes, feldspar grains, and shreds of muscovite(?) occur in the unit in trace quantities. The Kaibab erodes to a ledgy slope in most of the area and is generally poorly exposed. In some places the upper part of the Kaibab contains moderate amounts of quartz geodes, stringers of bedded gray chert, and gray chert nodules and fragments. A very persistent marker bed about 20–25 feet above the base contains abundant bedded and fragmental gray chert and fine quartz sand. These siliceous deposits may be slightly more abundant in the eastern part of the Circle Cliffs area than in other parts. Where chert is especially abundant the contact between the Kaibab and the overlying unit is difficult to identify. Characteristics that distinguish the Kaibab from overlying and underlying formations are (1) abundant specks of green glauconite and collophane, (2) an almost complete absence of sandstone, (3) an abundance of sponge spicule casts.

The Kaibab Limestone is fossiliferous and in places contains beds of coquina as much as 6 inches thick. Fossils collected from the lower part of the Kaibab and identified by E. L. Yochelson, of the U.S. Geological Survey (written commun., 1954, 1955), include:

crinoid columnals, ?monaxon sponge spicules, productoid brachiopod cf. *Juresania*, pectenoid pelecypod, *Permophorus* aff. *P. subcostatus* (Meek and Worthen), *Permophorus* cf. *P. Albequus* (Beede), *Permophorus* sp. (large), a small subulitid gastropod, and a generically indeterminate fragment of a gastropod that had revolving ornamentation.

In a collection made about 6 feet below the upper contact, Yochelson (written commun., 1956) identified:

crinoid columnals, an indeterminate nuculoid pelecypod, ?*Astartella* sp. indet., ?*Schizodus* sp. indet., *Permophorus* sp. indet. (small), ?*Aviculopecten* sp. indet., an euomphalid gastropod, an indet. gastropod, ?*Composita* sp. indet., and a spinose productoid brachiopod cf. *Juresania*.

Remains of a lithistid sponge were examined by R. M. Finks, Department of Geology, Queens College, New York, who reported (written commun., 1956) that the sponge probably represents a new genus and species occurring also in the Leonard and Word Formations of the Glass Mountains, Texas; according to Helen Duncan, of the U.S. Geological Survey (written commun., 1956), this sponge is probably not the sponge common in the Kaibab Limestone of the Grand Canyon area.

The Kaibab of the Circle Cliffs area is entirely of marine origin, and the uniform lithology of the formation leads to the opinion that the original eastern edge of Kaibab deposition is to the east of the present outcrop area. The patterns of distribution and thickening of the unit indicate that the formation was tilted regionally to the west or northwest following its deposition, and that a slight angular unconformity separates it from overlying rocks.

PERMIAN-TRIASSIC UNCONFORMITY

The regional Permian-Triassic unconformity was discussed in some detail by McKee (1938, p. 54–61; 1954a, p. 33–36), Dake (1920, p. 66–74), and Longwell (1925). The exact horizon of this unconformity was somewhat arbitrarily chosen because of an abundance of unconformities and a dearth of diagnostic fossils in key beds. The Kaibab Limestone—or where it has been removed, the Cutler Formation—is unconformably overlain by a chert-rich unit, herein called the basal unit of the Moenkopi Formation, that ranges from a sandstone to a sandy dolomite; this basal unit is unconformably overlain by the Sinbad Limestone Member of the Moenkopi Formation. Overlying red beds of the Moenkopi are in smooth sedimentary contact with the Sinbad, and with the basal unit of the Moenkopi where the Sinbad is absent.

The unconformity between the basal unit and the Kaibab has a maximum relief of about 70 feet. It is irregular and hummocky. The bedding of rocks underlying the surface is not disturbed, so the surface is due to erosion by surface water and not to development of a karst topography.

TRIASSIC SYSTEM

Rocks of Triassic age in the Circle Cliffs area are the Moenkopi and Chinle Formations, and of Triassic(?) age, the Wingate Sandstone, Kayenta Formation, and the lower part of the Navajo Sandstone (fig. 2). These formations are largely continental in origin except for the Moenkopi Formation, which was deposited in a marine, near-shore marine, and fluviatile environment (Stewart and others, 1959, p. 499).

MOENKOPI FORMATION

To facilitate description and identification, the Moenkopi Formation is divided, in ascending order, into the basal unit, the Sinbad Limestone Member, the lower ledge-forming unit, the middle slope-forming unit, and the upper ledge-forming unit. Sources of the Moenkopi Formation were in west-central and southwestern Colorado, southern Arizona and New Mexico, and northwestern Colorado (Wilson, 1958). Gradations of facies of the unit indicate a northwestward trend of drainage (Wilson, 1958) and a change from fluviatile to marine deposition.

BASAL UNIT

The basal unit of the Moenkopi Formation is white to light-gray fine-grained dolomitic sandstone to sandy dolomite and is 15–25 feet thick in most places. It contains abundant fragments of gray chert and in some places as much as 50 percent bedded chert. No fossils have been found in this unit, and its age is uncertain.

The basal unit is exposed mainly as a rubble of chert fragments capping benches and ledges of Kaibab Limestone. In the eastern and central parts of the Permian outcrop, it rests unconformably on either the Kaibab or, locally, beds of the White Rim Sandstone Member of the Cutler Formation as much as 8–10 feet below the top

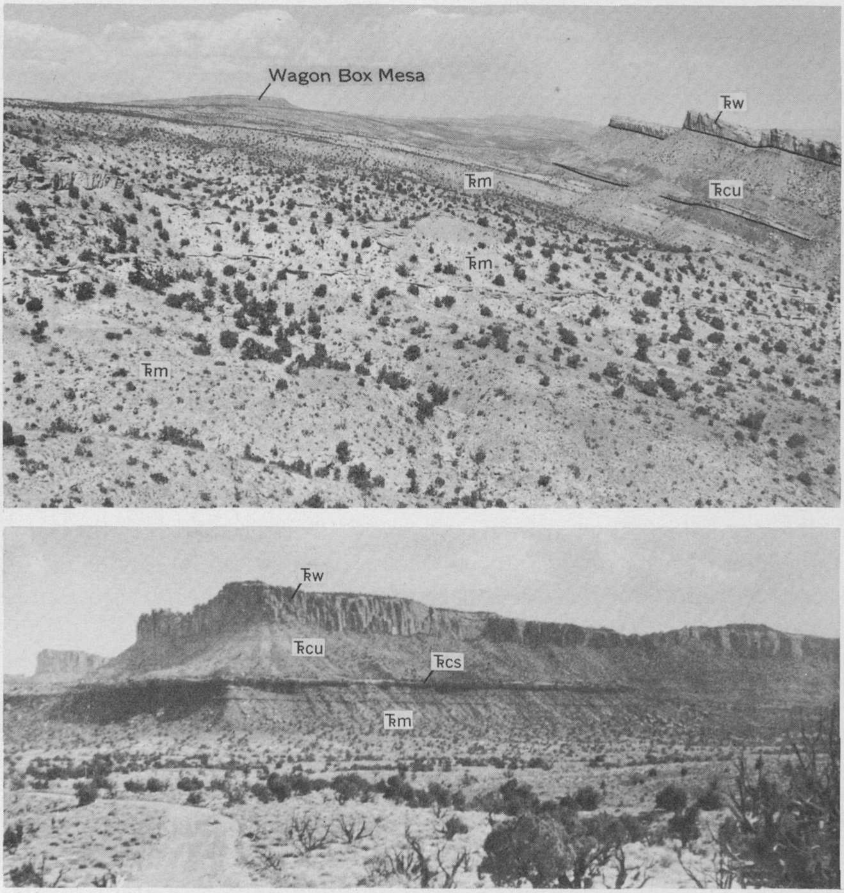

FIGURE 2.—Triassic rocks in southeast Circle Cliffs. Upper figure shows Moenkopi Formation (T̄Rm), Chinle Formation undifferentiated (T̄Rcu), and Wingate Sandstone (T̄Rw). Lower figure shows divide between Moody and Silver Falls Canyons. Moenkopi Formation (T̄Rm), Shinarump Member of the Chinle Formation (T̄Rcs), Chinle Formation undifferentiated (T̄Rcu), and Wingate Sandstone (T̄Rw).

of the upper unit. Locally, where the basal unit is a dolomite and rests conformably on the Kaibab, the contact between it and the Kaibab appears gradational. In these places the basal unit resembles, and probably is at least in part, a residual deposit that grades almost imperceptibly downward from a sandy dolomite into the nearly pure dolomite of the Kaibab.

The basal unit does not crop out continuously in the east-central part of the Permian outcrop, and in the southeastern part of the Circle Cliffs area, in particular, its outcrop is very discontinuous. Here it is generally only 5–10 feet thick and in many places has been reworked and incorporated into a facies of the overlying Sinbad Limestone Member of the Moenkopi Formation. Although distinction of the two units is difficult in such places, the basal unit is generally characterized by abundant well-sorted fine-grained sandstone instead of the poorly sorted fine- to coarse-grained sandstone in the Sinbad, by white to gray color instead of the orange brown of the Sinbad, and by bedded chert, which is absent in the Sinbad. Erosion at the edges of the Sinbad sea removed this basal unit as well as the Kaibab in places.

In summary, the basal unit of the Moenkopi is both a fluvial and a residual deposit. It may be Permian or Triassic in age, but because of its extensive unconformable relation to the Kaibab, it is included in the Moenkopi Formation on the maps and stratigraphic sections accompanying this report.

SINBAD LIMESTONE MEMBER

The Sinbad Limestone Member of the Moenkopi Formation rests on either the Kaibab or the White Rim Sandstone Member of the Cutler Formation in the southern and eastern areas of its outcrop; elsewhere except in one exposure it rests on the basal unit of the Moenkopi Formation. The basal contact is an erosional unconformity except in the northwest corner of the outcrop area, where a 5-foot-thick bed of green siltstone separates the Sinbad and the basal unit of the Moenkopi. The siltstone probably is equivalent to the red mudstone that separates the Sinbad from the Kaibab in the Capitol Reef area. In the Capitol Reef area the red mudstone thins markedly to the south toward the Circle Cliffs area before passing out of sight under younger rocks (Smith and others, 1963, p. 12).

The Sinbad Limestone Member grades from a conglomeratic dolomitic sandstone in the east to a dolomite in the west. It is commonly brownish orange to yellow orange. The Sinbad is as much as 120 feet thick, thin to thick bedded, and locally crossbedded. Oolitic textures are very common, as are beds composed of a coquina of gastropod and other fossil fragments.

The Sinbad is absent in the eastern part of the Circle Cliffs area and thickens to about 80 feet in the northwestern part (fig. 3). It is about 120 feet thick in a tributary canyon between White Canyon and Horse Canyon. Crossbeds in sets 3–4 feet thick and 6–10 feet long are common, especially where the formation is sandy or oolitic. In areas where the outcrop is continuous, the Sinbad is a relatively pure oolitic dolomite containing only a small percentage of sand grains. A sample obtained from an outcrop 1 mile northeast of the northeast end of Wagon Box Mesa was analyzed by Wayne Mountjoy (written commun., 1956), who reported a 1.27 calcium : magne-

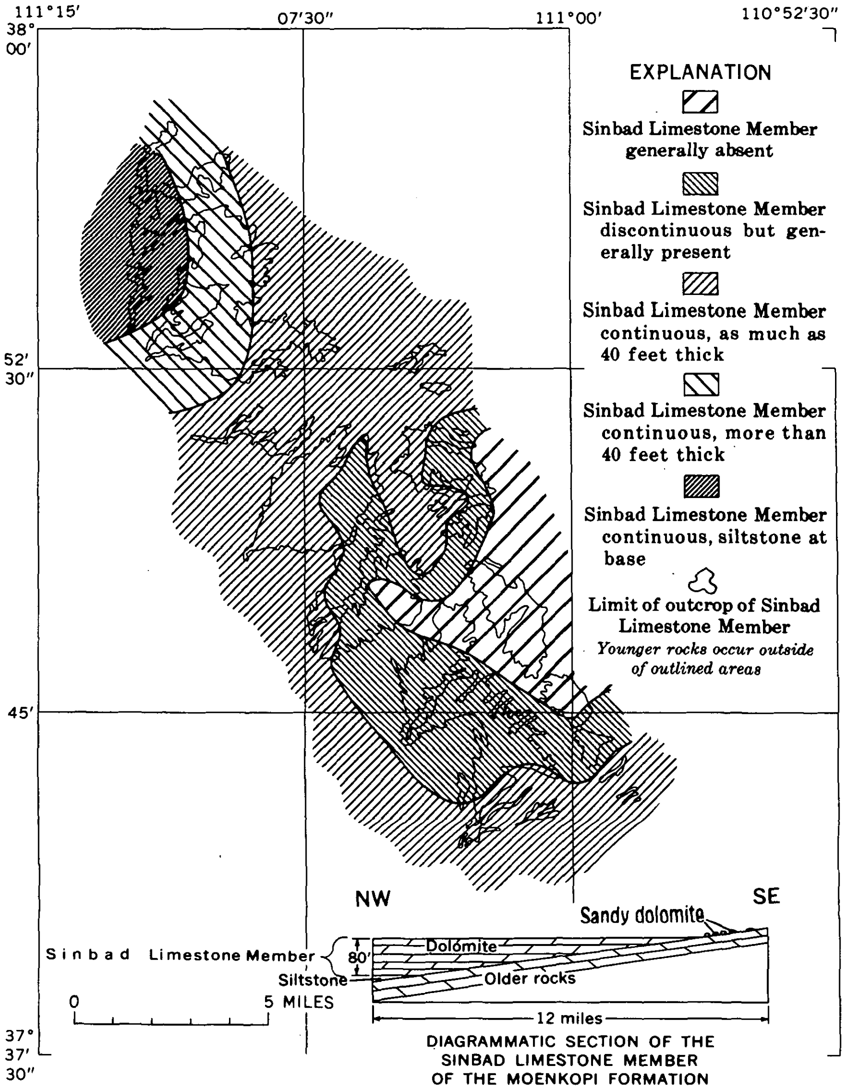

FIGURE 3.—Distribution of the Sinbad Limestone Member of the Moenkop Formation in the Circle Cliffs area. Compiled by L. D. Carswell and E. S. Davidson, 1956–57.

sium ratio in the soluble carbonate mineral. X-ray diffractograms completed by A. J. Gude 3d (written commun., 1956) showed that the carbonate was dolomite. In the eastern exposures, where the outcrops are discontinuous, the unit commonly is a sandy dolomite or a dolomite-cemented sandstone and locally is saturated with asphalt. The sandstone facies is conglomeratic and contains abundant fragments of gray chert which probably were derived from either the underlying basal unit of the Moenkopi or the Kaibab.

The sandstone matrix is poorly sorted and fine to coarse grained and is composed of quartz and chert fragments.

Fossils collected from the Sinbad consist mainly of fragments of pelecypods and gastropods that are not diagnostic for correlation or dating purposes. J. B. Reeside, Jr., and N. J. Silberling, of the U.S. Geological Survey, examined the collections and reported that they consist of indeterminate gastropods, pelecypods, algal debris, a radially ribbed dysodont pelecypod, and *Aviculopecten*? sp. According to Reeside (written commun., 1954), "this porous rock with gastropods is found at a number of places associated with *Meekoceras* and other Lower Triassic ammonites, and in my judgment is to be attributed to the Triassic rather than the Permian wherever it occurs in the Plateau region." Although the *Meekoceras* fauna has not been collected in the Circle Cliffs area, the dolomite unit is almost certainly equivalent to the Sinbad, and it is lithologically the same as the Sinbad of the Capitol Reef area from which the *Meekoceras* fauna was collected. The *Meekoceras* fauna is middle Early Triassic in age (McKee, 1954a, p. 15). The Sinbad of the Circle Cliffs area probably is also correlative with at least part of the Timpoweap Member of the Moenkopi Formation which crops out in the Grand Canyon area.

Oolitic texture, crossbedding, and coquina beds indicate that the Sinbad was deposited in a shallow-water marine environment. The eastern part of the Circle Cliffs area was at the edge of the Sinbad sea, near which the sandstone and conglomeratic facies were deposited.

LOWER LEDGE-FORMING UNIT

The lower ledge-forming unit of the Moenkopi consists of interlayered sandstone and siltstone beds that erode differentially, giving the outcrops a ledge-and-bench topographic expression. Normally, this unit is brownish red, but due to a widespread impregnation by oil or asphalt, and dependent on the asphalt content, the red rock is shaded from light grayish red to light gray or black. The most asphaltic rock is light yellow and locally dark gray in weathered outcrops. The unit is about 200–245 feet thick and grades into the overlying slope-forming unit of the Moenkopi. Ripple marks and small-scale crossbedding are common. The sandstone is largely quartz with some feldspar and mica and is cemented primarily with iron oxide.

The lower ledge-forming unit is asphaltic in a considerable area of its outcrop (fig. 4); the asphalt content ranges from black rock oozing asphalt to light-grayish-red rock that shows only faint traces of asphalt. The rock that is moderately to heavily impregnated with

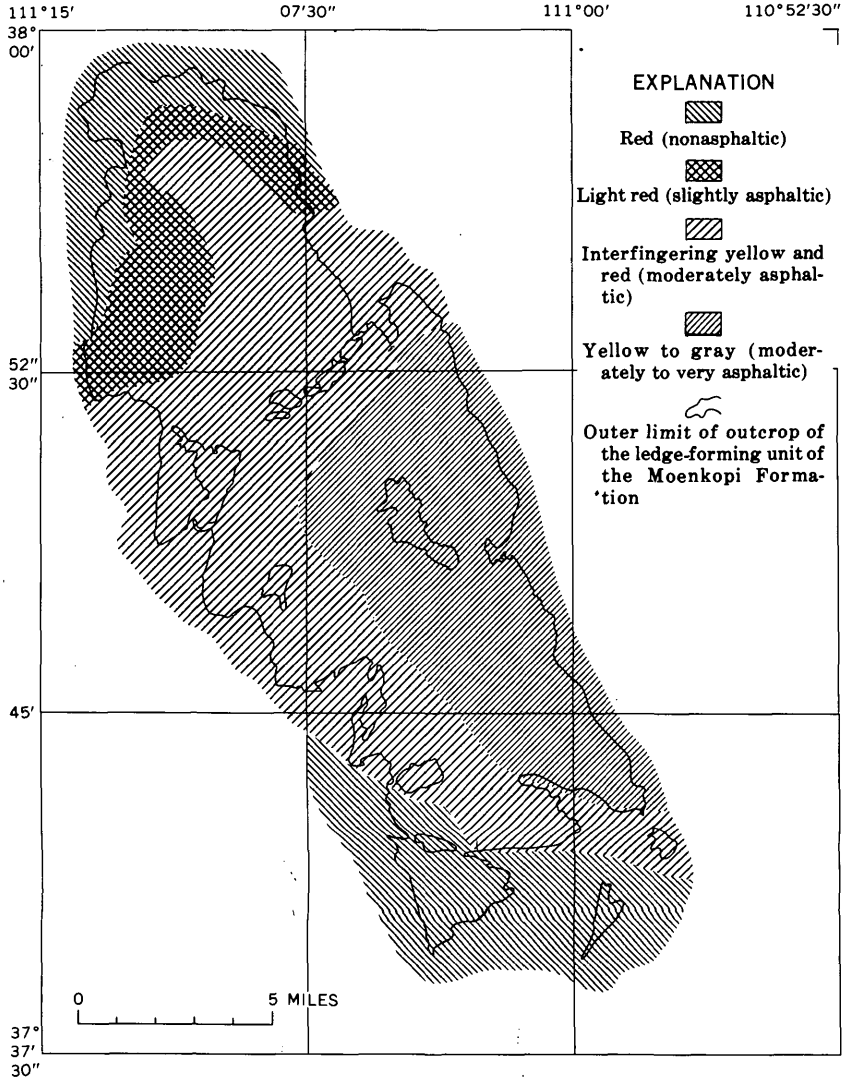

FIGURE 4.—Distribution of asphalt in the Moenkopi Formation. Compiled by L. D. Carswell and E. S. Davidson, 1956–59.

asphalt contains abundant and widely disseminated pyrite, which is not present in the normally red Moenkopi, but may have originated through a combination of iron from the Moenkopi with sulfur from the intruded asphalt. The rock moderately impregnated with asphalt is light yellow in weathered outcrops, probably due to oxidation of the disseminated pyrite to a limonitelike material. Because of the reaction of the introduced pyrite to weathering, the rock outcrop color can be used to differentiate the degree of asphalt introduction. The yellow to gray rock is most asphaltic, the interfingered yellow and red rock is intermediate in asphalt content, and the light-grayish-red rock is only slightly asphaltic (fig. 4).

The control and age of the asphalt introduction cannot be determined directly, but several observations may be pertinent to understanding this introduction. The area most heavily impregnated with asphalt slightly overlaps the area where the Sinbad is absent, and the asphalt content decreases in a zonal pattern that closely parallels the thickening pattern of the Sinbad (fig. 3). The area of high asphalt content coincides very closely with an area where little or no sediment of the Shinarump Member of the Chinle Formation was deposited, and the major Shinarump channel and its tributaries (fig. 16) describe a broad arc around the area of high asphalt content. The Sinbad and Shinarump distribution patterns may delineate a structural high into which the asphaltic material rose. However, the middle units of the Moenkopi do not seem to thin in the high area, and the mottled-siltstone unit of the Chinle Formation is present in the structural high. Assuming a structural-high asphalt-control hypothesis tenable, the peak of the high would have coincided with the area of moderately asphaltic to very asphaltic rock, which does not correlate readily with the crest of the Circle Cliffs anticline. Therefore, the structural high must have existed prior to formation of the Circle Cliffs structure. Asphalt occurs in the Shinarump, and, in the heavily faulted area east of Wagon Box Mesa, alteration associated with faults has overlapped the alteration caused by the asphalt introduction. The asphalt introduction must postdate the Shinarump but predate the major faulting and, by inference, the Circle Cliffs anticlinal folding, which occurred in the Late Cretaceous to early Eocene.

Fossils collected from the lower ledge-forming unit include fish scales and myalinids. The fish scales were collected from a very carbonaceous appearing outcrop, stratigraphically near the middle of the unit. This locality is in a small tributary of Muley Twist Canyon at about lat 37°47′ N., long 111°30′ E. D. H. Dunkle (written commun., 1955), of the U.S. National Museum, examined the scales and stated:

These isolated fish scales seem to be identical with those reported by S. P. Welles (1947) from the Moenkopi formation in Arizona and identified by that author as pertaining to the subholostean genus, *Boreosomus*. *Boreosomus* is, in the strict sense, a marine fish known in great detail from the lower Triassic of Greenland, Spitzbergen, and Madagascar.

The myalinids were collected from beds near the top of the unit about 1 mile east of the Hotshot prospect (pl. 1, sheet 2). They were identified by Bernhard Kummel (written commun., 1953), of Harvard University, as

poorly preserved specimens of *Myalina* cf. *spathi* Newell and Kummel. This species is common in the Dinwoody formation of western Wyoming. Myalinids of this type are common in shallow water, near shore, generally calcareous clastic strata of Lower Triassic age in Wyoming, East Greenland, Spitzbergen and Siberia.

The lower ledge-forming unit probably is a near-shore or lagoonal deposit, according to the fossil evidence and to sedimentary facies studies by Wilson (1958). The crossbedded sands represent deposition predominantly in stream channels, and the rippled silts, in tidal flats or river flood plains. The source area of the materials was to the east and south, in the Uncompahgre and Mogollon Highlands (Poole, 1961).

SLOPE-FORMING UNIT

The slope-forming unit of the Moenkopi Formation consists of reddish-brown feldspathic and micaceous siltstone or mudstone cemented by red iron oxide. It contains a few thin very fine grained to fine-grained brown to light-greenish-gray sandstone beds that crop out in ledges. The unit is about 250 feet thick, and forms a smooth slope. It is mostly very thin bedded and shows some ripple marks. The lower 40–50 feet is asphaltic in a few places, and, as in the lower ledge-forming unit, the asphaltic rock weathers light yellow. The rocks of the slope-forming unit are conformably overlain by sandstone and siltstone beds of the upper ledge-forming unit. The slope-forming unit is probably of shallow-water marine origin and possibly was deposited slightly farther offshore than the underlying ledge-forming unit.

UPPER LEDGE-FORMING UNIT

The upper ledge-forming unit of the Moenkopi is composed of mudstone, sandstone, dolomitic sandstone, and minor dolomite beds that crop out in resistant ledgy cliffs or steep slopes everywhere in the Circle Cliffs area. It is about 45 feet thick and is continuous except where displaced by channel-filling sediment of the Shinarump Member of the Chinle Formation. Several individual beds can be traced on the outcrop for 10 miles and correlated with fair certainty throughout the whole area (fig. 5). The mudstone beds are dark reddish brown, micaceous, and very thin bedded to laminated. The mudstone is soft and forms gentle recessed slopes between ledges of the sandstone or dolomite beds. The sandstone beds are greenish gray to yellowish gray, very fine grained, thin bedded, dolomitic, and silty. The dolomite beds are yellowish gray to light yellow and silty. Both the sandstone and the dolomite beds are resistant to erosion and stand out in prominent thin ledges.

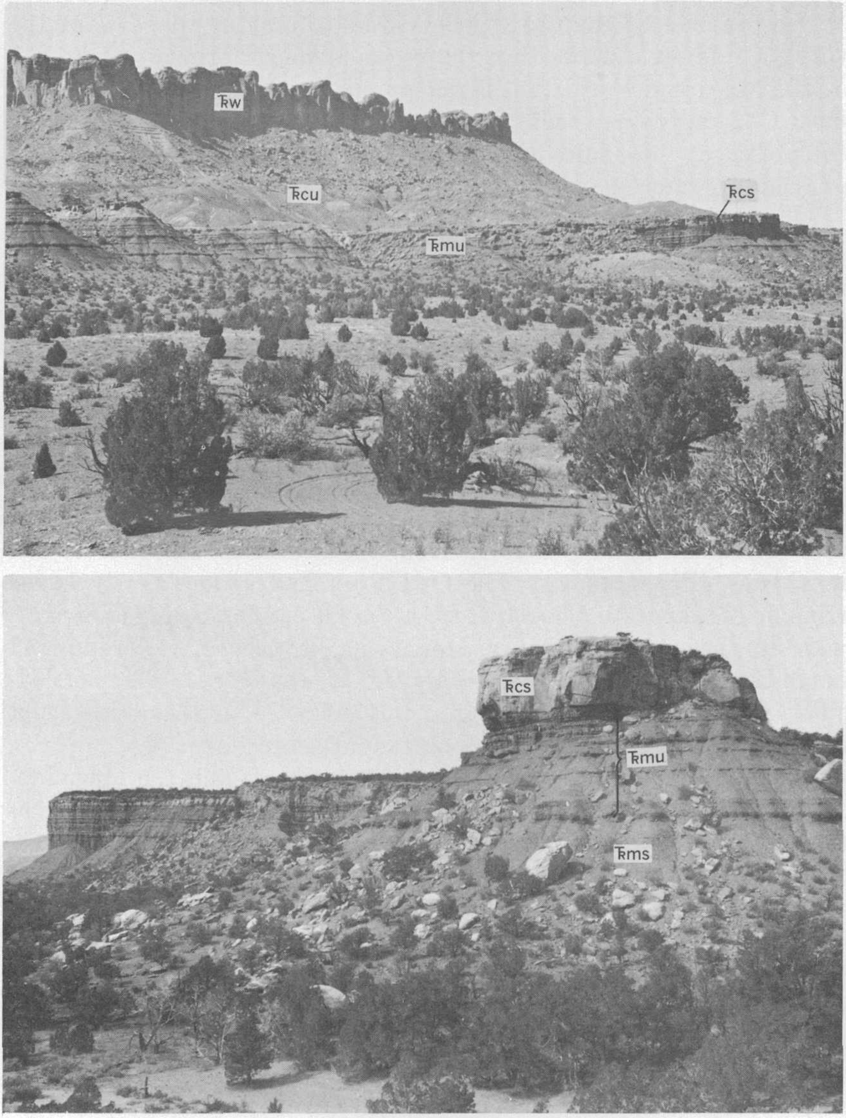

FIGURE 5.—Upper ledge-forming unit of the Moenkopi Formation on slope below bench capped by the Shinarump Member of the Chinle Formation. TRw, Wingate Sandstone; TRcu, Chinle Formation undifferentiated; TRcs, Shinarump Member of Chinle Formation; TRmu, Moenkopi Formation, upper ledge-forming unit; TRms, Moenkopi Formation, slope-forming unit. Upper figure: Northern Circle Cliffs area, at Moki Ruins. Lower figure: Western Circle Cliffs area, near Blue Goose prospect.

The presence of the upper ledge-forming unit in all parts of the Circle Cliffs area shows that the regional unconformity at the top of the Moenkopi Formation is not angular. The widespread distribution of individual beds, the rippling of the sandstone beds, and the presence of dolomite beds indicate that the formation is probably of shallow-water marine origin.

CHINLE FORMATION

Intertonguing fluvial mudstone, sandstone, and siltstone units of red, blue, and gray hues are combined in the Chinle Formation of the Circle Cliffs area. In ascending order the units are the mottled-siltstone unit, Shinarump Member, Monitor Butte Member, Petrified Forest Member, Owl Rock Member, and Church Rock Member. The thickness of Chinle ranges from 740 feet in the east to about 550 feet in the west. The Shinarump, Monitor Butte, and Petrified Forest Members were deposited by streams on an alluvial plain that sloped northward from a source area in and near southern Arizona; these streams flowed generally from the southeast and east to the northwest (Poole, 1961). The Owl Rock had a dominantly lacustrine origin, and the Church Rock a fluvial origin; sediment sources were in the ancestral Rocky Mountains in western Colorado and north-central New Mexico (Stewart and others, 1958). The mottled-siltstone unit is fluvial in origin, but evidence in the area is not conclusive enough to pinpoint a particular source area.

The regional unconformity between the Chinle and the Moenkopi Formations is represented mainly by the erosional unconformity at the base of the Shinarump Member of the Chinle. In the Circle Cliffs area the relief of the contact between the basal mottled-siltstone unit of the Chinle and the Moenkopi Formation is not more than 30 feet, but where this unit is absent the relief of the contact between the Shinarump and older rocks is as great as 200 feet. The mottled-siltstone unit and the Moenkopi are eroded and deeply channeled in places, and in these places the channels are filled by sandstone of the Shinarump. Thus, a significant unconformity may separate the Shinarump and the mottled-siltstone unit, although Stewart, Williams, Albee, and Raup (1959, p. 502) reached a contrary conclusion.

MOTTLED-SILTSTONE UNIT

The mottled-siltstone unit generally rests unconformably on the Moenkopi Formation and has been included in the Chinle Formation in this study. This unit is reddish brown and mottled white, and consists of siltstone and a few local sandstone lenses. It generally is 15–20 feet thick and locally is as much as 50 feet thick owing to channel-filling deposits underlying the more widespread upper beds.

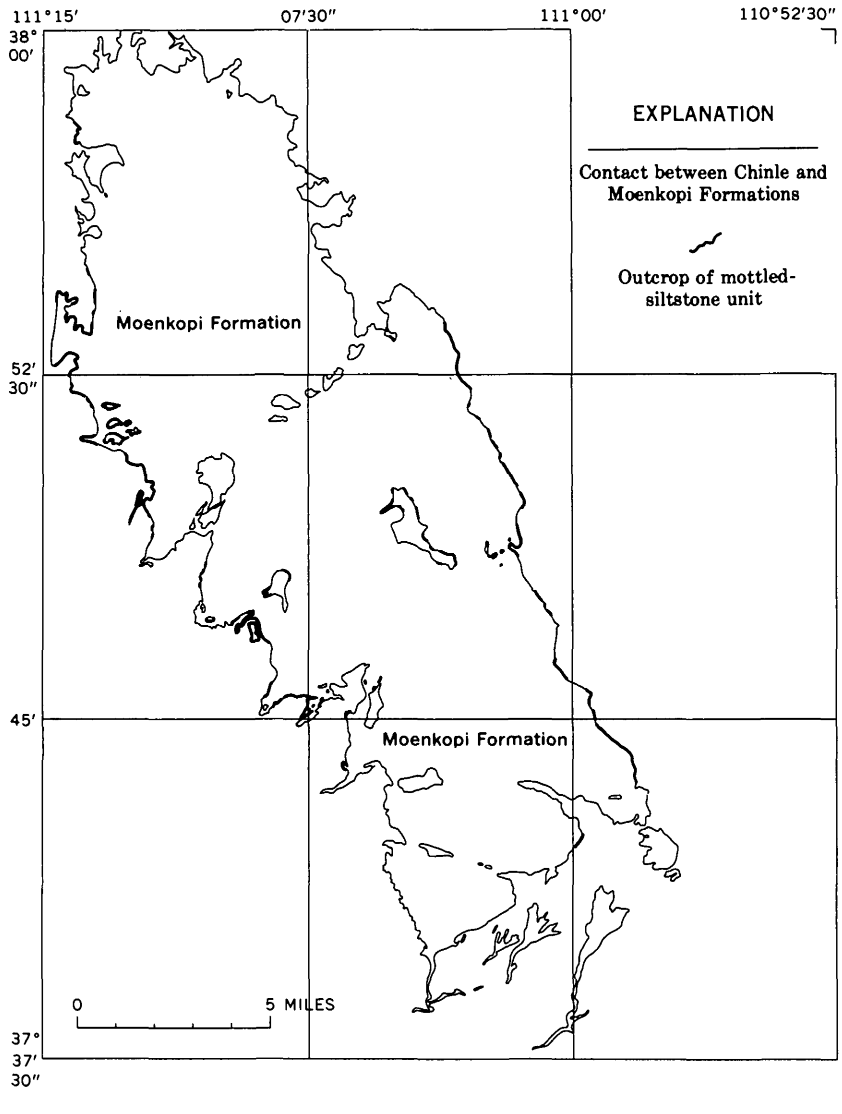

FIGURE 6.—Distribution of the mottled-siltstone unit of the Chinle Formation. Compiled by L. D. Carswell and E. S. Davidson, 1956–57.

The mottled siltstone, although not thick enough to constitute a mappable unit, is widely distributed in the Circle Cliffs area, and a map showing its distribution is included in this report (fig. 6).

The basal contact of this unit is an erosion surface on which the relief averages about 2 feet and is nowhere more than 30 feet (fig. 7). In some places the surface has the form of stream channels cut in the top of the Moenkopi. In a few other places, such as

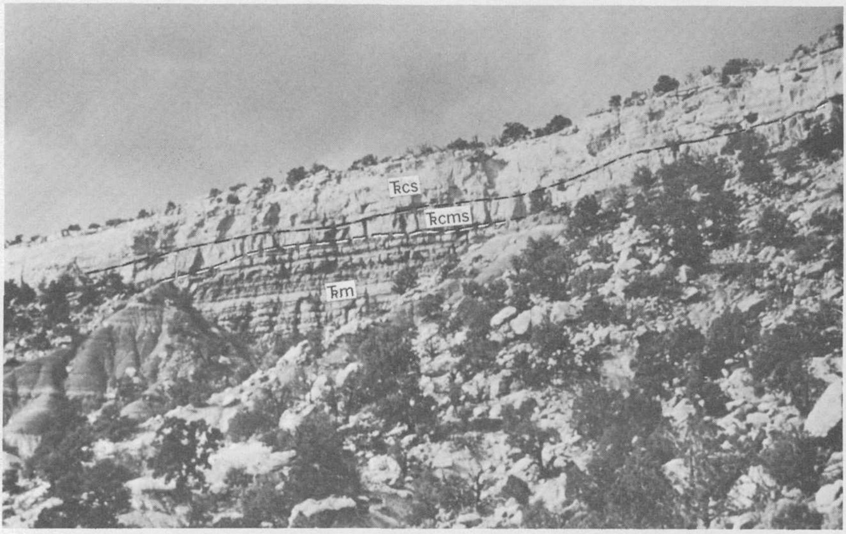

FIGURE 7.—Mottled-siltstone unit of the Chinle Formation (TRcms) on Wagon Box Mesa, underlain by Moenkopi Formation (TRm); overlain by Shinarump Member of the Chinle Formation (TRcs).

at the northwest tip of Wagon Box Mesa, the mottled-siltstone unit appears to grade downward into unaltered silt of the Moenkopi Formation. This latter type of contact is not common and may indicate weathering and partial reworking of the Moenkopi at these places prior to the deposition of the mottled-siltstone unit.

