Geology of the Capitol Reef Area, Wayne and Garfield Counties, Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 363

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

Smith, Huff, Hinrichs, Luedke—GEOLOGY, CAPITOL REEF AREA, WAYNE AND GARFIELD COUNTIES, UTAH—Geological Survey Professional Paper 363

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE CAPITOL REEF AREA, WAYNE AND GARFIELD COUNTIES, UTAH

By J. Fred Smith, Jr., Lyman C. Huff, E. Neal Hinrichs, and Robert G. Luedke

ABSTRACT

The Capitol Reef area includes about 900 square miles in western Wayne and north-central Garfield Counties, Utah. It is along the border between the High Plateaus of Utah and the Canyon Lands sections of the Colorado Plateaus province. Capitol Reef National Monument is in the eastern part of the mapped area.

Sedimentary rocks exposed in the area range from the Coconino sandstone of Permian age to the Flagstaff limestone of early Tertiary age and have an aggregate thickness of more than 10,000 feet. The Coconino sandstone, more than 800 feet thick, consists of sandstone crossbedded on a large scale. The overlying Kaibab limestone, also of Permian age, is 250 to 350 feet thick and includes beds of siltstone, limestone, dolomite, crossbedded sandstone, and chert nodules and layers.

The Triassic system consists of the Moenkopi and Chinle formations and the Wingate sandstone. The Moenkopi formation is mapped as two units: (1) the lower unit comprises basal beds of siltstone and upper beds of the Sinbad limestone member containing limestone, dolomitic limestone, dolomite, and calcareous sandstone; (2) the upper unit consists of a lower part of chiefly sandstone and siltstone and an upper part of chiefly siltstone. The thickness of the Moenkopi ranges from about 760 to about 970 feet. The Chinle formation is mapped as three members and ranges in thickness from about 440 to 540 feet. The basal Shinarump member is composed chiefly of medium- to coarse-grained crossbedded sandstone that contains claystone beds and lenses, silicified and carbonized logs, and carbonized plant remains. The Shinarump member is a nearly continuous unit in about the western three-quarters of the area of its exposure and is discontinuous in the eastern one-quarter. The middle member of the Chinle consists of variegated bentonitic claystone, siltstone, and clayey sandstone, and some conglomeratic sandstone at the top. The upper member consists of variegated siltstone and lenticular beds of sandstone and limestone. Both the upper and middle members contain silicified logs. A pronounced erosional unconformity is at the contact between the Moenkopi and Chinle formations, and locally basal beds of the Shinarump have filled channels cut into the Moenkopi. The Wingate sandstone is a very fine grained sandstone crossbedded on a large scale and is from 320 to 370 feet thick.

Above the Wingate is the Kayenta formation of Jurassic(?) age; it is about 350 feet thick. It consists of lenticular beds of crossbedded and even-bedded sandstone, siltstone, and clay-pebble conglomerate. The Navajo sandstone of Jurassic and Jurassic(?) age is chiefly fine-grained sandstone that is crossbedded on a large scale and ranges from 800 to 1,100 feet in thickness. Formations of the San Rafael group of Jurassic age include the Carmel formation, the Entrada sandstone, and the Curtis and Summerville formations. The Carmel formation increases in thickness from east to west across the area—from about 300 feet to almost 1,000 feet. It consists of limestone, sandstone, claystone and siltstone, and gypsum; the percentage of limestone increases to the west. The Entrada sandstone, 475 to 780 feet thick, is reddish-brown thin- to thick-bedded sandstone and some siltstone and claystone. It is uniform lithologically over the area except in the southeast where it contains more massive crossbedded sandstone. The Curtis formation of grayish-green thin- to thick-bedded sandstone and some siltstone has a maximum thickness of 80 feet and is lacking in the southeastern part and probably in the western part of the mapped area. Uniformly reddish-brown thin-bedded siltstone and mudstone and fine-grained sandstone compose the Summerville formation, which is about 200 feet thick. The Morrison formation of Jurassic age is composed of two members, the lower Salt Wash sandstone member and the upper Brushy Basin shale member. Lenticular beds of conglomeratic sandstone, siliceous-pebble conglomerate, and siltstone and claystone compose the Salt Wash; this member ranges from 30 to 236 feet in thickness. Variegated claystone and conglomeratic sandstone lenses compose the Brushy Basin; this member ranges from 160 to 225 feet in thickness.

Rocks of Cretaceous age include the Dakota sandstone, the Mancos shale, and the Mesaverde formation. The Dakota is lacking in places, has a maximum thickness of 50 feet, and is composed of sandstone and conglomeratic sandstone. The Mancos consists of five members—in ascending order, the Tununk shale, the Ferron sandstone, the Blue Gate shale, the Emery sandstone, and the Masuk—with a total thickness of about 3,000 feet. The Mesaverde formation consists of about 300 feet of sandstone and thin interbeds of shale.

Sedimentary rocks of Tertiary age rest with angular unconformity on the older units in the northwestern part of the area. These Tertiary beds are nonmarine limestone, tuff, tuffaceous sandstone, conglomerate, siltstone, and claystone of the Flagstaff limestone. Their thickness cannot be measured in this area, but it is estimated to be more than 500 feet.

Igneous rocks and associated tuffaceous sedimentary rocks of Tertiary age cover about 100 square miles of the mapped area. Lavas of chiefly porphyritic andesite and some andesite scoria constitute the bulk of the igneous rocks. Dikes and sills crop out particularly in the northeastern part of the area. Tuffaceous sedimentary rocks are interbedded with the lava flows and in places form a greater percentage of the stratigraphic section than do the lavas.

The deposits of Quaternary age include pediment gravel, boulder deposits of diverse materials of more than one origin, till, outwash gravel, terrace gravel, landslide deposits, colluvial sand and gravel, rock glaciers, alluvial-fan deposits, and allu-

vium. The pediment gravels are dated as pre-Wisconsin because of their topographic positions. They are higher than early Wisconsin deposits and were extensively eroded before deposition of the Wisconsin stage till. The boulder deposits contain many boulders derived from the lavas exposed on the tops of Boulder and Thousand Lake Mountains, but these deposits also contain some fragments and irregular blocks as much as 100 feet long that can be identified as being derived from formations of Tertiary, Cretaceous, and Jurassic age. These boulder deposits probably include till, landslide deposits, and small remnants of pediment gravel. The deposits are maturely dissected in most places and their topographic form indicates their pre-Wisconsin age but not their exact manner of origin. The boulder deposits are considered to be chiefly pre-Wisconsin, although in a few places some Recent deposits such as small patches of colluvium are included in the same map unit.

Till forming three moraines was deposited from glacial ice that formed on the top of Boulder Mountain—the northeastern part of the Aquarius Plateau—and flowed down valleys on the mountainsides. Outwash gravel extends beyond the margins of some of the moraines. Because of their lack of weathering and erosion these deposits are correlated with the Wisconsin stage of the Great Lakes region and with the Bull Lake and Pinedale glacial stages of the Rocky Mountain region. Terrace gravel along the Fremont River is considered to be early Wisconsin. Extensive landslide deposits are on the flanks of Boulder and Thousand Lake Mountains. Most of the landsliding probably took place during the Wisconsin stage, but some movement has occurred recently.

The Recent deposits include rock glaciers, alluvium, alluvial fan deposits, and colluvial sand and gravel.

Structurally the Capitol Reef area is in a marginal belt between large basins and upwarps on the east and generally north-trending normal faults—the High Plateau faults—on the west. Principal structural features are the northwest-trending Waterpocket Fold near the east edge of the area, the northwest-trending Teasdale anticline through the central part of the area, the northwest-trending Teasdale fault on the southwest side of the Teasdale anticline, and the north-trending Thousand Lake fault in the western part of the area. The total structural relief between the crest of the Teasdale anticline and the trough of the Henry Mountains structural basin east of the Waterpocket Fold is more than 7,800 feet. The deformation that formed the main folds and the northwest-trending faults preceded the deposition of the Flagstaff limestone and probably occurred between the middle and end of the Paleocene epoch. Movement along the Thousand Lake fault may have started also before deposition of the Flagstaff, but local evidence indicates that the movement was after deposition of the lavas tentatively assigned to the Miocene. In at least one place, movement along this fault is later than the deposition of early Wisconsin terrace gravels.

Uranium minerals or abnormal radioactivity are widespread areally and stratigraphically in the Capitol Reef area, but no economically important uranium deposits had been found by the end of 1955. Uraniferous rock occurs in the Moenkopi formation, all three members of the Chinle formation, the Curtis formation, and the Salt Wash member of the Morrison formation. Most of the uranium is in the Shinarump member of the Chinle formation and the Salt Wash member of the Morrison formation.

Uranium deposits or uraniferous rock in the Shinarump member have four principal associations: (1) the deposits are most common in the area of discontinuous Shinarump; (2) they are most concentrated in beds where strata of the Shinarump filled channels cut into the underlying Moenkopi formation; (3) they are associated with or are in the vicinity of carbonaceous material; and (4) they are associated with claystone or clayey beds.

The known uranium deposits in the Salt Wash member occur in conglomeratic sandstone lenses at or near the top of the member. These deposits consist of carnotite and uraniferous material disseminated in conglomeratic sandstone and locally concentrated in pockets containing abundant carbonized plant fragments.

Geochemical studies were concerned principally with altered or bleached mudstone adjacent to the Shinarump member, adjacent to a dike, and adjacent to joints in the Moenkopi formation. Increase and decrease of certain metals in the bleached beds near the Shinarump relative to the unbleached red beds suggest that the fluid that bleached and chemically altered the mudstone was probably an acid and mildly reducing solution. Alteration of red beds probably by hydrothermal solutions near the dike and by ground water along joints caused little or no chemical change.

The close association of uranium minerals with reducing carbonaceous material suggests that the original precipitation of the minerals was due to chemical reduction caused in part at least by the organic material. The amount of original carbonaceous material may have been much greater than that now seen in the rocks. An original abundance of carbonaceous material may have been great enough to serve as a reducer for precipitation of considerable amounts of uranium minerals.

Several copper prospects and two manganese prospects are in the mapped area. The Teasdale, Fruita, and Thousand Lake anticlines have ample closure for oil and gas accumulation, but a well drilled on the Teasdale anticline failed to produce any oil or gas.

INTRODUCTION

The Capitol Reef area encompasses about 900 square miles in Wayne and Garfield Counties, Utah, and is between lat 38°00′ and 38°30′ N. and long 111°00′ and 111°37′30″ W. (fig. 1). The area mapped in this study is along the border between the High Plateaus of Utah and the Canyon Lands sections of the

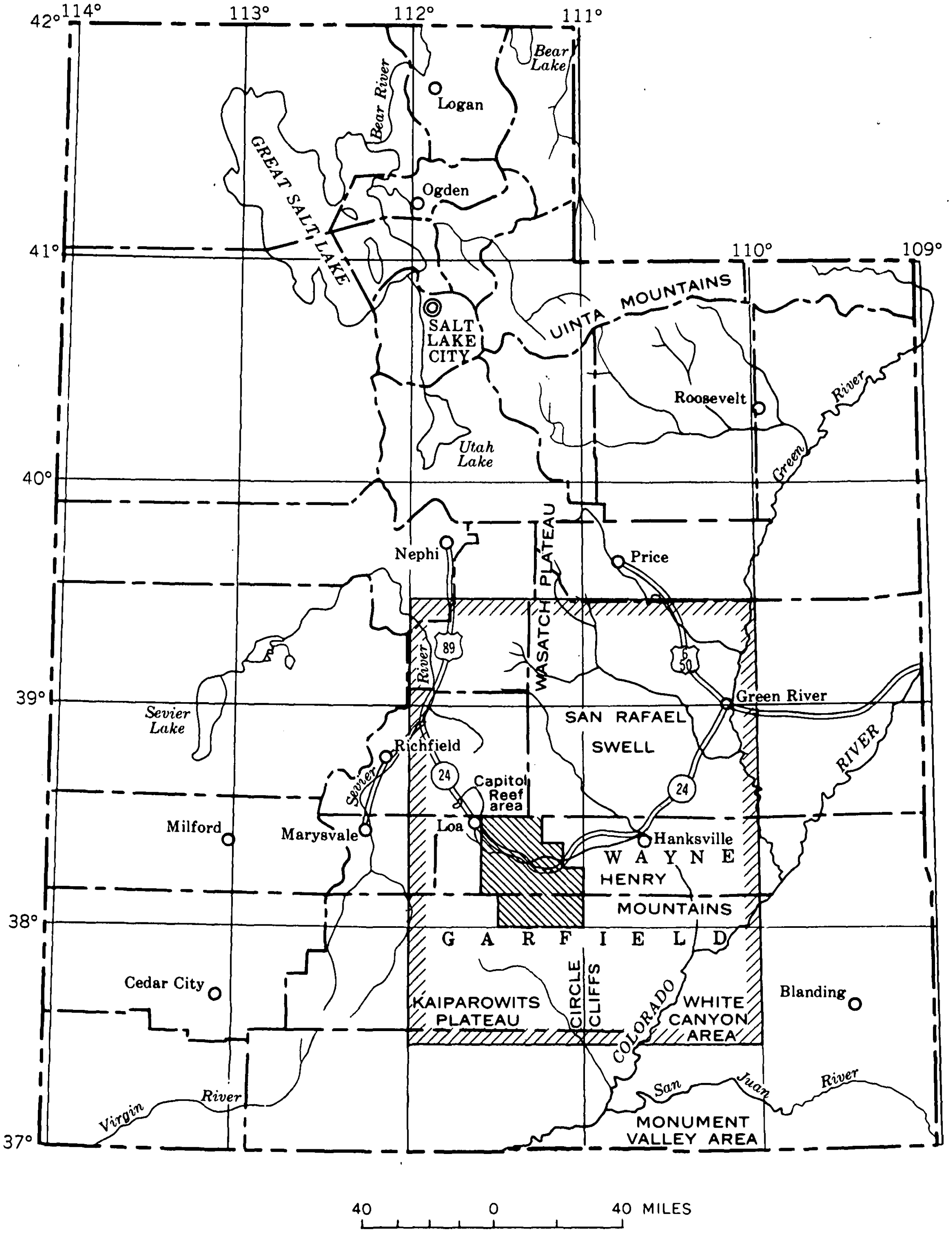


FIGURE 1.—Index map of Utah showing the location of the Capitol Reef area and of other areas in southeastern Utah. Area inside hachured lines shown on figure 2.

Colorado Plateaus province (fig. 2) and takes its name from the Capitol Reef National Monument, a tract of escarpment and canyon land in the eastern part of the area.

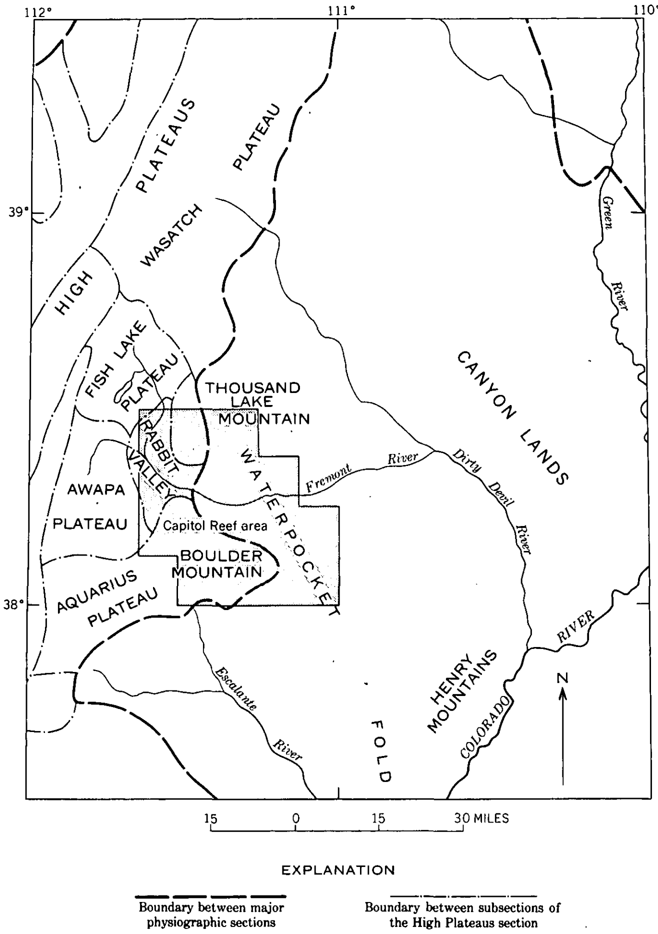


Figure 2.—Index map showing physiographic subsections in and near the Capitol Reef area, Utah.

Chief objectives of the geologic work were to study the uranium deposits and radioactive localities, to determine their relationship to stratigraphy, structure, and geologic history, and to establish geologic indicators of ground favorable for concealed uranium deposits. The geologic investigations were made on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

Fieldwork was begun in July 1951 and completed in July 1954. The geology was mapped on preliminary 7½-minute topographic quadrangle maps at a scale of 1:24,000 and with the use of aerial photograph contact prints at scales of approximately 1:20,000 and 1:47,000. Final compilation was on the topographic sheets at a scale of 1:48,000 for reduction to the publication scale of 1:62,500. Twenty-four stratigraphic sections ranging from 50 to 1,100 feet in thickness were measured and described in the field. Geochemical studies chiefly of uraniferous rock and of bleached red beds were made by L. C. Huff.

ACKNOWLEDGMENTS

As in most areal geologic studies, many people were extremely helpful in many ways during the course of the work. Thanks are extended to the many residents of Wayne County who helped in many ways, and to the many prospectors and mining people for being most cooperative in giving us data about their prospects and claims.

During June 1952, J. D. Sears of the U.S. Geological Survey was a member of the field party, and we benefited from his extensive geologic experience. During 1952, R. F. Flint and C. S. Denny of the U.S. Geological Survey mapped and studied the Quaternary deposits chiefly on the north side of Boulder Mountain (Flint and Denny, 1958). The association with these experienced glacial geologists was beneficial to us for our observations on the Quaternary geology in other parts of the area. Saw Alaric, now of the Geological Survey of Burma, worked with us for 6 weeks in 1953 while he was an exchange student in the United States. Special thanks are due Charles C. Kelly, then Superintendent of the Capitol Reef National Monument, for assistance and information regarding the region in general and the National Monument in particular.

PREVIOUS WORK

Classic reports of early scientific exploration of the Henry Mountains by Gilbert (1877) and of the High Plateaus of Utah by Dutton (1880) include some information on the geology of the Capitol Reef area. Gregory and Moore (1931) examined the geology of the area in connection with their work in the Kaiparowits region to the south. Dake (1919, 1920) outlined the stratigraphic sequence in the area and related it to the rest of the Colorado Plateau. The northeastern part of plate 1 covers the southern part of the San Rafael Swell area mapped by Gilluly (1929). After the Capitol Reef National Monument was established in 1937, Gregory and Anderson (1939) published a geographic and geologic sketch of the region. Hunt (1953) included the southeastern part of the Capitol Reef area in his mapping and study of the Henry Mountains region.

HISTORY

Cliff dwellings and artifacts are evidence of Indian habitation of the Capitol Reef area long before the arrival of the white man. Petroglyphs have been found in several places within the Capitol Reef National Monument and projectile points have been found over the entire area. Other archeological relics in the area include manos, metates, baskets, shields, sandals, and much pottery. At several places layers of carbonized wood, some ringed with boulders, mark ancient hearth sites at various levels within alluvial sediments along streams. Cliff dwellings of the Capitol Reef area were built of sandstone blocks cemented with adobe and are like those found elsewhere on the Colorado Plateau but are smaller and fewer in number. Some of the structures are too small for habitation and probably were used for storing corn or other grain. From the nature of these structures it seems probable that the Indians visited this area for many years, possibly growing corn here during the summertime and spending the winter in warmer and lower lands near the Colorado River. Archeologists believe these prehistoric inhabitants were related to the people of the Developmental-Pueblo culture, which flourished from 700 to 1100 A.D. in New Mexico and Arizona (Morss, 1931; Wormington, 1947, p. 59–73: 1955, p. 154–157, p. 163–190).

The first white men to enter the Capitol Reef area were in a party led by the famous explorer John C. Fremont. The party discovered the river that is now appropriately named the Fremont and crossed Rabbit Valley in January 1854. They may have crossed Capitol Reef along the Fremont Gorge (Gregory and Anderson, 1939, p. 1832) or may have crossed the divide north of Thousand Lake Mountain and viewed Capitol Reef from the west. Little is recorded of this expedition except that the party exhausted its food supply and survived for many days by eating their pack horses, that 1 member died of starvation, and that 2 were killed by Indians. Fremont's expedition was only one of many government expeditions made to explore the country to find possible railroad routes. Other government explorers who visited the area previous to the visits of Gilbert and Dutton included Thompson in 1872 (Thompson, 1875) and Howell in 1872 and 1873 (Howell, 1875).

Systematic scouting by the Church of Jesus Christ of Latter-day Saints introduced the epoch of colonization in southern Utah. During 1870 an expedition led by Jacob Hamblin followed the Fremont River through Rabbit Valley and Capitol Reef and investigated agricultural lands en route. In June 1874, a party of 17 men led by Andrew Jackson Allred visited Rabbit Valley and in the following year Allred and others established Fremont, the first settlement in the Capitol Reef area. The towns of Loa, Lyman, Bicknell, Teasdale, and Grover were all established by Mormon settlers within the next 10 years. Many interesting narratives of the early settlers are given by Snow (1953) in a history of Wayne County.

GEOGRAPHY

The largest towns in the Capitol Reef area are Torrey, Teasdale, Bicknell, Lyman, and Fremont, each of which has a population of between 100 and 400 people. Loa, the county seat of Wayne County, is just west of the mapped area. The main access to this area is by Utah State Highway 24 from Salina in Sevier County. Other roads connect the area with Escalante to the south and with Hanksville and Green River to the east and northeast.

The principal scenic attraction of the area is the Capitol Reef National Monument, a wonderland of scenic rock beauty. Capitol Reef was named by early government explorers in admiration of its rocky cliffs and its many rounded sandstone hilltops shaped like the dome of the Nation's Capitol in Washington, D.C. The picturesque name "reef" was fiirst applied to an inland feature by sailors participating in a gold rush to the rocky ridgelike gold "reefs" of Bendigo, Australia, and mining people have spread this use of the term worldwide. Capitol Reef is far removed from any ocean, but it is a perfect example of a rocky barrier. Its only crossing for automobiles in the mapped area is where State Highway 24 follows the winding course of Capitol Wash. This is a dry wash through a gorge only 30 feet wide in places, with sandstone cliffs on each side that tower hundreds of feet above. Usually at least once each year this route is blocked by flood waters.

Altitudes within the Capitol Reef area are between 11,328 feet on the top of Boulder Mountain and 4,960 feet where the Fremont River leaves the area at the east edge. The three major highlands are Boulder Mountain, Thousand Lake Mountain, and the Waterpocket Fold, part of which is known as Capitol Reef. This reef or fold extends from the east flank of Thousand Lake Mountain eastward and southward across the area covered by this report and for about 40 miles beyond. Lowlands separate and surround the major highlands, but the lowlands are themselves a maze of irregular cliffs, canyons, and ridges and include very little flatland. The most extensive flat areas are the top of Boulder Mountain at an altitude of about 11,000 feet and the alluvial lowlands along Rabbit Valley near the towns of Bicknell, Lyman, and Fremont at an altitude of about 7,000 feet.

All streams in the area are within the Colorado River drainage system. The Fremont River, the principal stream, enters the north edge of the mapped area from the north, flows along Rabbit Valley, and leaves Rabbit

Valley southeast of Bicknell to flow between Thousand Lake and Boulder Mountains and in a canyon across the north flank of Miners Mountain. It leaves the area after crossing Capitol Reef through a deep gorge downstream from Fruita. Among the other larger streams are Pleasant and Oak Creeks, which head on the east flank of Boulder Mountain, cross the Waterpocket Fold in gorges, and empty into the Fremont River. Boulder Creek, which heads on the south side of Boulder Mountain, drains into the Escalante River outside of the Capitol Reef area.

Of the smaller streams only a few of those heading high on Thousand Lake and Boulder Mountains are perennial. Precipitation on the tops of these mountains percolates downward through joints in the capping volcanic rocks and emerges as springs or seeps near the bases of the cliffs that surround the mountains. From there, small streams flow along irregular valleys in landslide or glacial materials. Far down the mountain flanks the streams enter topographically well-developed valleys. Most of these streams have been diverted for irrigation or water supply. The towns of Bicknell, Lyman, Teasdale, and Torrey obtain water supplies from springs or streams flowing from nearby mountains.

Small streams elsewhere in the area, as those heading among the cliffs and ridges of Capitol Reef, flow only in immediate response to precipitation and are dry most of the year. These rocky areas have little soil cover, and ground-water percolation is negligible. Rain quickly runs off the bare rock slopes and collects rapidly in washes and gulches. Sudden thunderstorms may result in flash floods and rapid erosion; quite commonly the flood waters move boulders several feet in diameter.

CLIMATE AND VEGETATION

The large differences in altitude and landform within the Capitol Reef area cause marked local differences in climate (data on climate are from records of the U.S. Weather Bureau and from Hambidge, 1941). These differences in turn influence the kind and amount of natural vegetation and wildlife. The average January temperatures are 21°F at Loa and 24°F at Teasdale. The average July temperature is 66°F at Loa and Teasdale, and it is 78°F at Hanksville, about 25 miles east of the mapped area, but with a climate similar to that in the eastern part of the area. The highest temperatures recorded are 110°F at Loa and 100°F at Fruita. The lowest temperatures recorded are −37°F at Loa and −7°F at Fruita; lower temperatures undoubtedly occur on the mountain tops, but no measurements have been made there.

Precipitation in the area ranges from about 5 inches to about 30 inches; the differences in precipitation are dependent chiefly on altitude. The average annual precipitation is about 8 inches at Teasdale and about 7 inches at Loa. Precipitation increases with altitude, and from the character of the float it is estimated to be 24 to 30 inches near the mountaintops. Snow accumulates on the mountains during the winter and melts slowly to maintain high stream discharge during the spring, chiefly from late April to early June. Rain is comparatively rare during spring months but more frequent during the summer. During July and August, sudden cloudbursts may produce devastating floods along desert washes (Woolley, 1947, p. 83–96).

Vegetation of the Capitol Reef area has been studied by Dixon (1935); only a brief summary of the essential features of the flora is appropriate in the present report. The vegetation grows in zones dependent upon altitude. These general zones and their more common types of vegetation are given in table 1. Altitudes listed for the zone boundaries are approximations and are shown to overlap, because many local irregularities occur along the borders of these zones. Also many irregularities in the courses of surface and ground water have produced local boundaries of vegetation zones that do not conform with altitudes.

TABLE 1.—*Vegetation zones in the Capitol Reef area, Utah, and their relation to altitude and precipitation*

[Modified from Dixon (1935)]

Vegetation zone	Altitude limits (feet)	Precipitation (inches per year)	Common names of dominant types of vegetation	Common names of subordinate types of vegetation	Remarks
Subalpine	>9,600	20–25	Grasses in meadows; sedges and rushes around swamps and ponds; Engelmann spruce on ridges.	Alpine fir	Probably great evaporation by wind.
Mountain forest (aspen-fir).	8,800–10,100	20–30	Douglas-fir, white fir, aspen, blue spruce	Dense fir forest with some grassy meadows and aspen groves.	Probably zone of highest precipitation.
Pine forest (yellow pine-oak).	7,300–9,000	10–20	Ponderosa pine, juniper, scrub oak (Gambel oak), spruce, fir, other pines.	Willows and narrow-leafed cottonwoods along streams; Douglas-fir near seeps; pines on ridges; mountain mahogany.	
Semidesert (pinyon-juniper).	5,500–7,500	8–10	Pinyon pine, Utah juniper, one-seed juniper; sagebrush and grasses in open glades.	Willows and narrow-leafed cottonwoods along streams. Isolated groups of Ponderosa pines near seeps or springs.	
Desert (northern desert shrub).	<6,200	8	Sagebrush, shadscale, rabbitbrush, grasses, Mormon tea, herbaceous plants.	Low cactus and yucca, saltbush; broad-leafed cottonwoods along streams.	Vegetation sparse.

ECONOMY

The economy of the Capitol Reef area is largely agricultural and is based primarily upon cattle, sheep, dairy products, poultry, and timber (Snow, 1953). Fruit, hay, and garden vegetables also are raised, but mostly for domestic supply. During 1951 to 1955, prospecting for uranium deposits increased markedly. Uranium ore has been produced from some claims, but not in important amounts through 1955. Tourist facilities are of ever increasing economic importance as roads are improved.

The population of the Capitol Reef area is sparse and did not change appreciably during the 1940–50 decade. Most people live in the small towns and they farm nearby land. They range their cattle and sheep on the mountains during the summer and chiefly in the lower parts of the Henry Mountains region to the east during the winter. The sparseness of the population is attributable to the relatively small proportion of arable land and to the scarcity of water, which at present is used almost completely for irrigation.

Cattle, horses, and sheep have been poisoned by eating weeds in certain parts of the Capitol Reef area. The "alkali disease or blind stagger" of cattle is caused by loco weed—various species of *Astragalus* and related plants that have a high selenium content. These poisonous plants grow largely in areas underlain by Mancos shale (pl. 1). Poisoning also may be caused by *Delphinium*, which contains poison as an alkaloid. This plant appears to be poisonous wherever it grows, and little is known about the relation of the plant to geologic formations (Helen L. Cannon, oral communication, 1952).

The scenic beauties of Wayne County and in particular of the rugged terrain of the Waterpocket Fold including Capitol Reef were early recognized by local inhabitants. In 1921 a local club was organized in Torrey to advertise the "Wayne Wonderland." Through the efforts of this club, and particularly of members E. P. Pectol and Joseph Hickman, 160 acres of public land near Fruita was withdrawn to make a state park in 1925. In 1937 an area of about 56 square miles was established as Capitol Reef National Monument by Presidential proclamation. The monument office is about 1¼ miles west of Fruita, and the residence of the monument superintendent is in Fruita. The large number of visitors to the monument shows that its scenic beauty is one of the major attractions of the area.

STRATIGRAPHY

Sedimentary rocks exposed in the Capitol Reef area range from the Coconino sandstone of Permian age to the Flagstaff limestone of early Tertiary age and have an aggregate thickness of more than 10,000 feet (table 2). Tertiary lavas and tuffaceous sedimentary rocks cover much of the western part of the area, and lava caps Boulder and Thousand Lake Mountains. Dikes and sills have intruded the sedimentary strata chiefly in the northeastern part of the mapped area. Surficial deposits of Quaternary and Recent ages cover the older beds in many places, in particular on the flanks of Boulder and Thousand Lake Mountains.

Color terms used in describing the rocks are those of the Rock Color Chart of the National Research Council (Goddard and others, 1948). Measured stratigraphic sections of the bedrock units are given on pages 84–96.

TABLE 2.—*Generalized section of sedimentary rocks exposed in the Capitol Reef area, Utah*

System	Series	Group, formation, member		Thickness (feet)	Lithology
Quaternary	Recent to Pleistocene	Boulder deposits, pediment gravel, till, outwash gravel, terrace gravel landslide deposits, rock glacial, colluvial sand and gravel, alluvial-fan deposits, alluvium.			Bedded silt, sand, and gravel; till, boulder accumulations, landslide debris, slope wash.
		Unconformity			
Tertiary		Flagstaff limestone		500+	White locally fossiliferous limestone, white biotitic tuff, tuffaceous sandstone, and conglomerate.
		Unconformity			
Cretaceous	Upper Cretaceous	Mesaverde formation		300+	Yellow sandstone; thin interbeds of shale.
		Mancos shale	Masuk member	600-800	Lenticular sandy gray shale, sandy carbonaceous shale, and sandstone; some gray shale.
			Emery sandstone member	250±	Massive sandstone in lower part; lenticular carbonaceous shale, sandstone, and coal in upper part.
			Blue Gate shale member	1,400+	Blue-gray shale.
			Ferron sandstone member	250+	Sandstone and thin beds of shale in lower part; lenticular carbonaceous shale, sandstone, and coal in upper part.
			Tununk shale member	575±	Blue-gray shale.
	Lower(?) Cretaceous		Dakota sandstone	0-50	Light-colored sandstone and conglomeratic sandstone, locally coal bearing.

TABLE 2.—*Generalized section of sedimentary rocks exposed in the Capitol Reef area, Utah*—Continued

System	Series	Group, formation, member		Thickness (feet)	Lithology
Jurassic	Upper Jurassic	Morrison formation	Unconformity Brushy Basin shale member	160–225	Variegated claystone, and lesser amounts of siltstone, sandstone, and conglomeratic sandstone lenses.
			Salt Wash sandstone member	30–236	Lenticular conglomerate and conglomeratic sandstone with siliceous pebbles; siltstone and claystone lenses.
		San Rafael group	Unconformity Summerville formation	200	Reddish-brown thin-bedded siltstone and mudstone and fine-grained sandstone; veinlets and thin layers of gypsum.
			Curtis formation	0–80	Grayish-green thin- to thick-bedded sandstone and some siltstone.
			Unconformity Entrada sandstone	475–780	Reddish-brown thin- to thick-bedded sandstone and some siltstone and claystone.
	Upper and Middle Jurassic		Carmel formation	308–988+	Yellow to grayish-orange very fine to fine-grained calcareous and noncalcareous sandstone; green and red calcareous and noncalcareous claystone and siltstone; fossiliferous limestone and sandy limestone; white to gray gypsum, some coarsely crystalline thick beds.
Jurassic and Jurassic(?)		Glen Canyon group	Unconformity Navajo sandstone	800–1,100	White to pale-yellow chiefly fine-grained sandstone; crossbedded on a large scale.
Jurassic(?)			Kayenta formation	350±	Lenticular beds of white to reddish-brown very fine to medium-grained crossbedded and even bedded sandstone, reddish-brown siltstone, and clay-pebble conglomerate.
Triassic	Upper Triassic		Wingate sandstone	320–370	Light-orange to reddish-brown very fine grained sandstone; crossbedded on a large scale.
		Chinle formation	Unconformity Upper member	90–195	Variegated siltstone and lenticular beds of sandstone and pale-red to greenish-gray limestone.
			Middle member	255–345	Variegated bentonitic claystone, siltstone, and clayey sandstone; siltstone and very fine to fine-grained sandstone; top of member consists of sandstone and conglomeratic sandstone; contains silicified wood.
			Shinarump member	0–90	Light-gray to yellow, medium- to coarse-grained crossbedded sandstone, conglomeratic locally: silicified and carbonized logs and plant fragments.
	Middle(?) and Lower Triassic	Moenkopi formation	Unconformity Upper part	500–775	Reddish-brown thin-bedded mudstone and siltstone underlain by chiefly reddish-brown very fine to fine-grained sandstone, both even bedded and lenticular, and mudstone and siltstone; gypsum in layers and veinlets; ripple marked.
			Sinbad limestone member	70–136	Yellowish-gray and pale yellowish-orange limestone, dolomitic limestone, dolomite, and calcareous sandstone; fossiliferous.
			Basal part	45–109	Pale reddish-brown evenly bedded and thin-bedded siltstone; yellowish gray near base; layers and veinlets of gypsum; ripple marked in places; chert pebble conglomerate locally at base.
Permian			Unconformity Kaibab limestone	250–350	White calcareous siltstone; silty, locally fossiliferous limestone; dolomite; many chert layers and nodules; crossbedded fine-grained sandstone.
			Coconino sandstone	800+	White to gray very fine to fine-grained sandstone; crossbedded on a large scale.

PERMIAN SYSTEM

COCONINO SANDSTONE

The Coconino sandstone is exposed only in the deeper canyons in the central part of the mapped area west of Capitol Reef—as those of the Fremont River, north Sulphur Creek, Capitol Wash, and Pleasant Creek. Beds of the Coconino sandstone form steep slopes and cliffs and are well exposed but difficultly accessible in the steep to vertical canyon walls.

Very fine to fine-grained well-sorted white to gray quartz sandstone in wedge-shaped lenses of large sweeping tangential crossbeds form the Coconino. Most grains are well rounded and frosted and are cemented by both siliceous and calcareous cement.

The maximum exposed thickness of the Coconino is in the canyon of the Fremont River where about 800 feet of beds crops out, but the base is not exposed. The well log of the Pacific Western Oil Co., Teasdale 1 drilled on Miners Mountain in sec. 17, T. 30 S., R. 6 E., shows a total thickness of about 1,250 feet of Coconino (Walton, 1954).

The Coconino sandstone has not been traced south from the Capitol Reef and Circle Cliffs areas to the type section in the Grand Canyon region of Arizona. As McKee (1934, p. 77–115; 1952, p. 53) points out, the Coconino thins to the north in Arizona and may pinch out in the area covered by younger rocks south of the Circle Cliffs. The Coconino of the type section in Arizona may not connect with the Coconino in Utah of the present report. However, until a lack of connection is proved, it seems reasonable to use the name Coconino for the sequence of crossbedded sandstone strata in Utah beneath the Kaibab limestone of Permian age (Gilluly and Reeside, 1928, p. 63; Hunt, 1953, p. 46). Many workers (Baker, 1946, p. 50 and pl. 8; Hunt, 1953, p. 40) suggest that the Coconino is a westward equivalent of the Cedar Mesa sandstone and White Rim sandstone members of the Cutler formation.

Eolian deposition of the Coconino is manifest by the wedge-shaped crossbedded units, the well-rounded frosted quartz grains and, from studies in Arizona, by the type of ripple marks and lack of washing and slumping of vertebrate footprints (McKee, 1934; Reiche, 1938, p. 916–918).

KAIBAB LIMESTONE

The Kaibab limestone, about 250 to 350 feet thick, is exposed where streams have cut canyons across or into Miners Mountain. The Kaibab crops out on cliffs or steep rubble-covered slopes. Along the deeper canyons, as that of the Fremont River, the Kaibab limestone and the underlying Coconino sandstone form light-colored vertical or near-vertical cliffs.

Impure cherty limestone and dolomite with interbedded sandstone and siltstone compose the Kaibab limestone. Gray shale lenses occur locally. Many of the sandstone and siltstone beds are calcareous, and in some beds the choice between identifying the rock as calcareous sandstone or sandy limestone is arbitrary. Chert nodules and layers and geodes are abundant, particularly near the top of the formation. Beds of the Kaibab most commonly are very pale orange, white, pale yellowish orange, and yellowish gray; they weather slightly darker.

The sandstone in the Kaibab is most commonly very fine grained but contains medium and coarse grains in some beds. It consists chiefly of quartz grains with scattered muscovite in some beds and very minor amounts of dark minerals, chiefly magnetite or hematite. The grains are commonly well rounded and well sorted, though not in all beds. The cement is both calcareous and siliceous. Sandstone units are both even bedded and crossbedded in layers from a few inches to 4 feet thick, although 6- to 10-foot sandstone beds are not uncommon. Most of the crossbedding is chiefly of the planar type as defined by McKee and Weir (1953). Such strata are interbedded with limestone and calcareous siltstone. Sandstone is most abundant in the lower part of the formation. Along Pleasant Creek a sandstone sequence in the lower part has large sweeping crossbeds similar to those in the Coconino sandstone. This sandstone bed of the Kaibab forms a prominent ledge and cliff above dolomite and dolomitic limestone. A similar bed crops out in the canyon of north Sulphur Creek.

The limestone beds are in part sandy and in part dense and hard. In places they contain much silt, and locally they are dolomitic. Some of the impure silty limestone looks much like chalk. Beds are generally 1 to 4 feet thick; laminations show on weathered surfaces in places. The limestone contains calcite stringers and calcite and quartz crystals in pockets and in many vugs in some beds, and it weathers with a pocked surface. In thin section the dense limestone may be seen to contain many siliceous spicules. Dolomite is interbedded with the limestone. A sample of dolomite from the lower part of the Kaibab along Pleasant Creek contains 52.69 percent calcium carbonate, 39.29 percent magnesium carbonate, and 4.27 percent acid insoluble material (analysts: E. C. Mallory and D. L. Skinner, U.S. Geological Survey).

Gray chert nodules and layers are abundant in beds of carbonate rocks in the Kaibab. Nodules generally are about ½ to 2 inches across, but some are as much as 1 foot long and 5 inches thick. In places the nodules form almost continuous layers. Chert beds occur in lenses several tens of feet long and with a general thickness of 2 to 6 inches and a maximum observed thickness of 1 foot.

Almost round geodes with knobby white quartz exteriors and crystalline quartz or crystalline calcite interiors are characteristic of the Kaibab. They range from about ½ to about 3 inches in diameter. In places they litter slopes where they have weathered from the beds.

Some of the thicker ledge-forming beds can be traced almost continuously through exposures of the Kaibab limestone in a single canyon, but single beds cannot be correlated with certainty from canyon to canyon. Many beds pinch out in a few tens of feet or a few hundred feet, and rocks grade laterally into other types; for example, sandstone may grade into sandy limestone.

Asphalt occurs as coatings and blebs in vugs and in some of the geodes; some round blebs of asphalt are almost one-half an inch in diameter. The sandstone and sandy limestone beds are very petroliferous in several exposures, particularly in canyons along the east side of Miners Mountain. Most of the petroliferous beds and asphalt are in the upper 30 feet of the formation. In a few places, asphalt coats fracture surfaces in the chert layers.

The Kaibab limestone is from about 250 to almost 350 feet thick. The thickest stratigraphic section measured is 348 feet in the canyon of Pleasant Creek. Differences in thickness probably result largely from erosion of the upper part of the Kaibab before deposition of the overlying Moenkopi formation (p. 13).

The contact between the Kaibab limestone and the underlying Coconino sandstone is transitional. Approximately the lower 100 feet of the Kaibab comprises limestone, dolomite, sandstone, and gradations between all three types. Some of the sandstone lenses have large tangential crossbeds like those in the Coconino. For the present report the contact selected is at the lowest limestone unit of this transitional zone. Interbedded lithologic units similar to units in the Coconino and Kaibab in the lower part of the Kaibab in the Capitol Reef area may indicate that the two formations intertongue, though no definite intertonguing nor lateral gradation of the two was observed.

Although the Kaibab limestone is very fossiliferous in this area, fossils are poorly preserved and our collections add little to paleontologic data used in correlations by McKee (1938, 1954b). J. Steele Williams of the U.S. Geological Survey identified *Neospirifer pseudocameratus* (Girty) and "several specimens of a species that is close to if not identical with the form described by McKee (1938, p. 245) as *Avonia subhorrida newberryi*" in a collection from about 50 feet below the top of the Kaibab ¼ mile east of Carcass Creek and ¼ mile south of the Fremont River. This collection also contains unidentifiable brachiopods. Williams identifies *Neospirifer pseudocameratus* (Girty) from the upper 20 feet of the Kaibab south of the Fremont River and west of the Torrey-Grover road. Some fragmentary unidentifiable bryozoans were collected 134 feet below the top of the formation along Pleasant Creek, and crinoid plates and stems were found in a bed nearly 300 feet below the top in the same stratigraphic section. Thus, identifiable fossils have been found only in the upper 50 feet of the formation. McKee (1954b, p. 23) points out that beds containing *Neospirifer pseudocameratus* (Girty) are younger than marine beds of the type Kaibab limestone that contain *Dictyoclostus bassi* McKee.

Dictyoclostus beds are also below *Neospirifer* beds in the southern Wasatch Mountains of central Utah (Baker and others, 1949, p. 1189) and in the Confusion Range of western Utah (Newell, 1948, p. 1054). McKee (1954b, p. 24) suggests that the Permian beds in the San Rafael Swell, Capitol Reef, and Circle Cliffs areas have an onlap relationship to the east and that the lower beds containing *Dictyoclostus* fauna do not extend into this area.

The limestone and dolomitic limestone beds containing marine fossils indicate that most of the Kaibab was deposited in a marine environment. Much of the crossbedded sandstone probably was deposited very near shore and some may have been deposited in the general beach zone. Part of the time the area evidently was above water level when the eolian sandstone similar to that of the Coconino with the large sweeping crossbeds was deposited. The sequence of the Kaibab suggests that a sea advanced across the Coconino sandstone and that this sea moved back and forth across the area during deposition of the lower part of the Kaibab. After about 100 feet of the Kaibab had been deposited, the environment was more continuously marine. The sea probably was shallow and the position of the Capitol Reef area probably was near or at the shoreline during most of the time.

TRIASSIC SYSTEM

MOENKOPI FORMATION

The Moenkopi formation crops out over much of the central part of the mapped area; it ranges in thickness from about 760 to about 970 feet. Many dip slopes along the flanks of Miners Mountain are formed on strata of the Moenkopi. Small exposures of Moenkopi are along Oak Creek and in North and South Coleman Canyons (pl. 1). Topographically the area of outcrop of the Moenkopi is very irregular, with numerous gentle to steep slopes alternating with low rocky cliffs. Exposures generally are very good.

In the Capitol Reef area the Moenkopi is divisible into four units: (1) a basal red-brown siltstone, (2) the yellowish-gray to yellowish-brown Sinbad limestone member, (3) a red-brown fine-grained sandstone, mudstone, and siltstone unit, and (4) an upper unit of red-brown mudstone and siltstone with some thin beds of claystone and very fine grained sandstone. On the geologic map (pl. 1) the Moenkopi is shown as two units with the contact between the two drawn at the top of the Sinbad limestone member. The base of the Sinbad is easily identified, but it is not mapped because in many places it would be objectionably close cartographically to contacts above or below.

Each unit of the Moenkopi has a fairly distinct topographic expression. The basal siltstone crops out on canyon sides beneath the cliff-forming Sinbad and in most places forms steep slopes covered with talus from the overlying beds. The Sinbad limestone member characteristically is exposed on cliffs or on long dip slopes. Blocky ledges and steep-sided box canyons quite commonly are developed in the third unit as a result of erosion of the thick sandstone layers with interbedded mudstone and siltstone. The uppermost unit where protected by the overlying resistant Shinarump member of the Chinle formation forms vertical or almost vertical slopes beneath the cliff formed of the

Shinarump, and where not protected it forms smooth, rounded hills in front of the cliff.

The basal unit consists chiefly of even thin-bedded siltstone, but it contains some very fine grained sandstone, mudstone, claystone, and locally conglomerate at the base. Most of this unit is pale reddish brown, but the lower part and in places the upper few feet are yellowish gray to grayish orange. Beds range from ⅛ to about 2 inches in thickness and generally are slightly less than half an inch. Many beds are mica-

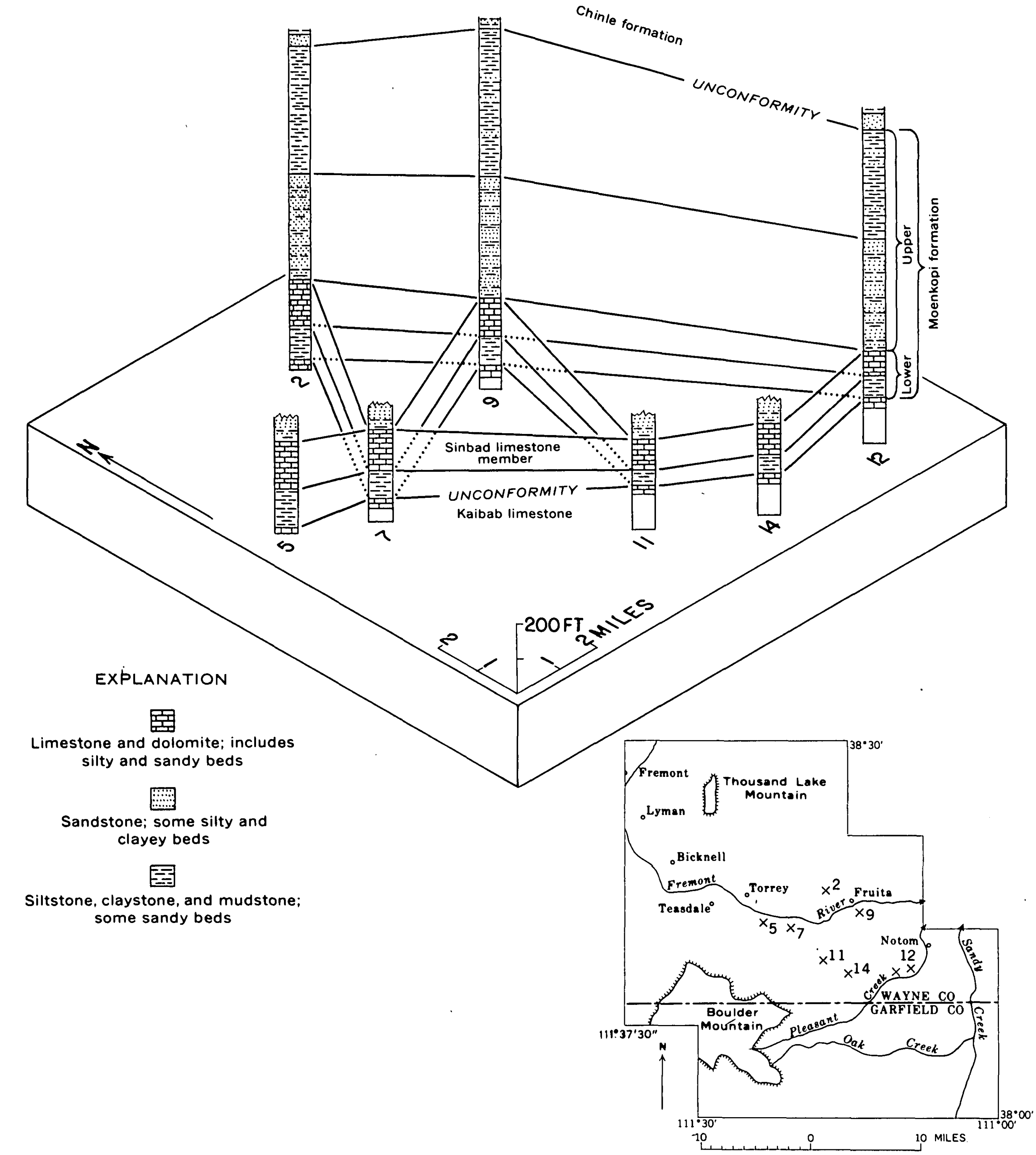


FIGURE 3.—Diagrammatic sections of the Moenkopi formation in the Capitol Reef area. Sketch map shows location of sections.

ceous. Gypsum veinlets and stringers are abundant both parallel to and across the bedding. Ripple marks occur on some beds. Small platy fragments commonly litter exposures of the basal unit.

Locally, conglomerate forms the bottom beds of the basal unit. The conglomerate contains chiefly angular fragments of chert and chert and quartz nodules like those in the underlying Kaibab limestone; the source evidently was the Kaibab. The pebbles generally are ¼ to ¾ inch across and the largest fragment noted was about 3 inches. The matrix varies from siltstone to medium-grained sandstone. In places the sandstone and conglomerate beds are crossbedded on a small scale. The maximum observed thickness of the conglomerate is 16 feet in an exposure southeast of Carcass Creek. At this same locality the conglomerate, in the most continuous outcrop found, is exposed for about 700 feet along the hillside. Beneath the conglomerate the top of the underlying Kaibab is scoured irregularly to depths of several feet. Similar conglomerate at the base of the Moenkopi has been noted in many adjoining and nearby areas (Hunt, 1953, p. 53; Baker, 1946, p. 55 and 57; Gregory and Moore, 1931, p. 48–49; Gilluly, 1929, p. 82).

The basal siltstone unit has a measured thickness of 45 to 109 feet. In a general way the thickness decreases southeastward, but not uniformly (fig. 3).

The Sinbad limestone member, named for the Sinbad area in the San Rafael Swell (Gilluly and Reeside, 1928, p. 65), is composed of limestone, dolomite, dolomitic limestone, and calcareous sandstone and siltstone. Table 3 gives the percentages of calcium carbonate, magnesium carbonate, and acid insoluble material of three samples of this member. Rocks composing the Sinbad are chiefly very pale orange, grayish orange, yellowish orange, and yellowish brown; the outcrop is chiefly dull yellowish gray. Limestone, dolomitic limestone, and dolomite occur in beds from about 6 inches to 10 feet thick and form ledges and low cliffs. Over much of the mapped area the top bed of the member is dolomitic and has a rough weathered surface on which dolomite rhombohedra may be observed with a hand lens. Some limestone beds are composed almost entirely of fine-grained oolites; the oolitic limestone beds are 2 to 8 inches thick and compose units as much as 6 feet thick. Stylolites occur in some beds. Limestone, particularly in the upper part of the member, is fossiliferous in places. Locally in the limestone, vugs as much as 1 inch long contain hard asphalt fillings. Calcareous siltstone occurs in beds ⅛ to ½ inch thick making up units generally 2 to 4 feet and as much as about 20 feet thick. The beds are crinkled locally. The Sinbad is 70 to 136 feet thick in measured sections. The thickness decreases to the southeast (fig. 3).

TABLE 3.—*Analyses, in percent, of carbonate rocks from the Sinbad limestone member of the Moenkopi formation, Capitol Reef area, Utah*

[Analysts: E. C. Mallory and D. L. Skinner, U. S. Geol. Survey]

Laboratory No.	Specimen classification [1]	Location	Analysis [2]			Others, by difference
			Calcium carbonate ($CaCO^3$)	Magnesium carbonate ($MgCO^3$)	Acid insoluble	
238599	Dolomite	Sulphur Creek, sec. 7, T. 29 S., R. 6 E.	49.20	37.44	9.63	3.73
238600	Impure dolomitic limestone.	Sulphur Creek, sec. 7, T. 29 S., R. 6 E.	59.94	4.30	32.50	3.26
238601	Limestone	Sec. 17, T. 30 S., R. 6 E.	93.15	1.42	3.92	3.92

[1] Classification based on Pettijohn (1949, p. 312–313).
[2] Figures represent calcium and magnesium that are soluble when the sample is boiled with dilute hydrochloric acid, but do not necessarily mean that all the calcium and magnesium are present as carbonate. The acid-insoluble figure was obtained by filtering and weighing the residue remaining after treatment with dilute hydrochloric acid.

Pale reddish-brown fine-grained sandstone, mudstone, and siltstone compose the third unit of the Moenkopi. In most places, beds range from about ½ inch to 12 feet in thickness and are lenticular. Mudstone and siltstone beds generally are thinner and darker than sandstone beds. Crossbedding and ripple marks are very common, and scour and fill structures from a few inches to about 15 feet deep are present in places. Most of the sand grains are quartz, are moderately well rounded, and are well sorted. Most of the sandstone is well cemented with calcite. Some sandstone units are lighter than the common reddish-brown ones, and some are much thicker. For example, a 32-foot-thick bed of very fine grained very pale orange sandstone crops out just north of the Fremont River about 2 miles northeast of Teasdale. This sandstone is crossbedded on a small scale in places, contains some lenses of red clay 1 to 4 inches thick, and some angular fragments of clay. Petroliferous sandstone beds occur in the lower part of this unit on the northeast side of Miners Mountain. The Moenkopi in the Capitol Reef area is not as petroliferous as it is in the San Rafael Swell to the northeast or the Circle Cliffs to the south. The thickness of this third unit is between 300 and 350 feet.

The fourth and uppermost unit of the Moenkopi consists of pale reddish-brown and dark reddish-brown mudstone, claystone, siltstone, and very fine grained sandstone. Beds generally are between 1 and 3 feet thick, and some are finely laminated. Ripple marks are abundant. Along many joints the reddish-brown sandstone is light yellowish gray through thicknesses of several inches. The top 1 to 2 feet of the formation just below the overlying Shinarump member of the Chinle formation is light yellowish gray, greenish gray, or tan in nearly all exposures. In a few places at the top of the Moenkopi, but generally below the light-gray zone, mottled or "pinto" beds in shades of purple, gray, and orange occur through thicknesses of a few feet; the maximum observed thickness of such beds is 40 feet. North of Twin Rocks a zone of purplish beds 3 to 4 feet thick and 100 to 200 feet wide crops out for several hundred feet along an east-northeast trend. Lithologically these purplish beds are the same as the adjoining red mudstone. Beds, veinlets, and pods of white and pink gypsum are abundant. Beds of gypsum as much as 2 feet thick occur in the Moenkopi in the canyons about 3 miles north of Torrey. Where this upper unit forms a cliff beneath the Shinarump member of the Chinle formation, the beds commonly weather to form fluted walls. In measured sections the top unit is 313 to 425 feet thick; its thickness decreases southeastward.