The siltstone unit is very distinctive because of its mottled maroon and white coloring, ledge-forming outcrop, and vertical fracturing (fig. 7). Most commonly it consists only of well-cemented siltstone containing scattered medium- to coarse-grained fragments of quartz, but locally carbonaceous material is included. Myriad slickensided surfaces are characteristic of the unit. A 1- to 3-inch zone containing hematite-rich siltstone nodules is commonly present at the base of the uppermost, and most widespread, siltstone bed, which is about 15–20 feet thick. In a few places, notably on the largest mesa capped by Shinarump east of Wagon Box Mesa and near some of the mesas northeast of the Blue Bird prospect in Horse Canyon (pl. 1, sheet 1), 20–30 feet of mottled fine-grained sandstone fills channels and depressions below the more common widespread siltstone unit.

All color gradations and stages in the process of bleaching from maroon to grayish-white can be found. The mottling is clearly the result of bleaching by solutions that percolated downward from the top of the unit. The bleaching first followed vertical cracks down into the rock, and then extended along horizontal bedding planes to adjacent vertical cracks; as a result, balls of maroon rock were left in a matrix of white rock. If the bleaching continued, the whole rock is altered to white. Some of this bleaching extended into the underlying Moenkopi Formation, but there it is not as complete nor as widespread as in the mottled-siltstone unit.

The lithology of the mottled-siltstone unit is rather unusual; thin-section examination shows the unit to be composed almost entirely of angular grains of quartz and some kaolinite in the matrix and in microfractures; the amount of heavy minerals, mainly tourmaline, is notably greater than in either the Moenkopi or the overlying Shinarump. In addition, shreds of muscovite and scattered grains of chert are present. Feldspar is conspicuously absent. The cement is primarily silica, but some sections show considerable iron oxide and kaolinite cement. Sutured quartz grains were noted only in the hematized siltstone nodules. In an outcrop about 1 mile southeast of the Rainy Day mine (pl. 1, sheet 1), an arkose cemented by carbonate underlies the mottled-siltstone bed. The grains in the arkose are generally subrounded to angular, but many of the quartz grains have euhedral outlines. Some of the quartz grains have stylolitic boundaries where they contact other quartz grains.

The mottled-siltstone unit has been interpreted as a weathered zone of slightly reworked Moenkopi silt and some introduced coarser clastic grains (Stewart and others, 1959, p. 504). However, the angularity of the quartz grains in the Circle Cliffs area precludes such an origin because if the well-rounded grains in the Moenkopi were reduced to the angular shapes noted in the mottled-siltstone unit, they would be clay size. Most of the unit represents introduced sediment and not reworked Moenkopi, although some reworked Moenkopi surely is included in the unit, especially in places where the contact between the two appears to be gradational. One is tempted to lend more authority to the arkose outcrop southeast of the Rainy Day mine than perhaps should be done, and to conclude that the mottled unit represents a fluvially deposited arkosic unit that consists primarily of angular quartz grains, kaolinite, heavy minerals, and iron oxide (primarily hematite), and has undergone severe lateritic-type weathering.

Beds of mottled siltstone and sandstone probably correlative with the mottled-siltstone unit are exposed northeast of Moab, near the Dewey Bridge on the road from Cisco to Moab, and in the San Rafael Swell, Capitol Reef, Orange Cliffs, and Zion Park regions. Robeck (1956) applied the name Temple Mountain Member of the

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Chinle Formation to these beds in the San Rafael Swell, but because of the largely undeserved confusion and difference of opinion concerning the unit there and regionally (Abdel-Gawad and Kerr, 1963; Kerr and Abdel-Gawad, 1964; Johnson, 1964), particularly as to whether the unit is an alteration phenomenon ("purple white" or "pinto" effect) or a stratigraphically separable though altered unit, I prefer not to extend the name Temple Mountain Member to the Circle Cliffs area.

SHINARUMP MEMBER

The Shinarump Member of the Chinle Formation (Stewart, 1957) is a gray to yellowish-white sandstone that is widespread in the Circle Cliffs area. It was deposited in channels and as a blanket deposit by streams that meandered over the Moenkopi terrain (fig. 8). Lithologically, the sandstone is a feldspathic medium-grained sandstone that contains subordinate lenses of clayey silt and pebble or cobble conglomerate. Regional studies of the orientation of cross-strata (Poole, 1961) indicate that the source of the Shinarump was to the south and southeast.

The contact between the Shinarump and older rocks in the area is an erosional unconformity and shows little or no angularity. Some of the larger channels in the unconformity surface extend down through the mottled-siltstone unit of the Chinle Formation and the upper ledge-forming unit and most of the slope-forming unit of the underlying Moenkopi Formation. The upper contact

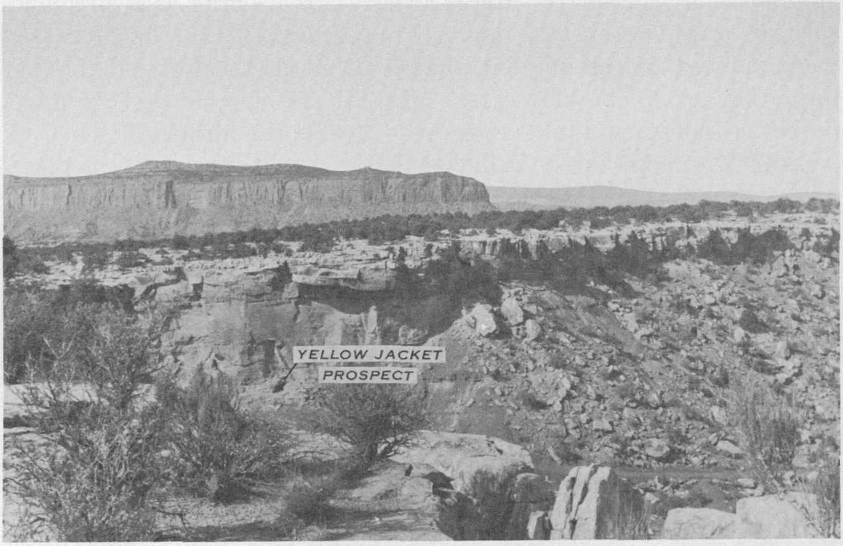


FIGURE 8.—Shinarump Member of the Chinle Formation, a channel and blanke deposit, at Yellow Jacket prospect.

of the Shinarump is indefinite and gradational because the Shinarump grades into, and intertongues with, the overlying Monitor Butte Member of the Chinle Formation. The stream that deposited the sand of the Shinarump flowed generally northwest (fig. 14). The largest channel, some of which is preserved in the Stud Horse Peaks, is about 190 feet deep and as much as 8,000 feet wide. Most other channels are less than 100 feet deep and 3,000 feet wide. Kleinhampl and Koteff (1960, p. 98–102) pointed out that channels can be identified by botanical methods because the pinyon : juniper ratio on benches and mesas capped with Shinarump is greater over thick deposits than over thin deposits.

The Shinarump generally can be divided into three units, which are best exposed on Wagon Box Mesa. These units, in ascending order, are medium-grained very thick bedded sandstone; interlayered thin-bedded sandstone, siltstone, and mudstone; and poorly sorted slabby thin- to thick-bedded sandstone.

The lowest unit is a relatively clean light-yellow medium-grained quartzose sandstone that forms the major part of the fill in the large channels, where it is as much as 100 feet thick. The dip of crossbedding in this unit nearly everywhere parallels closely the trend of the stream channel. The sandstone is not very carbonaceous, and conglomerate beds are sparse. The unit seems too uniform in lithology, bedding, and texture, and too noncarbonaceous, to be a favorable host for uranium minerals.

Overlying, grading into, and intertonguing with the upper part of the lowest unit is a discontinuous greenish-gray interlayed siltstone, mudstone, and sandstone unit. This unit seems to mark the top of the large channels and resembles deposits in the flood plains of modern large streams. It contains a high percentage of clay and mica and probably was deposited in quiet water or by sluggish streams.

The uppermost sandstone unit forms most of the Shinarump cap in the Circle Cliffs area and is the only Shinarump unit present on the west side of the area, where it fills myriad small channels that are about 30 feet deep and as much as half a mile wide. The unit is generally 40–60 feet thick where it constitutes the entire Shinarump, but over large channels occupied by lower units it is as much as 120 feet thick, owing mainly to thickening at the expense of the overlying Monitor Butte Member of the Chinle. It contains conglomeratic beds, is very kaolinitic, and commonly includes considerable carbonaceous charcoaly material, some of which has been silicified or partly replaced by pyrite or hematite. The general downdip direction of the crossbeds in this unit is north to northwest. In the

Stud Horse Peaks channel, the crossbeds of this unit dip northeast parallel to the channel course; but on Four Mile Bench, in the southern area of Shinarump exposure, the channel courses trend westward, and crossbeds in the upper unit dip generally north. The unit is probably most favorable for uranium deposition because of the lenticularity of the beds, the common occurrence of pods and layers of clayey and carbonaceous materials, and the general high carbon and pyrite contents. The sandstone unit intertongues with the overlying Monitor Butte Member of the Chinle; it is generally thicker over the major channel courses, and it intertongues with the Monitor Butte mudstone and siltstone on the edges of the courses.

The Shinarump is feldspathic sandstone composed of quartz, feldspar, kaolin, and some flakes of muscovite and biotite. The feldspar is commonly microcline, perthite, and minor plagioclase. The quartz grains are subangular to subrounded and poorly sorted, and they commonly show overgrowths. Tourmaline, apatite, zircon, and magnetite-ilmenite occur in trace amounts. The cementing material commonly is kaolin, and the sandstone, therefore, is friable. Locally, however, the groundmass contains considerable carbonate, and the sandstone is moderately well cemented. The pebbles in the conglomeratic beds and scattered through the sandstone beds consist principally of gray quartzite, clear quartz, carbonaceous material, and fragments of gray siltstone and mudstone probably derived from the underlying Moenkopi Formation. The fragments derived from the Moenkopi are generally most common in the lowest 5 feet of the Shinarump, directly overlying the Moenkopi. In the Colorado Plateau the average ratio of quartz, quartzite, and chert pebbles in the Shinarump is 82 : 16 : 2 (Albee, 1957, p. 135–142). The ratio in the Circle Cliffs area is 52 : 25 : 23 (Albee, 1957), which shows that quartzite and chert pebbles are more abundant there than in the Colorado Plateau as a whole. The ratio of chert and quartzite to quartz pebbles increases to the south, as reported by Stewart, Williams, Albee, and Raup (1959, p. 507). This increase reflects the influence of a source area to the south, where the chert-rich Kaibab Limestone and other sedimentary rocks must have been exposed to erosion.

Fossil material from the Shinarump was collected by Frank Kleinhampl in 1955 from sec. 32, T. 32 S., R. 7 E., about 3,000 feet N. 25° W. from the Lamp Stand, a prominent butte at the north edge of the area (pl. 1, sheet 1). R. W. Brown, of the U.S. Geological Survey, identified this fragmentary plant material (written commun., 1956) as "possibly a small leaf of *Sphenozamites rogersianus* Fontaine." If the identification of this fragment is correct, a Triassic age can be assigned. A sample collected from a coal bed that crops out several miles west of the Blue Bird prospect contained pollen grains of *Ephedra chinleana* (Daugherty) R. A. Scott. Concerning this species, Scott (1960, p. 271–272) wrote: "The known stratigraphic range of this fossil *Ephedra* species is limited to the Upper Triassic."

The Shinarump is one of the main host rocks for uranium minerals in the Circle Cliffs area, but by 1958 no uranium ore bodies of more than 10,000 tons in size had been discovered. This, in part at least, may be due to the relatively "clean" nature of the sandstone—specifically, the relative lack of clay, clay-pellet conglomerate, and charcoaly wood fragments, most of which are present in substantial amounts at places where larger ore bodies occur in the Shinarump.

ALTERATION ASSOCIATED WITH THE SHINARUMP MEMBER

The upper few feet of the Moenkopi Formation is generally altered where the formation is overlain by the Shinarump Member of the Chinle Formation. The Moenkopi is not altered where it is overlain by mudstone of the Monitor Butte Member of the Chinle. The altered rock is light gray to dark gray where unweathered and pale yellow where weathered, which contrasts with the reddish-brown unaltered Moenkopi siltstone and with the light-yellow to gray Shinarump. The altered zone generally ranges from 1 inch to 25 feet in thickness, but normally it is about 5 feet thick. The differences in thickness are not directly related to the thickness of the Shinarump, as the altered zone occurs both under deep channels filled with Shinarump and in places where the Shinarump is only about 1 foot thick. The altered zone transects beds of the Moenkopi and is roughly parallel to the Shinarump-Moenkopi contact. The gray color, as judged from chemical analysis, is primarily due to reduction of ferric oxide in the reddish-brown rock to a ferrous form, accompanied by formation of pyrite and perhaps the addition of asphaltic material.

The gray alteration probably resulted from downward percolation of water of a reducing character from the Shinarump. It is so widespread that it is not regarded as a prospecting guide or as an indication of uranium-bearing rock.

The gray alteration associated with the Shinarump is very different from the alteration associated with the mottled-siltstone unit that overlies the Moenkopi and is overlain by the Shinarump. The mottled-siltstone unit changed from purplish red or reddish brown to white; chemically, the alteration is probably a bleaching effect and is due to complete removal of iron oxide from the red rock to produce a white rock. The purple and white altered rock is restricted to the mottled siltstone and is transected by channels filled with

Shinarump. In the Blue Goose prospect area, the mottled-siltstone alteration appears to be overlapped by the gray alteration associated with the Shinarump.

Where the mottled-siltstone unit is transected by channels, the alteration peculiar to it is not found. Elsewhere, the altered zone does not follow or parallel the Shinarump-Moenkopi contact, and it may exist whether or not the Shinarump is present. In contrast, the Moenkopi is altered only where it is overlain by the Shinarump or by some other sandstone unit of the Chinle Formation.

In summary, the alteration of the mottled-siltstone unit probably predates deposition of the Shinarump and is not related to the Shinarump. The gray alteration of the Moenkopi Formation postdates deposition of the Shinarump and is related to the Shinarump. The gray alteration is not closely correlated with uranium mineralization.

MONITOR BUTTE MEMBER

The Monitor Butte Member of the Chinle Formation (Witkind and Thaden, 1963, p. 26–28; Stewart, 1957, p. 452–453) is a greenish-gray bentonitic mudstone containing lenses of gray sand and brown conglomerate. It is equivalent to the D division of the Chinle described by Gregory (1917, p. 43). The Monitor Butte is 100–200 feet thick; the range in thickness is due mainly to the arbitrary contacts between the Monitor Butte and the underlying and overlying units—it intertongues with both the underlying Shinarump and the overlying Petrified Forest Members of the Chinle Formation. The lower contact has been placed (pl. 1) at the change from massive crossbedded white sandstone to green mudstone. In a few places the contact is placed at an upward change from thick-bedded sandstone to interlayered thin-bedded to laminated sandstone and green mudstone. The upper contact is placed at the change from green to red or at the top of the uppermost rippled sandstone beds. This contact is not shown on the geologic map but is noted in the stratigraphic sections.

The mudstone beds are dominantly greenish gray, and less commonly grayish red to reddish brown. They are lenticular and horizontally thin bedded or ripple laminated and split into shaly to blocky layers. The mudstone consists of mixtures and interbeds of bentonitic claystone, silty claystone, and clay-rich siltstone. The sandstone beds are gray to light brown and are very strikingly lenticular. The sandstone is moderately well sorted, very fine grained to fine grained, micaceous, and locally conglomeratic. Thin lenticular beds of conglomerate are common in the member. They are composed of pebbles and cobbles of light-brown limestone in a sandstone matrix, siliceous and carbonate geodes, and limonite concretions. The sandstone and conglomerate beds include minor amounts of charcoaly fragments and some silicified wood fragments.

Characteristic of the sandstone beds in this unit are their lenticularity and peculiar slump structures. The beds are almost everywhere very thin bedded and ripple laminated, which probably indicates that they were deposited in a horizontal position. Yet on the outcrop many of these lenses are shaped like great inverted troughs, dipping steeply down on either side and pitching under the green mudstones at angles of as much as 20°. No great amount of fracturing is noted where these odd structures occur; the folding is probably attributable to penecontemporaneous slumping on a jelly-like foundation of bentonitic mudstone. Sandstone lenses of this member are especially abundant and are thick near or directly over large channels occupied by the Shinarump. In such areas, a definite contact between the Shinarump and the Monitor Butte Members does not exist because of the intertonguing of the two members. This buildup of sandstone of the Monitor Butte over Shinarump stream courses probably indicates that the major stream courses established when the Shinarump was being deposited persisted during deposition of the Monitor Butte Member.

The Monitor Butte Member is generally unfossiliferous, although it has yielded a few indeterminate phytosaur teeth.

PETRIFIED FOREST MEMBER

The Petrified Forest Member, which is about 150–350 feet thick in the Circle Cliffs area, is variegated in shades of purple, red, yellow, and greenish gray and is composed of bentonitic mudstone, sandstone, and minor conglomerate.

The mudstone beds are poorly exposed, as they weather to gentle slopes covered to a depth of several inches by a frothy deposit of weathered mudstone chips. Lithologically, the mudstone is very silty to sandy clay containing scattered quartz grains, ranging in size from silt to coarse sand, and local lenses of medium-grained sandstone. The mudstone is bentonitic, firmly cemented, and calcareous and locally contains limestone nodules and rounded limestone fragments to boulder size. Locally, thin beds of gypsum are abundant.

The sandstone beds form well-exposed ledges and steep cliffs. The beds are tabular, contain ripple-laminated to medium-scale crossbeds, and split into shaly to slabby layers. The grains range from very fine to medium in size; generally they are moderately well to well sorted and weakly cemented. The sandstone is feldspathic and locally is conglomeratic, containing pebbles and cobbles of mudstone and limestone. Conglomerate beds are uncommon and thin; they consist of pebbles and cobbles of mudstone and limestone in a silty sandstone matrix.

A sandstone bed in the upper part of the member crops out fairly continuously in the northern part of the Circle Cliffs area and is probably equivalent to the informal Capitol Reef bed (Stewart, 1957, p. 457) to the north. The bed contains moderate amounts of silicified logs as much as 3 feet in diameter and 40 feet long and fragments of broken logs. These logs are brightly colored and are avidly sought by collectors for cutting and polishing. Some of the logs contain carnotite in sufficient quantities to create radioactivity anomalies noticeable in airborne exploration. A few attempts have been made—principally in Moody Canyon and in the northwestern part of the Circle Cliffs area—to collect this material for its uranium content, but the logs and fragments have not yet been found in sufficient quantity to permit economic exploitation.

OWL ROCK MEMBER

The Owl Rock Member was named and defined from exposures in Monument Valley, Ariz. (Witkind and Thaden, 1963, p. 30–32). In the Circle Cliffs area, the member is composed of resistant thin lenticular beds of green limestone interbedded with red, brown, and greenish-gray sandstone and mudstone. It ranges from about 150 to 250 feet in thickness and crops out in a steep slope under the cliff formed by the Wingate Sandstone. Characteristics that distinguish the Owl Rock from the conformably underlying Petrified Forest Member are the presence of limestone beds and a markedly smaller amount of bentonite in the mudstone and sandstone. A few conglomerate beds, containing limestone, siltstone, and chert pebbles, occur in the unit.

The sediment of the Owl Rock was deposited in a lacustrine and fluvial environment. No fossils were recovered from the rocks during this investigation.

CHURCH ROCK MEMBER

Brown sandstone crops out discontinuously in the southeastern part of the area as a 15- to 25-foot-thick ledge between the base of the Wingate Sandstone and the top of the Owl Rock Member of the Chinle. The sandstone is fine to medium grained, massive, and cross stratified on a small scale. The most conspicuous outcrops are at the south end of Deer Point and in the main and tributary canyons of East Moody Canyon. Although the Church Rock Member exposed in Monument Valley (Witkind and Thaden, 1963, p. 32–34) and in the Hite area near the Colorado River cannot be traced into the Circle Cliffs area, the unit described here is referred to as the Church Rock because of its lithology and stratigraphic position. The sediments were deposited in lakes and by streams on an alluvial plain that sloped away from a source area in the ancestral Rocky Mountains (Stewart and others, 1958).

TRIASSIC AND JURASSIC SYSTEMS

GLEN CANYON GROUP

The Glen Canyon Group consists of two prominent cliff-forming light-colored sandstone units separated by a slope-and-valley-forming reddish-brown sandstone. The lower sandstone is the Wingate Sandstone of Late Triassic age; the upper is the Navajo Sandstone of Triassic(?) and Jurassic age; the medial unit is the Kayenta Formation of Late Triassic(?) age (Lewis and others, 1961, p. 1439–1440). The Wingate and Navajo Sandstones are largely eolian in origin, and the Kayenta Formation is fluvial. Measured sections 12 through 15 are typical of the Glen Canyon Group in the Circle Cliffs area.

WINGATE SANDSTONE

The Wingate Sandstone is a prominent massive cliff former that bounds the interior of the Circle Cliffs area. The name "Circle Cliffs" probably originated from the oval-shaped bounding rim of these cliffs. The sandstone generally ranges in thickness from 230 feet in the east to 350 feet in the west and northwest. It is distinctive because of its cliff exposure, very thick bedding, and large-scale crossbeds.

The Wingate erodes to towering cliffs that overhang in canyons and stand as nearly vertical irregular walls in more exposed places. The tops of the cliffs are rounded, and the faces are rugged, irregular, and interrupted by vertical joints. Exposed horizontal surfaces weather to rounded shapes. Weathered surfaces of the sandstone typically contain rounded "bird-hole" solution cavities; and where weathering has been intense, the holes are bounded by a delicate lacy pattern of thin sandstone walls.

The Wingate Sandstone is light brownish orange and is very well sorted, very fine to fine grained, and quartzose. Some medium to coarse grains of quartz are scattered throughout the unit, and a 2- to 6-foot-thick bed of poorly sorted very fine grained to medium-grained sandstone is at the base. The Wingate is moderately friable to moderately well cemented with calcium carbonate. The beds are planar and trough cross-stratified in sets that are 40–60 feet thick and 100 feet long. The crossbeds dip northeast to southeast. Horizontal parting planes separate the crossbed sets in the unit. In the uppermost 100 feet, discontinuous thin beds of red siltstone and gray carbonate rock occur locally along the parting planes. These beds probably were deposited in small lakes.

The Wingate is generally conformable, but locally unconformable, with the underlying Chinle and the overlying Kayenta Formations.

The contact with the Chinle is sharp and well defined with little or no relief, except in the Long Canyon area in the northwestern part of the Circle Cliffs area where 15–25 feet of poorly sorted fluvial sandstone beds forms the base of the Wingate and fills erosional pockets in the top of the Chinle. The upper contact is an undulatory surface with a maximum relief of about 40 feet. It is erosional and unconformable but probably does not represent a significant time break. In the southeastern part of the area, the Wingate and Kayenta appear to intertongue in a zone 40 to 50 feet thick.

The normally light-brownish-orange Wingate has been altered to white throughout an irregular area in the northwestern part of the Circle Cliffs area. The zone of altered rock extends from the base almost to the top of the formation. The boundary between the white rock and the orange rock is fairly regular; in places it follows parting planes between crossbed sets, and elsewhere it cuts across the bedding and parting planes. Thin-section studies, by G. A. Miller, and chemical analyses indicate that the color difference is due primarily to loss of ferric iron in the white rock. Black opaque minerals have been altered to a material resembling leucoxene (white under reflected light), and all interstitial limonite has been removed. Otherwise the white and orange rocks are identical. Light brownish orange is the original color and is characteristic of the Wingate in unweathered outcrops and in drill-hole samples. The white rock has probably resulted from leaching by ground water, derived from precipitation and from runoff in the Boulder Mountain area, before canyon cutting exposed and drained the sandstone.

The Wingate of the Circle Cliffs area is probably equivalent to the Lukachukai Member of the Wingate in northeastern Arizona and northwestern New Mexico. It is primarily eolian in origin; west and northwest winds created very thick dunal deposits.

KAYENTA FORMATION

The Kayenta Formation is a ledge-forming reddish-brown sandstone and is about 320–400 feet thick in the Circle Cliffs area. It caps most of the Wingate cliffs and forms extensive benches and slopes in the western and southern parts of the area. It forms the floor of Muley Twist Canyon, which is walled by the Navajo and Wingate Sandstones.

The Kayenta is composed of thin to very thin bedded sandstone and minor siltstone. It is dominantly reddish brown to dark purplish red, but some beds are grayish white. The beds are lenticular, split into flaggy to massive layers, and are trough cross-stratified on a small to medium scale. Some beds, particularly in one 20- to 40-foot-thick unit in the uppermost one-third of the formation and other thinner beds in the upper part of the formation, display large-scale trough cross-stratification commonly associated with sandstone of eolian origin. The sandstone and siltstone are micaceous and feldspathic, and many of the beds contain abundant mud chips. Calcareous sandstone beds are moderately common, and there are a few beds of light-yellow limestone. The sandstone is largely medium to coarse grained and thick to very thick bedded in the eastern part of the Circle Cliffs area and fine to very fine grained and thin to very thin bedded in the western part. More siltstone occurs in the western part of the area than in the eastern part.

The Kayenta Formation and the overlying Navajo Sandstone are conformable and do not appear to intertongue in the area mapped, but they are difficult to distinguish where crossbedded rock forms the top of the Kayenta and where the lower part of the Navajo contains many carbonate beds. The uppermost bed of the Kayenta commonly is a grayish-red-purple poorly sorted siltstone or mudstone that grades laterally into crossbedded and horizontally stratified siltstone, sandstone, and calcareous sandstone beds. Locally, the unit is mottled green and brown; the green color extends downward along vertical fractures and is assumed to be an alteration phenomenon associated either with weathering or with percolation of ground water from the overlying Navajo. Except for its weak cementation, this bed is similar to the mottled-siltstone unit of the Chinle Formation.

Some poorly preserved pelecypods in unidentifiable condition were collected from a calcareous sandstone in this formation, and three-toed dinosaur(?) tracks were noted at a few localities in the northern part of the area. The bedding structures indicate a dominantly continental and fluvial origin for this formation. From studies of cross-stratification, Poole (1961) concluded that the source of Kayenta was to the east; the grain-size distribution of the sandstone beds in the Circle Cliffs area supports this interpretation.

NAVAJO SANDSTONE

The Navajo Sandstone is a cliff-forming white sandstone that generally ranges in thickness from 950 feet in the northern part of the area to 1,400 feet in the southern part. It is composed dominantly of well-sorted very fine to fine subrounded frosted quartz grains and is crossbedded on a large scale. It ranges from friable to well cemented, the degree of cementation depending primarily on the amount of carbonate in the rock. A few thin carbonate beds occur chiefly in the lower 400–500 feet of the formation in the southern part of the area. Some of these carbonate beds, which are generally limestone or sandy limestone and not more than 10 feet thick, may be traced 10–15 miles. A few lenses of red siltstone are interbedded in the Navajo Sandstone in the southern part of the area.

The crossbeds in the Navajo are in sets as much as 70 feet thick and 150 feet long. The tops and bottoms of the sets are principally plane surfaces, but some show trough-type truncations. The very large scale cross-stratification, the fine grain size, and the excellent size sorting of the grains in the Navajo are typical of windblown dune deposits. The wind that formed the sand dunes blew from the west and northwest, as indicated by the orientation of the cross strata.

Many of the tributary streams that cut across the bedding strike along the Waterpocket fold have potholes along their courses in the upper part of the Navajo, generally within a few hundred feet of the Carmel contact. These potholes are called waterpockets because in rainy seasons they are a source of drinking water. Some of these tributaries have permanent flows sufficient to support a lush semi-tropical vegetation.

Nodules of black manganese wad have been found as float lying on and near the Navajo, especially the uppermost beds, in the eastern and southeastern parts of the area. None of this material has been seen in outcrop, but possibly a few small bedded or vein deposits of manganese occur in the Navajo Sandstone or Carmel Formation. A manganese deposit occurs near the Navajo-Carmel contact in Harris Wash, about 1 mile south of the map boundary.

The Navajo is chiefly eolian in origin, but some short-lived lakes or standing bodies of water are indicated by the thin interbedded carbonate and red siltstone beds.

JURASSIC SYSTEM

SAN RAFAEL GROUP

Members of the San Rafael Group in the Circle Cliffs area are, in ascending order, the Carmel Formation, the Entrada Sandstone, and the Summerville Formation. The most complete exposure of rocks of the group is in Hall Creek Valley (fig. 9). The position of the Curtis(?) Formation is marked by a thin discontinuous calcareous bed. The San Rafael Group is 1,100–1,300 feet thick and is largely continental or near-shore marine in origin. Wright and Dickey (1958) stated that the source areas of the Carmel and the Entrada were to the east, at the east and south edges of the Colorado Plateau. The depositional centers were in an ancient geosyncline in the eastern Great Basin. Cross strata in the Curtis dip northeast from a source area in the ancient geosyncline, indicating that the geosyncline was uplifted prior to the deposition of the Curtis (Wright and Dickey, 1958).

FIGURE 9.—Hall Creek Valley near Burr Trail. Wingate Sandstone (T̶Rw); Kayenta Formation (T̶Rk); Navajo Sandstone (JT̶Rn); Carmel Formation (Jc); Entrada Sandstone (Je); Summerville Formation (Js); Salt Wash Sandstone Member (Jms) and Brushy Basin Shale Member (Jmb) of the Morrison Formation; Dakota Sandstone (Kd); Tununk Shale Member (Kmt), Ferron Sandstone Member (Kmf), Blue Gate Shale Member (Kmb), Emery Sandstone Member (Kme), and Masuk Member (Kmm) of the Mancos Shale; and Mesaverde Formation (Kmv).

CARMEL FORMATION

The Carmel Formation is bright-red slabby and ledgy interbedded sandstone and mudstone. It ranges in thickness from about 200 feet in the southern part of the valley to 300 feet in the northern part and is divided into a lower, limy unit and an upper, gypsiferous unit.

The contact between the Carmel Formation and the Navajo Sandstone is generally sharp and smooth. In the northern part of Hall Creek Valley the contact is placed at the base of a 5- to 10-foot-thick massive brown sandstone. The sandstone is not very easily identified south of Burr Trail, and southward from there the contact is placed at the break from large-scale crossbeds of the Navajo to the horizontally stratified or small-scale-crossbedded sandstone of the Carmel. In contrast to the normal bright red of the Carmel siltstone, the lower 10–25 feet of the Carmel is commonly the same color as the Navajo, so that a color change does not everywhere mark the contact. The sandstone beds assigned to the Carmel were probably reworked from the Navajo.

The lower, limy unit of the Carmel is composed of bright-red siltstone and subordinate sandstone, conglomerate, and thin beds of yellowish-gray to pink limestone. This unit of the Carmel is probably equivalent, in part at least, to the Twin Creek Limestone of Middle and Late Jurassic age, which crops out in northern Utah (Imlay, 1953, p. 54–59), and the Middle Jurassic Judd Hollow Tongue of the Carmel (Phoenix, 1963, p. 32–33), which crops out in the Lees Ferry area. (See also Wright and Dickey, 1963.) The limy unit is probably of marine and near-shore marine origin. It is about 90 feet thick in the northern part of Hall Creek Valley and 135 feet thick in the southern part. This unit, because of the limestone beds, is more resistant to erosion than either the underlying Navajo Sandstone or the overlying gypsiferous unit. The result in Hall Creek Valley—and, in fact, northward from the Colorado River along the Circle Cliffs anticline, Capitol Reef, and the San Rafael Swell—is a striking series of steeply dipping red flatirons of Carmel shielding white mounds of Navajo Sandstone to the west (fig. 9).

Marine fossils, mainly pelecypods, are found in the limestone beds to the north in the Capitol Reef area and along the San Rafael Swell. These fossils are Middle and earliest Late Jurassic in age (Smith and others, 1963).

The upper, gypsiferous unit of the Carmel is soft earthy red siltstone containing intercalated very thin gypsum beds and a few sandstone lenses, especially near the top of the unit. The bedding in this unit is undulatory and contorted, especially in the several small bends on the flank of the Circle Cliffs anticline. The unit is about

70 feet thick in the southern part of the area and 215 feet thick in the northern part. The gypsum beds pinch out to the south and only a few beds occur in the southernmost part of the area, although the reddish-purple siltstone there contains some gypsum flakes. The gypsiferous unit probably was deposited in a shallow-water marine environment.

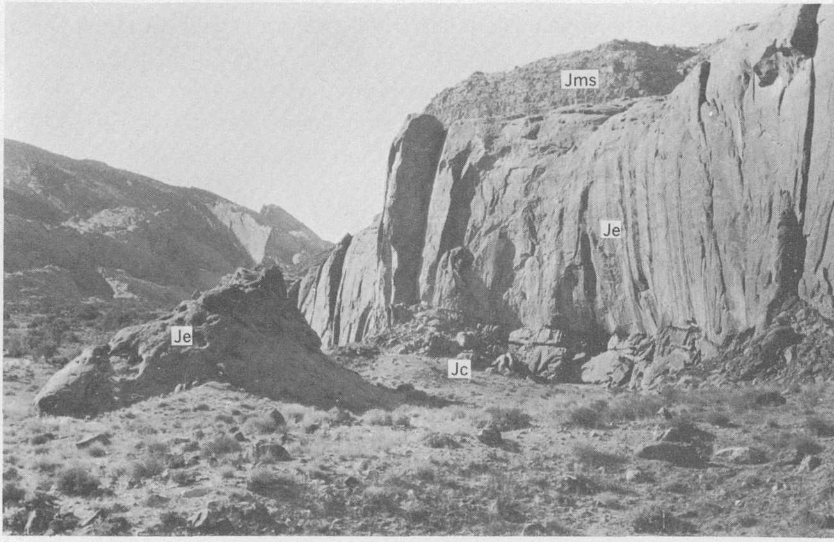
South of Burr Trail the upper 50 feet of the gypsiferous unit contains numerous isolated lenses of buff sandstone with medium- to large-scale crossbeds. The sandstone is similar in all respects to that of the overlying Entrada Sandstone. The bedding of some of these lenses is contorted, probably owing to slumpage and flowage on the unconsolidated silt and gypsiferous base. The lenses resemble sand dunes, and I regard them as sand-dune tongues of the Entrada. The lenses are overlain by reddish-purple gypsiferous siltstone everywhere in the mapped area and, therefore, were mapped as Carmel (fig. 10).

The contact of the Carmel and Entrada is placed at the break between the gypsiferous siltstone of the Carmel and the nongypsiferous siltstone and sandstone of the Entrada. South of Burr Trail, massive buff crossbedded sandstone of the Entrada rests on the reddish-purple gypsiferous siltstone of the Carmel; but north of Burr Trail, as much as 30 feet of red siltstone and sandstone forms the base of the Entrada and separates the reddish-purple gypsiferous siltstone of the Carmel from the overlying massive buff sandstone of the Entrada. This contact was chosen because the lower massive crossbedded sandstone of the Entrada rises in the section and pinches out to the north (J. C. Wright, written commun., 1957).