The types of original structures in the Moenkopi are described in detail by McKee (1954a, p. 56–67). Of the original structures McKee lists, the following occur in the formation in the Capitol Reef area: (1) cross-stratification, particularly in the third unit from the base and locally in sandstone of the Sinbad limestone member and in the basal conglomerate; (2) gnarly or contorted bedding; (3) ripple marks, most abundant in the uppermost unit but also present in other parts of the formation; (4) flow marks in siltstone; (5) cubic casts, presumably salt crystals, noted only in the upper 50 feet of the formation; (6) core-and-shell structure in mud, particularly in the third unit from the base; and (7) shrinkage cracks, in siltstone, mudstone, and claystone.

The total measured thickness of the Moenkopi is 766 to 968 feet. The thickness increases northwestward in general concordance with the regional thickening (McKee, 1954a, p. 23) and is variable locally. The greatest thickness differences in the Capitol Reef area are in the basal unit (45–109 feet) and in the top unit (313–425 feet). These thickness differences in the basal unit probably result largely from deposition on an irregular surface of Permian rocks. Thickness variations in the uppermost unit result in part at least from erosion prior to deposition of the Chinle formation. The Sinbad member decreases in thickness to the southeast and is missing east of Capitol Reef and in the southern part of the Circle Cliffs (McKee, 1954a, p. 28; Stewart and others, 1959). This northwestward thickening of the Sinbad fits the regional pattern of thickening of the limestone members of the Moenkopi (McKee, 1954a, p. 79).

Evidence of an erosional unconformity between the Moenkopi formation of Triassic age and the underlying Kaibab limestone of Permian age occurs in many places in northern Arizona and southern Utah (McKee, 1938, p. 57–58; Gilluly, 1929, p. 81–82; Gilluly and Reeside, 1928, p. 64–65; Gregory and Moore, 1931, p. 45–46; Dake, 1920). Similar evidence is in the Capitol Reef area. Features indicative of the erosional unconformity include a local basal conglomerate of the Moenkopi that filled scours or channels in the Kaibab in places and the gentle truncation of a few feet of beds of the Kaibab by basal siltstone of the Moenkopi in a few hundred feet laterally. Also, differences in thickness of the Kaibab and of the basal unit of the Moenkopi probably are in part at least the result of erosion of the Kaibab prior to deposition of the Moenkopi and deposition of the basal Moenkopi on a broadly uneven surface. In places the contact is regular and even but may be recognized by the change in rock composition and color (fig. 4).

The Moenkopi formation is considered to be of Early and Middle(?) Triassic age (Harshbarger and others, 1957). Except for *Lingula* specimens (identified by John B. Reeside, Jr., U.S. Geological Survey, written communication, 1954) from 10 to 51 feet above the Sinbad limestone member, all invertebrate fossils collected from the Moenkopi in the Capitol Reef area are from the Sinbad limestone. Bernhard Kummel, Jr., U.S. Geological Survey, identifies (written communication, 1953) *Pseudomonotis* sp., *Hemiprionites* sp., *Anasibirites* spp., *Xenoceltites* sp., and indeterminate pelecypods, gastropods, and an echinoid from the upper 15 feet of the Sinbad south of the Fremont River in sec. 29, T. 29 S., R. 5 E. He states that "*Anasibirites*, *Hemiprionites*, and *Xenoceltites* are very characteristic genera of the *Anasibirites* zone, upper Owenitan (= Meekoceratan)." Of a collection made by George A. Williams (formerly with the U.S. Geological Survey) 8 feet above the base of the Sinbad in sec. 7, T. 29 S., R. 6 E., Kummel states that a poor specimen suggests *Parananites* sp., "a common ammonoid in the *Meekoceras* zone of northern Utah and Idaho." Gregory (1950, p. 60) recognized six subdivisions of the Moenkopi in southwestern Utah; the basal unit, the Timpoweap, contains *Meekoceras*. McKee (1954a, p. 31–33), in discussing the regional stratigraphy of the Moenkopi, considers the Sinbad correlative with the Timpoweap on the basis of meekoceratan fauna in each. Dating of the upper beds of the Moenkopi in the Capitol Reef area is not possible on fossil evidence, but they can be correlated with Moenkopi elsewhere on the basis of lithology and stratigraphic position.

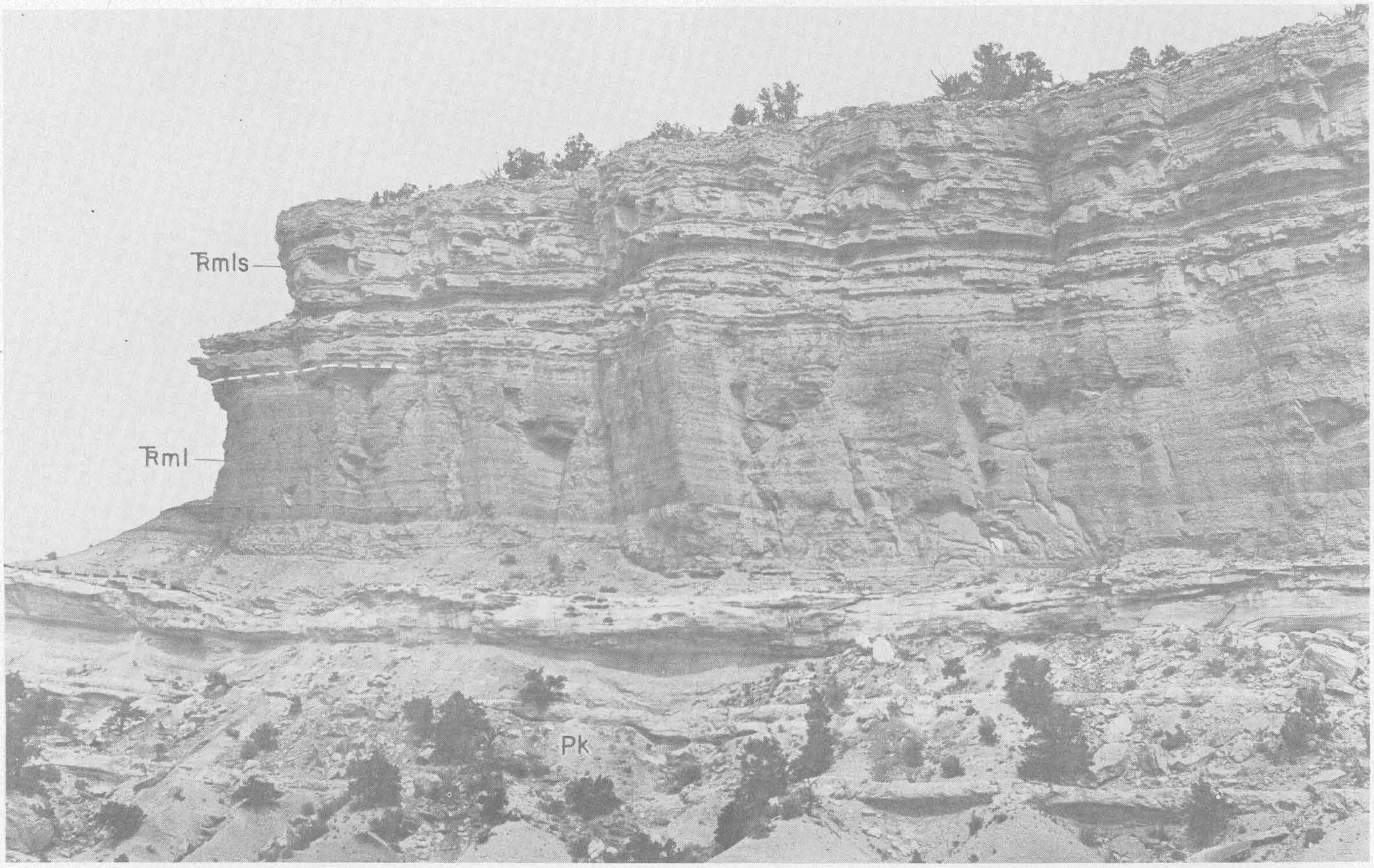


FIGURE 4.—Photograph showing contact between light-colored Kaibab limestone (Pk) and overlying dark siltstone (ꝶml) of the Moenkopi formation. Sinbad limestone member (ꝶmls) of the Moenkopi formation makes ledge at top of cliff. View of wall in Capitol Wash.

Peabody (1948) made a comprehensive study of reptilian and amphibian tracks in the Moenkopi, particularly in northeastern Arizona. Rather poor casts of dragged tracks similar to the *Chirotherium* tracks pictured by Peabody occur in many places in the upper part of the third unit in the Capitol Reef area. Three-toed tracks, probably reptilian, as much as three-fourths inch long also occur in places, particularly in the uppermost unit. These tracks may be taken as an indication that many vertebrate animals lived in the area during deposition of the Moenkopi.

The Moenkopi was deposited in part on a broad flat flood plain, in part probably on tidal flats, and in part in a shallow marine sea (McKee, 1954a, p. 28). Initially, streams reworked the cherty soil formed from the Kaibab and deposited conglomerate in shallow valleys. Even-bedded silts and muds were then deposited on mud flats, sometimes under water as indicated by ripple marks and sometimes above water as indicated by mud cracks. The surface on which these beds were deposited was broadly uneven and irregular. When the sea transgressed the area from the west or northwest, the Sinbad limestone member was deposited. Then followed more mud-flat and flood-plain deposits represented by the siltstone and sandstone of the third unit from the base of the formation. Parts of these beds were in brackish water, probably on tidal flats, as indicated by the presence of *Lingula*. Also during this stage of deposition, streams were slightly more vigorous at times, with some scouring and filling of channels. Deposition of the upper unit of the Moenkopi probably was largely on tidal mudflats, as the sediments formed even-bedded mudstone, siltstone, claystone, and very fine grained sandstone containing many ripple marks throughout and containing casts of salt crystals in the upper part.

CHINLE FORMATION

The Chinle formation is exposed as a band along Capitol Reef and in many smaller outcrops on the southwest side of Miners Mountain, near Teasdale, in the southern canyons, and at the south edge of the mapped area in the north tip of the Circle Cliffs. The Chinle is divided into three members—the basal Shinarump member of chiefly crossbedded sandstone; a middle member of siltstone, claystone, and sandstone; and an upper member of siltstone, sandstone, and limestone (fig. 5)—and ranges in thickness from 440 to about 540 feet. The Shinarump member is more resistant to

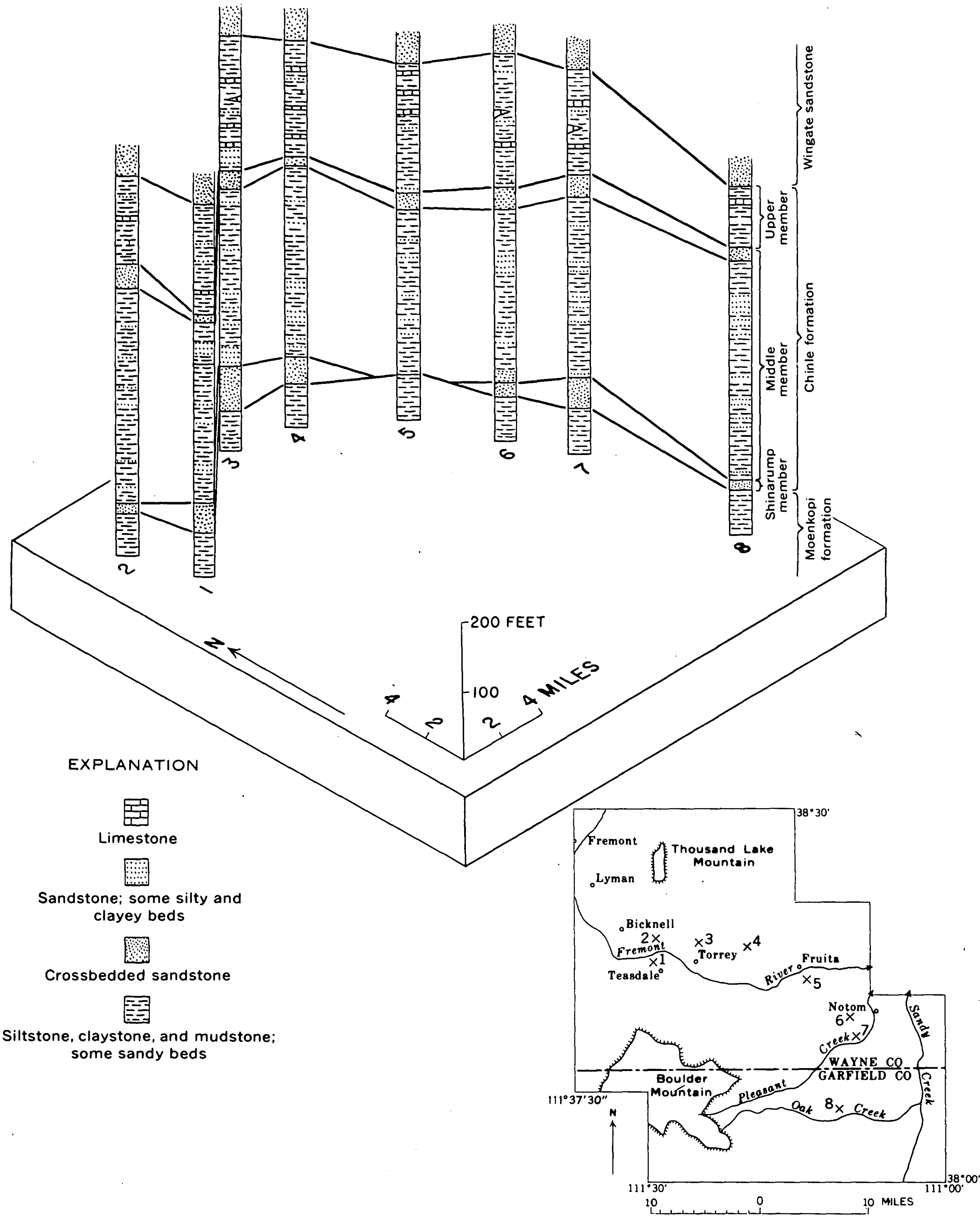


Figure 5.—Diagrammatic sections of the Chinle formation in the Capitol Reef area. Sketch map shows location of sections.

erosion than the underlying Moenkopi and the overlying beds of the Chinle; therefore, the Shinarump forms cliffs and low hogbacks. The Shinarump characteristically crops out as a light or almost white band between the red Moenkopi and the variegated middle Chinle. Exposures of the middle and upper members of the Chinle are chiefly along steep partly talus-covered slopes beneath the cliff formed by the overlying Wingate sandstone and above a smaller cliff formed by the underlying Shinarump member (fig. 6). In most

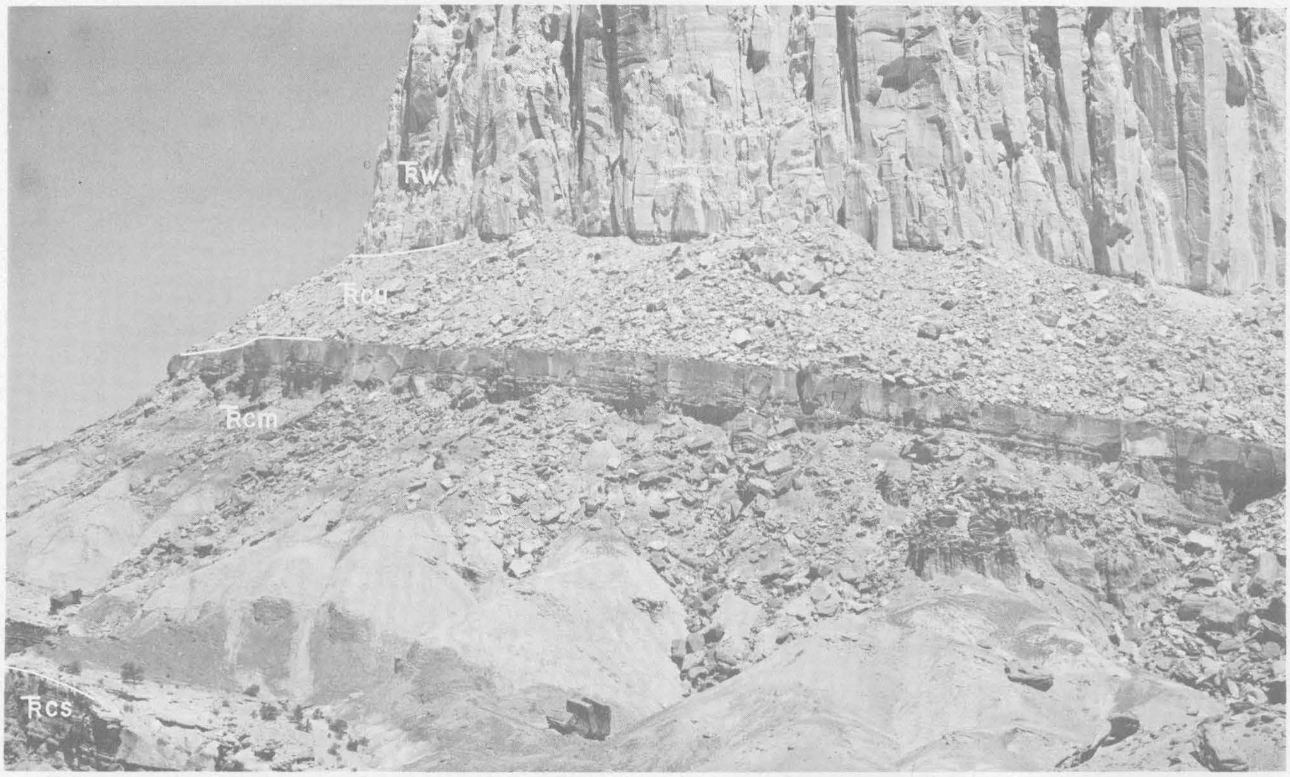


FIGURE 6.—Photograph showing Chinle formation and Wingate sandstone on north side of Grand Wash. Shinarump member (Ꞧcs) of Chinle, light-colored ledge in lower left; middle member of Chinle (Ꞧcm) extends to top of dark ledge about center of main slope; upper member of Chinle (Ꞧcu) extends to base of cliff. Wingate sandstone (Ꞧw) forms cliff at top.

places, middle beds of the Chinle extend almost to the edge of the cliff formed by the Shinarump member so that benches of exposed Shinarump are not common.

The Late Triassic age of the Chinle formation is well established (Gregory, 1950, p. 71), in large part from its phytosaur remains (Camp, 1930) and flora (Daugherty, 1941). Plant fossils collected in the Capitol Reef area and identified by Roland W. Brown, U.S. Geological Survey, include *Palissya* sp., *Sphenozamites rogersianus* Fontaine, and a fragment of cycad leaf, not specifically identifiable, from a gray siltstone in the Shinarump member along the road just west of Fruita. Mr. Brown reports (written communication, 1955) that the material of the Shinarump does not permit a closer age determination than Triassic, probably the latter half. Mollusks collected in the W½ sec. 32, T. 28 S., R. 4 E., from the sandstone that forms the top of the middle member were identified by John B. Reeside, Jr. (written communication, 1956) as "*Unio*" *dumblei* Simpson, originally described from the Dockum group (Triassic) of Texas.

SHINARUMP MEMBER

The Shinarump member consists chiefly of gray and very pale orange to pale yellowish-orange crossbedded medium- to coarse-grained sandstone. The sandstone is generally well sorted and ranges from fine to very coarse grained. It contains some lenses of gray and greenish-gray siltstone and mudstone, a few conglomeratic layers, isolated pebbles, carbonized plant fragments, and carbonized and silicified logs. Lensing and lateral gradation of lithologic types cause many variations.

Sandstone units range from about 3 inches to about 12 feet in thickness and are crossbedded, with both planar and trough types of crossbedding as defined by McKee and Weir (1953). In many places, surfaces between crossbedded units dip in various directions and at differing angles. On many smooth cliff faces, particularly where the rock is stained by wash from the overlying Chinle, bedding is not apparent and the Shinarump appears as one massive sandstone unit.

The sand grains are mainly subangular to rounded clear quartz and minor feldspar, altered feldspar or tuff, mica, and widely scattered zircon; the sand-size material is commonly at least 99 percent quartz. Some quartz grains have secondary silica overgrowths. The cement is chiefly siliceous and very locally is calcareous. In places the grains are largely bound by interstitial clay, and some of the sandstone is fretwork with little or no cement. Pyrite nodules as much as 3 inches thick and 6 inches long occur in the Shinarump along the reentrant east of Holt Draw (pl. 1). Iron oxide specks, probably derived from pyrite, are common locally and give the rock a brownish appearance.

Conglomeratic beds contain pebbles of two main types: pebbles of resistant siliceous rock and, more commonly, soft pebbles of clay and siltstone. Generally the two types do not occur in the same beds. Conglomeratic beds of siliceous pebbles in the Capitol Reef area are much less common than in northeastern Arizona or in the Monument Valley and White Canyon areas of southeastern Utah (fig. 1). Although the percentage of pebbles in the Shinarump member in the Capitol Reef area was not determined statistically, it probably amounts to little more, if any, than 1 percent. Conglomeratic beds are most abundant along south Sulphur Creek and Tantalus Flats but even there form a small percentage of the rock. The resistant pebbles are chiefly quartz with smaller percentages of quartzite, chert, and silicified limestone; they are well rounded, and, although some have a maximum length of about 2 inches, most are $\frac{1}{8}$ to $\frac{1}{2}$ inch long. Stewart and others (1959, p. 507–508) report that pebbles from the Shinarump in the Capitol Reef area are 60 percent vitreous quartz, 16 percent quartzite, 13 percent chert, and 11 percent other materials, of which about 5 percent is silicified limestone. Pebbles occur in beds one pebble thick and a few inches to several feet long, scattered through beds as much as 3 feet thick, and as isolated pebbles in sandstone. The soft greenish-gray, yellow, and red clay and siltstone pebbles and cobbles are abundant in places, particularly near the base of the Shinarump. They are angular to subrounded and many are flattened and elongate. Roughly rectangular fragments with rounded edges and as much as 1 foot long occur locally at or near the base of the Shinarump. These soft rock fragments probably were derived from adjacent beds of the Moenkopi.

Siltstone and mudstone lenses range from partings about $\frac{1}{16}$-inch thick to layers about 4 feet thick; most commonly the lenses are 1 to 4 inches thick and a few inches to 15 feet long. A bed of clay or mudstone with varying amounts of sandstone forms the base of the Shinarump member in some places; areas where this bed is well developed are at the Oyler mine, south locally from Grand Wash to Capitol Wash, and along Oak Creek. This basal bed generally is 6 inches to 1 foot thick, but at some places it is as much as 8 feet thick. Locally it contains much carbonaceous matter and also gypsum and alunite. Where it contains no sandstone stringers, as in places along Oak Creek, this basal mudstone is like the underlying light-gray and tan top beds of the Moenkopi, and the Shinarump and Moenkopi contact was selected on the recognition of minute carbonaceous fragments in the Shinarump member. A 1- to 2-foot-thick bed of siltstone containing a 4-inch-thick layer of radioactive red chert comprises the Shinarump near its pinchout in sec. 36, T. 29 S., R. 6 E. The red chert has small coatings of hard petroliferous material and green and blue copper stains. Alunite in pods and layers as much as 4 inches thick and about 30 feet long is present in places chiefly at or very near the base of the formation, as at the Oyler mine and in the southwestern part of sec. 34, T. 28 S., R. 5 E. Gypsum veinlets both parallel to and across the bedding are present throughout the formation but are most abundant with the siltstone, mudstone, or clay.

Plant remains such as carbonaceous fragments and parts of carbonized and silicified logs are abundant. The fragments are scattered throughout the sandstone or are concentrated along bedding surfaces or in pockets. On the west side of Bear Canyon near its junction with Oak Creek, the Shinarump contains highly carbonaceous beds and lenses of coal from 1 inch to more than $1\frac{1}{2}$ feet thick. Carbonized logs generally are 1 foot or less in diameter, have a maximum observed length of 14 feet, and commonly are flattened; most are only 2 or 3 feet long. Silicified logs are less abundant than carbonized logs in the Shinarump in the Capitol Reef area. A few silicified logs have thin outer coatings of black powdery carbonaceous material.

In the Capitol Reef area the Shinarump member (fig. 5) ranges in thickness from 0 to about 90 feet. The Shinarump is missing locally, particularly along the eastern exposures and south of Fruita for a maximum distance of slightly more than $1\frac{1}{2}$ miles. The thickness changes from as little as 2 feet to as much as 40 feet in lateral distances of about 200 feet. Slight differences in thickness are reflected topographically in places along Capitol Reef; thicker sections form small promontories, and thinner sections form small reentrants (fig. 7). The thickest Shinarump is northwest of Torrey. The Shinarump is discontinuous along Oak Creek and in the Coleman Canyons, indicating that between the main part of the Capitol Reef area and the Circle Cliffs the Shinarump probably consists of a series of discrete lenses. A continuous body of Shinarump may exist, however, between the two areas beneath Boulder Mountain.

The contact between the Chinle formation and the underlying Moenkopi formation is a pronounced erosional unconformity.

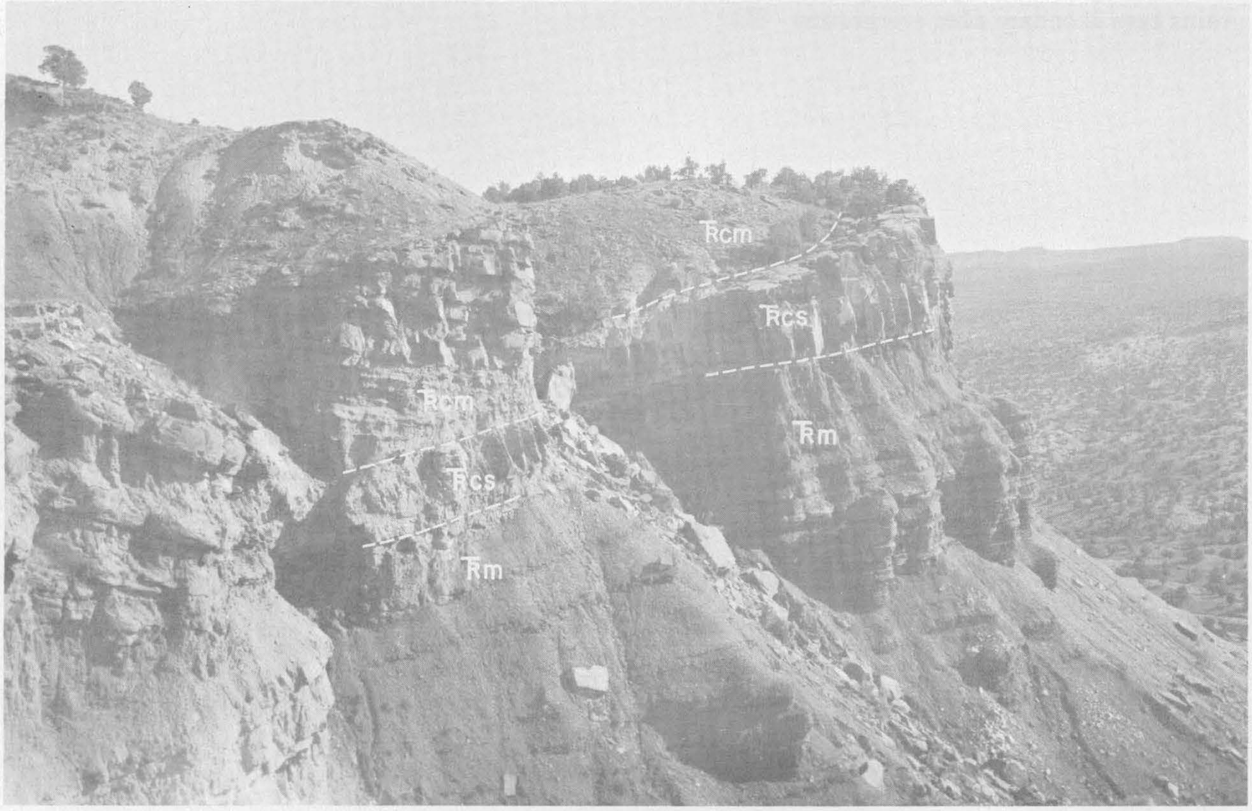


FIGURE 7.—Photograph showing Shinarump member and basal part of middle member of Chinle formation in NE¼ sec. 12, T. 30 S., R. 6 E. Contact between Shinarump member (T̄Rcs) and Moenkopi (T̄Rm) is even and regular. Thickness of Shinarump differs in area of photograph; the thick part forms the small promontory on the cliff face and the thin parts form small reentrants. In the left half of the photograph the basal beds of the middle member of the Chinle formation (T̄Rcm) have a westward dip (to the right), which is opposite to the regional northeasward dip (to the left).

The Shinarump member of the Chinle formation rests on the Moenkopi formation in much of the mapped area, but locally for distances of a few hundred feet to more than a mile the Shinarump is lacking and the middle member of the Chinle rests directly on the Moenkopi. The contact of the Moenkopi formation and the Shinarump member of the Chinle formation is distinct (fig. 8) in most places, as it generally marks a change from mudstone or siltstone to sandstone, conglomeratic sandstone, or a mixture of clay and sandstone. Locally, however, siltstone of the Shinarump member overlies siltstone of the Moenkopi formation, and the units are distinguished by the presence of carbonaceous fragments in the Shinarump and their lack in the Moenkopi. Where the Shinarump is missing, the contact between the Moenkopi and the middle member of the Chinle is at a marked change in bedding and color in most places. It is not easily recognized in all localities. For example, south of Pleasant Creek, "pinto" beds, in which the regular bedding is obscured, form the top of the Moenkopi, and very similar beds form the base of the Chinle. The formational contact cannot be selected definitely in a zone 15 to 20 feet thick. Layers of radioactive red chert ¼ to 1 inch thick crop out in the contact interval.

Regionally over the Colorado Plateau the contact is an erosional unconformity and in places an angular one (Gilluly and Reeside, 1928, p. 66–67; Gregory and Moore, 1931, p. 52; Baker, 1933, p. 36–37, and 1946, p. 59; Dane, 1935, p. 63; McKnight, 1940, p. 61–62; McKee and others, 1953, p. 41–42). Evidence in the Capitol Reef area of pre-Shinarump erosion of the top of the Moenkopi is abundant, particularly as ½-foot to 10-foot-wide scours in which 1 to 3 feet of beds of the Moenkopi has been removed. Most obvious and pronounced erosion took place along larger channels, as at the Oyler mine (pl. 2) on Grand Wash and south of Holt Draw in the SE¼ sec. 35, T. 28 S., R. 4 E., where as much as 15 feet of the Moenkopi was scoured. North of Sheets Gulch, 25 feet of the Moenko-

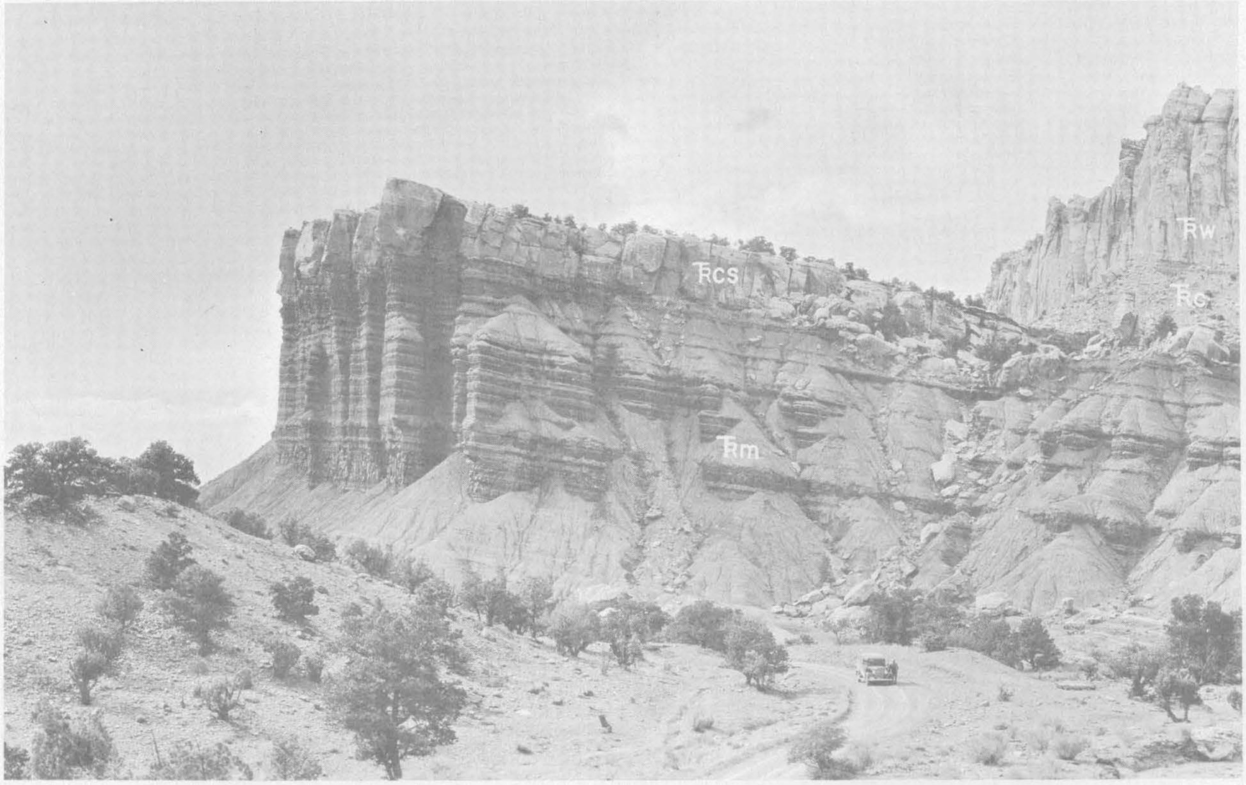


FIGURE 8.—Photograph showing contact between dark even-bedded Moenkopi formation (Ꞧm) and overlying Shinarump member (Ꞧcs) of the Chinle formation. View north of Egyptian Temple north of Capitol Wash in Capitol Reef National Monument. Chinle formation (Ꞧc) above Shinarump member. Wingate sandstone (Ꞧw) forms cliff on skyline at right edge of photograph. Photograph by George A. Grant, U.S. National Park Service, 1935.

pi was eroded in a lateral distance of about 670 feet along the margin of what appears to be a wide flat channel or swale. In places, channels eroded into the top surface of the Moenkopi do not have two equally developed sides. In many other places, the contact is almost flat with no indications of irregular erosion of the top of the Moenkopi. Most all evidence, however, points toward extensive erosion of the Moenkopi.

Some disagreement exists regarding the time when the channels in the top of the Moenkopi were formed. McKee and others (1953, p. 44–45) and Camp and others (1947) consider erosion of the channels and deposition of the Shinarump as two separate cycles—first erosion and then deposition. Gregory also indicated that the erosion and the deposition were essentially two cycles (Gregory and Moore, 1931, p. 52; Gregory, 1938, p. 48). Stokes (1950) suggests that the Shinarump is a pediment deposit and that the same streams that eroded the surface of the Moenkopi deposited the Shinarump, so that erosion and deposition were both aspects of the same general process. We did not find sufficient evidence to strongly support either idea. We feel that erosion probably started relatively soon after deposition of the Moenkopi ceased, but before the Shinarump was being deposited, and that erosion probably was continued by the streams that transported and deposited the sediments that make up the Shinarump. Fragments of Moenkopi in the basal Shinarump in places evidently were at least partly consolidated before they were deposited in the Shinarump.

The fluviatile origin of the Shinarump member is indicated by the lenticularity of the beds, the crossbedding, the presence of transported logs, the scour and fill structures, and the irregular thin lenses of conglomerate. This member of the Chinle is largely fluviatile throughout the Colorado Plateau (McKee and others, 1953, p. 44; Hunt, 1953, p. 55; Gregory, 1950, p. 65–66; Stewart and others, 1959). Recent work on the Colorado Plateau indicates that the Shinarump probably consists of a series of large lenses; this has been established particularly by the regional stratigraphic studies of Stewart and others (1959) and by areal mapping studies in the Clay Hills (Mullens, 1960) and White Canyon (Thaden, R. E. and others, oral communication, 1954) areas east of the Colorado River in Utah. In the White Canyon area, lenses of Shinarump crop out just outside the margins of the more or less continuous Shinarump. If, as appears likely, the member in the Capitol Reef area is a similar large body with marginal lenses, the main body probably is in the western two-thirds of the mapped area. The eastern strip of exposures from north of Fruita to south of Pleasant Creek is near a possible pinchout of the major body (pl. 1 and fig. 9). The isolated lenses on Oak Creek and in North and South Coleman Canyons are just outside a pinchout of the major body. Sufficient data are not available to locate in greater detail the main mass or masses of Shinarump. Areas where the Shinarump is lacking probably are chiefly areas of nondeposition. The large ones may represent, in part at least, slight topographic highs, either erosional or structural or both, during the time of deposition of the Shinarump.

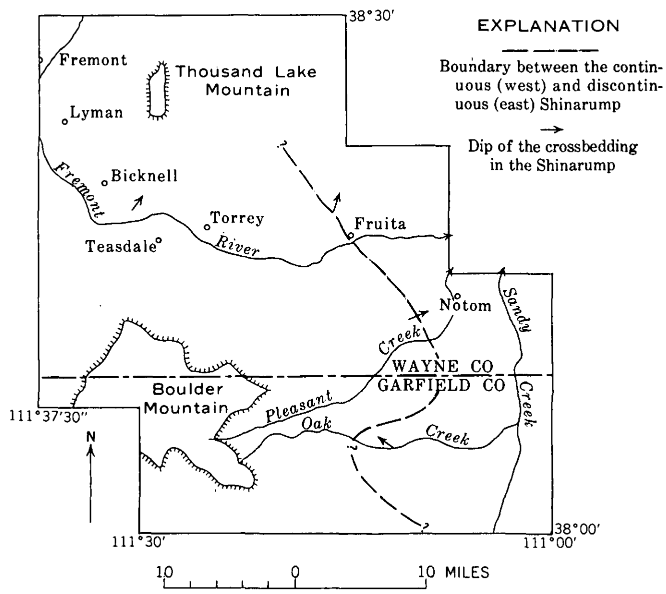


FIGURE 9.—Sketch map showing the principal directions of dips of crossbedding in the Shinarump member of the Chinle formation and the approximate location of the boundary between the continuous and discontinuous Shinarump.

Crossbedding suggests northeastward-flowing streams in the area of the main mass of the Shinarump member. In addition to our general observations, George A. Williams, Howard F. Albee, and Omer B. Raup made statistical analyses of the crossbedding at four localities in the Capitol Reef area. Their results indicate northeastward-flowing streams except on Oak Creek (fig. 9). The outcrop on Oak Creek probably is part of an isolated marginal lens, and the stream that deposited the sand may have been diverted locally along an older valley.

The east and northeast margins of the main body of the Shinarump member may represent a zone beyond which only the larger streams were capable of transporting sediments as coarse as those in the Shinarump. The almost right-angle relation between the inferred direction of streamflow and the line of discontinuity lends some support to the idea that deposition decreased beyond this zone. Deposits of streams with greater sediment-transporting power may remain as tongue-like lenses now covered by younger rocks east and northeast of Capitol Reef.

The Shinarump member in the Capitol Reef and Circle Cliffs areas contains smaller pebbles and much less conglomerate than it does farther south (Gregory and Moore, 1931, p. 52–53; McKee, 1937). Sedimentary structures in the Capitol Reef area indicate a generally southwestern source for the Shinarump, and the member may be continuous with the Shinarump in the Circle Cliffs by way of the area of Boulder Mountain. The depositing streams may have flowed northward in the Circle Cliffs area and then northeastward in most of the Capitol Reef area. The direction of stream flow was controlled by a higher area to the east that diverted the streams probably into an arcuate pattern. Decrease in numbers and sizes of pebbles from Arizona north may have been due to attrition and to a decrease in transporting power of the streams. On the other hand the source area may have been southwest of the Capitol Reef area and one from which fewer and smaller pebbles were derived. On present evidence we favor a more southern source and a general decrease in pebble sizes and numbers northward.

MIDDLE AND UPPER MEMBERS

The middle and upper members of the Chinle are extremely varied in lithology and color, though on a broad scale the colors and lithologic types are reasonably persistent throughout the mapped area. These units consist of loosely consolidated variegated claystone and siltstone, very fine to coarse-grained sandstone, and some impure limestone lenses and poorly sorted conglomerate lenses. Large silicified logs which are chiefly brown and red are abundant.

The middle member of the Chinle formation is subdivided into three parts: (1) a lower part of chiefly claystone and clayey sandstone, (2) a middle part of siltstone and sandstone, and (3) an upper part of sandstone and conglomeratic sandstone that forms a prominent ledge. The lowest part is composed dominantly of greenish-gray bentonitic claystone and clayey sandstone in beds 2 to 3 feet thick. Commonly, colored grains and biotite flakes are contained in the clayey sandstone. Very fine to medium-grained gray and brown sandstone lenses are interlayered with the claystone. This sandstone is composed chiefly of subangular to well-rounded quartz grains, is crossbedded locally, is generally ripple laminated, and composes about 20 percent of the unit; it occurs in beds from 1 to 10 feet thick. Petrified wood and in places carbonaceous material are common. In places, the sandstone lenses, particularly at or near the base, are contorted and dip at odd angles to the normal bedding (fig. 7).

The middle part of the middle Chinle consists of reddish-brown, light-brown, and grayish-red siltstone and lenticular beds of very pale orange, greenish-gray, and pale-red very fine to fine-grained sandstone containing clay pebbles locally. Subangular to subrounded grains of clear and pink quartz and some mica flakes and magnetite grains make up the sandstone, which is slightly calcareous. Botryodial concretions, some of which occur as geodes with quartz or calcite crystals inside, crop out in lenticular beds.

The upper part is a hard sandstone that forms a prominent ledge over nearly all the mapped area. This unit consists of thin- to medium-bedded fine- to medium-grained gray and reddish-brown sandstone of chiefly quartz and interstitial clay. It contains lenses of siltstone- and claystone-pebble conglomerate. The base of the unit is irregular locally. Scours and channels in the underlying beds are filled with conglomeratic sandstone. Silicified logs are abundant locally in this unit and in the upper part of the unit below. Three-toed tracks and fragments of fossil bone and teeth occur in this sandstone.

The contact between the Shinarump member and the overlying middle member of the Chinle is transitional. This relation has been observed by most geologists who have worked on the Colorado Plateau (Gregory, 1950, p. 66; Hunt, 1953, p. 55; Gilluly and Reeside, 1928, p. 67; McKnight, 1940, p. 64–65; Baker, 1946, p. 59). In places the contact is reasonably sharp where light sandstone is overlain by green or red siltstone or very fine grained sandstone. Elsewhere, however, sandstone of the Shinarump grades into sandstone of the middle Chinle. The contact is chosen with difficulty on the basis of darker sandstone of the Chinle that may have ripple laminations and may be more micaceous. It is not uncommon for the two formations to intertongue (fig. 10).

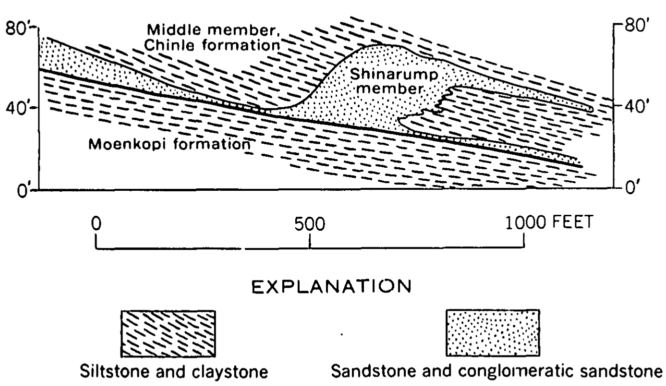


FIGURE 10.—Sketch showing relation of Shinarump and middle members of the Chinle formation on the northeast side of Sheets Gulch. Relatively steep sharp contact on updip (left) side of thick sandstone of the Shinarump, intertonguing contact on downdip (right) side.

In places it is difficult to determine whether beds of the Shinarump were scoured before middle member beds were deposited. As scour and fill took place during the deposition of each member, some scour and fill structure is to be expected at the contact between the two.

The upper member of the Chinle consists chiefly of pale reddish-brown siltstone and very fine-grained sandstone and pale-red and light greenish-gray limestone in lenses 2 to 3 feet thick. The limestone beds are prominent on the slopes and form ledges. Lenses of sandstone and siltstone- and claystone-pebble conglomerate crop out prominently in places in the upper part of the upper member. This upper sandstone and conglomeratic sandstone is crossbedded in part and contains many bone and teeth fragments.

The middle and upper members of the Chinle range from 396 to 479 feet in thickness but generally range between 440 and 470 feet in thickness (fig. 5). No systematic change in thickness is apparent in the mapped area. The upper Chinle ranges from 90 to 195 feet in thickness and in most places is about 35 to 40 percent of the total thickness of the middle and upper members; it comprises only 27 percent (126 feet) about 2½ miles southeast of Bicknell and only 21 percent (90 feet) on the north side of Oak Creek. The middle member of the Chinle ranges from 255 to 345 feet in thickness. The total thickness of the Chinle formation ranges from 440 to 540 feet. This difference in thickness of the entire formation results in part from deposition on an irregularly eroded surface of the Moenkopi, in part from variation in the amount of deposition and compaction of the Chinle, and probably in lesser part from erosion of the top of the Chinle.

In northeastern Arizona, units of the Chinle above the Shinarump member are given member names, which are in ascending order, the Monitor Butte, Petrified Forest, Owl Rock, and Church Rock members (Witkind and Thaden, 1962) equivalent to the D, C, B, and A divisions of Gregory (1917). The lowest of the three parts of the middle member of the Chinle in the Capitol Reef area is similar lithologically to and in the same stratigraphic position as the Monitor Butte member. The upper two parts of the middle member of the Chinle are not lithologically the same as the Petrified Forest member, though they are in the same stratigraphic position. The upper member of the Chinle in the mapped area is similar lithologically to the Owl Rock member.

The middle and upper members of the Chinle are interpreted to be fluviatile and lacustrine deposits. Crossbedded and lenticular sandstone and conglomerate probably are stream deposits, and the finer grained clastic rocks are in large part overbank deposits on broad alluvial plains. An analysis of crossbedding in the sandstone bed at the top of the middle member near

Oak Creek indicates that streams depositing this sand flowed from the south (Omer B. Raup, written communication, 1954). Much of the claystone originated as volcanic debris (Allen, 1930), as indicated by the presence of montmorillonitic clays, remnants of glass shards (Waters and Granger, 1953), and abundant coarse biotite flakes. The origin of the sandstone beds with attitudes at variance to the normal bedding near the base of the middle part of the Chinle has not been explained satisfactorily. In some places they seem to be large foreset beds and in others they seem to have slumped soon after deposition.

WINGATE SANDSTONE—GLEN CANYON GROUP

The Wingate sandstone together with the Kayenta formation and the Navajo sandstone make up the Glen Canyon group, a thick sequence consisting mainly of sandstone. The formations of the Glen Canyon group are shown in figure 11. The Wingate and the Navajo are almost entirely massive sandstone that contains large sweeping crossbeds. The Kayenta, the middle formation of the group, is thinner bedded and contains smaller scale crossbedding and more varied lithologic types than the other two formations.

FIGURE 11.—Photograph showing Glen Canyon group on north side of Fremont River just east of Fruita, Utah. Lower cliff is Wingate sandstone (R̅w); beds in ledge above are Kayenta formation (Jk); rounded domes of massive beds toward top are Navajo sandstone (Jn). Vertical distance from valley floor to top of high pinnacle on left skyline is about 1,300 feet.

The Wingate is exposed in the highest and most impressive cliffs of the Capitol Reef area. It is a vertically jointed tightly cemented sandstone. Most erosion of the cliffs results from the undermining and collapse of large joint blocks in the Wingate by the removal of the weaker beds of the Chinle below. Exposures of the Wingate are excellent but chiefly inaccessible on the cliff faces. The thickness is reasonably consistent at about 320 feet, but the measured maximum is 370 feet.

The Wingate consists of sandstone in large sweeping crossbeds. The sandstone is composed chiefly of very fine grained well-sorted homogeneous quartz grains. The grains are partly rounded and are coated with a thin layer of iron oxide. Near its base the Wingate contains thin lenses and scattered medium to coarse rounded amber quartz grains, a few granules, and, locally, angular fragments of siltstone like that of the underlying Chinle. Iron oxide and silica probably form most of the cement, but calcareous cement is present in places. The Wingate is reddish brown to light orange over most of the area. In many places, however, it is creamy white or white, particularly near faults and in much of the outcrop from near Pleasant Creek to north of Fruita. Gray limestone lenses as much as 10 feet thick and about 500 feet long occur near the Cocks Comb and elsewhere locally in the lower part of the formation.

The contact between the Wingate and the underlying Chinle is unconformable and quite sharp over most of the mapped area, though in part it appears conformable. In places the Wingate truncates beds of the Chinle across thicknesses of 3 to 4 feet along lateral distances of several hundred feet; wedge-shaped cracks 1 to 2 feet deep in the top of the Chinle are filled with Wingate sandstone; and fragments of siltstone from the Chinle are included in the basal beds of the Wingate. Elsewhere the contact is very regular, and top strata of the Chinle, with no truncation, can be traced for long distances adjacent to the contact. In the Capitol Reef area this contact probably represents a rapid change in depositional environment accompanied by some erosion of the top of the Chinle. On parts of the Colorado Plateau, the Chinle and Wingate contact is considered to represent only a change in sedimentary environment and to be conformable (Baker, 1946, p. 62–63, and 1933, p. 41–42; Dane, 1935, p. 72–74).

No fossils have been found in the Wingate sandstone, and its age assignment as Triassic is based largely upon its stratigraphic relationships to the Chinle in southwestern Utah and northern Arizona (Averitt and others, 1955, p. 2523).

The Wingate is interpreted to be chiefly an eolian deposit because of the long sweeping crossbeds and the well-sorted very fine grains. Fresh-water limestone was deposited in a few local basins formed in the dune areas. Studies of the orientation of crossbeds indicate that the sand was transported from the northwest (Stewart and others, 1959, p. 525).

JURASSIC(?) SYSTEM

KAYENTA FORMATION—GLEN CANYON GROUP

The Kayenta formation, about 350 feet thick, crops out in a broad band along Capitol Reef, as narrow disconnected bands south of the Teasdale fault, and on broad benches in the southern part of the mapped area. This formation caps the cliff formed by the Wingate and forms a series of dip slopes and structural benches alternating with low cliffs and rocky ledges (fig. 11). The large natural bridge near Fruita has been formed by erosion of this formation. Exposures of the Kayenta generally are good, but many are nearly inaccessible.

Lenticular and tabular beds of interbedded sandstone and siltstone or mudstone and some conglomerate compose the Kayenta. Filled scours are quite common. On the whole the formation is somewhat darker than the underlying Wingate sandstone and much darker than the overlying Navajo sandstone.

Sandstone in the Kayenta formation is chiefly grayish orange, yellowish gray, moderate reddish orange, pale red, and pale reddish brown. It is composed of very fine to fine-grained subangular to subrounded quartz sand grains, some of which are frosted. Generally less than 1 percent of the sand grains is stained brown or red by iron oxide. Most of the sandstone beds are well sorted. Some beds contain layers of medium- to coarse-grained sandstone. The sandstone beds of the Kayenta have a chiefly siliceous, but locally calcareous, cement, although some beds have little cement and are friable. The beds range in thickness from paper thin to about 12 feet and are both even bedded and crossbedded. In contrast to the Navajo and Wingate, the crossbedding of the Kayenta is in sets of cross-strata commonly only a few feet thick. Tabular lenses of sandstone are as much as 30 feet thick and several hundred feet long; nearly all units thicken and thin in short distances. Irregularly nodular sandstone concretions are present in places.

Conglomeratic beds are scattered throughout the Kayenta and are particularly numerous in scour and fill structures. Pebbles are chiefly angular fragments of claystone and siltstone or, very rarely, limestone. Chunks and irregular cobbles of red clay as much as 8 inches long occur in pockets of scour fills.

Red siltstone and claystone occur in even beds generally from 2 to 4 inches thick and form lenses from 1 to 30 feet thick and several hundred feet long. Locally clay layers are present at the bases of the sandstone and conglomerate scour fills.

A white fine-grained well-sorted sandstone about 50 feet thick crops out over much of the area within about 100 feet of the top of the Kayenta. This sandstone has large sweeping crossbeds and is much like the Navajo sandstone. It is overlain by even-bedded and small-scale crossbedded sandstone and siltstone like the rest of the Kayenta.

The thickness of the Kayenta is about 350 feet. Any two observers might obtain different thicknesses because of the gradational lower and upper contacts of the Kayenta and the choice in choosing contacts. Difficulties of measuring thicknesses are increased by the inaccessible position of the lower contact at or near the top of a cliff face in many places.

The Kayenta formation grades into and appears to intertongue locally with the underlying Wingate sandstone. In most places this gradational or intertonguing zone is less than 20 feet thick, and the contact can be easily identified and mapped at the base of strata that are evenly bedded or crossbedded on a small scale, in contrast to the strata of the Wingate that are crossbedded on a very large scale.

No fossils have been found in the Kayenta formation in the Capitol Reef area. Vertebrate fossils do occur in the formation in northern Arizona, but the age assignment is still considered questionable (Averitt and others, 1955, p. 2523–2524).

Lenticular beds, crossbedding, and scour and fill structures attest the fluviatile origin of most of the Kayenta formation. A statistical analysis of crossbedding in the formation in Capitol Wash indicates that the streams that deposited the sand flowed from the northeast, although crossbeds have random dips and the consistency factor for these readings is low (George A. Williams, written communication, 1954). The Navajo-like sandstone about 100 feet below the top of the Kayenta probably was wind deposited, but was succeeded by more fluviatile deposits.

JURASSIC AND JURASSIC(?) SYSTEM

NAVAJO SANDSTONE—GLEN CANYON GROUP

The Navajo sandstone covers broad strips in the mapped area—along the Waterpocket Fold and Capitol Reef, on the sides of Thousand Lake Mountain, and on the east and north sides of Boulder Mountain. The formation is about 800 to 1,100 feet thick. The spectacular domes, ridges, and whaleback and haystack forms along the crest of the reef, which are eroded in the Navajo, inspired the name "Capitol Reef." Part of the development of these curious erosional forms has resulted from great gashes eroded along numerous joints. Many weathered surfaces have a checkerboard or "elephant hide" appearance formed by differential weathering along networks of small joints and along crossbedding. Exposures of the Navajo generally are excellent, but they are almost inaccessible in many places, particularly along Capitol Reef.

The Navajo is composed of loosely cemented chiefly fine-grained well-sorted well-rounded quartz sand grains, many of which are frosted. Grains in the Navajo are coarser than those in the Wingate sandstone. The fresh rock is white but, locally, weathered surfaces are streaked with yellow bands of limonite stain. In a few places red iron oxide coats grains. In some canyons on the south side of Thousand Lake Mountain, broad bands of red sandstone contrast sharply with white sandstone. Crossbedding on a grand scale is characteristic of the Navajo, and single lenses or sets of cross-strata are as much as 100 feet thick. The crossbeds within each set form sweeping arcs that are concave upward, approach the bottom of the lens at low angles, and are truncated sharply at the contact with the overlying set. Locally bedding-plane surfaces as much as one-half mile long truncate all lower units. Limestone lenses occur in the Navajo in adjoining areas (Hunt, 1953, p. 62; Gilluly and Reeside, 1928, p. 72), but none were noted in the Capitol Reef area.

The thickness of the Navajo ranges from 1,000 to 1,100 feet around Boulder Mountain and from 800 to 900 feet along the Waterpocket Fold. In this region the Navajo thins eastward, and across the Henry Mountains region the thickness decreases from more than 800 feet on the west to slightly more than 500 feet on the east (Hunt, 1953, p. 62).

The contact between the Navajo sandstone and the underlying Kayenta formation is gradational locally, and the two formations probably intertongue. For description and mapping (pl. 1), the contact is placed at the top of the uppermost Kayenta-type bed. All even-bedded and small-scale crossbedded units are included in the Kayenta.