ENTRADA SANDSTONE

The Entrada Sandstone of the Circle Cliffs area, exposed only in Hall Creek Valley, is divided into an upper massive "slick-rim" sandstone, a medial earthy hoodoo-weathering siltstone, and a lower "slick-rim" sandstone (fig. 10*B*). These units are identical with the upper sandy, medial silty, and lower sandy members, respectively (Harshbarger and others, 1957, p. 35–38), in the Navajo country, which names will be used in this report. The total thickness of the Entrada ranges from 700 to almost 900 feet in Hall Creek Valley.

Lower sandy member.—The lower sandy member of the Entrada Sandstone is massive very fine grained to fine-grained brown sandstone containing moderate amounts of medium to coarse frosted grains of pink and gray quartz. The member also contains a few interbeds of red siltstone and shaly siltstone, especially in the northern part of Hall Creek Valley. In many places this member is



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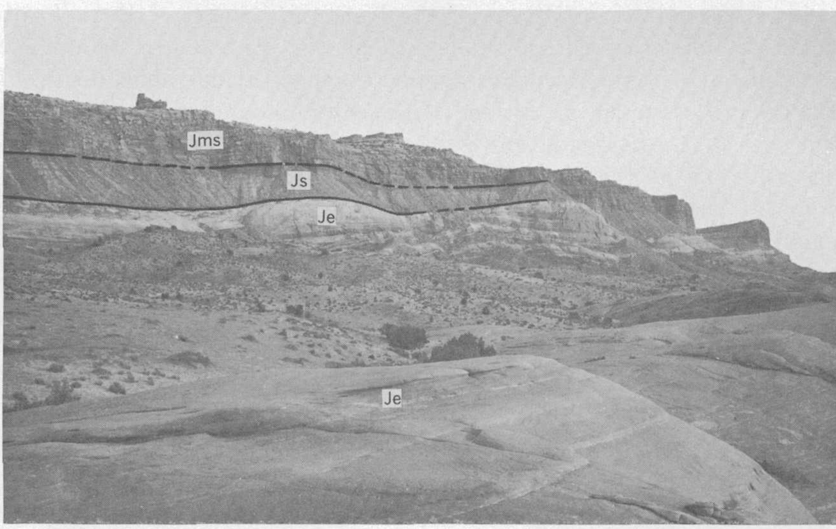

B

FIGURE 10.—Upper and lower contacts of the Entrada Sandstone in Hall Creek Valley. *A*, Carmel-Entrada contact, showing Carmel Formation (Jc), a sandstone tongue (eolian(?) origin) of Entrada Sandstone (Je), and Salt Wash Sandstone Member of the Morrison Formation (Jms). *B*, Entrada-Summerville contact, showing lower sandy, medial silty, and upper sandy members of the Entrada Sandstone (Je), Summerville Formation (Js), and Salt Wash Sandstone Member of the Morrison Formation (Jms).

covered with recent deposits of windblown sand largely derived from the underlying bedrock. The bedding is varied. In some places the unit is horizontally stratified in 2-inch- to 6-foot-thick layers; in other places medium- to large-scale high-angle crossbeds are common, and the beds of cross-strata sets are separated by horizonal parting planes as much as 20 feet apart. The lower sandy member is generally about 250 feet thick in the northern part of Hall Creek Valley and thickens to the southeast, where it is 363 feet thick (section 17).

Pipelike slump structures are common at the contact between the lower sandy member and the Carmel Formation. These structures are roughly circular in plan view, 50–150 feet in diameter, and extend 30–60 feet downward into the Carmel. The central parts of the structures are filled with structureless sandstone similar to the overlying sandstone. The beds of the Carmel are brecciated at the contact of the pipe structure, and in one exposure the bedding of the Carmel siltstone at the edges of the cylinder dips away from the structure. The beds in the overlying Entrada Sandstone are slumped over the structure, but this slumpage dies out upward within about 60 feet. This strange type of structure is ascribed to ground water forcing its way up through the soft unconsolidated tidal-flat siltstone of the Carmel (Hawley and Hart, 1934; Gabelman, 1955; Phoenix, 1958) to form a cylindrical opening or depression into which the overlying sand sifted. The fine sand is winnowed out by the upward flow of water, and well-sorted coarse sand remained in the pipe. In present-day circumstances, chiefly along rivers and beaches and near springs, the same upward movement of ground water under artesian pressure through sand results in "quicksand." Here, the grains are well sorted and partially suspended by the upward flow of water, so that a heavy object may easily sink into the poorly supported sand structure. In other places the sandstone of the Entrada seems to have settled down into the Carmel; this process produced a rolling contact similar to an erosional contact.

To the north, the lower unit is inseparable from the overlying medial unit because the "slick-rim" type of resistant sandstone which characterizes the lower unit rises slightly in the section and grades into red siltstone similar to that of the medial unit (J. C. Wright, written commun., 1957).

Medial silty member.—The medial silty member of the Entrada Sandstone is reddish-brown siltstone, very fine grained sandstone, and mudstone. The rocks are friable and earthy, weather easily, and generally are incompletely exposed. Both contacts of the member are gradational in Hall Creek Valley. Where exposed, the medial

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silty member is dominantly horizontally stratified in beds 1 inch to 8 feet thick. A few resistant sandstone beds tend to emphasize the bedding. The member is 320–360 feet thick.

Upper sandy member.—The upper sandy member of the Entrada Sandstone grades laterally from a thin-bedded white and brown sandstone to a massive "slick-rim" cliff-forming brown sandstone. It is 170–250 feet thick. The sand grains are composed of quartz and are dominantly very fine to fine, but very coarse grains are common in a few beds. In a distance of 1,000 feet along the strike, the member changes from a horizontally stratified white and brown or white slope-forming sandstone to a large-scale trough-cross-stratified cliff-forming sandstone. The "slick-rim" cliff-forming sandstone appears to be slightly more widespread than the horizontally stratified sandstone. Like the lower sandy member, the cliff-forming sandstone is divided by numerous parallel parting planes and is very thick bedded. The beds are commonly contorted, probably because of slumpage shortly after their deposition.

CURTIS(?) FORMATION

The Curtis(?) Formation is not a mappable unit in the Circle Cliffs area and where present was mapped with the overlying Summerville Formation (pl. 1). It is a discontinuous 5-foot-thick white calcareous sandstone or sandy limestone containing fairly abundant specks of glauconite and red and black chert pebbles. The sandstone is probably correlative with the Curtis Formation, which crops out to the north in the Capitol Reef and San Rafael Swell areas; but because of the discontinuity of the formation, the correlation is questionable. The Curtis(?) rests unconformably on the underlying Entrada; the unconformity is most obvious where the upper sandy member of the Entrada is a "slick-rim" sandstone that displays slumpage structures (fig. 10*B*).

SUMMERVILLE FORMATION

The Summerville Formation, a poorly exposed sequence of reddish-brown to light-gray sandstone and siltstone beds, is 50–190 feet thick in the Circle Cliffs area. The formation crops out on a smooth slope under the hogback-forming cap of the Salt Wash Sandstone Member of the Morrison Formation, and on this slope the sandstone beds stand out in thin resistant ledges or "ribs." The unit consists of thin beds of brown to white very fine grained to fine-grained sandstone separated by soft earthy red to brown siltstone and mudstone beds. The upper part of the Summerville contains lenticular beds of white sandstone, which are cross-stratified on a small scale. Disseminated flakes and fracture fillings of gypsum are common in the siltstone and mudstone, and a few thin limestone beds are intercalated at the base and top of the formation. The sandstone beds in the upper part of the section measured near Bitter Creek Divide (section 16) contain rounded fragments of red, yellow, light-green, and black chert.

The Summerville is structurally concordant with the overlying Morrison Formation, and in Hall Creek Valley the contact between the two formations lacks the angular unconformity and erosional channels that are so common in the San Rafael Swell area to the north.

MORRISON FORMATION

The Morrison Formation (Cross, 1894, p. 2; Emmons and others, 1896, p. 60–62) is exposed in the eastern part of the Circle Cliffs area, where it is about 470–740 feet thick. Details of origin, lithology, and regional variation of this formation were discussed by Craig and others (1955).

The formation consists of lenticular gray sandstone, conglomerate, and variegated mudstone strata of fluvial origin. The Morrison in the Circle Cliffs area is separable lithologically into two members. The lower, Salt Wash Sandstone Member consists of sandstone and minor mudstone and conglomerate; the upper, Brushy Basin Shale Member consists of mudstone containing a few thin interbeds of sandstone and conglomerate.

SALT WASH SANDSTONE MEMBER

The Salt Wash Sandstone Member (Lupton, 1914, p. 127; Gilluly and Reeside, 1928, p. 82) is a lenticularly stratified gray to light-red sandstone that includes minor amounts of interbedded conglomerate and reddish- to greenish-gray mudstone. It is a cliff former, and is usually seen in steep-walled canyons, hogbacks, and benches. The Salt Wash is about 300–450 feet thick in the Circle Cliffs area. A prominent and nearly continuous 4- to 5-foot-thick bed of calcareous sandstone, which marks the base of the Salt Wash, is well exposed from the area of "The Post" (Hall Creek Valley near the south end of Swap Mesa) north and can be located with some difficulty south of "The Post." The sandstone is distinctive because it includes abundant large chalcedony fragments as much as 1 foot in diameter that are various shades of red, yellow, blue green, and black; the fragments are prized as a source of polished rock specimens.

The lenticular sandstone lenses of the Salt Wash are made up of sets of medium-scale cross-strata. South of "The Post," the sandstone lenses are as much as 40 feet thick, can be traced for several miles, and contain few mudstone interbeds; thus, they give the Salt Wash a massive appearance. North of "The Post," mudstone interbeds are common and the sandstone is considerably more lenticular, as the lenses are only 2–40 feet thick and can be traced for only a few hundred feet.

The sandstone is quartzose and contains small amounts of feldspar and gray, red, and green chert. Fragments of carbonaceous wood are common in the unit, and some of these fragments have been replaced by chalcedony, producing red, blue, and yellow rock fragments. The rock is moderately well cemented to friable. The cement is primarily carbonate, but some silica occurs as cement and as overgrowths on grains. Thin conglomerate beds are intercalated with the sandstone, but, in general, the larger grains and pebbles are scattered through the sandstone or are strung out in thin layers along bedding planes. The coarse material consists of quartzite, wood fragments, gray and pink chert, clear quartz, and minor red, black, and green chert. The maximum pebble size is about 2 inches, and the average size is about three-quarters of an inch. Limestone pebbles containing impressions and molds of crinoid stems and bryozoan fragments occur locally. Fossils in chert pebbles collected from the Salt Wash were reported (Craig and others, 1955, p. 150) to be late Paleozoic in age and, therefore, the pebbles probably were derived from exposures of the Kaibab Limestone to the south. Stratigraphic studies by Craig and others (1955, p. 145) indicate that the Salt Wash was deposited by streams that flowed north to northeast across the Circle Cliffs area.

The mudstone beds of the Salt Wash are generally red in the Circle Cliffs area, but they are more commonly green or greenish gray in the lower part of the member and near uranium-bearing areas. The mudstone, composed of clay- to silt-sized particles, is generally sandy; it contains quartz grains as large as medium sand.

Several uranium prospects are located in the lower part of the Salt Wash, but none of these appear to be of much economic value. Most of the uraniferous material is accompanied by selenium, and this element encourages the abundant growth of loco weed (*Astragalus pattersoni*) at the base of the Salt Wash cliffs. The prospects are in a transition zone where massive and nearly tabular-bedded sandstone grades to very lenticular intercalated sandstone and mudstone.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin Shale Member (Gregory, 1938, p. 59) is composed of mudstone, claystone, and minor sandstone and conglomerate that are variegated greenish to yellowish gray and reddish purple. The lower part of the member is banded purple, red, and some yellow, and the upper part is chiefly gray. The entire unit is slope forming and weathers to a colorful badland topography of gently rounded knolls and hills. The member contains bentonitic clay, and weathered slopes have a "popcorn" or frothy surface owing to the swelling of the clay. The maximum thickness is about 300 feet, and the minimum is less than 100 feet. Some of the upper part of the Brushy Basin as mapped may be equivalent to the Cedar Mountain Formation (Stokes, 1944, p. 965) of Early Cretaceous age, which has been traced southward to Notom Junction, several tens of miles north of the Circle Cliffs area, but the present study has yielded no evidence to support this correlation.

The mudstone beds are thinly laminated to structureless, and their components generally range in size from clay to silt; varied small amounts of coarser fragments are strung out along bedding planes. The sandstone is white to gray and fine to medium grained and has a green clay matrix. It generally contains abundant red and green chert pebbles. The conglomerate is composed of red and green chert pebbles in a matrix of very coarse grained sand to granule-sized gravel. The mudstone, sandstone, and conglomerate of the Brushy Basin are characterized by red and green chert pebbles and greenish-gray and purplish colors, whereas the Salt Wash is characterized by gray to clear pebbles and red and light-gray colors.

The contact with the Salt Wash is placed at the base of the lowest sandstone or conglomerate containing abundant red and green chert pebbles. The conglomerate is nearly continuous in outcrop from the northern part of the area to the "Red Slide," near the south end of Big Thomson Mesa; but south and southeast of "Red Slide" the conglomerate is less continuous, and the contact is placed arbitrarily at the base of the lowest red and green chert conglomerate or at the top of the uppermost massive white sandstone. Consequently, the contact in the southern part of the area is shown on the map (pl. 1) as gradational or intertonguing. Locally in the northern part of the area, the entire lower purplish part of the Brushy Basin is absent where the Salt Wash has thickened abruptly, but the conglomerate rises in the section and can be traced through without a break.

The Brushy Basin was deposited in a fluvial and lacustrine environment. Much of the bentonitic clay probably was derived from volcanic-ash falls (Craig and others, 1955, p. 156–157).

CRETACEOUS SYSTEM

The Cretaceous formations cropping out in the Circle Cliffs area were mapped and described by Hunt, Averitt, and Miller (1953, p. 77–86), and only a limited amount of time was spent examining these formations during the present study. The formations were deposited near the west edge of a geosyncline whose axis is in the High Plains (Hunt and others, 1953, p. 77). Most of the discussion by Fisher, Erdmann, and Reeside (1960) of the stratigraphy, origin, age, and correlation of Cretaceous formations in the Book Cliffs, 100 miles to the north, is applicable to the formations of the Circle Cliffs area.

The rocks are typical of marine and coastal-plain deposits and reflect successive advances and retreats of the shoreline. Most of the sandstone units, such as the Dakota Sandstone and the various sandstone members of the Mancos Shale, were deposited in a near-shore fluvial or marine environment. The coaly sediment was deposited in swamps, the crossbedded clean sandstone along stream courses, and the ripple-laminated and horizontally stratified yellow fine-grained sediment in shallow waters near the shore. The mudstone, siltstone, and shale beds, especially of the Mancos, were deposited in deeper water offshore.

The Dakota Sandstone, the lowest of the Cretaceous formations, lies on the eroded surface of the Morrison Formation in the Circle Cliffs area.

DAKOTA SANDSTONE

The Dakota Sandstone (fig. 11), as mapped in this investigation (pl. 1), is 100–150 feet thick and is divisible into two units, which are gradational and intertongue at their contact. Probably only the lower unit is correlative with the Dakota Sandstone as mapped south of the Circle Cliffs area. The lower unit typically is a crossbedded white sandstone, and the upper is an interbedded sequence of yellow-brown mudstone and fossiliferous sandstone. The lower unit was deposited in a fluvial stream and swamp environment, and the upper unit in a marine or near-shore environment. Stokes (1950) and Katich (1954, p. 45) suggested that much of the Dakota Sandstone was deposited during pedimentation, but only part of the lower unit possibly fits into this class of deposit in the Circle Cliffs area.

The lower unit is 2–30 feet thick. It consists of thinly to thickly crossbedded poorly sorted white quartzose sandstone and local conglomerate beds consisting of abundant black, red, and green chert pebbles in a coarse sandstone matrix. Black and gray coaly and carbonaceous mudstone interbeds are very common and locally are diagnostic of the unit; some beds are stained with an asphaltic or petroliferous residue. No fossils have been recovered from this unit in the Circle Cliffs area.

Rocks of the upper unit resemble those of the overlying Mancos Shale. They consist dominantly of yellow-brown and less commonly of gray fossiliferous sandstone and mudstone and minor amounts of black, coaly shaly-splitting mudstone. The sandstone is yellow brown to brownish white, well sorted, fine to medium grained, and ripple laminated. The mudstone is yellow brown to dark gray,

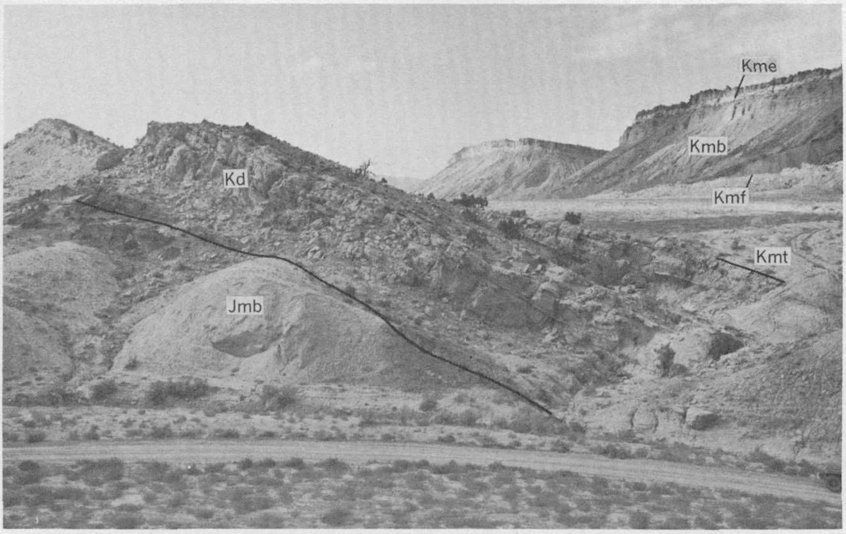


FIGURE 11.—Dakota Sandstone at "The Post," Hall Creek Valley. Brushy Basin Shale Member of the Morrison Formation (Jmb); Dakota Sandstone (Kd); and Tununk Shale Member (Kmt), Ferron Sandstone Member (Kmf), Blue Gate Shale Member (Kmb), and Emery Sandstone Member (Kme) of the Mancos Shale.

horizontally stratified, and thin bedded to laminated. The uppermost sandstone beds in the upper unit contain abundant *Ostrea* and *Exogyra* shells.

The contact between the Dakota Sandstone and the Morrison Formation is easily located in most of the northern part of the Circle Cliffs area, where a basal sandstone or conglomerate of the Dakota is present and the contact is markedly erosional. In the southern part of the area, however, gray mudstone of the Dakota commonly rests on gray mudstone of the Brushy Basin Shale Member of the Morrison Formation, and it is very difficult to accurately locate the contact. In general, distinction is based on the fact that the Brushy Basin mudstone is bentonitic and the Dakota mudstone is coaly and nonbentonitic. The contact is erosional and is not angular in the Circle Cliffs area.

The upper contact is very sharp although gradational; gray sandy mudstone and claystone of the Tununk Shale Member of the Mancos Shale rest on the uppermost sandstone of the Dakota. The sandstone forms a prominent hogback, and the break in the dip slope of the hogback coincides very nearly with the contact.

The Dakota is considered to be Early(?) and Late Cretaceous in age. According to Katich (1954, p. 43, 45–46), the Dakota of the region is Early Cretaceous in age and may correlate with rocks of Washita age in the High Plains. However, Fisher, Erdmann, and Reeside (1960, p. 25) tentatively assigned it an early Late Cretaceous age.

MANCOS SHALE

The Mancos Shale in the Circle Cliffs area is divided into five members that total about 3,450 feet in thickness. All the contacts, both between the members and at the top and bottom of the formation, are gradational and arbitrary. In ascending order, the members are the Tununk Shale, Ferron Sandstone, Blue Gate Shale, Emery Sandstone, and Masuk (fig. 9). Deposits of heavy minerals, marking ancient shorelines, have been discovered in sandstone beds of the Mancos in the Henry Mountains region and in the Upper Cretaceous Straight Cliffs Formation of the Kaiparowits Plateau, but none were noted in the mapped area. Salt crusts are very common on outcrops of the Mancos, especially near springs and seeps and along ephemeral-stream courses. Details of the stratigraphy and origin of the Mancos and associated formations in the Circle Cliffs and adjoining regions were discussed by Spieker and Reeside (1925; 1926), Hunt, Averitt, and Miller (1953, p. 79–86), and Katich (1954). No stratigraphic sections of the Mancos were measured during the present study, but several sections from nearby areas were recorded by Hunt, Averitt, and Miller (1953, p. 79–86).

TUNUNK SHALE MEMBER

The Tununk Shale Member is dark gray mudstone or slightly fissile shale and includes a few thin bentonite interbeds and, near the top and bottom, some sandstone beds. The Tununk is gradational with the uppermost sandstone bed of the Dakota Sandstone and intertongues and intergrades with the overlying Ferron Sandstone Member. It is 550–650 feet thick; the range in thickness is largely because of intertonguing with the Ferron Sandstone Member. The Tununk weathers easily and is generally covered by a few inches to several feet of soil or alluvium. Planar erosional surfaces tend to form at the base of the escarpment formed by the overlying Ferron Sandstone Member, especially south of Swap Mesa. Beds at the base of the unit contain abundant fossil oysters (*Gryphae newberryi*).

The Tununk is considered to be Late Cretaceous in age. However, according to Katich (1954, p. 43, 46) the Tununk is "Albian to lower Carlile in age"; that is, the lower part is probably Early Cretaceous and the upper part Late Cretaceous in age.

FERRON SANDSTONE MEMBER

The Ferron Sandstone Member consists of fine-grained ripple-laminated to even-bedded brown sandstone, white crossbedded sandstone, and gray mudstone; the upper part contains considerable coal and coaly mudstone. The Ferron ranges in thickness from 200 feet in the northern part of the mapped area to 350 feet in the area of "The Post" and the Burr Trail. Its contact with the Tununk Shale Member is gradational and intertonguing. One tongue of sandstone is mapped separately from the Burr Trail area north to the mouth of Divide Canyon, where it merges into the sandy mudstone of the Tununk.

The contact between the Ferron and the overlying Blue Gate Shale Member is generally sharp, and the marine bluish-gray mudstone of the Blue Gate rests directly on the lenticular sandstone or coaly beds of the upper part of the Ferron. The Ferron is early and middle Carlile in age (Katich, 1954, p. 48).

BLUE GATE SHALE MEMBER

The Blue Gate Shale Member ranges in thickness from about 1,200 feet in the southern part of the mapped area to 1,500 feet in the northern part. It is composed of dark-bluish-gray finely laminated mudstone with a few beds of bentonite, shaly sandstone, and sandy limestone. The upper part of the Blue Gate contains more calcareous sandstone beds than the member as a whole and grades into the overlying Emery Sandstone Member. The contact between the two was arbitrarily chosen.

East and south of Swap Mesa, a locally conglomeratic sandstone bed at the base of the Blue Gate rests on the eroded surface of the Ferron Sandstone Member and grades into the overlying Blue Gate Shale Member. The bed thickens to 30 feet from a few feet within short distances, and most of the change occurs at the top of the unit. Hunt, Averitt, and Miller suggested (1953, p. 83) that the sandstone is a transgressive beach deposit.

Spieker and Reeside (1925, p. 438) stated that much, if not all, of the Blue Gate of the Wasatch Plateau is Niobrara in age. Cephalopods collected from the upper 600 feet of the Blue Gate in the Henry Mountains are early Montana in age (Spieker and Reeside, 1926, p. 438; Reeside, 1927, p. 1, 5). The Blue Gate, of the Henry Mountains and Circle Cliffs areas at least, is probably Niobrara and early Montana in age.

EMERY SANDSTONE MEMBER

The Emery Sandstone Member, as mapped in this study, is about 120–300 feet thick. Part of this range is due to the difficulty in choosing the same lower contact in all areas, but a greater part is due to uncertainty in the upper contact. In the southern part of the Emery outcrop area, a sandstone considered by Hunt, Averitt, and Miller (1953) to be the basal unit of the overlying Masuk Member was mapped with the Emery in the present investigation. This sandstone interfingers with silt and shale of the Masuk about 3 miles south of Bitter Creek Divide, and from there to the north edge of the mapped area the contact has been dropped stratigraphically to the horizon that was used by Hunt, Averitt, and Miller (1953).

The Emery Sandstone Member consists of a massive sandstone overlain by coaly and carbonaceous shale and an upper lenticular unit of white sandstone that contains a few gray shale interbeds. The massive sandstone is light yellow to light brown, fine grained, even bedded to ripple laminated, and cliff forming. The coaly shale beds are lenticular and interbedded with white crossbeded fine- to medium-grained sandstone. The upper sandstone is white to light gray, crossbedded, and lenticular; it closely resembles the fluvial Shinarump Member of the Chinle Formation and is regarded as being of fluvial continental but near-shore origin. Because the upper sandstone bed is more closely allied to the Emery in lithology and environment of origin, it was mapped as part of the Emery Sandstone Member instead of a part of the marine Masuk Member. Fossils collected from the Emery are early Montana in age (Katich, 1954, p. 48).

MASUK MEMBER

The Masuk Member is 700–900 feet thick and consists of silty gray mudstone and light-yellow sandstone. The number and thickness of the sandstone beds increase upward; thus the contact between the Masuk and the overlying Mesaverde Formation is transitional. In the mapped area, the Masuk forms a steep smooth slope protected at the top by the cliff-forming Mesaverde Formation.

The composition of the lowermost beds of the Masuk grades upward from finely laminated gray mudstone to silty and sandy, coaly and carbonaceous mudstone. The sandstone is fine to medium grained and thin bedded to very thick bedded. Hunt, Averitt, and Miller (1953, p. 85) reported that fossil shark teeth and marine shells indicative of shallow-water deposition occur in the lower part of the member.

MESAVERDE FORMATION

The Mesaverde Formation is light-brown massive ledge-forming sandstone that caps Tarantula Mesa and nearby small mesas in the northeastern part of the area (pl. 1, sheet 1). Most of the formation has been removed by erosion, and no more than 400 feet remains. The thick sandstone beds are separated by thin beds of platy sandstone or gray sandy mudstone, which are more abundant in the lower part of the exposed section. The sandstone is generally fine grained but contains some pebbles and cobbles. According to Hunt, Averitt, and Miller (1953, p. 86), the deposit represents a clean beach deposit similar to the lower parts of the Ferron and Emery Sandstone Members of the Mancos Shale.

TERTIARY AND QUATERNARY SYSTEMS

The weakly consolidated to unconsolidated sedimentary rocks in the Circle Cliffs area are classified as alluvial, landslide, and eolian deposits. Nearby Boulder Mountain was glaciated during the Pleistocene Epoch (Gould, 1939), but no deposits definitely of glacial origin were found in the Circle Cliffs area. Most of the deposits are Quaternary in age, but deposits associated with a few topographically high erosion surfaces are late Tertiary in age. The relative ages of some of the deposits are unknown, but the bouldery deposits in the extreme northwestern part of the mapped area are the oldest; the alluvial fill of the present stream system and the closely associated windblown-sand deposits are the youngest.

BOULDERY DEPOSITS

The bouldery deposits, which crop out only in the northwestern part of the Circle Cliffs area (pl. 1, sheet 1) are probably landslide material (Flint and Denny, 1958, p. 145–146). The deposits are coarse very poorly sorted debris consisting of rounded basalt boulders and finer material. The surface of the deposits is very hummocky and has local relief of as much as 100 feet. The deposits were apparently truncated by the highest pediment surface, whose age is regarded by Cooley (1960, p. 24, 26) as Pliocene or older. Some of the bouldery material near the bottom of canyons probably was emplaced by later sliding.

The principal sources of the bouldery deposits were the basaltic lava flows exposed in the Aquarius Plateau less than a mile to the northwest and the gravel or weakly cemented conglomerate of Tertiary age that underlies the lava flows. The gravel bed contains material derived from source areas south and southwest of the Circle Cliffs area (Cooley, 1960, p. 27–30).

PEDIMENT DEPOSITS AND PEDIMENTS

Remnants of at least two pediments separated vertically by a distance of 300–500 feet occur in the northwestern part of the Circle Cliffs area (pl. 1, sheet 1). The surface of Long Neck Mesa near the west edge of the area is a remnant of the lower pediment, and Impossible Peak and the small mesa directly north are remnants of the higher surface. Remnants of both pediments occur throughout the quadrangle, but those of the lower pediment are more extensive.

These pediments, and similar pediments in the adjacent Boulder Mountain area, were mapped and described by Flint and Denny (1958, p. 154–156).

The pediments in the Circle Cliffs area, which are gently sloping surfaces cut on the Navajo Sandstone and the older parts of the bouldery landslide deposits, are covered by 10- to about 100-foot-thick deposits of streamlaid detrital material. The upper and lower surfaces of the deposits slope 2°–4° S., roughly parallel to the present drainage, and are as much as 1,300 feet above the present streams, at altitudes of 6,600–8,280 feet.

The pediments are covered by gravelly deposits derived chiefly from rocks exposed at Boulder Mountain. The thickness of the cover averages about 40 feet, but it may be about 100 feet on some of the larger pediment remnants. The gravel is nonstratified to crossbedded (Flint and Denny, 1958, p. 154; M. E. Cooley, oral commun., 1960) and consists of rounded boulders and fragments of volcanic rocks in a weakly cemented calcareous matrix of very fine to medium sand. The boulders are as much as 4 feet in diameter, and the fragmental material is 1–2 inches in diameter. The gravel deposits are locally underlain by an orange pebbly sand.

The pediment surfaces are pre-late Pleistocene in age and were formed before the landslide deposits on the Chinle slopes. Their height above the present canyon bottoms suggests that they are much older, and the highest pediment may have been formed during the Zuni cycle (McCann, 1938) of middle to late Pliocene age. The lowest pediment is probably preglacial and may have been formed during the early Pleistocene (M. E. Cooley, oral commun., 1960).

TERRACE GRAVEL

Deposits mapped as terrace gravel are principally in the Death Hollow and White Canyon drainages (pl. 1, sheet 1), but one outcrop was noted near the top of Burr Trail (pl. 1, sheet 1; fig. 12).

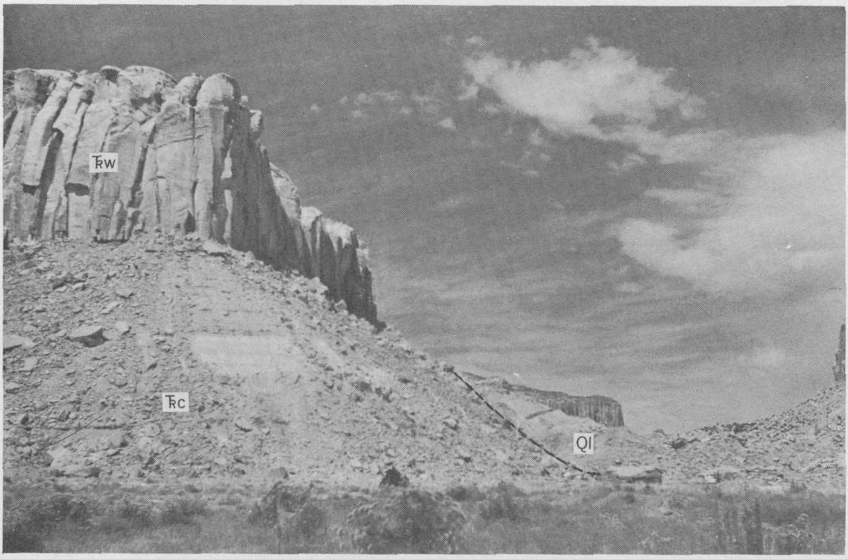
The gravel deposits crop out on low flat-topped hills about 80–120 feet above the level of the present stream courses. The bedrock of all these hills is the Moenkopi Formation. The composition of the gravel varies with the location. The deposits in the White Canyon and Death Hollow drainages are weathered and friable and composed of angular fragments of red siltstone, sandstone, chert, and dolomite, which were probably derived locally from the Moenkopi Formation and the Kaibab Limestone. The gravel body at the head of Burr Trail is firmly cemented by carbonate and consists of sandstone and chert cobbles and pebbles, probably derived mainly from the Shinarump Member of the Chinle Formation, although minor amounts came from the Moenkopi and Kaibab.

FIGURE 12.—Terrace gravel, interior of the Circle Cliffs area, near Burr Trail. Moenkopi Formation (Ћm) and terrace gravel (Qg).

The gravel deposits represent earlier levels of the stream system in the Circle Cliffs area. They are younger than the deposits veneering pediments in the extreme northwestern part of the area and evidently are older than the landslide deposits on the Chinle slopes, because the bases of these slides are at the bottoms of the deepest canyons in the area. The gravel deposits are probably middle to late Pleistocene in age, but their age and relation to the other Quaternary units are not precisely known.

LANDSLIDE DEPOSITS

A common type of landslide deposit in the Circle Cliffs area consists of large blocks of rock that have moved downslope with only slight distortion of the original bedding and structure and an overlying landslide rubble of the same type of rock (fig. 13). Most of the blocks are on the steep slopes of the Chinle Formation, but landslide blocks of Dakota Sandstone and Morrison Formation are found in Hall Creek Valley and on the mesas to the east of the valley. The blocks are generally mudstone capped with sandstone. Exposures of the blocks are generally poor because most are covered



A

B

FIGURE 13.—Landslide remnants. *A*, Block landslide in Silver Falls Canyon. Chinle Formation (T̄Rc), Wingate Sandstone (T̄Rw), and landslide deposits (Ql). *B*, Landslide rubble in the upper part of the "Red Slide"; demoiselles formed as a result of erosion.

by a rubble of fragments of the same type of rock that constitutes the block.

The block landslides commonly are mistaken by prospectors for deep-seated blocks of faulted bedrock. The blocks are as much as several hundred feet long, and the beds dip more steeply into the slope than do the beds in nearby outcrops (fig. 13*A*). The blocks may be single or they may be step faulted and have sandstone caps arranged in steps that parallel the face of the block and increase in height toward the rear, or higher, end of the block. On slopes of the Chinle the blocks consist stratigraphically of as much as 70 feet of Chinle, which may be overlain by as much as 100 feet of Wingate Sandstone. Blocks in Hall Creek Valley and on the mesas to the west consist of several tens of feet of mudstone of the Morrison and Dakota, generally capped by slightly faulted and rotated beds of Dakota Sandstone.

Other landslides consist of rubble that moved by creep, rockflow, and mudflow. Such rubble generally mantles the block landslides and many of the Chinle slopes. The upper surface of the rubble is rough and uneven and has a local relief of 30–40 feet produced mainly by boulder accumulations. It consists of mud derived from the Chinle Formation and sand and boulders (as much as 30 ft in diameter) derived from the Wingate Sandstone. Rubble similarly derived from the Morrison Formation and the Dakota Sandstone masks block landslides in Hall Creek Valley.

A large mudflow locally referred to as the "Red Slide" occurs in the southeastern part of the Circle Cliffs area. This mudflow, which consists of material derived from the Chinle Formation and the Wingate Sandstone, blocked Hall Creek Valley, as shown by 60 feet of finely laminated mudstone resembling lacustrine sediments that crop out upstream from the "slide" and overlie the mudflow material. The material composing the rubble landslide deposits is very well cemented, unsorted, and unstratified. The cementation is so strong that pillars or pedestals of slide material 10–20 feet high and 3–4 feet in diameter will support a boulder cap weighing about a ton. These pedestals (fig. 13*B*) were called demoiselles by Gregory and Moore (1931, pl. 28) and are erosional remnants of the upper part of the landslide deposit.

The landslides have reached into the bottoms of the deepest canyons in the Circle Cliffs area, and they postdate the latest period of canyon cutting. Some slides are Recent in age and overlie Recent alluvium, but most probably occurred during the latest glaciation of the area (Wisconsin age) when the climate was more humid than it is now.

OLDER ALLUVIUM IN HALL CREEK

A terraced alluvium as much as 100 feet thick crops out in Hall Creek Valley and is mapped with alluvium of Quaternary age (pl. 1). The upper surface of the deposit is about 100 feet above the creekbed near Thomson Mesa. The terraced alluvium is a moderately well cemented mixture of rounded cobbles and sand of local origin. At the "Red Slide" the gravel grades into fine-grained finely laminated gray to light-brown sediment. This change indicates that a small lake formed upstream from the slide.

The terraced alluvium is generally younger than most of the landslide material, but on the east side of Hall Creek it is overlain by landslide rubble consisting mainly of rock fragments from the Morrison Formation and the Dakota Sandstone. This alluvium may be equivalent to the late Wisconsin alluvium of Hunt (1956, p. 38).

FAN DEPOSITS

Fan-shaped deposits of unstratified sand and boulders spread out from the base of Wingate and Chinle landslide masses in the northern part of the Circle Cliffs area. The deposits consist of unstratified mixtures of sand and clay and sandstone boulders derived from the Wingate. The material probably was reworked from the landslide deposits by water washing over the edges of the cliffs behind the landslides.

The fan deposits are incised 10–15 feet by present-day stream gullies and are overlain by alluvium associated with the present stream system. The fan material is unweathered and probably is only slightly older than the alluvium lining the present stream courses.

TALUS

Talus, the loose rock rubble at the base of all steep cliffs in the area, was generally mapped as landslide rubble; only talus cones of significant areal extent, notably those in The Gulch, were mapped separately. The cones taper upward from a broad base and rest against cliffs of Wingate Sandstone and steep slopes of the Chinle Formation. The rock fragments in the cones are angular, a few inches to a few feet in diameter, and generally not firmly cemented together.

STREAM ALLUVIUM

Deposits of stream alluvium are widespread in the Circle Cliffs area, but the thickest and most extensive are in Hall Creek Valley and in the northern part of the Circle Cliffs interior. The alluvium generally is confined to flood plains and channels of the present streams. The deposits are from 10 to about 40 feet thick and consist of unconsolidated stratified or unstratified mixtures of locally derived sand, silt, clay, and gravel. Some of the material mapped as alluvium has been reworked by wind into dunes and loess, and some, especially in Hall Creek Valley, is windblown material that has been partly reworked by water.

The alluvium has been terraced by erosion, probably since about 1880 (Hunt, 1956, p. 39), and its top lies about 10–25 feet above the present stream level. Where rainfall is adequate, the alluvium will support a lush cover of vegetation, but the deposits probably are too thin in most areas to provide a source of ground water adequate for even domestic use.

Most of the alluvium in the Circle Cliffs area is post-Wisconsin or late Pleistocene to Recent in age. Remains of Indian camps, identified by abundant scattered fragments of pottery and arrowheads, are fairly common in the northern part of the Circle Cliffs area wherever the land is tree covered. Most of the remains have been found in the upper few feet of the alluvium.

WINDBLOWN-SAND DEPOSITS

Deposits of windblown sand occur in Hall Creek Valley and on all the benches and mesas in the area. The deposits constitute a mappable unit in only a few places, notably in the extreme northwest and in the Escalante River area.

The mapped deposits are generally mesa- and bench-covering blankets a few tens of feet thick. Locally, great piles of sand extend down into the deepest canyons from the tops of the cliffs rimming the canyons. The sand is unconsolidated and mostly very fine to fine. The grains are angular to subangular, and their surfaces are pitted and striated. The sand deposits provide soil for growth of vegetation and also serve as ramps between the canyons and the tops of the benches, providing access for cattle.

STRUCTURE

Structurally, most of the Circle Cliffs area consists of the breached Circle Cliffs anticline, whose shape and trend have been the major influences on the formation of the local topography. The anticline is about 65 miles long and plunges southward to the Colorado River, where it is coaxial with the smaller, northward-plunging Beaver anticline. To the north, the anticline crest is en echelon with the Teasdale anticline. The Circle Cliffs anticline is flanked on the east by the Henry Mountains syncline and on the west by the Kaiparowits basin and the Boulder Mountain segment of the Aquarius Plateau. The relief of folding, from the crest of the Circle Cliffs anticline to the trough of the Henry Mountains syncline, is almost 1¾ miles vertically in 9–10 miles horizontally. The general configuration of the anticline is shown by sections *A–A′* and *B–B′* on plate 1 (sheet 1).

In the northwest corner of the area a small segment of the trough of the Harris syncline crosses the mapped area. This syncline is almost 50 miles long and can be traced 4–5 miles north and about 45 miles south of the segment shown.

METHOD OF REPRESENTING STRUCTURE

Attitudes of strata, faults, and throughgoing joints are shown by appropriate symbols on plate 2. The shape of the strata is shown by structure contours drawn through points of equal altitude (in reference to mean sea level) on the top of the White Rim Sandstone Member of the Cutler Formation.

The structure contours were determined by field mapping of the contoured horizon where that horizon is exposed at the surface, and by field mapping of other key beds where the contoured horizon is not exposed or has been removed by erosion. Points of equal altitude on the key beds were adjusted to the approximate altitude of the contoured horizon by subtraction of the appropriate stratigraphic thickness. Most of the contours at the southwest side of the mapped area were constructed on formations of the Glen Canyon Group, and those on the northeast side of the area were drawn on beds of Cretaceous age. Contours along the Waterpocket fold were constructed by drawing numerous cross sections across the fold, using the appropriate stratigraphic thickness of the formations in the section, and assuming that the folding is of the parallel, or concentric, type in which the stratigraphic thickness of the beds remains unchanged in the fold. This assumption is probably invalid, because thinning and thickening in parts of the fold are very likely; but the general picture across the fold is reasonable.

The crest and trough axes shown on plates 1 and 2 represent the intersections between the axial planes of the folds and the strata cropping out at the surface. The dip of the axial planes was assumed to be vertical for purposes of structural contouring. If, instead of being vertical, the axial plane of the Circle Cliffs anticline were to dip southwest, the intersection between the axis and the contoured horizon would be displaced to the southwest from the crestline. The amount of displacement would be dependent on the interval from the surface to the top of the White Rim Sandstone Member, which is the contoured horizon. The same condition is true of the other major anticlines and synclines shown on the structure map.

Nearly all faults were observed in the field, and except where otherwise noted, they are probably vertical or within about 10° of vertical. The joints shown on plate 2 are mainly in the Wingate and Navajo Sandstones and in the Salt Wash Sandstone Member of the Morrison Formation, and they were transferred to the map from aerial photographs.

CIRCLE CLIFFS ANTICLINE

The Circle Cliffs anticline, the dominant structural feature in the mapped area, trends slightly west of north and is doubly plunging. The west flank dips gently west; but the east flank, which is known as the Waterpocket fold, dips steeply into the Henry Mountains syncline (pl. 2, fig. 9). Closure on the crest of the anticline is about 1,200 feet, embracing an oval area about 30 miles long and 9 miles wide.

The anticline is fairly smooth and uniform. The few irregularities or minor folds superimposed on the major structure include a nose that is about 200 feet higher than the average curvature of the anticline in the northwest corner of the mapped area, and a small shelf or collapse structure in the southernmost part of the area. The other irregularities are anomalies on the steep east flank, where closely spaced contours indicate a local steepening of dip and widely spaced contours indicate a shallowing of the dip.

HENRY MOUNTAINS SYNCLINE

The broad Henry Mountains syncline, which was mapped and described in detail by Hunt, Averitt, and Miller (1953), is east of the Circle Cliffs anticline; it trends and generally plunges north to northwest. Several minor folds occur in the syncline, one of which, the Muley Creek anticline, was pierced by an oil-test well (Alexander and Clark, 1954). The anticline trends north 6–7 miles and roughly parallels the trough of the Henry Mountains syncline. Another minor fold in the syncline is a small rise, or "saddle," in the troughline where the strata are about 200–300 feet higher than the same strata in the structural basins north and south of the rise.

FAULTS

Many small faults, some traceable for about 5 miles, offset strata on the west flank of the Circle Cliffs anticline. Faults are uncommon in the steeply folded east flank. Nearly all the faults on the west flank apparently resulted from caving of the rock strata. Where faults are abundant, most of the fault blocks are grabens, and the overall pattern of faulting indicates a foundering of the west-central part of the anticline. The faults are not in general alinement with the dominant joint patterns, probably because the jointing reflects separate diastrophic events, which Kelley suggests (1955, p. 49–53) might be both early and late Tertiary in age. Stream directions in the Circle Cliffs area are independent of fault trends and commonly cross rather than follow fault breaks.

All faults are high angle and, where the dip may be measured, normal faults. Apparently little or no strike-slip movement has occurred in the mapped area. Most faults show some drag, which is expressed by folds subparallel to the fault plane, and many die out along their strike into small monoclinal, anticlinal, and synclinal features. Thus, many faults show considerably more displacement along their central parts than elsewhere. The maximum throw of the mapped faults is about 50 feet.

JOINTS

Most joint systems in the Colorado Plateaus are regional in extent, and those in the Circle Cliffs are no exception. The dominant joint trends—northeast and north to northwest—continue far away from the Circle Cliffs anticline (Kelley, 1955, fig. 2).

Some of the joints were almost certainly associated with the folding of the Circle Cliffs anticline. Examples of these are the joints that curl around so that they are perpendicular to the strike of strata in the southeastern part of the area, and the profusion of north-, northwest-, and east-trending joints, many of which are cemented with calcium carbonate, that are on a structural anomaly east of the crest of the anticline. Much of the present drainage parallels joints rather than dip slopes, especially in the northwestern part of the area.

Although some joint systems probably formed during the folding of the Circle Cliffs anticline, others evidently formed later, possibly during the mid-Tertiary tectonic episode in the Basin and Range province to the west and south.

PERIODS OF DEFORMATION

The tectonic history of the rocks exposed in the Circle Cliffs area is intimately allied with the history of the Colorado Plateau as a whole. The history of development of the Colorado Plateau is treated comprehensively by Hunt (1956), and most of the following discussion is of diastrophic events documented by unconformities and tectonic features in the Circle Cliffs area.

Information regarding Paleozoic and Precambrian deformation is meager; Heylmun (1958, p. 1800–1801) suggested that regional westward tilting occurred before deposition of the Devonian rocks and again after deposition of the Mississippian rocks. Local thinning of Pennsylvanian and Permian rocks (Wolfcamp age) about 18 miles west of the Circle Cliffs anticline delineates a domal high, which Heylmun (1958, p. 1791, 1802) referred to as an ancestral Circle Cliffs uplift.

Northwestward tilting at the close of the Paleozoic Era resulted in an erosional unconformity between the Kaibab Limestone and overlying Triassic rocks that is angularly discordant to the east (McKee, 1954a, p. 35). The tilting was also responsible for the northwestward thickening of the Moenkopi Formation (McKee, 1954a, p. 23).

The erosional unconformity between the Moenkopi Formation and the overlying Chinle Formation probably is due to additional northwestward or northward regional tilting. The unconformity is not angular, as the Chinle rests on nearly the same horizon of the Moenkopi throughout the Circle Cliffs area (except in the Shinarump channel systems) and appears also to be concordant over a larger area (Spieker, 1954, p. 9).

Contacts of formations of the Glen Canyon Group are disconformable both within the group and with formations overlying and underlying the group, but none of these local disconformities have much regional structural significance. The disconformable contacts were caused mainly by changes in the depositional environment rather than by large-scale regional tilting or hiatuses in deposition.

The contact between the Entrada Sandstone and the overlying Curtis(?) or Summerville Formation displays marked local angularity throughout the Hall Creek area (fig. 10*B*) and to the north, but this discordance probably represents local slumping and folding within the Entrada itself. Regionally, this contact is of tectonic significance because a geosyncline that had existed to the west since Cambrian time was uplifted in the period between the deposition of the Entrada Sandstone and the deposition of the overlying Curtis(?) Formation (Wright and Dickey, 1958). The Entrada Sandstone and the underlying Carmel Formation were a part of the geosynclinal pile, whereas the Curtis(?) Formation and, later, the Morrison Formation were deposited by streams flowing northeastward from the site of the geosyncline.

The Dakota Sandstone-Morrison Formation contact appears conformable in the Circle Cliffs area. Although the Cedar Mountain Formation of Early Cretaceous age could not be distinguished at the top of the Morrison and may be absent, the Dakota-Morrison contact probably does not reflect a major depositional break or period of folding, at least in the mapped area. The contact of the Dakota with the Mancos Shale, the member contacts within the Mancos, and the Mancos Shale-Mesaverde Formation contact are gradational or conformable and do not represent major tectonic events. The folding of the Circle Cliffs anticline postdates the deposition of the Mesaverde Formation in the area.

The Circle Cliffs anticline is the most clearly exposed tectonic feature in the area, but information to date its origin is lacking. The lower members of the Mancos Shale—up to and including the Emery Sandstone Member—are folded in the Circle Cliffs anticline and do not display any marked lithologic or thickness changes in the area of folding such as would be expected if they had been deposited while the Circle Cliffs area was being uplifted. The Masuk Member was eroded from the more tightly folded areas, but its lithology, too, does not reflect intense nearby diastrophism during deposition. It may be concluded with reasonable certainty only that the folding must have occurred after the deposition of the Emery Sandstone Member of the Mancos Shale. On the Aquarius Plateau, a few miles west of the Circle Cliffs, flat-lying beds tentatively correlated by Spieker (1954, p. 10–11) with the Flagstaff Limestone of late Paleocene and early Eocene(?) age rest unconformably on the folded Navajo Sandstone; therefore, rock relations in and near the mapped area indicate that folding of the Circle Cliffs anticline occurred some time between the depositions of the Emery Sandstone Member of the Mancos Shale and the Flagstaff Limestone, or between the middle of Late Cretaceous and late Paleocene time.

At least three unconformities representing periods of folding in the Late Cretaceous and Paleocene are known in the Wasatch Plateau region north of the Circle Cliffs area. The oldest is between the Ferron Sandstone Member of the Mancos Shale and the Star Point Sandstone, the lowest unit of the Mesaverde Group in that area; the second is between the Blackhawk and Price River Formations of the Mesaverde Group; and the third is between the North Horn Formation and the Flagstaff Limestone. West of the Circle Cliffs area, at Bryce Canyon, an unconformity presumably equivalent to that under the Flagstaff Limestone separates the Kaiparowits Formation and strata of probable Wasatch age (Spieker, 1954, p. 10). The lower part of the Flagstaff is late Paleocene in age, the North Horn is Late Cretaceous to middle Paleocene in age (Spieker, 1949, p. 27), and the Kaiparowits is Late Cretaceous in age (Gregory, 1951, p. 45; Katich, 1954, p. 53).

Indirect relations indicate that the unconformities between the Ferron and Star Point (Walton, 1954, p. 81) and between the Blackhawk and Price River (Spieker, 1946; 1949; 1954, p. 10) may predate the Circle Cliffs folding. The upper part of the Price River is equivalent to the lower part of the Kaiparowits, and hence the Kaiparowits postdates the second unconformity. About 30 miles west of the Circle Cliffs, the Kaiparowits is folded over the East Kaibab monocline. This monocline, the Circle Cliffs anticline, and the intervening Kaiparowits basin are considered by myself and other workers to be closely related in age and origin, and their relations to the Kaiparowits at East Kaibab monocline indicate that they are younger than that unit. Thus, if the unconformity between the Kaiparowits and the sequence at Bryce Canyon is the same as that between the North Horn and Flagstaff, the folding of the East Kaibab monocline, and hence of the Circle Cliffs anticline, is middle to late Paleocene in age.

The Colorado Plateau was uplifted and tilted in Tertiary, and perhaps in Quaternary, time (Hunt, 1956, p. 57–64; Walton, 1954, p. 81–82; Spieker, 1954, p. 13). Deformation of this age is not reflected in the consolidated rocks of the Circle Cliffs area, except possibly by the joint systems.

URANIUM DEPOSITS

The presence of uranium-mineral concentrations in the Circle Cliffs area was the primary reason for remapping the area, and mineral prospecting by commercial interests and by the U.S. Atomic Energy Commission continued during the present study. Other metals that may attract future prospecting in this area are manganese, selenium, and titanium.

GENERAL CHARACTER AND DISTRIBUTION

Uranium minerals occur in the Moenkopi, Chinle, and Morrison Formations and are associated with some of the faults in the Circle Cliffs area. The only minable deposits are in a mineralized zone a few feet thick at the base of the Shinarump Member of the Chinle Formation and in a zone near the base of the Salt Wash Sandstone Member of the Morrison Formation.

Uranium deposits at the base of the Shinarump are associated almost entirely with channels (fig. 14), which generally range from a few tens of feet to 8,000 feet in width and from 10 to 100 feet in depth. The deposits are not restricted to any preferred position relative to the channel cross section, but all are restricted to a zone a few feet thick at the Shinarump-Moenkopi contact. The Moenkopi is always slightly radioactive in a zone a few inches to 1 foot thick adjacent to the Shinarump channel contact, but minable concentrations of uranium occur only in irregular elongate ridges, probably former streambanks, that extend as much as a few feet above the channel. In places the rock in the ridges is fractured, perhaps as a result of slumpage, and some of the wider fractures are filled with sandstone that probably sifted in when the Shinarump was being deposited in the channel.

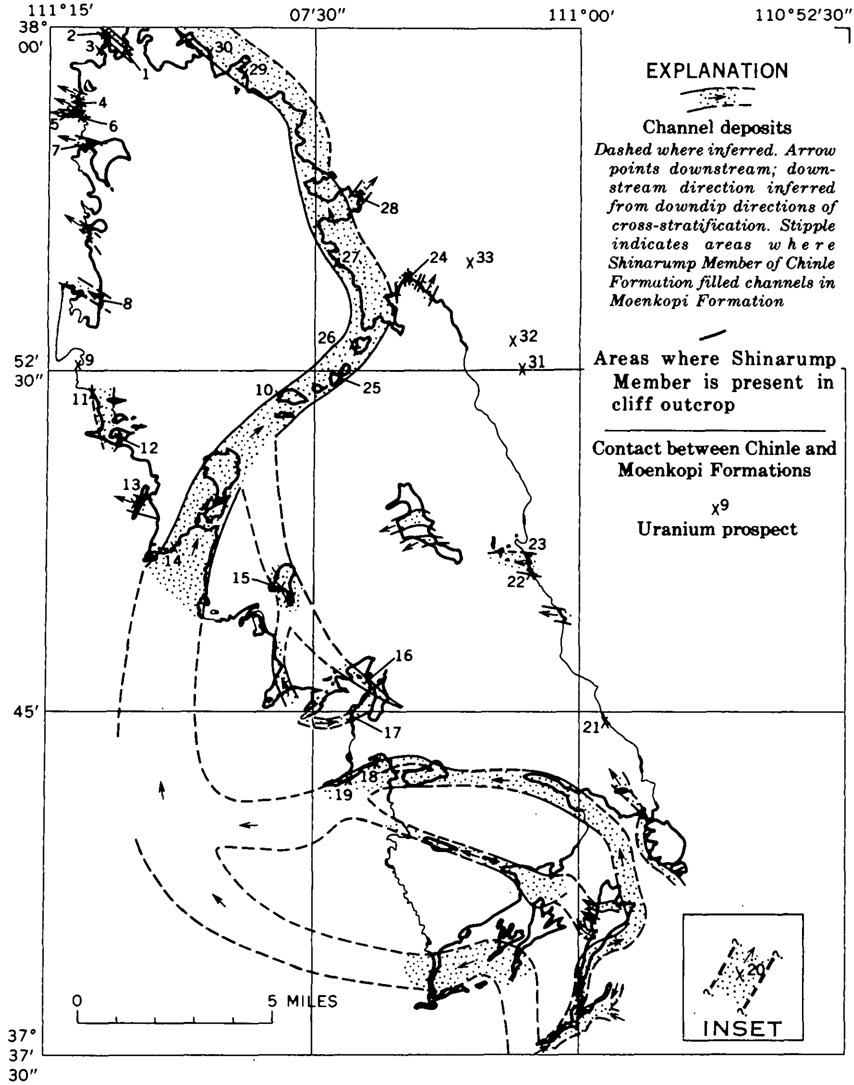


FIGURE 14.—Uranium prospects and distribution and channel pattern of the Shinarump Member of the Chinle Formation. Compiled by L. D. Carswell and E. S. Davidson, 1956–57. Inset (prospect 20) is 5 miles north of its actual position. Uranium prospects named on plate 1 and described on pages 71–91.

Most of the uranium ore mined in the Circle Cliffs area before 1958 was derived from these mineralized ridges in the Moenkopi. The mineralized ridges from high-grade ore pods that are a few square feet in cross section and as much as several hundred feet long. Where the ridge flattens out or merges into the general slope of the channel flank, the uranium is dissipated along a wide zone at the Shinarump-Moenkopi contact and is not minable. This type of deposit is shoestring-shaped in plan view, and because of the limit in cross-sectional area, it presents a very difficult drilling target and does not constitute a large ore body. The mined bodies are exposed at the surface and small enough to be mined profitably by two or three men. The Rainy Day, Stud Horse, Yellow Jacket, and Sneaky-Silver Falls prospects are typical of this type.

In channels, the most uniformly mineralized deposits are those that occur mainly in the Shinarump, particularly where the few feet of basal sandstone contains abundant 1/4-inch to 1-foot fragments of mudstone and at least moderate amounts of charcoaly wood. Such deposits contain widely disseminated uranium minerals and may be large enough to constitute practicable drilling targets. The grade of ore allowing, deposits of this type are the only ones that can be expected to exceed 10,000 tons in size. The Centipede and Horsehead prospects are typical of this type.

Several deposits in Shinarump channels consist of uranium minerals localized in scattered fragments and large logs of charcoaly wood. The uranium mineral concentrations are very spotty in such deposits because only a small proportion of the total amount of charcoaly wood is mineralized. The deposits generally are not minable. The Lone B and Cool prospects are typical of this type.

Deposits near the base of the Morrison Formation are confined to the lowermost sandstone unit of the Salt Wash Member. Uranium in the Dream prospect, the most thoroughly explored deposit, is evenly disseminated in a 3- to 4-foot-thick sandstone bed that contains abundant small pieces and flakes of charcoaly wood. Why uranium is concentrated in nearly minable deposits in some places near the base of the Salt Wash is not entirely clear; sandstone of the Salt Wash is not mineralized at other places where geologic conditions appear identical.

Some uranium-mineral claims have been located in the faulted rocks west of Wagon Box Mesa, and a radioactivity survey of several square miles in the faulted area was made in 1956. Most of the following discussion is abstracted from the resulting unpublished reports by D. D. Schultz and G. E. Thomas, who were members of the U.S. Geological Survey party in the Circle Cliffs area at that time. The faults are as much as a mile long and have a maximum displacement of about 40 feet. Nearly all are vertical or high-angle normal faults. The units displaced by the faults are the lower part of the Moenkopi Formation, the Kaibab Limestone, and the upper part of the Cutler Formation. Bleached zones a few feet wide occur along the fault traces. Locally, the fault surfaces are mineralized by copper carbonate minerals, pyrite, marcasite, and a mixture of hematite and limonite that may be a weathering product of the iron sulfides. No uranium minerals were identified in the mineralized rock, but a uranium mineral is probably responsible for the radioactivity along the fault surfaces. Most fault surfaces are more radioactive than the country rock, and those in the Moenkopi are more radioactive than surfaces of the same fault in the underlying Kaibab Limestone or sandstone of the Cutler Formation. However, uranium is not abundant in the fault zones, and the grade of the deposit is nowhere high enough to encourage mining.

I think that the assemblage and distribution of the minerals along the fault zones indicate that the mineralization resulted from redeposition of chemicals leached by ground water from overlying rocks. Other workers believe that the faults were channelways for hydrothermal solutions that rose from below and that the minerals were deposited from such solutions. Some drilling was done by the U.S. Atomic Energy Commission near the faulted zones, but the data thus obtained did not indicate whether downward-leaching ground water, upward-rising hydrothermal solutions, or laterally traveling solutions were responsible for the occurrences.

Members of the Chinle Formation other than the Shinarump locally contain low-grade concentrations of uranium. A few discrete sandstone lenses in the Monitor Butte Member contain uranium, especially in Wolverine Canyon and on the west side of Moody Creek. The lenses generally consist of sandstone containing chips and pellets of carbonaceous mudstone. The lithology is favorable for uranium deposition, but the lenses are widely separated. The mineralization, consequently, is sporadic and low in grade. In places, large charcoaly and silicified logs in beds near the base of the Petrified Forest Member of the Chinle Formation are heavily impregnated with carnotite. This type of occurrence is not minable and constitutes little more than a mineralogical oddity. Most of the mineralized logs have been found on the west side of the Circle Cliffs area.

MINERALOGY OF DEPOSITS

The primary uranium mineral in radioactive deposits in the Shinarump Member of the Chinle Formation and in the Moenkopi Formation probably is uraninite; but in the weathered parts of the deposits and also in the Monitor Butte Member of the Chinle, uranium occurs in carbonate, phosphate, sulfate, silicate, arsenate, and hydrated oxide minerals which were described by Weeks and Thompson (1954, p. 21). The deposits also contain pyrite, marcasite, sphalerite, and galena. Spectrographic analyses show that nickel, silver, molybdenum, cobalt, yttrium, and ytterbium also are associates of uranium ore in the area (Davidson, 1959, p. 444–446).

Carnotite is the only uranium mineral noted in logs in the Petrified Forest Member of the Chinle and in the Salt Wash Sandstone Member of the Morrison.

RELATION OF ASPHALT TO URANIUM DEPOSITS

The lowermost beds of the Shinarump Member contain asphalt in places. Generally the asphalt occurs as brown specks disseminated in the rock, but locally it is so abundant that brownish-black liquid asphalt seeps out along the contact with the Moenkopi. Where asphalt occurs in the Shinarump, some has penetrated into the upper few feet of the Moenkopi, and the ridges of Moenkopi on the channel contacts are heavily impregnated. A few selected samples of asphaltic Moenkopi from the Rainy Day mine and the Rocky Mountain Co. prospects were analyzed for organic carbon content in an effort to correlate the carbon content with the uranium content (table 1). The gray Moenkopi contains 0.16–1.68 percent organic carbon, but there seems to be no direct correlation between organic material and uranium content. One sample of red unaltered and virtually nonradioactive Moenkopi collected in the mine area contained 0.17 percent organic carbon.

TABLE 1.—*Uranium and organic carbon content in rocks of the Moenkopi Formation at the Rainy Day mine*

[Analyst, Wayne Mountjoy]

Lab. No.	Field No.	U (percent)	Organic carbon [1] (percent)	Color	Remarks
225241	RD-17	4.15	0.65	Gray	Ore.
222940	RD-102	2.60	1.68	do	Do.
222932	RD-101	1.05	.46	do	Do.
222941	RD-2	.09	.46	do	Subore.
222933	RM-3	.028	.28	do	Radioactive rock from Rocky Mountain Co. prospect.
222931	RM-4	.018	.19	do	Do.
244719	RD-22B	.003	.16	do	Slightly radioactive.
244727	RD-21A	.001	.17	Red	Nonradioactive.

[1] Total carbon was determined by the combustion method, and mineral carbon by the rapid gasometric method; organic carbon is the difference between the two.

CORRELATION OF TECTONIC STRUCTURE AND URANIUM DEPOSITS

Although considerable work was done in an effort to correlate several deposits in the Circle Cliffs area with some phase of the regional geologic structure, no correlation was established. Deposits having a production of several hundred tons or more occur in many different positions on the Circle Cliffs anticline, and none seem related either to faults or to joints.

CRITERIA AND ORIGIN OF URANIUM DEPOSITS

In the Circle Cliffs area as elsewhere on the Colorado Plateau, the occurrence of uranium can generally be correlated with certain lithologic and geologic features, but these features are not always associated with economically minable deposits. Most of the geologic conditions around any mine or prospect are duplicated in barren areas of the Circle Cliffs district, and an ore body should not be expected in all places having the geologic attributes of the more mineralized prospects. Therefore, favorable criteria, which are simply the factors that aid in locating uranium deposits sufficiently concentrated to encourage prospecting, are not specific evidence of an ore body. But if the criteria are present, the chances of finding an ore body are much greater than if they are not. Botanical prospecting methods have been investigated (Kleinhampl and Koteff, 1960), but they have not proved to be any more specific than the geologic criteria.

In the Circle Cliffs area the principal criteria of favorable environments for uranium deposits, primarily in the Shinarump Member of the Chinle Formation, are—

1. A channel eroded in the top of the Moenkopi and filled with sandstone of the Shinarump. Channels about 3,000 feet or less wide and about 40 feet or less deep probably are most favorable for minable uranium concentrations, mainly because these channels contain more mudstone than the larger channels.
2. Material that is capable of precipitating uranium from solution. Charcoaly material (Moore, 1954; McKelvey and others, 1955; Gruner, 1956, p. 514) or hydrogen sulfide and the sulfide ion (Gruner, 1952; 1956, p. 514; Miller and Kerr, 1954) released upon decay of organic matter have long been regarded as effective precipitants; more recently Gruner (1958) pointed out that crude oils and "dried" crude oils also may precipitate uranium. The intimate association of iron and copper sulfides with uranium indicates that the precipitating atmosphere was reducing in nature. As discussed above, no direct unit-for-unit correlation between organic carbon content and uranium content was found in the Circle Cliffs area.
3. A lenticular sandstone that is continuous with the rest of the sandstone and that contains abundant fragments and thin beds of mudstone and abundant organic material or some other reducing material. In the Circle Cliffs area this type of sandstone occurs only along the base of the Shinarump channels, and it is not very thick or continuous there. This rock would probably be a more effective host rock if it were capped or

overlain by a few feet of mudstone; unfortunately, this type of occurrence is rare in the area.

4. Lenses and blanket deposits of mudstone interbedded with and capping a mudstone-fragment conglomerate are major criteria in uranium mines of other districts, but such lenses are very uncommon in the Circle Cliffs district.
5. Proximity to the regional pinchout of the Shinarump, as suggested by Johnson (1959, p. 83, 91, pl. 6), because the lithologies outlined in 3 and 4 above commonly occur within 10–20 miles of such a regional pinchout.

The nature of uranium-transporting solutions has long been a subject of controversy and will not be reviewed here. The relative merits of hydrothermal solutions, ground water, or a combination of these, and of petroleum and carbon dioxide-charged solutions were discussed in detail by McKelvey, Everhart, and Garrels (1955) and by Gruner (1956). The distribution and position of uranium deposits in the Circle Cliffs area indicate that the ore solutions migrated along the beds and did not rise from below in the immediate vicinity of the prospects. The temperatures or the possible natures of the solutions are not known.

FUTURE OF THE AREA

The most favorable ground for additional prospecting is considered to be in the western and northern parts of the area, mainly because there the Shinarump channels are moderate in size, and the proportion of mudstone interbeds and fragments in the channeling sandstone is greater than in other parts of the area. However, no mines of consequence have yet been developed in the Shinarump in these parts of the area, and the depth of burial of the unit would probably preclude its exploration in many places. No pattern of ore bodies of significant size exists to allow confident prediction of more ore bodies.

In the Salt Wash Sandstone Member of the Morrison, the regional change in lithology in the Circle Cliffs area from a blanket-type sandstone to the south to a more lenticular sandstone to the north may partly cause uranium ore bodies to be concentrated near the area of lithologic change. The Dream and Solitude prospects are in the area of change; however, no minable deposits have been found, and the Salt Wash is too deeply buried to encourage exploration.

PRINCIPAL PROSPECTS

The best known and partly developed prospects in the Circle Cliffs area are described below, and their locations are plotted in figure 14. Claims were staked nearly everywhere on exposures of the Chinle and Morrison Formations, but not all claims have been equally explored. Several thousand feet of wagon drilling was done by private companies and by the U.S. Atomic Energy Commission on the mesas capped with Shinarump, in areas adjacent to prospects, and elsewhere; however, none of this drilling revealed ore bodies large enough to encourage extensive development. Analyses of ore samples from several prospects are combined in table 2. Uranium content, determined by chemical analysis, is reported as U; the radioactivity of the rock, converted to equivalent uranium content, is reported as eU.

TABLE 2.—*Analyses of uranium content in samples from the Buff and Red Cliff prospects*

[Analysts: C. G. Angelo, H. H. Lipp, J. S. Wahlberg, D. L. Schafer, and D. L. Ferguson]

Lab. No.	Field No.	Prospect	Stratigraphic assignment	eU (percent)	U (percent)
222927	B-2	Buff	Channel sample 6 in. above and below contact.	0.49	0.10
244733	CCR-54-7	do	2 ft of Shinarump Member of Chinle Formation, and 0.3 ft of Moenkopi Formation.	.31	.062
261133	RC-1	Red Cliff	1 ft of Moenkopi Formation below contact.	.005	.006
261134	RC-2	do	1 ft of Shinarump Member of Chinle Formation above contact.	.015	.012

The Black Widow, Hotshot, Yellow Jacket, and Stud Horse prospects and the Rainy Day mine are the only workings in the Circle Cliffs district from which more than a few truckloads of ore had been shipped as of 1956; the Rainy Day mine had produced more than 75 percent of the total. During the period of the study, shipping costs required that trucked ore average at least 0.25 percent U_3O_8 to make a mining operation profitable.

BUFF AND RED CLIFF PROSPECTS

The Buff (fig. 14, No. 1) and Red Cliff (fig. 14, No. 2) prospects are on the same small Shinarump channel in the northwestern part of the Circle Cliffs area. Exploration consists of 30–40 feet of drift at the Buff and about 70–80 feet of inaccessible drift at the Red Cliff.

The Shinarump channel is 800–1,000 feet wide and about 10 feet deep at the Buff prospect and no more than 20 feet deep at the Red Cliff prospect. Except for the ore-bearing unit described below, the Shinarump sandstone filling the channel is moderately well sorted medium-grained sandstone. The Moenkopi Formation underlying the channel-filling sandstone is reddish-brown siltstone or mudstone that is bleached light greenish gray in a 1- to 2-foot-thick zone under the channel base. Stringers of gypsum fill fractures in both the Shinarump and the Moenkopi.

The better grade ore is in the bleached Moenkopi at the Buff prospect and in the Shinarump at the Red Cliff prospect (table 2). The mineralized rock at the Buff prospect is so badly out of equilibrium that the actual uranium content is only one-fifth of the equivalent uranium content, indicated by radioactivity (table 2). The uranium ore is low grade and spotty in distribution and is confined to the upper 1 foot of the Moenkopi and the lower 2 feet of the Shinarump.

At the Red Cliff prospect the ore occurs in the lower part of a 2- to 6-foot-thick bed of brown, iron oxide-stained conglomerate composed of fragments of gray to light-yellow mudstone and black, charcoaly wood imbedded in a kaolinite-cemented matrix of medium-grained sandstone. The lower 1–3 feet of the ore-bearing bed contains copper minerals on fracture surfaces and is stained brown by iron oxide.

COOL PROSPECT

The Cool prospect (fig. 14, No. 3) consists of about 200 feet of drift and crosscuts. The Shinarump above the contact with the Moenkopi is interlayered medium-grained brown and light-yellow sandstone and gray siltstone. It contains very abundant charcoaly fragments and a few large charcoaly logs. Most of the radioactivity detected is in the large logs, but some radioactivity was detected in a 6-inch-thick zone at the contact. Radiometric examination of mineralized logs indicated that the highest grade is about 0.5 percent equivalent uranium.

BART, CENTIPEDE, AND MIDAS PROSPECTS

The Bart, Centipede, and Midas prospects are along a closely spaced system of Shinarump channels that trends N. 70° W. in the northwestern part of the Circle Cliffs area. The sandstone of the Shinarump is medium grained and kaolinitic and generally contains moderate amounts of mudstone and charcoaly wood fragments.

The Bart prospect (fig. 14, No. 4) is a 6-foot-long north-trending adit driven near the north edge of a channel that is about 400 feet wide and 10–40 feet deep. The base of this channel was covered by talus at the time of examination, but on the channel flanks the Moenkopi is bleached gray for as much as 6 feet beneath the Shinarump-Moenkopi contact. A weakly radioactive zone only a few inches thick occurs at the Shinarump-Moenkopi contact in the adit.