The Navajo is assigned a Jurassic and Jurassic(?) age from its stratigraphic relationships in other areas (Averitt and others, 1955, p. 2523–2524).

The Navajo is interpreted as an eolian deposit on the basis of the giant tangential crossbeds and the fine-grained well-sorted and frosted sand grains. Some water-laid deposits are in the Navajo in the Henry Mountains region (Hunt, 1953, p. 62). The long even planes that bevel underlying crossbeds indicate that at times during deposition of the Navajo there were periods of local planation.

JURASSIC SYSTEM—SAN RAFAEL GROUP

Beds of the San Rafael group crop out in a long belt on the northeast side of Capitol Reef and as discontinuous exposures partly covered by surficial deposits on the flanks of Boulder and Thousand Lake Mountains. In ascending order the San Rafael group consists of the Carmel formation, the Entrada sandstone, the Curtis formation, and the Summerville formation.

CARMEL FORMATION

The Carmel formation forms long dip slopes on the back or east side of the Capitol Reef and locally forms thin caps on prominent knobs of the Navajo sandstone along the crest of the reef. Other good exposures of the formation are along the west side of Thousand Lake

Mountain and in the general area of Black Ridge on the north side of Boulder Mountain. Only the lowermost beds of the Carmel are exposed beneath the cover on the northeast and east sides of Boulder Mountain. In the mapped area the Carmel ranges in thickness from slightly more than 300 feet to almost 1,000 feet.

Interbedded sandstone, siltstone and claystone, limestone, and gypsum compose the Carmel formation (fig. 12). This formation has large lateral changes in thickness and in rock types. Chief colors are shades of gray and yellow, but the most striking are the dark reddish browns and grayish reds of some siltstone and claystone beds. These red beds contrast with the white gypsum and other light-colored rocks to give the Carmel a distinctive banded appearance that contrasts with the uniformly white to buff Navajo sandstone below and uniformly brown and reddish-brown Entrada sandstone above.

Limestone is most common in the lower half of the formation in the northern and western parts of the mapped area. The limestone is dense and contains sand and silt in varying amounts. Beds range in thick-

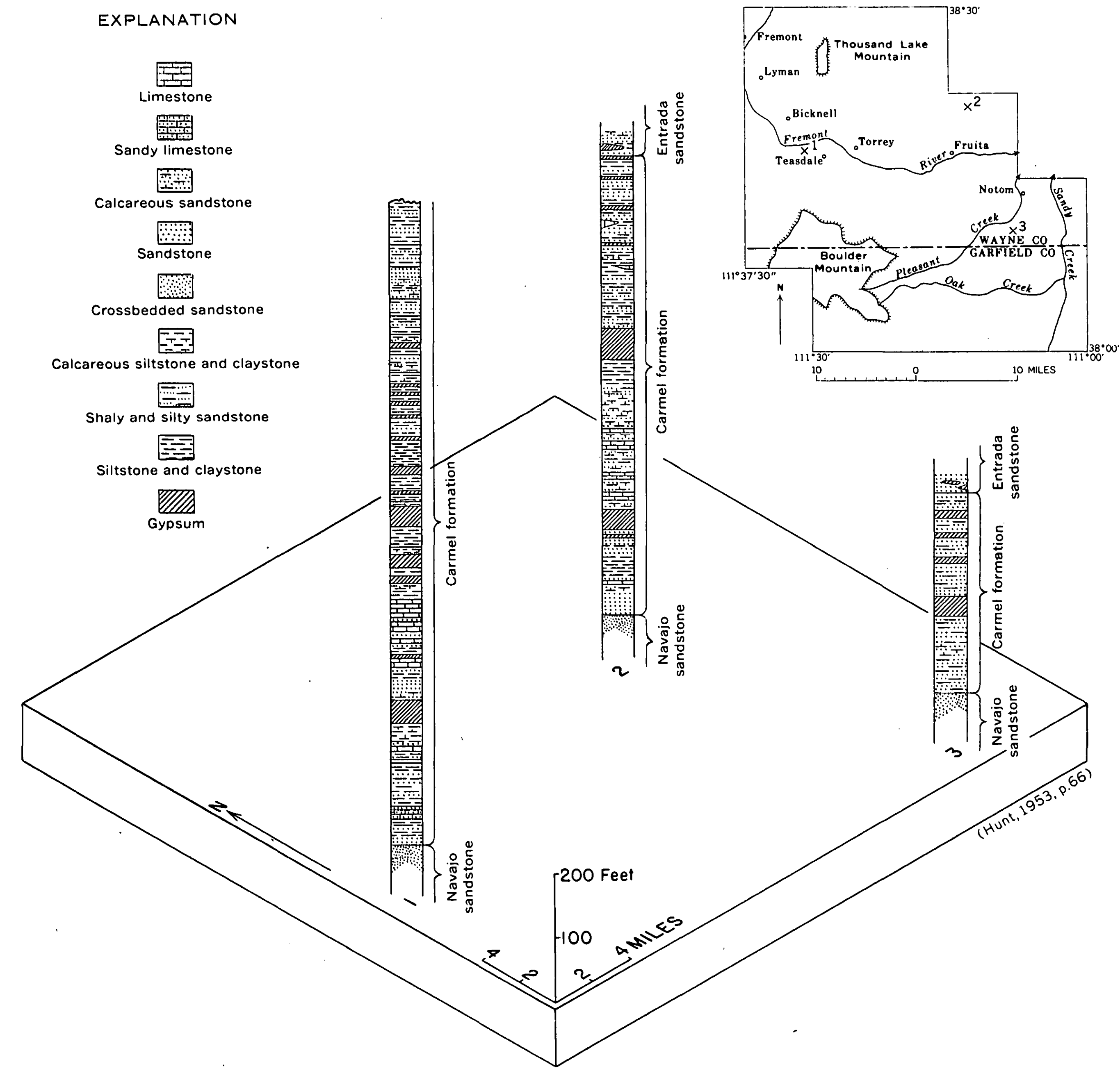


Figure 12.—Diagrammatic sections of the Carmel formation in the Capitol Reef area. Sketch map shows location of sections. Section 3 after Hunt, 1956, p. 66.

ness from 1 inch to 4 feet, but generally are only a few inches thick. Some units of yellowish-gray silty limestone occur as ⅛- to ¼-inch beds which weather into platy fragments. Many of these thin beds are covered with cuspate ripple marks. Sandy limestone and interbedded calcareous sandstone are very fossiliferous in a zone generally about 40 to 80 feet above the base of the formation.

Gypsum occurs as veinlets and as thin and thick massive beds. Most of the beds are 1 to 2 feet thick, but several are much thicker. One gypsum unit on Black Ridge has a total thickness of 80 feet, including 2 thin limestone layers. Gypsum beds 30 to 40 feet thick occur in the lower more calcareous part of the formation in the western part of the area and west of South Desert. Most gypsum is above the lower more calcareous part of the formation. The gypsum beds are generally white, massive, and finely crystalline or granular. In some beds the finely granular gypsum is snowy white and encases gypsum crystals; in other beds the granular gypsum is greenish gray or green. Beds and veinlets ⅛- to ½-inch thick commonly consist of acicular crystals normal to the bed or veinlet. Locally, thin bands and disklike fragments of gypsum are moderate orange pink. The gypsum beds weather to form rounded ledges with steep sides and hackly surfaces. Weathered surfaces commonly have a grayish tint from dirt that has washed or blown onto them.

Abundant evidence of flowage and solution of gypsum exists in the Carmel formation in this area. One gypsum bed on the side of Black Ridge ranges in thickness from 8 to 18 feet, not as a continuous change in one direction but as an irregular thinning and thickening. Although gypsum is prominent in the formation on the south side of Thousand Lake Mountain and around Black Ridge, it is absent in a fault block of Carmel that dips 48° just west of the Sunglow Forest Camp, east of Bicknell (pl. 1). This block contains some sandy beds which are crumpled and others with odd turtleback-shaped forms. These crumpled beds are in about the same stratigraphic positions as the two prominent gypsum beds on Black Ridge and probably crumpled as the adjacent gypsum was removed by squeezing and solution during deformation.

Sandstone beds are abundant everywhere in the Carmel formation. The sandstone is chiefly fine grained and composed of well-sorted rounded quartz grains. Quartz forms 95 percent or more of the grains in most beds; biotite is the most common other mineral. Beds range in thickness from about ⅛ inch to 10 feet and are most commonly 4 inches to 2 feet thick. Most sandstone units have even bedding but some have gentle wavy bedding and in places very small scale crossbedding. About 390 feet above the base of the Carmel near Sunglow Forest Camp, a medium-grained calcareous sandstone contains angular to rounded pebbles and cobbles as much as 4 inches long of sandstone, siltstone, limestone, and some quartz and dark-gray chert. Some of the limestone pebbles contain fossils similar to those found in the lower part of the formation.

Many siltstone and claystone layers are interbedded with the other lithologic types in the Carmel formation. Some of these fine-grained beds contain sand grains. Some are calcareous, particularly in the western part of the area. Most siltstone and claystone strata are poorly exposed. The bedding is indistinct, but beds seem to range between about ⅛ inch and 1 foot in thickness. Some fine clastic units are greatly deformed where they are beneath or between gypsum beds. A particularly good exposure of deformed beds is 460 feet above the base of the formation on the southeast side of Black Ridge. Here a thick bed of gypsum above the deformed unit differs as much as 10 feet in thickness in lateral distances of 30 to 50 feet probably because of flowage. The flowage of the gypsum probably caused the deformation of the siltstone also.

The maximum measured thickness of the Carmel formation is 988 feet on Black Ridge west of Teasdale. There the upper part of the formation is largely covered and the top is not exposed, but the thickness is estimated to be about 1,000 feet. West and southwest of South Desert the thickness is slightly more than 700 feet, southwest of Notom Bench it is 308 feet (Hunt, 1953, p. 66), and west of Sandy Ranch it is 336 feet (Hunt, 1953, p. 68). The increase in thickness is from southeast to west and northwest, from the more sandy facies to the more calcareous facies (fig. 13).

The contact between the Carmel formation and the underlying Navajo sandstone is well defined, particularly in the western part of the mapped area. The basal Carmel beds seem to be transitional between the two formations along the Waterpocket Fold. This transition zone contains interbeds of even-bedded reddish sandstone, white, yellowish-gray, and light-yellow crossbedded sandstone, and 10 to 20 feet of crossbedded fine-grained Navajo-like sandstone. The contact is placed at the base of a reddish-brown to light-yellow silty fine-grained sandstone which forms a prominent reddish-brown band of outcrop. In most places sharp contacts separate these transition beds from the overlying Carmel and from the underlying Navajo. At neither contact are there indications that pre-Carmel erosion was extensive nor that the time interval was long between deposition of the two formations, although the contact is disconformable. The lower contact is chosen as the formational contact because it is interpreted to represent the initial change from eolian conditions of the Navajo. Both Gregory and Anderson (1939, p. 1842–1843) and Hunt (1953, p. 62) place the formational contact at the top of the transition zone, and Hunt considers the well-bedded sandstone a fluvial deposit in the Navajo. The following stratigraphic section measured just west of the Capitol Reef National Monument boundary at the east end of Capitol Wash illustrates this transition zone:

	Feet
Carmel formation:	
11. Sandstone, grayish-green and red, clayey; gypsiferous	--
10. Sandstone, very pale orange, medium-grained; slightly calcareous; bedding poorly developed	4.0
Transition zone:	
9. Sandstone, white to yellowish-gray, fine-grained; eolian-type crossbedding. This and unit 8 below erode to a massive ledge	9.0
8. Sandstone; similar to unit 9 above but poorly developed bedding; contact with unit 9 irregular	6.0
7. Shale, reddish-brown, sandy; units 2–7 erode to slope or series of ledges and recesses	.5
6. Sandstone, pale-red, fine-grained, earthy, calcareous, lenticular; irregular contact with units above and below	3.0
5. Like unit 7	.5
4. Like unit 6	2.0
3. Like unit 7	.3
2. Like unit 6	4.0
1. Sandstone, upper 3 feet reddish-brown, lower 6 feet white to light-yellow, fine-grained, friable; rounded and frosted quartz grains; forms persistent red band; erodes to form recess above Navajo sandstone or to form ledge. Contact generally sharp; locally indistinct with beds below	9.0
Navajo sandstone:	
Sandstone, white to light-yellow, fine-grained; eolian-type crossbedding on a large scale.	

The Carmel formation is considered Middle Jurassic and earliest Late Jurassic in age (Imlay, 1952, p. 963). Ralph W. Imlay, of the U.S. Geological Survey, identified the following fossils collected between 40 and 60 feet above the base of the Carmel in the W½ sec. 17, T. 29 S., R. 4 E., west of Teasdale and in the SE¼ sec. 25, T. 28 S., R. 3 E., southwest of Sunglow Forest Camp: *Ostrea* sp., *Trigonia americana* Meek, *Trigonia* cf. *T. americana* White, *Trigonia montanaensis* Meek, *Trigonia* cf. *T. montanaensis* White, *Trigonia quadrangularis* Hall and Whitfield, *Camptonectes platessiformis* White, *Camptonectes stygius* White, *Cardinia* sp., *Lyosoma* cf. *L. phaseolaris* (White), *Astarte meeki* Stanton, *Meleagrinella curta* (Hall), *Meleagrinella* sp., and *Pentacrinus asteriscus* Meek and Hayden.

Imlay states (written communication, 1953) that these collections "contain the same species as have been found in the lower part of the Carmel in other parts of Utah, in the Twin Creeks limestone of Idaho and Wyoming, and in the Sawtooth and Rierdon formations of Montana."

The Carmel probably is equivalent to at least part of the restricted Arapien shale of central Utah (Spieker, 1946, p. 122–123, and 1949, p. 11, 18; Hardy, 1952, p. 14). The two formations have many lithologic and some faunal similarities (Hardy, 1952, p. 26–27, 67–71; Imlay, 1952, p. 965).

In this area the Carmel consists of deposits of a marginal area of deposition where clastic beds grade northwestward into marine beds deposited in the Twin Creek sea that advanced from the northwest (Baker and others, 1936, p. 54; Imlay, 1952, p. 963). The gypsum probably accumulated in shallow evaporite basins or lagoons near the seashore. Lateral changes in rock types across the mapped area represent very well the environmental changes in this marginal area. The most prominent changes in types are the westward and northwestward increase in limestone and decrease in proportion of coarser clastic rocks (fig. 13).

ENTRADA SANDSTONE

The Entrada sandstone forms a long continuous band of outcrop on the northeast side of the Waterpocket Fold. Beds of the Entrada are less resistant than formations above and below, and they erode to form valleys and low hills. Where capped by resistant beds, the Entrada is exposed at the bases of steep to vertical cliffs; good examples of such cliffs are along the northeast side of South Desert and in the "cathedrals" capped with the Curtis formation in Middle Desert at the north edge of the mapped area. Locally the Entrada in the eastern part of the area weathers into knobby pinnacles, the "hoodoo" or "rock baby" badlands typical of the Entrada in other areas. Isolated and partly covered beds of the Entrada crop out high on the west side of Thousand Lake Mountain and on the north slope of Boulder Mountain. In the Capitol Reef area the formation ranges in thickness from about 475 to 780 feet.

The Entrada consists chiefly of even-bedded earthy fine-grained and very fine grained sandstone with subordinate interbedded siltstone and claystone. Grains are mostly quartz and are subangular to subrounded. Sorting of the sand grains is moderately good to good, but many beds of fine-grained sandstone also contain coarse to very coarse grains; this dual grain size is a characteristic of the Entrada (Imlay, 1952, p. 962). The larger grains are better rounded than the smaller ones.

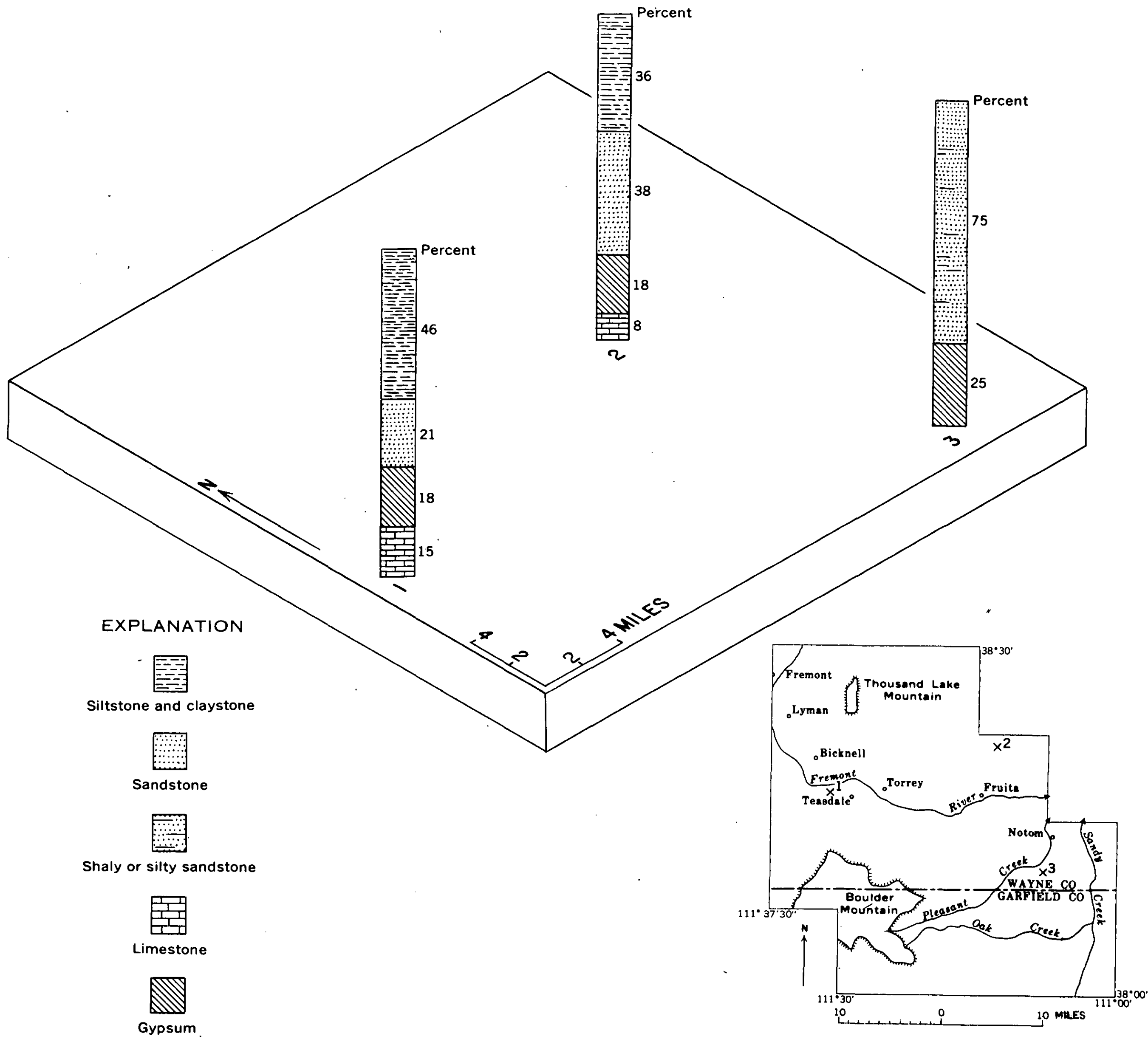


FIGURE 13.—Percentages of lithologic types in three sections of the Carmel formation in the Capitol Reef area. Sketch map shows location of sections from which percentages were determined. (Section 3 after Hunt, 1953, p. 66.)

The Entrada sandstone is almost uniformly brown and reddish brown, but it contains some thin beds that are moderate reddish orange, moderate orange pink, and white. The red and brown are due to iron stain both in the cement and on the quartz grains.

Nearly all the beds are calcareous, and commonly the lighter beds are more calcareous than the darker ones. The Entrada exposed on the north side of Red Canyon in the E½ sec. 11, T. 27 S., R. 3 E., contains silty limestone in beds 4 to 12 inches thick interbedded with sandy siltstone and mudstone. Near the top of this exposure are beds of coarse-grained calcareous sandstone composed of well-rounded grains of clear, amber, pink, and reddish quartz.

Over most of the area the formation is even bedded in beds generally about ¼ to 6 inches thick. Locally, the beds are 1 to 5 feet in thickness, and the thickest is about 10 feet. In many exposures the rock seems to be structureless with no apparent bedding, particularly in the more earthy layers.

Massive crossbedded fine- to medium-grained sandstone, more typical of the sandy facies of the Entrada, intertongues with the earthy facies in the southeastern part of the area. The crossbedded units are more resistant to erosion than the earthy ones. The maximum observed thickness of a crossbedded sandstone in this area is about 40 feet.

The Entrada sandstone is variable in thickness within this area. The maximum measured thickness is 782 feet about 1½ miles north of the Fremont River in South Desert. It is 476 feet thick along Burro Wash south of Notom Bench, about 700 feet in the upper part of Halls Creek about 4 miles south of the Capitol Reef area (Hunt, 1953, p. 66 and 71), and 675 feet thick along Starvation Creek about 2 miles northeast of the northeast corner of the Capitol Reef area (Gilluly, 1929, p. 103). The only complete section of the Entrada in the western part of the Capitol Reef area is on the north side of Boulder Mountain, where exposures are so poor that an exact thickness cannot be measured; here the thickness is estimated to be about 550 feet.

On a broad scale the conformable contact between the Entrada sandstone and the underlying Carmel formation is a zone of marked change between the more varied composition and color of the Carmel and the more uniformly fine-grained to very fine grained brown to reddish-brown earthy sandstone and some siltstone of the Entrada. In detail, however, the separation is not distinct in all places. As beds are traced laterally they appear to belong in the Carmel at one place and in the Entrada at another. A gypsum bed is selected as the top bed of the Carmel along much of the eastern part of the area.

The Late Jurassic age of the Entrada sandstone is determined from its stratigraphic position between the Carmel and the Curtis formations in which fossils of Late Jurassic age have been found (Baker and others, 1936, p. 58). The Entrada sandstone probably is equivalent to the Twist Gulch member of the Arapien shale in the Wasatch Plateau region (Spieker, 1946, p. 124–125; Imlay, 1952) or to part of the lower part of the Twist Gulch formation of Hardy (1952, p. 22–23, 27–28).

Judging from the generally even bedding, most of the Entrada in this area was deposited in water, and probably in quiet water. The crossbedded sandstone in the southeast probably was stream deposited in part and perhaps wind deposited in part. Most of the Entrada in the Capitol Reef area belongs to the red earthy sandstone facies (Baker and others, 1936, p. 46, 54–55) considered to be largely of subaqueous origin (Craig and others, 1955, p. 132).

CURTIS FORMATION

The Curtis formation, which is missing in part of the area, has a maximum thickness of about 80 feet, and crops out as chiefly a narrow band on the northeast and east sides of the Waterpocket Fold. It is exposed on a steep to vertical cliff in many places, particularly along the east side of South Desert, and caps the "cathedrals" in Middle Desert. The color contrast between the grayish yellow green of the Curtis and the reds and browns of the underlying Entrada sandstone and the overlying Summerville formation makes the outcrops of the Curtis conspicuous.

Fine-grained glauconitic sandstone and lesser amounts of siltstone compose the Curtis formation. Clear quartz makes up about 95 percent of the grains; accessory grains are pink, yellow, green, and black and include minor amounts of biotite. Sandstone beds generally are rather persistent and even. They are mostly from 6 inches to 2 feet thick, although they range in thickness from about 6 inches to 5 feet. A few layers have small-scale crossbedding and some faint markings which appear to be current lineations. The siltstone beds are thinner than the sandstone beds and are commonly 1 to 2 inches thick and as much as 6 inches. In general the grain size and the thickness of bedding decrease upward. All units have a carbonate cement.

In the northern part of the area the Curtis can be divided roughly into two units. The lower unit is chiefly sandstone in beds 6 inches to 2 feet thick, and weathers to form knobby surfaces in places. The upper unit also is chiefly sandstone but contains more siltstone and shaly beds.

A 2-foot-thick zone of concretions crops out locally about the middle of the formation. These concretions are 2 inches to 1 foot in diameter and have hard orange shells composed chiefly of small quartz crystals and interiors composed of calcite crystals. Many rugose carbonate concretions about 1 inch in diameter are concentrated locally in the upper one-third of the Curtis. Pods of charcoallike carbonaceous material with a maximum observed length of 4 inches crop out locally in the lower 2 feet of the formation.

The Curtis has a fairly uniform thickness of about 80 feet from the north edge of the area to south of The Notch on the east side of South Desert. From there it decreases to the south and pinches out near Cedar Mesa south of Oak Creek. As Hunt suggests (1953, p. 72),

> This thinning appears to be due partly to overlap southward against the Entrada, partly to thinning southward of beds within the Curtis, but mostly because of lateral change southward from Curtis to Summerville lithology.

No Curtis was recognized on the north flank of Boulder Mountain where exposures are poor, and the Curtis may pinch out to the west across the Capitol Reef area.

The contact between the Curtis and the underlying Entrada sandstone is an erosional unconformity and in places an angular unconformity (Hunt, 1953, p. 71). This unconformity is not considered to represent a long time break, and the deformed beds in the Entrada are local features. In many places the contact is regular and even and appears conformable. Figure 14 illustrates the outcrop appearance of the two formations and the color contrast between them.

Fossils from the Curtis in the San Rafael Swell to the northeast establish its Late Jurassic age (Gilluly and Reeside, 1928, p. 79). Beds about 175 feet thick near the top of the Twist Gulch member of the Arapien shale or the Twist Gulch formation of Hardy in Salina Canyon 35 miles northwest of the Capitol Reef area are similar lithologically and stratigraphically to the Curtis formation (Hardy, 1952, p. 27–28) and are considered probably correlative with the Curtis (Imlay, 1952, p. 965).

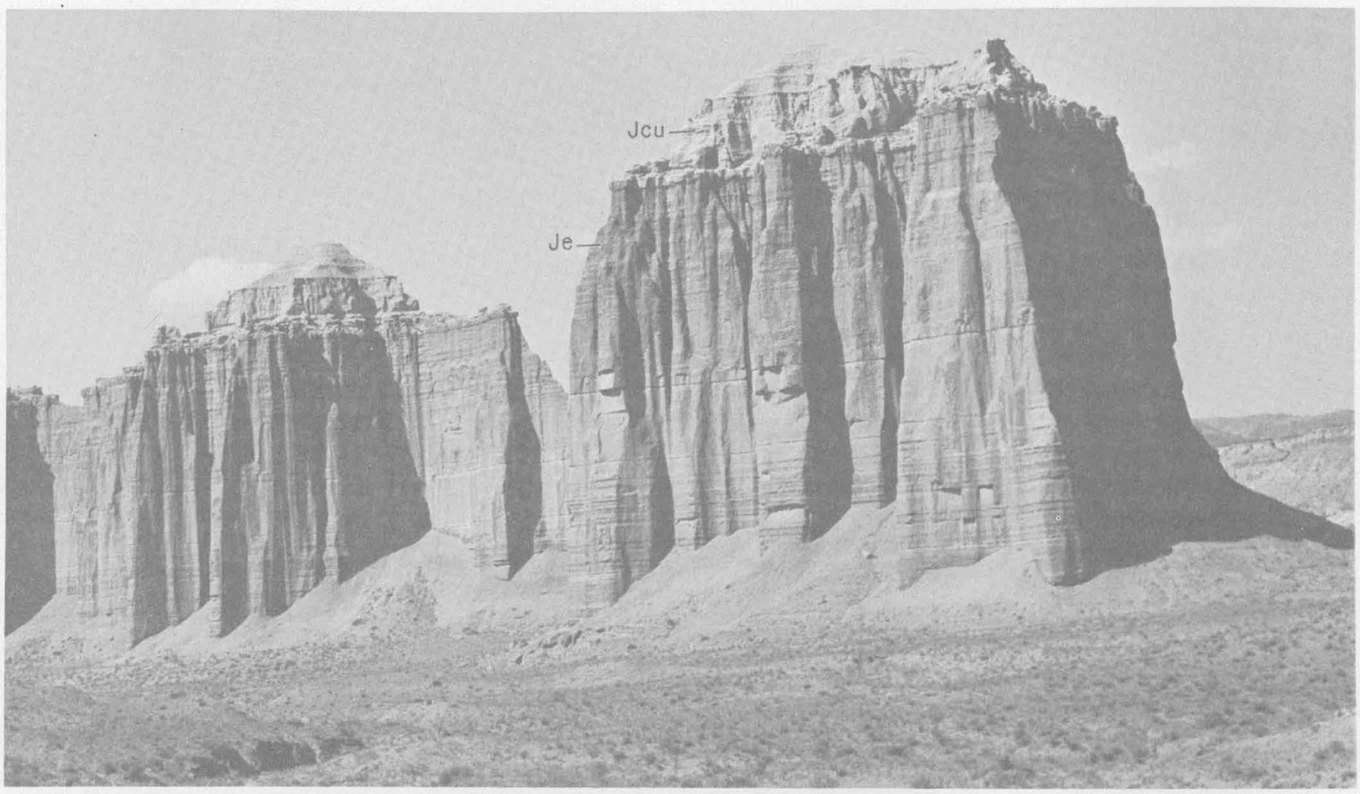


FIGURE 14.—Photograph showing Entrada sandstone (Je) overlain by Curtis formation (Jcu). Dark even-bedded unit is Entrada; light capping unit is Curtis. In Cathedral Valley in T. 26 S., R. 5 E., just north of mapped area.

The marine origin of the Curtis is known from the studies of areas north and northeast of the Capitol Reef area (Gilluly and Reeside, 1928, p. 79; Baker and others, 1936, p. 54). Small-scale crossbedding in some beds and faint relics of probable current lineations suggest that in the Capitol Reef area the Curtis was deposited along the seashore.

SUMMERVILLE FORMATION

The Summerville formation, about 200 feet thick, crops out as a band along the northeast side of the Waterpocket Fold. Along much of this distance, beds of the Summerville are well exposed on steep slopes or on cliffs capped by resistant beds of the overlying Salt Wash member of the Morrison formation. The Summerville is poorly exposed in two areas on the north side of Boulder Mountain.

The Summerville formation is composed chiefly of pale-brown to light-brown mudstone, siltstone, and fine-grained sandstone in thin, regular, even beds; the even bedding is characteristic of the formation. In and near Middle Desert the color of the uppermost part of the Summerville is between pale reddish brown and moderate reddish brown, redder than most of the formation in other parts of the area. Nearly all beds are poorly consolidated and have a calcareous cement. Some beds are shaly. Generally the mudstone and siltstone beds are 1 to 6 inches thick and the sandstone beds 6 inches to 2 feet thick. Some sandstone units and siltstone units are crossbedded on a small scale. White to very pale orange sandstone layers are visible on some cliff faces, but generally the layers are colored brown by wash from overlying strata. Gypsum in beds 1 to 2 inches thick and in crosscutting veinlets generally 1/8 to 1/4 inch thick is abundant locally, particularly in the upper part of the formation.

The Summerville formation is about 200 feet thick in most of the Capitol Reef area, but it is only 133 feet thick in the southeastern part of the area (Lawrence C. Craig, written communication, 1954).

The contact between the Summerville and the underlying Curtis formation is gradational. Beds of the Curtis become finer grained toward the top and are interbedded with brown finer grained sandstone and siltstone like that of the Summerville. The contact is placed at the top of this transition zone. In the southeastern part of the mapped area the Summerville rests unconformably on the Entrada sandstone where the Curtis is lacking.

A Late Jurassic age of the Summerville formation is indicated by its close relation to the Curtis formation that contains fossils of Late Jurassic age (Gilluly and Reeside, 1928, p. 79; Imlay, 1952, p. 964). The uppermost part of the Twist Gulch member of the Arapien shale or the Twist Gulch formation of Hardy in the western part of Salina Canyon at the south end of the Wasatch Plateau is similar lithologically and stratigraphically to the Summerville and may be correlative with it (Hardy, 1952, p. 28).

Chiefly because of its thin even bedding, the Summerville is interpreted as a marginal marine deposit formed largely in quiet water.

MORRISON FORMATION

Except for poorly exposed areas on the north side of Boulder Mountain, beds of the Morrison formation crop out only east and northeast of the Waterpocket Fold. The Morrison has an average thickness of about 400 feet and consists of two members, the lower Salt Wash sandstone member and the upper Brushy Basin shale member. Sandstone and conglomerate strata of the Salt Wash member cap cliffs of various heights (fig. 15) and form rough dip slopes. Beds of the Brushy Basin member erode to badlands topography.

The Late Jurassic age of the Morrison formation is well established (Baker and others, 1936, p. 58–63; Imlay, 1952, p. 953–960). Correlation of the Morrison formation in the Capitol Reef area with beds of the Morrison in other areas of the Colorado Plateau also is well established.

SALT WASH SANDSTONE MEMBER

The Salt Wash sandstone member (Lupton, 1914, p. 127) is composed of lenticular crossbedded channel sandstone and conglomeratic sandstone and lenticular siltstone and claystone. Sandstone and conglomerate

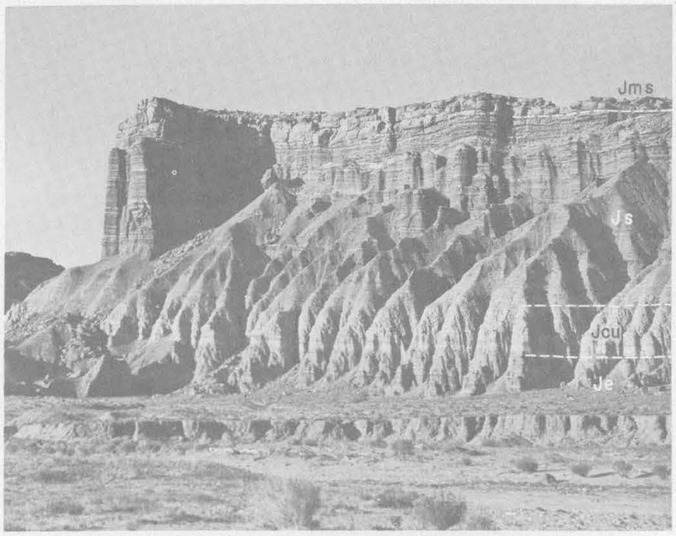


FIGURE 15.—Photograph showing Salt Wash sandstone member (Jms) of Morrison formation capping cliff on east side of South Desert. Summerville formation (Js) on most of cliff; Curtis formation (Jcu) is light-colored band near base of cliff; topmost beds of Entrada sandstone (Je) at base of cliff.

beds are chiefly gray in overall appearance, but they are a variety of colors including gray, white, grayish-orange pink, pale red, and pale greenish yellow. Siltstone, mudstone, and claystone are mostly moderate reddish brown to dark reddish brown, with some shades of gray, green, and red.

Lenticular beds with irregularly or sharply channeled bases are characteristic of the sandstone and conglomeratic units. Laterally, sandstone grades into conglomerate or conglomeratic sandstone or into siltstone or claystone. Because of the lenticularity of beds and the lateral gradations, the stratigraphic sequence differs within short lateral distances. The beds range in thickness from a fraction of an inch to a maximum noted of 10 feet. Some conglomerate and sandstone lenses composed of several beds are 30 to 50 feet thick. Crossbedding, particularly the festoon type of trough cross-stratification (McKee and Weir, 1953, p. 387), is very common in the sandstone and conglomeratic units.

The sandstone ranges from very fine grained to very coarse grained and commonly is fairly well sorted. Quartz generally composes 85 to 90 percent of the sand grains, and feldspar and chert the rest. Grains are subangular to moderately well rounded. Some quartz grains have prominent overgrowths of secondary silica. The cement is chiefly calcareous and composes 10 to 15 percent of the rock in many places; locally some of the cement is siliceous.

The conglomerate pebbles are chiefly gray chert but also are black and dark-gray chert, green and red chert, white and gray quartzite, and silicified limestone. Some pebbles of silicified limestone contain fossils of Paleozoic age. Most pebbles are less than 1½ inches in diameter, and the maximum cobble size noted is about 4 inches. Calcareous sandstone forms the matrix of the conglomerates. In places, conglomerate layers a single pebble thick are interbedded with sandstone.

Locally the sandstone and conglomeratic beds contain scattered specks, pods, and lenses of carbonaceous material. Most commonly the carbonaceous layers are 1 inch or less in thickness, are wavy, and extend laterally for distances of generally not more than 2 feet. Some of the carbonaceous material shows woody texture. Beds as much as 2 feet thick contain up to 15 percent carbonaceous material, with pockets of concentrated carbonaceous material about 6 to 10 inches thick and 3 to 6 feet wide and long. Silicified tree trunks and silicified wood fragments are also present.

Siltstone, mudstone, and claystone beds generally are 6 inches to 2 feet thick and are quite lenticular. The siltstone and claystone most commonly are calcareous, but some of the greenish claystone beds are not. Interbedded with the siltstone is very fine grained sandstone and locally calcareous sandstone or sandy limestone. In places there are limestone concretions and nodules a few inches long.

Elongate boulders of gray limestone as much as 2 feet long and 8 inches thick were observed along the wash east of The Notch; the location of these boulders suggests that they were derived from limestone in the Salt Wash, although no limestone outcrops were noted.

Gypsum seams both parallel to and across the bedding are present locally in the lower part of the Salt Wash member. The basal beds of the member are crumpled and wrinkled in places. The crumpling may have resulted from solution or movement of the gypsum.

The thickness of the Salt Wash member decreases generally to the north and northwest through this part of Utah (Craig and others, 1955, fig. 21); over most of the Capitol Reef area it is about 200 feet. Near Spring Canyon in the southeast corner of the area, the thickness is about 236 feet (Lawrence C. Craig, written communication, 1954), at The Notch on the east side of South Desert it is 208 feet, and along Hartnet Draw the top is lacking but the thickness probably is about 200 feet. In the northernmost part of the mapped area the thickness is extremely variable; on the east side of McDonald Basin the Salt Wash is 30 feet thick, and within 4 or 5 miles north of the area the thickness ranges from about 30 feet to almost 100 feet in distances of a few hundred feet. In the Last Chance country farther north the Salt Wash is missing locally.

The Salt Wash member of the Morrison formation unconformably overlies the Summerville formation. Generally the basal beds of the Morrison are much coarser than the beds of the Summerville, and the contact is easily identified. Basal rocks of the Morrison commonly are conglomeratic sandstone, crossbedded sandstone, or claystone or mudstone of different color and with less distinct and even bedding than that in the Summerville. In places along this unconformity, scours or channels in the top of the Summerville have been filled with conglomeratic sandstone or sandstone of the Salt Wash.

Vigorous stream action is indicated by the channel sandstone and conglomeratic sandstone, and quiet-water or flood-plain deposition by the siltstone, mudstone, claystone, and fine-grained sandstone of the Salt Wash member. The Salt Wash is regarded as a broad fan-shaped alluvial-plain deposit, the greatest thickness of which is just north of the Utah-Arizona border south of the Capitol Reef area (Craig and others, 1955, fig. 21, p. 150–152). Mullens and Freeman (1957), in a lithofacies study of the Salt Wash member, separate the depositional environments of the beds into stream deposits and flood-plain deposits—those deposits noticeably influenced by water currents and those not noticeably influenced by current action but rather by slack or quiet water. As indicated on their map showing the percentage of stream deposits, most of the Salt Wash member in the Capitol Reef area is in the region where the beds are about evenly divided between stream deposits and flood-plain deposits. The percentage of stream deposits decreases to the north but is still above 40 percent at the north end of the mapped area.

BRUSHY BASIN SHALE MEMBER

Variegated claystone and lesser amounts of siltstone, sandstone, and conglomeratic sandstone compose the Brushy Basin shale member. The lower part of the member is variegated and the upper part is light gray and almost white in places. Color bands that range from a few inches to about 20 feet in width and that conform to the bedding in general but not in detail are dark reddish brown, light brown, moderate reddish orange, pale red, grayish red, purple, yellowish gray, greenish gray, light greenish gray, and very light gray.

The claystone contains varying amounts of silt and very fine to fine-grained sand. Locally the siltstone and fine-grained sandstone are in thin lenses interbedded with claystone. Much of the clay is bentonitic and develops a characteristic popcornlike surface when drying after a rain. Some of the clay or siltstone is concretionary and some is silicified along thin layers.

Sandstone and conglomeratic sandstone occur in lenses throughout the Brushy Basin. Fine to coarse grains of clear quartz make up most of the sandstone and the sandstone matrix of the conglomeratic beds that contain gray and tan chert and less common red and green chert pebbles. The maximum pebble size is about 1 inch. Most beds are gray, but locally they are tinted by an orange or brown calcareous cement. The lenses have a maximum thickness of about 20 feet, but more commonly 8 to 10 feet, and a maximum observed length of about ¼ mile, but more commonly only 200 to 300 feet. Discontinuous lenses of sandstone and conglomeratic sandstone can be traced along the same horizon for about one-half mile. Although some sandstone and conglomerate layers are friable, generally they are firmly cemented and form ledges or cap hills.

Thin lenses of limestone and layers of limestone concretions occur in the Brushy Basin, particularly in the upper part. Limestone nodules from these beds rest on the slopes or accumulate at the base of steep slopes.

Silicified wood and bone fragments are abundant locally in the Brushy Basin. No other fossils were found in the mapped area, but a very few pelecypod shells have been found in the Henry Mountains region (Hunt, 1953, p. 76). The highly polished pebbles which have been identified in other areas as gastroliths or gizzard stones of dinosaurs are also abundant in places.

The upper part of the Brushy Basin member may include beds of Early Cretaceous age equivalent to the Cedar Mountain formation in the San Rafael Swell (Stokes, 1944, p. 965–967, and 1952, p. 1767–1769, 1774). According to Stokes (1952, p. 1770–1772) the lithologic features of the Cedar Mountain that may be used to distinguish it from the Morrison are fewer colors and less well defined color bands, the presence of numerous calcareous nodules, and an abundance of highly polished pebbles, the so-called gastroliths. These features characterize the upper beds of the Brushy Basin in parts of the Capitol Reef area. Where the Buckhorn conglomerate of Stokes (1944), the basal unit of the Cedar Mountain formation in the San Rafael Swell, is present the Brushy Basin and the Cedar Mountain can be distinguished without difficulty. Where the Buckhorn is lacking the distinction between the Brushy Basin and Cedar Mountain is difficult and indefinite. As lenses of probable Stokes' Buckhorn conglomerate are discontinuous in the Capitol Reef area and the beds above and below are similar where the Buckhorn is absent, the Cedar Mountain is not considered a mappable unit in this area. The Cedar Mountain can be recognized in places in the area mapped, and the horizon of the Buckhorn has been traced about as far south as Notom Bench (Lawrence C. Craig, oral communication, 1954; Katich, 1954, p. 44).

The thickness of the Brushy Basin member is somewhat variable in the mapped area, ranging from about 160 feet to about 225 feet. In general the increase in thickness is from south to north and is irregular.

The contact between the Brushy Basin member and the underlying Salt Wash member of the Morrison formation is transitional. It is placed (pl. 1) at the base of a thick sequence of varicolored claystone beds and just above a lenticular conglomeratic sandstone containing red, green, and white chert pebbles. This conglomeratic bed is included as a basal bed of the Brushy Basin by some workers (Craig and others, 1955, p. 156). The contact is placed above the conglomeratic sandstone in the present report because of the marked lithologic change from chiefly conglomeratic sandstone to chiefly claystone and because the position of this lithologic change is more readily mappable than the base of the conglomerate. Near the top of the Salt Wash, in places, are prominent lenses of sandstone and conglomeratic sandstone that are interbedded with and intertongue with siltstone, mudstone, and claystone. These lenses commonly stand as ridges because the softer finer grained beds adjacent to them have been eroded. The contact probably ranges through a stratigraphic interval of 30 to 50 feet because of the intertonguing and lithologic gradations.

Fine-grained clastic rocks of the Brushy Basin indicate that beds of this member were deposited under generally much more quiet depositional conditions than those of the Salt Wash member. Stream action is indicated by sandstone and conglomeratic sandstone lenses, and lacustrine conditions are indicated locally by limestone lenses and perhaps by some of the claystone beds. Ash falls contributed much of the material now forming the bentonitic clay.

CRETACEOUS SYSTEM

The formations of Cretaceous age mapped in the Capitol Reef area are the same as those mapped and described in detail for the Henry Mountains region by Hunt (1953, p. 77–86). Only a summary description is given here.

DAKOTA SANDSTONE

The Dakota sandstone, although locally absent, crops out east of the Waterpocket Fold. This formation is resistant to weathering and generally forms ledges or low hogbacks, in contrast to the smoother slopes on the Brushy Basin.

The Dakota varies considerably in composition, but it is predominantly a weak to moderately well cemented fine- to medium-grained light-colored sandstone. In a few places it is conglomeratic with pebbles of quartz and chert as large as one-half inch in diameter. Locally the numerous fossil shells in the Dakota make the beds appear conglomeratic; most of the fossils are species of *Gryphaea* and *Exogyra*. The Dakota contains thin beds or lenses of dark-gray carbonaceous shale and some shaly coal.

The thickness of the Dakota ranges from 0 to about 50 feet and probably averages 20 feet. It is missing east of South Desert.

The Dakota unconformably overlies the Brushy Basin member of the Morrison formation. The contact between the mudstone of the Brushy Basin and the sandstone and conglomeratic sandstone of the Dakota is distinct.

In this region the Dakota sandstone is considered to be of Late Cretaceous and possible Early (?) Cretaceous age (Katich, 1954, p. 45–46). Although the exact age is uncertain, the Dakota in the Capitol Reef area can be correlated with the sandstone unit at the base of the Upper Cretaceous marine deposits that is called Dakota in neighboring areas.

Hunt (1953, p. 79) considers the Dakota to consist of transgressive littoral deposits that were formed when the Cretaceous sea spread westward across this part of the Colorado Plateau.

MANCOS SHALE

The Mancos shale is exposed along a broad belt east of the Waterpocket Fold. It is composed of five members (Hunt, 1953, p. 79–85) with a combined thickness of about 3,200 feet in this area. In ascending order, the members are the Tununk shale member, Ferron sandstone member, Blue Gate shale member, Emery sandstone member, and Masuk member.

The sandstone members are resistant and are exposed either on broad gentle dip slopes or on cliff faces. The shaly members are easily eroded and typically form long asymmetric valleys with one side rising to a steep escarpment capped by the overlying sandstone member or the overlying Mesaverde formation. Where not overlain by sandstone along a cliff face, the shale is eroded into badland topography or gently undulating, low, rounded hills.

The Tununk and Blue Gate shale members are composed of dark-gray shale containing a few thin beds of bentonite and calcareous and shaly sandstone. The Masuk member contains some gray shale, but is composed predominantly of irregular-bedded sandy gray shale, sandy carbonaceous shale, and sandstone. Petrified wood is common in this member.

The Ferron and Emery sandstone members are lithologically similar. Each consists of a lower part of interbedded sandstone and shale, a middle part of massive sandstone, and an upper part of lenticular carbonaceous shale and coal-bearing shale and sandstone. Most of the sandstones are fine grained, yellow to tan, and friable to well cemented. They are relatively thin and even bedded, but contain some thicker units which are generally crossbedded. Carbonaceous material in the upper parts of the two sandstone members consists of coal, leaf impressions, and petrified wood.

The members of the Mancos are fairly uniform in thickness in the Capitol Reef area. The Tununk shale member averages about 575 feet, the Ferron sandstone member about 250 feet, the Blue Gate shale member about 1,400 feet, and the Emery sandstone member about 250 feet. The Masuk member is 600 to 800 feet thick.

The Mancos shale is transitional into the underlying Dakota sandstone, and the contact is placed at the position of change from dominantly shale to dominantly sandstone. Where the Dakota is lacking, the gray shale of the Tununk member of the Mancos shale rests on light-colored claystone of the Brushy Basin member of the Morrison formation. The contact commonly is not sharp, particularly if the area is one of very low relief. However, the color difference and the presence of *Gryphaea* shells in many places in the lower beds of the Tununk makes selection of the contact relatively easy.

The Late Cretaceous age of the Mancos shale is established from marine fossils (Hunt, 1953, p. 79–85; Spieker, 1931, p. 19; Spieker and Reeside, 1925, p. 436–440), although the lower part of the Tununk shale member may be of Early Cretaceous age (Katich, 1954, p. 46). The members of the Mancos shale in the Capitol Reef-Henry Mountains region may be correlated with considerable reliability to their counterparts in Castle Valley and the Book Cliffs to the north. Identifying correlatives in the Kaiparowits region to the southwest is more difficult, but the Mancos shale of the Capitol Reef area and the Henry Mountains region probably is correlative at least in part to the Tropic shale, Straight Cliffs sandstone, and Wahweap sandstone of the Kaiparowits region (Gregory and Moore, 1931, p. 112 and fig. 6).

Deposition of the Mancos shale took place in several stages that reflect a changing shoreline of the Cretaceous sea. The Tununk shale member represents offshore marine mud deposited when the sea spread westward. The Ferron sandstone member represents littoral deposits made during a partial retreat of the seashore, possibly when the rate of deposition in the Late Cretaceous sea exceeded the rate of subsidence of the geosyncline (Hunt, 1953, p. 83). Deposition of the marine muds of the Blue Gate shale member again represents a westward advance of the sea. Like the Ferron, the Emery sandstone member was deposited during a partial retreat of the Cretaceous sea. According to Hunt (1953, p. 85), the sediments representing the Masuk member are partly littoral and partly marine and indicate a rapid shifting of the seashore.

MESAVERDE FORMATION

The Mesaverde formation has been eroded from the Capitol Reef area except in the southeast corner, where it caps the underlying Masuk member of the Mancos.

The Mesaverde is composed of about 300 feet of light-yellow to tan fine-grained sandstone. The beds are generally thin to thick crossbedded units separated by thin shaly sandstone partings. This formation is in transitional contact with the underlying Masuk member of the Mancos shale.

The Mesaverde formation is of Late Cretaceous age. That part of the formation exposed in the Capitol Reef area and the adjoining Henry Mountains region probably is equivalent to the lower part of the Mesaverde formation exposed in Castle Valley and the Book Cliffs to the north (Hunt, 1953, p. 86). In many respects the Mesaverde is similar to the Ferron and Emery sandstone members of the Mancos shale, and the Mesaverde probably is a beach or littoral deposit similar to those members.

TERTIARY SYSTEM

FLAGSTAFF LIMESTONE

The Flagstaff limestone, 500 feet or considerably more in thickness, is exposed chiefly in the northwestern part of the area along the hills east of the Fremont River. Exposures are good in small patches, but they are not nearly as continuous as indicated on the geologic map (pl. 1) because most hillsides are covered with rubble. The cover is thin on most slopes, and continuous exposures are indicated where outcrops are no more than a few hundred feet apart. This part of the area has been greatly faulted, probably more so than is shown on the geologic map (pl. 1), and the rocks have slumped and slid in places. The Flagstaff also probably underlies the volcanic cap rocks of Boulder and Thousand Lake Mountains.

Difficulties in assigning definitive characteristics to the Flagstaff and its thickness and sequence of beds in the mapped area are (1) scattered small good exposures, (2) its deposition on a much eroded and probably irregular surface, (3) an eroded and probably irregular upper surface over which the lavas flowed, (4) post-volcanic faulting and perhaps pre-Flagstaff faulting, and (5) probable slumping and sliding of the beds in places.

The Flagstaff consists of limestone, tuff, sandy tuff, and tuffaceous sandstone, sandstone, siltstone, claystone, and conglomerate. In its type area on the Wasatch Plateau, the Flagstaff is chiefly limestone (Spieker, 1946, p. 136), but in the Capitol Reef area, exposures of tuff and tuffaceous beds are as abundant as those of limestone. No exact stratigraphic sequence is recognized in the generally poorly exposed beds. Just north of Bicknell (pl. 1), a general sequence seems to consist of lower beds of red and gray claystone, siltstone, and sandstone with conglomerate followed in ascending order by limestone and tuff and tuffaceous beds. North of Thousand Lake Mountain the basal beds are limestone. All rock types are interbedded in places.

Most of the limestone in the formation is yellowish gray and grayish-orange pink and weathers to tints of cream or pink. It is in beds commonly ½ to 8 inches thick. Some beds are sandy. Beds of yellowish-brown limestone and medium dark-gray dense limestone and some limestone-pebble conglomerate crop out in Lime Kill Hollow northwest of Lyman. These limestone beds are 2 to 3 feet thick and contain some chert. The conglomerates are in beds ¼ to 6 inches thick and contain smooth, but not well-rounded, pebbles and cobbles ¼ to 3 inches long. These beds in Lime Kill Hollow are below lighter colored limestone and tuffaceous beds on the surrounding hills and are exposed at no other locality.

A white algal limestone near the base of the Flagstaff forms a ridge crest just north of the mapped area north of Hens Peak. In places the algal bands ring smooth 1-foot-long blocks of hard conglomerate.

White and very light gray tuff, sandy tuff, and tuffaceous sandstone are prominent in the Flagstaff in the Capitol Reef area. Beds range in thickness from about $1/32$ to 8 inches and are in units 2 inches to 4 feet thick. Most layers are even bedded, but some of the tuffaceous sandstone is crossbedded on a small scale. The grain size ranges from silt to medium sand. The tuffaceous silty and very fine grained sandy rocks consist chiefly of angular quartz grains and scarce pumice fragments in a mostly calcite cement. In thin section some of the rock is seen to be a vitric tuff consisting of fragments of pumice, broken fragments of quartz and feldspar, and scattered biotite in a glass groundmass. Biotite is scattered through most of the tuff and tuffaceous beds. Nearly all these rocks except the vitric tuff are calcareous.

Conglomerate, conglomeratic sandstone, and sandstone crop out in several localities. Exposures of conglomerate are not as abundant as those of limestone and tuff, but the conglomerate beds generally are poorly cemented and pebbles probably derived from them cover the slopes in many places. Most of the sandstone and conglomerate is light gray to almost white, calcareous, in lenticular beds, and commonly crossbedded. The sand grains are chiefly clear quartz. The pebbles and cobbles are a variety of rock types—gray, white, and tan quartzite, some banded quartzite, dark-gray and black chert, some white and light-amber quartz, and light-gray and tannish-gray silicified limestone. Many silicified pebbles contain fossils, including, most commonly, Paleozoic corals and bryozoans and also crinoid stems and brachiopods. Light-gray silicified limestone pebbles with pitted weathered surfaces are rather characteristic of these beds, but not common in them. Most pebbles and cobbles are moderately well rounded to well rounded and range in size from about ¼ to 8 inches.

Pale reddish-brown sandstone and pebble conglomerate in beds generally ⅛ to 1 inch but as much as 1 foot thick crop out at the base of the exposed Flagstaff limestone in the hills north of Bicknell. Sand grains are chiefly quartz. Larger fragments are mostly volcanic rock and are angular to rounded and as much as 3 inches long. Elongate tuff pellets are scattered through the beds. The rock is fairly friable but has calcareous cement in some beds, particularly in the finer grained ones. Numerous layers 1 to 8 inches thick are crossbedded on a small scale.

The total thickness of the Flagstaff limestone probably is at least 500 feet and may be considerably more. The maximum thickness at any one locality is about 290 feet in the canyon north of Bicknell (pl. 1). The formation is more than 1,000 feet thick in the southern part of the Wasatch Plateau (Spieker, 1946, p. 136).

Neither a well-exposed upper nor lower contact of the Flagstaff limestone was found in the mapped area. The position of the Flagstaff with respect to older rocks in the northern part of the Capitol Reef area indicates that beds of the Flagstaff were deposited on an extensively eroded surface; probably a minimum of 4,000 feet of beds, including all the Cretaceous and much of the Jurassic rocks, was removed by the erosion prior to the deposition of the Flagstaff in the northwestern part of the area. Also the Flagstaff probably was much eroded in places before the younger lavas covered the area, although around Boulder and Thousand Lake Mountains the base of the lavas appears to be fairly regular and even.

The Flagstaff limestone is late Paleocene and probably early Eocene in age (La Rocque, 1951, p. 1457–1458; Spieker, 1954, p. 10).

Charophytes and ostracodes occur in the Flagstaff limestone in many outcrops west and southwest of Thousand Lake Mountain. From a series of samples collected at numerous localities, Raymond E. Peck of the U.S. Geological Survey identified the charophyte *Aclistochara* sp. (species undescribed) and the ostracodes *Metacypris* aff. *M. angularis* Peck, *Candona* sp., and *Paracypris* sp. In considering the age of these forms, Mr. Peck states (written communication, 1953):

> We are once again troubled by a lack of data on nonmarine microfossils in the interval between the Cretaceous Bear River and the Paleocene. The rocks represented by these samples are almost certainly younger than Bear River and are not younger than Paleocene. From the general aspect of the charophytes I judge the age to be Upper Cretaceous, possibly early Tertiary.

Fossils from three localities in the Capitol Reef area were identified by John B. Reeside, Jr. He states that all belong to one faunal assemblage, that "they lack all the familiar species that usually appear in Late Cretaceous lots and most of those that usually appear in early Tertiary lots," and that they probably are a Flagstaff fauna and "possibly as late as early Eocene." The localities and the fossils identified by Mr. Reeside are as follows. (1) About 2½ miles north-northwest of Lyman; limestone on west side near head of west tributary of Lime Kill Hollow, charophyte oogonia and stems(?), ostracodes, *Valvata* sp., *Goniobasis* aff. *G. tenera* Hall and varieties, *Lymnaea* sp., and *Gyraulus* sp.; (2) about 1 mile north-northwest of Bicknell; sandy limestone in first small canyon south of Shingle Mill Creek, charophyte oogonia, ostracodes, *Unio clinopisthus* White, *Valvata*? sp., *Goniobasis* aff. *G. tenera* Hall and varieties, *Lymnaea* sp. (same as from locality 1), *Gyraulus* sp. (same as from locality 1), and *Physa* sp.; (3) about three-fourths mile north of Bicknell on west side of canyon; limestone, charophyte oogonia, ostracodes, *Unio clinopisthus* White, *Unio haydeni* Meek, *Unio* cf. *U. washakiensis* Meek, *Goniobasis* sp., and *Lymnaea* sp.

The limestone just north of the mapped area north of Hens Peak has stromatolite fragments containing numerous spherical objects that resemble *Chlorellopsis coloniata*, according to Richard Rezak of the U.S. Geological Survey. Mr. Rezak reports (written communication, 1957) that the rock samples also contain fragments of gastropods, ostracodes, and poorly preserved vegetative structures of charophytes but that none of the fossils are useful for dating. They do indicate a fresh-water lake environment. The alga *Chlorellopsis coloniata* forms the greater part of many reefs in the Green River formation (Bradley, 1929, p. 209–210).

Although the fossil data permit a time range from Late Cretaceous to early Eocene for the Flagstaff limestone, field evidence seems to indicate most likely a late Paleocene and probably early Eocene age for the formation. This interpretation is based in part on correlation with dated beds of the Flagstaff to the north, on relations to Cretaceous and older beds, and on the pre-Flagstaff deformation and erosion (see p. 60).

According to Spieker (1946, p. 136 and 155; 1949, p. 32; 1954, p. 10–11) the Flagstaff limestone may extend far south of the Wasatch Plateau and may be represented by beds now called Wasatch in the Bryce Canyon-Cedar Breaks region. Our identification of blocks of Flagstaff in surficial deposits on the south flank of Boulder Mountain extends the recognized Flagstaff about 60 miles south-southeast of the Wasatch Plateau. The Wasatch formation in the Kaiparowits region (Gregory and Moore, 1931, p. 115) is similar to the Flagstaff. The white beds that consist of limestone, sandstone, conglomerate and "all the volcanic ash and tuff so far found in the Wasatch formation" in the Paunsaugunt region (Gregory, 1951, p. 50) are very similar to the Flagstaff in the Capitol Reef area. As the white beds are the youngest of three units of the Wasatch in the Paunsaugunt region (Gregory, 1951, p. 44–52), all the Wasatch in that area may be equivalent to Flagstaff or older beds.

The Flagstaff was deposited in a lacustrine environment (Spieker and Reeside, 1925, p. 448–449). Some of the sandstone beds probably are lakeshore deposits, and some of the crossbedded sandstone and conglomerate may be stream deposits in areas that temporarily were not covered by lakes. The large cobbles around which algae grew probably were not transported very far and may have been derived from steep slopes near a lake margin. Source areas for the tuffs and for the lava pebbles are presumed to be somewhere west of the Capitol Reef area.

IGNEOUS ROCKS AND ASSOCIATED TUFFACEOUS SEDIMENTARY ROCKS

Igneous rocks and associated tuffaceous sedimentary rocks cover about 100 square miles of the Capitol Reef area. Lava flows constitute the bulk of the igneous rocks. Sills and about 25 linear miles of thin dikes constitute the rest.

The lavas consist chiefly of porphyritic andesite and some andesite scoria. On the geologic map (pl. 1), areas of volcanic materials are shown as two units: (1) Chiefly lava flows with interbedded tuffaceous sedimentary rocks, and (2) chiefly tuffaceous sedimentary rocks with interbedded lava flows.

Mineral analyses of 18 thin sections of extrusive rocks and 7 thin sections of intrusive rocks were made by point count and mechanical stage. Refractive indices of cleavage flakes were measured in oils. The anorthite content of the plagioclase feldspars was determined by use of Tsuboi's curve that plots refractive index of cleavage flakes against percent anorthite content (Rogers and Kerr, 1942, p. 244). The anorthite content determined by indices was checked by measuring extinction angles of sections perpendicular to (001) and (010) cleavages (Wahlstrom, 1947, p. 73).

Rock names applied are used in a broad sense: basalt for the intrusive rocks, and chiefly porphyritic andesite for the extrusive rocks. For a possible more detailed breakdown, table 4 shows the results of chemical analyses made by the rapid-type methods similar to those described by Shapiro and Brannock (1956) and shows the CIPW normative values calculated from these analyses. Two specimens of intrusive rocks and 11 specimens of extrusive rocks were analyzed.

INTRUSIVE ROCKS

The intrusive igneous rocks consist of feldspathic basalt dikes, sills, and a few pluglike widened dikes. Several sills on cliff faces in the northeastern part of the area are not shown on the map (pl. 1) for cartographic reasons. The intrusive bodies generally are more resistant to erosion than the enclosing rocks and form low discontinuous walls or ledges. At a few places, dikes are less resistant and do not project above the enclosing rocks. Contacts between the basalt and the country rock are sharp and even, with little or no metamorphic effects except at one locality. The one exception noted is at the south end of a dike in sec. 23, T. 28 S., R. 4 E., where the contact is irregular and uneven and the surrounding Navajo sandstone has been changed to quartzite. At this contact zone, small dikelets and rounded blebs of basalt are within iron-stained bedded quartzite.

Most of the dikes trend within 15° of north, parallel to a prominent joint trend. A few dikes are intruded along faults of very small displacement. Some of the dikes are intersected by northwestward-trending faults, but the dikes are not offset by the faults and evidently are younger than them.

Most of the intrusive igneous rocks are fine grained and porphyritic; crystals of pyroxene are scattered in a groundmass of mostly plagioclase microlites. Some specimens are nearly equigranular, and others have a diabasic texture. The basalts are dark gray and have vesicles filled with white to transparent calcite and analcite. The most prominent crystals seen without the aid of a microscope are yellowish-brown pyroxene.

The mineral composition of the intrusive igneous rocks is shown in table 5. Ever-present minerals are plagioclase, pyroxene, magnetite, and calcite. The clinopyroxene is almost exclusively augite in crystals as much as 3 mm long. Most augite phenocrysts have hourglass extinction, and many are grouped in radiating, starlike clusters, a few of which have cores of magnetite crystals. As seen in thin section, calcite appears to have replaced crystals of olivine and some clinopyroxene.

TABLE 4.—*Chemical composition and CIPW normative value of representatives samples of igneous rocks of the Capitol Reef area, Utah*

[Analysts: P. L. D. Elmore, K. E. White, S. D. Botts, and P. W. Scott, U.S. Geological Survey]

	Extrusive rocks					
	1	2	3	4	5	6
Field	NW¼ sec. 31, T. 28 S., R. 4 E. CR-61	NW¼ sec. 6, T. 29 S., R. 4 E. CR-72	Near Donkey Point, Boulder Mountain CR-98	NW¼ sec. 28, T. 27 S., R. 4 E. CR-126	Near Donkey Point, Boulder Mountain 131a	Near Donkey Point, Boulder Mountain 131b
Laboratory	146627	146629	146632	146635	146636	146637
Rock type[1]	Porphyritic andesite	Porphyritic andesite	Porphyritic andesite	Porphyritic andesite	Porphyritic andesite	Andesite scoria
Chemical analyses						
SiO_2	56.5	63.1	56.5	58.1	56.7	56.8
Al_2O_3	16.6	15.8	17.0	16.9	16.6	17.4
Fe_2O_3	5.8	5.2	5.3	4.9	5.8	6.6
FeO	2.3	.23	2.7	3.0	2.5	1.4
MgO	2.9	1.7	2.6	2.5	2.9	3.0
CaO	6.1	4.8	5.9	4.9	5.8	5.9
Na_2O	3.7	3.9	4.1	3.3	3.6	3.8
K_2O	3.4	3.2	3.9	3.7	3.6	3.4
TiO_2	.98	.67	.98	1.0	1.0	.99
P_2O_5	.54	.40	.44	.56	.58	.54
MnO	.14	.05	.13	.12	.13	.12
H_2O	1.5	.67	1.0	1.8	1.7	.74
CO_2	.12	.15	.05	.12	.10	.08
Sum	101.00	100.00	101.00	101.00	101.00	101.00
CIPW[2] normative values						
Q	8.6	18.0	4.86	12.5	8.4	7.6
or	20.0	18.9	22.8	21.7	21.1	20.0
ab	31.4	33.0	34.6	27.8	30.4	32.0
an	18.6	16.1	16.7	20.5	18.6	20.6
C	------	------	------	------	------	------
wo	1.9	1.2	3.9	------	2.5	1.9
en	7.3	4.0	6.5	6.2	7.2	7.5
fs	------	------	------	------	------	------
il	2.0	.6	2.0	2.0	2.0	2.0
tn	------	.5	------	------	------	------
mt	4.9	------	6.3	7.2	5.6	1.6
hm	2.4	5.3	1.0	------	1.9	5.4
ap	1.3	1.0	1.2	1.3	1.3	1.3
cc	.3	.3	.1	.3	.2	.2
H_2O	1.5	------	------	------	------	------
CIPW symbol	II. (4)5.2.3(4)	II. (4)5.2.3(4)	II. (4)5.2.3(4)	II. (4)5.2.3(4)	II. (4)5.2.3(4)	II. (4)5.2.3(4)

[1] Field name used in this report.
[2] Washington (1917).

TABLE 4.—*Chemical composition and CIPW normative value of representatives samples of igneous rocks of the Capitol Reef area, Utah*—Continued

[Analysts: P. L. D. Elmore, K. E. White, S. D. Botts, and P. W. Scott, U.S. Geological Survey]

	Extrusive rocks—Continued					Intrusive rocks	
	7	8	9	10	11	1	2
Location	Near Deer Lakes, Boulder Mountain	SW¼ sec. 16, T. 29 S., R. 3 E.	SW¼ sec. 16, T. 29 S., R. 3 E.	E½ sec. 8, T. 27 S., R. 3 E.	NW¼ sec. 5, T. 27 S., R. 3 E.	NW¼ sec. 19, T. 29 S., R. 4 E.	SW¼ sec. 28, T. 28 S., R. 5 E.
Field	CR-235	CR-133a	CR-133b	CR-170	CR-227	CR-132	CR-176
Laboratory	146648	146639	146640	146643	146647	146638	146644
Rock type [1]	Andesite scoria	Porphyritic latite	Welded tuff	Porphyritic latite	Welded tuff	Basalt	Basalt
Chemical analyses							
SiO_2	56.0	65.6	64.1	69.2	62.7	41.0	43.8
Al_2O_3	17.6	16.6	16.0	15.8	17.2	13.6	14.0
Fe_2O_3	6.2	2.4	1.8	1.9	2.5	5.3	5.0
FeO	1.8	.57	1.1	.42	.85	4.9	3.6
MgO	3.0	.84	.85	.46	.90	7.2	6.4
CaO	5.8	2.2	1.7	1.0	2.5	13.6	12.3
Na_2O	3.8	4.0	3.8	3.8	4.2	1.4	2.6
K_2O	3.4	6.3	6.4	6.8	5.1	1.6	2.7
TiO_2	1.0	.72	.72	.61	.78	1.8	1.3
P_2O_5	.46	.18	.16	.16	.18	.81	1.0
MnO	.12	.05	.06	.03	.06	.14	.17
H_2O	.92	.53	3.1	.27	3.2	5.2	1.6
CO_2	.05	.15	+.05	.08	.05	3.4	5.8
Sum	100.00	100.00	100.00	101.00	100.00	100.00	100.00
CIPW [2] normative values							
Q	6.5	13.0	13.4	19.2	12.6	0.6	0.5
or	20.0	37.3	37.8	40.0	30.0	9.4	16.1
ab	32.0	34.1	32.0	32.0	35.6	12.1	22.0
an	21.1	8.6	7.2	3.1	11.1	25.9	18.1
C			.2	1.1	.7		.1
wo	1.7	.2				6.1	
en	7.5	2.1	2.1	1.1	2.3	18.0	16.0
fs						1.9	.8
il	2.0	1.4	1.4	.9	1.5	3.5	2.4
tn				.4			
mt	3.0		1.6		.7	7.7	7.2
hm	4.2	2.4	.6	1.9	2.1		
ap	1.3	.3	.3	.3	.3	2.0	2.4
cc		.3		.2	.1	7.7	13.2
H_2O						5.2	1.6
CIPW symbol	II. (4) 5. 2. 3 (4)	I''. 4 (5). 1 (2). 3	I''. 4 (5). 1 (2). 3	I''. 4 (5). 1 (2). 3	I''. 4 (5). 1 (2). 3	III. 5. 3. 3''	III. 5. 3. 3''

[1] Field name used in this report.
[2] Washington (1917).

TABLE 5.—*Mineral composition of intrusive igneous rocks, Capitol Reef area, Utah*

Location				Field	Rock type	Percent of total thin section										Average anorthite content of plagioclase
¼	Sec.	T. (south)	R. (east)			Plagioclase	Clinopyroxene	Magnetite	Olivine	Hornblende	Biotite	Analcite	Unknown or miscellaneous minerals	Iron hydroxide	Calcite	
SW	12	27	4	CR-155	Analcite basalt	61.5	18.0	3.0	12.0			1.0	[1 2] 2.5		2.0	(3)
NE	23	28	4	145	do	57.0	15.0	8.0	1.0			3.0		2.0	14.0	(3)
SE	10	28	6	147	do	23.0	28.0	4.5		12.5	9.5	1.0	[4] 10.0		11.5	(3)
SW	28	28	5	176	do	54.0	26.0	5.5			2.0	1.0		0.5	11.0	61
NW	19	29	4	132	do	58.5	16.0	8.0	2.0			1.5	[5] 10.0		4.0	(3)
		26	6	146	Basalt	52.0	19.0	4.5			13.0		[1 6 7] 2.0	0.5	8.5	(3)
NW	30	29	5	S-263	Olivine basalt	60.0	16.0	4.5	11.5		1.0		[8] 2.0		5.0	(3)

[1] Unknown; layers of very small pale-brown prisms perpendicular to edges of cavities; $n<$balsam; birefringence low; relief medium.
[2] Unknown; very small pale-green prisms in layers filling cavities and fractures in pyroxenes; $n>$balsam; birefringence low; relief medium.
[3] Indeterminable.
[4] Unknown; very small about equant crystals, yellowish brown; cavity fillings; $n<$balsam; birefringence very low; relief medium.
[5] Unknown; very small pale-brown prisms; $n<$balsam; birefringence medium; relief medium; pseudomorphic after olivine; cavity linings.
[6] Penninite.
[7] Small pale-blue prisms in plagioclase, probably apatite.
[8] Unknown; dark brownish-green crystals nearly indiscernible at 344 magnification; weakly and diffusely anisotropic; $n<$balsam; birefringence low; relief medium.

The dikes and sills of the Capitol Reef area are similar in composition to the analcite diabase from the area of the San Rafael Swell (Gilluly, 1927).

EXTRUSIVE ROCKS

The extrusive rocks are well exposed in general, particularly on Boulder and Thousand Lake Mountains, where the capping lava averages about 475 and 350 feet in thickness respectively (plate 1). Margins of the lava caps of these mountains are dark vertical cliffs which are notched here and there and are draped at the bases by aprons of talus and slide blocks (fig. 21). At several places, 2 or 3 flows in vertical sequence can be distinguished on the basis of gross texture and color. The rim at the head of East Boulder Creek on Boulder Mountain, for example, is composed of three flows: lower and upper dense flows and a middle comparatively more rubbly scoriaceous flow. Boundaries between dense and scoriaceous flows are irregular in detail, and generally the boundary surfaces are coated with red iron oxides.

Volcanic rocks north of Fremont are poorly to well exposed. They consist chiefly of dense flow rocks and some agglomerate and tuffaceous sedimentary rocks. An unusual unit in this part of the mapped area is a very even layered hard tuff about 2 feet thick. In this tuff, fine-grained yellowish-pink rock is interbedded with black glassy rock in layers from about ⅛ to 1 inch thick. Flakes of biotite are abundant in the pink layers.

Exposures of the lavas on the Awapa Plateau south of Rabbit Valley are good in the valleys and poor to good elsewhere. In this part of the mapped area the volcanic rocks are chiefly porphyritic andesite, some scoria, and at least one layer of black glassy welded tuff.

The most abundant lava is porphyritic andesite that is vesicular in some flows (table 6). This rock is almost black to dark and light brownish gray and contains light-gray phenocrysts of plagioclase. Weathered surfaces are generally lighter than fresh ones. Individual flows are as much as 100 feet thick and some can be traced for almost a mile, beyond which distance they become indistinguishable from adjacent flows.

Phenocrysts compose 35 to 65 percent of the porphyritic andesites. The ever-present minerals forming the phenocrysts are plagioclase feldspars, pyroxene, and magnetite. Most conspicuous phenocrysts are plagioclase, commonly about 10 mm long but as much as 15 mm long. The anorthite content of the plagioclase ranges from 41 to 63 percent. Next most conspicuous phenocrysts are dark-green clinopyroxene, chiefly augite as much as 8 mm across, and olivine in some rocks. Minerals that may or may not be present as phenocrysts are orthopyroxene, olivine, iddingsite, hornblende, biotite, and apatite (table 6). The groundmass of the andesite is composed chiefly of feldspar in most specimens and lesser amounts of pyroxene, magnetite, and hematite(?); maximum grain sizes in the groundmass range from 0.0025 to 0.5 mm. Feldspars are mostly untwinned in equigranular or felted masses of an index lower than 1.54.

Calcite fills vesicles in some of the andesite flows. A few subrounded quartz grains about 0.5 mm in diameter are surrounded by calcite in a vesicle in one thin section.

Andesite scoria is present in almost every large exposure of flow rocks. The scoria is porphyritic; laths of chiefly plagioclase phenocrysts are in a dark-red glassy groundmass. The anorthite content of the plagioclase phenocrysts is about 50 percent. Clinopyroxene and magnetite and some orthopyroxene are the next most common phenocrysts.

The welded tuff on the Awapa Plateau contains phenocrysts of chiefly almost white plagioclase and some clinopyroxene, magnetite, biotite, and hornblende. A black glassy groundmass forms more than 80 percent of the rock (table 6). As seen in thin section the groundmass contains many glass shards and flattened or collapsed pumiceous fragments.

On the basis of calculated norms (table 4) the extrusive igneous rocks can be divided into (1) those that contain 30 percent or more orthoclase and (2) those that contain less than 23 percent orthoclase; no samples contain between 23 and 30 percent. Rocks of the 2 groups can be placed in 2 geographic units in the Capitol Reef area. Those samples that contain 30 percent or more orthoclase are all from west of the Thousand Lake fault; they are from the Awapa Plateau (fig. 2) and from localities north of Fremont. Those samples that contain less than 23 percent orthoclase are from Boulder and Thousand Lake Mountains and from just west of the Thousand Lake fault in sec. 6, T. 29 S., R. 4 E., and sec. 36, T. 28 S., R. 3 E. The samples from Boulder and Thousand Lake Mountains and from sec. 36, T. 28 S., R. 3 E., were collected less than 500 feet above the base of the lavas, and the sample from sec. 6, T. 29 S., R. 4 E., was collected probably less than 500 feet above the base. Those samples collected from the Awapa Plateau and from localities north of Fremont are from an unknown distance above the base of the lavas, because the thickness of the lavas is unknown in those areas. We do not pretend to explain the areal or possible stratigraphic differences in the volcanic rocks, because these rocks are along the margin of an extensive area of volcanic rocks to the west; the answers should be found in a study of the larger area. In addition, chemical analyses of more samples might indicate that the geographic groupings are not real, although the samples

TABLE 6.—*Mineral composition of extrusive igneous rocks, Capitol Reef area, Utah*

Location				Field	Rock type	Phenocrysts (percent of total thin section)												Average anorthite content of plagioclase	Groundmass (percent)	
¼	Sec.	T. (south)	R. (east)			Plagioclase	Clinopyroxene	Orthopyroxene	Magnetite	Olivine	Iddingsite	Hornblende	Biotite	Analcite	Unknown or miscellaneous minerals	Iron hydroxide	Calcite		Plagioclase	Other
SW	23	30	4	CR-98	Porphyritic andesite	48.3	4.0	-------	1.5	0.5	2.5	-------	-------	-------	[1] 0.2	-------	-------	53	43.0	-------
SW	26	30	4	131a	do	28.5	5.0	1.0	2.5	-------	4.5	-------	-------	-------	-------	-------	-------	47	-------	58.5
NE	28	27	4	126	do	25.0	3.5	2.0	1.5	.1	2.0	-------	-------	-------	-------	-------	-------	53	65.9	-------
SW	16	29	3	133a	Porphyritic latitee	11.0	.2	.1	1.0	-------	-------	-------	0.5	0.5	-------	-------	-------	47	-------	86.7
SE	31	29	3	136b	Porphyritic andesite	27.0	4.0	-------	3.5	-------	-------	-------	.5	-------	-------	-------	-------	61	-------	65.0
NW	31	28	4	61	do	28.5	2.0	-------	1.0	-------	4.0	-------	-------	-------	-------	-------	1.5	63	-------	63.0
NE	36	28	3	64	do	39.5	5.0	-------	3.0	-------	1.5	-------	-------	-------	-------	-------	3.0	61	-------	48.0
NW	6	29	4	72	do	37.5	4.0	-------	.5	-------	-------	0.2	.2	-------	-------	4.0	-------	44	-------	53.6
NW	6	29	4	69	do	28.5	6.0	-------	2.5	-------	-------	1.0	2.0	1.0	-------	-------	6.0	41	-------	52.9
NW	6	29	4	67	do	33.0	4.5	-------	2.5	-------	-------	-------	1.5	-------	-------	-------	14.5	44	-------	43.5
NW	6	29	4	66	do	25.0	5.0	-------	3.5	.5	3.0	-------	-------	-------	-------	-------	-------	63	63.0	-------
SW	6	29	4	65	do	30.0	1.5	-------	1.5	-------	3.5	-------	-------	-------	-------	-------	-------	61	-------	63.5
NE	20	29	3	134	Porphyritic olivine andesite	26.5	6.0	-------	2.5	5.0	-------	-------	-------	.1	-------	-------	-------	45	13.5	45.5
E	31	29	3	135	do	33.5	8.0	.5	5.5	4.0	-------	-------	-------	-------	-------	-------	-------	51	25.0	23.5
SE	31	29	3	136a	do	40.0	4.5	-------	5.0	1.0	3.5	-------	-------	-------	-------	-------	-------	53	46.0	-------
Boulder Mountain (1 mile south of Donkey Point)				107	do	32.5	3.0	1.0	2.0	3.0	6.0	-------	-------	-------	-------	-------	-------	50	52.5	-------
¼	Sec.	T. (south)	R. (east)																	
SW	26	30	4	131b	Andesite scoria	24.0	8.5	.5	7.0	-------	-------	-------	-------	-------	-------	Tr.	-------	49	-------	60.0
SW	16	29	3	133b	Welded tuff	12.5	.5	.1	.5	-------	-------	-------	2.0	.1	-------	-------	-------	[2] 4–44	-------	84.3

[1] Small pale-blue prisms in plagioclase; probably apatite. [2] Range of anorthite content.

for analysis were not chosen with any such groupings in mind. On the basis of present data, however, it is suggested that the lavas in the two groups differ because they came from different sources or because the composition of the magma changed with time.

TUFFACEOUS SEDIMENTARY ROCKS

On the basis of size of included fragments, the tuffaceous sedimentary rocks are divided into bouldery beds, gravel beds, and fine-grained beds. Exposures of these deposits generally are poor except in road cuts. Much of the area mapped as tuffaceous sedimentary rocks and included lava flows (pl. 1) consists of gently sloping even surfaces covered with scattered boulders and cobbles.

The bouldery beds are thick and massive and are composed of poorly sorted fragments ranging from sand size to boulders as much as 6 feet long. The boulders are angular blocks of gray, red, and black lava. The gravel beds are several feet thick and contain cobbles and rounded pebbles of lava. These beds grade into sand and granule beds that contain rounded and frosted quartz grains, which must have been derived from outside the area of volcanic rocks. The fine-grained beds are thin bedded and generally in beds 1/10 to 1 inch thick. They contain silt- and sand-size fragments of lava, rounded tuff pellets with spongy or pumiceous texture, and in places sand-size clear euhedral crystals of quartz. These beds commonly are white to greenish gray and are slightly consolidated locally.

AGE OF IGNEOUS ROCKS

Available data within the mapped area indicate only that the effusive rocks are younger than the Flagstaff limestone of late Paleocene and probably early Eocene age and that they are older than the pre-Wisconsin pediment gravels and other deposits of Quaternary age. The beds of the Flagstaff were eroded before extrusion of the lavas. Also, the area has been eroded extensively since extrusion.

Callaghan (1938, 1939) classifies the igneous rocks in the Marysvale region farther west in the High Plateaus section into units of earlier Tertiary, later Tertiary, and Pliocene(?) and Pleistocene(?) ages. No definite correlation can be made between igneous rocks in the Marysvale region and those in the Capitol Reef area until the intervening area has been studied. On the basis of a study of the Cenozoic geology of the Colorado Plateau, Hunt (1956, p. 82) concludes that the beginning of volcanism in the western part of the Colorado Plateau was during Miocene time.

The volcanic rocks and associated tuffaceous sedimentary rocks in the Capitol Reef area are dated tentatively as Miocene(?). We realize that they may be earlier or later in the Tertiary and perhaps early Pleistocene. Also they may be products of several volcanic episodes and may have been erupted during more than one Tertiary epoch.

The youngest beds cut by the dikes and sills are in the Curtis formation of Late Jurassic age. However, the dikes certainly are younger than the probable Paleocene joints and faults along which they were intruded. The intrusive rocks may be about the same age as the lavas.

PHYSIOGRAPHY AND QUATERNARY DEPOSITS

In the Capitol Reef area it is appropriate to consider the physiography with the Quaternary deposits because the physiographic development must be interpreted chiefly from these deposits. The relative ages of these surficial deposits can be judged from their degree of weathering and erosion since deposition and from their physiographic relationships to each other and to erosional surfaces in neighboring areas.

The Colorado Plateaus province, which includes the Capitol Reef area, is one of flat-topped plateaus and mesas, chimneylike buttes, vertical cliffs, and steep-walled canyons. The mapped area includes two principal physiographic sections: On the west are the Awapa and Aquarius Plateaus, parts of the High Plateaus of Utah section, and, on the east, are the Capitol Reef, the Waterpocket Fold, and adjacent areas, parts of the Canyon Lands section (fig. 2). These two physiographic sections present strong contrasts in topography and in their Quaternary deposits.

Boulder Mountain is the northernmost tip of the Aquarius Plateau. The mountain is a flat-topped upland about 15 miles across that is underlain by a series of horizontal lava flows. Blue Bell Knoll, a low knoll on top of Boulder Mountain, has an altitude of 11,328 feet and is the highest point in the Capitol Reef area. Thousand Lake Mountain is similar geomorphically to Boulder Mountain but much smaller; the crest of Thousand Lake Mountain is at 11,306 feet. The almost flat tops of both mountains are rimmed by vertical cliffs ranging from 100 to 600 feet in height. The top of Boulder Mountain has an irregular outline deeply indented by several broad glaciated valleys. West of Boulder Mountain and separated from it by an escarpment lies the Awapa Plateau, at an altitude of from 8,000 to 9,000 feet.

The Aquarius and the Awapa Plateaus are separated from Thousand Lake Mountain by Rabbit Valley, a broad alluvial lowland at an altitude of about 7,100 feet that is traversed by the Fremont River. Southeast of this lowland the Fremont River enters a narrow valley bordered by rugged cliffs.

The dominant topographic feature of the eastern or Canyon Lands section of the Capitol Reef area is a large monocline or bedrock flexure, the Waterpocket Fold. Capitol Reef National Monument includes the most accessible and scenic part of the series of cliffs and escarpments comprising this monocline. The Fremont River crosses the Waterpocket Fold below Fruita in a precipitous gorge several hundred feet deep and continues eastward to where it leaves the Capitol Reef area at an altitude of about 5,000 feet, the lowest point within the mapped region.

Grand Wash, Capitol Wash, Pleasant Creek, Sheets Gulch, and Oak Creek also cross the Waterpocket Fold in precipitous gorges. The old road from Fruita to Hanksville is located in the gorge along Capitol Wash (fig. 25), which is typical of all these gorges crossing the fold. At its narrowest point this gorge is only 25 feet wide at road level, and sandstone cliffs tower hundreds of feet above the road on each side.

The highest parts of the Waterpocket Fold, at altitudes between 7,000 and 8,000 feet, consist of massive Navajo sandstone and the overlying thin-bedded limestone and siltstone of the Carmel formation. Typically the Navajo crops out as bare knobs and ridges with rounded tops and steep sides. Much of this area is inaccessible, even to hikers, because of vertical rock walls and deep, narrow canyons.

The road from Grover south around the east side of Boulder Mountain offers superlative viewpoints, as at East End Point and Point Lookout, from which one can observe the marked contrast between the High Plateaus and the Canyon Lands. Dutton (1880, p. 285 and p. 286) set forth the difference in glowing terms. He described the plateau summit as follows: "Today we are among forests of rare beauty and luxuriance; the air is moist and cool, the grasses green and rank, and hosts of flowers deck the turf like the hues of a Persian carpet." The Canyon Lands when viewed from the east rim of the Aquarius Plateau presented (p. 286):

> a sublime panorama. The heart of the inner Plateau Country is spread out before us in a bird's eye view. It is a maze of cliffs and terraces lined off with stratification, of crumbling buttes, red and white domes, rock platforms gashed with profound canons, burning plains barren even of sage—all glowing with bright color and flooded with blazing sunlight. Everything visible tells of ruin and decay. It is the extreme of desolation, the blankest solitude, a superlative desert.

PRE-WISCONSIN DEPOSITS

Pediment gravels and boulder deposits, both considerably weathered and extensively dissected, are believed to be of pre-Wisconsin age. Throughout the Rocky Mountain region the older or pre-Wisconsin Quaternary deposits commonly are deeply weathered (Hunt and Sokoloff, 1950, p. 111), but in the Capitol Reef area such deep weathering and soil are rarely found. Flint and Denny (1958) believe that although some of the surficial deposits are probably of pre-Wisconsin age, none of the existing soils or other weathering phenomena furnish sufficient proof for such a classification. The identification of deposits of pre-Wisconsin age is admittedly difficult; nevertheless, the present writers believe that the extensive dissection of much of the Quaternary mantle is sufficient evidence to classify the deposits in large areas as probable pre-Wisconsin.

Pre-Wisconsin glacial deposits on or near the Colorado Plateau have been identified in the San Juan Mountains, Colo. (Atwood and Mather, 1932); in the La Sal Mountains, Utah (Richmond, 1962); in the San Francisco Mountains, Ariz. (Sharp, 1942); in the Uinta and Wasatch Mountains, Utah (Atwood, 1909); on Grand Mesa, Colo. (Retzer, 1954); and possibly in the Wasatch Plateau (Spieker and Billings, 1940, p. 1196). Thus, many nearby areas have pre-Wisconsin deposits at altitudes comparable to that of Boulder Mountain.

The presence of probable pre-Wisconsin drift implies that the Capitol Reef area was glaciated before the Wisconsin stage and that extensive deposits of till, outwash, and landslide materials accumulated. Very probably this early glaciation was followed by a period during which these deposits were weathered and dissected, and eventually the deposits were covered with a deep soil. Then a period of accelerated wind erosion, possibly during a prolonged drought, removed most of the soil cover except for the lime-rich or caliche horizon at the base of the soil profile on the pediment gravels. Sand blasting which accompanied the wind erosion fluted and faceted the tops of many large boulders projecting above the general surface of these deposits.

PEDIMENT GRAVEL

Pediment gravel caps many flat-topped hills and benches in the Capitol Reef area. The gravel-covered pediment surfaces all slope gently (1°–4°) away from nearby uplands and truncate the bedrock underneath irrespective of bedrock structure.

The pediment gravel is composed chiefly of partly rounded lava boulders and many smaller fragments plus a small proportion of granules and sand. Boulders 3 to 5 feet in length are abundant, and some are more than 15 feet in length. The cobbles and smaller fragments are also mostly lava, but they include silicified quartz-pebble conglomerate, rounded and polished pebbles of chert, quartz, and quartzite, angular pebbles of dense white limestone, and, in places, fragments of less durable rocks, such as gypsum and mudstone.

The pediment gravel consists of long, poorly defined, lenticular beds, about 2 to 6 feet thick, of open-textured gravel alternating with a few thin sand beds. The total thickness of these gravel beds generally is between 20 and 50 feet, though on some pediments it is much greater. The pediment gravel 2 miles northwest of the Cocks Comb is 100 feet thick.

No accumulation of leached clay due to weathering nor any obvious decay of pebbles was found on pediment gravels in the mapped area. The tops of many boulders exposed above the general pediment level have grooved or fluted surfaces typical of sand blasting that, judging from their common orientation, were caused by prevailing southwest winds. Some boulders have an iron or manganese surface staining. Otherwise, the lava boulders appear to be almost as fresh and as unweathered as the lava exposed in places on Boulder Mountain.

The pediment gravels commonly have a well-developed caliche or lime-enriched weathered zone. From the land surface to depths of 10 or 15 feet, each pebble and boulder in the gravel has a thick coat or layer of white caliche on its underside. The caliche layer is thicker upon pediment boulders than it is upon boulders of Wisconsin-age deposits of the same general altitude, and it is thicker and better developed on boulders in higher pediments than in the lower ones. The maximum thickness of caliche observed on boulders of highest and oldest pediments is about 1 inch. Thus, the amount of the caliche apparently depends in part upon the time that it has been accumulating. Profiles of soils with caliche developed in pediment gravel on the top of Lion Mountain and on a hill near Teasdale are given by Flint and Denny (1958).

The pediment gravels are at different altitudes and differ greatly in height above the neighboring lowlands; the highest cap local divides. On the north side of Lion Mountain, 3 miles south of Grover, pediment gravel is about 500 feet above the neighboring lowlands, and east of Sand Creek, northwest of Torrey, pediment gravel lies about 700 feet above the creek. Some low-lying pediment gravels are terracelike forms only 20 to 40 feet above neighboring lowlands. These wide differences in the amount of dissection since deposition of the pediment gravels indicate corresponding differences in ages.

The pediment gravels are believed to be of pre-Wisconsin age. The glacial deposits of Wisconsin age in the Capitol Reef area have been only slightly eroded, even along stream valleys. By contrast, the amount of erosion required to dissect the pediment surfaces and leave some of them hundreds of feet above the neighboring lowlands is judged to be greatly in excess of post-Wisconsin erosion. For this reason the higher pediment gravels are believed to be unquestionably of pre-Wisconsin age. Among the lower pediment gravels the one just south of Grover, which is separated from the moraine of early Wisconsin age by Carcass Creek, appears to have been formed and somewhat dissected before the till was deposited. Thus the low-lying pediment gravels are probably also of pre-Wisconsin age.

The physiographic evidence for the pre-Wisconsin age of the pediments appears indisputable. The absence of remnants of typical pre-Wisconsin soil developed on pediment gravel is explained by assuming its essential complete removal. The interpretation made here tentatively is that the pediment gravels had a deep soil cover in pre-Wisconsin time and that the clayey horizon of this soil has been washed off or blown away, leaving only the lower, lime-enriched horizon. The pediment gravel is highly permeable and probably did not retain enough moisture to support vegetation during prolonged droughts. A lack of or much decreased vegetative cover rendered the soil susceptible to deflation. It is quite possible that there were pre-Wisconsin periods of aridity and soil deflation in the Capitol Reef area, because such dry periods are known from other parts of the Colorado Plateau (Richmond, 1962). The presence of sand-blasted lava boulders on pediment surfaces also indicates a pre-Wisconsin period of wind erosion and aridity. None of the boulders in the Wisconsin stage deposits are sand blasted.

Whether the pediments and their gravel cover were formed by stream or by slope wash or by a combination of both processes is not known. The low lying pediments between Teasdale and Torrey all have modern streams near their margins and appear to have formed partly by the sideward shifting of similar streams. The higher pediments retain little evidence of their origin. Many of the boulders within the high pediment gravels are so large that it is difficult to conceive of stream velocities sufficient to transport them. Possibly these large boulders are relicts of much older deposits formed originally when the lava cliffs of Boulder and Thousand Lake Mountains were closer. If so, these large boulders may have been moved only moderate distances horizontally by gravity and slope wash. On the other hand, these large boulders may be relicts of an early Pleistocene glacial drift or of landslides containing large boulders far from the parent cliff.

BOULDER DEPOSITS

The boulder deposits include materials of diverse lithology and topographic expression and are characterized by boulder-covered slopes. The deposits are maturely dissected in most places; locally they cap hilltops at accordant levels, and elsewhere they form a mantle on slopes. Boulder deposits lack the morainic forms of the Wisconsin drift, the somewhat similar irregular and hilly topography of the Wisconsin landslides, or the benchlike form of the pediment gravels. The boulder deposits include a variety of materials that cannot be differentiated practically; they can be described only in very general terms because of their diverse origin.

The deposits consist predominantly of a poorly sorted mixture of silt, sand, and small rock fragments. Boulders of lava derived from the flows exposed near the tops of Thousand Lake and Boulder Mountains are abundant both in the deposits and on the surface; they commonly are 2 to 3 feet in length, and a few exceed 10 feet. The deposits change in lithology from place to place. Some include polished pebbles of chert and quartzite like those in the pediment gravels. Others contain irregular blocks 20 to 100 feet long of lava, volcanic breccia, or sedimentary rocks easily identified as being derived from local Tertiary, Cretaceous, and Upper Jurassic formations. Along lower Fish Creek, Carcass Creek, and Pleasant Creek the boulder deposits consist either of bouldery gravel similar to the pediment gravel or of a till-like mixture of boulders, silt, and clay.

The boulder deposits are unconsolidated and slump readily, and the original structure of the deposits is visible in only a few exposures along gullied creek bottoms. Boulder deposits along Government Creek several miles southwest of Teasdale consist of closely spaced fault blocks of lava and tuffaceous sedimentary rocks that have a wide range of attitude and are overlain by about 30 feet of poorly sorted boulder lava gravel. Farther west along a road cut near Pine Creek, blocks of lava, lava gravel, and tuffaceous rocks cut by more than 20 small faults are exposed within a distance of 200 feet. The gently sloping boulder-covered surface above this exposure gives virtually no indication of the structural complexity of the underlying materials. At other exposures, beds are folded on a small scale as well as faulted. At some exposures the materials are greatly mixed and resemble till.

One particularly puzzling area mapped as boulder deposits is along the west flank of Thousand Lake Mountain. Here an extensive area consists of many faulted blocks of sedimentary rock tentatively interpreted as ancient landslide deposits but which could conceivabiy be part of a tectonic fault complex which should be mapped as bedrock.

Boulder deposits mantle the flanks of Thousand Lake and Boulder Mountains and their foothills at altitudes ranging from 7,000 to 10,000 feet. The deposits are maturely dissected to a series of erosional slopes lacking kettles or other poorly drained depressions. In the area north of Lyman, hilltops capped by boulder deposits crudely define a possible ancient surface of erosion or accumulation. Elsewhere scattered masses of boulder deposits occur at widely different heights. Large areas of boulder deposits lie below some of the prominent points of Boulder Mountain, such as Donkey Point, Chokeberry Point, Bowns Point, and Trail Point.

Although no soil profile resembling that developed on pre-Wisconsin deposits elsewhere has been found on the boulder deposits, many of the lava boulders do show the effect of advanced weathering (fig. 16). Some

FIGURE 16.—Photograph showing weathered lava boulder from pre-Wisconsin deposits (boulder deposits) just beyond terminus of Miller Creek moraine of Wisconsin age.

boulders have exfoliated or split. In many, olivine has been dissolved from the rock surfaces; on others, iron and manganese have accumulated as surface coatings. Locally the degree of weathering of these boulders is distinctly greater than that of nearby boulders in deposits of the Wisconsin stage (fig. 17).

Caliche occurs on many boulders of the boulder deposits. The thickness of the caliche differs with altitude; at 7,000 feet it averages about ¼ inch in thickness, but at 8,000 feet it is only a thin film. The caliche coating the boulders in the boulder deposits is consistently thicker than caliche coating boulders of the Wisconsin deposits at the same altitude. Thus, the caliche thickness is of considerable help in distinguishing these deposits. Very probably most of the boulder deposits, like the pediment gravels, once were covered with a deep soil that has largely been removed so that only the caliche or carbonate-rich lower layer remains.

The mature dissection of most of the boulder deposits shows that they are erosional remnants of deposits

FIGURE 17.—Photograph showing fresh lava boulder in terminal Wisconsin moraine of Miller Creek glacial lobe.

FIGURE 18.—Photograph showing pre-Wisconsin(?) till overlain by Wisconsin outwash gravel. Road cut on Torrey-Grover road near Fish Creek crossing.

whose original topographic forms have been destroyed. In this respect they, like the pediment gravels, differ markedly from the glacial till and landslide deposits which have undergone little topographic modification by erosion. For this reason, and because of differences in weathering and caliche accumulation, most of the boulder deposits are tentatively assumed to be of pre-Wisconsin age. However, in some places it is impractical to separate small areas of colluvial and talus deposits of probable Wisconsin and perhaps later age from nearby areas of boulder deposits. Hence the boulder deposits cannot be considered entirely pre-Wisconsin in age.

The boulder deposits mapped near the mouths of Fish and Carcass Creeks and near Bowns Reservoir and Tantalus Flats along Pleasant Creek are identified tentatively as pre-Wisconsin till. Where the Torrey-Grover road crosses lower Fish Creek, similar material is exposed in road cuts (fig. 18). Texturally it is typical till, but unlike the Wisconsin till upstream it is weakly cemented and slightly weathered. In one exposure the till is overlain by Wisconsin outwash deposits, and any pre-Wisconsin soil that may once have been present was removed before the gravelly outwash was deposited. The till along lower Fish and Carcass Creeks has a subdued rolling topography except where dissected to a depth of about 100 feet along the creeks and the Fremont River.

A much larger area of probable pre-Wisconsin till is exposed along lower Pleasant Creek. The surface is one of poorly defined longitudinal ridges, unlike the knob and kettle topography of moraine of Wisconsin age. Pronounced weathering of this material is evident only in the area near Tantalus Flats, where the till is partly buried beneath sandy alluvium deposited by Tantalus Creek. Some exposures contain as much as 10 feet of weathered till in which at least half the lava boulders are kaolinized, iron stained, and soft enough to be cut with a knife. A 2-foot layer of reddish-brown clay comparable to the residual clay of typical pre-Wisconsin soil (Hunt and Sokoloff, 1950) overlies this weathered till and underlies a thin layer of alluvium.

These remnants of pre-Wisconsin till, mapped with the boulder deposits on plate 1 are correlated tentatively with the Cerro till of the San Juan Mountains, Colo. (Atwood and Mather, 1932, p. 101–111); with the Harpole Mesa tills of the La Sal Mountains, Utah (Richmond, 1962); and with the Illinoian till of the San Francisco Mountains, Ariz. (Sharp, 1942). Our interpretation requires at least one Pleistocene glacial stage in the Capitol Reef area prior to the Wisconsin.

WISCONSIN DEPOSITS

Wisconsin age glacial deposits in the Capitol Reef area retain their original depositional forms; they were identified as glacial deposits by Dutton (1880, p. 35, 41–42, 263, 264, 270, 279, 285), and this identification has been confirmed repeatedly by later studies. Because of their slight weathering and erosion, these deposits are considered to be late Pleistocene and are correlated with the Wisconsin or latest glacial stage of the Great Lakes region (Gould, 1939, p. 1380) and with the Bull Lake and Pinedale glacial stages of the Rocky Mountains (Holmes and Moss, 1955; Flint and Denny, 1958).

Late in the ice age a cold climate and abundant precipitation or a combination of both factors permitted a large icecap to form on the top of Boulder Mountain. This glacier overflowed the mountain rim and sent long tongues of ice down several valleys. Melt water from the ice deposited outwash gravels along drainage routes, and abundant moisture apparently caused many landslides in areas not covered by the ice. Wisconsin age deposits shown on the geologic map (plate 1) and discussed here include till, outwash gravel, terrace gravel, and landslide deposits.

TILL

The glacial moraines of the Capitol Reef area are composed chiefly of unstratified massive till of which the bulk is an unsorted mixture of clay, sand, and pebbles together with many boulders 1 to 3 feet in length. One boulder over 30 feet long was noted. Most fragments are lava, but a few are conglomerate, sandstone, siltstone, shale, and limestone. Poorly developed striated fragments occur in the till but are uncommon; the lava apparently does not lend itself to the development of striations. Some lava boulders have flat or "soled" surfaces and most have edges and corners partially rounded by abrasion. In many areas, the partly rounded lava boulders mantle the land surface.

Locally, the till is overlain by outwash gravel or overlies or contains lenses of such gravel. The moraines composed of till and some outwash gravel are jumbles of ridges and irregular knobs and kettles.

The till was deposited from glaciers that moved down valleys. The maximum thickness of the till is unknown but probably exceeds 200 feet, because in some places moraines rise as much as 200 feet above the adjacent drift-covered valley floor.

The top of Boulder Mountain and several valleys that drain its flanks were glaciated. Valley glaciers or glacial lobes deposited moraine along Donkey, Fish, Carcass, Pleasant, Oak, East Boulder, West Boulder, and Miller Creeks (pl. 1 and Fig. 19). A particularly prominent valley glacier occupied the Fish Creek and Carcass Creek valleys and extended as a broad ice tongue into the lowlands near Grover to an altitude of about 7,000 feet. Outwash gravel from the melting

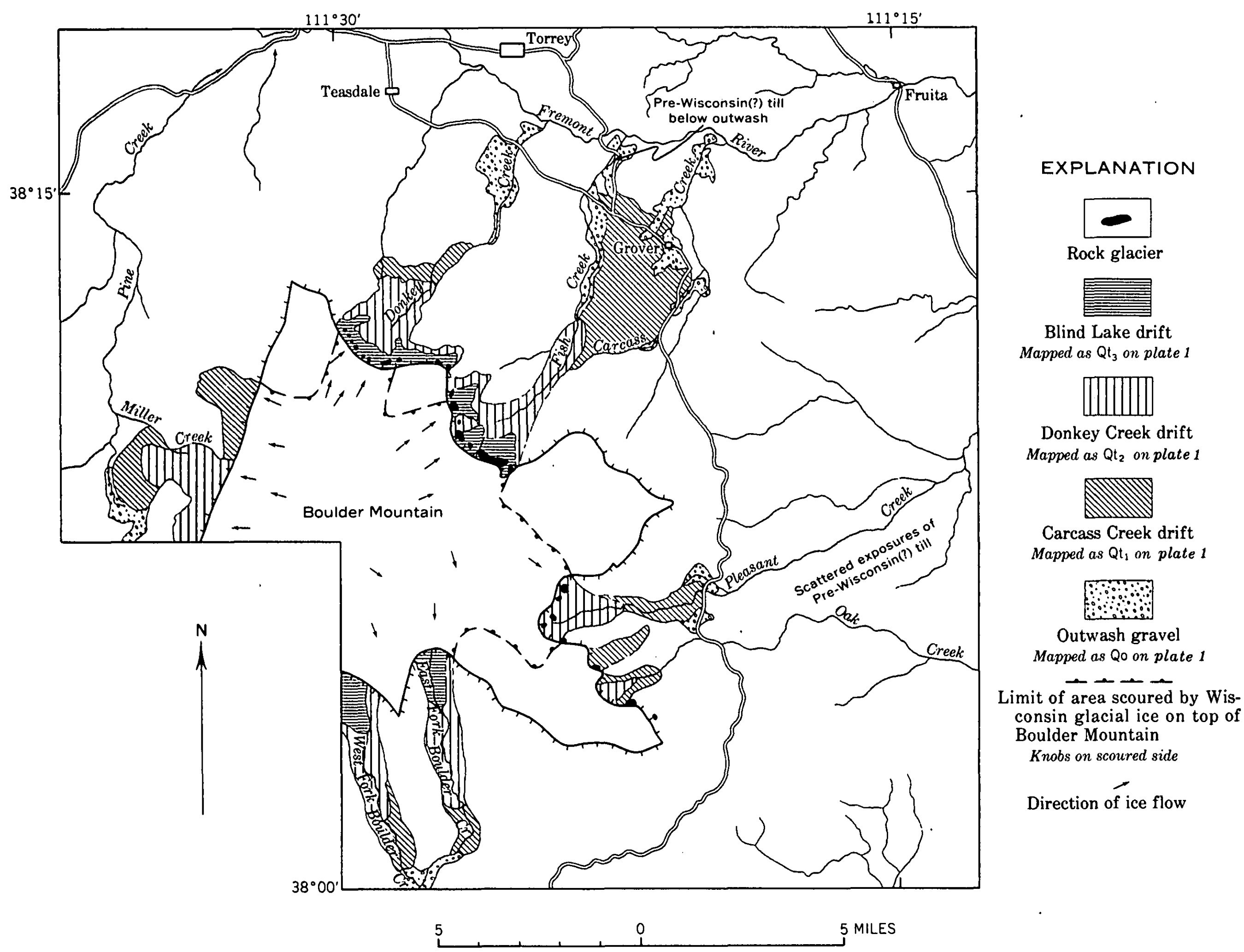


FIGURE 19.—Map of Boulder Mountain and vicinity showing extent of glaciation.

ice was deposited beyond this tongue along both Fish and Carcass Creeks to form deltalike deposits in the Fremont River gorge. This valley glacier deposited a low, inconspicuous terminal moraine, a bulky recessional moraine several miles above the terminal moraine, and a second but small recessional moraine near the head of the valley around the shore of Blind Lake.

The Donkey Creek valley glacier also deposited a small terminal moraine and a large bulky first recessional moraine. Outwash gravel from both of these moraines can be traced down Donkey Creek to the Fremont Valley. This outwash permits a correlation between the glacial drifts on the mountains and the alluvial deposits in the Fremont Valley. Details concerning this correlation are given with the description of the outwash gravel.

The Miller Creek valley glacier on the west side of Boulder Mountain was unusual; it was a narrow tongue in the mountain but expanded into a curious mushroom-shaped terminus where it extended over the flat surface of the Awapa Plateau. The terminal moraine has only a sparse tree cover and exhibits excellent knob and kettle topography.

Of all the valley glaciers, the one at the head of Oak Creek and another in a similar cirquelike amphitheater just north of Oak Creek were the only ones not connected with glacial ice on the mountain top. These indicate that not all the valley glaciers were nourished by the ice on Boulder Mountain.

Boulders in the till show little evidence of exfoliation, weathering, or sandblasting. The soil on the moraines is thin and poorly developed. Caliche is limited to thin coatings on the undersides of surficial boulders at altitudes of less than 8,400 feet. Soils developed on till at a high altitude (without caliche) and at a low altitude (with caliche) are described by Flint and Denny (1958). Scarcity of weathering and soil formation and lack of significant gullying of hillsides or filling of morainal depressions are indications of the youthfulness of these deposits and of their very probable Wisconsin age.

On the basis of the bulk and distribution of the moraines, three subdivisions of the Wisconsin till can be identified. These can be traced from valley to valley around Boulder Mountain (pl. 1). The subdivisions can be identified with greatest reliability in the valleys. Near the lava cliff on Boulder Mountain the moraines have been disturbed or partly obliterated by minor landsliding, and tracing their continuity is difficult.

Correlation of the tills on Boulder Mountain with those of other regions is highly tentative. The oldest till of the Capitol Reef area, the Carcass Creek drift of Flint and Denny (1958), may be equivalent to the Bull Lake glacial stage of the Rocky Mountain area. The intermediate-age till in the bulky recessional moraines and the youngest till in the smaller recessional moraines, the Donkey Creek and Blind Lake drifts respectively of Flint and Denny (1958), may be the equivalent of drift of the Pinedale glacial stage of the Rocky Mountain area.

The large area on top of Boulder Mountain (pl. 1) was scoured by Wisconsin glacial ice. Throughout this area unweathered lava either crops out as bare rock knolls and roches moutonnées or underlies shallow basins thinly veneered with drift. The surface of the lava has been abraded and grooved by glacial ice. The surface is smoothed rather than polished, probably because of the coarse texture of the rock, but the alinement of grooves and of linear topographic depressions particularly as revealed by aerial photographs faithfully record the direction of ice movement.

Abraded and grooved bedrock afford the best criteria for determining the limit of glaciation on the top of Boulder Mountain. Terminal moraines can be identified locally, but they are low and indistinct. No significant accumulations of outwash were observed. Outside the glaciated area the topography is gently rolling and the lava is covered with a thin residual soil.

Many irregular grassy depressions and rock-rimmed lakes or swamps are within the glaciated portion of the plateau top. In some of these grassy depressions, patches of turf-covered pebbles 2 to 6 inches across are separated by networks of turf-free pebbles. These features, which have been named patterned ground, seem to form in environments where the daily temperatures change across the freezing point, but the exact origin is still in doubt (Gerald M. Richmond, oral communication, 1953). The patterned ground on Boulder Mountain may be a relict from the Pleistocene; it does not have the fresh appearance of present-day patterned ground (Flint and Denny, 1958).

The direction of ice movement, indicated by arrows on plate 1, shows that an icecap covered much of the flat top of Boulder Mountain and moved outward toward the major reentrants in the plateau top (Gould, 1939, p. 1376). At times the ice probably fell as avalanches over summit cliffs, but during glacial maximums the cliffs may have been completely covered with ice and the reentrant valleys buried by glaciers to depths of more than 500 feet.

It is not known how many times Boulder Mountain was covered with ice. The icecap probably disappeared during the interstadial interval following deposition of till of the early Wisconsin substage (fig. 20) and possibly during the time between deposition of the two late Wisconsin tills (fig. 20), the Donkey Creek and

Blind Lake interval of Flint and Denny (1958). It is possible that during some stages more ice accumulated on the flanks of the mountain than on the top. In particular, the glaciers of the Blind Lake substage may have been nourished by snow that accumulated at the base of the summit cliff; those in the Oak Creek reentrant, for example, were not associated with glaciation of the mountain top.

OUTWASH GRAVEL

The outwash gravel was deposited by streams draining the melting glacial ice lobes. The outwash is chiefly unconsolidated, open-textured gravel forming lenses with low-angle cross-laminations and composed of pebbles and boulders of lava and pebbles of quartzite, chert, limestone, and sandstone. The largest boulders, which are 2 to 3 feet in length, are smaller and appreciably more rounded than those of the associated till. Outwash sand interbedded with the gravel is coarse, gray, well sorted, and composed mostly of lava grains and has high-angle cross-laminations. Many outwash deposits are partly concealed beneath thin layers of alluvium or colluvium.

Outwash gravel underlies flat lowlands near and downstream from the moraines. The distribution of the outwash gravel and of the till in the moraines reveals their genetic relationship (pl. 1). In the Capitol Reef area the greatest accumulation of till is in the terminal moraines and in the first bulky recessional moraines. Similarly, the greatest accumulation of outwash is just downstream from these moraines, indicating that melting balanced ice advance so that the ice margins must have remained relatively stationary at these places for considerable periods of time.