The Midas (fig. 14, No. 6) and Centipede (fig. 14, No. 5) prospects are on a small channel a few tens of feet south of the Bart prospect. This channel is 200–400 feet wide and 25–40 feet deep. The radioactive rock is in a 1-foot-thick zone that straddles the Shinarump-Moenkopi contact at both prospects. At the Midas prospect most of the radioactive rock is in the bleached Moenkopi and is localized on the channel flank in a small ridge of fractured rock that trends parallel to the channel.

The Centipede prospect, near the central part of the channel, was actively prospected during this study. Figure 15 shows the workings, geologic contacts, and the location of channel samples. The highest radioactivity in the Centipede prospect is in sandstone of the Shinarump Member where it contains moderate to large amounts of mudstone and charcoaly wood fragments. This material, in the ground opened, is confined to a 2-foot-thick bed at the base of the Shinarump, but some radioactivity was detected in a 2-inch-thick bed of charcoal-rich sandstone (table 3, sample 261156) in the back

TABLE 3.—*Analyses of uranium content in samples from the Centipede prospect*

[Analysts: W. W. Niles, eU; H. H. Lipp and D. L. Ferguson, U]

Lab. No.	Field No.	Stratigraphic assignment	eU (percent)	U (percent)
261151	CCM2-B	Above Shinarump-Moenkopi contact; 1.5 ft of Shinarump Member of Chinle Formation.	0.015	0.005
261152	CCM2-C	Below Shinarump-Moenkopi contact; 1 ft of gray Moenkopi Formation.	.098	.002
261147	CCM1-B	Above Shinarump-Moenkopi contact; 1.5–2.0 ft of Shinarump Member of Chinle Formation.	.26	.16
261148	CCM1-C	Below Shinarump-Moenkopi contact; 1.0 ft of light-brown Moenkopi Formation.	.057	.06
261156	CCM3-C	Base of sample 1.5 ft above Shinarump-Moenkopi contact; 0.5 ft of Shinarump Member of Chinle Formation.	.46	.66
261157	CCM3-D	Above Shinarump-Moenkopi contact; 1.5 ft of Shinarump Member of Chinle Formation.	.18	.16
261159	CCM3-F	Below Shinarump-Moenkopi contact; 0.4 ft of gray Moenkopi Formation.	.10	.12

of the end of the drift. The radioactivity in the prospect is probably caused by uraninite. Chalcopyrite and pyrite are present in the radioactive sandstone. Sphalerite and galena probably are also present, as spectrographic analyses show more lead and zinc in radioactive rock than in nonradioactive rock. The visible metallic minerals fill interstices and replace the quartz, feldspar, and kaolin of the rock matrix. Some of the quartz-grain boundaries show stylolitic intergrowths, which indicate solution of silica.

HORSEHEAD PROSPECT

The Horsehead prospect (fig. 14, No. 7) is similar to the Centipede prospect in occurrence and mineralogy. The prospect is in the center of a channel filled with Shinarump that is 400–600 feet wide and

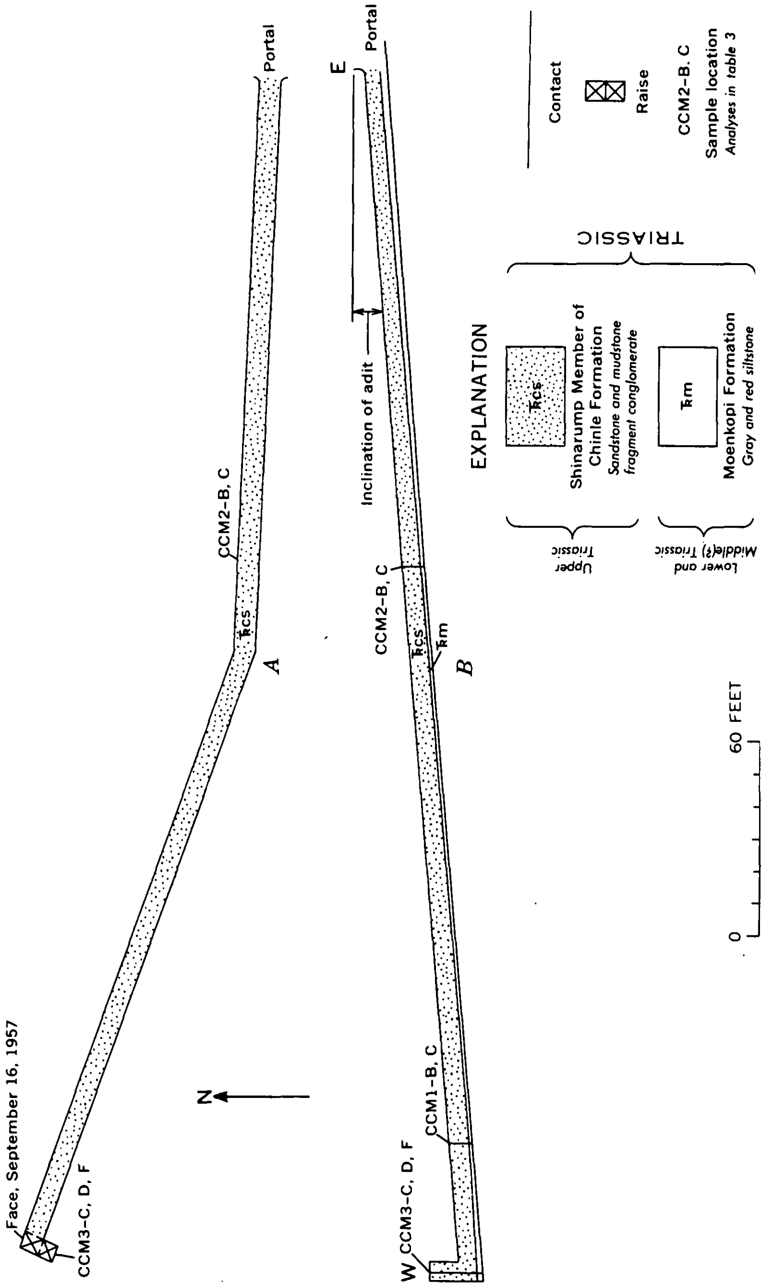


FIGURE 15.—Map of Centipede prospect and longitudinal section of drift, generalized from both walls. Mapped by E. S. Davidson and G. A. Miller, 1957.

about 30 feet deep. About 50 feet of drifting N. 87° W. along the deepest part of the channel had been completed at the time of the examination.

The sandstone of the Shinarump that fills the channel is thick bedded, medium grained, and kaolinitic, and it contains small amounts of charcoaly material and mudstone fragments. The basal bed of the Shinarump is a medium-grained sandstone containing abundant fragments of gray mudstone and moderate amounts of charcoaly material. Gypsum stringers cut across, and lie along, bedding planes. The most radioactive rock is in a 1- to 3-foot-thick zone at the base of the Shinarump and in the upper 1 foot of gray Moenkopi. Chalcopyrite and pyrite are associated with the radioactive rock, and secondary yellow and green uranium minerals occur in fractures and along bedding planes. A grab sample of highly radioactive sandstone had an equivalent uranium content of 2.57 percent, an actual uranium content of 3.44 percent, and trace amounts of zinc, nickel, and lead. A 1-foot-long vertical channel sample collected in the drift 12 feet from the entrance contained 0.13 percent uranium.

BLUE GOOSE PROSPECT

The Blue Goose prospect (fig. 14, No. 8) is near the center of a shallow but wide northwest-trending channel. The channel is about 800 feet wide, trends about N. 55° W., and is generally about 10 feet deep, although in places it is almost 20 feet deep. At this prospect the channel base of the Shinarump transects the mottled-siltstone unit of the Chinle and a few feet of the topmost beds of the Moenkopi. About 65 feet of northwest-trending drift had been completed at the time of this study. The sandstone of the channel is moderately clean, light brown, and fine to medium grained, and it contains only a few mudstone fragments and layers of charcoaly material. Low-grade radioactive material and associated copper minerals occur in the lower 2 feet of the Shinarump and in the upper 6 inches of the Moenkopi. The ore host is a lens 1–2 feet thick and about 25 feet wide of fine- to medium-grained sandstone containing abundant mudstone fragments and moderate amounts of carbonaceous material. Copper staining is obvious on rocks exposed at the face of the cliff. Green and yellow uranium minerals coat fractures and bedding planes.

HORSE CANYON PROSPECT

The Horse Canyon prospect (fig. 14, No. 9) consists of about 30 feet of drift in sandstone of the Monitor Butte Member of the Chinle Formation. The sandstone fills a small channel about 300 feet wide and 10–15 feet deep cut into the underlying mottled-siltstone unit of the Chinle. The Shinarump is absent at this prospect. The sandstone is medium grained and contains moderate amounts of stringers and chips of greenish-gray mudstone and many gray mudstone interbeds in the lower few feet. It also contains as much as 1 percent of charcoaly fragments, and some of this material is highly radioactive. Radioactive material (mainly green zeunerite(?)) and copper staining are present in the lower 10 feet of the sandstone, but appreciable radioactivity is distributed sporadically only in the lower 1 foot.

STUD HORSE PROSPECT

Several hundred feet of exploratory drifting, complemented by several hundred feet of exploratory drilling, yielded discouraging results at the Stud Horse prospect (fig. 16), on one of the Stud Horse Peaks (fig. 14, No. 10).

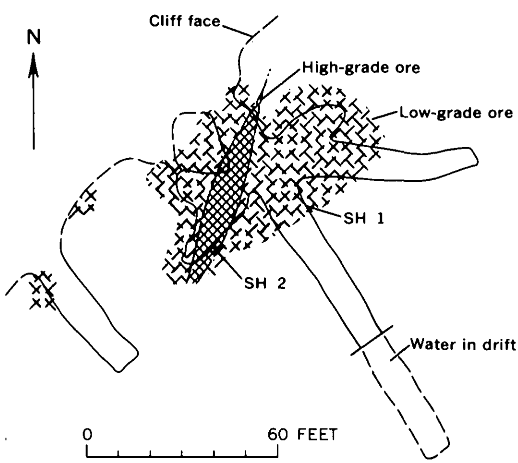


FIGURE 16.—Occurrence of uranium ore at Stud Horse prospect. Letters and number indicates location of sample listed in table 4.

The drifts are on the west side of the largest channel filled with Shinarump in the Circle Cliffs area. Here the channel is at least 4,500 feet wide and slightly more than 100 feet deep and trends northeast (fig. 14). The highest grade ore was mined from a pod at the top of the Moenkopi along a small "bank" on the northwest flank of the channel. The pod is 1–1½ feet thick, less than 10 feet wide, and 70 feet long (fig. 16). Some lower grade ore is present in a 1-foot-thick basal bed of sandstone of the Shinarump, which contains abundant fragments of mudstone and chips of charcoaly material. Zeunerite, autunite, and uraninite were identified in the ore zone. Megascopic chalcopyrite, pyrite, and carbonaceous material (probably oil residue) accompany the ore, and spectrographic analyses indicate that galena and sphalerite are also present. Copper staining is evident on the cliff outcrop from 10 feet above the Shinarump-Moenkopi contact to 6 feet below it. The Moenkopi is bleached gray for 6 or 7 feet, and in places 10 feet, below the contact. The location of two channel samples of the ore zone is shown in figure 16; the sample analyses are given in table 4.

TABLE 4.—*Analyses of uranium content in samples from the Stud Horse prospect*

[Analysts: D. L. Schafer, R. P. Cox, J. S. Wahlberg, and H. H. Lipp]

Lab. No.	Field No.	Stratigraphic assignment	eU (percent)	U (percent)
222939	SH-1	Below Shinarump-Moenkopi contact; 1 ft of Moenkopi Formation.	0.11	0.11
222930	SH-2	Below Shinarump-Moenkopi contact; 1 ft of Moenkopi Formation.	1.1	1.92

GLEN RAE PROSPECT

The Glen Rae prospect (fig. 14, No. 11) is on the west edge of a channel that is about 2,000 feet wide and is 30–40 feet deep at its lowest point. Downcutting at the prospect is no more than a few feet, and the Shinarump rests on the mottled-siltstone unit of the Chinle. Workings consist only of a 10-foot-long drift and two 5-foot-long angled crosscuts. Some copper staining, pyrite cubes altered to limonite, and low to moderate radioactivity occur in the lower 2 feet of the Shinarump and in the upper 1 foot of the mottled-siltstone unit. The Shinarump here is moderately clean sandstone containing only small amounts of clay pellets and charcoaly material. Two uranium-indicator plants, princessplume and ricegrass, were noted on slopes below the prospect.

BLUE BIRD PROSPECT

The Blue Bird prospect (fig. 14, No. 12) is on the west edge of the same channel as the Glen Rae. It consists of two adits, each driven about 50–60 feet. Copper minerals and low to moderate radioactivity are localized in the lower 2 feet of a pebbly sandstone at the base of the Shinarump. In general, the highest count of disseminated radioactivity is found where the percentage of clay fragments in the sandstone is greatest. In places some carbonaceous material is present that also is radioactive.

LONE B PROSPECT

The Lone B prospect (fig. 14, No. 13) is in the center of a channel that is about 1,400 feet wide and not more than 20 feet deep. Exploration consists of two large 100-foot-long adits.

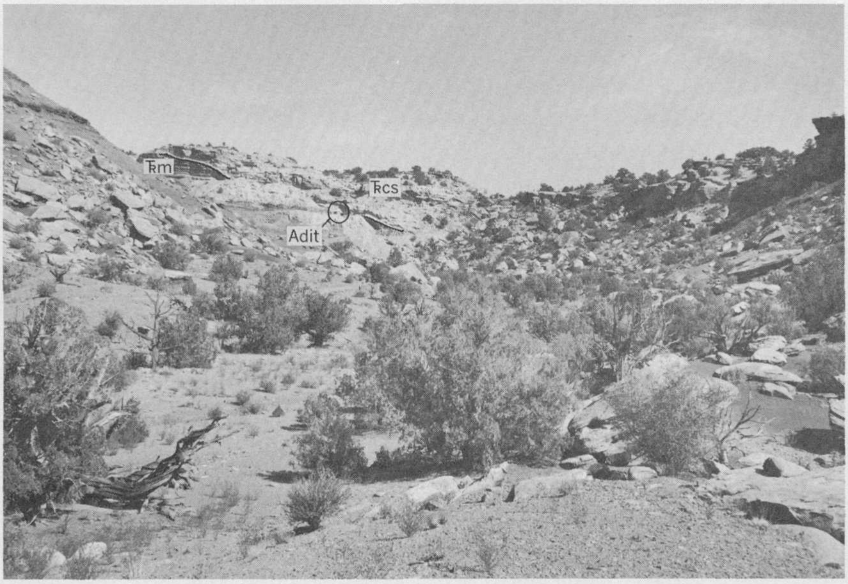
The lowest 4–5 feet of the Shinarump in the prospect area is medium-grained sandstone that contains abundant fragments of charcoaly material and moderate to small amounts of clay pellets. The underlying Moenkopi is bleached to gray from reddish brown for 3–4 feet under the contact. No uranium minerals were identified at this prospect, and radioactivity is confined to charcoaly material in the lower few feet of the Shinarump. Some of the charcoaly material is very radioactive, but the radioactivity is very spotty and the overall uranium-ore grade is probably very low. Some of the charcoaly fragments have been replaced by pyrite, but these fragments are not necessarily radioactive. Locally the upper 1 foot of the Moenkopi contains abundant pyrite cubes, but the Moenkopi is virtually devoid of uranium.

BLACK WIDOW PROSPECT

The Black Widow prospect (fig. 14, No. 14) is high on the west edge of the main Shinarump channel, where the channel is only 15–20 feet deep. Exploration at this prospect consists of slightly more than 100 feet of drift. The main adit, which yielded the only ore, and a 5-foot-long doghole are shown in figure 17. The other drifts, 600 feet south of the main adit, consist of one 40-foot-long adit and two 10-foot-long dogholes.

The geology is rather unusual at the main adit in that the uranium minerals are disseminated in and near a pod of Shinarump sandstone that appears to underlie siltstone of the Moenkopi Formation (fig. 17). The pod of sandstone probably filled an undercut streambank in the Moenkopi. The cliff rim now exposes the undercut podlike filling and the overlying Shinarump as separate deposits divided by siltstone of the Moenkopi, but the two Shinarump deposits were probably continuous before the present slope was exposed. The pod pinches out in the drift a few feet from the adit entrance. Locally, the pod is heavily asphaltic and contains some charcoaly material, much of which is radioactive. The highest radioactivity is at the bottom of the pod. Copper minerals are disseminated through the sandstone pod and form a halo around it. Some copper minerals were found on joints in the red unbleached Moenkopi adjacent to the pod near the lower right corner of the adit (fig. 17*B*). The doghole (fig. 17*B*), 3 feet above the thickest part of the pod of Shinarump sandstone, and the adits are in a more typical position at the Shinarump-Moenkopi contact on the sloping channel edge.

Radioactive minerals occur in the exploratory drifts of the Black Widow prospect in a 1- to 2-foot-thick mudstone-fragment conglomerate above the contact and in the upper 6 inches of the Moenkopi. The Moenkopi is bleached light to dark gray in a 2- to 3-foot-



A

FIGURE 17.—Prospect localities in typical channels filled with the Shinarump Member of the Chinle Formation; Moenkopi Formation (Ҡm) and Shinarump Member of the Chinle Formation (Ҡcs). *A*, Sneaky-Silver Falls prospect. *B*, Black Widow prospect. *C*, Yellow Jacket prospect.

thick zone under the contact. Near the pod of Shinarump the bleached zone is 6–8 feet thick. The uranium ore is very low grade and discontinuous and consists mainly of secondary green uranium minerals on joint and bedding-plane surfaces.

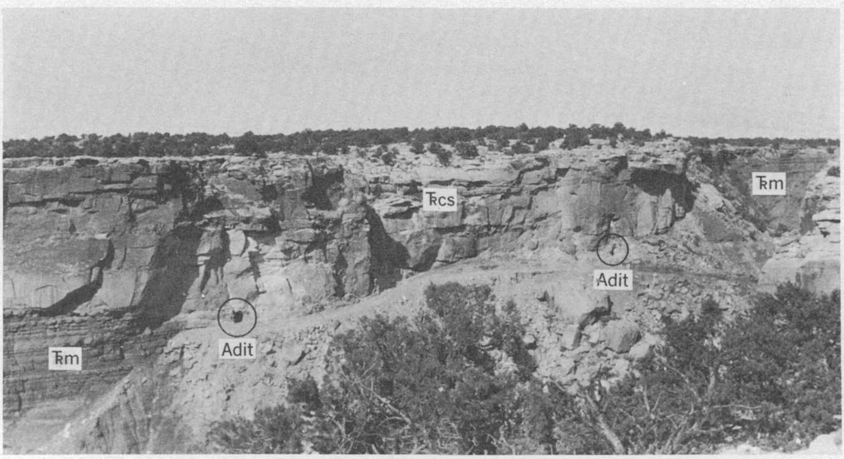
MESA PROSPECT

The Mesa prospect is on a small butte in the central part of the Circle Cliffs area (fig. 14, No. 15). The Shinarump capping the butte is a remnant of channel-filling sandstone which is about 4,000 feet wide and 60–70 feet deep at the south end of the butte. Exploration consists of more than 100 feet of drift in several places. The lower 3 feet of the Shinarump contains moderately abundant fragments of mudstone and as much as 1 percent of charcoal material that decreases in amount upward. No significant radioactivity was noted in the adits during the examination.

YELLOW JACKET PROSPECT

The Yellow Jacket prospect (fig. 14, No. 16) is on a cliff that crosscuts a deep narrow channel filled with Shinarump; the channel is 1,500 feet wide and 90 feet deep (fig. 17). This prospect comprises three adits totaling slightly more than 200 feet in length (fig. 18).

B



C

The northernmost adit is on the north side of the channel, and the two other adits are in the central and lowest part of the channel. Except for the lower few feet, the Shinarump is a clean white medium-grained sandstone containing only a few mudstone and charcoaly wood fragments. As much as 4 feet of conglomerate containing abundant fragments of mudstone and charcoaly material occurs in the central and lowest part of the channel. The lower foot

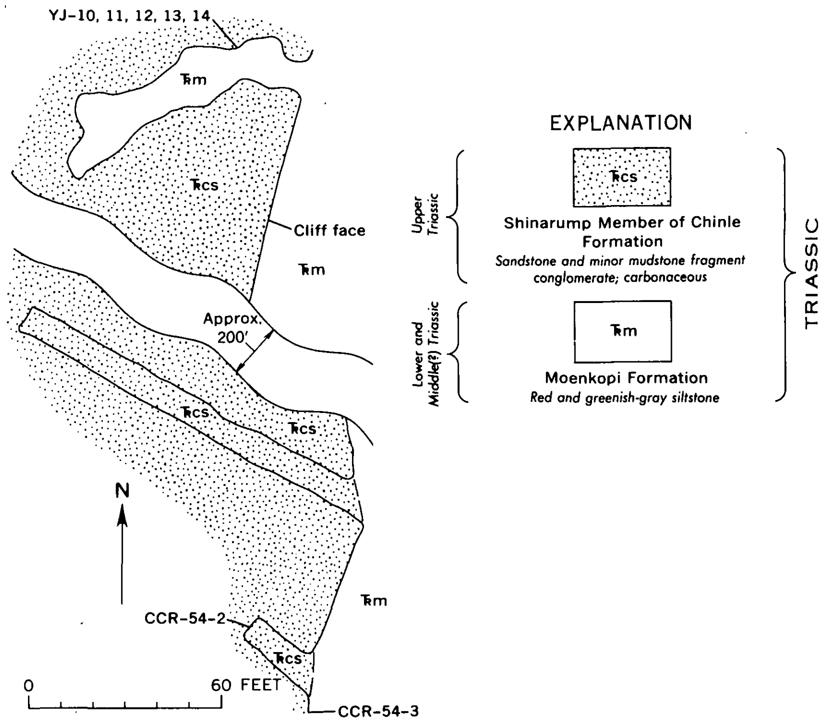


FIGURE 18.—Yellow Jacket prospect. Mapped by E. S. Davidson and G. A. Miller, 1957. Letters and number indicate location of sample listed in table 5.

of Shinarump at the northernmost adit is interlaminated light-brown sandstone and gray mudstone. Some organic material, probably "dead oil" or asphaltic residue of oil, occurs in the lower few feet of the Shinarump and in the upper few inches of the Moenkopi. In the adits exploring the central part of the channel, uranium minerals are localized almost entirely in the lower few feet of the conglomerate and the uranium grade increases downward toward the contact. In places in the conglomerate, fragments of charcoal and mudstone are moderately radioactive. In the northernmost adit on the flank of the channel, the most continuous and highest grade uranium ore occurs in the upper 6–8 inches of the Moenkopi, and only spotty radioactivity occurs in the interlaminated sandstone and mudstone of the Shinarump. The upper surface of the Moenkopi is cut into ridges and rills paralleling the channel trend. Uranium minerals tend to be concentrated in the ridges. The Moenkopi underlying the channel is bleached gray in a zone as much as 4 feet thick near the northern adit and as much as 2 feet thick near the deepest part of the channel. The bleached zone ranges from several inches to several feet in thickness in the area.

Copper minerals accompany the uranium minerals but have a slightly wider and more continuous distribution than the radioactive minerals. Some typical sample analyses are given in table 5; the sample locations are shown in figure 18.

TABLE 5.—*Analyses of uranium content in samples from the Yellow Jacket prospect*

[Analysts: D. L. Schafer, R. P. Cox, J. S. Wahlberg, H. H. Lipp, D. L. Ferguson, C. G. Angelo, and W. W. Niles]

Lab. No.	Field No.	Stratigraphic assignment	eU (percent)	U (percent)
244738	CCR-54-2	Channel sample 2 ft long of basal part of Shinarump Member of Chinle Formation.	0.29	0.16
244737	CCR-54-3	Channel sample 3 ft long of uppermost part of Moenkopi Formation.	.004	.004
222936	YJ-1	Grab sample, laminated sandstone and mudstone of basal 1 ft of Shinarump Member of Chinle Formation at northern adit.	.31	.29
261160	YJ-10	Channel sample 3 in. long of basal part of Shinarump Member of Chinle Formation.	.14	.20
261161	YJ-11	Uppermost 6 in. of gray Moenkopi Formation	.16	.15
261162	YJ-12	Channel sample 4 in. long of gray Moenkopi Formation under YJ-11.	.079	.19
261163	YJ-13	Channel sample 4 ft long of gray Moenkopi Formation under YJ-12.	.007	.006
261164	YJ-14	Channel sample 6 in. long of red Moenkopi Formation under YJ-13.	.009	.001

HOTSHOT PROSPECT

The Hotshot prospect (fig. 14, No. 17) is in the central and lowest part of a channel about 400 feet wide and 10–15 feet deep. Exploration consists of about 50 feet of drift across the trend of the channel.

The Shinarump in the mined part is medium-grained limonite-stained sandstone containing moderately abundant layers of conglomerate. The conglomerate contains numerous fragments of charcoaly material and greenish-gray mudstone. Copper staining is noticeable in the Shinarump and in the upper few feet of the Moenkopi. Some asphaltic material also is present. This deposit attained some notoriety during the early days of extensive uranium mining on the Colorado Plateaus because it is so weathered that the uranium minerals are badly out of equilibrium. Radioactivity indicates much greater amounts of uranium than are detected by chemical analyses. Sample HS–1 in table 6 is typical of most of the uranium ore taken from this prospect. Sample CCR–54–1 was taken 6 feet inside of the portal on the north wall of the drift and at right angles to the Shinarump-Moenkopi contact. Copper minerals and yellow uranium(?) minerals were recognizable in the sample, which is higher in grade than typical rocks of the prospect.

TABLE 6.—*Analyses of uranium content in samples from the Hotshot prospect*

[Analysts: C. G. Angelo, H. H. Lipp, J. S. Wahlberg, D. L. Schafer, and R. P. Cox]

Lab. No.	Field No.	Stratigraphic assignment	eU (percent)	U (percent)
222935	HS-1	Lowermost part of Shinarump Member of Chinle Formation.	0.32	0.079
244739	CCR-54-1	Channel sample 3 ft long of lowermost part of Shinarump Member of Chinle Formation.	.19	.20

SNEAKY-SILVER FALLS PROSPECT

The Sneaky-Silver Falls prospect (fig. 14, No. 18; fig. 17*A*) is on the north edge of a Shinarump channel which is as much as 4,000 feet wide and 100–130 feet deep. The channel is about 20 feet deep at the north adit and 65–70 feet deep at the southernmost adits. Exploration consists of about 200 feet of drift along the north flank of the channel.

Radioactive minerals are restricted to the lower 1 foot of the Shinarump Member of the Chinle Formation and to the upper few inches of the Moenkopi Formation. The uranium distribution is spotty and discontinuous. The highest grade rock in the Shinarump is in a conglomerate composed of mudstone and charcoaly wood fragments in a medium-grained sandstone matrix. Some radioactivity occurs in interlaminated gray mudstone and white sandstone. Clean sandstone, the dominant rock type filling the channel, is almost devoid of radioactive minerals. The highest grade and most continuous uranium-bearing rock in the Moenkopi is localized along ridges that parallel the channel trend. The main southern adit exposed such a ridge for 30 feet of drift nearest the cliff face; beyond, the ridge flattens out into the smooth flank of the channel, and the uranium minerals are disseminated along the Shinarump-Moenkopi contact. Chalcopyrite and pyrite accompany and envelop the uranium ore. Copper staining is evident on the cliff outcrop at the Shinarump-Moenkopi contact and in areas of anomalously high radioactivity.

DUKE PROSPECT

The Duke prospect (fig. 14, No. 19) is on the same channel as the Sneaky-Silver Falls prospect, and the geologic conditions are very similar in both. However, the mudstone-fragment conglomerate at the base of the Shinarump may be less continuous and more lenticular at the Duke prospect. Exploration has consisted mainly of about 100 feet of bulldozing on the Shinarump-Moenkopi contact. A 1¼-foot-long channel sample of the basal part of the Shinarump yielded 0.004 percent uranium on analysis.

SUN DOG PROSPECT

The Sun Dog prospect is in the southeastern part of the Circle Cliffs area (fig. 14, No. 20) and consists of a 130-foot-deep vertical shaft sunk almost entirely in the Shinarump. Red and gray mudstone of the Moenkopi lies on the dump. None of the Shinarump on the dump is very radioactive, but some of the sandstone is stained with copper minerals. The Shinarump in the Circle Cliffs area is generally about 40–50 feet or less thick, except where it fills channels in the underlying Moenkopi. Because the Shinarump exposed in this shaft is more than 100 feet thick, the shaft is almost certainly sunk in a channel deposit. The crossbeds on the surface exposure trend northeast, but they may not reflect the trend of the channel. The shaft was inaccessible at the time of examination, and the lower part of the sandstone was not examined.

BETTY JACK PROSPECT

The Betty Jack prospect (fig. 14, No. 21) is in a small outlying outcrop of the Shinarump Member. The Shinarump at the prospect is a white kaolinitic fine- to medium-grained sandstone with local streaks and partings of fine charcoaly woody material. It rests on the mottled-siltstone unit of the Chinle, and no channeling is apparent. The Moenkopi underlying the mottled unit is not bleached in this prospect. Workings consist of a 125-foot-long incline and about 70 feet of crosscuts (fig. 19). In places the thin beds containing charcoaly material are highly radioactive; one small grab sample contained 1.58 percent uranium. The highest radioactivity was found near the center point of the incline; radioactive minerals are sporadically distributed in the stringers of charcoaly material opened at the bottom of the incline.

RAINY DAY MINE AND ROCKY MOUNTAIN CO. PROSPECTS

The Rainy Day mine and Rocky Mountain Co. deposits (fig. 14, Nos. 22, 23) have been described previously (Davidson, 1959). The channel in which the deposits occur is about 3,500 feet wide and not more than 25 feet deep. The Rainy Day mine is on the steep south bank of the channel, and the Rocky Mountain prospects are along the gentle north flank of the channel.

Uranium ore in the Rainy Day mine occurs in a pod 1,800 feet long but only a few square feet in cross section. This pod is localized in the top of a small ridge or bank of Moenkopi at the edge of the channel. Chalcopyrite and pyrite occur in a zone that envelops the ore. Organic material, consisting of charcoaly material and asphalt or "dead oil," is ubiquitous in the Shinarump, and 1.68 percent asphaltic material was contained in one sample of the ore.

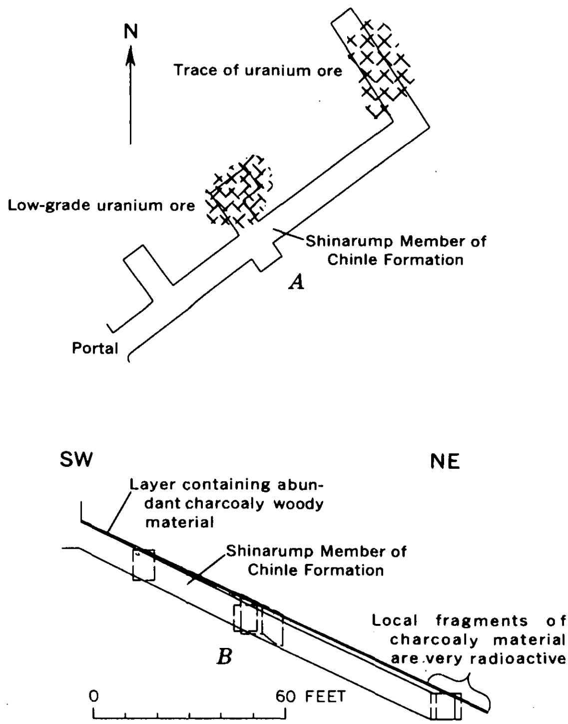


FIGURE 19.—Map and longitudinal section of Betty Jack prospect. Mapped by E. S. Davidson and G. A. Miller.

The Rocky Mountain prospects explore the Shinarump-Moenkopi contact with several hundred feet of drift. In these drifts, most of the radioactive minerals are in the upper few inches of Moenkopi and along the Shinarump-Moenkopi contact.

COPPERHEAD PROSPECT

The Copperhead prospect (fig. 14, No. 24) is on one of the several small channels associated with the main Shinarump channel crossing the Circle Cliffs area. The adit is at the base of the deepest part of the channel; the channel here is about 1,800 feet wide and 30–40 feet deep. Workings consist of about 80 feet of drifts and crosscuts. The sandstone filling the channel is white and medium grained and contains abundant pebbles of chert and quartz, some 6 inch to 1 foot in diameter fragments of mudstone, and small amounts of charcoaly material and asphalt. The lowest 1 foot of Shinarump contains moderate amounts of pyrite, marcasite, and chalcopyrite; and where these sulfide minerals impregnate the rock, scattered concentrations of radioactive minerals occur. One analyzed grab sample of ore contained 1.38 percent uranium.

HOPE PROSPECT

The Hope prospect (fig. 14, No. 25) consists of bulldozer cuts on the east edge of the main Shinarump channel. The channel is no more than 30–40 feet deep at this prospect. The Shinarump consists of a few feet of interlayered micaceous gray mudstone, very fine grained sandstone, and medium-grained sandstone overlain by kaolinitic medium-grained pebbly sandstone. Copper stain appears on fractures in the Shinarump and Moenkopi. Low-count radioactivity was detected at a few places along the Shinarump-Moenkopi contact.

ZELDA PROSPECT

The Zelda prospect (fig. 14, No. 26) is in the Moenkopi Formation, about 20 feet beneath the base of the main Shinarump channel. Exploration consists of a 150-foot adit.

The Moenkopi at the adit is weathered yellow in outcrop; the fresh rock ranges from gray to black, but weathered rock on the dump is light bluish gray. The coloration, which probably was the cause for exploration, is due to moderate amounts of pyrite-bearing asphalt or "dead oil" in pods and stringers along bedding planes and fractures. In the general area, about 10 feet of the Moenkopi underlying the Shinarump-Moenkopi contact is bleached light gray, but some of the Moenkopi that is exposed between the contact "bleached zone" and the prospected rock is reddish brown. No radioactivity or copper stain were noted at this prospect.

THREE PARDNERS PROSPECT

The Three Pardners prospect (fig. 14, No. 27) consists of a 25-foot-long adit and several dogholes along the cliff face. It is on the west edge of the main Shinarump channel where the channel depth is probably about 40 feet.

At the prospect the basal part of the Shinarump consists of 6–8 feet of medium-grained sandstone that contains abundant mudstone chips. The basal unit is overlain by interlayered mudstone and sandstone. Copper stains occur in the lowest 1 foot of the mudstone-chip sandstone and in the uppermost 1 foot of the Moenkopi. Some copper stain occurs at the contact of the mudstone-chip sandstone with the overlying interlayered sandstone and mudstone.

Uranium minerals coat grains and bedding planes in the basal and upper parts of the mudstone-chip sandstone and in the upper 1 foot of the Moenkopi, but their distribution is not continuous. Although the lithology of this prospect is promising, the distribution and grade of uranium content are not encouraging.

DODIE PROSPECT

The Dodie prospect (fig. 14, No. 28), also known as the Midas No. 3, is near the center of a channel that may be distributary to the main Shinarump channel. The channel on which the prospect is located is about 1,300 feet wide and as much as 50–60 feet deep; at the Dodie prospect it is 15–25 feet deep.

The Shinarump in the channel is uniform in lithology and consists of medium-grained kaolinitic sandstone that contains a few discontinuous lenses of mudstone-chip conglomerate. Copper stain occurs in a 2-foot-thick zone of Moenkopi under the Shinarump-Moenkopi contact. Moderate radioactivity occurs at the contact and in the upper few inches of the Moenkopi.

RED HEAD PROSPECT

The Red Head prospect (fig. 14, No. 29), also known as the Torpedo Head, is on the flank of the main Shinarump channel where the channel is about 40 feet deep. Exploration consists of two 6-foot-long adits.

The Shinarump at the prospect is white medium-grained pebbly sandstone. The lower few feet contains small amounts of charcoaly material, green mudstone stringers, and mudstone fragments ½–1 foot in diameter. Some gypsum stringers occur along bedding planes and fractures in the upper 1 foot of the Moenkopi and in the lower few feet of the Shinarump. Limonite, probably altered from pyrite, has colored the lower few feet of the Shinarump and the upper few feet of the Moenkopi light yellow to light brown. Copper stain, probably due to weathering of chalcopyrite, occurs in the upper 1 foot of the Moenkopi and in the lower few inches of the Shinarump. Radioactive minerals are distributed unevenly in the copper-stained rock and are concentrated mainly in the Moenkopi where its contact with the overlying Shinarump is irregular. Uranium mineralized rock in the prospect is too low in grade to encourage additional exploration.

MOQUI PROSPECT

The Moqui prospect (fig. 14, No. 30) consists of two adits, which are 60 feet and 40 feet long, respectively. The basal 15 feet of the Shinarump explored by these adits is an interlayered sequence of 2-foot-thick fine-grained sandstone beds and 1-foot-thick gray mudstone beds. The interlayered beds are overlain by white kaolinitic medium-grained pebbly sandstone. Very little copper stain or radioactivity was noted in either adit.

OLYMPIC PROSPECT

The Olympic prospect (fig. 14, No. 31) is an adit driven about 40 feet horizontally across the northeast-dipping contact between the Salt Wash Sandstone Member of the Morrison Formation and the underlying Summerville Formation. The Salt Wash is composed of slightly carbonaceous medium-grained sandstone that contains a few green mudstone interbeds near the base. A sample of the mudstone contained 0.033 percent uranium and 2 ppm (parts per million) selenium.

DREAM PROSPECT

Exploration at the Dream prospect (fig. 14, No. 32) consists of a 100-foot-long inclined shaft, a 10-foot-long drift to the north at the bottom of the shaft, and bulldozer trenches and cuts at the surface. Details of the exploration, the geologic contacts, and the radiometric and chemical analyses of samples collected at this prospect are shown in figure 20.

The bed of economic interest is a 4-foot-thick very fine grained to medium-grained light-brown limonite-stained sandstone that is evenly interlaminated with ⅛- to ¼-inch-thick layers of dark carbonaceous clayey material. Where exposed in a bulldozer trench 240 feet north of the Dream portal, the mineralized bed is less carbonaceous and less sandy than in the shaft. In the shaft the bed is coarser grained near the base and locally conglomeratic in the lower 1 foot. Flecks of carnotite are disseminated evenly on bedding planes in the carbonaceous material. The basal unit of the Salt Wash underlies the mineralized bed and grades laterally from a whitish-gray very calcareous siltstone to medium-grained crossbedded gray very calcareous sandstone. It contains abundant chert nodules about 2 feet below its upper contact and is more lime-rich in that zone. No carbonaceous material or notable radioactivity were found in this unit.

Above the main mineralized bed is about 1 foot of slightly to moderately radioactive gray fine-grained ripple-laminated sandstone containing a small amount of carbonaceous material. The next overlying units consist of crossbedded light-yellow medium-grained sandstone containing little carbonaceous material and a few 4- to 5-inch-thick interbeds of gray mudstone with virtually no radioactivity.

Moderate to high levels of radioactivity occur in the carnotite-bearing bed for about 50–60 feet along the strike near the shaft,

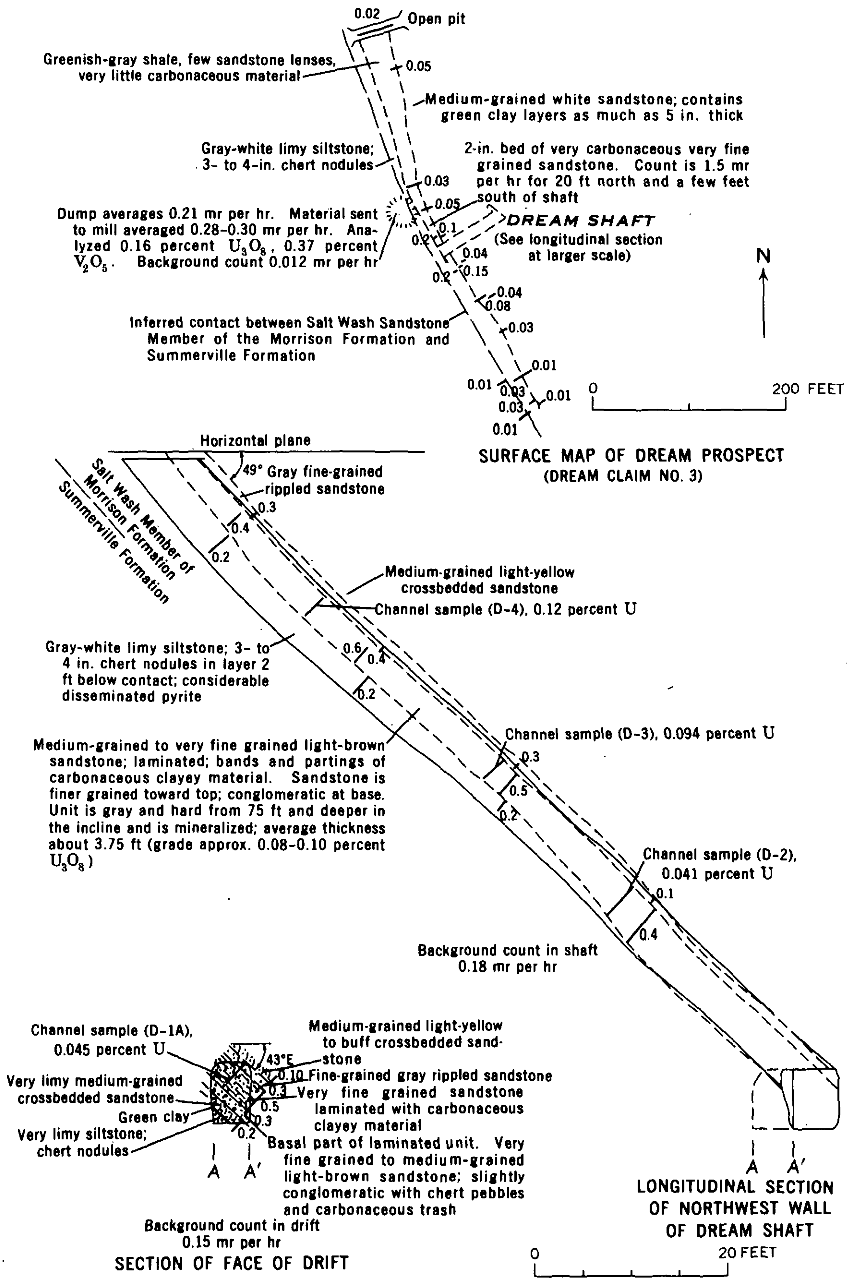


FIGURE 20.—Dream prospect, Garfield County, Utah. Numbers indicate location of scintillometer reading and value, in milliroentgens per hour.

and slight radioactivity is noted in the trench exposure 240 feet to the north. In the shaft the mineralized bed averages about 0.10 percent or less uranium and contains 15–625 ppm selenium. A picked grab sample contained 0.53 percent uranium and 2,250 ppm selenium. The grade does not improve with depth, nor does the ore-bearing bed thicken substantially downdip.

SOLITUDE PROSPECT

The Solitude prospect (fig. 14, No. 33) is explored by an 180-foot-long adit through the upper part of the Summerville Formation and about 54 feet of the overlying Salt Wash Sandstone Member of the Morrison Formation. The adit crosscuts the strata, which strike northwest and dip 48° NE. The basal beds of the Salt Wash are not radioactive, but the 6-inch- to 1-foot-thick carbonaceous mudstone beds and interlayered fine-grained white sandstone beds at the end of the adit are slightly radioactive. Channel samples of the beds exposed at the end of the adit were analyzed (table 7) and show that the uranium grade is too low to encourage further prospecting.

TABLE 7.—*Analyses of uranium and selenium in samples from the Solitude prospect*

[Analysts: H. H. Lipp, D. L. Ferguson, G. T. Burrow, and W. W. Niles. Stratigraphically, SO-1A is the highest bed and SO-1F is the lowest]

Field No.	Description	eU (percent)	U (percent)	Selenium (ppm)
SO-1A	Very fine grained sandstone, interlaminated with abundant carbonaceous mudstone.	0.005	0.004	4
SO-1B	Very fine grained sandstone and black carbonaceous mudstone.	.013	.009	1
SO-1C	Ripple-laminated very fine grained sandstone with some laminae of carbonaceous material.	.008	.005	.5
SO-1D	Very fine grained sandstone interlaminated with abundant carbonaceous mudstone.	.010	.006	4
SO-1E	Black very fine grained sandstone, carbonaceous fragments as much as 6 mm in diameter.	.038	.044	1
SO-1F	Fine-grained friable sandstone, massive, with some charcoaly wood fragments and laminae of carbonaceous material.	.003	.002	.5

METALLIFEROUS DEPOSITS OTHER THAN URANIUM

MANGANESE

Some nodules of black manganese minerals lie on the uppermost beds of the Navajo Sandstone in the eastern and southeastern parts of the area. None of this material was seen bedded in the sandstone, but a deposit of such material in Harris Wash about 1 mile southeast of the mapped area has been prospected. Possibly a few small bedded or vein deposits, similar to those described by Baker, Duncan, and Hunt (1952), occur near the Navajo-Carmel contact in the Circle Cliffs area. A small deposit near the middle of sec. 36,

T. 32 S., R. 7 E., consists of crosscutting veinlets of manganese oxides near the middle of the Navajo Sandstone; the deposit does not contain recoverable ore (Baker, Duncan, and Hunt, 1952, p. 142–143).

SELENIUM

A grab sample of carnotite ore collected at the Dream prospect contained 0.53 percent uranium and 0.2 percent selenium. Channel samples collected from exposures in the inclined shaft at the prospect contained from 15 to 625 ppm selenium. No other prospects in the Salt Wash Sandstone Member of the Morrison Formation showed so high a concentration of selenium, but no effort was made to systematically sample the Salt Wash for selenium. Selenium may occur in commercial quantities in the Salt Wash in the mapped area, but it probably would have to be recovered as a byproduct of uranium.

TITANIUM

Deposits of heavy minerals containing titanium (ilmenite and leucoxene) and unusual amounts of rare earths have been located a few tens of miles southwest of the Circle Cliffs area in the Straight Cliffs Formation of the Kaiparowits region. The deposits may be beach deposits that coincide with shorelines of Cretaceous seas. Some black sandstone beds that contain moderate amounts of heavy minerals are in the Ferron and Emery Sandstone Members of the Mancos Shale in the Henry Mountain basin, but none appear to have commercial significance.

STRATIGRAPHIC SECTIONS

The stratigraphic sections measured or otherwise described and calculated during this survey are listed in the following tabulation. Sections of the San Rafael Group at Bitter Spring in Hall Creek Valley, sec. 29, T. 33 S., R. 8 E., and of the Morrison Formation at "The Post," lat 37°50′ N., long 110°58′ W., are not included, as they are available in the report by Craig, Holmes, Freeman, Mullens, and others (1959).

List of stratigraphic sections

Section No.	Formation	Locality	Latitude	Longitude
1	Kaibab Limestone and Cutler Formation.	White Canyon	37°53′00″	111°09′10″
2	do	East-central Circle Cliffs	37°45′	110°00′
3	do	do	37°47′30″	110°01′00″
4	do	Central Circle Cliffs, North Fork Creek.	37°47′	110°05′30″
5	Cutler Formation, Kaibab Limestone, and Moenkopi Formation.	East-central Circle Cliffs, near Burr Trail.	37°50′20″	111°02′30″
6	Moenkopi Formation	East-central Circle Cliffs, south of Rainy Day mine.	37°46′	111°01′
7	do	Horse Canyon	37°56′00″	111°12′
8	Chinle Formation	do	37°57′	111°13′
9	do	Silver Falls Canyon	37°44′	111°07′
10	do	East-central Circle Cliffs, Burr Trail.	37°50′10″	111°02′10″
11	do	Deer Point	37°42′00″	110°57′00″
12	Glen Canyon Group	Canyon 2 miles NE of Deer Point.	37°44′30″	110°57′30″
13	do	Burr Trail	37°51′	111°02′
14	Kayenta Formation	Northwest Circle Cliffs, sec. 1, T. 33 S., R. 5 E.		
15	do	Silver Falls Canyon	37°40′30″	111°12′
16	San Rafael Group	2 miles northwest of Bitter Creek Divide, Hall Creek.	37°59′30″	111°05′
17	do	Red Slide	37°42′	110°56′30″
18	Morrison Formation	Long Canyon	37°40′	110°53′
19	do	Big Thomson Mesa	37°43′	110°56′
20	Dakota Sandstone	The Post	37°50′	110°58′20″

SECTION 1.—*Kaibab Limestone and Cutler Formation*

[In White Canyon, 2 miles northwest of Stud Horse Peaks, north-central Circle Cliffs area, Garfield County; lat 37°53′00″, long 111°09′10″. Measured by E. S. Davidson]

	Thickness (ft)
Moenkopi Formation (incomplete):	
Base of Sinbad Limestone Member of Moenkopi Formation.	
Erosional unconformity.	
Basal unit of Moenkopi Formation:	
Sandstone, white, dolomitic, fine-grained; contains abundant bedded white to gray chert in 1- to 2-in.-thick bands	9.3
Sandstone, white, fine-grained; contains as much as 30 percent fragments of white to gray chert	3.0
Sandstone, white, fine-grained; contains as much as 50 percent bedded white to gray chert	5.0
Total basal unit of Moenkopi Formation	17.3

SECTION 1.—*Kaibab Limestone and Cutler Formation*—Continued

	Thickness (ft)
Erosional unconformity.	
Kaibab Limestone:	
Dolomite, light-yellow, dense; beds 1–2 ft thick; contains moderately abundant gastropod fragments, sponge spicules, specks of glauconite and collophane, some chert nodules and quartz geodes and a few 1- to 2-in.-thick layers of light-green glauconitic dolomitic fine-grained sandstone	33.4
Dolomite, light-yellow; contains abundant fine quartz grains and bedded and fragmental gray and white chert, some fine-grained glauconitic sandstone. Unit is poorly exposed	4.8
Dolomite, light-yellow; beds 2 ft thick; contains few scattered specks of glauconite, quartz geodes in some beds; 2-ft-thick bed at base is a coquina of pelecypod, gastropod, and bryozoan fragments and sponge spicules, some replaced by collophane	21.6
Dolomite, light-yellow; contains as much as 20 percent fine to coarse grains of quartz, some pebbles of fine-grained sandstone, and some specks of glauconite	.8
Total Kaibab Limestone	60.6
Cutler Formation:	
White Rim Sandstone Member—upper unit:	
Sandstone, light-yellow to light-brown, beds 1–2 ft thick, poorly sorted, fine- to medium-grained; dolomite cement	6.4
Dolomite, light-yellow, thick-bedded; contains fragments of gastropods and pelecypods and some fine to medium quartz grains	7.0
Sandstone, white, horizontally stratified, thin- to thick-bedded, fine- to medium-grained; some dolomite cement	21.6
Sandstone, light-yellow, dolomitic, horizontally stratified, thin-bedded, poorly sorted, medium-grained	10.8
Sandstone, white to gray, horizontally stratified, thin-bedded, friable, fine- to medium-grained	41.6
Dolomite, light-yellow; contains as much as 25 percent fine grains of quartz, moderate amounts of pelecypod and gastropod fragments, and few subrounded to angular pebbles of black chert	2.0
Sandstone, light-yellow to white, horizontally stratified, thin-bedded, poorly sorted, fine- to coarse-grained; some dolomite cement	5.4
Sandstone, white, thick-bedded, small- to large-scale trough-type crossbedded, friable, fine-grained; contains some medium to coarse grains of quartz; gradational with underlying unit	32.4
Sandstone, white, horizontally stratified, thick-bedded, friable, fine-grained; gradational with underlying unit	16.2
Sandstone, white, medium- and large-scale crossbedded in beds as much as 15 ft long, friable, fine-grained	10.8
Total exposed upper unit of White Rim Sandstone Member of Cutler Formation	154.2

SECTION 2.—*Kaibab Limestone and Cutler Formation*

[In NW cor. sec. 23 (unsurveyed), T. 35 S., R. 8 E., east-central Circle Cliffs area, Garfield County; lat 37°45′, long 110°00′. Measured by E. S. Davidson and Gilbert Thomas]

	Thickness (ft)
Moenkopi Formation (incomplete):	
Conglomerate; consists of ¼- to 2-in. fragments of chert in a matrix of brown fine-grained sandstone containing as much as 5 percent medium sand; very thin bedded to thin bedded, probably equivalent to Sinbad Limestone Member	3.0
Erosional unconformity.	
Kaibab Limestone:	
Dolomite, cherty, dark-yellow-brown; contains sponge spicules, as much as 5 percent chert fragments, 1–2 percent quartz geodes, as much as 5 percent specks of green apatite, and less than 1 percent hematite nodules; unit is moderately porous	7.1
Dolomite, pale-yellow; contains as much as 10 percent fine quartz sand and 20 percent small chert nodules, abundant quartz-geodes, and less than 1 percent specks of green apatite	10.2
Dolomite, pale-yellow to white, fine- to medium-grained; contains sponge spicules; beds 1–2 ft thick	23.9
Dolomite, pale-yellow-white, fine-grained; contains less than 1 percent medium to coarse grains of quartz and quartz-filled geodes, abundant specks of green apatite; fossiliferous (gastropods)	2.0
Total Kaibab Limestone	43.2
Cutler Formation:	
White Rim Sandstone Member—upper unit:	
Sandstone, dolomitic, fine-grained to very coarse grained, poorly sorted; contains less than 1 percent ¾- to 2-in. quartz-filled geodes	2.6
Sandstone, gray to white, fine-grained, friable, slightly dolomitic at top	3.0
Dolomite, pale-yellow to yellow-brown, fine-grained, porous; beds 4 ft thick; locally composed of as much as 80 percent quartz grains	20.0
Covered, probably dolomite	2.0
Sandstone, fine-grained, well-sorted, friable; blocky beds 2–4 ft thick; contact covered	12.7
Sandstone, gray-white, fine- to coarse-grained, poorly sorted, slightly dolomitic, thick-bedded	8.3
Sandstone, dolomitic, pale-yellow, fine- to medium-grained; contains as much as 50 percent carbonate and less than 1 percent hematite nodules	6.0
Sandstone, white, fine- to medium-grained, poorly sorted; slightly dolomitic	2.5
Dolomite, sandy, pale-yellow, fine-grained; contains as much as 30 percent fine to coarse quartz sand and less than 1 percent hematite nodules and traces of petroliferous material	2.5

SECTION 2.—*Kaibab Limestone and Cutler Formation*—Continued

	Thickness (ft)
Cutler Formation—Continued	
White Rim Sandstone Member—upper unit—Continued	
Sandstone, dolomitic, yellow-brown, fine- to medium-grained; contains quartz-filled geodes at base	0.5
Sandstone, gray-white, fine- to medium-grained, poorly sorted, friable; horizontally stratified beds 0.5–1 ft thick	6.3
Total upper unit	66.4
White Rim Sandstone Member—lower unit:	
Sandstone, white, fine-grained, friable; composed of clean quartz sand, in planar and trough cross-stratified beds as much as 30 ft long, generally dipping southeast; individual cross-strata ¾–1 in. thick, sets of cross-strata 8–10 ft thick	108.0
Base of exposure, not base of unit.	
Total exposed White Rim Sandstone Member of Cutler Formation	174.4

SECTION 3.—*Kaibab Limestone and Cutler Formation*

[SW¼ sec. 14, T. 35 S. (unsurveyed), R. 8 E., east-central Circle Cliffs area, Garfield County; lat 37°47'30", long 110°01'00". Measured by E. S. Davidson and Gilbert Thomas]

	Thickness (ft)
Moenkopi Formation (incomplete section):	
Conglomerate, poorly sorted; ¼- to ⅜-in. fragments of white chert in matrix of medium-grained to very coarse grained quartz sandstone with yellowish-orange dolomite cement; petroliferous; probable Sinbad Limestone Member	8.2
Erosional unconformity.	
Kaibab Limestone:	
Dolomite, light-brown to pale-yellow; contains spicules, less than 1 percent hematite nodules, and a few specks of green apatite	8.4
Dolomite, medium-grained; contains as much as 20 percent fine grains of quartz, abundant nodules of chert, and specks of green apatite; scattered thin parting-plane laminae consist of fine-grained sandstone and green apatite	5.2
Dolomite, dense; contains numerous small cavities, abundant sponge spicules, as much as 2 percent specks of green collophane; local layers as much as 1 ft thick contain 1–5 percent quartz geodes; fossiliferous (gastropods)	15.6
Sandstone, medium- to coarse-grained, discontinuous; contains abundant specks of green glauconite and collophane	.2
Total Kaibab Limestone	29.4

SECTION 3.—*Kaibab Limestone and Cutler Formation*—Continued

	Thickness (ft)
Cutler Formation:	
White Rim Sandstone Member—upper unit:	
Sandstone, white, fine-grained to very fine grained, grades upward into poorly sorted fine- to coarse-grained dolomitic sandstone; unit contains a few quartz geodes	5.6
Dolomite, sandy; contains 30–50 percent quartz grains	20.5
Sandstone, dolomitic, fine- to coarse-grained; contains as much as 30 percent dolomite; thick-bedded	4.6
Sandstone, dolomitic, pale-yellow to gray-white, generally fine-grained; contains a few coarse quartz grains; friable; beds 1–4 ft thick; contains as much as 20 percent dolomite	19.7
Sandstone, dolomitic, fine-grained to very fine grained; dolomite forms 20–50 percent of unit; contains a few molds of sponge spicules	14.2
Sandstone, dolomitic, fine-grained to very coarse grained, poorly sorted, planar cross-stratified in beds 2 ft long	1.0
Dolomite, sandy, yellow, thick-bedded; contains as much as 10 percent quartz grains, and specks and globules of petroliferous material	4.0
Sandstone, fine- and medium-grained, very thick bedded; contains some sets of planar cross-strata 6 ft long	18.1
Total thickness upper unit	87.7
White Rim Sandstone Member—lower unit:	
Sandstone, white, fine-grained, friable, in planar sets of southeast dipping cross-strata, individual cross-strata 1–2 in. thick; sets of cross-strata as much as 60 ft long	20.0
Base of exposure, not base of unit.	
Total exposed White Rim Sandstone Member of Cutler Formation	107.7

SECTION 4.—*Kaibab Limestone and Cutler Formation*

[At North Fork Creek, a tributary of Silver Falls Creek, central Circle Cliffs area, Garfield County; lat 37°47′, long 111°05′30″. Measured by E. S. Davidson]

	Thickness (ft)
Moenkopi Formation (incomplete section):	
Basal unit:	
Sandstone, gray to light-yellow, fine-grained, white dolomite cement; contains 25–60 percent gray chert nodules and angular fragments of gray chert, some chert is in beds 2 in. thick and averaging 2 ft in width; contains few quartz geodes with calcite crystals in center, some glauconitic sandy layers, especially near base of unit	17.9
Unconformity—sharp erosional contact.	

SECTION 4.—*Kaibab Limestone and Cutler Formation*—Continued

	Thickness (ft)
Kaibab Limestone:	
Dolomite, light-yellow; horizontally stratified in beds 1–3 ft thick; contains very fine grains of quartz, abundant specks of glauconite and collophane, moderately abundant thin layers of glauconitic sandstone, chert, and quartz geodes; unit is highly fossiliferous (fragments of gastropods, pelecypods, and sponge spicules)	23.8
Dolomite, light-yellow, horizontally stratified in beds 1 to 2 ft thick; locally oolitic (1 mm or less); contains some layered bedded chert in upper 3 in.; fossiliferous (gastropod, bryozoan stems, sponge spicules); abundant specks of collophane and glauconite	16.6
Dolomite, light-yellow; contains as much as 5 percent medium grains of well-rounded quartz, 1 percent specks of collophane, trace quartz crystal lined geodes averaging 1 in. in diameter; fossiliferous (gastropods, bryozoan stems, sponge spicules)	2.5
Total Kaibab Limestone	42.9
Cutler Formation:	
White Rim Sandstone Member—upper unit:	
Sandstone, white to light-yellow, fine- to medium-grained, friable; some dolomite cement	0.2
Sandstone, dolomitic, light-yellow, fine- and medium-grained, crossbedded; beds in sets 1–2 ft long and 1–2 ft thick; individual beds 6 in. thick; rounded quartz grains well cemented with dolomite; weathered surface is spiny	4.5
Dolomite, sandy, light-yellow, oolitic; horizontally stratified in beds 2–4 ft thick; contains 20–30 percent fine and medium well-rounded grains of quartz and locally more quartz grains than dolomite; spiny surface on outcrop	18.4
Sandstone, light-yellow, poorly sorted fine- and medium-grained; heavily cemented with yellow dolomite; sharp lower contact; transitional with overlying bed	2.5
Sandstone, light-gray, fine- and medium-grained, friable; horizontally stratified in beds 1 in.–2 ft thick; splits every 2 or 3 ft, giving a thick-bedded appearance; local stringers of light-yellow heavily dolomite-cemented sandstone; one 2-ft thick yellow dolomite bed 3 ft above base	19.0
Dolomite, sandy, very light yellow; weathers gray; contains 20–30 percent fine to medium grains of quartz and a few 6-in.-thick beds of fine-grained white sandstone; spiny surface on weathered outcrop	24.0
Sandstone, white to light-yellow, horizontally stratified, friable, fine- to medium-grained; contains abundant quartz crystal lined geodes in upper 2.5 ft	5.0
Total upper unit	73.6
White Rim Sandstone Member—lower unit:	
Sandstone, white to very light brown; friable, fine-grained with few medium grains of quartz; planar crossbedded laminae 10 ft long; upper contact is sharp erosional break at section locality	3.0
Total exposed White Rim Sandstone Member of Cutler Formation	76.6

SECTION 5.—*Moenkopi Formation, Kaibab Limestone, and White Rim Sandstone Member of Cutler Formation*

[In NE cor. sec. 20 and NW cor. sec. 21, T. 34 S., R. 8 E. (unsurveyed), east-central Circle Cliffs area, Garfield County (near Burr Trail); lat 37°50'20", long 111°02'30". Measured by E. S. Davidson and Gilbert Thomas]

	Thickness (ft)
Chinle Formation (incomplete):	
Mottled-siltstone unit:	
Lower 3 ft moderate-brown mudstone; contains abundant scattered coarse to very coarse grains of quartz. Next 4 ft mottled white and purple-white fine-grained to very fine grained sandstone containing scattered coarse to very coarse grains of quartz. Upper 2 ft mudstone; weathers yellow brown; contains abundant hematite nodules	9. 7
Moenkopi Formation:	
Mudstone, dark-reddish-brown to reddish-brown, laminated to very thin bedded, shaly; contains local 1-in.-thick lenses of gray very fine grained micaceous sandstones. (This unit locally removed by pre-Chinle erosion)	21. 6
Siltstone to very fine grained sandstone, reddish-brown to greenish-yellow, cuspate ripple marked, in beds ½- to 1 in. thick; very micaceous; slightly calcareous	2. 6
Mudstone, dark-reddish-brown to reddish-brown, shaly, slightly ripple-laminated to horizontally stratified; laminae 1/16–⅛ in. thick; micaceous; contains a resistant ledge of rippled red siltstone 18.9 ft above base of unit	32. 1
Sandstone, greenish-gray, very fine grained to silty, ripple-laminated; small-scale cross-stratified in beds ¼–3 in. thick; slightly calcareous	4. 5
Silty mudstone and mudstone, reddish-brown; upper 2 ft bleached gray white; contains local lenses of shaly greenish-gray micaceous siltstone and very fine grained sandstone; 6-in.-thick beds of greenish-gray calcareous very fine grained sandstone 40.8–45 ft above base; ripple cross-stratification common throughout unit	116. 2
Mudstone, gray to greenish-gray; weathers light yellow; contains discontinuous lenses of very fine grained sandstone at 5- to 6-ft intervals; petroliferous	29. 9
Sandstone, greenish-gray, very fine grained, micaceous; yellowish-brown on surface; contains specks of hematite altered from pyrite	1. 5
Mudstone and siltstone, gray to yellow-brown; weathers pale green to yellow gray; shaly; very thin bedded; unit contains local discontinuous thin lenses of very fine grained sandstone; petroliferous	23. 0
Sandstone, brown to black; weathers yellow to gray, fine grained to very fine grained; ripple marks in beds ⅛–¼ in. thick; contains abundant gypsum on bedding and fracture planes; highly petroliferous; forms ledge	30. 0
Mudstone, gray, shaly; weathers light yellow; contains local very thin to thin beds of fine-grained sandstone; locally contains gypsum along bedding planes and fractures; poorly exposed; contact with unit below gradational	17. 2

SECTION 5.—*Moenkopi Formation, Kaibab Limestone, and White Rim Sandstone Member of Cutler Formation*—Continued

	Thickness (ft)
Moenkopi Formation—Continued	
Sandstone, light-yellow to reddish-brown; slabby to shaly; beds as much as 1 ft thick; ripple marks and small-scale cross-stratification; petroliferous; locally contains limonite and hematite nodules and concretions	153. 2
Sandstone, very pale yellow to white; unit contains as much as 30 percent chert nodules, and abundant quartz geodes. Upper part of unit is fine-grained sandstone containing as much as 10 percent dolomite cement and abundant ¼–⅜-in. thick beds of chert; locally upper 5 ft contains more than 50 percent bedded chert; petroliferous	18. 2
Total Moenkopi Formation	450. 0
Kaibab Limestone:	
Dolomite, pale-yellow; beds 1–2 ft thick; contains quartz geodes, sponge spicules, as much as 5 percent green specks of apatite, and 1- to 2-in.-thick beds of chert	22. 7
Sandstone, gray to white, fine-grained, friable; contains as much as 5 percent quartz geodes and chert nodules	1. 7
Dolomite, very thick bedded; contains abundant quartz geodes	5. 8
Dolomite, pale-yellow to white; contains as much as 5 percent quartz geodes, a moderate number of specks of green apatite, and, in lower 2–3 ft, as much as 5 percent fine quartz sand; petroliferous; contains gastropods and sponge spicules	14. 7
Total Kaibab Limestone	44. 9
Cutler Formation:	
White Rim Sandstone Member—upper unit:	
Sandstone, yellowish-gray, fine-grained, well-sorted; friable except in upper 2 ft, which is poorly sorted fine-grained dolomitic sandstone containing as much as 20 percent dolomite; locally petroliferous; fossiliferous (gastropods, pelecypods, and brachiopods)	9. 3
Dolomitic sandstone, medium- to coarse-grained, poorly sorted	1. 4
Sandstone, gray and white, fine-grained, friable, thin- to thick-bedded	6. 9
Sandstone, light-yellow, fine-grained, thick-bedded; cemented with dolomite; base of exposure not base of unit	4. 7
Total exposed upper unit of White Rim Sandstone Member of Cutler Formation	22. 3

SECTION 6.—*Moenkopi Formation*

[In east-central part of sec. 15, T. 35 S., R. 8 E. (unsurveyed), east-central Circle Cliffs area, Garfield County; lat 37°46′, long 111°01′. Measured by E. S. Davidson and Gilbert Thomas]

	Thickness (ft)
Chinle Formation:	
Mottled-siltstone unit:	
Mudstone, mottled light-gray, white, and purplish-brown; contains abundant medium to coarse grains of quartz sand; firmly cemented	7.0
Moenkopi Formation:	
Mudstone, dark-reddish-brown, micaceous, interbedded with greenish-gray micaceous siltstone to fine-grained sandstone; upper 5 ft purplish brown	10.4
Siltstone to very fine grained sandstone, light-greenish-gray, blocky splitting; contains ripple-laminated layers about 1 in. thick	2.5
Mudstone, dark-reddish-brown; beds ⅛ in. thick; interbedded with ¼-in.-thick beds of yellow to greenish-gray very fine grained micaceous sandstone	22.8
Sandstone, greenish-gray to yellowish-gray, very fine grained, thin-bedded	.8
Mudstone, dark-reddish-brown, very thin bedded	6.1
Sandstone, light-yellow to greenish-gray, very fine grained, micaceous	1.0
Mudstone, dark-reddish-brown, very thin bedded; contains a few interbeds of yellow micaceous very fine grained sandstone	2.1
Sandstone to siltstone, yellow to greenish-gray; fine sand to silt; very micaceous; ripple-laminated beds 1/32–4 in. thick	4.5
Mudstone, dark-reddish-brown; beds 1/16–⅛ in. thick; contains layers of greenish-gray micaceous very fine grained sandstone about every 3 ft	76.4
Siltstone to sandstone, brown, silty to very fine grained, micaceous, probably feldspathic	1.6
Mudstone, light-yellowish-gray; upper 8 ft dark reddish brown to brownish red; beds less than 1/16 in. thick; forms slope	49.8
Siltstone and fine-grained sandstone, light-greenish-gray, very thin bedded; abundant cuspate ripples; micaceous	1.0
Siltstone and mudstone, light-greenish-gray, shaly, pyritic, ripple laminated; beds 1/16–⅛ in. thick	15.5
Siltstone, yellowish-gray, ripple laminated; contains less than 0.5 percent pyrite; forms massive ledge	2.0
Siltstone, gray; weathers light yellow; shaly; ripple laminated; very thin bedded; contains a few layers of mudstone and less than 0.5 percent pyrite	9.0
Siltstone, light-greenish-gray; weathers pale light yellow; contains less than 0.5 percent pyrite cubes	1.5
Mudstone, light-gray, slightly micaceous; contains less than 5 percent brownish-red beds; forms slope	24.0
Sandstone, brownish-black to black; weathers gray; fine grained; cross stratified; highly pertroliferous; pyritic	10.4
Sandstone, dark-gray; weathers light gray; medium grained to very fine grained; contains ripple marks, small-scale cross-strata, and local 1- to 3-ft-thick layers of very thin bedded shaly siltstone; highly petroliferous	66.1

SECTION 6.—*Moenkopi Formation*—Continued

	Thickness (ft)
Moenkopi Formation—Continued	
Sandstone, dark-gray, very fine grained, thin-bedded, petroliferous; ripple-laminated beds ⅛–½ in. thick; ledge former	57.2
Siltstone and mudstone, red, thin-bedded to very thick bedded, micaceous	10.8
Siltstone, red, ripple-laminated	19.1
Sandstone, very fine grained, petroliferous; beds 1–8 ft thick	46.8
Conglomerate, pebbles of chert in a matrix of medium-grained sandstone; cemented by yellowish-orange carbonate; locally petroliferous; probably Sinbad Limestone Member	5.2
Total Moenkopi Formation	446.6
Kaibab Limestone:	
Dolomite, cherty, dark-yellow-brown (not measured).	