The outwash deposits provide a stratigraphic tie between the glacial moraines on the north flank of Boulder Mountain and the sedimentary fill of the Fremont River valley. Extensive outwash deposits are along Fish and Carcass Creeks downstream from the Fish Creek-Carcass Creek moraine. This outwash was deposited by streams from the glacial lobe that formed this moraine. In the Fremont River Valley, these outwash streams deposited a deltaic fan that dammed the river to form a glacial lake in which sandy lake sediments were deposited. Lake deposits and outwash overlying older till, probably pre-Wisconsin till, are exposed near the mouth of Fish Creek. Locally the outwash deposits may be as much as 50 feet thick.

Extensive outwash deposits also are associated with the Donkey, Miller, Pleasant, and Boulder Creeks moraines. Along Donkey Creek, most of the outwash is believed to correlate with the earliest moraine. This early Wisconsin outwash was entrenched by Donkey Creek. Late Wisconsin outwash, correlating with the recessional moraine, was deposited in the entrenched inner valley of the creek. The later outwash is covered by Recent alluvium which has been trenched by still later erosion. These relationships are well illustrated where the Grover-Teasdale road crosses Donkey Creek.

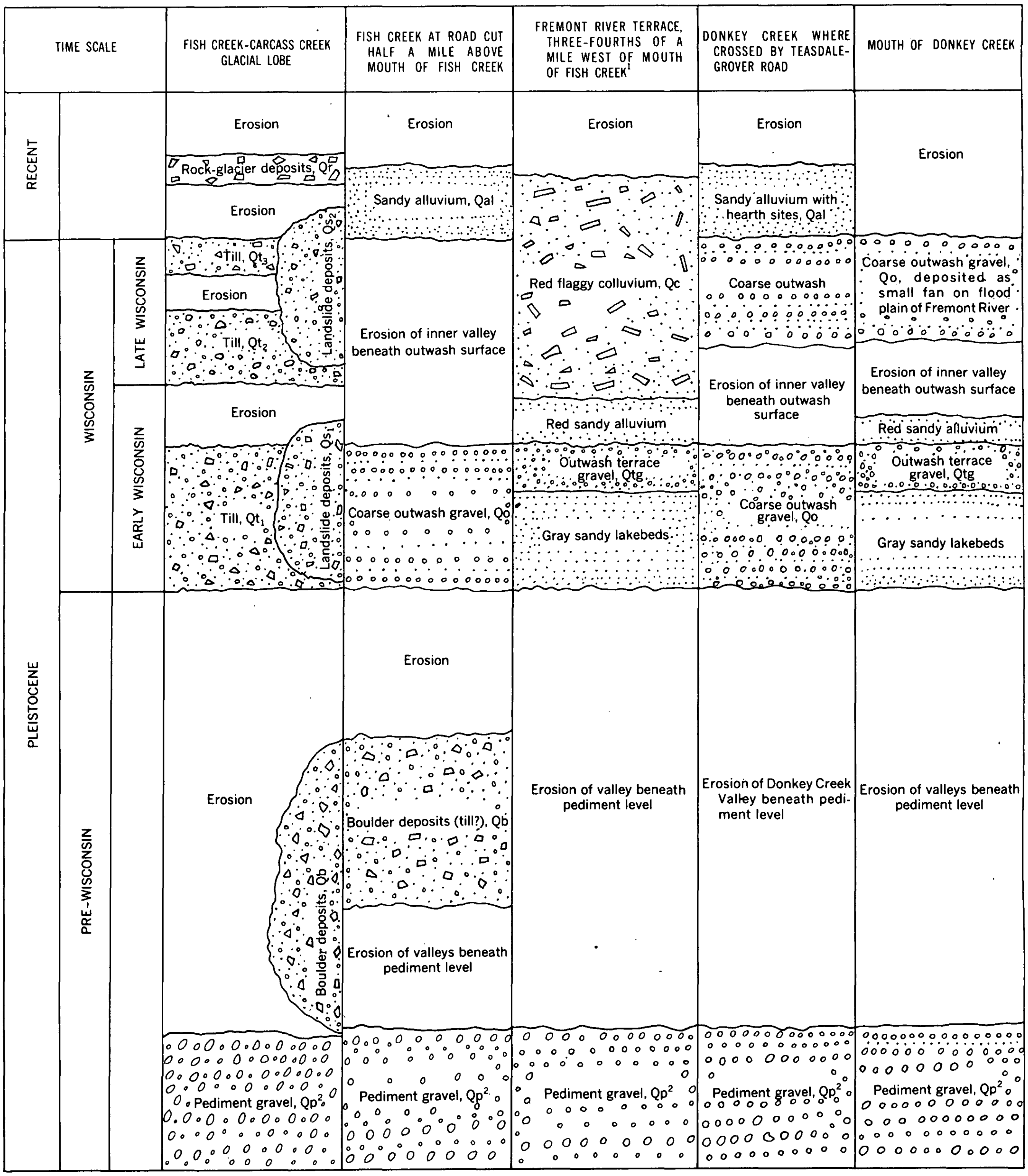
A suggested correlation of the deposits along Donkey Creek and at other areas is given in figure 20. This correlation shows not only the deposits but also the erosion intervals that were important in the physiographic development of the Capitol Reef area.

TERRACE GRAVEL

Terrace gravels and sands along the Fremont River and a few of its tributaries are believed to be either outwash or related deposits of Wisconsin age. The terrace gravels resemble the outwash but are slightly finer grained. Terrace gravel contains a few rounded boulders of lava, chiefly less than 2 feet in diameter, numerous pebbles of lava from Boulder Mountain, chert and quartzite from the Salt Wash member of the Morrison formation or from the Flagstaff limestone, and limestone probably from the Carmel formation. The terrace gravels range from less than 20 to more than 40 feet in thickness.

The Fremont River terrace where crossed by the Torrey-Grover road is more than 1,000 feet wide and about 50 feet above river level. The terrace consists of about 20 feet of gravel resting on an erosional terrace cut in the bedrock. The height of the terrace above the river increases downstream. At the mouth of Carcass Creek it is about 150 feet above the river, and Johnson Mesa, the large terrace remnant at Fruita, is about 250 feet above the river. Where the Fremont River leaves the mapped area, the highest of several terrace levels is about 200 feet above the river. Narrow rock-cut terraces with thin veneers of gravel are at various levels in the Fremont gorge through Capitol Reef. Similar terraces are from 50 to 200 feet above Oak and Pleasant Creeks. The highest terraces along these streams are assumed to be correlative.

The Fremont River terrace upstream from the mouth of Fish Creek and at the mouth of Donkey Creek is underlain by gray sandy lakebeds. These lakebeds apparently were deposited when outwash along Fish and Carcass Creeks first reached the Fremont River valley and later were covered with about 10 feet of gravelly outwash derived probably from Donkey Creek. The outwash terrace gravel and the correlative outwash along Donkey Creek apparently were dissected before late Wisconsin time; the late Wisconsin outwash along Donkey Creek floors an entrenched inner valley cut below the level of the early Wisconsin outwash. In the



[1]Flint and Denny 1958.

[2]From variations in altitude and other relations it is known that the pediment gravel, Qp, represents great variation in age.

FIGURE 20.—Correlation of surficial deposits of representative localities between Boulder Mountain and the Fremont River. Surficial deposits shown on geologic map (pl. 1) are indicated by appropriate map symbols (not all surficial deposits are shown on the geologic map).

Fremont River valley, a late Wisconsin outwash stream deposited a small alluvial fan, also beneath the level of the early Wisconsin outwash. The relations between the terrace and the outwash gravels are the chief basis for the detailed correlation given in figure 20.

The distribution of terrace gravels reflects the width and alinement of valleys during early Wisconsin time, when the terrace gravels were deposited. In general during this time the main valleys must have been very much like they are now, with gorges and valley floors in about their same general positions. The present height of the terraces above river or creek levels gives a measure of erosion since early Wisconsin time. Such erosion has been more extensive downstream than upstream, indicating that the overall relief of the area is increasing. The erosion indicated is comparable in magnitude to that measured elsewhere on the Colorado Plateau (Richmond, 1962; Sharp, 1942, p. 490).

LANDSLIDE DEPOSITS

Landslide deposits cover large areas on the flanks of Thousand Lake and Boulder Mountains. The landslides have hummocky boulder-strewn surfaces similar in general appearance to glacial moraines but of an entirely different mode of origin. These landslides originated through the slumping and settling of unfrozen ground; they did not result from the action of glacial ice.

The landslide deposits contain many fragments of lava but also contain a high proportion of the sedimentary rocks composing the mountains. The composition of the slides differs from place to place. Landslide deposits beneath the lava cliffs at the mountain tops consist of slices of little-disturbed lava several thousand feet in length derived by the breaking off and settling of long slices of the rimrock (fig. 21).

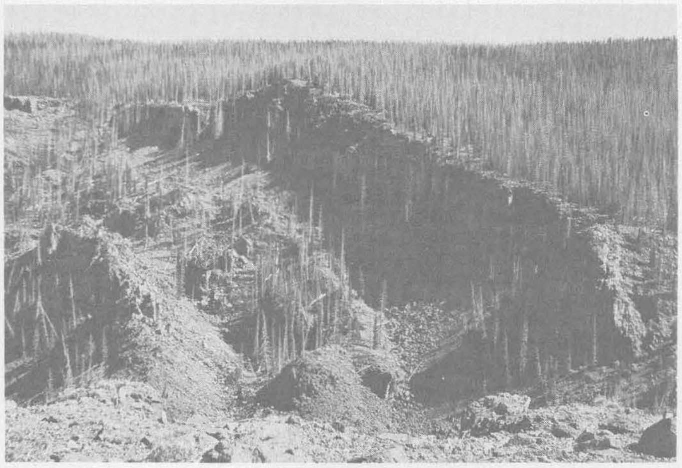


FIGURE 21.—Photograph showing landslide blocks of lava on Boulder Mountain southeast of Government Point.

Farther down the slope the slides consist of large blocks and arcuate slices of sedimentary rock that are faulted, shattered, and rotated, and that have slid from their original positions, yet still retain much of their original identity. Farther still down the slope towards the toe of the slides, individual slump blocks are small and broken, and the slides have the character of earth flows. In many slides the blocks of sedimentary rocks composing them crudely approximate their true stratigraphic position, with the youngest beds near the heads of the slides and the oldest beds near the toes.

The landslide deposits have topographic expression which differ according to their location and composition. Near the mountain tops, just below the lava rims, a typical landslide consists of extremely rough, jagged ridges of lava which crudely parallel the cliffs (fig. 21). On both Thousand Lake and Boulder Mountains, these high-altitude slides form shelflike belts about a mile wide. Drainage within these belts is entirely unorganized; there are many small lakes and undrained depressions.

The long, lobate slides at somewhat lower altitudes in the larger monglaciated valleys have been termed tonguelike complex landslides by Flint and Denny (1958). One of the best examples is along Bullberry Creek, northeast of Government Point, on the north side of Boulder Mountain (fig. 22). This slide is over 3 miles long and over 1 mile wide; its head is the irregular floor of a circular amphitheater in the lava cliff and its foot is a lobate mass of debris similar to a terminal moraine. The entire surface of the slide is covered with irregular transverse ridges, knobs, and small undrained depressions.

Small landslides occur at many places on the flanks of the mountains. The smaller slides are commonly simpler structurally and show better their mode of origin than the larger ones. The upper ends of these small slides consist of series of thin transverse fault blocks or slices which have slid down and rotated from their original positions to form steplike surfaces. Each "tread" dips back toward the mountain and forms a small undrained depression. In these small slides, as in the larger ones, the lower ends are lobate bulging earthflows.

Soils on the landslide deposits are poorly developed, the boulders unweathered, and the caliche sparse. The general lack of weathering, of stream dissection, and of filling of topographic depressions indicates that the landslides are relatively youthful features. During 1952 a partly opened earth fissure was found on the tonguelike complex slide along Bullberry Creek. Recent movement of about 4 feet at one point along this fissure was revealed by a 4-foot-wide split in a living

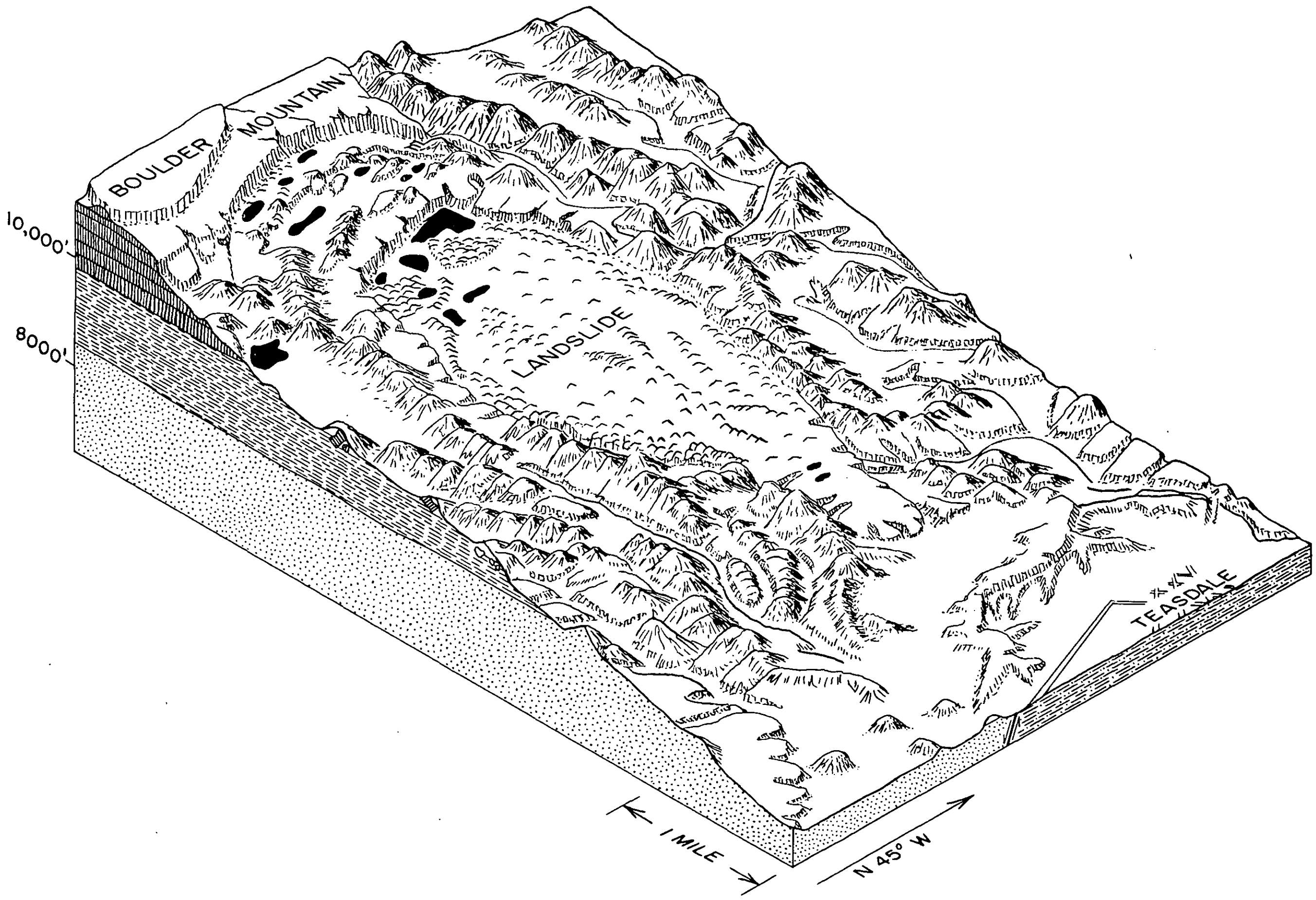


FIGURE 22.—Sketch showing tonguelike complex landslide along Bullberry Creek on the north side of Boulder Mountain. (Note vertical exaggeration.)

fir tree. Similarly, recent movement at the toes of many slides is revealed by tears and breaks in the turf cover. Landslides are known to have broken the Forest Service telephone line on Boulder Mountain (Don Seaman, Forest Ranger of Dixie National Forest, oral communication, 1953). In the eighties an earthquake shook the Teasdale area and the Teasdale water supply became salty, cloudy, and unpalatable (Snow, 1953, p. 250). This earthquake probably caused movement of the landslide deposits along the headwaters of Bullberry Creek, which is used for the Teasdale water supply. Although some landslide movement still occurs periodically, no rapid movement of large slides has been recorded since the area was first settled. The rate of movement of many of the active Capitol Reef landslides may be slow and have escaped notice. Very probably most movement of the landslides of the Capitol Reef area took place during or shortly after Wisconsin glaciation when precipitation was high and the ground saturated.

Landslide deposits of the Capitol Reef area are closely associated with other Pleistocene deposits that contain abundant lava boulders, and in many places they are difficult to identify. Criteria found particularly useful in identifying and mapping landslide deposits and in distinguishing them from other Quaternary deposits are as follows:

1. Glacial till in moraines occupies valleys so situated on the sides of Boulder Mountain that they received the overflow of glacial ice from the mountain top. Landslide deposits occur chiefly in the nonglaciated areas below promontories of Boulder Mountain, such as Chokecherry and Government Points.
2. Landslide deposits are not accompanied by outwash; most till and moraines are.
3. Many landslide deposits near their heads are composed mostly of large slices of lava rock that form rugged, irregular transverse ridges. Farther down the slide the rock slices are much fractured and faulted but not thoroughly mixed; sedimentary rock types predominate locally. Rock types in the till, on the other hand, are thoroughly mixed, and partly abraded lava fragments predominate.
4. Landslide surfaces are irregular and poorly drained but lack the lateral, terminal, or recessional morainal ridges characteristic of the glacial till.

5. Extent of weathering, soil formation, degree of boulder exfoliation, the lack of sand-blasted boulders, and, particularly, the lack of topographic dissection permit a distinction between landslide deposits and the pre-Wisconsin deposits.

Landslides commonly develop where thick layers of competent rock overlie a plastic substratum. In the Capitol Reef area the thick layer of lava flows on Boulder and Thousand Lake Mountains is the competent caprock. Clayey beds like those in the Flagstaff limestone, the Mancos shale, the Brushy Basin member of the Morrison formation, and the Summerville formation form the incompetent, plastic substrata. Cohesion of clays is decreased greatly by saturation (Terzaghi, 1950, p. 101); the ground must have been highly saturated during the Wisconsin stage when many of the landslides were formed (Flint and Denny, 1958).

Two ages of landslide deposits were mapped, an older set and a younger group (pl. 1). The older landslide deposits are older than the earliest Wisconsin till and the younger landslide deposits are younger than the late Wisconsin till in the middle moraine. These age subdivisions are broad categories and not intended to be specific. Actually, some blocks in both the older and younger landslide deposits probably have moved in Recent time. We believe, however, that most of the landsliding took place during the Wisconsin stage. In many places the distinction between the older landslide deposits and the bouldery accumulations, parts of which possibly moved slightly during the Wisconsin stage, is quite arbitrary. The age of landslide deposits on Thousand Lake Mountain, because of lack of glacial deposits there, is based upon analogy with landslide deposits of Boulder Mountain.

RECENT DEPOSITS

The Recent deposits include thin, scattered deposits of the comparatively short interval since the last glacial stage. These deposits locally overlie late Wisconsin glacial deposits and some are known definitely to be Recent because of deposition still in progress or because buried artifacts show deposition since Indian occupation.

These deposits indicate that the Wisconsin stage was followed by a warm period during which glacial ice melted completely from the area. Then there must have been a short time when ice accumulated at scattered places beneath the rim of Boulder Mountain to form rock glaciers. Following this began the present warm period characterized by absence of glacial ice.

The Recent deposits shown in plate 1 and described here include alluvium, rock glaciers, colluvial sand and gravel, and alluvial fan deposits.

ALLUVIUM

The alluvium consists of stream deposits of clay, silt, sand, and gravel that underlie the flat lowlands bordering the streams. The composition of the alluvium differs widely from place to place. Along Bullberry Creek near Teasdale the alluvium contains many lava boulders, whereas along the west fork of Fish Creek it is chiefly well-sorted white sand derived from the Navajo sandstone. The Moenkopi formation yields alluvium containing many platy fragments of siltstone. Some of the alluvium, particularly in the smaller valleys, is a homogeneous reddish-brown silt containing a few scattered pebbles. Some of this silt may have been deposited originally as loess and reworked by the streams. Most drainage basins contain a mixture of rock types, and the composition of the alluvium reflects the mixture.

The bedding and stratification of the alluvium varies considerably, depending upon the size of the included fragments. Gravel units form lenses and channel fills having gently dipping cross-laminations and, where particularly coarse, an open texture. Sandy alluvium forms thin regular beds with steeply dipping cross-laminations. Silty alluvium commonly forms evenly stratified beds which may be as much as 5 to 10 feet thick. Bouldery alluvium cannot be distinguished from glacial outwash; its identification as glacial or nonglacial depends on the local geology. Locally the alluvium contains organically-rich layers that probably represent old soils and, in a very few places, as along Tantalus Creek, contains peat layers indicative of ancient swamps. A section of alluvium east of Teasdale is given by Flint and Denny (1958, p. 148).

In places, fragile snail shells are abundant in the alluvium. Vertebrate fossils found in the alluvium include the skull of a bighorn sheep, an elk antler, the jawbone of a deer(?), and several other bones which could not be identified. In many places in the alluvium, thin lenses of charcoal mark the sites of former Indian fireplaces or hearths. Some of the hearths are ringed with boulders. One stone point was found by Flint and Denny (1958, p. 148) at a depth of 6 feet in alluvium in a small arroyo near the Fremont River just south of the mouth of Donkey Creek.

The thickness of the alluvium probably ranges from about 10 feet to slightly more than 40 feet, except along the Bicknell Bottoms where a thick local accumulation of alluvium probably resulted from damming of the Fremont River by recent movement along the Thousand Lake fault.

Deposition of the alluvium commonly is related to heavy local rainfall and to resulting flash floods. In the Capitol Reef area as a whole, hardly a summer elapses without a flash flood and alluviation. Among most streams, however, recent erosion has dissected the alluvium. The alluvium is trenched to a depth of about 25 feet along Bullberry Creek just east of Teasdale and about 10 feet along lower Donkey Creek. This erosion of alluvium is of considerable economic importance because it slowly destroys some of the best agricultural land. The trenching of the alluvium is no doubt influenced by climatic factors and by grazing practice, but the relative importance of these factors and the rate of trenching cannot be calculated quantitatively in this area. Several longtime residents of Teasdale are of the opinion that the deeply entrenched area along Bullberry Creek just east of Teasdale is in essentially the same condition now as it was when the area was first settled about 70 years ago. Yet there are obvious signs of active erosion along this stream.

ROCK GLACIERS

Rock glaciers in the mapped area are local accumulations of large angular lava boulders. The rock glaciers are irregularly lobate in outline, are from one to several thousand feet across, and are all at the foot of the lava cliff, high on Boulder Mountain. Most of the rock glaciers are on the north side of Boulder Mountain in the Donkey and Fish Creek reentrants, but a few are near the headwaters of West Boulder and Pleasant Creeks (fig. 23).

FIGURE 23.—View southeastward from Donkey Point showing flat top of Boulder Mountain and most of broad half-bowl-shaped reentrant at margin of north side of mountain rim near Blind Lake. Glacial ice flowed over the rim along this and similar reentrants; scalloped top edge of rim probably was scoured in part by glacier. Lakes and nearby treeless marshy areas are back of youngest moraine. Bare area of angular boulders to right of nearer treeless area is a rock glacier.

Talus at the foot of the lava cliff on Boulder Mountain is somewhat similar to and closely associated with the rock glaciers. The rock glaciers are larger, have somewhat lower slopes than the talus, and commonly near their lobate margin have a series of subparallel boulder ridges. In contrast, the talus contains cobbles and pebbles as well as boulders and has a uniformly sloping surface corresponding to the angle of repose of slide rock. Of these two kinds of deposits, only the rock glaciers are large enough to be shown on the geologic map (pl. 1). Rock glaciers have been interpreted as coarse cliff debris which has been incorporated in and moved for short distances by small glaciers (Capps, 1910; Kesseli, 1941; Sharp, 1938). The rock glaciers contain large boulders because of the coarse nature of the available rock and because they have not moved far enough to accumulate rock flour (Capps, 1910, p. 364). Surfaces of these rock glaciers also may be bouldery because many small fragments fell into the voids when the interstitial ice melted. The rock glaciers probably are younger than the youngest moraine; they may record a post-Wisconsin cold period that occurred less than 4,000 years ago (Matthes, 1939, p. 519).

COLLUVIAL SAND AND GRAVEL

The colluvial deposits are chiefly mixtures of sand, gravel, and silt which accumulated in lowlands at the foot of hills and cliffs. In contrast to alluvium, colluvium is locally derived by slope wash of detritus from adjacent uplands and is not deposited by main streams.

Like alluvium, the composition of colluvium differs considerably from place to place. A fine-grained white well-sorted sand forms broad colluvial mantles at the base of hills of Navajo, Wingate, and Entrada sandstone. This colluvium is readily susceptible to erosion by wind and by water when the vegetation is disturbed.

Colluvium derived from silty rocks such as in the Moenkopi formation is a red silty sand containing many platy siltstone fragments. Colluvium derived from boulder accumulations and pediment gravels contains many large lava boulders and, in many places, can be distinguished from the parent material only with difficulty. Thickness of the colluvium ranges from 0 to about 20 feet; bouldery colluvium is commonly thicker than the silty and sandy colluvium.

Typical colluvium derived from the Moenkopi formation locally covers terrace gravels along the Fremont River valley (fig. 20). This colluvial mantle is thickest near the steep valley sides and thins to a featheredge towards the river. This colluvium is believed to be chiefly of Recent origin but may be in part late Wisconsin. Some of the other colluvial deposits in the Capitol Reef area may also be partly late Wisconsin in age.

ALLUVIAL FAN DEPOSITS

The alluvial fan deposits are poorly sorted mixtures of silt, sand, pebbles, cobbles, and boulders analogous in composition to alluvium. The fan deposits have crudely defined lenticular beds with low-angle cross-lamination. Topographically the fans are low cones or cone segments having their apex where a stream channel leaves the neighboring mountains. Across the fans the stream channel is poorly defined.

These fan-shaped deposits have been made chiefly where small mountain streams discharge abruptly upon a flat valley floor. The largest alluvial fans are along the east side of Rabbit Valley (pl. 1), where the maximum thickness of the alluvial-fan deposits is unknown but may be considerably more than 100 feet locally. Alluviation that caused the development of these large fans probably is a consequence of post-early Wisconsin movement on the Thousand Lake fault at the east end of the Bicknell Bottoms. Material comprising these alluvial fans probably was deposited after early Wisconsin time and in places is being deposited at present.

EROSIONAL FEATURES OF THE CAPITOL REEF

The erosional features in most of the Capitol Reef area are similar to those in other parts of the Canyon Lands section of the Colorado Plateau. The geologic units that form the cliffs, slopes, benches, domes, or other physiographic forms reflect their susceptibility to erosion (fig. 24). The vast area of bare rock is a most impressive feature of Capitol Reef. Except for thin belts of alluvium in the larger valleys, scattered patches of colluvium, and gravel on a few terrace remnants, no significant accumulations of surficial materials are found along the reef.

The manner in which each geologic formation retains its own characteristic physiographic expression is exemplified in the great cliff paralleled by the highway from Torrey through Fruita and beyond to Capitol Wash. A 300- to 400-foot vertical wall of chiefly massive pink Wingate sandstone dominates the scene at the crest of the cliff. The cliff formed by the Wingate is the "Vermilion Cliff" of early geologists who traced it for hundreds of miles across the Colorado Plateau. Below the vertical cliff formed by the Wingate is a long slope underlain by varicolored clay and mudstone of the Chinle formation and in most places a lower ledge of white sandstone formed by the Shinarump member of the Chinle. Along the road at the base of the cliff, beneath the Shinarump member, irregular red ledges are formed by erosion of the interbedded sandstone and mudstone of the Moenkopi formation.

Resistant rock units like the Wingate sandstone form steep cliffs which are eroded not by removal of small fragments but by splitting off of large sandstone joint blocks from the cliff faces. Underlying weaker beds erode or slump to undermine the cliff faces and cause splitting off of blocks of the more resistant units above. In this manner the vertical cliffs of Wingate sandstone recede slowly by erosion, yet retain the same impressive height. Although the manner in which this cliff recedes is evident, it should not be assumed that the recession is rapid or that rock falls from the cliff face occur frequently. Residents have noted but few rock falls from cliffs, and it requires examination of many miles of cliff face to identify, from the unweathered appearance of the sandstone, places of recent rock falls.

The Navajo sandstone, which is exposed along the central and highest part of Capitol Reef, characteristically erodes to pinnacles and rounded domes with striking resemblance to the rounded domes of many capitol buildings (fig. 11) and forms the narrowest

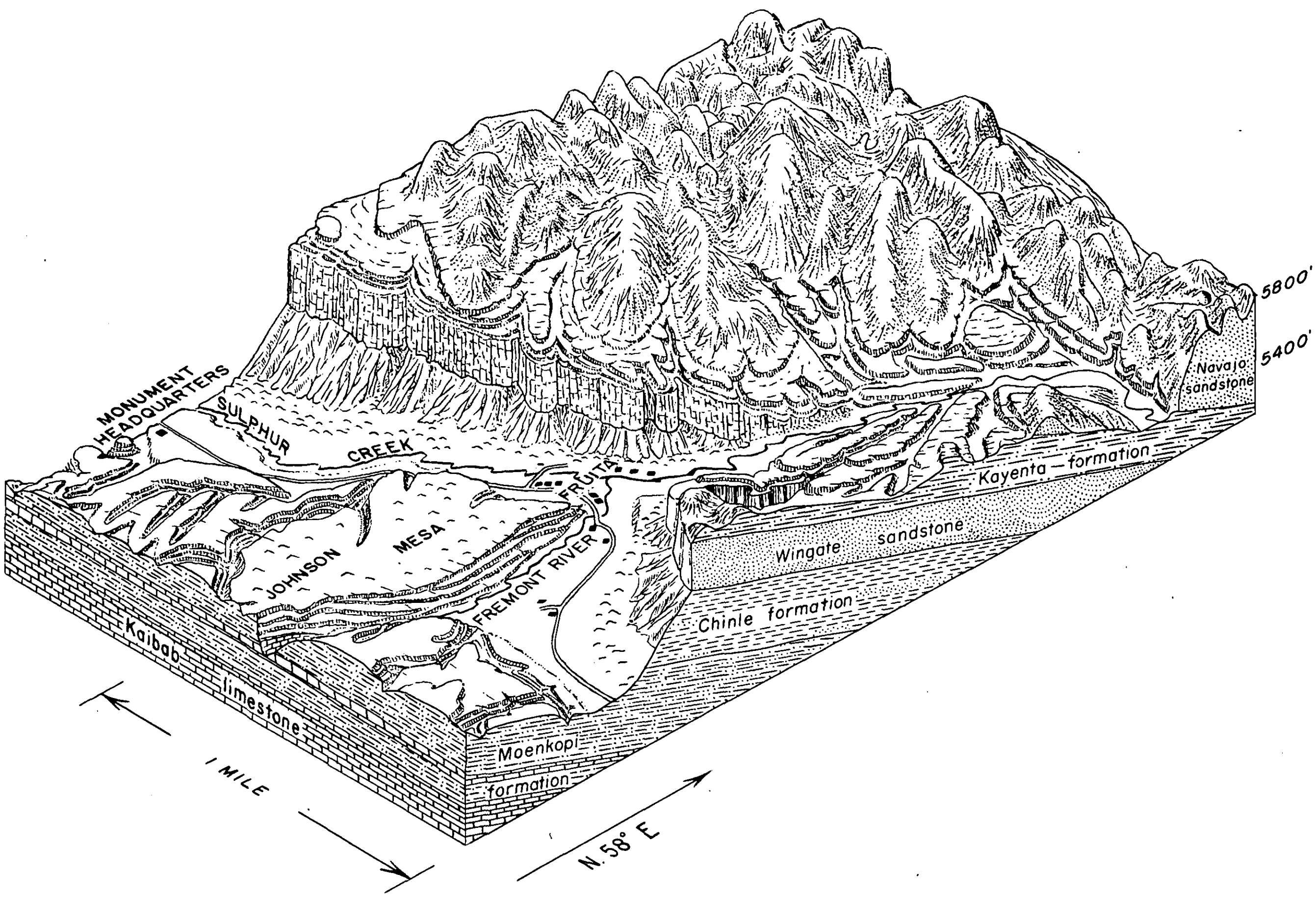


FIGURE 24.—Sketch showing terrain along Capitol Reef northeast of Fruita, Utah. (Note vertical exaggeration.)

part of the Capitol Wash gorge where the road crosses the reef (fig. 25). The Navajo sandstone forms the "White Cliffs" of the early geologists which, like the Vermilion Cliffs, can be traced for many miles across the Colorado Plateau. The Navajo weathers and erodes largely by the grain by grain removal of sand from the rock surface; weakly cemented laminae are attacked first by erosion that etches the crossbedding of the sandstone into picturesque relief.

Erosion of the Mancos shale produces badland topography. Vegetation is almost completely lacking on the Mancos shale, and the shale exposures are intricately dissected in a dendritic pattern by thousands of small gullies. In general, silty and clayey units like the Mancos, the Chinle, and the Brushy Basin are easily eroded and comparatively rapidly removed to expose underlying resistant beds. Combinations of stripped surfaces and cliffs form many physiographic features of the Capitol Reef area, such as box canyons, gorges, mesas, buttes, and plateaus.

The scarcity of surficial deposits on Capitol Reef appears to be caused largely by the rapidity with which weathering and erosion products are removed. The sedimentary rocks exposed along Capitol Reef weather to form sand, silt, and clay which are easily washed or blown away. In marked contrast to Capitol Reef are the flanks of Boulder and Thousand Lake Mountains, where surficial deposits are abundant and most slopes are smooth. The surficial deposits in the mountain areas are characterized by an abundance of large resistant lava boulders. Apparently these boulders protect the rocks beneath from erosion and particularly from gullying; any incipient gully in a boulder-covered surface becomes a lodging place for boulders, and, therefore, is protected from erosion. Such boulder-strewn surfaces remain comparatively smooth and ungullied.

Many physiographic features observed within the area of the Capitol Reef can be mentioned only briefly here. Numerous examples of drainage captures, wind gaps, stream meanders, entrenched stream meanders, sand dunes, flood plains, stream bars, hogbacks, and other physiographic features can be found within the area. A natural bridge 72 feet high and with a span of 133 feet is one outstanding tourist attraction; it is 3 miles by trail from Fruita. This natural bridge was made by a stream diversion through a thin wall-like

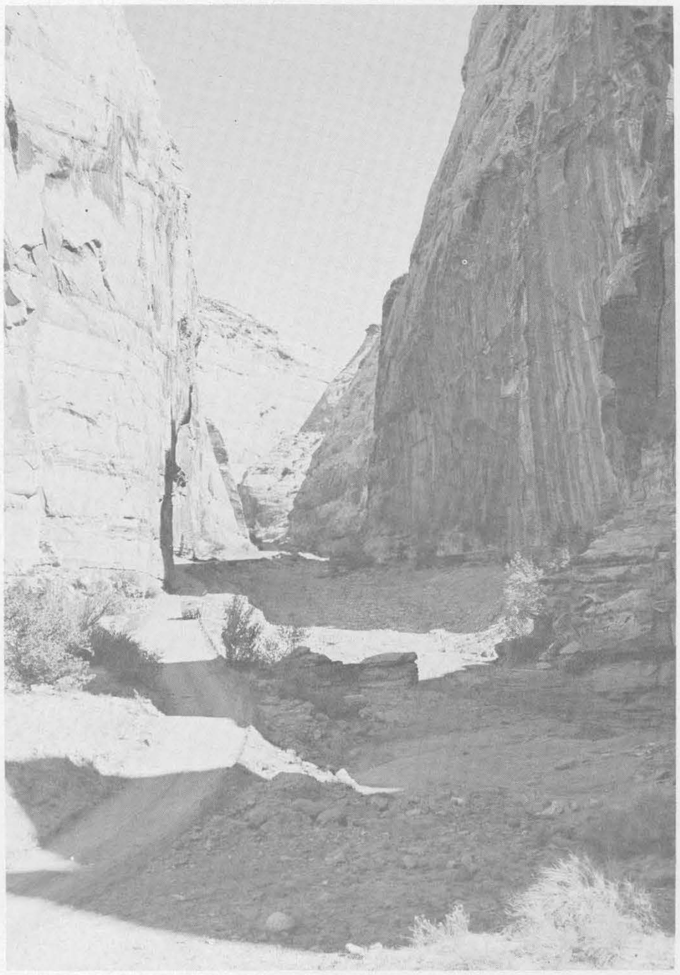


FIGURE 25.—Photograph of the gorge of Capitol Wash where it crosses Capitol Reef. Walls are Navajo sandstone.

sandstone ridge. Another scenic attraction accessible by foot trail from Fruita is Cohab Canyon, a hanging gorge used as a hideout, according to legend, during the days of polygamy in Utah by men sought for "cohabitation with plural wives." The trail to Cohab Canyon offers many spectacular viewpoints of the Fremont Canyon and the Capitol Reef cliff. A trip to this canyon is highly recommended, even for the monogamous.

STRUCTURE

Structurally the Capitol Reef area is in a marginal belt between large basins and upwarps on the east and generally northward-trending normal faults, the faults in the High Plateaus section, on the west.

The principal structural features of the Capitol Reef area are the Waterpocket Fold, the Teasdale anticline, the Teasdale fault, and the Thousand Lake fault (fig. 26). The Teasdale anticline and the Waterpocket Fold are well reflected by the topography, as are most of the upwarps and monoclines on the Colorado Plateau.

To show the structure of the area, structure contours at 200-foot intervals are drawn on the top of the Chinle formation (pl. 1). In areas distant from the exposed top of the Chinle, thicknesses above or below this top are used to correct to the contoured horizon. The areas of Boulder Mountain, the Awapa Plateau, and west of Thousand Lake Mountain are not contoured, owing to the scarcity of control points on pre-Tertiary formations and the difficulty of projecting points from the Tertiary units to the contoured horizon. A pronounced angular unconformity is between the rocks of Mesozioc and Tertiary ages.

FOLDS

WATERPOCKET FOLD

The Waterpocket Fold is one of the large monoclines of the Colorado Plateau. It extends from the Colorado River south of the Henry Mountains northwestward along the east side of the Circle Cliffs and to the north end of Thousand Lake Mountain, a total distance of almost 100 miles. In the Capitol Reef area, dips along the Waterpocket Fold are generally east and northeast and range from about 10° to almost 35°. Local bends in the structure alter the northwest strike of beds along the monocline. One such bend is in the vicinity of Oak Creek at the southeast end of the Teasdale anticline and another is in the area north of Fruita at the southeast end of the Fruita anticline (pl. 1).

TEASDALE ANTICLINE

The Teasdale anticline (Hansen and Bell, 1949, p. 284–285) is a prominent structural and topographic feature that trends northwestward through the central part of the Capitol Reef area. The general trend of about N. 55° W. changes to N. 75° W. north of Grover. This anticline plunges northwestward and southeastward and is highest structurally near the common corner of secs. 8, 9, 16, and 17, T. 30 S., R. 6 E. The northwestern part of the fold is broad and rounded and has gentle dips. The southeastern part is narrow and has steep dips. A small structural high is along the crest near the northwest end of the anticline (pl. 1).

Most dips on the Teasdale anticline range from 20° to 50° SW. on the southwest limb and from 10° to 14° NE. on the northeast limb. This asymmetry with the steeper dips to the southwest is in contrast to the asymmetry of the major uplifts on the Colorado Plateau, such as the Circle Cliffs and the San Rafael Swell, where the steeper limbs are on the east sides.

Closure on the Teasdale anticline is slightly more than 1,200 feet and is limited by a structural low on the

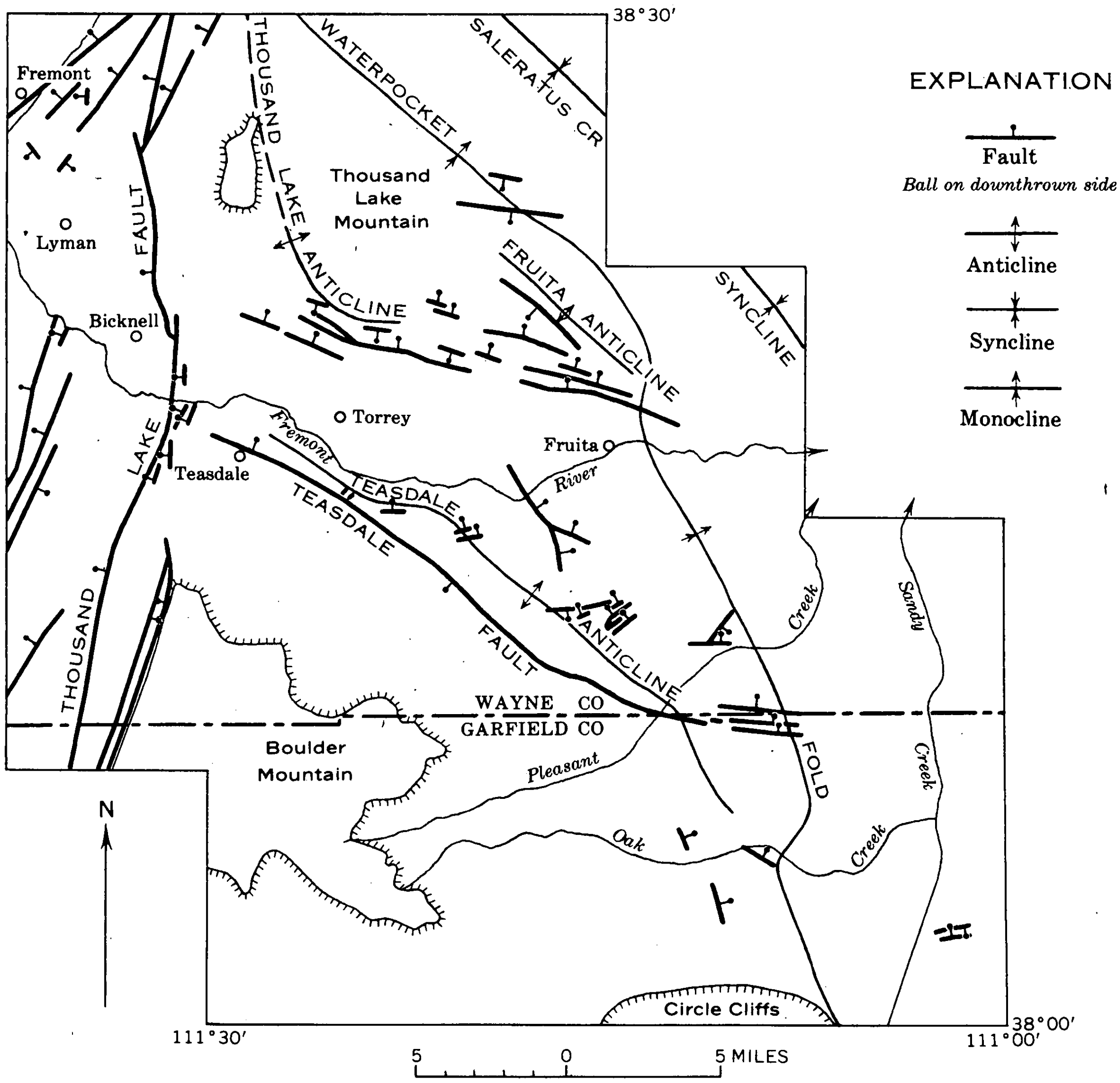


Figure 26.—Sketch map of the Capitol Reef area showing locations of major structural features.

north. Structural relief between the crest of the Teasdale anticline and the trough of the Henry Mountains structural basin east of the Waterpocket Fold is more than 7,800 feet.

Small subordinate folds are superposed as draglike wrinkles no more than 20 feet wide on the flanks of the Teasdale anticline; they probably represent minor adjustments at the time of folding.

FRUITA ANTICLINE

The Fruita anticline is a doubly plunging asymmetrical anticline along the Waterpocket Fold. Dips on the southwest limb are more gentle than those on the northeast limb, which is part of the Waterpocket Fold. The Fruita anticline trends about N. 40° W., is about 6 miles long, and has a vertical closure of about 200 feet.

CIRCLE CLIFFS UPWARP

The Circle Cliffs upwarp, one of the major structures of the Colorado Plateau, has a gently dipping west flank and steeply dipping east flank that is part of the Waterpocket Fold. Description of this upwarp is not included in the present report because only the northern tip of the fold extends into the mapped area and published reports on the entire fold are available (Gregory and Moore, 1931; Steed, 1954).

Beds are nearly flat in the area of Dry bench and Oak Creek between the Circle Cliffs upwarp and the Teasdale anticline.

THOUSAND LAKE ANTICLINE

The term "Thousand Lake anticline" is applied to the elongate dome that underlies Thousand Lake Mountain and is structurally highest on the southeast flank of the mountain. This fold trends slightly west of north for most of its length but bends rather sharply to the southeast and east in its southern part near north Sulphur Creek and Cooks Mesa. The east limb is part of the Waterpocket Fold. Across the south end of Thousand Lake Mountain the anticline is broad and roughly symmetrical with gentle dips on each limb; at the north end of the mountain the anticline is more narrow and the east limb dips more steeply than the west limb. Vertical closure on this structure is slightly more than 400 feet.

Structural control on this fold is poor. The Thousand Lake Mountain area is largely covered by deposits of Quaternary age, and most exposures of pre-Tertiary rocks are well down the mountain flanks.

SALERATUS CREEK SYNCLINE

The Saleratus Creek syncline (a name recently applied by Kelley, 1955a) is a broad, symmetrical, flat syncline that trends northwest, plunges southeast, and has dips of about 5° near the trough. The trace of the axial plane is concave southwestward. Two parts of this syncline are in the mapped area (pl. 1); a more complete picture of the fold may be gained from Gilluly's map of part of the San Rafael Swell (Gilluly, 1929, pl. 30).

ANTICLINE NEAR VELVET RIDGE

An anticline trends eastward in the area of Velvet Ridge north of the Teasdale bench. This fold has gentle dips and may have a vertical closure of about 150 feet. It is in the trough area between the northwest end of the Teasdale anticline and the south end of the Thousand Lake anticline.

FAULTS

TEASDALE FAULT

The Teasdale fault is a high-angle to vertical normal fault whose southwest side is downthrown as much as 1,100 feet. The fault is about 25 miles long and is a zone composed of 2 dominant faults and many small branching faults and cross faults. From a mile northwest of Teasdale the fault trends about S. 40° E. to the crest of the Teasdale anticline, south of Pleasant Creek; at the southeast end the trend changes to about S. 80° E. Fault surfaces observed at a few localities are nearly vertical and have poorly preserved vertical slickensides.

The Teasdale fault parallels the southwest limb of the Teasdale anticline for several miles. Beds in and adjacent to the fault zone have dips ranging from 20° SW. through vertical and overturned to 75° NE. Dips are consistently steep on the southwest downthrown side near the fault, but flatten to almost horizontal within less than one-half mile except where the fault crosses the crest of the Teasdale anticline.

Several short faults branch from the main fault near its southeast end. Numerous transverse faults with throws of 10 feet or less occur just north of the Teasdale fault, particularly north of the Cocks Comb and along the upper part of south Sulphur Creek. Northwest sides are downthrown along nearly all the transverse faults. Several antithetic faults with only a few inches of throw break the beds on the downthrown side of the main fault zone.

East of the crest of the Teasdale anticline the Teasdale fault zone consists of several eastward-trending faults that extend for about 3½ miles into the Waterpocket Fold. These faults have their north sides downthrown and have maximum vertical displacements of perhaps 100 feet.

THOUSAND LAKE FAULT

The Thousand Lake fault is one of the High Plateaus faults recognized and named by Dutton (1880, p. 33). It is a zone of high-angle faults downthrown to the west and trending generally northward.

On the west side of Thousand Lake Mountain the total vertical displacement along the zone of faults composing the Thousand Lake fault is about 2,500 feet. The displacement appears to exceed 3,000 feet if it is based on the positions of the lavas on the top of the mountain and on the hills west of the mountain. Part of the difference in altitude between the lavas on Thousand Lake Mountain and in the area to the west evidently resulted from flow of the lavas over an uneven surface. To the south on the west flank of Boulder Mountain the displacement is not so great.

The zone of the Thousand Lake fault continues to the northeast as the Paradise fault (Spieker, 1931, p. 33; Intermountain Association of Petroleum Geologists Field Trip Map Sub-Committee, 1954, pl. 1, sheet 2). The zone probably ends a short distance south of the Capitol Reef area, as it is not shown on the map of the Kaiparowits region (Gregory and Moore, 1931, pl. 2). The graben along Cook Pasture at the west edge of the top of Boulder Mountain is considered a part of the broad zone of the Thousand Lake fault. Throws along the faults bounding the graben probably are not more than 400 feet.

FAULTS FROM UPPER SAND CREEK TO NORTH OF FRUITA

This zone of faults trends northwestward for about 15 miles from northeast of Fruita to about 4½ miles north of Teasdale. These are normal faults and have dips of generally 80° or more. Most have the north sides downthrown. The maximum length of a single fault is about 6 miles, and the faults have a slight en echelon pattern. The maximum measured throw is 360 feet on the fault crossing the N1/2 sec. 31, T. 28 S., R. 5 E. In most places, throws are less than 100 feet. Throws on these faults decrease in very short distances, and the faults end abruptly. Beds on the downthrown sides commonly bend up sharply adjacent to the faults but assume their normal attitudes in a few feet or few tens of feet away from the faults.

OTHER FAULTS

Many other normal faults are in the area but are not as concentrated nor in such pronounced zones as those already discussed.

In the northwestern part of the mapped area, several high-angle normal faults trend chiefly northeastward and have their west sides downthrown. Exact throws are not determinable because of the poor exposures, but maximum throws probably are not more than 300 feet. Many beds in this general area appear to have slumped or slid down the slopes. For example, beds of Flagstaff limestone, lava, and gravel around the west margin of Horse Valley (pl. 1) have strikes that form a gentle arc concave eastward and have east dips, suggesting that Horse Valley may be a large block that has slumped westward and been tilted eastward. More faults are probably in this northwestern part of the mapped area than are shown on the geologic map (pl. 1).

Several northeastward-trending high-angle normal faults cross the area of volcanic rocks west of Boulder Mountain and south of Rabbit Valley (pl. 1). Throws on any of these faults probably do not exceed 100 feet. These faults are west of and parallel to the Thousand Lake fault and belong to the same group as those west of the Thousand Lake fault farther north. The two groups are separated by the Quaternary fill in Rabbit Valley and Bicknell Bottoms.

A Y-shaped fault on the north side of Miners Mountain (pl. 1) has a maximum throw of 175 feet near the split in its trace. The fault surface where observed is vertical, and in places a partly eroded scarp marks the position of the fault along the mountain top. A group of northeastward-trending faults on the east side of Miners Mountain parallels a shallow synclinal flexure on the flank of the Teasdale anticline.

Several small reverse faults cut the Moenkopi formation on the flanks of the Teasdale anticline. They have displacements of as much as 10 feet and are too small to be shown on the geologic map (pl. 1).

JOINTS

Joints are numerous throughout the area and are most prominent in the massive sandstone units (Coconino, Wingate, and Navajo) where steep-sided ravines and gullies are eroded along them. In many places along Capitol Reef, the terrain formed on the Navajo sandstone is almost impassable because of dissection along joints. Joints are common also in other units, particularly in the Moenkopi formation, the Shinarump member of the Chinle formation, and the Salt Wash member of the Morrison formation. In the thin-bedded and very fine grained clastic rocks, the joints commonly are obscure but are marked by veinlets of gypsum or limonite and in a few places by thin sandstone dikes.

Along the Waterpocket Fold south of about lat. 38°13′ N. the most prominent joints trend N. 15° to 20° W. North of this latitude their trends range from about N. 15° E. to N. 15° W., with many almost north. Most of the joints are vertical or nearly so. Most of the diabase dikes were intruded along N. 15° E. or N. 15° W. joints.

In the mapped area, prominent cross joints trend N. 50° to 80° W. at three places along the Waterpocket Fold. These localities are along warps in the fold (pl. 1): (1) in the synclinal trough along Oak Creek south of the southeast extension of the Teasdale anticline as it projects into the Waterpocket Fold, (2) in the synclinal trough north of Fruita and on the south side of the southeast extension of the Fruita anticline as it projects into the fold, and (3) in the area of Deep Creek east of Thousand Lake Mountain.

AGE OF FOLDING AND FAULTING

The tectonic history of parts or all of the Colorado Plateau has been reviewed within the past few years (Spieker, 1946, 1949, 1954; Kelley, 1955a; Hunt, 1956), so no attempt is made in the present report to reconsider the subject on a regional basis.

The major folds in the Capitol Reef area are younger than the Mancos shale of Late Cretaceous age and older than the Flagstaff limestone of late Paleocene and probable early Eocene age. Flagstaff limestone rests with angular unconformity on beds of the Carmel(?) of Jurassic age just north of the mapped area along a high ridge north of Thousand Lake Mountain. Evidently all formations older than the Flagstaff were domed to form a topographic high that was stripped by erosion before deposition of the Flagstaff. This pre-Tertiary truncation of Cretaceous and older beds was recognized long ago (Dutton, 1880, p. 280–281).

In the Kaiparowits region, horizontal Eocene beds overlie the upturned youngest Cretaceous beds (Gregory and Moore, 1931, p. 116). These Eocene beds probably are equivalent to the Flagstaff limestone (Spieker, 1954, p. 10–11). On the Wasatch Plateau a local angular unconformity is at the base of the Flagstaff (Spieker, 1946, p. 133–137; 1954, p. 10–12).

A monocline formed before deposition of the Flagstaff on the west side of the Wasatch Plateau is similar to the monoclines of the Colorado Plateau. Spieker (1946, p. 155–156; 1954, p. 10–13) suggests that this monocline and the major upwarps of the Colorado Plateau were formed between the middle and latter part of the Paleocene, prior to deposition of the Flagstaff limestone. Relations in the Capitol Reef area are compatible with such a time of folding. It is only necessary to allow enough time after deformation and before deposition of the Flagstaff for at least 4,000 feet of beds to have been eroded and the region made low enough to receive lacustrine sediments of the Flagstaff.

Faults in the Capitol Reef area cut the volcanic and all older rocks, and on physiographic evidence in the Bicknell Bottoms the Thousand Lake fault appears to have moved after deposition of the early Wisconsin terrace gravel along the Fremont River. The northwestward-trending faults and joints, the faults along the Teasdale anticline, and the faults and joints along the Waterpocket Fold probably were formed at the same time as the Waterpocket Fold and Teasdale anticline.

The Thousand Lake fault and those faults west of it belong to the High Plateaus faults. Many High Plateaus faults on the Gunnison and Wasatch Plateaus are older than mid-Tertiary and some are as old as Late Jurassic (Spieker, 1949, p. 77–81; 1954, p. 13). Movement along the Hurricane fault in southwest Utah began after deposition of Eocene strata and before extrusion of the lava flows tentatively assigned to the Miocene (Gardner, 1941). Whether the movement along the Thousand Lake fault started that early is not known, but, if it did, it was renewed after the outpourings of Miocene(?) lava and again following the deposition of the early Wisconsin terrace gravels.