SECTION 7.—*Lampstand Draw section A*

[Sec. 13, T. 33 S., R. 6 E. (unsurveyed), northwest Circle Cliffs area. Lat 37°56′00″, long 111°12′. Section begins 1¼ mile up the creek from place where the Long Canyon–The Peaks road crosses Horse Canyon, then transfers ½ mile up creek and continues to promontory to west. Measured by J. H. Stewart and G. A. Williams]

	Thickness (ft)
Shinarump Member of Chinle Formation:	
Sandstone, pale-greenish-yellow; weathers moderate reddish orange; very coarse grained; poorly sorted (not measured).	
Moenkopi Formation:	
Claystone and siltstone, grayish-red and pale-reddish-brown; weathers moderate reddish orange and pale reddish brown; upper 3 ft bleached to dark yellowish orange; micaceous; firmly cemented; calcareous; very thinly laminated to thin bedded; papery to slabby splitting; weathers to form steep frothy slope; upper 73 ft forms vertical cliff in which ripple-laminated and pseudo-cross-laminated siltstone is common; thin laminae of siltstone are pale greenish yellow and form conspicuous color bands	295.0
Siltstone and claystone, pale-reddish-brown and grayish-orange; weathers pale reddish brown; firmly cemented; calcareous; predominantly shaly splitting with minor flaggy and slabby splitting; abundant ripple marks; weathers to ledges and slopes; contains many lenticular siltstones which form benches and which are current-ripple-laminated with common pseudo-cross-laminations; ledges smaller than in underlying unit	158.6
Siltstone and claystone. Siltstone is pale yellowish orange and pale reddish brown (weathers same) and very fine grained, has limonite spots, is firmly cemented (calcareous), forms lenticular ledges, is current-ripple-laminated with common pseudo-cross-lamination, is shaly to blocky splitting, and weathers to discontinuous ledges. Claystone is grayish red (weathers same) and micaceous, has very thin current-ripple laminae, is papery to shaly splitting, and weathers to steep rubbly slope. Basal 5–10 ft of entire unit altered to moderate yellow; color change crosses stratification. Unit forms steep ledgy slope	91.8

SECTION 7.—*Lampstand Draw section A*—Continued

	Thickness (ft)
Moenkopi Formation—Continued	
Sinbad Limestone Member:	
Dolomite, pale-olive, grayish-yellow, and grayish-olive; weathers dusky yellow; dense to fine grained; contains sparse medium-sized crystals; well-cemented; thin parallel laminae to thin parallel beds; sparse thin medium-scale trough and planar sets of high-angle cross-laminations; platy to blocky weathering; weathers to form steep ledgy slope or vertical cliff; abundant poorly preserved fossils, mostly pelecypods; sparse thin to thick sets of laminae of moderate-yellow interbedded siltstone. Section transferred ½ mile north on top of this unit	44.3
Siltstone and dolomite in lenticular units. Siltstone is moderate yellow and dark yellowish orange (weathers same), is firmly cemented, argillaceous, and thinly laminated to parallel-laminated, and has shaly splitting. Dolomite is grayish yellow (weathers grayish-orange) dense, very thin to thin parallel bedded, and flaggy to blocky splitting. Units weather to form a reentrant or steep rubble-covered slope. Locally the units are absent. They are separated from Kaibab dolomite by an erosion surface which locally shows 5–10 ft of relief	7.9
Total Moenkopi Formation	597.6

Unconformity.
Kaibab Limestone:
Dolomite, pale-greenish-yellow (not measured).

SECTION 8.—*Lampstand Draw section B*

[Sec. 3, T. 33 S., R. 6 E. (unsurveyed), northwest Circle Cliffs area, Garfield County; lat 37°57′, long 111°13′. Section is on promontory about 1⅝ mile N. 65° W. of top of Lampstand Draw section A. Measured by J. H. Stewart and G. A. Williams]

	Thickness (ft)
Wingate Sandstone (incomplete):	
Top of section, not top of outcrop.	
Sandstone, very pale orange; weathers pale yellowish orange; very fine grained; well sorted (not measured).	
Chinle Formation:	
Owl Rock Member:	
Claystone and siltstone, pale-reddish-brown and minor pale-olive; weathers pale reddish brown; firmly cemented, slightly calcareous; bedding concealed; tabular; weathers to form steep loose slope; limy siltstone or limestone ledges 9 and 14 ft above base; siltstone ledges 27 and 14 ft below top that do not persist laterally; contains no pure limestone	84.7

SECTION 8.—*Lampstand Draw section B*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Owl Rock Member—Continued	
Sandstone, pale-reddish-brown with blotches of light-greenish-gray; weathers pale reddish brown; fine grained; moderately sorted; composed of angular clear quartz and abundant orange accessory minerals; firmly cemented, slightly calcareous; tabular; contains small-scale planar sets of cross-laminae and parallel laminae; platy splitting; weathers to form inconspicuous ledge in steep slope	10. 1
Siltstone and claystone, pale-reddish-brown and minor light-greenish-gray; weathers pale reddish brown; firmly cemented, calcareous and argillaceous; bedding concealed; weathers to form steep loose slope; limy siltstone in 3-ft-thick bed at 65.8 ft above base, and in 2-ft-thick bed at 73.2 ft	86. 4
Total Owl Rock Member	181. 2
Petrified Forest Member:	
Sandstone, grayish-purple, light-greenish-gray, and grayish-red; weathers pale red purple and very pale orange; medium grained, moderately sorted; composed of subangular clear quartz and abundant orange and black accessory minerals; weakly cemented, calcareous; tabular; small- to medium-scale trough sets of cross-laminae; shaly to slabby splitting; weathers to form steep vertical cliff with steep rubbly slope below	39. 2
Siltstone, predominantly pale-reddish-brown with minor greenish-gray mostly confined to lower part; weathers moderate red; contains sparse to abundant medium to coarse sand grains; composed of clear quartz and black and orange accessory minerals; firmly cemented, calcareous; bedding concealed; weathers to form steep rubbly slope; variegated in color; medium- to fine-grained sandstone beds as much as 4 in. thick at several levels; near base of unit, a very thin bed of granule conglomerate contains sparse pebbles	83. 4
Sandstone, predominantly dusky red, minor light greenish-gray; weathers moderate yellowish brown; medium grained; moderately sorted; composed of subangular clear quartz and abundant orange and black accessory minerals; poorly cemented, calcareous; tabular; large-scale planar and trough sets of cross-laminae; minor ripple laminae; splitting obscure; weathers to form steep bare-rock slope; light greenish gray confined to very thin beds at 3-ft intervals between sets of cross-laminae and occasionally in cross-laminations	12. 8
Claystone, pale-reddish-brown, dusky-red, and grayish-red-purple; weathers same; firmly cemented, argillaceous; stratification concealed; weathers to form steep frothy slope; white bleached spots and nodules contain fragments of the surrounding clay	51. 2
Total Petrified Forest Member	186. 6

SECTION 8.—*Lampstand Draw section B*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Monitor Butte Member:	
Claystone, predominantly greenish-gray; some variegated brownish gray and dark reddish brown with greater amount of dark reddish brown near top; weathers to light greenish gray; firmly cemented, calcareous and argillaceous; contains sparse siltstone, sandstone, and conglomerate beds which extend only short distances and are grayish red, very dusky red purple, and pale green. Conglomerate beds composed of limestone pebbles. Siltstones and sandstones highly micaceous, current ripple-laminated, commonly pseudo-cross-laminated, and shaly to slabby splitting. Entire unit weathers to form steep frothy slope and minor ledges	129. 6
Siltstone and sandstone interbedded, pale-reddish-brown; very pale green in sandy ledges; weathers pale reddish brown. Sandstone is very fine grained, is composed of clear quartz, and contains common mica flakes and abundant limonite spots. Unit firmly cemented, calcareous, lenticular; bedding mostly concealed, but ledges current ripple-laminated and sparsely pseudo-cross-laminated. Shaly to blocky; weathers to form steep rubbly slope	32. 4
Claystone and siltstone, light-bluish-gray and medium-bluish-gray; lower 5 ft pale yellowish orange; weathers light bluish gray; commonly contains mica flakes; firmly cemented, calcareous and argillaceous; lenticular; bedding in claystone concealed; siltstone forms lenticular beds as much as 4 ft thick throughout unit; shows current ripple lamination and common pseudo-cross-lamination; at many places beds dip at gentle angles from regional dip; shaly to blocky splitting; entire unit weathers to a steep frothy and rubbly slope; sandstones of the Shinarump Member interfinger with this unit laterally	37. 8
Total Monitor Butte Member	199. 8
Mottled-siltstone unit:	
Claystone and siltstone, grayish-red and pale-reddish-brown; weathers pale reddish brown; firmly cemented, calcareous; bedding in claystone concealed, siltstone current ripple-laminated; common pseudo-cross-lamination, shaly to flaggy splitting; weathers to form steep slope and minor ledges. Siltstone from 7.4 ft to 12.3 ft, pale yellowish orange in lower part and grayish purple in upper part; contains very coarse grains of subrounded clear quartz and orange accessory minerals; manganese nodules	19. 2
Total Chinle Formation	586. 8
Moenkopi Formation:	
Claystone and siltstone, grayish-red and pale-reddish-brown (not measured).	

SECTION 9.—*Silver Falls section B*

[Secs. 25 and 26, T. 35 S., R. 7 E. (unsurveyed), lat 37°44', long 111°07', at southwest side of the farthest outlying mesa between Dry Fork and South Fork of Silver Falls Creek. Measured by L. C. Craig, G. A. Williams, H. F. Albee, and J. H. Stewart]

	Thickness (ft)
Wingate Sandstone (incomplete):	
Conglomeratic sandstone, grayish-red to pale-greenish-yellow; weathers to pale reddish brown; very coarse grained to fine grained; poorly sorted; well rounded abundant white and black accessory minerals, also yellow and clear quartz; well cemented, argillaceous, very weakly calcareous; tabular to irregular; structureless to faintly parallel structured with small cross-laminated lenses; slabby weathering; contains granules and pebbles as much as 1-in. in diameter, mostly angular and composed of gray chert; basal contact bevels Owl Rock Member disconformably, cutting out as much as 5 ft of beds in 15 ft along contact	1.8
Unconformity.	
Chinle Formation:	
Owl Rock Member:	
Same as below but locally weathers to vertical slopes with hoodoo shapes; tabular with medium-scale trough sets of cross-laminae, subparallel laminae, or ripple laminae; common light-greenish-gray circular spots appear to have black, carbonaceous center	16.9
Siltstone, pale-red, firmly cemented, highly calcareous; hackly weathering; forms steep rubbly slope broken by 1.5-ft ledge at 45 ft and 3.5-ft ledge at top of unit. Ledges are conglomeratic sandstone that is pale red mottled with light greenish gray and that weathers light brown; composed of reddish and greenish calcareous siltstone pebbles as much as 1-in. in diameter and minor clear quartz, pinkish to white chert granules, and sparse interstitial clear quartz. Unit is tabular, parallel to subparallel bedded, slightly calcareous	66.9
Limestone and siltstone, alternating. Limestone is moderate orange pink and very light gray, weathers pale red with very light gray mottling, is very finely crystalline, has black to red silica-filled stringers, and is tabular; it is thick bedded to very thick bedded and hackly splitting, and weathers into ledges. Siltstone is pale red, light olive gray, and very light gray; weathers pale red; is well sorted; is composed of sparse clear quartz and white mineral; is firmly cemented, calcareous; forms a tabular unit with parallel-laminated sets; is platy to papery and in part hackly; and weathers to steep slope. In ascending order, this unit consists of siltstone, 12.1 ft; limestone, 2.8 ft; siltstone, 15.9 ft; limestone, 5.0 ft; siltstone, 12.6 ft; limestone, 6.0 ft; siltstone, 7.9 ft; limestone, 5.3 ft; siltstone, 4.5 ft; and limestone, 5.9 ft	78.0
Total Owl Rock Member	161.8
Petrified Forest Member:	
Claystone, pale-reddish-brown, pale-red, and light-brown, silty; hackly weathering; forms steep earthy to fine-rubble-covered slope; contains light-gray granule nodules about 20 ft above base; entire unit forms pinkish faintly banded interval on distant cliffs	60.6

SECTION 9.—*Silver Falls section B*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Petrified Forest Member—Continued	
Sandstone and siltstone, pale-red, pale-brown, pale-reddish-brown, and very dusky red purple; where sand is coarse, very light gray; well sorted; composed of rounded clear quartz grains and common pink and black accessory minerals; firmly to weakly cemented, calcareous; sandstone is tabular with lenticles of medium-scale trough crossbed sets; most cross-strata alternately light gray and very dusky red purple; hackly fracture; weathers to a steep slope	42.4
Claystone, pale-reddish-brown to light-brown to pale-red; middle mottled light greenish gray to moderate yellowish brown, highly silty to very fine grained sandy; hackly fracture; weathers to shallow frothy surface; entire unit poorly exposed	74.2
Claystone; pale red purple to grayish red purple in lower third, pale reddish brown in middle third, and pale red in upper third; slightly silty lower third and upper third, highly silty middle third; hackly fracture when fresh; weathers to a deep frothy surface; at top is 6-in. layer of white fine- to medium-grained poorly sorted sandstone composed of clear quartz with abundant red, green, and black accessory minerals and sparse biotite flakes; tabular; small-scale trough sets of cross-laminae; sandstone forms indistinct ledge capping steep badland slope on claystone; unit forms prominent brightly colored band above gray Monitor Butte Member; lower half of unit contains abundant granule- to boulder-sized limestone nodules	177.4
Total Petrified Forest Member	354.6
Monitor Butte Member:	
Alternating sandstone and siltstone. Sandstone is light brown to grayish yellow, weathers light brownish gray, is fine grained to very fine grained, and moderately sorted, is composed of clear quartz, common black minerals, sparse to common biotite flakes, and interstitial limonite(?), is firmly cemented and calcareous; sandstone units are lenticular and have thin to very thin sets of ripple laminae and cross-laminae. Siltstone is light olive gray, weathers light gray, is poorly cemented and calcareous; it is thinly laminated and irregular splitting; weathers to gentle slope. At the base of the unit, a thin lenticular conglomerate contains pebbles as much as ⅜-in. in diameter and composed predominantly of limestone; sandstone lenses are at 7.3 ft, 21.2 ft, 27.5 ft, and 31.8 ft; between 33.8 ft and 37.1 ft, sandstone lenses predominate; each sandstone lens has a different attitude, possibly representing contorted bedding	37.1
Silty claystone, pale-green to medium-light-gray; weathers light gray; well-sorted; composition masked; poorly cemented, calcareous; tabular; shaly; weathers to a steep slope; expands slightly when wet (bentonitic?); contains rounded limonite concretions as much as 4-in. in diameter; unit contains several prominent steeply dipping sandstone beds in lower 20 ft (foresets?)	157.2
Total Monitor Butte Member	194.3

SECTION 9.—*Silver Falls section B*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Shinarump Member:	
Sandstone, grayish-yellow to moderate-yellow; weathers to brownish black; predominantly coarse grained with minor very coarse grains; poorly sorted; composed of subangular clear quartz and rare black grains; brown-stained interstitial clay; clay binding, slightly calcareous; lenticular unit of medium-scale trough sets of cross-laminae, slabby to platy, forms thin capping ledge that pinches out 25 ft southwest but swells to 40 ft thick ¼ mi northeast	1.8
Total Chinle Formation	712.5

Unconformity: Sharp scour contact.
Moenkopi Formation (not measured).

SECTION 10.—*Chinle Formation*

[In south-central part of sec. 16, T. 34 S., R. 8 E. (unsurveyed), in east-central Circle Cliffs area, Garfield County; on southeast side of Burr Trail; lat 37°50′10″, long 111°02′10″. Measured by E. S. Davidson and Gilbert Thomas]

	Thickness (ft)
Wingate Sandstone (incomplete):	
Sandstone, fine-grained, slightly friable, subrounded to subangular grains, well-sorted; contains local layers of well-rounded medium to coarse grains of quartz; lower 4 ft contains abundant medium to coarse grains of quartz and lower 0.6 ft contains thin beds of coarse-grained sandstone	80.6
Chinle Formation:	
Owl Rock Member:	
Sandstone, grayish-purple with local greenish-gray streaks and splotches, fine-grained, ripple-laminated, massive splitting; contains abundant mica and an unidentified green mineral that may be chlorite or epidote, interstitial white clay (may be what is referred to locally as the so-called Hite Bed of Church Rock Member)	6.6
Mudstone, reddish-brown, slickensided; contains scattered chert pebbles	.9
Sandstone, light-reddish-brown, very fine grained with a few scattered medium grains of quartz, slightly dolomitic; lower 1 ft is conglomerate composed of gray chert pebbles in poorly sorted fine-grained sandstone matrix	4.3
Siltstone to sandstone, pale-red-purple; composed of silt to very fine sand, crossbedded	2.2
Conglomerate; small pebbles of chert and siltstone in a matrix of moderate-brown mudstone	.4
Mudstone, moderate-brown with a few greenish spots, very thinly bedded	38.6
Conglomerate, reddish-brown mottled greenish-gray; contains well-rounded fragments of reddish-brown mudstone and gray siltstone as much as 1 in. in diameter; matrix of dolomitic fine- to medium-grained sandstone	1.1

SECTION 10.—*Chinle Formation*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Owl Rock Member—Continued	
Mudstone, moderate-brown with a few greenish-gray specks	9.9
Dolomite, greenish-gray; contains a few gray chert nodules	1.9
Sandstone and siltstone, mottled reddish-brown and greenish-gray; consists of silt to very fine sand; slightly dolomitic in lower 6 ft, grading upward into moderate-brown thinly laminated mudstone	17.8
Limestone, mottled reddish-brown and greenish-gray; contains as much as 50 percent fragments of greenish-gray dolomite in lower 3 ft; a few rounded nodules of greenish-gray and gray chert; fracture surfaces are coated with finely crystalline dolomite	5.2
Mudstone, mottled greenish-gray and brown; weathers light yellowish brown; contains local lenses of limy mudstone	44.0
Limestone (dolomite?) mottled greenish-gray and red; contains a few chert pebbles and abundant resistant limy nodules; massive; hackly fractures	7.1
Mudstone, reddish-brown mottled greenish-gray; contains a 3-ft bed of siltstone 7.4 ft above base	48.6
Limestone, light-brownish-gray mottled greenish-gray, fine-grained, blocky, probably dolomitic	2.8
Mudstone, mottled green and reddish-brown; displays slickensided surfaces	2.3
Limestone, greenish-gray, dense, thick-bedded; contains as much as 10 percent white chert nodules $1/16$- to $1/2$-in. in diameter and a few limy concretions with hematite borders	2.1
Sandstone, light-brown; weathers lighter; fine grained and very fine grained; contains much silt; slightly bentonitic; grades upward into light-brown mudstone which is mottled bluish-green in upper 10 ft of unit	60.9
Total Owl Rock Member	256.7
Petrified Forest Member:	
Sandstone, fine-grained, lenticular, blocky fracturing; contains as much as 10 percent interstitial white clay and a trace of green chlorite(?), abundant muscovite on parting planes, and brownish-black biotite(?)	0.8
Sandstone, moderate-brown with abundant greenish-gray splotches, very fine grained, silty, thinly laminated to slightly ripple laminated; contains local lenses a few inches thick of thinly laminated greenish-gray sandstone; unit is bentonitic, feldspathic; contains moderate amounts of green chlorite(?) and brown biotite	28.7
Sandstone, gray-white to grayish-purple and white, medium-grained, well-sorted, planar and trough crossbedded; contains local layers of variegated bentonitic sandstone; kaolinitic; contains abundant greenish flakes of chlorite(?) and greenish-brown flakes of biotite(?); weathers to rounded forms	20.7

SECTION 10.—*Chinle Formation*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Petrified Forest Member—Continued	
Conglomerate; contains banded grayish-purple and gray-white medium- to coarse-grained quartz sandstone, fragments of purplish- and greenish-gray mudstone and pebbles of reddish-brown siltstone, in matrix of bentonitic grayish-purple and white siltstone	3. 4
Mudstone, pink to pale-red-purple, bentonitic	35. 0
Mudstone, light-brown, bentonitic; poorly exposed	17. 7
Mudstone, grayish-purple to grayish-purple and white; contains abundant flakes of gypsum and dense nodules of limestone; bentonitic	9. 8
Covered interval, probably same as overlying unit	4. 0
Mudstone, reddish-brown; bentonitic; contains local lenses of poorly sorted medium-grained kaolinitic sandstone, scattered nodules of chert, fragments of petrified wood, and gypsum flakes on slope	32. 4
Total Petrified Forest Member	152. 5
Monitor Butte Member:	
Mudstone, gray, bentonitic, micaceous	5. 2
Covered; probably medium-grained gray kaolinitic sandstone containing abundant micas, and traces of malachite as coating on fractures and bedding planes, conglomeratic at base	5. 4
Mudstone, grayish-purple, bentonitic; contains 1-ft layer of gray calcareous chert nodules	37. 8
Mudstone, variegated reddish-brown, brown and grayish-purple, bentonitic	108. 0
Total Monitor Butte Member	156. 4
Mottled-siltstone unit:	
Sandstone, mottled grayish-purple and white, fine-grained to very fine grained; contains scattered coarse quartz grains	6. 0
Total Chinle Formation	571. 6
Moenkopi Formation:	
Mudstone and siltstone, reddish-brown thin-bedded (not measured).	

SECTION 11.—*Chinle Formation*

[Southeast Circle Cliffs area, east of Deer Point; lat 37°42′00″, long 110°57′00″. Measured by E. S. Davidson and Albert Specht]

	Thickness (ft)
Wingate Sandstone:	
Sandstone, light-brown, fine-grained with abundant well-rounded coarse grains of quartz; large-scale planar and trough cross-stratified (not measured).	
Chinle Formation:	
Owl Rock Member:	
Limestone, light-purple; increasing amount of claystone toward base of unit	2.5

SECTION 11.—*Chinle Formation*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Owl Rock Member—Continued	
Siltstone and mudstone, purple-brown, thinly laminated	22.5
Sandstone, light-greenish-gray; weathers brown; rippled and small planar type crossbeds; very fine grained; contains local lenses of brown siltstone; ledge forming	15.5
Siltstone, brown; contains local lenticles of greenish-gray silty limestone	38.7
Limestone, greenish-gray, thin-bedded, silty, slope forming	12.9
Siltstone to sandstone, light-gray; weathers light brown; blocky splitting; ripple-laminated; composed of silt to very fine sand; ledge-forming	10.5
Mudstone and siltstone, reddish-brown and greenish-gray, poorly exposed, slope-forming	16.2
Limestone, greenish-gray, ledge-forming	5.0
Mudstone and siltstone, reddish-brown and greenish-gray, slope-forming	11.9
Pebble conglomerate, light-greenish-gray; consists of medium- to coarse-grained sandstone matrix and pebbles of greenish-gray limestone; grades into underlying unit	1.0
Mudstone and siltstone, reddish-brown and greenish-gray, very calcareous in upper 6 ft, poorly exposed, slope-forming	70.8
Limestone, greenish-gray with red streaks, medium crystalline; contains some interbeds of greenish-gray mudstone in lower 4 ft	12.9
Mudstone, light-brown to light-grayish-purple, calcareous; contains local lenses of purplish and light-greenish-gray limestone	15.7
Limestone, light-greenish-gray, finely crystalline with abundant coarse crystals of calcite and coarse grains of quartz	4.0
Mudstone, light-brownish-red, very slightly bentonitic	28.2
Total Owl Rock Member	268.3
Petrified Forest Member:	
Mudstone, variegated hues of purple, brownish-red, and yellow, bentonitic	56.4
Sandstone and pebble conglomerate, reddish-brown, medium- to coarse-grained arkosic sandstone; contains pebbles of brown limestone	7.0
Mudstone, variegated purple and reddish-brown, bentonitic; sandy at top	29.2
Mudstone, brownish-orange, bentonitic	38.6
Mudstone, variegated purple, pale-red-purple, yellow, bluish-gray, bentonitic, lenses of brown sandstone in upper 10-ft	32.9
Claystone to mudstone, reddish-brown, bentonitic; contains abundant masses of nodular calcareous concretions in upper 15-ft and lenses of purplish-gray medium-grained calcareous sandstone in upper 10-ft; abundant chips and flakes of fibrous limy gypsum on surface of outcrop	56.4
Total Petrified Forest Member	220.5

SECTION 11.—*Chinle Formation*—Continued

	Thickness (ft)
Chinle Formation—Continued	
Monitor Butte Member:	
Sandstone, gray to dark-brown, thick-bedded, ripple-laminated and small-scale crossbedded, fine- and medium-grained; few thin beds of interlaminated brown mudstone and brown fine-grained sandstone; 100-ft to south this unit interfingers with overlying bentonitic mudstone	6. 6
Conglomerate, gray; medium- to coarse-grained matrix of quartz and limestone; pebbles of limestone and siltstone average ½ in. in diameter; maximum size 3 in.; calcite cement; some interstitial white clay	2. 0
Mudstone and claystone, variegated blue-green, bluish-gray and purple; local beds of limestone in globular masses; some lenses of gray to white sandstone; some fissures filled with calcite crystals	89. 4
Sandstone and mudstone, brown, thin-bedded and ripple-laminated, fine- and medium-grained, feldspathic. Mudstone is gray and finely laminated	4. 8
Sandstone, grayish-white, thick-bedded, ripple-laminated and small-scale crossbedded, fine- and medium-grained; contains some greenish-gray clay partings, a few greenish-gray clay-balls	9. 5
Sandstone and shale, black and white; interbedded medium-grained kaolinitic sandstone and very carbonaceous gray to black shale	. 3
Total Monitor Butte Member	112. 6
Total Chinle Formation	601. 4
Moenkopi Formation (incomplete):	
Siltstone, brown, ripple laminated, ledge-forming	6. 0
Base of section, not base of exposure.	

SECTION 12.—*Glen Canyon Group*

[In east-central Circle Cliffs area; lat 37°44′30″, long 110°57′30″. Measured by E. S. Davidson and Albert Specht]

	Thickness (ft)
Carmel Formation (incomplete):	
Silt and shale, moderate red to moderate reddish-brown (not measured). Sandstone, brown, flat-bedded, poorly sorted, fine-grained to very coarse grained	5. 0
Navajo Sandstone (measured by planetable and graphic methods):	
Sandstone, white, fine-grained, friable, quartzose with a few scattered dark minerals; large-scale crossbedded; beds as much as 200 ft long and in sets 50 ft thick; smaller in upper 100 ft of unit; numerous carbonate-cemented fissures in upper part of unit, increasing in quantity upward; a few calcareous sandstone beds separate the sets of cross-strata 150–600 ft below top; average spacing of parting planes in middle 800 ft of unit is almost 100 ft; spacing of parting planes in lowest 100 ft is 5–25 ft; some parting planes in lowest 100 ft marked by brown calcareous sandstone	1, 036. 0

SECTION 12.—*Glen Canyon Group*—Continued

	Thickness (ft)
Kayenta Formation:	
Sandstone, reddish-brown, massive; small-scale trough crossbedded; fine-grained; some gray and greenish-gray mudstone chips	6. 6
Sandstone, light-gray; weathers light brownish red; very thick bedded; flaggy-splitting; medium and coarse grained; abundant gray and brown mudstone chips; small-scale trough crossbedded in sets 6–8 ft long	83. 6
Sandstone, white, massive, friable, very large scale planar and trough cross-stratified with local beds of small-scale trough cross-strata sets; sharp erosional contact with overlying unit	30. 8
Sandstone, brown, thin- to thick-bedded, medium-grained, small-scale trough crossbedded; abundant brown mudstone chips, lenses of very coarse sandstone with abundant mudstone chips; sandstone is feldspathic and slightly micaceous	22. 0
Sandstone, white, very thick bedded, friable, fine- and meduim-grained, quartzose; small- and medium-scale planar and trough crossbedded	41. 6
Sandstone, brown to brownish-red, arkosic, thick-bedded, flaggy splitting, horizontally stratified and small-scale trough cross-stratified; medium grained, local concentrations of coarse and very coarse quartz grains at base	92. 4
Total Kayenta Formation	277. 0
Wingate Sandstone (measured by planetable and graphic methods):	
Sandstone, light-brownish-orange, very large scale planar and trough crossbedded, well-sorted, very fine grained to fine-grained with a few coarse grains of quartz; sharp contact with overlying Kayenta Formation; few lenticles of calcareous sandstone that weather into lacy structures, especially in upper half of unit	225. 0
Sandstone, white, small-scale trough and planar crossbedded, fine-grained, friable; sharp contact with underlying Chinle Formation	8. 0
Total Wingate Sandstone	233. 0
Chinle Formation (incomplete):	
Owl Rock Member (incomplete):	
Limestone, purplish-gray	3. 0
Mudstone, reddish-brown (not measured).	
Base of section, not base of exposure.	

SECTION 13.—*Glen Canyon Group*

[At Burr Trail, midwestern part of sec. 15, T. 34 S., R. 8 E., Circle Cliffs area, Garfield County; lat 37°51′, long 111°02′. Navajo and Wingate Sanstone measured by planetable method; Kayenta Formation measured on ridge 1,000 ft southeast of Burr Trail in Muley Twist Canyon. Measured by E. S. Davidson and Gilbert Thomas]

	Thickness (ft)
Carmel Formation (incomplete):	
Sandstone, brown, coarse-grained	6–8
Navajo Sandstone:	
Sandstone, white, poorly sorted	1. 0

SECTION 13.—*Glen Canyon Group*—Continued

	Thickness (ft)
Navajo Sandstone—Continued	
Sandstone, white, very fine grained to fine-grained, well-sorted, cross-stratified; cemented by calcium carbonate; in upper 100 ft cross-stratified trough sets are 40–50 ft long; throughout rest of unit cross-stratified planar and trough sets are as much as 200 ft long	966.0
Sandstone, white, fine-grained, well-sorted; crossbedded in planar sets 4–8 ft thick	10.0
Sandstone, greenish-gray, fine-grained; contains abundant coarse quartz grains, some interstitial green clay	1.0
Total Navajo Sandstone	978.0
Kayenta Formation:	
Siltstone and mudstone, grayish-red and purple with green streaks perpendicular to the bedding, irregular masses of bleached green rock extending down into unit; contains a few medium-sized quartz grains and a few iron-oxide cemented nodules of siltstone with limonitic centers	1.7
Sandstone, reddish-brown, fine-grained; interbedded ripple-stratified micaceous fine-grained silty sandstone in lenticular units about 1 in. thick	12.4
Sandstone, pale-red to pale-red-purple, fine-grained; trough and high-angle planar cross-stratification; trough cross-stratified in sets 10 ft long and 3 ft thick; high-angle planar cross-stratified in sets 0.5–1 ft thick; unit forms ledges and slopes	45.0
Sandstone, white, medium-grained, well-sorted; trough cross-stratified in sets 4–5 ft long and 2–3 ft thick	10.0
Sandstone, purplish-red, fine-grained, thin-bedded; contains a few ledge-forming beds; upper 6 ft similar to overlying unit	10.0
Sandstone, gray, fine-grained; calcareous; rippled and contorted laminar beds; forms small ledges	3.8
Sandstone, pale-red-purple, fine-grained, friable, massive	1.3
Sandstone, light-purplish-red; weathers light yellow; fine-grained; well-sorted; planar cross-stratified in sets 4–5 ft thick and 25 ft long	17.8
Covered, probably same as underlying unit	5.0
Sandstone, pale-red-purple; weathers yellowish-brown; fine-grained with abundant scattered grains of medium-sized clear and reddish quartz, poorly sorted; planar cross-stratified in sets 10–15 ft long and 3–5 ft thick	20.2
Covered. Float indicates siltstone and fine-grained sandstone with local lenses of medium-grained sandstone cemented by carbonate; unit as a whole reddish brown to purplish red, in beds ⅛–¼ in. thick	20.0
Sandstone, fine-grained with some scattered medium grains, poorly sorted, calcareous; high-angle planar cross-stratified; some penecontemporaneous slump bedding	8.5
Sandstone, pale-red-purple, fine-grained; micaceous; beds form ledges 2–6 ft high; unit is ripple cross-stratified and planar cross-stratified in sets as much as 20 ft long; thin bedded; contains discontinuous lenses of calcareous fine-grained white sandstone	39.0

SECTION 13.—*Glen Canyon Group*—Continued

	Thickness (ft)
Kayenta Formation—Continued	
Sandstone, white to pale-red-purple, medium- to coarse-grained, abundant ⅛- to 2-in. pebbles of greenish-gray siltstone and mudstone; poorly sorted; trough cross-stratified in sets 2–3 ft long, 1 ft thick; cemented by calcium carbonate	1. 6
Sandstone, pale-red-purple; weathers brown, fine-grained; planar cross-stratification in sets 30 ft long and 5–6 ft thick; unit forms ledge	13. 5
Sandstone, pale-red-purple to pale-red, fine-grained, friable, beds ⅛ to ⅜ in. thick; local planar cross-stratified in sets 3 ft long; unit mostly slope forming except for one ledge-forming calcareous sandstone near top	47. 1
Sandstone, white, fine- to medium-grained, well-sorted; cross-stratified in sets 1 ft thick; lower 2 ft contains abundant green and dark-reddish-brown mudstone chips; carbonate cement	25. 0
Mudstone, dark-reddish-brown	. 7
Sandstone, very light orange, fine-grained, well-sorted, slabby to massive, ripple-stratified and horizontally stratified; beds ⅛ to 1 in. thick forming massive ledges 2–5 ft thick; local trough cross-stratified in sets 1–2 ft thick and 1 ft long; few high-angle planar cross-stratified sets 4 in. thick	24. 6
Total Kayenta Formation	307. 2
Wingate Sandstone:	
Sandstone, very light brown to brown, very fine grained to fine-grained, well-sorted; trough type cross-stratified in sets 40–60 ft thick and 100 ft long; cliff forming; weathers into rounded forms; contains abundant round solution cavities on weathered surfaces	232. 0
Chinle Formation (reported in section 10).	

SECTION 14.—*Kayenta Formation*

[In SE cor. sec. 1, T. 33 S., R. 5 E., northwest part of Circle Cliffs area, Garfield County Measured by G. A. Miller]

	Thickness (ft)
Navajo Sandstone:	
Sandstone, white, large-scale trough and planar cross-stratified, well-sorted, very fine grained (not measured).	
Kayenta Formation:	
Limestone, gray to dusky-red, thin-bedded, sandy	3. 0
Sandstone, light-gray to moderate-reddish-orange, horizontally stratified, silty, very fine grained, limonite speckled; abundant dark heavy minerals	5. 0
Covered, float of gray slabby sandy limestone	10. 0
Sandstone, red and very dark red, very thin bedded to thick-bedded, very fine grained to fine-grained	32. 0
Sandstone, white, small-scale trough crossbedded, well-sorted, fine-grained to very fine grained	12. 0

SECTION 14.—*Kayenta Formation*—Continued

	Thickness (ft)
Kayenta Formation—Continued	
Mudstone, dusky-red, thinly bedded; contains grains ranging in size from silt to coarse sand, mudstone pebbles	1.0
Sandstone, white, large-scale crossbedded, fine-grained to very fine grained; few red mud splits less than 1 ft thick	64.0
Sandstone, red to very dark red, very thin bedded, calcareous; fills lows in underlying sandstone unit	4.0
Sandstone, white to light-gray, large- and small-scale trough and planar crossbedded, well-sorted, very fine grained	36.0
Sandstone, yellow-brown to light-red, thin-bedded to very thin bedded, poorly sorted, silty to fine-grained	26.0
Sandstone, orange-red to very dark red, very thick bedded to thick-bedded, poorly sorted, very fine grained to fine-grained	38.0
Sandstone, light-red to orange-red, very thin bedded to thin-bedded, silty, very fine grained to fine-grained	42.0
Sandstone, light-red to pink-red, massive to trough crossbedded, fine-grained to very fine grained	67.0
Total Kayenta Formation	340.0
Wingate Sandstone:	
Sandstone, light-red to orange, large-scale planar and trough cross-bedded, very fine grained to fine-grained (not measured).	