Evidence for movement along the Thousand Lake fault after deposition of the early Wisconsin terrace gravels is based chiefly on physiographic relations along the Bicknell Bottoms and in the area just to the east in sec. 7, T. 29 S., R. 4 E. East of the Thousand Lake fault zone these gravels end abruptly at the fault. West of the fault they are not exposed in the Bicknell Bottoms area. Farther northwest comparable terrace gravels are at the Lyman Cemetery in sec. 8, T. 28 S., R. 3 E., and other terrace remnants are still farther north along the Fremont River valley. It seems likely that the terrace gravels were deposited across the Bicknell Bottoms. Subsequently, either they were completely eroded or were buried by younger material. As the topography does not indicate such extensive dissection as to have caused complete removal of the gravel, probably the Bicknell Bottoms were tilted downward to the east by faulting along the east side and the terrace gravels were buried beneath younger deposits. Profiles of the terrace upstream and downstream (fig. 27) from the fault indicate a vertical displacement of about 280 feet. This displacement might be even greater as the area may have been bent down more adjacent to the downthrown side of the fault. In addition, the present

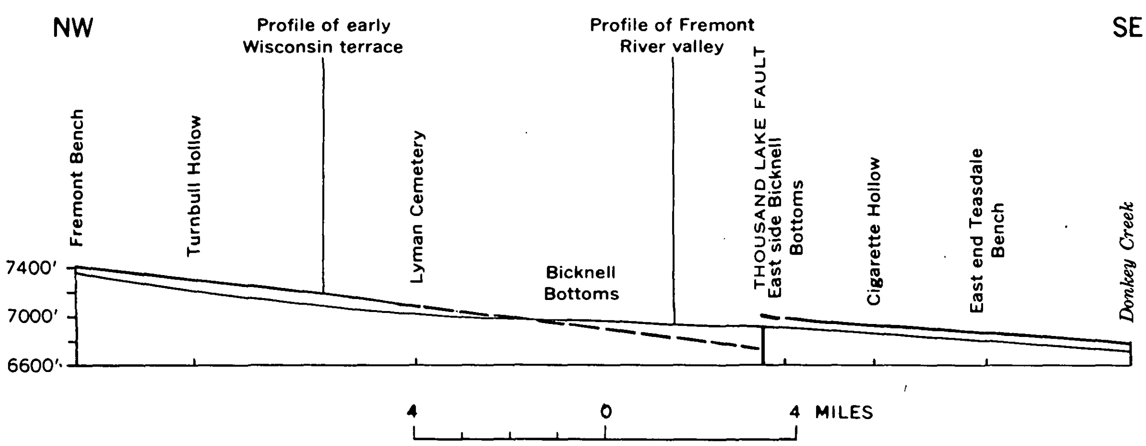


FIGURE 27.—Profile of Fremont River valley and of early Wisconsin terrace showing projected profile of terrace below Bicknell Bottoms. Indicated vertical displacement of terrace by Thousand Lake fault is about 280 feet. (Note vertical exaggeration.)

gradient of the Fremont River is less across the Bicknell Bottoms than it is both upstream and downstream from there. Such a decrease in gradient would be expected if a barrier were raised across the stream, in this case a barrier produced by faulting. Deposition back of the barrier would have taken place in the area of lower gradient, and the terrace gravels would have been buried. Late Pleistocene or more recent movement of considerable magnitude along faults is recorded from other areas of the High Plateaus and nearby (Spieker and Billings, 1940, p. 1192–1193; Hunt and others, 1953, p. 38–39).

In summary, the major deformation that formed the main folds and the northwestward-trending faults preceded the deposition of the Flagstaff limestone and probably occurred between the middle and latter parts of the Paleocene epoch. Movement along the Thousand Lake fault may have started also before deposition of the Flagstaff but from local evidence postdates the lavas tentatively assigned to the Miocene. In at least one place, movement along this fault followed the deposition of early Wisconsin terrace gravels.

CAUSE OF FOLDING

Baker (1935, p. 1501–1504) suggests that the monoclines of the Colorado Plateau were formed by deep-seated thrusting as a result of compressional stresses rather than by vertical movement. Spieker (1946, p. 155; 1954, p. 11–12) also concludes that deep-seated thrusting was necessary to explain the formation of a fold before deposition of the Flagstaff along the west side of the Wasatch Plateau, and Kelley (1955a, p. 63–74; 1955b, p. 798–799, 802) agrees with the concept of formation of the structures by compressional forces.

Relations between the detailed changes in trend of the Waterpocket Fold and the fracture pattern along and adjacent to the fold in the Capitol Reef area suggest also that relatively compressional stresses were responsible for the deformation. The dominant vertical fractures roughly parallel to the N. 15° W. trend of the fold presumably developed from compression. The cross fractures previously mentioned (p. 60) probably represent shear or incipient shear in conjunction with the compressive stresses.

ECONOMIC GEOLOGY

During the field study (1951–54) for this report a small amount of uranium was shipped from the area, and sand and gravel were used locally for road construction. Potential mineral resources of the Capitol Reef area include uranium, vanadium, copper, manganese, gypsum, building stone, sand and gravel, and oil and gas. Figure 28 shows the observed occurrences of uranium, vanadium, copper, lead, and manganese minerals and of localities of abnormal radioactivity. The study reported here was made chiefly to investigate the uranium deposits.

URANIUM DEPOSITS

Data on the uranium deposits were obtained from 1951 to 1954 and do not include later prospecting developments. No economically important uranium deposits had been developed through the year 1955. Geochemical studies of the uranium deposits were made to investigate the chemical processes involved in the deposition of uranium and the potentialities of chemical prospecting for uranium deposits. These chemical studies supplement the geologic studies of the uranium deposits. The results of both types of study are used in evaluating prospecting guides to ore and in considering problems of ore genesis.

The presence of uranium in the Capitol Reef area has been known for many years. The most active prospecting, however, began in 1953. Prospecting and mining have been prohibited within the Capitol Reef National Monument since it was established in 1937, except for a period from 1953 to 1955. As no commercial uranium deposit was discovered within the monument during that time, the monument was closed to prospecting after May 1955. The oldest uranium prospect in the Capitol Reef area is the Oyler mine, on the north side of Grand Wash in the Capitol Reef National Monument. This deposit was claimed first in 1901 and worked intermittently for radium. Butler (Butler and others, 1920, p. 632–633) states that at the time of his examination of this area it was the only prospect from which ore had been shipped. More recent reports on the Oyler mine are given by Everhart (1950, p. 4–6) and by Wyant and others (1952, p. 28).

Uraniferous rock is widespread areally in the Capitol Reef area. Uranium minerals or abnormal radioactivity occur in several stratigraphic units: the Moenkopi formation, the Shinarump member of the Chinle formation, the middle and upper members of the Chinle formation, the Curtis formation, the Salt Wash member of the Morrison formation, and the volcanic rocks a few miles west of the mapped area. Occurrences of uranium are different in each stratigraphic unit and are discussed separately in the following pages, in ascending stratigraphic order.

URANIUM IN THE MOENKOPI FORMATION

Occurrences of uranium minerals and abnormal radioactivity in the Moenkopi formation are not widespread in the Capitol Reef area. Of significance is the locality in secs. 10 and 11, T. 29 S., R. 4 E., about 1½

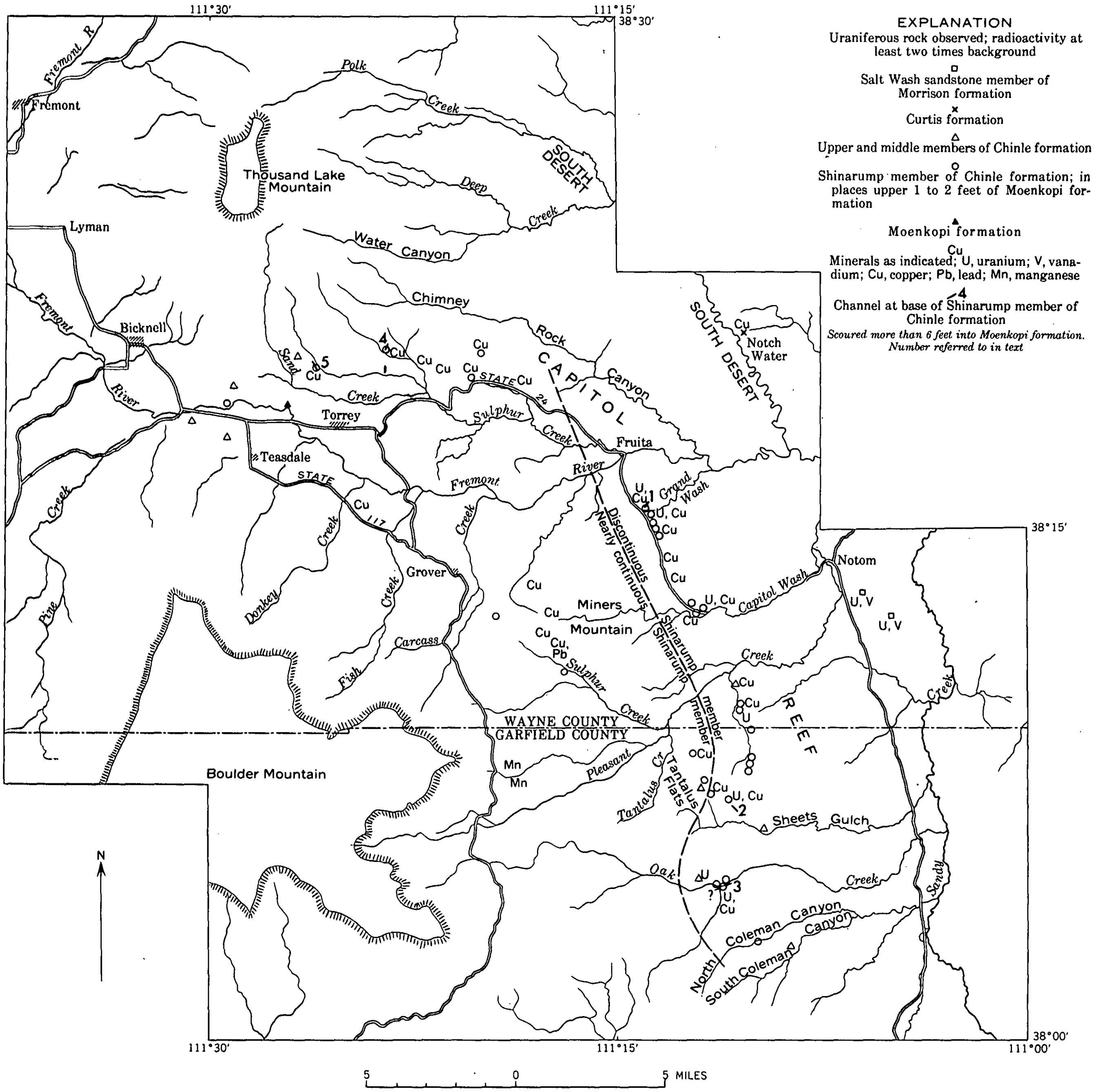


FIGURE 28.—Mineral and abnormal-radioactivity map of the Capitol Reef area, Utah.

miles northwest of Torrey. Here the uranium is at and near the base of a massive sandstone bed about 32 feet thick. This bed is in the upper part of the third unit from the base of the Moenkopi and is about 400 feet below the top of the formation.

The sandstone in this bed is fine grained and pale pinkish red. Locally it is crossbedded on a small scale in units 2 inches to 1 foot thick. Near the base of the bed, in places, the sandstone is almost white and contains scattered clay pebbles and gray clay and siltstone layers and lenses 1 to 4 inches thick.

Irregular scours as much as 1 foot deep in siltstone and claystone below the massive sandstone have been filled with sandstone. Abnormal radioactivity on surface exposures is associated with these scour fills in places. Abnormally radioactive black spots as much as ⅛ inch in diameter are scattered through the lower 4 to 12 inches of the sandstone.

In an exploratory inclined shaft the uraniferous rock is a black layer generally from about ¼ to 1¼ inches thick, located in the lower 2 feet of the sandstone. Chiefly, this black layer is parallel to the bedding, but in one place it rolls across bedding for as much as 2 inches. In another place the layer crosses the bedding for about 1½ inches along a hairline fracture. At the bottom of the incline the black layer is along a contact between small-scale crossbedded units where the crossbeds dip in opposite directions, one essentially north, the other south. Black spots like those on the surface exposures are dispersed throughout the sandstone adjacent to the black layer and of decreasing concentration away from it. These black spots are alined along crossbeds and also scattered randomly.

Specimens of the black layer were examined in the laboratory by John W. Adams of the U.S. Geological Survey (written communication, 1955). He believes that the black material is a hydrocarbon compound. It occurs as aggregates of isotropic grains that individually are less than 0.1 mm in diameter. The black material, by virtue of its low specific gravity, can be floated in carbon tetrachloride and separated from the sand grains. An X-ray powder pattern made from a concentrate of the black material was poor and unidentifiable. From its radioactivity Adams estimates that the black hydrocarbon (?) contains most, if not all, of the uranium in the samples. Material forming the black spots is like that forming the black layer and presumably is a hydrocarbon (?) compound also.

Uraniferous material at the base of the same sandstone bed crops out a few hundred feet southeast of the top of the exploratory incline. At this exposure small scours in the underlying siltstone are filled with sandstone. Spots of black material, like that described previously, and specks of metazeunerite ($Ca(UO_2)_2(AsO_4)_2.8H_2O$) (Edward J. Young, U.S. Geological Survey, written communication, 1956) occur in the sandstone in and near the small scours. A 1-foot channel sample taken from the surface exposure of highest radioactivity contained 0.48 percent U_3O_8.

The area of this uraniferous rock in the Moenkopi formation was explored by private drilling and by the inclined shaft without discovering significant ore bodies. Several tons of ore was obtained by hand sorting the rock.

Other beds in the Moenkopi formation are petroliferous. None found, however, contained as much uranium as the one northwest of Torrey. A sample of petroliferous sandstone from just above the Sinbad member in the NE¼ sec. 13, T. 30 S., R. 6 E., collected by Ralph L. Erickson, was chemically analyzed by Albert C. Horr of the U.S. Geological Survey. The petroliferous material in this sandstone has an ash content of 1.51 percent, 0.005 percent of which is uranium.

Locally the top 1 or 2 feet of the Moenkopi contains uranium minerals or are abnormally radioactive. Such occurrences are closely related to the overlying Shinarump member of the Chinle formation and are discussed with deposits in that formation.

URANIUM IN THE SHINARUMP MEMBER OF THE CHINLE FORMATION

Uranium minerals and localities of abnormal radioactivity are widespread in the Shinarump member of the Chinle formation and are more abundant in that unit than in any other stratigraphic unit in the Capitol Reef area (fig. 28). The presence of uranium has been known for many years (Butler and others, 1920, p. 632–633), but most deposits are small. All the accessible outcrops of the Shinarump were examined and most were tested with a Geiger counter or a scintillation counter. The average or background radioactivity along outcrops of the Shinarump member generally ranges between 0.02 and 0.08 milliroentgens per hour.

Uranium deposits or uraniferous rock in the Shinarump member have four principal associations: (1) the deposits are most common in the area of discontinuous Shinarump, (2) they most commonly are concentrated in beds where strata of the Shinarump filled channels cut into the underlying Moenkopi formation, (3) they are associated with or are in the vicinity of carbonaceous material, and (4) they are associated with claystone or clayey beds.

The Shinarump member is discontinuous from about 2½ miles northwest of Fruita southeastward along the Waterpocket Fold to Oak Creek and North and South Coleman Canyons (pl. 1 and fig. 28). West of the Waterpocket Fold the Shinarump is almost continuous. Because these areas differ in respect to abundance and concentration of uraniferous rock, they are described separately.

AREA OF DISCONTINUOUS OCCURRENCE OF THE MEMBER

Most localities of uraniferous rock in the Shinarump member of the Chinle formation and the upper 1 to 2 feet of the Moenkopi formation are in this area of discontinuous Shinarump, from northwest of Fruita southeast to South Coleman Canyon. (See fig. 28). The Shinarump is lenticular and relatively thin in this area. It probably is marginal to the main mass of Shinarump to the west and forms fingerlike lenses that extend northeastward to where the member ultimately pinches out. A similar occurrence in the White Canyon area, Utah (fig. 1), is reported by Alfred F. Trites, Jr. (oral communication, 1954). Finch (1959, p. 148, 159) suggests that most uranium deposits in the Shinarump are in zones or belts near the pinchouts of extensive bodies of Shinarump. The relative abundance of uraniferous rock in the area of discontinuous Shinarump in the Capitol Reef area partly supports Finch's idea.

OYLER MINE AND VICINITY

The Oyler uranium deposit is in a channel (fig. 28, channel 1) that was cut into the Moenkopi formation and filled with sediments of the Shinarump member of the Chinle formation. This channel fill is from 20 to nearly 30 feet wide and about 7 feet deep (pl. 2). The channel trends about N. 30° E. through the major part of the workings but bends toward the north or northwest in the northwestern part. On plate 2, upper left, contours of the base of the Shinarump are drawn with the actual 13° NE. dip of the beds. On plate 2, upper right, they are drawn with the beds projected to a horizontal plane; this map was drawn to determine the course of the channel when it was cut. On both maps the trend is about the same, but the map showing the beds horizontal indicates an elongate "low" in the main central part of the channel floor. Miller (1955, p. 168) indicates that the richest ore in the Happy Jack mine in the White Canyon area, Utah, is in lows within the channel. The small part that can be seen of the Oyler channel may be in a low in relation to the entire channel, so it is not possible to evaluate the relation between lows in the channel and grade of ore. The channel margins are very steep in places (pl. 2). Wyant and others (1952, p. 28) consider the individual ore bodies in the channel to be "localized by small primary sedimentary structures that resemble monoclinal folds or synclines."

The basal Shinarump member in and near the Oyler mine is an almost continuous layer of tan and yellow clay that is from ½ to 1½ feet thick (pl. 2, lower left). This clay contains sandstone stringers, fragments of carbonized wood and plants, and pods and stringers of alunite. The alunite layers are 1 to 2 inches thick and as much as 30 feet long. Nearly all uranium minerals and radioactive material and most copper minerals present in the Oyler tunnel are in this basal clay bed. Most carbonized wood in the clay is radioactive. Crusts of efflorescent gypsum coat the clay in places, and veinlets of gypsum cut the clay and the underlying Moenkopi.

Crossbedded sandstone overlies the clay bed and in places lies on the Moenkopi formation (pl. 2). Part of the sandstone is a fairly clean quartz sand that contains few clay pebbles or carbonaceous fragments. Part of the sandstone contains interstitial claystone, much carbonaceous material, and many clay pebbles. Carbonized logs as much as 5 feet long are exposed in the sandstone at the Oyler mine.

Beds of the Moenkopi formation just beneath the Shinarump member of the Chinle formation are bleached greenish gray or tan generally through a thickness of 1 to 2 feet. At the Oyler mine this bleached zone is unusually thick—8 feet at the west side of the west adit. The thickness of the bleached zone decreases away from the mine.

Most ore minerals in the Oyler mine are secondary. The most abundant uranium mineral is a zippeite-like mineral (Weeks and Thompson, 1954, p. 42–43) reported as zippeite many years ago by Hess (1924, p. 70–73). It is interlayered with gypsum in the basal clay layer and occurs as fracture coatings in black manganese nodules in siltstone in the top of the Moenkopi formation. Smaller amounts of metatorbernite and johannite (Weeks and Thompson, 1954, p. 30) also are in the clay bed. Finely disseminated grains of pitchblende, chalcopyrite, and pyrite were found in black coaly material in the clay (Alice D. Weeks, written communication, 1952). Chalcopyrite and pyrite also occur in the siltstone surrounding the black nodules in the upper foot of the Moenkopi, and chalcopyrite was exposed in one place about 1½ feet below the top of the Moenkopi. Copper sulfate minerals occur in spots and as stains in the basal clay in the Shinarump member and the upper 1 to 2 feet of the Moenkopi. Wyant and others (1952, p. 29) report uraniferous asphaltite pellets from the Oyler mine, though no asphaltite was recognized at the Oyler during the investigation for the present report. Gruner and Gardiner (1952, p. 21–22) list the following minerals from the Oyler mine: schoepite, becquerelite, sklodowskite, alunite, lepidocrocite, gypsum, and basic copper sulfates.

Many fractures are in the sandstone of the Shinarump member of the Chinle formation and some are in the underlying siltstone of the Moenkopi. Most fractures do not cross the basal clay bed of the Shinarump. None of the fractures seem to have any direct relation to concentrations of uranium or copper minerals or to the most highly radioactive rock in the Oyler mine.

The Shinarump member pinches out northwest of the Oyler mine and is covered by alluvium in Grand Wash about 60 feet east of the mine portal. It probably pinches out to the east also, as it is absent just south of the alluvium in Grand Wash. Clay in the basal Shinarump is radioactive for about 400 feet northwest of the mine and also east to the place where it is covered by the alluvium along Grand Wash. In this area near the Oyler mine, maximum radioactivity is 4 to 5 times background. The abnormal radioactivity is spotty and generally decreases away from the mine. Copper staining in the bleached uppermost beds of the Moenkopi is common throughout this area.

The west margin of a channel is exposed on an isolated knob just south of the Oyler mine. This channel fill may be a remnant of a southwest extension of the Oyler channel. About 9 feet of beds of the Moenkopi is truncated by the sandstone of the Shinarump member. The channel margin trends about N. 45° E. Specks and coatings of metatorbernite are in the basal clay bed of the Shinarump.

AREA BETWEEN GRAND AND CAPITOL WASHES

Radioactivity above background was detected and uranium and copper minerals were found at numerous localities along the base of the Shinarump member of the Chinle formation and in the upper 1 foot of the Moenkopi formation from Grand Wash to Capitol Wash (pl. 1 and fig. 28). At some localities the radioactive rock is in scour fills about 2 feet deep. Secondary copper minerals, without associated radioactive rock, are common along this strip of exposures and occur particularly in the upper foot of the Moenkopi.

The basal Shinarump member and the upper 2 feet of the Moenkopi are stained by specks and coatings of metatorbernite and secondary copper in a prospect pit in the NW¼ sec. 36, T. 29 S., R. 6 E. Beds of the Shinarump fill a scour that on the outcrop is 2 to 3 feet deep and about 35 feet wide. This scour appears to trend about north to N. 10° E. Locally, the basal 2 feet of the Shinarump consists of a mixture of thin clay, siltstone, and sandstone beds and stringers, and of carbonaceous wood fragments and seams (fig. 29). Radioactivity is highest, about 10 times background, in the lower 6 inches of this trashy bed of sandstone, clay, and carbonaceous material. Sandstone with carbonaceous fragments but with little clay overlies the trashy sandstone; this upper sandstone is not abnormally radioactive.

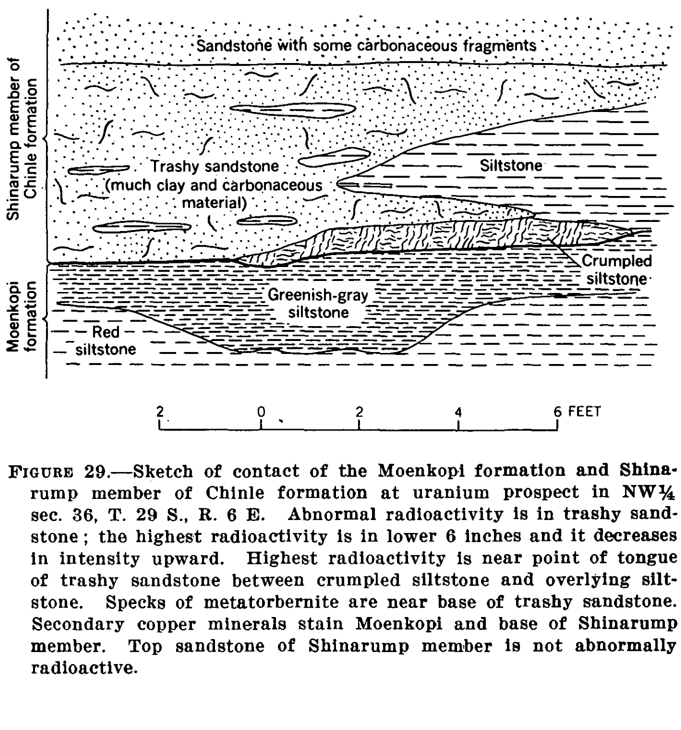


FIGURE 29.—Sketch of contact of the Moenkopi formation and Shinarump member of Chinle formation at uranium prospect in NW¼ sec. 36, T. 29 S., R. 6 E. Abnormal radioactivity is in trashy sandstone; the highest radioactivity is in lower 6 inches and it decreases in intensity upward. Highest radioactivity is near point of tongue of trashy sandstone between crumpled siltstone and overlying siltstone. Specks of metatorbernite are near base of trashy sandstone. Secondary copper minerals stain Moenkopi and base of Shinarump member. Top sandstone of Shinarump member is not abnormally radioactive.

In the west-central part of sec. 36, T. 29 S., R. 6 E., a layer of red chert, 2 to 8 inches thick, contains coatings of asphaltic material. Secondary copper minerals occur on small fracture surfaces in the chert. The red chert is at the base of the Shinarump member in a bed of clay and siltstone. Northward this clay bed is interlayered with sandstone containing carbonaceous fragments and is similar to the clay bed in the basal Shinarump elsewhere. The maximum thickness of the interlayered clay and sandstone at the base of the Shinarump is 8 feet. It contains secondary copper minerals and pyrite and is radioactive locally, chiefly in the lower 2 feet. The red chert with the asphaltite is also radioactive, and the uranium is in the asphaltite. An analysis by Albert C. Horr shows that the asphaltite contains 31.97 percent ash and that the ash contains 6.51 percent uranium. The asphaltite is not abundant enough to be of economic significance.

From sec. 36, T. 29 S., R. 6 E., south to Capitol Wash, secondary copper minerals are scattered throughout the basal 1 foot of the Shinarump member of the Chinle formation and the upper 1 to 2 feet of the Moenkopi. Gypsum is abundant in both units near the contact. Alunite is common in discontinuous beds 1 to 2 inches thick. No abnormal radioactivity was noted at most exposures, but some carbonaceous fragments are radioactive. Along Capitol Wash just north of where State Highway 24 crosses the outcrop of the Shinarump (pl. 1), gray siltstone that contains many carbonaceous fragments and some sandstone stringers is abnormally radioactive. Scattered specks of malachite and metatorbernite and powdery coatings of jarosite occur in the rock. One-inch thick lenses and pods of alunite are at the base of the Shinarump along the west side of the road. At the same locality on the east side of Capitol Wash, the Shinarump is somewhat thicker than normal in this vicinity and may be in a channel trending northward. Because the base of the formation is not exposed along the wash, it is not possible to determine whether the underlying Moenkopi is scoured.

AREA BETWEEN CAPITOL WASH AND SHEETS GULCH

Along the strip of the exposed Shinarump member of the Chinle formation between Capitol Wash and Sheets Gulch (pl. 1 and fig. 28), copper-stained rock or localities of abnormal radioactivity are not so common as north of Capitol Wash. Uraniferous rocks do crop out at several scattered localities.

North and south of Pleasant Creek the Shinarump member is missing. About three-quarters mile south of the Pleasant Creek Ranch (pl. 1), uraniferous red chert crops out in layers about 1 inch thick at the contact between the Moenkopi formation and the middle member of the Chinle formation. Malachite coats and forms spots on fracture surfaces in the chert.

Just east of the center of sec. 32, T. 30 S., R. 7 E., on a westward-projecting bluff of the Shinarump member, the basal few inches of the Shinarump and the greenish-gray siltstone in the upper 1 to 2 feet of the Moenkopi are locally radioactive. Metatorbernite, azurite, malachite, and gypsum occur chiefly in the Moenkopi. Faint radioactivity was detected and secondary copper minerals were found in places as far north as the Shinarump pinchout. On the north side of the westernmost outcrop of the Shinarump, sandstone of the Shinarump is stained dark brown with iron and manganese oxides along fractures that trend about N. 5° W. This sandstone is abnormally radioactive near the fractures. Metatorbernite, the uranium mineral at this locality, occurs only at the base of the Shinarump and in the top of the Moenkopi, not along the fractures in the higher sandstone. The Shinarump on this western projection is thicker than it is to the north and south. No evidence was found to indicate that the Shinarump occupies a channel cut into the Moenkopi.

Radioactivity 2 to 3 times background was detected at numerous localities along the contact of the Moenkopi formation and the Shinarump member of the Chinle formation in the W1/2 sec. 5, T. 31 S., R. 7 E. No concentrations of uranium minerals were found along the contact.

A broad bench on the Chinle formation occupies parts of secs. 7 and 18, T. 31 S., R. 7. E. On the southwest side of this bench, beds of the Shinarump member overlie successively older beds of the Moenkopi from north to south. In a lateral outcrop distance of about 650 feet, approximately 25 feet of the Moenkopi is truncated by Shinarump. The truncated beds of the Moenkopi may be along the north flank of a very broad channel or swale, the south flank of which has been removed by erosion. This broad channel or swale trends about N. 70° W. A northwestward-trending channel (fig. 28, channel 2) exposed on a cliff in the small reentrant on the south side of the bench probably is a part of the broad channel or swale. The Shinarump here consists chiefly of massive quartz sandstone that is fairly free of clay and carbonaceous fragments, though local lenses in it contain clay pebbles and stringers. At its base, however, the Shinarump is a fine-grained sandstone that locally contains much interstitial siltstone and claystone. Metatorbernite, azurite, and malachite occur chiefly in the lower 4 inches of the Shinarump and the upper 1 foot of the Moenkopi near a prospect adit (pl. 1 and fig. 28) in sec. 18 along the flank of the swale or broad channel. Radioactivity at the adit and in the drifts ranges from about 2 to 5 times background. Radioactive rock is scattered and is restricted to a zone within a few inches of the contact between the Shinarump and Moenkopi. Pyrite occurs locally in the sandstone, mainly as nodules, and iron and manganese oxides stain the sandstone in places at this prospect.

Abnormal radioactivity was detected and secondary copper minerals were found at widely scattered localities along the Moenkopi and Shinarump contact in Sheets Gulch.

OAK CREEK AND NORTH AND SOUTH COLEMAN CANYONS

Along Oak Creek, uraniferous rock is chiefly in the top 1 foot of the Moenkopi formation and in a basal bed of claystone, siltstone, and sandstone of the Shinarump member, which is 1 to 3 feet thick. Here the Shinarump ranges in thickness from 0 to about 20 feet. The basal bed of the Shinarump contains some clay pebbles in the lower few inches and much carbonaceous material. At an exposure on the west side of Bear Canyon (fig. 30), 2 coaly beds in the Shinarump are as much as 1½ feet thick. Although bedrock exposures are too poor over part of the Oak Creek area to afford adequate control, structure contours of the base of the Shinarump suggest that the sediments of the Shinarump filled a northeastward-trending channel in the underlying Moenkopi formation (fig. 28, channel 3; fig. 30).

At Oak Creek, uraniferous rock is exposed in several places for a distance of about 3,500 feet and fairly continuously along 1 outcrop for a distance of about 400 feet. The U_3O_8 content of representative samples ranges from 0.002 to 0.11 percent in 1- to 4-foot grab samples. Specks of metatorbernite occur at a few exposures. Uranium minerals are not discernible at most of the outcrops of radioactive rock. The uranium appears to be associated intimately with carbonaceous material in the basal bed of the Shinarump member at most localities. Pyrite, jarosite, and gypsum occur both with and away from uraniferous rock. Local layers of alunite are near or at the base of the Shinarump.

The Shinarump is absent throughout most of the Coleman Canyons area but occurs at 2 localities in North Coleman Canyon and at 2 in South Coleman Canyon (pl. 1). At its western exposure in North Coleman Canyon the Shinarump has a maximum thickness of about 15 feet. It consists of a massive unit of medium- to coarse-grained crossbedded sandstone that contains thin clay partings near the top.

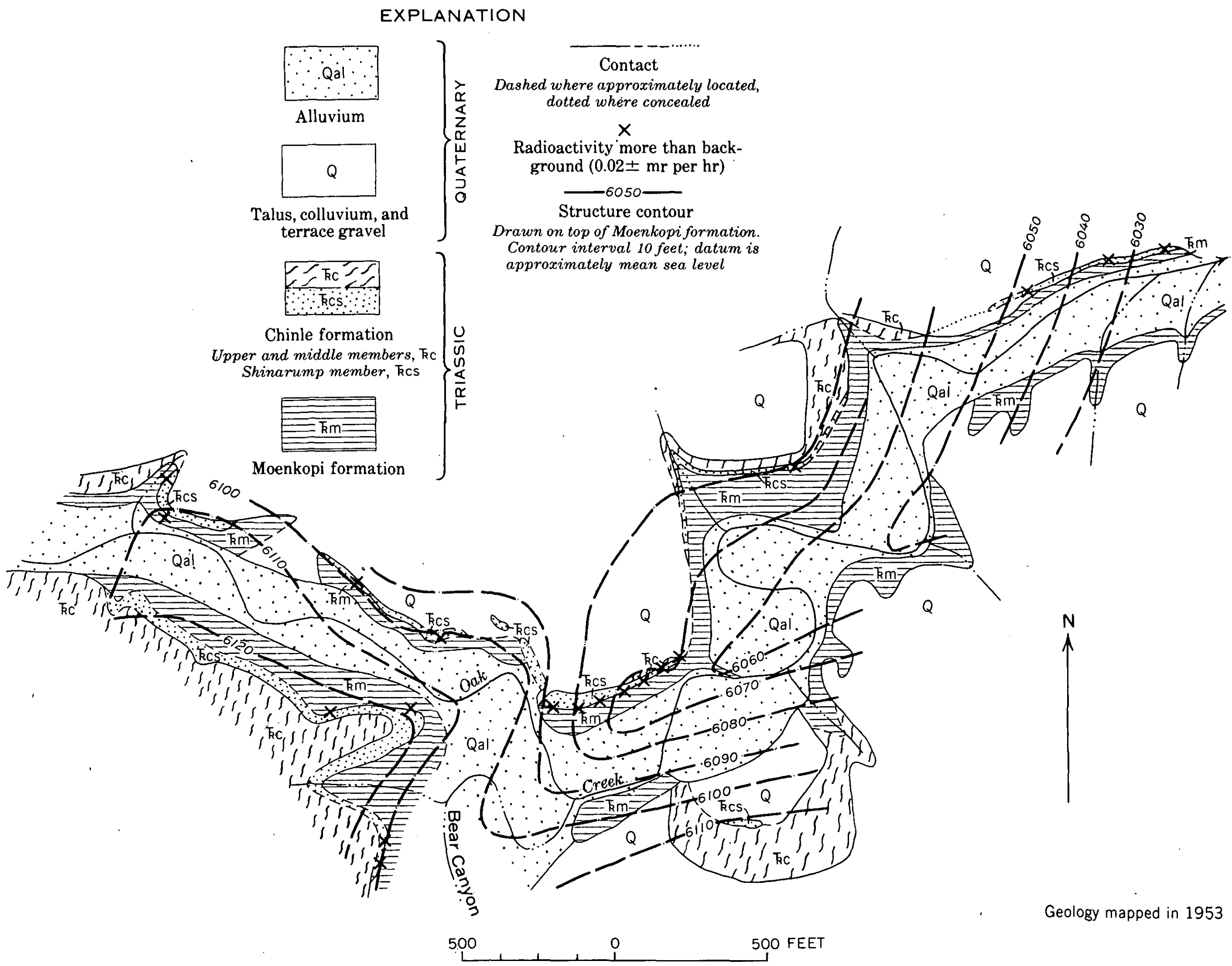


Figure 30.—Geologic and structure-contour map of exposure of the Shinarump member of the Chinle formation along Oak Creek, Capitol Reef area, Utah.

At its thickest part the Shinarump occupies a channel cut about 4 feet into the Moenkopi. This channel trends about N. 40° E., but an exact trend cannot be determined owing to the irregular contact and inadequate exposures. For about 1 foot at its base the Shinarump contains clay and chert pebbles, carbonized plant and wood fragments, silicified wood fragments, iron oxide and jarosite, and stringers of gypsum and alunite. The basal 1 foot of the Shinarump is abnormally radioactive in small spots, particularly near coaly fragments. The highest radioactivity detected was about 10 times background.

The Shinarump member in South Coleman Canyon is a lens about 12 feet thick. It consists chiefly of medium-grained sandstone interbedded with claystone and carbonaceous material, particularly in the lower 3 feet. At 1 place in the lower 1 foot, radioactivity of 2 times background was detected, but elsewhere in the canyon it remained at background.

AREA OF NEARLY CONTINUOUS OCCURRENCE OF THE MEMBER

The area where the Shinarump member is nearly continuous includes the exposures of Shinarump west of a line between Tantalus Flats and a point about 2½ miles northwest of Fruita or about a mile east of Chimney Rock (pl. 1 and Fig. 28). The Shinarump in this western two-thirds of the Capitol Reef area seems to be almost continuous. Also, the thickness of the Shinarump is generally greater and is much more uniform than it is in the area of discontinuous Shinarump. Uraniferous rock localities are widely scattered in this area of nearly continuous Shinarump, but they are not as abundant as they are in the area of discontinuous Shinarump to the east.

AREA FROM CHIMNEY ROCK WEST TO THE THOUSAND LAKE FAULT

The Shinarump member in the area from Chimney Rock west to the Thousand Lake fault (pl. 1) is almost continuous but in places differs in thickness in short distances. It ranges in thickness from 0 to 90 feet and is lacking in 2 places. The member consists chiefly of medium- to coarse-grained crossbedded sandstone that locally contains carbonaceous fragments and clay pebbles and lenses. Uraniferous rock, associated with carbonaceous material or with clay stringers, is randomly distributed. In places, particularly in the west half of this area, the Shinarump caps steep cliffs and is almost inaccessible.

Secondary copper minerals are quite abundant and uraniferous rock less so, as far west as Sulphur Creek. The copper is concentrated chiefly in the upper 1 foot of the greenish-gray to tan top beds of the Moenkopi formation and is common locally along fracture surfaces in the upper 1 foot. Iron oxide and jarosite occur in the base of the Shinarump member of the Chinle formation but seem to have no definite association with uraniferous rock. Alunite forms layers 1 to 3 inches thick and pods 5 to 6 inches long and as much as 4 inches thick at the bottom of the Shinarump along much of the outcrop in secs. 32 and 33, T. 28 S., R. 5 E.; copper occurs locally along this area. Rock along and near the alunite does not seem to be more abnormally radioactive than rock away from it.

Two well-developed channels filled with beds of the Shinarump member in the top of the Moenkopi are exposed in this area from Chimney Rock to the Thousand Lake fault. Scours 1 to 3 feet deep are quite common, particularly in sec. 34 and the W½ sec. 35, T. 28 S., R. 5 E.

One of the well-developed channels (fig. 28, channel 4) filled with sandstone beds of the Shinarump member is exposed in the NW1/4 sec. 32, T. 28 S., R. 5 E. (pl. 1). This channel trends N. 30° E. and on the outcrop is about 20 feet deep and about 150 feet wide. The east side of the channel is generally steep to vertical and at a few places the banks are slightly undercut. The west side slopes gently. On the east point of a cliff 3,000 feet south of this channel, an inaccessible channel margin is exposed. This inaccessible channel may be a southward extension of the main channel; the Shinarump has been eroded from the intervening area. The beds of the Shinarump that filled the main channel consist of medium- to coarse-grained quartz sandstone that contains clay-pebble lenses and scattered carbonaceous layers as much as 1 inch thick and 4 to 5 inches long. Just above the channel-fill beds, a 2-foot-thick unit of shale, claystone, and sandstone contains seams of carbonaceous material that are 2 inches thick and as much as 10 feet long. In places at the base of the channel-fill beds, a layer of claystone and siltstone contains pods and stringers of alunite. The only abnormal radioactivity detected at this channel was about 3 times background along a seam of carbonaceous material ½ inch thick and 5 inches long. This carbonaceous material is near the base of the Shinarump in the channel. No uranium or copper minerals were observed.

The other well-exposed channel (fig. 28, channel 5) in this area of the nearly continuous Shinarump member is on the southwest side of Holt Draw in the SE1/4 sec. 35, T. 28 S., R. 4 E. (pl. 1). The Shinarump in this channel has been prospected by a nearly horizontal drift trending about S. 25° W. for 220 feet from the outcrop and by 2 crosscuts. One crosscut extends southeastward for 120 feet, and the other extends northwest for 140 feet. The channel is asymmetric, with the east side steeper than the west. The maximum depth of the channel is about 15 feet and the width about 250 feet. On the outcrop the east margin of the channel trends about N. 30° W. and slopes steeply southwestward; the west margin trends about N. 10° W. and slopes very gently northeastward. Medium- to coarse-grained quartz sandstone composes most of the beds of the Shinarump. Silica overgrowths on quartz grains are very common. A discontinuous clay bed in the channel at the base of the Shinarump is as much as 1 foot thick. Clay pebbles are scattered throughout most of the channel-fill rocks but are concentrated only in widely distributed lenses. All the beds of the Shinarump contain little carbonaceous material. On the surface exposure, high radioactivity is restricted to a gray clay lens at the base of the Shinarump and to a clay lens 1½ feet above the base. Both clays are in a zone 20 feet wide at the deepest part of the channel. In the prospect workings, radioactivity is barely above background at only a few spots along the base of the Shinarump. Metatorbernite forms specks on the basal clay at the surface exposure. Brochantite and chalcanthite occur in clay partings and spot the sandstone as much as 6 feet above the base of the Shinarump at the adit. The sandstone is not abnormally radioactive except adjacent to the clay, which makes up a very small percentage of the rock. Iron oxide stains the rock in many places. A layer of alunite ½ inch thick and 4 feet long parallels bedding in the sandstone at one place in the prospect workings. Many joints trending chiefly N. 10° E. to N. 10° W. cut the sandstone but are not traceable through or into clay or siltstone beds. Iron oxide is concentrated along some joints, but no abnormal radioactivity was detected near them.

An outer carbonized layer, about ¼ inch thick, of a silicified log near the base of the Shinarump has a radioactivity of 5 times background. This log is about 1,000 feet west of Twin Rocks at the north edge of sec. 2, T. 29 S., R. 5 E.

AREA FROM SHEETS GULCH AND TANTALUS FLATS NORTHWEST TO THE THOUSAND LAKE FAULT

The Shinarump member along the area from Sheets Gulch and Tantalus Flats northwest to the Thousand Lake fault (pl. 1) appears to be a nearly continuous unit, but it is covered by Quaternary deposits in many places. Outcrops of the Shinarump are near the Teasdale fault along most of this area. Sandstone with some clay stringers and pebbles makes up most of the member. Conglomerate lenses, particularly along Sulphur Creek, are more abundant than in the Shinarump elsewhere in the Capitol Reef area. Iron oxide and manganese oxide minerals are common in the sandstone in many places, perhaps because of the nearness of the Teasdale fault. Although no uranium minerals were found along this strip of exposures, radioactivity above background was detected at two localities, N1/2 sec. 28, T. 30 S., R. 6 E., and NE1/4 sec. 14, T. 30 S., R. 5 E.

URANIUM IN THE MIDDLE AND UPPER MEMBERS OF THE CHINLE FORMATION

Radioactive material occurs in several places in the middle and upper members of the Chinle formation, but no large concentrations of this material were found in the Capitol Reef area. For the most part the abnormal radioactivity is in widely scattered fossil logs—in South Coleman Canyon, just north of Oak Creek, east of Sand Creek, and northwest of Teasdale (pl. 1 and fig. 28). Very small amounts of carnotite ($K_2(UO_2)_2(VO_4)_2 \cdot 1-3H_2O$), metarossite ($CaV_2O_6 \cdot 2H_2O$), and schroeckingerite ($NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$) have been identified from the fossil logs north of Oak Creek; mineral identifications were made by Arthur J. Gude 3d and Edward J. Young of the U.S. Geological Survey. Abnormal radioactivity also was detected in scarce fossil bone fragments in the Chinle and in a sandstone lens in the middle member north of Oak Creek.

Radioactive fossil logs are very common on the northeast side of Black Ridge, about 2 miles northwest of Teasdale (pl. 1). At this locality the logs range from 2 to 10 feet in length and from ½ to 2 feet in diameter. The logs are composed chiefly of silica in the form of opal, jasper, or crystalline quartz lining cavities. All the logs are highly fractured. Some have a brown or black coating of iron or manganese minerals. Some of the logs with the highest radioactivity have thin powdery coatings of an unidentified yellow uranium mineral locally along fracture surfaces. In this local area the logs are particularly abundant along a horizon in the middle of the upper member of the Chinle. This zone of logs has been prospected extensively by bulldozing.

At 1 place north of Oak Creek, a part of a thin sandstone lens interbedded with claystone is abnormally radioactive to about 2 times background. This sandstone lens is near the radioactive silicified logs in that same vicinity. The sandstone and conglomeratic sandstone at the top of the middle member of the Chinle formation were checked in several places but no abnormal radioactivity was detected.

URANIUM IN THE CURTIS FORMATION

On the east side of South Desert near The Notch, carbonaceous fragments 1 to 3 inches long and about 1 inch thick near the base of the Curtis formation are abnormally radioactive. Secondary copper minerals occur with the carbonaceous material. The beds at the base of the Curtis near Notch Water are similar lithologically to beds at the base of the formation over the rest of the mapped area. No other occurrences of abnormal radioactivity in the Curtis formation were found, although a detailed examination for abnormal radioactivity in the Curtis was not made.

URANIUM IN THE SALT WASH MEMBER OF THE MORRISON FORMATION

In the Capitol Reef area the known uranium deposits in the Salt Wash member of the Morrison formation occur in conglomeratic sandstone lenses at or near the top of the member. These deposits consist of carnotite and uraniferous material disseminated in conglomeratic sandstone and locally concentrated in pockets containing abundant carbonized plant fragments. These pockets are generally 2 to 6 feet long, 2 to 3 feet wide, and 2 to 6 inches thick. The uraniferous rock has a U_3O_8-V_2O_5 ratio ranging from about 1:1 to 1:6. It also contains more than 10 percent calcium carbonate and commonly as much as 17 percent.

The deposit at the prospect adit in sec. 7, T. 30 S., R. 8 E., north of Notom Bench (pl. 1) is typical of the uranium deposits in the Salt Wash member. This deposit is in a conglomeratic sandstone lens in the upper part of the Salt Wash. This lens is about 50 feet thick and 200 to 300 feet wide. Exact dimensions cannot be measured because the lens forms a ridge and the margins have been eroded throughout most of its length. Much of the slope is rubble covered, but the lenticular conglomeratic sandstone appears to interfinger at the lens margins with siltstone and claystone. Crossbedded sandstone and conglomerate beds alternate within this lens. The sandstone is light tan, friable in fresh exposures, and medium to coarse grained. It is composed chiefly of quartz sand grains but contains scattered pebbles and stringers of pebble conglomerate and some carbonaceous material. Pebbles in the conglomerate are chiefly chert and quartzite, with maximum diameters of about 1¼ inches; scarcer green and purple clay pebbles are as much as 2 inches in diameter. Carnotite occurs along crossbeds in the sandstone and the conglomerate and as pebble coatings in the lower part of the conglomeratic sandstone lens. Abnormal radioactivity occurs intermittently through a vertical distance of 30 feet above the base of the lens, and radioactivity is slightly above background discontinuously for about 300 feet along the rubble-strewn hillside. A 2-foot channel sample collected from sandstone crossbeds contains 0.036 percent U_3O_8 and 0.22 percent V_2O_5, and a 3-foot channel sample of conglomerate overlying the sandstone contains 0.11 percent U_3O_8 and 0.20 percent V_2O_5 (S. P. Furman, Wayne Mountjoy, J. W. T. Meadows, E. C. Mallory, J. P. Schuch, U.S. Geological Survey, written communication, 1954).

In the NE¼ sec. 18, T. 30 S., R. 8 E., southeast of Notom Bench (pl. 1), uraniferous rock is in a similar conglomeratic sandstone lens, which is the second sandstone below the top of the Salt Wash member. Uraniferous material occurs in spots along with abundant carbonized plant fragments, estimated to compose as much as 15 percent of the rock in places, and with much iron oxide stain, some pyrite and jarosite, and calcite. In this same lens are pockets or concentrations of fossil plant fragments. These pockets have maximum dimensions of about 3 feet by 6 feet by 6 inches and contain the highest concentration of uraniferous material in the lens. The observed pockets are restricted largely to the conglomeratic sandstone lens but do not seem to be along any particular trend within the lens.

URANIUM IN VOLCANIC ROCKS

No abnormal radioactivity was detected in any lavas or ash beds in the mapped area. However, at several localities from about 2 to 12 miles west on the Awapa Plateau, prospectors using scintillation counters have detected radioactivity of 2 to 3 times background. At two of the localities, the radioactivity seems to result from the mass of the rock because no increased activity could be determined on single specimens. A cobble of porphyritic andesite from Big Hollow (pl. 1) on the Awapa Plateau contains amygdules of fluorescent silica. The uranium content of this silica is 30 parts per million.

While making a reconnaissance for uranium-bearing carbonaceous materials in southern Utah, Zeller (1955, p. 2, 3, 7) collected several samples of volcanic rock from the southern and western part of the Aquarius Plateau. A sample from a white tuff interbedded with lava flows about 15 miles west of the Capitol Reef area contained 2 ppm uranium, and a sample from a volcanic flow rock in the same general area contained 9 ppm uranium. Another sample of volcanic flow rock from about 10 miles southwest of the Capitol Reef area contained 5 ppm uranium. These figures are in the general range of normal uranium content in volcanic flow rocks (McKelvey and others, 1955, p. 481–482).

On the basis of present data the areas of volcanic rocks in and adjacent to the Capitol Reef area cannot be considered as favorable areas for economic deposits of uranium.

GEOCHEMICAL STUDIES

By Lyman C. Huff

Geochemical studies were made chiefly to investigate the chemistry of uranium deposition and the possibilities of geochemical prospecting for uranium deposits under the existing conditions. The description of the geochemical studies is given here so that both geologic and geochemical data can be discussed in connection with the origin of the uranium deposits and the prospecting guides. Chemical data were obtained for (1) typical sedimentary rocks, (2) bleached sedimentary rocks, and (3) uranium ore and mineralized rock.

TYPICAL SEDIMENTARY ROCKS

The major chemical constituents in representative samples of the sedimentary rocks were investigated by the rapid methods similar to those described by Shapiro and Brannock (1956). The 21 samples analyzed are mudstone, sandstone, limestone, and tuff that range in age from Permian to Tertiary (table 7). Most of the eight carbonate rocks sampled contain appreciable silica. Both samples from the Kaibab limestone and one from the Sinbad limestone member of the Moenkopi formation are dolomite. The dolomite from the Sinbad member is from the uppermost bed of the member and is a persistent bed throughout exposures of this member in the Capitol Reef area. All other carbonate rocks sampled, including those from the Chinle, Carmel, and Flagstaff formations and another from the Sinbad member of the Moenkopi, are nonmagnesian limestone.

The silica in the eolian sandstone ranges from 85 to 98 percent; the highest content is in a sample of Coconino sandstone (laboratory No. 146649). Three of the eight sandstones analyzed, those from the Chinle, Kayenta, and Entrada formations, have appreciable amounts of carbonate that occurs as cement.

The complex chemical composition of mudstone samples reflects their varied mineral composition. Most of the silica, which constitutes as much as 64.2 percent of a sample, occurs as fine quartz grains. Silica, alumina, calcium, alkalies, alkaline earths, and water of crystallization probably occur in the clay minerals. The total iron content, averaging between 3 and 5 percent, is

TABLE 7.—*Chemical composition of representative sedimentary rocks of the Capitol Reef area, Utah*

[Analysts: P. L. D. Elmore, K. E. White, S. D. Botts, and P. W. Scott, U.S. Geological Survey]

	Coconino sandstone	Chinle formation			Wingate sandstone	Kayenta formation	Navajo sandstone	Entrada sandstone	Kaibab limestone	
		Shinarump member		Middle member						
	E½ sec. 17, T. 29 S., R. 6 E.	NE¼ sec. 6, T. 29 S., R. 6 E.	Oyler channel 6 feet above base.	NE¼ sec. 6, T. 29 S., R. 6 E.	NE¼ sec. 6, T. 29 S., R. 6 E.	NE¼ sec. 25, T. 29 S., R. 6 E.	Capitol Wash.	NE¼ sec. 36, T. 27 S., R. 3 E.	SW¼ sec. 8, T. 29 S., R. 6 E.	SW¼ sec. 8, T. 29 S., R. 6 E.
Field	CR-238	CR-26	CR-53	CR-18	CR-23	CR-35	CR-239	CR-162	CR-28	CR-200
Laboratory	146649	146623	146626	146620	146622	146625	146650	146653	146624	146645
Rock type	Sandstone	Sandstone	Sandstone	Sandstone, conglomeratic; carbonate cement	Sandstone	Sandstone; sandstone and conglomerate unit	Sandstone	Sandstone, very fine grained, silty, calcareous	Dolomite, silty	Dolomite
SiO_2	98.4	74.8	89.5	37.6	85.2	50.9	95.4	71.3	24.5	4.4
Al_2O_3	1.0	5.1	5.9	8.8	5.2	2.0	2.0	7.9	1.4	.82
Fe_2O_3	.12	5.4	.73	1.4	.20	1.1	.14	1.2	.50	.34
FeO	.00	.20	.04	.04	.00	.02	.02	.14	.23	.08
MgO	.06	.12	.09	.27	1.4	8.7	.09	1.5	15.2	20.8
CaO	.04	1.7	.06	25.8	1.8	14.4	.07	6.9	22.1	28.5
Na_2O	.02	.18	.09	.26	.12	.10	.08	1.4	.11	.08
K_2O	.08	2.0	1.3	2.8	2.5	.90	1.0	2.2	.33	.16
TiO_2	.04	.27	.80	.20	.18	.10	.04	.24	.07	.04
P_2O_5	.02	.22	.16	.13	.05	.05	.02	.12	.30	.17
MnO	.00	.00	.00	.20	.02	.02	.00	.05	.01	.00
H_2O	.25	4.3	1.8	2.0	1.2	.46	.36	2.4	.49	.22
CO_2	<.05	.05	<.05	19.9	2.4	20.6	<.05	5.8	33.0	44.2
Sum	100.	94.	101.	99.	94.	[1] 99.	[1] 99.	101.	[1] 98.	100.
Total S as SO_3		6.0			6.					

	Moenkopi formation		Chinle formation	Carmel formation		Flagstaff limestone	Moenkopi formation		Chinle formation		Flagstaff limestone
	Sinbad limestone member		Middle member						Shinarump member	Middle member	
	SW¼ sec. 23, T. 29 S., R. 5 E.	SW¼ sec. 23, T. 29 S., R. 5 E.	N½ sec. 8, T. 29 S., R. 6 E.	SW¼ sec. 17, T. 29 S., R. 4 E.	SW¼ sec. 25, T. 28 S., R. 3 E.	NE¼ sec. 26, T. 28 S., R. 3 E.	W½ sec. 33, T. 28 S., R. 5 E.	N½ sec. 17, T. 29 S., R. 4 E.	Lat 38°13′ N., Long 111°12′ W.	SE¼ sec. 26, T. 29 S., R. 6 E.	NE¼ sec. 36, T. 28 S., R. 3 E.
Field	CR-1	CR-4	CR-20	CR-92	CR-120	CR-204	CR-94	Oyler-531	CR-10	Oyler-206	CR-105
Laboratory	146617	146618	146621	146630	146634	146646	146631	146652	146619	146651	146633
Rock type	Dolomite	Limestone, sandy	Limestone	Limestone, sandy and silty	Limestone, sandy	Limestone, sandy	Mudstone, red, silty	Mudstone, red	Mudstone, gray	Mudstone	Tuff, sandy, biotitic
SiO_2	9.1	30.8	2.7	7.0	24.4	11.1	62.4	44.8	64.2	57.7	64.2
Al_2O_3	2.4	2.5	.60	.78	1.2	1.9	20.6	10.8	21.5	16.8	15.0
Fe_2O_3	.48	.40	.30	.76	.70	.87	4.9	4.1	2.0	4.7	1.2
FeO	.17	.07	.03	.06	.12	.02	.28	.60	.23	.62	.52
MgO	18.0	1.9	.74	1.2	2.4	1.1	.98	7.4	.81	2.4	2.1
CaO	27.5	34.4	54.1	46.6	38.6	47.0	.08	10.2	.05	.44	2.6
Na_2O	.10	.09	.09	.12	.08	.16	.14	.16	.13	.36	1.8
K_2O	.52	.43	.15	.27	.25	.25	3.2	2.8	2.7	4.4	3.2
TiO_2	.10	.09	.02	.04	.04	.08	.82	.49	.88	.80	.24
P_2O_5	.07	.37	.02	.03	.03	.03	.24	.20	.19	.14	.18
MnO	.01	.00	.01	.00	.01	.02	.02	.01	.00	.02	.02
H_2O	.56	.77	.25	3.4	.58	2.1	6.5	3.4	8.3	9.8	8.8
CO_2	41.0	27.9	42.0	31.7	31.6	36.0	.07	15.2	<.05	.13	.10
Sum	100	100	101	92	100	101	100	100	101	98	100
Total S as SO_3				7.5						2.6	

[1] Sample contains organic matter.

somewhat less than the average of many shale analyses (Clarke, 1924, p. 34 and 552). Trace constituents in mudstone are discussed in a later section in connection with the studies of the bleached mudstone.

The sample of bedded biotite tuff (laboratory No. 146633) from the Flagstaff limestone has a calculated CIPW norm (Washington, 1917) near that of rhyolite and approaching quartz latite. Part of the silica is in detrital quartz grains in the rock.

BLEACHED SEDIMENTARY ROCKS

Bleached red beds are prominent in many places in the Capitol Reef area, particularly along contacts of mudstone with sandstone. The bleaching of the mudstone from red to gray and green may have been caused by several processes: (1) much may be related to the activity of weathering and ground water, (2) some may be related to magmatic or hydrothermal processes accompanying the intrusion of dikes, and (3) that near uranium-bearing units may be related to the uranium-bearing solutions. The bleached beds were investigated to determine if possible the causes of the bleaching and the possible relations of bleaching to uranium deposition. Preliminary studies of bleached sedimentary rock have been presented by Huff (1955).

To investigate bleaching near ore, samples were collected along sections measured through the upper part of the Moenkopi formation, the Shinarump member, and the overlaying parts of the Chinle formation. Representative samples were obtained both near to and distant from uranium deposits along 2 stratigraphic sections close to the Oyler mine and 2 others away from any known mineralized rock. The Oyler mine is the richest known uranium deposit in the Capitol Reef area, but it is small in comparison with many uranium deposits on the Colorado Plateau. In order to include some samples from the vicinity of at least one producing mine, a few samples were collected near the Jomac mine in the White Canyon area, San Juan County, Utah, outside the Capitol Reef area. Samples were collected close enough together to include bleached mudstone, unbleached mudstone, and all other lithologic types.

Samples were collected of a bleached zone around an igneous dike about 3 miles south of Torrey (pl. 1) and of bleached rock along joints in weathered exposures of the Moenkopi formation. These consist of paired samples of bleached and unbleached rock from the same beds.

Several hundred samples of bleached and unbleached mudstone were collected. In much of the area of study the soil cover is thin or absent, and samples were collected of rock chips from outcrops or of handfuls of loose rock from shallow pits. Some samples were collected in pairs to check reproducibility of the sampling and of the analytical processes. Samples were stored in half-pint dairy cartons or in metal-clasp manila envelopes.

The samples were analyzed by colorimetric and spectrographic tests. The total heavy-metal test used is a rough field-type test designed for geochemical prospecting that will detect traces of copper, lead, and zinc (Huff, 1951). Also, specific colorimetric analyses were made for copper, lead, and zinc in many samples collected in and near the Shinarump member of the Chinle formation. Seventy-eight mudstone samples were analyzed in the U.S. Geological Survey laboratories by semiquantitative spectrographic methods. The uranium content was determined by a specific test for uranium that will detect as little as 4 ppm (Lovering and others, 1956, p. 664).

The acidity and the oxidation potential of typical samples were measured. Acidity (pH) of some powdered mudstone was measured by a method used commonly for soils (U.S. Dept. of Agriculture, 1951, p. 237). The oxidation potential (Eh) of several samples was measured with the help of Robert M. Garrels and Harold Bloom of the U.S. Geological Survey, by using a platinum instead of a glass electrode in the pH meter (ZoBell, 1946). Nitrogen was bubbled through the sample during the measurement to stir the suspension and to expel oxygen. The meter used gave stable Eh potentials after bubbling nitrogen for about 15 minutes.

The semiquantitative spectrographic analyses indicate the gross composition of the mudstones. Of 37 elements looked for, 27 elements were detected in the mudstone samples. The elements detected differ greatly in their ranges of concentration (fig. 31). Some of the elements detected, like silica, that have

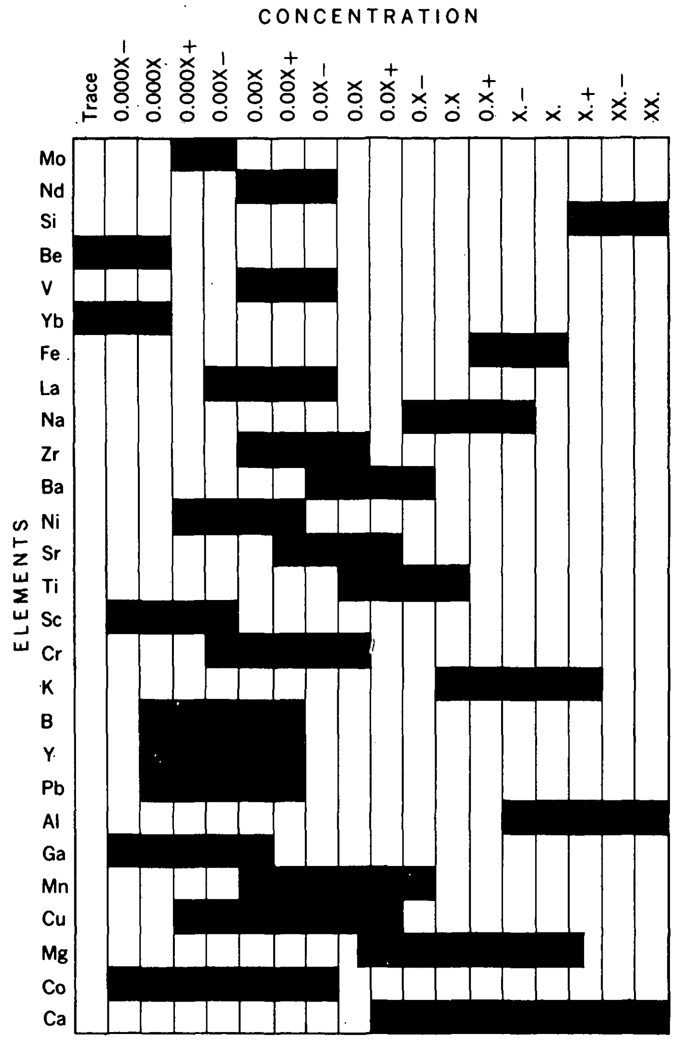


FIGURE 31.—Diagram showing range of concentration of 27 elements (nine other elements looked for but not detected were: Ag, As, Cd, Hg, Pt, Sb, Sn, U, and W; Zn detected in only one sample) within 78 mudstone samples as determined by semiquantitative spectrographic analysis. The concentrations of the elements as determined by semiquantitative spectrographic analysis are bracketed into groups each of approximately one-third of an order of magnitude, X+ indicating the higher portion (10 to 5 percent), X the middle portion (5 to 2 percent), and X— the lower portion (2 to 1 percent). Comparisons of this type of semiquantitative result with those obtained by quantitative methods, either chemical or spectographic, show that the assigned group includes the quantitative value in about 60 percent of the analyses. Analysts: N. M. Conklin and J. C. Hamilton, 1954–55, U.S. Geological Survey.

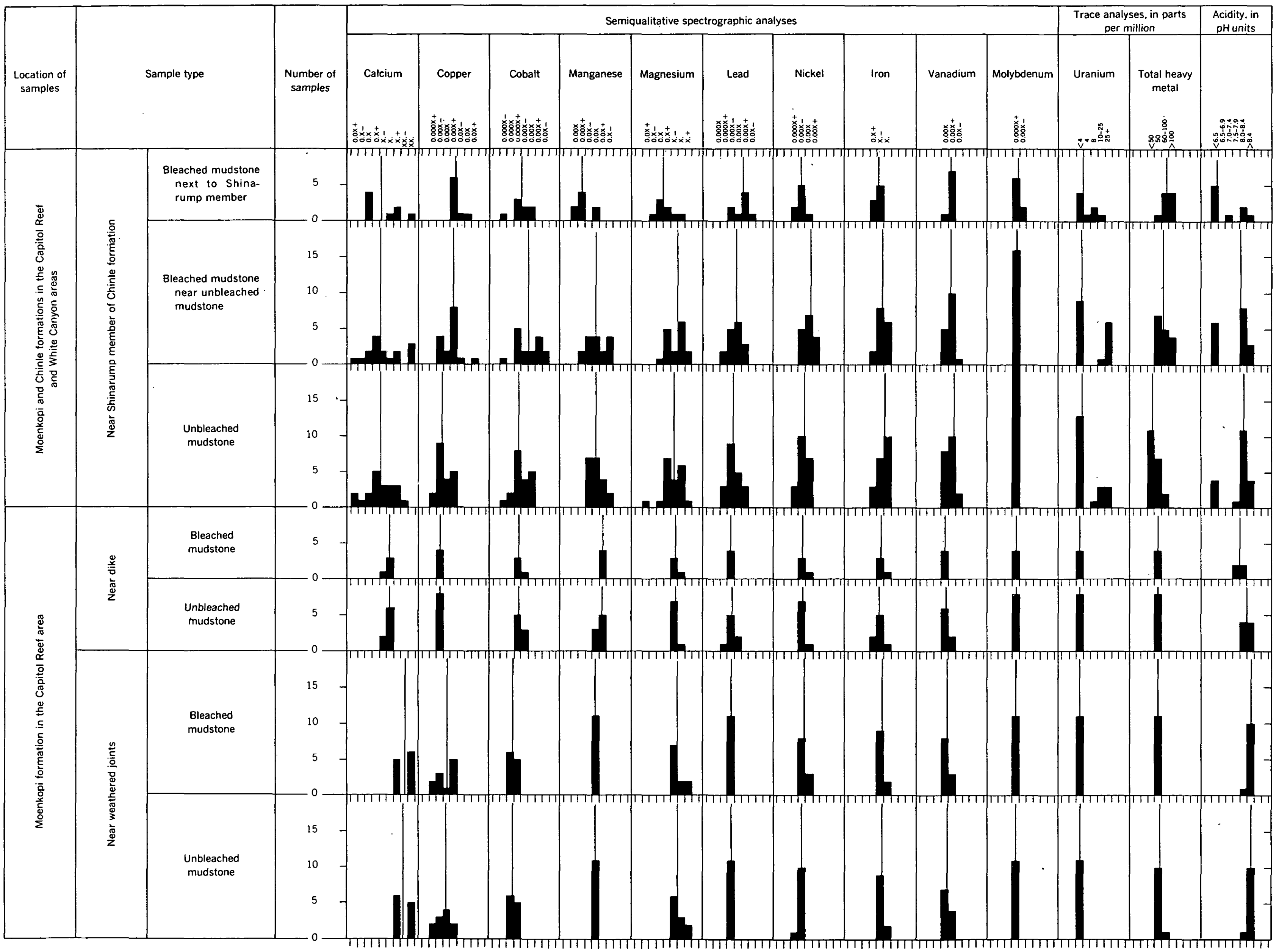


Figure 32.—Histograms showing concentration of selected elements among 78 mudstone samples classified by type. The vertical line in each group indicates the median concentration. Semiquantitative spectrographic analyses (as described for fig. 31) by N. M. Conklin and J. C. Hamilton, 1954–55; trace analyses by H. E. Crowe, J. H. McCarthy, and C. E. Thompson, U.S. Geological Survey.

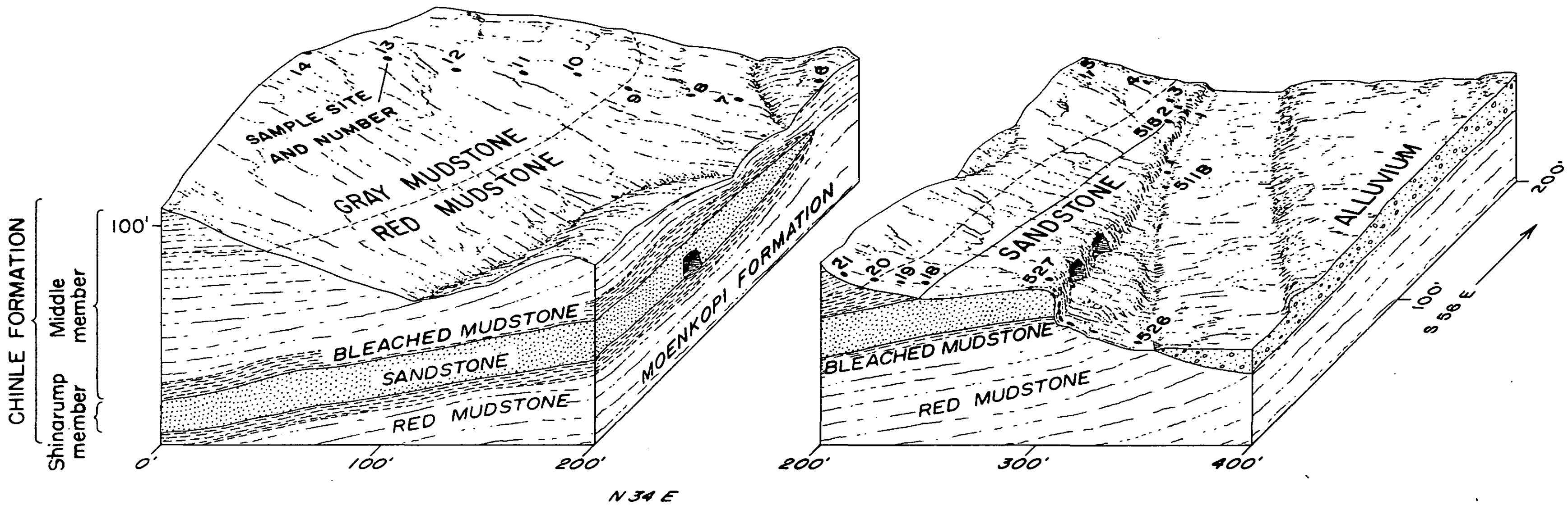


FIGURE 33.—Block diagram showing geochemical-sample sites in the bleached and unbleached mudstone near the Oyler mine.

comparatively narrow ranges in concentration probably were little modified during the bleaching process. Other elements that have wider ranges in concentration seem most likely to have been increased or decreased during the bleaching.

Elements of wide ranges in concentration are compared by histograms to distinguish differences according to geologic environment (fig. 32). To facilitate comparisons the medians for each group are shown.

The bleached and unbleached mudstone have essentially no difference in composition near the dike and near the weathered joints. The major variations in composition among the samples occur in mudstone collected close to the Shinarump member of the Chinle formation. These samples collected close to the Shinarump include some collected close to and distant from uraniferous rock. To include some samples from the vicinity of a producing mine, sampling had to be extended outside of the Capitol Reef area, and Figure 32 includes eight samples from the Jomac mine, White Canyon area, Utah, that are very similar chemically to those of the Capitol Reef area.

Bleached mudstone beds near the Oyler mine are typical of bleached beds near the Shinarump member elsewhere. Here the beds of the Moenkopi and Chinle in contact with the sandstone beds of the Shinarump member of the Chinle have been bleached conspicuously from red to gray. An accompanying block diagram (fig. 33) shows these relationships. Bleached beds like those near the Oyler mine occur at most places along the Shinarump and Moenkopi contact.

A wide range in concentration of copper and lead in bleached mudstone near the Shinarump member is shown by semiquantitative spectrographic analyses (fig. 32) and by chemical anayses of samples arranged stratigraphically (tables 8 through 11). These bleached beds have less manganese, magnesium, and iron, and more zinc, copper, lead, and total heavy metals, and perhaps molybdenum than the unbleached ones. In comparison with mudstone elsewhere both bleached and unbleached mudstone near the Shinarump member appear to have a high uranium and vanadium content and a low calcium content.

The pH (tables 8–11 and fig. 32) and a few Eh measurements indicate that the bleached mudstone near the Shinarump is acidic and reduced as compared with unbleached mudstone. The pH and Eh are related to the chemical constituents of the rock and may indicate something of the conditions of deposition of the chemical constituents. However, the conditions may have been changed considerably by weathering processes.

The chemical cause of the bleaching is not known. The increase in zinc, copper, lead, and perhaps molybdenum and the loss of iron and manganese occurred chiefly in the part of the bleached mudstone closest to the Shinarump member of the Chinle formation. The decrease in calcium and the increase in uranium and possibly vanadium appear to extend throughout both bleached and unbleached mudstone near the Shinarump. None of these chemical changes coincides exactly with the color line. The color change may represent largely a reduction and hydration from hematite grain coating in the red mudstone to limonite grain coating in the bleached mudstone (Alice D. Weeks, oral communication, 1954). Such a chemical change would not be detected by analytical methods used for the Capitol Reef samples.

TABLE 8.—*Chemical analyses, in parts per million, of samples collected from the Moenkopi formation and Shinarump member of the Chinle formation near the Oyler mine*

[Two determinations are listed for analyses of duplicate samples. Analysts: H. E. Crowe, W. H. Mountjoy, and J. P. Schuch, U.S. Geological Survey]

Laboratory	Field	Description	Total heavy metal	Zinc	Lead	Copper	pH	Uranium
52–5536	6	Fine-grained sand and siltstone, reddish-brown, 16.7 feet above top of Shinarump.	0 0	10	10	10	8.1 8.2	<4
–5535	5	Fine-grained sand and siltstone, reddish-brown, 11.4 feet above top of Shinarump.	0 0	10	10	10	8.3 8.3	<4
–5534	4	Fine-grained clayey sandstone, reddish-brown, 5.9 feet above top of Shinarump.	90 30	20	10	20	6.1 6.1	<4
–5533	3	Clayey sandstone, yellow iron stain, 4.7 feet above top of Shinarump and at top of bleached zone.	150 170	170	10	50	4.7 4.8	<4
–5532	2	Sandy claystone, light olive-gray, 3.8 feet above top of Shinarump.	330 300	300	10	50	4.2 4.2	4
–5531	1	Claystone, light olive-gray in bleached zone 1.1 feet above top of Shinarump.	450 450	500	10	100	4.2 4.0	8
53–1309	515	Sandstone, coarse-grained, white. Typical sandstone of the Shinarump 5.6 feet above sample 514 (field No.) and 1.6 feet below top of Shinarump.	25 50	30	50	10	7.5 7.5	<4
–1308	514	Sandstone, coarse, white. Typical sandstone of the Shinarump 1.5 feet above base of Shinarump.	25 50	30	30	20	7.1 7.1	<4
–1307	513	Claystone, silty, yellowish-gray; 4.1 feet below top of Moenkopi.	50 100	100	50	200	5.8 5.6	8
–1306	512	Claystone, light olive-gray with streaks of pale iron stain; 7.1 feet below top of Moenkopi and at bottom of bleached zone.	1,000 1,000	200	30	1,800	8.2 8.0	<4
–1305	511B	Claystone, silty, reddish-brown, micaceous, 8.6 feet below top of Moenkopi.	50 100	50	20	20	8.2 8.1	<4

TABLE 9.—*Chemical analyses, in parts per million, of samples collected from the Moenkopi formation and Shinarump member of Chinle formation near the Oyler mine*

[Analyst: H. E. Crowe, U.S. Geological Survey]

Laboratory	Field	Description	Total heavy metal	Zinc	Lead	Copper	pH	Uranium
52-5553	23	Siltstone, reddish-brown, 21.8 feet above top of Shinarump.	0	20	10	10	8.2	<4
5552	22	Sandy silt, reddish-brown, 14.2 feet above top of Shinarump.	0	20	10	20	7.9	<4
5551	21	Clayey siltstone, reddish-brown 8.8 feet above top of Shinarump.	0	20	10	20	7.6	<4
5550	20	Siltstone, yellowish-orange, 6.0 feet above top of Shinarump and at top of bleached zone.	250	300	10	50	4.8	<4
5549	19	Claystone, light olive-gray, 3.6 feet above top of Shinarump.	300	700	20	150	3.5	<4
5548	18	Claystone, light olive-gray, 0.5 feet above top of Shinarump.	350	350	50	100	3.7	<4
53-1321	527	Sandstone, coarse, white, 13.6 feet above Field No. 526 and 5.6 feet below top of Shinarump.	25	30	30	10	7.6	<4
1320	526	Sandstone, coarse, white, 1.4 feet above base of Shinarump.	25	30	50	20	7.1	<4
1314	520	Claystone, yellowish-gray, 0.4 feet below top of Moenkopi.	150	200	70	130	6.6	800
1313	519	Claystone, silty, yellowish-gray, 0.9 feet below top of Moenkopi.	500	400	90	500	8.3	<4
1312	518	Claystone, silty, yellowish-gray, 4.9 feet below top of Moenkopi and at bottom of bleached zone.	100	100	20	70	8.4	<4
1311	517	Claystone, silty, reddish-brown, micaceous, 10.4 feet below top of Menkopi.	100	50	20	30	8.1	16
1310	516	Claystone, silty reddish-brown, micaceous, 21.6 feet below top of Moenkopi.	50	50	20	30	8.2	<4

TABLE 10.—*Chemical analyses, in parts per million, of samples of the Chinle formation near Fruita, where the Shinarump member and associated bleached beds of the Moenkopi are lacking*

[Two determinations are listed for analyses of duplicate samples. Analyst: H. E. Crowe, U.S. Geological Survey]

Laboratory	Field	Description	Total heavy metal	pH	Uranium
52-5640	156	Silty claystone, greenish-gray, 34.1 feet above base of Chinle	0 0	7.9	<4
5639	155	Silty claystone, dusky-yellow, 26.6 feet above base of Chinle	0 0	7.6	<4
5638	154	Siltstone, light olive-brown, 19.1 feet above base of Chinle	0 0	8.8	<4
5637	153	Siltstone, dusky red-purple, 12.0 feet above base of Chinle	0 0	8.7	<4
5636	152	Claystone, pale-purple, 6.1 feet above base of Chinle	0 0	8.6	<4
5635	151	Claystone, pale-purple, 2.0 feet above base of Chinle and top of Moenkopi	0 0	8.7	<4
53-1324	530	Claystone, silty, micaceous, brownish-red, 10.6 feet below top of Moenkopi	50	8.7	<4
1323	529	Claystone, silty, micaceous, brownish-red, 26.5 feet below top of Moenkopi	50	8.9	<4
1322	528	Claystone, silty, micaceous, brownish-red, 47.7 feet below top of Moenkopi	50	8.6	<4

TABLE 11.—*Chemical analyses, in parts per million, of samples collected from the Moenkopi formation and Shinarump member of Chinle formation near Teasdale*

[Analyst: H. E. Crowe, U.S. Geological Survey]

Laboratory	Field	Description	Total heavy metal	Zinc	Lead	Copper	pH	Uranium
52-5680	206	Claystone, dark reddish-brown, 24.7 feet above top of Shinarump.	0	10	10	20	7.6	<4
5679	205	Claystone, dark reddish-brown 11.0 feet above top of Shinarump.	0	10	10	10	4.7	<4
5678	204	Claystone, dark reddish-brown 9.7 feet above top of Shinarump.	0	10	10	10	4.7	<4
5677	203	Silty claystone, light olive-gray, 7.2 feet above top of Shinarump and at top of bleached zone.	30	50	10	20	4.5	<4
5676	202	Silty claystone, light olive-gray, 6.0 feet above top of Shinarump.	120	70	20	10	5.4	<4
5675	201	Silty claystone, light olive-gray, 2.5 feet above top of Shinarump.	100	50	10	20	7.4	<4
53-1331	537	Sandstone, coarse, with brown carbonate cement, 55.0 feet above base of Shinarump and 5.5 feet below top.	25	100	250	20	5.8	<4
1330	536	Sandstone, coarse, white, 27.5 feet above base of Shinarump.	25	50	20	20	7.9	<4
1329	535	Sandstone, coarse, conglomeratic, brownish-gray, iron-stained, 5.5 feet above base of Shinarump.	2,000	2,000	20	60	8.3	<4
1328	534	Claystone, silty, yellowish-gray, 1.0 feet below top of Moenkopi.	100	80	20	70	8.1	<4
1327	533	Claystone, silty, yellowish-gray, 3.0 feet below top of Moenkopi and at bottom of bleached zone.	50	80	20	40	8.3	<4
1326	532	Claystone, silty, micaceous, reddish-brown, 12.5 feet below top of Moenkopi.	25	50	20	10	8.2	<4
1325	531	Claystone, silty, micaceous, reddish-brown, 29.0 feet below top of Moenkopi.	50	50	20	20	8.3	<4

The time relationship of the chemical changes and bleaching also is not known. Some of the chemical changes may have accompanied bleaching, but others may have occurred much later. Some uranium in unbleached mudstone near ore, for example, may be due to some leaching and redeposition of uranium during weathering.

The bleaching of the mudstone is related in part to the position of the beds adjacent to permeable sandstone. Mudstone directly above and below the Shinarump member commonly is bleached. Mudstone where the Shinarump is lacking is not bleached in many places. Near Teasdale, away from known uranium deposits in the Shinarump, the basal middle mudstone of the Chinle and the topmost mudstone of the Moenkopi are bleached and have small anomalies of heavy metals (table 11). At one sampled locality where the Shinarump is lacking, the basal mudstone of the Chinle and the topmost mudstone of the Moenkopi are not bleached and have no heavy-metal anomalies (table 10). At the edge of a bleached zone the color line locally cuts across beds, indicating that the bleaching is epigenetic. The bleaching is interpreted to be the chemical effect of solutions that saturated the permeable Shinarump, chiefly because of the close relationship between the bleached beds and the Shinarump.

The chemical changes may indicate the kind of fluid which caused the bleaching. Chemical changes associated with bleaching include loss of iron, manganese, and magnesium and addition of zinc, copper, uranium, and possibly a little molybdenum, cobalt, and nickel. Acid solutions can carry significant quantities of zinc, copper, cobalt, nickel, and molybdenum in solution, and mildly reducing solutions can dissolve significant amounts of iron and manganese (Krumbein and Garrels, 1952). The fluid that bleached and chemically altered the mudstone probably was an acid and mildly reducing solution. Possibly the ore-bearing solution caused the bleaching and chemical changes in the mudstone adjacent to the Shinarump member and possibly hydrothermal solutions genetically related to the intrusion caused the bleaching near the dike. Some of the bleaching in these rocks may have occurred much later and may be related in part to weathered pyrite in the zone of oxidation. Bleaching along the joints must be the result of ground-water activity because of the relationship of the bleached joints to the land surface. The possible relation of bleaching and chemical alteration to ore deposition is considered in greater detail under the discussion of the origin of the uranium deposits.

URANIUM ORE AND MINERALIZED ROCK

Copper and uranium minerals occur with practically no vanadium in the ore deposits of the Shinarump member of the Chinle formation. Representative samples of uranium ore and mineralized rock were analyzed by flourimetric and spectographic methods. The uranium content of 5 samples listed in table 12 ranges from 0.14 to 0.30 percent. Although of little economic significance because they were made of spot or grab samples, these analyses show that the ore contains abnormal amounts of uranium, copper, lead, zinc, molybdenum, and arsenic. These ore samples are similar in composition to ores from the Shinarump member studied elsewhere on the Colorado Plateau by Leonard B. Riley and Eugene M. Shoemaker of the U.S. Geological Survey (written communication, 1952).

Distribution of the ore minerals shows some other stratigraphic relationships. Lead, in the mineral galena, is known only from the Kaibab limestone. Copper minerals occur without uranium and vanadium in the uppermost part of the Kaibab limestone and in the Sinbad limestone member of the Moenkopi formation. Uranium and vanadium minerals occur without copper in the Salt Wash member of the Morrison formation.

ORIGIN OF THE URANIUM DEPOSITS

The origin of the uranium deposits involved both chemical and geological processes. A chemical explanation is required for the chemical process governing ore deposition. A geologic explanation is required for obtaining the necessary chemical conditions and to identify the original source of the uranium and the means by which it was concentrated in uraniferous deposits. The origin of the uranium deposits on the Colorado Plateau is a subject of considerable interest but of little agreement among geologists. The following explanation of the origin of the uranium deposits must be considered merely as an opinion that we hope may contribute to a better understanding of these deposits.

CHEMISTRY OF ORE DEPOSITION

The behavior of the ore metals under different conditions of acidity and oxidation is fairly well known. Most of the ore metals such as iron, uranium, vanadium, copper, and zinc are appreciably soluble in mildly reducing acid solutions and can be precipitated either by additional reduction or by neutralizing the acid (Krumbein and Garrels, 1952; Garrels, 1953, 1954, and 1955; Huber, 1958). If precipitation is caused by additional reduction, the minerals formed contain ions in

TABLE 12.—*Semiquantitative spectrographic analyses*[1] *of uranium ore and mineralized rock from the Capitol Reef area*

[Symbol: N.d., not determined. Analysts: P. R. Barnett, P. J. Dunton, and R. G. Havens, 1952–55. U.S. Geological Survey; uranium content of some U samples determined by assay]

Sample No.	Laboratory No.	Si	Al	Fe	Ti	Mn	P	Ca	Mg	Na	K	Ag	As	B	Ba	Be	Ce	Co	Cr	Cu
RGL-17 [2]	76159	xx.	x.	x.	0.x	0.0x	x.	x.	0.x	0.x	x.	0.000x	------	0.00x	0.x	0.000x	0.0x	0.000x	0.00x	0.0x
FS-12 [3]	76162	xx.	.0x	x.	.00x	x.	------	xx.	.x	.0x	------	.000x	------	------	.x	------	------	.00x	.000x	.0x
FS-14 [3]	76164	x.	.x	.x	.0x	x.	------	xx.	.x	.0x	------	.000x	------	------	x.	------	------	.0x	.000x	.0x
S-255-A [2]	216458	xx.	x.	x.	.x	.00x	.x	.x	.x	.x	x.	------	0.0x	.00x	.0x	.000x	.0x	.00x	.00x	.0x
S-260-C [4]	216463	xx.	x.	x.	.x	.00x	------	.0x	.x	.x	.x	.000x	.0x	.0x	.0x	.000x	.0x	.000x	.00x	.0x
FS-1 [5]	56728	x.	x.	x.	.x	.00x	------	.x	.x	x.	x.	.00x	.0x	.000x	.0x	.000x	------	.00x	.00x	x.
RGL-3 [6]	58290	xx.	x.	x.	.x	.00x	------	x.	.x	.x	.x	.00x	.x	.00x	.x	.000x	------	.00x	.00x	x.

Sample No.	Laboratory No.	Ga	Ge	La	Mo	Nb	Nd	Ni	Pb	Sc	Sr	Tl	U	V	Y	Yb	Zn	Zr	U (assay)
RGL-17 [2]	76159	0.000x	------	0.00x	0.0x	------	0.0x	0.00x	0.x	0.00x	0.0x	------	0.x	0.0x	0.0x	------	0.0x	0.0x	0.30
FS-12 [3]	76162	------	------	------	.00x	------	------	.00x	.0x	.000x	.0x	------	.x	.00x	.0x	------	------	.0x	.62
FS-14 [3]	76164	------	------	------	.00x	------	------	.00x	.0x	.000x	.x	------	.x	.00x	.0x	------	.0x	.0x	.16
S-255-A [2]	216458	.000x	------	.00x	.00x	0.00x	------	.00x	.00x	.00x	.0x	------	.x	.00x	.00x	0.000x	.0x	.0x	.14
S-260-C [4]	216463	.000x	------	.00x	.0x	.0x	------	.00x	.0x	.00x	.0x	------	.x	.0x	.00x	.000x	.0x	.0x	.30
FS-1 [5]	56728	.000x	------	------	.0x	------	------	.00x	.x	.00x	.0x	------	.x	.00x	.0x	------	------	.0x	N.d.
RGL-3 [6]	58290	.00x	0.000x	------	.0x	------	------	.00x	.x	.00x	.x	------	x.	.00x	.0x	------	.0x	.0x	N.d.

[1] Semiquantitative spectrographic determinations made by the rapid visual-comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 90 percent of the determinations.
[2] Carbonaceous sandstone of the Shinarump member of the Chinle formation with clay pebbles from prospect, Oak Creek area.
[3] Silicified log from Chinle formation near Oak Creek.
[4] Silty sandstone of the Shinarump member of the Chinle formation with intermixed carbonaceous and clay fragments, prospect south of Fruita.
[5] Carbonaceous sandstone of the Shinarump member of the Chinle formation from prospect pit south of Grand Wash.
[6] Carbonized wood from the Shinarump member of the Chinle formation, Oyler mine.

NOTE.—Looked for but not found: Au, B, Cd, Hf, Hg, In, Ir, Li, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Th, Te, and W.

their reduced forms such as U^{+4}, V^{+3}, Cu^{+1}, Fe^{+2}, and S^{-2}. Pitchblende, pyrite, and chalcopyrite are examples of minerals in this assemblage that have been identified at the Oyler mine. If precipitation is caused by neutralization, the minerals formed contain ions in their oxidized form such as U^{+6}, V^{+5}, Cu^{+2}, Fe^{+3}, and S^{+6}. A zippeitelike mineral $(UO_2)_2(SO_4)(OH)_2 \cdot 4H_2O)$, metatorbernite $(Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O)$, johannite $(Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O)$, gypsum, alunite, and malachite are examples of minerals in this assemblage at the Oyler mine. Although there may be complicating factors, such as the effect of temperature and pressure, we believe that it will be helpful in understanding the chemistry of the uranium deposits, such as that at the Oyler mine, if the minerals are classified in these two broad groups: (1) minerals precipitated by reduction and (2) minerals precipitated by neutralization or oxidation. For brevity these can be called the reduced and oxidized assemblages.

The origin of the minerals of the oxidized assemblage is relatively easy to explain. The reduced assemblage was emplaced first. When the region was dissected, the ore and all other rocks near the land surface were subjected to weathering and oxidation, and the original ore minerals were oxidized. The transition from oxidized ore near the land surface to reduced ore at depth in many places throughout the Colorado Plateau is convincing evidence that the oxidation process has been and still is going on (McKelvey and others, 1955, p. 493). Textural evidence from several districts supports this relationship. Thus the oxidized assemblage was derived by oxidation of the original reduced assemblage.

The conditions during the original precipitation of the reduced-ore assemblage are more conjectural. Almost without exception the uranium deposits contain organic material. The organic material is commonly coaly fragments, but in a few places it is asphaltic material. Textural evidence in these deposits indicates that the organic materials were replaced in part by minerals of the reduced assemblage (McKelvey and others, 1955, p. 493). An obvious possibility is that the ore metals were carried in solution in the oxidized state and were reduced and precipitated while the carbonaceous material was oxidized and removed as carbon dioxide or carbonated water. It has been suggested that insufficient organic matter was present to serve as reductant (McKelvey and others, 1955, p. 506–507), but calculations show that the weight of the woody materials required would be less than that of the ore metals precipitated (R. M. Garrels and A. M. Pommer, written communication, 1955). The close association of ore minerals with the reducing carbonaceous material, however, seems to be fairly convincing evidence that the original precipitation of the ore was due to chemical reduction caused in part at least by the organic material. The amount of carbonaceous material may have been much greater originally than now without leaving obvious textural evidence of its removal. For these reasons, our interpretation is that there was an abundance of original carbonaceous material which precipitated most of the ore.

RELATION OF MUDSTONE BLEACHING AND ORE

All mudstone in contact with the Shinarump member has been bleached. The bleaching affected the basal part of the middle member of the Chinle, which is above the Shinarump, and the upper part of the Moenkopi formation, which is below the Shinarump. The chemical studies described previously indicate that the bleaching was accompanied by chemical changes such as the addition of uranium, zinc, and copper, which are not characteristic of bleaching caused by ordinary weathering processes.

Several geologic features indicate that this mudstone may have been bleached long before possible weathering. Bleaching of mudstone above the ore-bearing unit probably took place when the ore-bearing Shinarump member was saturated with the fluid that did the bleaching. Such saturation seems unlikely under vadose conditions. Joints and small faults that cut the bleached zone have no appreciable effect upon the shape or thickness of the zone; probably the bleaching occurred before much of the jointing and faulting, which in turn probably preceded most weathering. Elsewhere on the Colorado Plateau, bleached beds have been observed with unweathered primary ore beneath the ground-water table (Daniel R. Shawe, written communication, 1954). This association has not been found in the Capitol Reef area but it may be simply because exploration has not extended beneath the ground-water table. The chemical and geological evidence outlined above leads us to believe that the chemical alteration and much of the bleaching probably accompanied ore deposition.

The chemical relationship between the ore deposition and the bleaching of the mudstone is critical in evaluating their possible genetic relationship. The bleaching of the mudstone and the deposition of the ore, as indicated previously, are both chemical reductions. To activate these processes simultaneously would require large quantities of a chemical reductant. Some chemical reductant, in the form of carbonaceous material, is present in the Shinarump member and commonly near ore. If we hypothesize an original abundance of carbonaceous material scattered throughout the Shinarump member, we can use this carbonaceous material to explain the chemical and geologic features indicated previously and possibly a few others as well. It would explain not only why carbonaceous material is most abundant near ore—this is simply in residual pockets of unoxidized carbonaceous material—but also would help explain at least part of the carbonate throughout the rest of the Shinarump member, although the percentage of carbonate in the member in the Capitol Reef area is not high. This carbonate was derived from oxidation of carbon.

GEOLOGIC PROCESSES OF URANIUM DEPOSITION

Many different hypotheses have been proposed for the origin of the Colorado Plateau uranium deposits (McKelvey and others, 1955, p. 498–505). Of these the two which have received the most support are: (1) the ore was deposited by hypogene fluids derived from deep-seated igneous intrusions, and (2) the ore was deposited by ground water intermixed with some connate water. A distinction should be made between the source of the uranium and the source of the transporting fluid because they may not necessarily be the same. One possibility is that the uranium was present originally in the ore-bearing or associated formations and merely transported and concentrated by fluids coming from a considerable distance. Because of the limited geologic evidence available from the small scattered uranium deposits in the Capitol Reef area, we consider it inadvisable at this time to advocate any particular hypothesis for the origin of these uranium deposits.

Geochemical considerations are helpful in evaluating the various hypotheses for the origin of the uranium deposits. Of these we believe that the distribution of the carbonaceous material and of the bleached red beds deserves special mention. Carbonaceous material readily concentrates uranium from solution. If we assume an original abundance of uraniferous carbonaceous material, as proposed previously, then the oxidation and removal of the carbonaceous material might concentrate all of the original uranium in a few residual pockets of carbonaceous material. This mechanism helps explain how uranium may have been extracted from the entire bleached zone and concentrated in the few ore bodies, but it tells little concerning the source of the fluid which transported the uranium. More field and laboratory data are needed to establish the chemical conditions which controlled uranium deposition. Even if these are established definitely, it may not solve the intriguing riddle of the origin of these deposits.

GUIDES FOR PROSPECTING

The guides for prospecting are based both on the geological and geochemical characteristics of the uranium deposits. The following guides are those considered most applicable to a search for uranium deposits in the Capitol Reef area.

STRATIGRAPHIC GUIDES

Uraniferous rock has been found in most of the pre-Quaternary sedimentary units on the Colorado Plateau (Isachsen and others, 1955). In the Capitol Reef area its has been found in four formations: the Moenkopi, Chinle, Curtis, and Morrison. The stratigraphic units in which uranium deposits most likely may be found in the Capitol Reef area, however, are the Shinarump member of the Chinle formation and the Salt Wash member of the Morrison formation.

THINNING AND PINCHING OUT OF ORE-BEARING SHINARUMP MEMBER OF THE CHINLE FORMATION

In the Capitol Reef area the uranium deposits in the Shinarump member of the Chinle formation are most abundant in the area along the Waterpocket Fold where the Shinarump is discontinuous. This distribution of uranium partly supports the concept that these deposits may be close to pinchouts of the Shinarump (Finch, 1959, p. 148, 159; Trites and others, 1956, p. 284). Consequently, we believe that the best areas for prospecting for uranium deposits in the Shinarump member in the Capitol Reef area are in the area where the Shinarump member beds are discontinuous.

RELATION TO CHANNELS

Many uraniferous deposits are in beds of Shinarump member that filled channels cut into the underlying Moenkopi. The relationship between ore and channels has been observed in many parts of the Colorado Plateau (Witkind, 1956; Wright, 1955, p. 140–142; Miller, 1955, p. 165, 169; Trites and Chew, 1955, p. 240, 245; Wood and Grundy, 1956). Not all the known channels contain ore, however, and ore occurs in only limited segments of the productive channels. Nevertheless the search for channels and the tracing of channels by drilling is accepted as one of the best guides for prospecting these deposits.

In the Capitol Reef area, most of the mineralized rocks in the Shinarump member occupy shallow channels. This relationship between channel sedimentary rocks and uraniferous rock can be observed at the Oyler mine (pl. 2). Elsewhere the relationship between uraniferous rock and channels is not completely known. Enough evidence is available, however, to permit the acceptance of channels as one of the best guides to ore in the Shinarump member of the Chinle formation.

Lenses or channel deposits of conglomeratic sandstone also seem to be the most favorable localities for uranium deposits in the Salt Wash member of the Morrison formation. Most of the known uraniferous rock in this member in the Capitol Reef area is in conglomeratic sandstone lenses in the upper part of the member.

MINERALOGY AND RADIOACTIVITY

Occurrences of ore minerals and abnormal radioactivity are used so commonly as prospecting guides that their use need hardly be elaborated. Uranium minerals from the Shinarump member of the Chinle formation include johannite, metatorbernite, metazeunerite, pitchblende, and a zippeitelike mineral. Copper minerals commonly are associated with the uranium minerals, and localities where copper minerals occur should be examined for uraniferous rock. Alunite crops out as layers and pods at the base of the Shinarump near many exposures of uraniferous rock or of secondary copper minerals. A definite association between uranium minerals and alunite in the Capitol Reef area is not established, but localities near exposures of alunite should be investigated for abnormal radioactivity. In the Salt Wash member of the Morrison formation, carnotite is the most abundant ore mineral in the uranium deposits. Very small quantities of carnotite, metarossite, and schroekingerite were found in scattered silicified logs in the middle and upper members of the Chinle formation.

CARBONACEOUS MATERIAL AND BEDS, LENSES, OR POCKETS OF CLAY OR CLAYSTONE

Carbonized plants, plant fragments, or wood and clay either as layers or as mixtures with sandstone characterize rock that contains uranium in any quantity in the Capitol Reef area. Most radioactive rock in the Shinarump member of the Chinle formation is in a basal clay and sandstone layer containing carbonaceous material; commonly it is a trashy mixture of clay pellets and clayey sand with carbonaceous material. Asphaltic carbonaceous matter is associated with uraniferous rock in scattered localities along the Moenkopi and Chinle contact. Carbonaceous material also is associated with uraniferous rock in the Salt Wash member of the Morrison formation.

BLEACHED MUDSTONE

A local greater thickness of bleached mudstone near ore is a useful prospecting guide in places on the Colorado Plateau (Weir, 1952, p. 20; Wood and Grundy, 1956, p. 654). Near some uranium deposits, as at the Oyler mine, in the Capitol Reef area the bleached mudstone at the top of the Moenkopi formation is uncommonly thick. Near most localities of uraniferous rock in the area, however, the bleached mudstone is not abnormally thick.

GEOCHEMICAL GUIDES FOR ORE

Tests for traces of uranium and heavy metals may have some value as geochemical-prospecting aids. Some ore deposits are characterized by dispersion of an associated element beyond that of the ore metal of primary economic interest. These elements of extensive dispersion have been named "pathfinder" elements because of their possible use in geochemical prospecting (Warren and others, 1952). By this terminology the zinc and copper in the bleached zone that lacks any trace of uranium might find use as pathfinder elements in locating uranium deposits. Chemical tests will not be of much practical use in tracing bleached rock that can be identified by simple inspection. However, the chemical tests may find use in distinguishing between bleaching by weathering with no appreciable zinc and copper anomaly and bleaching with prospecting significance.

Uranium itself occurs in abnormal amounts in a zone surrounding the ore bodies. Some studies of uranium deposits (Fix, 1956; Denson and others, 1956) indicate that uranium is appreciably soluble in normal ground water and subject to downward leaching and reprecipitation. Some of the uranium in the unbleached mudstone beneath ore may be of comparatively recent origin and have postdated the bleaching. The testing of mudstone beneath an ore horizon for recently deposited uranium appears to be a possible direct approach for geochemical prospecting and deserves more investigation.

MINERAL DEPOSITS OTHER THAN URANIUM

COPPER

Several old copper prospects are located on Miners Mountain (pl. 1 and fig. 28). The shafts and drifts are now chiefly caved and inaccessible. According to Butler and others (1920, p. 632), "a few hundred pounds of high-grade ore is reported to have been shipped" from this area, but during the present work we found no evidence of recent copper production.

The copper occurs chiefly as azurite and malachite that form circular spots about one-quarter inch in diameter in the Sinbad limestone member of the Moenkopi formation. These copper minerals also form irregular veinlets or coat fracture surfaces. In the NE¼ sec. 17, T. 30 S., R. 6 E., chalcopyrite and pyrite are disseminated in limestone. Zones of mineralized rock appear to be lenticular, not more than 3 or 4 feet long, and restricted chiefly to one bed at any one locality. In the south-central part of sec. 17, T. 30 S., R. 6 E, secondary copper minerals form thin coatings on limestone in the Sinbad and on siltstone beds below the Sinbad limestone member. In the NW¼ sec. 8, T. 30 S., R. 6 E., the azurite and malachite occur in a clay lens in the limestone.

The azurite and malachite probably were formed by the oxidation of the disseminated chalcopyrite. The veinlets and fracture coatings of secondary copper minerals developed from movement of copper by water along fracture surfaces. Though the copper-bearing rock is colorful, the bodies are small and the copper content of the rock small.

In the E½ sec. 20, T. 30 S., R. 6 E., copper and lead occur in the Kaibab limestone on the southwest side of Miners Mountain. Azurite, the most abundant copper mineral, impregnates the calcareous siltstone and silty limestone in patches a few inches across. It also forms coatings on chert nodules. Brown and black iron and manganese oxides stain the beds also. Galena, including some cubic crystals as much as ⅛ inch across, occupies veinlets up to ¼ inch thick and 3 inches long. The galena occurs in tan silty limestone about 30 feet along the bedding from the copper-bearing rock. Much crystalline calcite is associated with the galena. The calcite is dispersed irregularly through a zone about 10 feet thick and about 20 feet long. The limestone is broken by many fractures, but the galena is not concentrated along these fractures. Butler and others (1920, p. 632) report cerussite and plumbojarosite probably from this same locality.

No obvious local controls determine the location of the copper or lead minerals in the Capitol Reef area. The sulfide minerals mostly are disseminated irregularly in the limestone of the Sinbad member. Blocks of vuggy brecciated limestone on the dump at one prospect suggest that the metals may have been introduced along fracture zones. However, the general lack of exposures of such brecciated rocks in place precludes the determination of the attitudes of the brecciated zones and their relationship to the mineralized rock. On a broad scale, most of the known occurrences of copper or lead minerals are in limestone of the Sinbad limestone member of the Moenkopi formation and in silty limestone of the Kaibab limestone. Also, these occurrences are near the structurally highest part of the Teasdale anticline.

No abnormal radioactivity was detected at any of the copper prospects or at the galena locality observed on Miners Mountain. Lack of abnormal radioactivity on Miners Mountain has been reported previously (Gott and Erickson, 1952, p. 5).

The copper minerals associated with uraniferous rock or at the same stratigraphic positions as uraniferous rock are considered in the discussion of uranium deposits (p. 62).

MANGANESE

A manganese deposit is north of Spring Gulch about 0.6 mile east of the road around the east side of Boulder Mountain (pl. 1 and Fig. 28). The ore is in a buff limy medium-grained sandstone about 35 feet above the base of the Carmel formation. The manganese impregnates the sandstone and occurs in cylindrical masses.

This deposit was examined by Baker and others (1952, p. 142). As little development work has been done since their examination, part of their description is repeated here:

Manganese oxide occurs along the outcrop for a distance of 100 feet and through a maximum thickness of 9 feet of sandstone. The manganese occurs as pyrolusite in more or less cylindrical, pipelike masses as much as 2 inches in diameter around central cavities or tubes and in irregular lenses as much as 1½ feet thick and 5 or 6 feet long. The manganese oxide impregnates the sandstone by replacing the cement and, to a lesser extent, the sand grains. All the ore contains abundant unreplaced grains of quartz sand. Considerable iron oxide is associated with the manganese oxide. It is most abundant near the margins of the manganiferous rock * * *. In the vicinity are several prominent northward-trending joints, but manganese oxide does not occur along them.

About 1,500 feet to the southeast, across the canyon, manganese occurs in the Navajo sandstone as pyrolusite impregnating the sandstone along a shatter zone locally about 5 feet wide. The shatter zone can be traced for a distance of several hundred feet and is concealed at both ends by surficial materials.

GYPSUM

Thick beds of gypsum crop out in the Carmel formation, particularly in the area of Black Ridge west of Teasdale. Similar beds probably are covered by Quaternary deposits on the flanks of Boulder Mountain. The maximum observed thickness of a single bed is 80 feet. Gypsum from a similar lithologic sequence is mined near Sigurd, Utah, about 50 miles northwest of the Capitol Reef area, and is used in the manufacture of wallboard and plaster (Lenhart, 1949).

BUILDING STONE

Some fine-grained sandstone beds in the Moenkopi formation split readily along bedding planes, particularly where they are above or below siltstone beds, and across bedding, most easily along fractures. These beds are chiefly in the zone near the contact between the lower and upper units of the upper part of the Moenkopi formation. From these beds, flagstones or rectangular building stones may be obtained. They have been quarried in several places for buildings in the local communities. The Capitol Reef National Monument headquarters building near Fruita (pl. 1) is constructed of this sandstone of the Moenkopi.

SAND AND GRAVEL

Sand and gravel deposits for aggregate and general construction uses are available, particularly from the pediment gravels and from the terrace gravels along the Fremont River. Many of these deposits contain cobbles and boulders, chiefly of volcanic rocks, and require screening, crushing, or very selective quarrying for most uses.

OIL AND GAS

The oil and gas potentiality of the Capitol Reef area has not yet been fully tested by drilling. The area contains three favorable structures—the Teasdale, Fruita, and Thousand Lake anticlines (fig. 26). The Fruita and Thousand Lake anticlines offer some possibility of yielding oil from the Moenkopi formation, and all three offer the possibility of yielding oil or gas from older formations. Only the Teasdale anticline has been tested at depth.

The Pacific Western Oil Corp. Teasdale 1, in the NW1/4 NE1/4 sec. 17, T. 30 S., R. 6 E., on the crest of the Teasdale anticline was drilled to a depth of 4,932 feet in 1949. According to Walton (1954), this well penetrated about 60 feet of Middle Cambrian shale at the bottom. L. F. Wells (1954, section *D–D′*) indicates that the bottom of the hole was in the Bowman limestone of Cambrian age. Walton's log (1954) shows that oil-stained beds were found in the Coconino sandstone of Permian age and in the upper part of the Hermosa limestone of Pennsylvanian age. The Parry Oil Co. Teasdale 1, in the NE1/4 NW1/4 sec. 20, T. 29 S., R. 5 E., was drilled to a depth of 523 feet in 1950 (Hansen and Scoville, 1955, p. 108). No information is available concerning the dry well in the NW1/4 SE1/4 sec. 32, T. 30 S., R. 7 E., which was located during fieldwork. Neither of these last two wells is on a prominent structure.

Six wells have been drilled about 5 miles northeast of the northeast corner of the Capitol Reef area on an anticline having 600 feet of closure (Hager, 1954). Five of these wells yielded gas from the Sinbad limestone member and from a sandstone bed higher in the Moenkopi formation. The gas capacity in 4 wells ranged from 1 million to 21 million cubic feet. The gas-bearing sandstone in the Moenkopi probably is equivalent to the sandstone unit that overlies the Sinbad member in the Capitol Reef area.

On the Teasdale anticline the beds of the Moenkopi are breached by erosion, and any gas that may have been accumulated in the past has escaped. The Moenkopi has not been breached on the Fruita or Thousand Lake anticlines; vertical closures are about 200 feet and 400 feet respectively on these anticlines. If gas accumulated in these structures, some may remain there.

Hunt (1953, p. 216) suggests that the major upwarps in southeastern Utah possibly are "rejuvenated ancient folds and that Pennsylvanian and even pre-Pennsylvanian formations may thin out by angular unconformity against the flanks" to form stratigraphic traps. If such conditions do exist, he suggests that the margins of the Henry Mountains structural basin might be areas for such traps. The eastern part of the Capitol Reef area is marginal to the Henry Mountains basin and might be in a region in which the possible stratigraphic traps exist in the older formations. At present we do not have the data to predict the existence of such traps.

MEASURED STRATIGRAPHIC SECTIONS

The stratigraphic sections include 1 section of the Kaibab limestone, 2 of the Moenkopi formation, 2 of the Chinle formation, 1 of the Kayenta formation, 2 of the Carmel formation, 1 of the Entrada sandstone, 1 of the Curtis formation, 1 of the Summerville formation, 1 of the Morrison formation, and a partial section of the Flagstaff limestone. In one group the formations are given in stratigraphic sequence. In the other group the additional sections of the Moenkopi, Chinle, and Carmel formations are included.

These stratigraphic sections were measured chiefly by use of an Abney level set at the dip of the beds. Corrections for the eye height of the measurer were made to fit the dip of the beds. In places, ledges or vertical slopes were measured by tape and by planetable and alidade. Colors are those of the "Rock-Color Chart" of the National Research Council (Goddard and others, 1948). The colors were determined in the field.

Partial section of Flagstaff limestone on east side of canyon north of Bicknell, SE¼ sec. 23, T. 28 S., R. 3 E.