SECTION 15.—*Kayenta Formation*

[Southeast side of Silver Falls Creek Canyon about 1 mile northeast of junction with Escalante River; lat 37°40′30″ N., long 111°12′ W. Measured by R. F. Wilson and J. R. Gigone]

	Thickness (ft)
Top of section, not top of exposure.	
Navajo Sandstone (incomplete):	
Sandstone, very light gray and pinkish-gray in basal few feet and moderate-reddish-orange above; weathers same colors; fine grained to very fine grained; sparse scattered medium grains; well sorted; base sharp and even; unit contains a thick set of pale-red limy sandstone containing nodules of white chert 10 ft above base	30.0
Kayenta Formation:	
Siltstone, pale-reddish-brown in lower two-thirds and greenish-gray in upper third; weathers same colors; medium silt; micaceous; firmly cemented; stratification concealed; weathers to form covered slope; base sharp and even	18.1
Sandstone, pale-reddish-brown; weathers pale red; fine-grained, locally very fine grained and medium grained; well to moderately sorted; composed of reddish-stained quartz, light and dark accessory minerals, and mica; firmly cemented; trough and some planar sets of low-angle to very low angle medium- to large-scale cross-laminae and some horizontal laminae; weathers to form ledgy cliff; base sharp and irregular; unit contains scattered clay pellets in lenticular zones	89.2

SECTION 15.—*Kayenta Formation*—Continued

	Thickness (ft)
Kayenta Formation—Continued	
Sandstone, moderate-orange-pink; weathers light brown, very fine grained to fine grained, well-sorted; composed of frosted pinkish-stained quartz and sparse dark accessory mineral; firmly to poorly cemented; planar sets of medium-scale high-angle cross-laminae; weathers to form vertical cliff; base sharp and even	16.2
Silty sandstone to sandy siltstone, pale-reddish-brown to pale-red; weathers same colors; grades from very fine grained sandy siltstone to very fine grained silty sandstone, well-sorted; composed of reddish-stained quartz, a common dark accessory mineral, and mica; poorly to well-cemented; horizontal and wavy laminae; weathers to form slope	18.9
Sandstone, grayish-orange-pink, light-brown, pale-red, pale-reddish-brown, and minor moderate-reddish-orange; weathers same colors; fine grained to very fine grained; well sorted; composed of reddish-stained quartz, dark and sparse light accessory minerals, light and dark mica, and common scattered clay pellets; firmly cemented; horizontal laminae and small to large trough sets of small- to large-scale low-angle to very low angle cross-laminae; weathers to form ledgy cliff; base sharp and irregular and marked by scour surfaces; unit contains several clay pellet conglomerate lenses	173.4
Total Kayenta Formation	315.8
Wingate Sandstone (incomplete):	
Lukachukai Member (incomplete):	
Sandstone, light-brown to moderate-reddish-orange; weathers same colors and pale yellowish orange; very fine grained, locally very fine grained to fine grained; well sorted	74.8

SECTION 16.—*San Rafael Group*

[2 miles northwest of Bitter Creek Divide, sec. 25, T. 32 S., R. 7 E., lat. 37°59′30″, long. 111°05′. Measured by J. C. Wright and D. D. Dickey]

	Thickness (ft)
Morrison Formation (incomplete):	
Sandstone, crossbedded; fills channels; abundant chert pebbles in lower 1 foot and in some other layers	10.0

NOTE.—The Summerville-Morrison contact is placed at the base of the lowest crossbedded sandstone. The upper 14 ft of the underlying unit is light greenish gray and may be part of Morrison Formation.

Summerville Formation:	
Covered, probably red shale and siltstone, upper 14 ft is light greenish gray	44.0
Limestone, very light gray, dense, massive; has red cherty blebs	1.0
Covered, probably red shale and siltstone	17.0
Limestone, very light gray, dense, massive; has red cherty blebs; similar to top of Summerville Formation as defined at Summerville point; forms ledge; appears to be fairly continuous for several hundred yards	2.0

SECTION 16.—*San Rafael Group*—Continued

	Thickness (ft)
Summerville Formation—Continued	
Covered, probably red shale and siltstone	3.5
Sandstone, very limy, white, very thin to thin, even beds	2.5
Covered, probably red shale and siltstone	3.0
Sandstone, very limy, white, very thin to thin even beds, ripple laminated at the top of each bed; many layers have conspicuous coarse grains and granules of colored and black chert; forms ledge	3.0
Mostly concealed by red wash, probably shale and siltstone; forms slope	81.0
Total Summerville Formation	157.0

NOTE.—The Summerville-Curtis(?) contact is concealed, probably conformable.

Curtis(?) Formation:	
Limestone, very sandy, light-greenish-gray, cherty cement and nodules, thin bedding with reworked appearance; forms small ledge	3.0
Total Curtis(?) Formation	3.0

NOTE.—The Entrada-Curtis(?) contact shows gentle scours about 6 in. deep in the top of the Entrada; the Curtis(?) appears to contain reworked Entrada Sandstone.

Entrada Sandstone:	
Upper sandy member:	
Sandstone, light-brown, top 2–12 ft bleached greenish-gray, like Curtis(?) Formation, very fine grained, well-sorted, indistinctly very thin bedded to massive, some irregular flat bedding in unit; 150 yds north of the section a white slickrim sandstone with large-scale crossbedding occupies part of this interval; slickrim thickens northward from 25 ft to 60 ft in 100 yds by addition to the base of the sandstone; the top contact maintains an even interval of 38 ft below the base of the Curtis(?)	55.0
Siltstone, reddish-orange, earthy, poorly exposed; much of it in beds 5–15 ft thick; purple clay partings; lower 15 ft shows some light-greenish-gray mottling	153.0
Sandstone, light-greenish-gray, fine-grained, poorly to moderately cemented; composed of white well-rounded quartz grains and some light-red grains; indistinct thin crossbedding; several thin purple shale beds at bottom of unit	40.0
Total upper sandy member	248.0
Medial silty member:	
Covered; soil suggests earthy red siltstone; there may be small ledges of slickrim sandstone but none crop out; earthy siltstone, in beds less than 5 ft thick, probably is interbedded with subordinate thin shale; thickness computed from measured width and dip	359.0
Lower sandy member:	
Covered, probably sandstone, dark-pinkish-gray, very limy, very fine grained to medium-grained	15.5

SECTION 16.—*San Rafael Group*—Continued

	Thickness (ft)
Entrada Sandstone—Continued	
Lower sandy member—Continued	
Purple clay parting	1. 0
Covered, probably reddish-brown earthy siltstone and fine-grained sandstone	18. 5
Sandstone, pinkish-gray, very fine-grained to medium-grained, thin, even beds, some sets of medium-scale crossbeds, poorly exposed	25. 0
Siltstone, reddish-brown, poorly exposed	8. 0
Sandstone, very limy, dark-pinkish-gray; weathers same; very fine grained to medium grained; moderately sorted; permeable; contains pink, black, and white quartz grains; very thin to thin even beds; 83 ft above base, 6-in.-thick purple siltstone with 6 in. of white siltstone on either side	109. 0
Covered, probably reddish-brown, earthy siltstone	4. 0
Covered, probably red shale	6. 0
Covered, probably reddish-brown earthy siltstone	5. 5
Shale, moderate-red with light-greenish-gray mottling, thinly laminated	5. 0
Siltstone, reddish-brown; composed of earthy siltstone and fine-grained sandstone	14. 0
Sandstone, pinkish-white, well-sorted, fine-grained, bedding indistinct	23. 0
Covered; soil suggests reddish-brown earthy siltstone and fine-grained sandstone	11. 0
Sandstone, pinkish-white, very fine grained, well-sorted; contains some pinkish quartz and some black grains; no "Entrada berries" (coarse well-rounded quartz grains) noted; medium-scale crossbedding; forms soft rounded slickrim; concealed in many places; small covered zone in center probably is reddish-brown siltstone	15. 5
Total lower sandy member	261. 0
Total Entrada Sandstone	868. 0

NOTE.—The Carmel-Entrada contact is placed between the highest gypsum and lowest slickrim sandstone.

Carmel Formation:	
Gypsiferous unit:	
Siltstone, reddish and green, some gypsum seams	59. 0
Gypsum, white	3. 0
Siltstone, reddish, some gypsum beds and seams	11. 0
Siltstone, greenish, some red, some gypsum beds and seams	30. 0
Covered, mostly siltstone, reddish and greenish with red predominating, some gypsum seams and thin beds; some gypsum beds seem persistent but others are lenticular	42. 0
Gypsum, white	2. 5
Siltstone, reddish-brown	2. 5
Siltstone, light-greenish-gray, laminated, moderately cemented	4. 5
Siltstone and gypsum; siltstone is moderate reddish brown and contains gypsum seams; gypsum in beds 1–4 ft thick forms one-third of unit	34. 0

SECTION 16.—*San Rafael Group*—Continued

	Thickness (ft)
Carmel Formation—Continued	
Gypsiferous unit—Continued	
Siltstone, mostly concealed, light-greenish-gray, laminated, moderately cemented	23.0
Siltstone, very limy, orange-pink, small-scale crossbeds, abundant ripple marks; forms dip slope; thickness estimated	4.0
Total gypsiferous unit	215.5
Limestone unit:	
Limestone, orange-pink, slightly silty; becomes siltier upwards	3.0
Limestone, yellowish-gray, dense, thin beds, ripple marked	1.0
Conglomerate or breccia; more than half is matrix of siltstone that is reddish brown, limy, massive, contorted in places. Fragments range from pebbles to pieces more than 8 ft long, some angular, some rounded; most are limestone from underlying unit, but some large blocks are even-bedded siltstone and fine-grained sandstones; poorly exposed; probably formed by slump on depositional surface	19.5
Limestone, yellowish-gray, dense, very pure, thin beds, ripple-marked	6.0
Limestone, orange-pink, slightly silty; occurs as irregular flat very thin beds, a few thin interbeds of yellowish-gray limestone, and a few thin beds of limestone mud-chip conglomerate	5.0
Interbedded siltstone (two-thirds) and limestone (one-third); siltstone is reddish brown, thin to thick bedded; limestone is orange pink, slightly silty	10.0
Limestone, orange-pink, slightly silty, clayey	.5
Siltstone, reddish-brown, clayey, very limy; thin to thick irregularly flat bedded	5.0
Siltstone, reddish-brown, poorly sorted, slumped	.5
Siltstone, moderate-reddish-brown; contains some clay and very fine sand; very thin to thin even beds with some interlaminae of shale of same color; ripple marks; some beds limy	7.0
Siltstone, moderate-reddish-brown, poorly sorted with some clay and very fine sand; in slumped contorted units with fairly flat upper and lower surfaces	14.0
Sandstone, dark-grayish-orange, medium-grained	4.0
Sandstone, light-grayish-orange; weathers white; fine to very fine grained; thin to thick flat beds; reworked Navajo Sandstone	16.0
Sandstone, dark-grayish-orange, medium-grained, abundant medium to coarse gray frosted quartz grains; bedding indistinct; part is low-angle, small-scale crossbedded, and part is irregularly flat bedded; weathers to form conspicuous grayish-brown ledge	6.0
Total limestone unit	97.5
Total Carmel Formation	313.0
Navajo Sandstone (incomplete):	
Sandstone, light-grayish-orange, somewhat paler toward base, fine-grained, moderately sorted, porous	43.0

SECTION 17.—*San Rafael Group*

[At Red Slide, Hall Creek, sec. 9, T. 36 S., R. 9 E. (unsurveyed); lat 37°42′, long 110°56′30″. Measured by J. C. Wright and D. D. Dickey]

	Thickness (ft)
Morrison Formation (incomplete):	
Salt Wash Sandstone Member (incomplete):	
Top of measured section, not top of exposure.	
Chert and calcite, white; weathers to show colored clastic(?) chert granules; some pyrite	1.5
Summerville Formation:	
Shale and siltstone, moderate-red, 1-in. to 1-ft thick interbeds of pale-red siltstone	18.0
Shale, greenish-gray and dark-grayish-red, a few greenish-white silty fine-grained sandstone beds	12.0
Shale (65 percent), moderate-red, interbedded greenish-white silty fine-grained sandstone (35 percent) in beds 3–9 in. thick	11.0
Sandstone, silty, greenish-white, very fine grained; contains some gray frosted rounded medium grains ("Entrada berries"); thin to very thin even beds	6.0
Shale, with minor siltstone beds less than 1 in. thick; much of shale is silty	17.0
Shale, moderate-red, subordinate light-greenish-gray shale; about one-fourth light-greenish-gray siltstone in beds 6–12 in. thick	11.0
Shale, moderate-red; about one-fourth pale-red siltstone in beds 1–12 in. thick	16.5
Total Summerville Formation	91.5

NOTE.—The Summerville-Entrada contact is mostly concealed; it appears conformable from a distance.

Entrada Sandstone:

Upper sandy member:

Sandstone, reddish-orange; weathers same; very fine grained, well sorted; "Entrada berries" conspicuous about 20 ft above base and also about 15 ft below top, sparse elsewhere; forms rounded slickrim-type cliff. Bedding as follows:

	Feet above base
Top. Irregular flat thin beds	171.0–177.0
Small- to medium-scale cross-strata	142.5–171.0
Irregular flat thin beds	141.0–142.5
Small- to medium-scale cross-strata	138.0–141.0
Irregular flat thin beds	134.0–138.0
Medium- to large-scale cross-strata	95.5–134.0
Irregular flat thin beds	92.5– 95.5
Large-scale cross-strata in sets as much as 15 ft thick	68.5– 92.5
Irregular flat thin beds	66.0– 68.5
Similar to unit at base	30.0– 66.0
Irregular flat thin beds	26.5– 30.0
Base. Large-scale cross-strata in sets 3–6 ft thick	.0– 26.5

Total thickness 177.0

SECTION 17.—*San Rafael Group*—Continued

	Thickness (ft)
Entrada Sandstone—Continued	
Upper sandy member—Continued	
Sandstone, silty, light-reddish-brown, very small scale to medium-scale cross-strata	12.0
Total upper sandy member	189.0
Medial silty member:	
Covered by valley alluvium; presumably soft earthly siltstone with subordinate interbeds of slickrim sandstone; thickness computed from outcrop width	337.0
Lower sandy member:	
Sandstone, brown, very fine grained, some silt, moderately sorted; composed of rounded quartz grains, some of which are frosted; indistinct bedding, mostly irregular flat beds; a few medium-scale crossbeds in sets about 3 ft thick; weathers to rounded slickrim; middle part appears coarser and more distinctly crossbedded than the rest. Approximate thickness (precise dip determination impossible)	332.0
Covered except for a few small exposures of red siltstone, dusky-red clayey material in the upper few feet, and several massive beds, probably contorted; forms recess	19.5
Sandstone, white, fine-grained, well-sorted; composed of rounded quartz and a few reddish chert grains; well-cemented; probably medium- to large-scale planar sets of cross-strata, much jointed; forms ridge	12.0
Total lower sandy member	363.5
Total Entrada Sandstone	889.5
Carmel Formation:	
Gypsiferous unit:	
Shale and shaly siltstone, soft-weathering, mostly concealed, pale-red, pale-purple, and yellowish-gray	74.0
Limestone unit:	
Covered, probably reddish-brown siltstone	47.0
Shale, very limy, light-brown, some white bleached spots; weathers same	8.0
Shale, silty, and reddish-orange siltstone, partly concealed	11.0
Mostly covered; probably moderate-reddish-brown siltstone and minor sandstone	7.0
Siltstone, sandy, white, moderately sorted, very calcareous, well-cemented; massive with casts of channels at base; forms ledge	2.0
Covered, probably reddish-brown siltstone as indicated by abundant float	10.0
Sandstone, moderate-reddish-orange; weathers moderate brown; very fine grained; silty; well-cemented, calcareous	2.0
Breccia; siltstone matrix (85 percent) with angular silty limestone fragments a fraction of inch to 6 in. across; probably formed by slumping	12.0

SECTION 17.—*San Rafael Group*—Continued

	Thickness (ft)
Carmel Formation—Continued	
Limestone unit—Continued	
Siltstone, moderate-reddish-brown, partly thin-bedded, partly massive; includes a few beds of massive very fine grained sandstone, same color	16.0
Covered, probably similar to overlying unit	3.0
Sandstone, pale-reddish-brown, very fine grained, massive beds 0.5–2 ft thick, separated by siltstone partings; uppermost bed is limy and capped by 2 in. of very limy ripple-marked sandstone	8.0
Sandstone, moderate-orange-pink, fine- to medium-grained, well-sorted; composed of rounded quartz grains; thin even beds; very thin bedded at top; appears to be reworked Navajo Sandstone	8.0
Total limestone unit	134.0
Total Carmel Formation	208.0

NOTE.—The Navajo-Carmel contact truncates cross bedding in the Navajo and is overlain by reworked sand from the Navajo.

Navajo Sandstone:	
Sandstone, white, medium-grained, large-scale trough and planar sets of crossbeds	300.0

SECTION 18.—*The Morrison Formation in Long Canyon*

[Lat 37°40′, long 110°53′. Measured by G. A. Miller and B. L. Long]

	Thickness (ft)
Dakota Sandstone (incomplete):	
Conglomerate, light-brown, crossbedded; contains light brown, white, gray, and sparse black rounded chert pebbles (average diameter ¾ in., maximum 1½ in.) in matrix of coarse-grained cherty sandstone	15.0
Morrison Formation:	
Brushy Basin Shale Member:	
Mudstone, light-olive-green to gray, bentonitic; largely covered by landslide blocks of Dakota Sandstone	50.0
Mudstone, light-olive-green to light-gray, very bentonitic, massive, slightly sandy; weathers to light gray "popcorn" surface	82.0
Mudstone and sandstone. Mudstone is olive green, bentonitic, and very sandy; it weathers to a "popcorn surface." Sandstone is light olive brown to light gray and very fine grained; it contains sparse grains of red and green chert	9.0
Conglomerate, greenish-gray, crossbedded, lenticular; ¼ in. red and green chert pebbles in very coarse grained mudstone matrix containing red and green chert and sparse clear quartz grains; a few partings of green mudstone	2.0
Mudstone, bentonitic, light-olive-green to gray, massive; weathers to light gray "popcorn" surface	3.5

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SECTION 18.—*The Morrison Formation in Long Canyon*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Brushy Basin Shale Member—Continued	
Sandstone, mudstone and conglomerate, light-olive-green; sandstone is very fine grained to fine grained and contains sparse grains of red chert; mudstone is light green; conglomerate is olive green, lenticular, and contains abundant silicified wood fragments and pebbles of green mudstone. Unit poorly exposed	8.0
Mudstone, light-purple to light-olive-green; contains sparse 2-in. beds of very fine grained to medium-grained poorly sorted light-gray sandstone	6.0
Sandstone and conglomerate, light-gray; weathers dark brown; sandstone poorly sorted, fine to coarse grained, and very well cemented; conglomerate is mainly red and green chert pebbles averaging ¼ in. in diameter. Unit is bench and ledge forming	2.5
Conglomerate, greenish-gray, well-cemented; contains ⅜-in. red and green chert pebbles in matrix of very coarse sandstone and sparse interstitial green clay	1.0
Mudstone, light-gray-yellow grading downward to light-purple, bentonitic; contains well-cemented lenses of conglomerate containing ⅜–⅝-in. pebbles of red, green, and gray chert	33.0
Sandstone, light-gray; weathers to dark gray and dark brown; horizontally stratified; tightly cemented; well-sorted fine-grained sand with white interstitial kaolinite(?); locally cemented by carbonate	3.0
Mudstone, light-purple to light-green, bentonitic, sparse 2-in. beds of gray very fine grained sandstone	14.5
Sandstone, light-gray to white, crossbedded, fine- to medium-grained, well-cemented at base, friable at top; upper 5 ft slightly conglomeratic; contains 1-in. white and gray chert pebbles. To north of this section unit contains abundant red and green chert pebbles	14.0
Sandstone, light-gray, medium- to fine-grained, calcareous cement locally	1.5
Total Brushy Basin Shale Member	230.0
Salt Wash Sandstone Member:	
Mudstone, dark-reddish-brown, slightly silty	8.6
Sandstone, yellow-gray to light-brown, crossbedded, medium-grained, slightly conglomeratic; gray chert pebbles predominate over red and green chert	43.2
Sandstone, very light brown to light-yellow-brown, very fine grained, horizontally stratified in 1-ft beds; some red mudstone at top of unit; tongues with red mudstone to west	5.5
Sandstone, white to light-gray, trough crossbedded, medium- to coarse-grained; sparse conglomerate layers contain ½-in. pebbles of light-gray chert; lower 3 ft locally contains some red mudstone	19.8
Mudstone, red-brown, silty; contains local 1-ft beds of light-brown very fine grained sandstone	12.0

SECTION 18.—*The Morrison Formation in Long Canyon*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Salt Wash Sandstone Member—Continued	
Sandstone, conglomeratic, light-brown to very light gray, crossbedded to horizontally stratified near top; sandstone very fine grained, limonite speckled; conglomerate contains pebbles of gray-white chert and sparse red chert and reddish quartz	32.5
Sandstone, light-brown to brown, horizontally stratified in beds 1–2 ft thick, fine-grained to very fine grained, local layers of reddish mudstone	6.0
Sandstone and conglomerate, light-gray to light-brown, medium- to fine-grained; few beds of reddish mudstone in basal 15 ft	123.0
Mudstone, red; contains few thin beds of very fine grained silty reddish-brown sandstone	6.5
Sandstone, light-brown to very light gray, horizontally stratified, fine-grained to very fine grained; few interbeds of dark-reddish mudstone	11.5
Sandstone, very light gray, crossbedded, fine- to coarse-grained, locally conglomeratic, local beds of red mudstone as much as 6 in. thick	34.0
Mudstone and sandstone; mudstone reddish; sandstone light gray to light olive green and very fine grained	10.5
Sandstone, light-gray to white, crossbedded, very fine grained to coarse-grained, local conglomerate in beds as much as 2 ft thick	8.0
Sandstone, light-gray to light-brown, in beds as much as 1 ft thick with interbeds of reddish mudstone	16.0
Sandstone, conglomeratic, light-gray to white, medium- to fine-grained; conglomerate layers contain gray chert and quartz pebbles as much as ½ in. in diameter	10.0
Sandstone, light-pinkish-brown, horizontally stratified in beds 1 in. to 1 ft thick, fine-grained; few 2-in. beds of green siltstone near top of unit	4.0
Mudstone, reddish, silty and sandy, few local 3-in.-thick beds of very fine grained silty sandstone	8.5
Sandstone, very light gray to white, crossbedded, medium-grained to very fine grained with abundant grains of pink chert; locally conglomeratic near base, with chert and quartz pebbles as much as ½ in. in diameter	18.0
Sandstone, light-pinkish-brown, flat bedded in beds 3–5 ft thick	15.8
Sandstone, light-pinkish-brown to light-gray; weathers tan and dark brown, horizontally stratified in beds 1–3 in. thick, fine grained to very fine grained	4.6
Sandstone, light-gray to light-bluish-gray, horizontally stratified, very fine grained	4.0
Mudstone, dusky-red, interbeds of red sandy and silty mudstone	11.0

SECTION 18.—*The Morrison Formation in Long Canyon*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Salt Wash Sandstone Member—Continued	
Limestone, light-blue; contains as much as 50 percent medium-sized quartz grains	3.0
Total Salt Wash Sandstone Member	416.0
Total Morrison Formation	646.0
Summerville Formation:	
Siltstone and sandstone, not measured in detail	129.0

SECTION 19.—*Morrison Formation on northwest side of Big Thomson Mesa*

[Salt Wash Sandstone Member section begins at lat 37°43′, long 110°56′; Brushy Basin Shale Member section begins 2,000 ft to the north. Measured by G. A. Miller and B. L. Long]

	Thickness (ft)
Dakota Sandstone (incomplete):	
Conglomerate, gray; pebbles of gray and black chert in medium-grained sandstone matrix; well cemented; limonitic (not measured).	
Mudstone, gray, shaly, carbonaceous	5.0
Morrison Formation:	
Brushy Basin Shale Member:	
Mudstone, olive-green, poorly exposed, slightly sandy; contains a few 6-in.-thick beds of dark-green very fine grained well-cemented sandstone	75.0
Mudstone, light-olive-brown, bentonitic, very sandy, poorly exposed; sparse interbeds of olive-brown very fine grained to fine-grained sandstone 4–6 in. thick	18.0
Sandstone and conglomerate; sandstone is alternating olive green and light gray in bands 1–3 in. thick, crossbedded, fine to medium grained; conglomerate in lower part of unit is greenish gray, lenticular; contains pebbles of red and green chert, greenish-gray mudstone, and sparse gray chert	15.0
Mudstone, light-olive-brown to light-olive-green, some red especially near base, silty, bentonitic, poorly exposed	91.0
Conglomerate, light-gray, crossbedded; average diameter of pebbles ½ in., maximum 2½ in.; contains red and green chert, sparse red quartzite and gray chert, and some limestone fragments containing crinoids; matrix is coarse-grained to very coarse grained sandstone	19.5
Mudstone, dark-red, silty, poorly exposed	25.0
Sandstone, light-yellow-brown; weathers dark brown and dark gray; crossbedded; thick bedded; blocky; fine to very fine grained; calcareous cement	2.5
Mudstone, red with some gray, silty, slightly bentonitic; few lenticles of massive-light-brown very fine grained calcareous cemented sandstone 7 ft below top	22.5
Sandstone, light-gray; weathers dark brown; massive; very fine grained to medium grained; interstitial white clay (kaolinite?); calcareous cement	1.5

SECTION 19.—*Morrison Formation on northwest side of Big Thomson Mesa*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Brushy Basin Shale Member—Continued	
Conglomerate; not present at location of Brushy Basin section, largely covered at location of Salt Wash section; variegated red, green, and gray, crossbedded, abundant pebbles of red, green, yellow, and minor gray chert in matrix of gray coarse-grained sandstone	0–20
Total Brushy Basin Shale Member	270. 0–290. 0
Salt Wash Sandstone Member:	
Covered; float and outcrops several hundred feet away are red mudstone	10. 0
Sandstone, pale-grayish-yellow to light-gray with small irregular patches of yellow, very fine grained, thick-bedded; contains sparse limonite specks and sparse granules and pebbles of chert	12. 0
Sandstone and conglomerate, very light gray, yellowish-gray, pale-orange, and light-greenish-gray; contains abundant limonite specks and stained areas; sandstone in beds as much as 3 ft thick is medium coarse grained to medium grained, crossbedded, and has conglomeratic layers along bedding planes; conglomerate, yellowish gray; consists of pink quartzite and chert, light-gray chert, and sparse clear quartz; average diameter of subrounded to rounded pebbles is ¼ in., maximum 1 in. Upper 10 ft of unit is yellow gray to pale orange and is less conglomeratic than lower part	31. 5
Sandstone, silty, moderate-yellow-brown to dark-brown, very fine grained, horizontally stratified	1. 8
Sandstone and conglomerate; sandstone is dark yellowish orange to pale yellowish orange, medium fine grained, crossbedded in beds 1–3 ft thick; conglomerate interbeds are 3–5 ft thick, crossbedded, moderate yellow to pale yellowish-orange; pebbles average about 0.4 in. in diameter and are composed of yellow and gray chert and sparse red chert	7. 0
Conglomerate, brown to dark-gray, subangular to rounded pebbles of white, gray, and brown chert and sparse milky and rose quartz; average diameter of pebbles is about ¾ in., maximum 2 in	15. 0
Sandstone, light-brown to grayish-orange, medium-grained; principally quartz and abundant grains of white altered chert(?); abundant limonite specks	14. 0
Conglomerate, light-gray; basal 1 ft contains sparse blocks of sandstone 3 in. thick and 12 in. long and pebbles of light-gray chert, green mudstone, clear quartz, and sparse red chert; abundant granule-sized grains; grades upward into overlying unit	3. 0

SECTION 19.—*Morrison Formation on northwest side of Big Thomson Mesa*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Salt Wash Sandstone Member—Continued	
Sandstone and conglomerate, light-gray to pale-orange-brown, fine- to coarse-grained, calcite cement, crossbedded; pebbles average about 0.4 in. in diameter, mostly dark-gray silicified limestone, quartzite, and gray chert; sparse red chert; sand grains and chert pebbles rounded to subrounded, other pebbles subangular	30.0
Sandstone, pinkish- to yellowish-gray and very light gray; weathers white to light gray; very fine grained; well sorted; sparse granules and pebbles of dark-gray chert	5.0
Covered (talus and landslide); sparse outcrops in this interval within a few hundred feet of section are red mudstone and thin lenticular sandstone similar to underlying unit	143.5
Sandstone: lower 4 ft light gray, fine grained; upper 3 ft medium to coarse grained. Unit contains abundant grains of red chert, sparse granules of red and gray chert along some bedding planes; it is horizontally stratified and crossbedded, very lenticular, and appears to pinch out 20 ft north of section	7.0
Sandstone, light-grayish-yellow, fine-grained to very fine grained, laminated; laminae about 0.1 in. thick, conspicuous on weathered surface	5.5
Sandstone, light-reddish-brown to light-gray, medium- to medium-coarse-grained, crossbedded, abundant limonite specks; sparse pebbles of light-gray chert along bedding planes; forms cliff	22.0
Mudstone, reddish, poorly exposed	2.0
Conglomerate, light-gray to grayish-pink; average diameter of pebbles is about ½ in., maximum 2 in.; mostly white and red chert, some green chert, quartzite, sandstone, and clear quartz	5.0
Sandstone, conglomeratic, light-gray to pale-reddish-brown; weathers dark reddish brown. Average diameter of pebbles is about ½ in., maximum 1¾ in.; consist of chert, clear quartz, dark-gray quartz, quartzite, and sparse sandstone and silicified limestone; limestone pebbles contain impressions of crinoid stems. Unit is crossbedded, has numerous scour and fill structures; cliff former	28.0
Sandstone, very light gray, very fine grained; contains abundant black opaque minerals and green chert(?) grains; horizontally stratified; tightly cemented by calcium carbonate(?)	4.0
Mudstone, silty, dark-red	4.0
Sandstone, conglomeratic in lower 3 ft, light-gray, speckled with limonite, very fine grained to coarse-grained; pebbles angular to subangular, gray to grayish-red chert and sparse clear quartz, average about ½ in. in diameter; sparse coarse grains of white chert(?) in sandstone; unit forms cliff, fills scour in underlying unit	32.5
Sandstone, very silty, reddish-brown to light-red; very fine grained, poorly exposed	1.0

SECTION 19.—*Morrison Formation on northwest side of Big Thomson Mesa*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Salt Wash Sandstone Member—Continued	
Sandstone, light-reddish-brown, very fine grained to fine-grained; contains sparse flakes of green claystone; abundant limonite; horizontally stratified in beds as much as 1.5 ft thick; weathers pale red	5.5
Sandstone, white to very light gray, fine-grained with sparse pebbles of light-gray chert as much as ½ in. in diameter scattered along bedding planes; crossbedded; abundant limonite specks; sparse black opaque mineral grains; weathers pale yellowish brown; unit contains numerous scour structures; top of unit is horizontally stratified	11.7
Sandstone, very silty, light-yellowish-brown, very fine grained; abundant limonite stains on outcrop; occurs in beds about 6 in. thick	2.4
Sandstone, very light gray, very fine grained to fine-grained; sparse grains of red chert and flakes of olive-green mudstone locally; horizontally stratified in beds as much as 1.5 ft thick	3.3
Sandstone and mudstone; alternating pale-green mudstone and light-pinkish-red, very fine grained, well-sorted sandstone in beds 1–4 in. thick	3.0
Sandstone, silty, reddish-brown, very fine grained, tightly cemented, horizontally stratified	3.0
Sandstone, slightly conglomeratic, light-gray, fine- to medium-grained; pebbles rounded to angular light-red quartz and gray chert as much as 1 in. in diameter; pebbles scattered along bedding planes throughout unit; sparse black opaque mineral grains and sparse grains of weathered chert(?). Unit is the stratigraphically lowest scouring sandstone in the Salt Wash in this area	19.0
Sandstone, light-gray to pinkish-gray, very fine- to coarse-grained; horizontally stratified to crossbedded; crossbedded portions are poorly sorted	3.8
Sandstone, very light gray, very fine grained; locally yellow brown due to limonite specks; horizontally stratified in beds 1–1.5 ft thick	2.7
Sandstone, very silty, slightly calcareous, pale-reddish-brown, very fine grained to fine-grained, poorly sorted	1.0
Sandstone, light-gray, very fine grained, horizontally stratified; weathers yellowish brown	1.7
Sandstone, light-gray to olive-brown, very fine grained; contains abundant limonite specks, sparse black opaque minerals; laminated in beds about 0.6 in. thick; upper 2 in. of unit contains medium-grained sand and is poorly sorted; forms ledge	2.4
Mudstone, silty, very dusky red to dark-reddish-brown; sparse beds of light-grayish-green mudstone near top; upper 3 ft contains lenses of light-yellowish-gray very fine grained sandstone that contains sparse flakes of carbonaceous material	6.7

SECTION 19.—*Morrison Formation on northwest side of Big Thomson Mesa*—Continued

	Thickness (ft)
Morrison Formation—Continued	
Salt Wash Sandstone Member—Continued	
Sandstone, very tightly cemented with silica, yellowish-gray to light-olive-gray, very fine grained; weathers light olive gray; local blebs of green mudstone in lower 2 in.; forms conspicuous ledge	1.6
Mudstone, sandy, grayish-olive to grayish-green to pale-red along outcrop	1.0
Sandstone, yellowish-gray to greenish-gray, very fine grained, crossbedded, small flakes of carbonaceous material locally, very lenticular, grades into greenish-gray mudstone in nearby outcrops	2.2
Mudstone, silty, reddish-brown; contains 6-in.-thick beds of light-yellowish-green siltstone locally; upper 1 foot contains sparse light-pinkish-red nodules of calcareous siltstone	8.5
Sandstone, light-yellowish-gray, very fine grained, horizontally stratified, well-sorted; poorly exposed	.8
Limestone, cherty, light-yellowish-gray to bluish-gray; sugary to medium-crystalline; chert is red, in irregular beds near top of unit; weathers light olive gray; taken as base of Salt Wash Sandstone Member of Morrison Formation	2.5
Total Salt Wash Sandstone Member	466.6
Total Morrison Formation	736.6–756.6
Summerville Formation:	
Siltstone and sandstone, red, ribbed, thin-bedded (not measured).	

SECTION 20.—*Dakota Sandstone at "The Post"*

[East-central Circle Cliffs area, Garfield County; lat 37°50′, long 110°58′20″. Measured by G. A. Miller]

	Thickness (ft)
Mancos Shale:	
Tununk Shale Member:	
Mudstone, dark-gray, thinly laminated to very thin bedded, bentonitic, highly weathered, poorly exposed (not measured).	
Dakota Sandstone:	
Sandstone, light-brown to dark-gray, ripple-laminated, medium- to coarse-grained; contains granules of quartzite and tan chert; fossiliferous (*Ostrea*)	2.5
Sandstone, light-yellow, horizontally stratified and crossbedded, fine- to medium-grained; very coarse grains and granules of gray chert and quartz in upper 3 ft	7.0
Sandstone, brown to dark-gray, horizontally stratified in ledgy beds 1–2 in. thick, carbonaceous, fine-grained to very fine grained	1.5
Shale and coal	1.5
Sandstone, gray, massive, carbonaceous, very poorly sorted fine- to coarse-grained	1.0
Shale and coal	2.5
Siltstone, gray; weathers to light gray; massive; sandy	2.5

SECTION 20.—*Dakota Sandstone at "The Post"*—Continued

Dakota Sandstone—Continued	*Thickness (ft)*
Shale, light-gray, very sandy, some ledges of fine-grained sandstone	3.0
Sandstone, brown to white, horizontally stratified to crossbedded, limonitic, fine-grained to very fine grained, beds near top are ripple laminated	7.0
Shale, gray to light-olive-gray, sandy, few thin beds of fine-grained sandstone	12.0
Sandstone, white to pale-yellow, red near top; weathers light brown; crossbedded; well sorted; fine to very fine grained	26.0
Sandstone, largely covered, float similar to overlying unit	8.6
Conglomerate and sandstone, light-yellow to gray; conglomerate weathers dark gray to black, crossbedded; pebbles as much as 2 in. in diameter of dark-gray to black chert, gray chert, and sparse quartzite	11.0
Total Dakota Sandstone	86.1

Morrison Formation (not measured).

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