	Feet
Tertiary:	
Flagstaff limestone (top and base not exposed):	
6. Tuff, sandy tuff, and tuffaceous sandstone	40+
5. Limestone, yellowish-gray (5*Y* 7/2), and interbedded yellowish-gray (5*Y* 7/2) and white (*N* 9) tuff	20
4. Sandstone, yellowish-gray (5*Y* 7/2), very fine grained, friable, calcareous	15
3. Claystone and some siltstone, pale greenish-yellow (10*Y* 8/2), very calcareous; abundant ostracodes	18
2. Claystone and some siltstone, pale reddish-brown (10*R* 5/4), very calcareous	20
1. Sandstone and pebble conglomerate, pale reddish-brown (10*R* 5/4), fairly friable; calcareous cement in some beds; beds ⅛ inch to 1 foot thick, generally ⅛ to 1 inch; crossbedded in some beds 1 to 8 inches thick; sand grains chiefly quartz; pebbles chiefly volcanic rocks, angular to rounded, commonly ¼ inch or less in diameter, largest 3 inches; scattered elongate tuff pellets	180
Total Flagstaff limestone exposed	293

Sections of Morrison, Summerville, and Curtis formations at The Notch and east of South Desert

	Feet
Cretaceous:	
Mancos shale:	
Tununk shale member: Gray shale *Gryphaea* zone at base. Contact, though unconformable with underlying Brushy Basin shale member of the Morrison formation, is obscure on flats and very gentle slopes and can be recognized by *Gryphaea* zone.	
Unconformity.	
Jurassic:	
Morrison formation:	
Brushy Basin shale member:	
4. Claystone chiefly; variegated in bands of light greenish gray (5*GY* 8/1), light gray, (*N* 7), very light gray (*N* 8), yellowish gray (5*Y* 8/1), white (*N* 9), grayish red (10*R* 4/2), pale red (10*R* 6/2), pale red purple (5*RP* 6/2); lighter color beds increase toward top; color units or beds 1 to 20 feet thick and fairly regular for lateral distances of several hundred feet; contains scattered lenses of sandstone and conglomeratic sandstone, light gray; pebbles, gray and tan chert and quartz, average size about ¼ inch, maximum about 1 inch; locally many dark-gray chert pebbles, very minor small red and green chert pebbles in lens with maximum thickness of 8 feet, but thicker in few hundred feet laterally from line of section; much silicified wood. Weathers to form badlands; some hills capped with sandstone or conglomeratic sandstone. Contact with underlying Salt Wash member at conglomeratic sandstone below which sandstone and conglomeratic beds are more abundant.	
Total Brushy Basin shale member	225
Salt Wash sandstone member:	
3. Sandstone, conglomeratic sandstone, and claystone; 2 prominent zones of sandstone and conglomeratic sandstone alternating and intertonguing with 2 zones of chiefly claystone; sandstone at top; laterally each lithologic zone grades into the other, so they are persistent along line of section but cannot be traced laterally. Sandstone and conglomeratic sandstone, white (*N* 9) and almost white, weather to tan and brown; lenticular beds and many scour and fill structures; sandstone, fine-grained to very coarse grained, well sorted in many beds, calcareous in some beds; conglomeratic sandstone, with pebbles chiefly light-tan and gray quartzite and chert, generally 1 inch or less, maximum 2½ inches, well rounded; fewer dark pebbles and less conglomeratic than unit 2 below. Claystone, yellowish-gray (5*Y* 7/2) and pale olive (10*Y* 6/2), calcareous. Siltstone and very fine grained sandstone, pale reddish-brown (10*R* 5/4), pale-red (5*R* 6/2, and grayish-red (5*R* 4/2), chiefly quartz grains. Claystone, siltstone, and very fine grained sandstone in beds 6 inches to 2 feet thick: unit weathers to ledges of sandstone with softer slopes of claystone	108

Feet

2. Sandstone and conglomeratic sandstone, gray and white, weather same colors; lenticular and crossbedded; maximum thickness of single unit 10 feet; some crossbeds are alternate sandstone and pebble layer 1 pebble thick repeated through thickness of 3 or 4 feet; sandstone scoured locally with conglomerate a few inches to 3 feet thick filling scours. Sandstone, fine to mostly very coarse grained subangular to subrounded, well sorted in some beds; mostly quartz grains, minor feldspar and dark minerals; calcareous cement. In conglomerate, pebbles white and gray quartzite and chert and black and dark-gray chert, scattered white and light-gray limestone; most pebbles smooth and well rounded, 1½ inches or less in diameter, maximum size 3 inches. Weathers to form ledges as much as 20 feet high; upper surfaces of ledges generally smoothly knobby; forms irregular dip slopes; surface littered with pebbles in places.......... 68

1. Sandstone, claystone, and siltstone; beds wrinkled and crumpled and thin and thicken abruptly, perhaps because of solution of gypsum; abrupt changes from one lithologic type to another; chiefly claystone at base, locally 1 to 2 feet of sandstone; forms fairly continuous unit throughout area of South Desert and the Hartnet. Sandstone, grayish-orange pink (10*R* 8/2), white (*N* 9); pale-red (10*R* 6/2), and pale greenish-yellow (10*Y* 8/2), some mottled; very fine grained, subangular to moderately well rounded, well sorted; about 90 percent quartz grains, some feldspar, widely scattered dark minerals; calcareous cement; beds 2 inches to 1 foot thick. Claystone, pale-red (10*R* 6/2), grayish-red (5*R* 4/2), between moderate reddish-brown (10*R* 4/6) and dark reddish-brown (10*R* 3/4), and moderate orange-pink (10*R* 7/4), calcareous; beds crumpled, swell and thin, maximum thickness about 2 feet. Siltstone, mottled, yellowish-gray (5*Y* 8/1), grayish-yellow-green (5*GY* 7/2), and pale-red (10*R* 6/2); calcareous in all beds except green ones; beds crumpled, swell and thin, thicknesses 1 inch to 3 feet...................... 32

Contact with Summerville formation below is a pronounced erosional unconformity.

Total Salt Wash sandstone member............. 208

Total Morrison formation....................... 433

Unconformity.

Summerville formation: *Feet*

1. Siltstone and mudstone, pale-brown (5*YR* 5/2) and light-brown (5*YR* 6/4); calcareous; siltstone composed chiefly of quartz grains; some beds shaly, even bedded in beds 1 inch to 1 foot thick; some siltstone units crossbedded on a small scale, weather into thin sheets like leaves of a book; some shaly beds; 1 to 2 inches thick layers and ⅛ to ¼ inch veinlets of gypsum; forms steep to vertical slope below capping Salt Wash member of Morrison formation; even bedding prominent on steep slope. Gradational contact with Curtis formation below; contact placed at base of predominantly even-bedded pale-brown and light-brown siltstone and mudstone.

Total Summerville formation.................... 201

Curtis formation:

2. Sandstone and siltstone, grayish-yellow green (5*GY* 7/2), calcareous; sandstone chiefly fine grained, well sorted, about 95 percent quartz grains, some pink, yellow, and black accessory minerals, a little biotite; sandstone bed 1 to 3 feet thick, siltstone beds 1 to 5 inches thick; small-scale crossbedding in some units; more siltstone and generally thinner beds than in unit below; many rugose calcareous concretions about 1 inch in diameter....................... 25

1. Sandstone and some siltstone, grayish-yellow-green (5 *GY* 7/2); calcareous sandstone, chiefly fine-grained well-sorted, about 95 percent quartz, some biotite, pink, yellow, and black accessory minerals, and glauconite; sandstone beds 1 to 5 feet thick, siltstone beds 1 to 5 inches thick; small-scale crossbedding in some units; less siltstone and more thicker beds than in unit above; about 40 feet above base is 2-foot zone of ellipsoidal orange concretions 2 inches to 1 foot long, with extensions of calcite crystals; at base are several 4-inch-long pods of charcoallike carbonaceous material with associated secondary copper stains; radioactivity of pods as much as 3 times background. Entire formation forms steep to vertical slope. Contact with Entrada formation below is sharp and even and appears conformable here but is unconformable regionally..................... 55

Total Curtis formation......................... 80

Unconformity.

Entrada sandstone: Sandstone, chiefly light-brown (5YR 6/4), fine-grained, generally well sorted; contains scattered medium-size grains.

Section of Entrada sandstone, about 1½ miles south-southeast of Notch Water in South Desert

Jurassic:

Curtis formation: Chiefly fine-grained sandstone. Contact with underlying Entrada sandstone is sharp and even.

Unconformity.

Entrada sandstone: *Feet*

7. Sandstone, white (N 9), fine-grained and very fine grained, moderately well sorted, friable, calcareous; evenly bedded in beds 1 to 4 feet thick; chiefly quartz grains, mostly subangular, some well rounded; some red and black angular chert grains; about middle 5 feet interbedded white and dark-red sandstone in beds ½ to 2 inches thick; forms discontinuous ledge — 29
6. Sandstone, light-brown (5 YR 6/4 and 5 YR 5/6), very fine grained, massive, calcareous; at least 95 percent quartz grains, subangular to subrounded with scattered well rounded grains; chiefly well sorted with scattered coarser grains; weathers to knobby slope — 30
5. Sandstone, light-brown (5 YR 6/4 and 5 YR 5/6), moderate reddish-brown (10 R 4/6), dark reddish-brown (10 R 3/4), very fine grained, calcareous; beds 1 to 5 feet thick; at least 95 percent quartz grains, subangular to subrounded with scattered coarser grains; interbeds, 1 to 2 inches thick, of darker shaly sandstone; some knobby weathered surfaces — 304
4. Sandstone, light-brown (5 YR 6/4), light reddish-brown (10 R 4/6), dark reddish-brown (10 R 3/4), fine-grained; contains ½- to 1½ inch-thick lenses of darker silt, light-red (5 R 6/6) sandstone, and darker shaly sandstone; weathers to form massive bed — 10
3. Sandstone, chiefly light-brown (5 YR 6/4 and 5 YR 5/6), moderate reddish-brown (10 R 4/6), dark reddish-brown (10 R 3/4), very fine grained, calcareous; at least 95 percent quartz grains, some amber quartz grains, subangular to subrounded with scattered well rounded grains; well sorted, generally scattered coarser grains; beds commonly ¼ to 3 inches thick, some 4 to 5 feet; occasional 2- to 3-inch-thick beds of siltstone; few 3- to 6-inch-thick white (N 9) sandstone beds; darker red beds less calcareous, have iron oxide as stain on grains and in cement; weathers to smooth, somewhat rounded slopes covered by very fine grained debris and small platy fragments, forms powder under crusty surface — 286
2. Sandstone, light-brown (5YR 5/6) moderate-brown (5YR 4/4), moderate reddish-orange (10R 6/6), very fine grained chiefly, mostly quartz grains, calcareous, subangular to subrounded, a few well-rounded grains; mostly well sorted with scattered coarser grains; larger grains commonly well rounded and amber; much iron oxide stain on grains and cement; some platy beds of moderate orange-pink (5YR 8/4) siltstone; even bedded in beds ½ inch to 3 feet thick; gypsum veinlets and stringers chiefly in upper part, ¼-inch-thick plates of gypsum; weathers to smooth somewhat rounded slopes with powdery material beneath surface crust — 28
1. Sandstone, like unit 2; white gypsum stringers, ¼ to ½ inch thick, parallel to and at low angles to bedding, particularly in lower 20 feet. Contact with underlying Carmel formation fairly sharp but is conformable — 95

Total Entrada sandstone — 782

Carmel formation: Top bed gypsum, 1 foot thick.

Section of Carmel formation, T. 28 S., R. 6 E., east of South Desert and northwest of The Notch

Jurassic: *Feet*

Entrada sandstone: Sandstone, moderate reddish-brown (10R 4/6), fine-grained, well-sorted. Contact with underlying Carmel formation even and regular.

Carmel formation: Top bed gypsum, 1 foot thick.

16. Gypsum — 3
15. Sandstone, siltstone, and claystone, alternating; beds 2 to 5 feet thick; sandstone, most abundant, yellowish-gray (5Y 7/2 or 5Y 8/1) fine-grained, about 95 percent rounded grains of clear quartz, some biotite flakes and green mineral, well-cemented, calcareous; siltstone, yellowish-gray (5Y 7/2 or 5Y 8/1) beds 2 to 3 feet thick; some siltstone, pale reddish-brown (10R 5/4), with seams of gypsum, slightly calcareous; claystone, greenish-gray (5GY 6/1), calcareous, contains biotite flakes and gypsum veinlets; some thin lenticular beds of limestone — 30
14. Gypsum — 3
13. Sandstone, siltstone, claystone; like unit 15 — 42
12. Gypsum — 2
11. Sandstone, siltstone, and claystone; like unit 15 — 52
10. Gypsum, white, massive — 3
9. Sandstone, siltstone, claystone; like unit 15 — 132
8. Gypsum, white (N 9), massive; crudely layered; some slumped and folded layers; some zones contain clay; much composed of gypsum crystals about ¼ inch long encased in snowy fine-grained gypsum; some stringers of rose chert; weathers to form rounded shelf — 55
7. Siltstone, pale reddish-brown (10R 5/4); contains some fine-grained quartz grains; very slightly calcareous; bedding greatly disturbed by gypsum, many selenite veinlets; few beds mottled red and gray; some beds greenish gray, calcareous — 76

	Feet
6. Sandstone and limestone; sandstone, calcareous, light greenish-gray (5*G* 8/1) and greenish-gray (5*GY* 6/1), fine-grained, even beds 1 to 10 feet thick, some beds ripple marked; limestone, light olive-gray (5*Y* 6/1), even beds ½ to 2 feet thick, comprises about 25 percent of unit	149
5. Gypsum, chiefly, white (*N* 9), crystalline, massive; clayey layers near top	56
4. Sandstone, pinkish-gray (5*YR* 8/1); quartz grains, medium-grained, rounded, 2 to 3 percent pink and orange grains, few black and green grains; cement noncalcareous, largely gypsum; crossbedded; at top, light brownish-gray (5*YR* 6/1) to greenish-gray (5*GY* 6/1) siltstone	15
3. Siltstone, pale reddish-brown (10*R* 5/4), poorly cemented, noncalcareous; much gypsum, especially in veinlets	27
2. Sandstone, limestone, and claystone; sandstone at base, pale yellowish-orange (10*YR* 8/6), very fine to fine-grained, calcareous cement, thin-bedded, ½ to 1 foot thick, contains gypsum seams; limestone, light-gray (*N* 8) to yellowish-gray (5*Y* 8/1), weathers grayish orange (10*Y* 7/4), numerous fine sand grains; claystone, greenish-gray (5*GY* 6/1), some reddish and purple, noncalcareous, contains some gypsum. Lens of fossiliferous fine-grained pale reddish-brown (10*R* 5/4) calcareous sandstone 5 feet above base	33
1. Sandstone, near white (*N* 9) to yellowish-gray (5*Y* 8/1), at base darker from iron and manganese stain; chiefly medium grained but ranges from fine to coarse grained; well sorted in most beds; rounded and frosted quartz grains and about 1 percent dark minerals; well cemented, noncalcareous; bedding parallel, ½ to 2 feet thick; weathers to form grooved cliff; probably reworked sandstone from Navajo. Contact with Navajo sandstone below sharp	31
Total Carmel formation	709

Unconformity.

Jurassic and Jurassic(?):

Navajo sandstone: Sandstone, fine-grained, crossbedded on very large scale.

Section of Kayenta formation, secs. 4 and 5, T. 31 S., R. 7 E., about 2½ miles south of Pleasant Creek

Jurassic and Jurassic(?):

Navajo sandstone: Sandstone, fine-grained, large sweeping crossbeds. Contact with Kayenta formation sharp at this locality but gradational and probably intertonguing at other places in Capitol Reef area.

Jurassic(?):

Kayenta formation:

	Feet
5. Sandstone, chiefly white (*N* 9), pinkish-gray (5*YR* 8/1), and pale yellowish-orange (10*YR* 8/1), fine- to medium-grained subangular to subrounded grains, fair to good sorting; chiefly quartz grains, both frosted and clear; scattered dark minerals; beds ⅛ inch to 2 feet thick in layers 20 to 30 feet thick; both even bedded and crossbedded. Prominent darker bands at base, near middle, and at top, pale red (10*R* 6/2) and pale reddish brown (10*R* 5/4); contain irregular concretions up to 3 inches long. Lenses of moderate reddish-brown (10*R* 4/6) conglomerate with clayey limestone pebbles ⅛ to about 1 inch in diameter in a sandstone matrix. All beds slightly calcareous. Erodes as series of small ledges with intervening gentle to steep slopes	75
4. Sandstone, white (*N* 9) and very pale orange (10*YR* 8/2), weathered colors same; fine grained, subrounded, well sorted; more than 99 percent quartz grains, both frosted and clear, with little cement; some limonite stain on surface; large sweeping crossbeds similar to Navajo in units about 10 feet thick. About 40 feet above base is moderate reddish-orange (10*R* 6/6) band 2 feet wide, slightly calcareous; erosional contact with unit below, weathers to massive cliff unit, continuous over extensive area	52
3. Siltstone and sandstone; siltstone, pale reddish-brown (10*R* 5/4), quartz grains, some mica; sandstone, between moderate red (5*R* 5/4) and grayish red (5*R* 4/2), yellowish-gray (5*Y* 8/1), and pale red (5*R* 6/2), weathered colors same; very fine grained, quartz and some biotite and muscovite, subangular to subrounded, well-sorted; bedding ½ to 1½ inches thick, even, platy; very small scale crossbedding; little cement, friable; at top, light greenish-gray (5*GY* 8/1) and clayey beds about ½ inch thick, calcareous. Weathers to soft, gentle slope	12
2. Sandstone and conglomeratic sandstone, very pale orange (10*YR* 8/2), moderate reddish-orange (10*R* 6/6), pale reddish-brown (10*R* 5/4), and light-brown (5*YR* 6/4 and 5*YR* 5/6), weathered colors same; sandstone, very fine to fine-grained, subangular to subrounded, well-sorted; more than 99 percent quartz grains, frosted and clear. Conglomeratic beds with flattened clay pebbles, pale reddish-brown (10*R* 5/4) and moderate reddish-brown (10*R* 8/6), and few limestone pebbles in grayish-orange (10*YR* 7/4) sandstone matrix. Most beds lenticular and have scour and fill structures; bedding about 50 percent even bedded and 50 percent crossbedded. Weathers to form slopes, ledges, and cliffs	148

Section of Kayenta formation, secs. 4 and 5, T. 31 S., R. 7 E., about 2½ miles south of Pleasant Creek—Continued

Jurassic(?)—Continued

Kayenta formation—Continued — *Feet*

1. Sandstone, grayish-orange (10*YR* 7/4), moderate reddish-orange (10*R* 6/6), and between grayish-orange (10*R* 7/4) and dark yellowish-orange (10*YR* 6/6), weathered surfaces slightly darker; very fine to fine grained, subangular to subrounded, chiefly well sorted; grains more than 99 percent quartz, rest dark minerals and mica flakes; friable, little iron oxide cement; thin even beds in lenticular units 1 inch to about 12 feet thick; weathers to knobby forms on ledgy slopes. Contact with underlying Wingate sandstone somewhat gradational but appears sharp from a distance — 61

Total Kayenta formation — 348

Triassic:

Wingate sandstone: Sandstone, large sweeping crossbeds.

Section of Chinle formation northeast of Torrey, NE¼ sec. 32, NW¼ sec. 33, SW¼ sec. 28, T. 28 S., R. 5 E., (north of north Sulphur Creek)

Triassic: — *Feet*

Wingate sandstone: Sandstone, fine-grained, crossbedded; scattered coarse grains of quartz and chert near base. Contact with underlying Chinle formation sharp and unconformable. Upper Chinle beds truncated for few feet in distances of several hundred feet.

Unconformity.

Chinle formation:

Upper member:

16. Siltstone, pale red-purple (5*RP* 6/2); massive, bedding obscure; pale yellowish-green siltstone (10*GY* 7/2) in top 1 to 2 inches and along some joints; forms steep slope below cliff of Wingate sandstone — 9
15. Siltstone, pale reddish-brown (10*R* 5/4), yellowish-gray (5*Y* 7/2), and grayish-yellow green (5*GY* 7/2); mottled in places; forms moderate to steep slope covered with loose small round fragments — 62
14. Limestone, pale-red (5*R* 6/2) and grayish-green (10*GY* 5/2), dense and compact; forms ledge — 2
13. Siltstone, pale-red (5*R* 6/2), and in top 3 feet grayish-yellow green (5*GY* 7/2), calcareous; limestone lenses, moderate orange-pink (10*R* 7/4), 3 to 4 feet thick and about 20 feet long; breaks into small round fragments — 42
12. Siltstone, pale-red (5*R* 6/2) to moderate reddish-brown (10*R* 5/6), crumbly, weakly to moderately calcareous; limestone nodules on slope; forms moderately steep slope — 53
11. Sandstone, chiefly pale-red (5*R* 6/2), thinly laminated and crossbedded, weakly calcareous; fine grained to very fine grained with grain sizes decreasing upward; beds ⅛ to ¼ inch thick; top 6 feet pale reddish-brown (10*R* 5/4) to dark reddish brown (10*R* 3/4); bottom 4 feet pale red purple (5*RP* 6/2) to grayish red purple (5*RP* 4/2) — 28

Total upper member — 196

Middle member:

10. Sandstone, varies from yellowish-gray (5*Y* 8/1) to medium-gray (*N*5). medium-grained; quartz grains, rounded and well-sorted; 1/2- to 1-inch-thick crossbeds; a few lenses of claystone, 1/2 foot thick and 15 to 25 feet long, in lower 8 feet; conglomeratic lenses containing chert pebbles up to 1 inch long; forms massive ledge — 25
9. Sandstone, pale-red (5*R* 6/2), fine-grained, calcareous ½-inch-thick crossbeds; dark-green micaceous flakes along some beds; middle 2 feet, calcareous mudstone, mottled pale red (5*R* 6/2) and light greenish gray (5*G* 8/1); partially covered slope — 9
8. Conglomerate, grayish-yellow green (5*GY* 7/2); limestone pebbles as much as ½-inch long in calcareous claystone matrix — 3

8a. Siltstone, pale reddish-brown (10*R* 5/4) to moderate reddish-brown (10*R* 4/6), calcareous — 6

7. Conglomerate; rounded limestone pebbles 1/16 to 1½ inches across in light greenish-gray (5*R* 8/1) calcareous siltstone matrix; lower part has pale reddish-brown (10*R* 5/4) patches and streaks — 2
6. Claystone and silty claystone; moderate-red (5*R* 5/4), very soft, crumbly; spotted with light greenish gray (5*G* 8/1); fine-grained sandstone interbeds as much as 4 feet thick; upper 3 feet pale reddish-brown (10*R* 5/4) to moderate reddish-brown (10*R* 4/6) calcareous siltstone — 65
5. Claystone, greenish-gray (5*GY* 6/1), soft, crumbly; irregularly distributed parts of dusky-red (5*R* 3/4) claystone near top; some beds of calcareous medium-grained sandstone, between light olive gray (5*Y* 6/1) and greenish gray (5*GY* 6/1), that weathers to form isolated knobs; in upper part, soft fossil logs, 1 to 3 feet across, iron stained and partially replaced by gypsum; chiefly covered slope at top; forms rounded slopes — 124
4. Sandstone, mottled dusky-red (5*R* 3/4) and pale reddish-brown (10*R* 5/4), calcareous; crossbedded in ½- to 1-inch-thick beds and irregularly bedded; contains limestone nodules ½ to 3 inches long with concentric structure and geodes with calcite crystals inside — 3

	Feet
3. Claystone and sandstone; claystone, grayish-red (5*R* 4/2) to dusky-red (5*R* 3/4), mottled, soft; sandstone, pale reddish-brown (10*R* 5/4), fine-grained, muscovite flakes, crossbedded, lenticular in beds ½ to 1½ feet thick; top 3 feet, very fine grained sandstone and siltstone, dark yellowish-orange (10*YR* 6/6) and greenish-gray (5*GY* 6/1); upper contact irregular and rolling	21
2. Sandstone, yellowish-gray (5*Y* 8/1), medium-grained; calcareous grains rounded and well sorted; grains quartz and about 5 percent dark minerals; groups of iron-stained quartz grains; beds ½ to 2 inches thick, ripple marked; crossbeds as much as ½ foot thick; gradational into underlying Shinarump member; weathers to form moderate slope broken by low ledges	25
Total middle member	283
Shinarump member:	
1. Sandstone, chiefly very light gray (*N* 8) to yellowish-gray (5*Y* 8/1); mostly medium grained; some coarse grained and conglomeratic; bedding generally massive in lenticular beds 1 to 10 feet thick; crossbedded in some lenses; iron oxide stained sandstone, moderately reddish brown (10 *YR* 5/4); a few clay lenses up to 1 foot thick; forms cliff. Contact with Moenkopi formation below is an erosional unconformity	62
Total Chinle formation	541

Unconformity.

Moenkopi formation: Top 45 feet of medium light-gray (*N* 6) siltstone and grayish-purple (5*P* 4/2) siltstone overlying dark reddish-brown (10*R* 3/4) siltstone.

Section of Moenkopi formation, from north Sulphur Creek to east of Chimney Rock, through the W½ sec. 8, T. 29 S., R. 6 E.

Triassic:

Chinle formation: Shinarump member: Crossbedded sandstone; forms cliff. Contact with underlying Moenkopi formation is an erosional unconformity.

Unconformity.

Moenkopi formation:

Upper part:

	Feet
10. Siltstone, between pale reddish-brown (10*R* 5/4) and dark reddish-brown (10*R* 3/4), noncalcareous; ripple marked; beds 3 inches to 3 feet, generally 1 to 3 feet thick; some mudstone and very fine grained sandstone in beds ½ to 3 inches thick, very pale orange (10*YR* 8/2), grayish-orange (10*YR* 7/4), yellowish-gray (5*Y* 8/1), less than 1 percent of total section; some siltstone beds ½ to 3 inches thick are bleached to very pale green (10*G* 8/2); much white (*N* 9) gypsum in ½-inch-thick layers and veinlets parallel to and crosscutting bedding; pink gypsum in places; upper 153 feet forms cliff beneath cliff of overlying beds of the Shinarump; knobby weathered surface on cliff face; lower part forms rounded hills, ridges, and slopes covered with loose fine debris	363
9. Sandstone, pale-red (10*R* 6/2) and pale reddish-brown (10*R* 5/4), some grayish-orange (10*R* 3/4), well-sorted quartz grains, calcareous; beds chiefly 1 to 3 feet thick; weathered color same as fresh; forms relatively smooth dip slopes with low ledges on more resistant beds	53
8. Sandstone and siltstone, almost entirely pale reddish-brown (10*R* 5/4); beds range from about ½ inch to 12 feet in thickness; sandstone chiefly very fine grained, some fine grained; some beds calcareous; abundant ripple marks.	
d. Much fine-grained sandstone in beds about 10 feet thick; crossbedded on small scale	91
c. Much scour and channel fill with massive sandstone beds filling channels; deepest channel 15 feet	18
b. Thick and thin beds; at top, crossbedded very fine grained sandstone about 8 feet thick	97
a. Even bedded in beds generally ½ inch to about 1 foot thick, weathered color same as fresh; forms steep-sided canyons and gulches commonly with steep heads and intervening dip slopes; massive beds support steep gulch sides and dip slopes	45
Total upper part	667

Lower part:

Sinbad limestone member; Forms cliffs and steep canyon walls and broad dip slopes:

	Feet
7. Limestone, dolomitic in part, and sandstone, calcareous, between pale yellowish brown (10*YR* 6/2) and light brown (10*YR* 6/6), dark yellowish orange (10 *YR* 6/6); beds ½ to 1½ feet thick; sandstone, fine-grained quartz grains; weathered color about same as fresh; poorly exposed through about 50 percent of thickness	40

Section of Moenkopi formation, from north Sulphur Creek to east of Chimney Rock, through the W½ sec. 8, T. 29 S., R. 6 E.—Continued

Triassic—Continued
Moenkopi formation—Continued
Lower part—Continued — *Feet*
Sinbad limestone member—Continued

6. Limestone, dolomitic in part, yellowish-gray (5*Y* 7/2) and grayish-orange (10*YR* 7/4), beds generally 1 to 2 feet thick; finely laminated in places, some crinkled laminations; sandy in some beds; fossiliferous, contains pelecypods and gastropods; weathers slightly darker, forms cliffy slope with ledge at top — 33
5. Siltstone, pale yellowish-orange (10*YR* 8/6) and very pale orange (10*YR* 8/2), calcareous, beds 2 to 6 feet thick; crinkly laminations; weathers slightly darker and with chalky appearance — 21
4. Limestone, pale yellowish-orange (10*YR* 8/6), beds 2 to 8 inches thick; oolitic with oolites composing almost entire rock and about size of fine-grained sand; weathered color same as fresh, but surface coated reddish from beds above on cliff — 6
3. Limestone, near very pale orange (10*YR* 8/2); even bedded in beds 1 to 10 feet thick; cut by seams of crystalline calcite ⅛ inch thick; along base of cliff — 36

Total Sinbad limestone member — 136

2. Siltstone, pale reddish-brown (10*R* 5/4), platy and shaly, beds ⅛ to 1½ inches thick, chiefly less than ½ inch; ripple marks; flakes of mica along bedding surfaces; gypsum along bedding and in crosscutting seams; forms steep slope covered with platy fragments; weathered color same as fresh; steep slope owing to position below overlying cliff-forming Sinbad limestone member — 77
1. Siltstone, yellowish-gray (5*Y* 7/2) beds about ¼ inch think; weathered color about same as fresh; like overlying unit except for color; forms steep slope with overlying unit — 17

Total lower part — 230

Total Moenkopi formation — 897

Unconformity.

Permian: Kaibab limestone: Calcareous siltstone and silty limestone.

Section of Kaibab limestone, north side Pleasant Creek in S½ sec. 30, T. 30 S., R. 7 E.

Triassic: — *Feet*
Moenkopi formation: Siltstone, pale-orange to greenish-gray, thin-bedded. Contact with underlying Kaibab limestone is even and regular for short distances at this locality but is erosional and irregular over distances of several hundred feet with a few feet of the top beds of the Kaibab truncated by the Moenkopi.

Unconformity.

Permian:
Kaibab limestone:

16. Sandstone, white (*N* 9) to yellowish-gray (5*Y* 8/1), very fine grained, calcareous; massively bedded; much chert in angular and round nodules as much as 4 inches in diameter and in layers or stringers as much as 4 inches thick; thin interbeds of sandstone and chert near top; forms ledgy slope — 86
15. Sandstone, yellowish-gray (5*Y* 8/1), very fine grained, calcareous; even, thin to massive beds; some thin interbedded dense limestone; some beds fossiliferous — 128
14. Coquinite, sandy, calcareous; fossils include brachiopods, corals, and crinoid stems — 1
13. Sandstone, very light gray (*N* 8), fine-grained, calcareous — 4
12. Sandstone, white (*N* 9) to very pale orange (10*YR* 8/2), very fine to fine-grained; calcareous in some beds; others have little cement; rounded, fairly well-sorted grains; both horizontal and crossbedded units ranging from few inches to 10 feet thick — 30
11. Sandstone, white (*N* 9) to very pale orange (10*YR* 8/2); very fine to fine-grained, calcareous; interbedded limestone and sandy limestone — 39
10. Dolomite and limy dolomite, yellowish-gray (5*Y* 8/1); chert nodules ⅜ inch in diameter and gray chert stringers as much as 6 inches thick; ½-inch-thick beds of dense, platy yellowish-gray limestone — 7
9. Limestone, very pale orange (10*YR* 8/2), silty; contains many crinoid plates — 2
8. Dolomite and limy dolomite, yellowish-gray (5*Y* 8/1); beds 1 to 3 feet thick; chert nodules ⅜ inch in diameter and gray chert stringers as much as 6 inches thick; ½-inch-thick beds of dense, platy yellowish-gray limestone — 13
7. Sandstone, white (*N* 9) to very pale orange (10*YR* 8/2), crossbedded; sharply planed top and bottom — 15
6. Sandstone, yellowish-gray (5*Y* 7/2), fine- to medium-grained, even-bedded; maximum thickness of beds 1 foot — 3

	Feet
5. Limestone and dolomitic limestone, yellowish-gray (5*Y* 7/2); maximum thickness of beds 1½ feet; some dense light-gray (*N* 7) limestone stringers; many calcite nodules; contains crinoid stems; weathers to form very rough surface	10
4. Sandstone, yellowish-gray (5*Y* 7/2), fine-grained, massive; dark weathered surface; forms ledge	3
3. Limestone, yellowish-gray (5*Y* 7/2); numerous crinoid stems	2
2. Sandstone, yellowish-gray (5*Y* 7/2), fine-grained, massive; dark weathered surface; forms cap and ledge	2
1. Dolomite, limy and dolomitic limestone, yellowish-gray (5*Y* 7/2); maximum thickness of beds 1 foot; contains numerous calcite nodules and some chert nodules. Contact with underlying Coconino sandstone sharp at line of section, but this basal bed is not continuous and lower part of Kaibab contains beds that are like Coconino	3
Total Kaibab limestone	348

Coconino sandstone: Sandstone, fine- to medium-grained; crossbedded on large scale.

Section of Carmel formation, Black Ridge, NW¼ sec. 20, NE¼ sec. 19, T. 29 S., R. 4 E., west of Teasdale

Quaternary:
Boulder accumulation.
Jurassic:
Carmel formation (top not exposed):

	Feet
58. Sandstone, fossiliferous limestone, chert-pebble conglomerate; blocks and fragments on covered slope	64
57. Siltstone and sandstone, moderate reddish-brown (10*R* 4/6), dark yellowish-orange (10*YR* 6/6), yellowish-gray (5*Y* 7/2); calcareous; chiefly covered slope	33
56. Sandstone chiefly, greenish-gray (5*GY* 6/1) and between moderate greenish-yellow (10*Y* 7/4) and pale-olive (10*Y* 6/2), fine-grained, beds ⅛ to 4 inches thick, calcareous; about 99 percent quartz grains, subangular to well-rounded, some flat clay pebbles about ¼ inch long; some siltstone on poorly exposed slopes	51
55. Siltstone and sandstone, yellowish-gray (5*Y* 7/2), calcareous; beds ¼ to ¾ inch thick; siltstone, shaly; lower 1 foot and upper 2 feet red; scattered gypsum crystals in lower 2 to 3 feet	24
54. Gypsum, white, massive, granular; irregularly wavy contact with unit below; forms small ledge	1
53. Siltstone and very fine grained sandstone, yellowish-gray (5*Y* 7/2), calcareous; beds ¼ to ¾ inch thick and thin platy; cuspate ripple marks on thin red sandstone about 6 feet below top; fibrous gypsum in ½-inch-thick layers, and scattered gypsum crystals; upper 4 feet moderate-brown (5*YR* 3/4) siltstone; slope partially covered	31
52. Gypsum, white, sugary; caps low cliff and forms fairly continuous ledge	1
51. Siltstone, moderate reddish-brown (10*R* 4/6), calcareous; some limonite stain	2
50. Sandstone, chiefly pale yellowish-brown (10*YR* 6/2), yellowish-gray (5*Y* 8/1), very fine grained, calcareous; beds ⅛ to 2 inches thick; thin layers of gypsum	4
49. Siltstone and claystone, moderate reddish-brown (10*R* 4/6); beds ⅛ to ¼ inch thick; layers and crosscutting veinlets of gypsum	2
48. Gypsum, chiefly white (*N* 9); some siltstone and pink gypsum	1
47. Siltstone and claystone, between light greenish-gray (5*GY* 8/1) and greenish-gray (5*GY* 6/1), thin-bedded, very calcareous; films of gypsum on fracture surfaces	4
46. Gypsum, white (*N* 9), chiefly granular and earthy, layered; 6-inch bed of dense hard rock gypsum near base	2
45. Siltstone, between light brown (5*YR* 6/4) and moderate brown (5*YR* 4/4), very calcareous; much crystalline white (*N* 9) gypsum, seams of fibrous gypsum, and some moderate orange-pink (10*R* 7/4) gypsum	6
44. Sandstone and claystone, grayish yellow-green (5*GY* 7/2), very calcareous; beds 1/32 to ⅛ inch thick; gypsum in white films along bedding and small nodular pink masses; slope covered in most places	4
43. Siltstone, between light brown (5*YR* 6/4) and moderate brown (5*YR* 4/4), very calcareous; much crystalline white (*N* 9) gypsum, crosscutting seams of fibrous gypsum, and some moderate orange-pink (10*R* 7/4) gypsum; generally a covered slope	4
42. Covered chiefly; claystone, siltstone, and very fine grained sandstone, between dark reddish-brown (10*R* 3/4) and moderate reddish-brown (10*R* 4/6), light olive-gray (5*Y* 5/2), light greenish-gray (5*Y* 8/1), greenish-gray (5*Y* 6/1), yellowish-gray (5*Y* 7/2), dusky yellowish-green (5*GY* 5/2), noncalcareous to very calcareous	97
41. Gypsum, chiefly white (*N* 9); some moderate orange pink (10*R* 7/4) scattered through lower 2 feet; forms small ledge	4
40. Siltstone and claystone; uppermost 2 feet yellowish-gray (5*Y* 7/2) very calcareous siltstone; upper part greenish gray (5*GY* 6/1), light greenish gray (5*GY* 8/4), moderate reddish brown (10*R* 4/6), pale red (10 *R* 6/2); basal 3 feet between pale reddish brown (10*R* 5/4) and moderate reddish brown (10*R* 4/6); gypsum in thin layers and scattered crystals, increasing toward top; chiefly covered slope	30

Section of Carmel formation, Black Ridge, NW¼ sec. 20, NE¼ sec. 19, T. 29 S., R. 4 E., west of Teasdale—Continued

	Feet
Jurassic—Continued	
Carmel formation—Continued	
39. Gypsum, with thin irregular platy bedding; wavy contact with unit below	2
38. Claystone and siltstone; uppermost 2 feet moderate reddish-brown (10*R* 4/6) noncalcareous clay, contains much gypsum; below upper 2 feet, siltstone, yellowish-gray (5 *Y* 7/2), calcareous, thinly laminated, grading downward into claystone, yellowish-gray (5*Y* 7/2), calcareous; basal 1 foot claystone, dark reddish-brown (10*R* 3/4), calcareous; chiefly covered slope	34
37. Claystone and siltstone, yellowish-gray (5 *Y* 7/2), calcareous; siltstone weathers to form platy fragments; chiefly covered slope	14
36. Gypsum, white (*N* 9), massive; locally mixed bands and disklike fragments of moderate orange-pink (5*YR* 8/4) gypsum; 30 feet from top, 3 feet of silty limestone, yellowish-gray (5*Y* 8/1), beds ⅛ to 1 inch thick; 40 to 48 feet from top, silty limestone, yellowish-gray (5Y 8/1), platy, beds ⅛ to ¼ inch thick; lowest 6 feet, earthy with silt beds 1 to 2 inches thick; forms conspicuous steep slope around hillsides	80
35. Claystone, siltstone, and sandstone, noncalcareous claystone and siltstone, pale reddish-brown (10*R* 5/4), beds ½ inch to 1 foot thick; sandstone, light greenish-gray (5*GY* 8/1), very fine grained, beds ¼ inch to 1 foot thick; gypsum along fractures and parallel to bedding in lower 2 feet: beds much contorted and faulted, normal and thrust; forms red slope in most places; locally a cliff	22
34. Claystone and siltstone, between light greenish-gray (5*GY* 8/1) and greenish-gray (5*GY* 6/1), beds ⅛ to 1 inch thick, calcareous; gypsum, maximum thickness 1 inch, along bedding planes and joints in upper 4 feet; beds contorted and faulted in places	12
33. Clay, pale-olive (10*Y* 6/2), calcareous; chiefly covered slope	10
32. Gypsum, white (*N* 9), granular, earthy; thins and thickens in short distances; irregular contact on unit below	8–18
31. Clay, dark reddish-brown (10*R* 3/4), soft; lower 5 feet conglomeratic with chiefly long, 2 to 4 inches, flat pebbles of claystone and siltstone; chiefly covered slope	13
30. Gypsum and clay, interbedded and intermingled; gypsum both earthy and as fibrous crystals; interbedded layers and lenses with maximum thickness of 4 inches	12
29. Claystone and sandstone, yellowish-gray (5*Y* 7/2), very calcareous; beds 1/32 to 5 inches thick; sandstone very fine grained; cuspate ripple marks about middle; in upper 3 feet, gypsum, both massive and fibrous, in layers 1 to 4 inches thick	10
28. Siltstone, light olive-gray (5*Y* 6/1), soft, calcareous; chiefly covered slope	15
27. Limestone, yellowish-gray (5*Y* 8/1), sandy, thin bedded and platy; forms gently rounded conspicuous wide bench above cliff formed by unit below	30
26. Sandstone and limestone; beds ⅛ inch to 1 foot thick; sandstone, grayish orange-pink (5*YR* 7/2), very fine grained, calcareous, ripple marked in places; very small scale crossbedding (2–3 inches long and throughout bed ½ inch thick); limestone, yellowish-gray (5*Y* 8/1), sandy with very fine grained quartz; forms cliff with rounded top edge of very thin bedded sandy limestone	42
25. Siltstone, moderate reddish-brown (10*R* 4/6), sandy in places, massive; gypsum in veinlets ⅛ to 1 inch thick	15
24. Gypsum, white (*N* 9), massive; some sand; weathered surfaces red from wash of overlying unit; forms ledge	4
23. Limestone, yellowish-gray (5*Y* 7/2), subgranular; very thin, almost paperlike layers; ripple marks on some beds; forms conspicuous ledge around hillsides	15
22. Siltstone, sandstone, and limestone; middle and upper parts chiefly limestone, light olive-gray (5*Y* 6/1), platy; lower part very fine grained sandstone and sandy siltstone, yellow-gray (5*Y* 8/1), calcareous; chiefly covered slope	28
21. Sandstone, near yellowish-gray (5*Y* 7/2), very fine grained, slightly calcareous; chiefly subangular quartz grains, beds 4 to 8 inches thick; wavy and cross laminations; forms small ledge and a pair of ledges around hillsides with unit 19	2
20. Sandstone, between light olive-gray (5*Y* 6/1) and greenish-gray (5*GY* 6/1), very fine grained, calcareous; chiefly covered slope	3
19. Sandstone and gypsum; sandstone, near greenish-gray (5*GY* 6/1), very fine grained; scattered coarse well-rounded quartz grains; gypsum stringers and lenses, ⅛ to ½ inch thick in lower part, white; gypsum more abundant and more massive toward top, white and grayish-orange; forms small discontinuous ledge	5
18. Sandstone, between light-olive gray (5*Y* 6/1) and greenish-gray (5*GY* 6/1), calcareous; well-rounded quartz grains; chiefly covered slope	13
17. Gypsum, white (*N* 9), massive, finely crystalline, hard; weathered surface earthy and jagged or hackly; forms ledge on cliff, conspicuous around hillsides	38
16. Siltstone and sandstone, pale greenish-yellow (10*Y* 8/2) and moderate greenish-yellow (10*Y* 7/4), thinly laminated, slightly calcareous; sandstone very fine grained	18
15. Siltstone, dark reddish-brown (10*R* 3/4), calcareous; poorly exposed	8

	Feet
14. Sandstone, grayish-yellow (5*Y* 8/4), very fine grained, calcareous; beds ¼ to 5 inches thick	6
13. Limestone, pale greenish-yellow (10*Y* 8/2) and yellowish-gray (5*Y* 7/2); beds platy 1/16 inch to 1 foot thick; near top, harder beds 3 feet thick form persistent ledge	9
12. Silt and clay; very poorly exposed	15
11. Gypsum, white (*N* 9); forms top of cliff 3 to 15 feet high	2
10. Clay, light olive gray (5*Y* 5/2) and dusky-yellow (5*Y* 6/4), calcareous; some thin beds of sandstone, light yellowish-gray (5*Y* 7/2), fine-grained, calcareous; chiefly covered slope	68
9. Limestone, sandy, and sandstone, calcareous, pale yellowish-brown (10*YR* 6/2) and yellowish-gray (5*Y* 7/2), fine- to very fine grained; beds 1 to 3 inches thick, irregular; very fossiliferous; forms bench and together with pale-orange beds below makes conspicuous marker on hillsides	15
8. Limestone, sandy, and sandstone, calcareous, very pale orange (10*YR* 8/2) to pale reddish-orange (10*YR* 8/6); beds 4 inches to 1 foot thick; sandstone, fine-grained, with well-rounded quartz grains; pisolitic beds near base	3
7. Siltstone and clay, light olive gray (5*Y* 7/2) to moderate olive brown (5*Y* 5/4); very poorly exposed	5
6. Siltstone, shale, and sandstone interbedded, siltstone and shale, moderate reddish-brown (10*R* 4/6), dark reddish-brown (10*R* 3/4), and grayish-red (5*R* 4/2), calcareous; sandstone, pale yellowish-orange (10*YR* 8/6), and between very pale orange (10*YR* 8/2) and grayish-orange (10*YR* 7/4), fine-grained, calcareous, beds ½ to 1 foot thick; total sandstone thickness 3½ feet	17
5. Claystone, between yellowish-gray (5*Y* 7/2) and grayish-yellow (5*Y* 8/4), platy, slightly calcareous; upper 1 foot contains scattered small irregular quartz masses ¼ inch across; forms slight ledge	5
4. Siltstone, dark reddish-brown (10*R* 3/4), sandy	1
3. Sandstone, dark yellowish-orange (10*YR* 6/6), very fine grained, slightly calcareous; very poorly exposed	9
2. Sandstone, nearest dark yellowish-orange (10*YR* 6/6), fine- to medium-grained, slightly calcareous; thinly laminated and in beds 2 to 4 inches thick; forms slight ledge	2
1. Sandstone, dark yellowish-orange (10*YR* 6/6), fine-grained, friable; very poorly exposed. Contact with underlying Navajo sandstone is an erosional unconformity but is even and regular locally	3
Minimum Carmel formation (top not exposed); probably near total thickness	988

Unconformity.

Jurassic and Jurassic(?):

Navajo sandstone: Gray, massive, crossbedded sandstone.

Section of Chinle formation north of Oak Creek SW¼ sec. 30, T. 31 S., R. 7 E.

	Feet
Triassic:	
Wingate sandstone: Sandstone, pale greenish-yellow (10*Y* 8/2) and yellowish-gray (5*Y* 8/1); weathers moderate orange pink (10*R* 6/6); very fine grained subrounded clear quartz grains; common red, black, and white accessory minerals; firmly cemented, noncalcareous; coarse- to very coarse grained well-rounded clear quartz grains scattered throughout lower 3 feet: unit is tabular and contains large sets of cross-stratification; massive. Weathers to form vertical cliff. Contact with Chinle formation below is sharp and is even locally but is unconformable over the area.	
Unconformity.	
Chinle formation:	
Upper member:	
20. Siltstone, pale reddish-brown (10*R* 5/4), weathers pale red (10*R* 6/2); clear quartz grains and uncommon black and red accessory minerals, well sorted; very slightly calcareous; weathers to form steep slope and hackly to nodular surface	29
19. Siltstone, yellowish-gray (5*Y* 8/1) and pale-red (10*R* 6/2), weathers pale red (10*R* 6/2); dominantly quartz grains with common black accessory minerals; weakly cemented with calcareous cement; bedding obscure; weathers to form steep slope. 13 feet above base is pale yellowish-gray noncalcareous brittle siltstone. Upper 2½ feet is calcareous siltstone; contains clusters of very fine well-rounded sand grains; weathers to form minor ledge	28
18. Mudstone and minor sandstone; claystone and siltstone, pale-red (10*R* 6/2) to pale reddish-brown (10*R* 5/4); mudstone of silt-size clear quartz grains in a clay matrix, slightly calcareous; hackly weathering. Sandstone, moderate orange-pink (10*R* 7/4) and light greenish-gray (5*GY* 8/1); well cemented with calcareous cement; clear quartz grains and common black and orange accessory minerals; forms 1-foot bed 14 feet above base of unit and several 1- to 3-inch beds in upper 5 feet of unit; weathers to form steep rubble-covered slope	33
Total upper member	90

Section of Chinle formation north of Oak Creek SW¼ sec. 30, T. 31 E., R. 7 E.—Continued

Triassic—Continued

Chinle formation—Continued

Middle member:

	Feet
17. Siltstone, light greenish-gray (5*G* 8/1), weathers same color, very calcareous; predominantly quartz and limestone grains and very coarse grained well-rounded limestone pellets; firmly cemented; even beds as much as 2 feet thick; contains abundant bone fragments; forms prominent ledge	15
16. Siltstone, pale-red (10*R* 6/2), pale reddish-brown (10*R* 5/4), and moderate reddish-orange (10*R* 6/6), moderately calcareous; faint color bands 3 to 5 feet thick; weathers to form steep slope and hackly surface	47
15. Sandstone, grayish-red (10*R* 4/2) and grayish-orange (10*YR* 7/4); very fine grained, subangular clear quartz with abundant red, common black, rare green accessory minerals, rare muscovite and biotite; weak to well cemented, calcareous; unit is tabular and contains small- to medium-scale sets of crossbeds; 6- to 10-inch siltstone conglomerate 2 feet above base; weathers to form prominent ledge	46
14. Sandstone, pale reddish-brown (10*R* 5/4) mottled light greenish-gray (5*GY* 8/1); very fine to fine grained well sorted in upper two-thirds, medium-grained poorly sorted with much interstitial clay in lower one-third; subangular clear quartz with common black, red, and green accessory minerals, rare muscovite plates; weakly cemented, slightly calcareous; bedding obscure; weathers to form steep slope	26
13. Siltstone, moderate-red (5*R* 5/4), light greenish-gray (5*GY* 8/1), light brownish-gray (5*YR* 6/1), weathers pale red purple (5*RP* 6/2); sandy, grain size up to very coarse; abundant black, common red, rare green accessory minerals; subrounded coarse grains of limestone; weakly cemented, calcareous; limonite stain; bedding obscure; weathers to form steep frothy slope	19
12. Siltstone, pale reddish-brown (10*R* 5/4); predominantly quartz grains with common black accessory minerals; weakly cemented, calcareous; bedding obscure; weathers to form steep slope	13
11. Claystone, moderate yellowish-brown (10*YR* 5/4), weathers same color; silty; contains grains as coarse as very fine grained sand; visible grains clear quartz and rare black and red accessory minerals; weakly cemented, slightly calcareous; weathers to form steep slope and hackly to frothy surface	10
10. Siltstone, dark reddish-brown (10*R* 3/4), weathers same solor; sandy, as coarse as fine-grained sand; subangular clear quartz grains and very abundant black and white, common red, and rare green accessory minerals; common muscovite and rare biotite; weakly cemented, noncalcareous; concretionary silty limestone nodules abundant in top 4 feet; weathers to form steep frothy slope	23
9. Sandstone, yellowish-gray (5*Y* 7/2), weathers same color; fine to to very fine grained, fairly well sorted; subangular clear quartz and abundant black and white and rare red accessory minerals; poorly cemented, calcareous; unit lenticular with dominantly horizontal laminations and minor ripple laminations; at top mottled by abundant grayish-red (5*R* 4/2) angular to round granules of claystone; weathers to form ledges as much as 3 feet thick, and intervening slopes	14
8. Claystone, pale-green (5*G* 7/2), weathers very pale green (10*G* 8/2); silty and sandy; rare fine-grained subrounded clear quartz and common black accessory minerals; poorly cemented, calcareous; weathers to form frothy slope	6
7. Siltstone, mottled grayish-red (10*R* 4/2) and pale-olive (10*Y* 6/2); sandy; subrounded clear and amber quartz and abundant black and red and rare orange accessory minerals; sorting fair; weakly cemented, calcareous; bedding obscure; minor claystone, dark reddish-brown (10*R* 3/4); contains concretionary nodules and aggregates of nodules of fine-grained sand firmly cemented with lime; unit weathers to form dusky-red (5*R* 3/4) frothy rubble-covered slope	14
6. Siltstone and sandstone; siltstone, dusky-yellow (5*Y* 6/4) and pale-olive (10*Y* 6/2), sandy, poorly cemented, calcareous: sandstone, yellowish-gray (5*Y* 7/2), weathers pale-brown (5*YR* 5/2), very fine grained, poorly sorted; subangular clear quartz and common black and rare red accessory minerals; firmly cemented, calcareous; lenticular, ripple laminated to small-scale sets of crossbedding: siltstone weathers to form steep slopes with frothy surfaces; sandstone forms a 1½-foot ledge at base of unit	16

	Feet
5. Siltstone, claystone, and minor sandstone; siltstone and claystone, greenish-gray (5*GY* 6/1), weathers same; common mica flakes and rare black and red fine-grained sand grains; calcareous; bedding obscure. Sandstone, greenish-gray (5*G* 6/1), weathers same; fine to very fine grained, poorly sorted; chiefly quartz, abundant subrounded to rounded black and white accessory minerals; firmly cemented, calcareous; units lenticular, ripple-laminated strata; some medium-scale trough stratification; some limy concretions with abundant carbonaceous material. Weathers to form rubbly slope	27
4. Claystone, silty, largely greenish-gray (5*GY* 6/1); contains swelling clays; unit largely concealed	37
3. Sandstone, yellowish-gray (5*Y* 8/1) and pale-red (5*R* 6/2); weathers to moderate red (5*R* 5/4): fine- to medium-grained subangular to subrounded clear quartz and abundant black, common red, and rare green accessory minerals; common limonite stains; firmly cemented, calcareous; unit is lenticular, contains small- to medium-scale cross-stratification; poorly exposed but appears to be channel filling in beds below; weathers to form ledge locally	9
2. Siltstone, grayish-red (10*R* 4/2) and near top grayish-red purple (5*RP* 4/2); weathers to dark reddish-brown (10*R* 3/4); contains common mica flakes, near top common subrounded very fine grained quartz; noncalcareous; bedding obscure; mostly covered slope	11
Total middle member	333
Shinarump member:	
1. Sandstone, yellowish-gray (5*Y* 8/1), weathers very pale orange (10*YR* 8/2); fine- to medium-grained subrounded clear quartz and minor black and red accessory minerals; fair sorting; weakly cemented, argillaceous; unit is lenticular, contains small- to medium-scale sets of trough stratification; freckled appearance due to limonite spots; weathers to form prominent ledge. Contact with underlying Moenkopi formation is a channel surface that in places contains "trash" pockets with abundant carbonaceous materials and pebbles.	
Total Shinarump member	17
Total Chinle formation	440

Unconformity.

Moenkopi formation: Siltstone and mudstone, grayish-red (10*R* 4/2), weathers pale reddish brown (10*R* 5/4); light greenish-gray (5*GY* 8/1) mottling and bands toward top make upper part pale red purple (5*RP* 6/2); top 2 feet light greenish gray (5*GY* 8/1), weathers to very pale orange (10*YR* 8/2).

Section of Moenkopi formation north of Pleasant Creek, from N½ sec. 30, T. 30 S., R. 7 E., to northwest of Pleasant Creek Ranch

	Feet
Triassic:	
Chinle formation: Shinarump member: Sandstone, white to gray, fine- to medium-grained, thin- to thick-bedded, crossbedded. Contact with underlying Moenkopi formation is an erosional unconformity; weathers to form cliff.	
Unconformity.	
Moenkopi formation:	
Upper part:	
15. Mudstone, mottled, moderate reddish-brown (10*R* 4/6), dark yellowish-orange (10*YR* 6/6), yellowish-gray (5*Y* 8/1), and grayish-red purple (5*RP* 4/2); bedding obscure	5
14. Siltstone and mudstone, between pale reddish-brown (10*R* 5/4) and moderate reddish-brown (10*R* 4/6) and some moderate-brown (5*YR* 4/4), a few thin pale yellowish-orange (10*YR* 8/6) beds; very thin bedded; ripple marked; gypsum seams both parallel to and across bedding; weathers to form steep to vertical fluted knobby slopes in upper part where under Shinarump cliff, and more gentle soft slope where not under cliff	308
13. Sandstone and siltstone, between pale reddish-brown (10*R* 5/4) and moderate reddish brown (10*R* 4/6) and a few thin grayish-orange (10 *YR* 7/4) beds, slightly to moderately calcareous; sandstone, fine-grained; thin- to thick-bedded, crossbedded; scour and fill structures; ripple marked in some beds; weathers to form ledges, some massive, and intervening slopes	318
Total upper part	631
Sinbad limestone member; weathers to form ledgy cliffs and steep canyon walls:	
12. Limestone, dolomite, dolomitic limestone, dark yellowish-orange (10*YR* 6/6), medium- to thick-bedded; some small-scale crossbedding	16
11. Limestone, light olive-gray (5*Y* 8/1), dense, thin- to medium-bedded	10
10. Siltstone, between very pale orange (10*YR* 8/2) and pale yellowish-orange (10*YR* 8/6), calcareous; fine laminations in thin beds	4

Section of Moenkopi formation north of Pleasant Creek, from N½ sec. 30, T. 30 S., R. 7 E., to northwest of Pleasant Creek Ranch—Continued

	Feet
Triassic—Continued	
Moenkopi formation—Continued	
Sinbad limestone member—Continued	
9. Limestone, yellowish-gray (5*Y* 7/2), silty	2
8. Siltstone, between very pale orange (10*YR* 8/2) and pale yellowish-orange (10*YR* 8/6), calcareous; fine laminations in thin to thick beds; interbedded thin lenses of red and green claystone	19
7. Siltstone, pale reddish-brown (10*R* 5/4), calcareous, platy; many gypsum seams; 2-foot-thick band of pale-olive (10*Y* 6/2) siltstone	8
6. Siltstone, pale yellowish-orange (10*YR* 8/6), calcareous, clayey, thin-bedded; forms ledge	6
5. Siltstone, pale reddish-brown (10*R* 5/4), calcareous, platy	1
4. Siltstone, pale-olive (10*Y* 6/2), calcareous, platy	1
3. Siltstone, between very pale orange (10*YR* 8/2) and pale yellowish-orange (10*YR* 8/6), calcareous, thin- to medium-bedded; forms ledge	3
Total Sinbad limestone member	70
Basal part:	
2. Siltstone, between pale-red (10*R* 6/2) and pale reddish-brown (10*R* 5/4), calcareous, regular thin beds, platy, ripple-marked; much gypsum in veinlets parallel to and across bedding; weathers to form steep slope covered with platy fragments below Sinbad	46
1. Siltstone, dark yellowish-orange (10*YR* 6/6), calcareous, regular thin beds, platy, ripple-marked; much gypsum; like unit 2 above except for color; weathers to form steep slope below Sinbad. Contact with Kaibab limestone below is irregular along erosional unconformity	19
Total basal part	65
Total Moenkopi formation	766

Unconformity.

Permian:

Kaibab limestone: Sandstone, white (*N* 9) to light-gray (*N* 7), calcareous, fine-grained; massively bedded; petroliferous near top; many chert and calcite nodules and interbedded chert stringers.

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INDEX