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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STRATIGRAPHY AND STRUCTURE OF THE MINERS MOUNTAIN AREA, WAYNE COUNTY, UTAH

By

R. G. Luedke

U. S. Geological Survey

OPEN FILE REPORT

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ABSTRACT

The Miners Mountain area includes about 85 square miles in Wayne County, south-central Utah. The area is semiarid and characterized by cliffs and deep canyons.

Formations range in age from Permian to Upper Jurassic and have an aggregate thickness of about 3,500 feet. Permian formations are the buff Coconino sandstone and the overlying white, limy, chert-containing Kaibab limestone. Unconformably overlying the Kaibab is the lower Triassic Moenkopi formation of reddish-brown and yellow mudstone, siltstone, and sandstone; it contains the Sinbad limestone member (?) in the lower part. Thin, lenticular Shinarump conglomerate unconformably overlies the Moenkopi, but grades upward into the Upper Triassic Chinle formation of variegated mudstone with some interbedded sandstone and limestone lenses. Unconformably overlying the Chinle are the Wingate sandstone, Kayenta formation, and Navajo sandstone of the Jurassic (?) Glen Canyon group, which consist of red to white sandstone. Only the lower part of the Carmel formation of the Upper Jurassic San Rafael group is exposed in the area; it consists of variegated siltstone, sandstone, limestone, and gypsum.

The conspicuous structural feature in the area is the Teasdale anticline which trends northwest, is about 14 miles long, and is asymmetric with a steeper west flank. Bounding the anticline on the northeast and east is the Capitol Reef monocline, the northern part of the Waterpocket Fold. Strata in the area are broken by steeply-dipping normal faults with small displacements, except for the Teasdale fault which has a maximum displacement of over 1,000 feet. Jointing is prominent in some formations.

The major orogenic movement in the area is believed to be late Upper Cretaceous to early Tertiary. Epeirogenic uplift occurred intermittently throughout Tertiary and perhaps Quaternary time.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The Miners Mountain area includes about 85 square miles in southern Wayne County, south-central Utah (fig. 1), and is bounded by the Capitol Reef on the north and east, the Wayne-Garfield County line on the south, Boulder Mountain on the southwest, and Utah State Highway No. 237 on the west. The area is in the western part of the Canyon Lands section of the Colorado Plateaus province (Fenneman, 1931). Parts of the Capitol Reef National Monument and the Dixie National Forest are in the area.

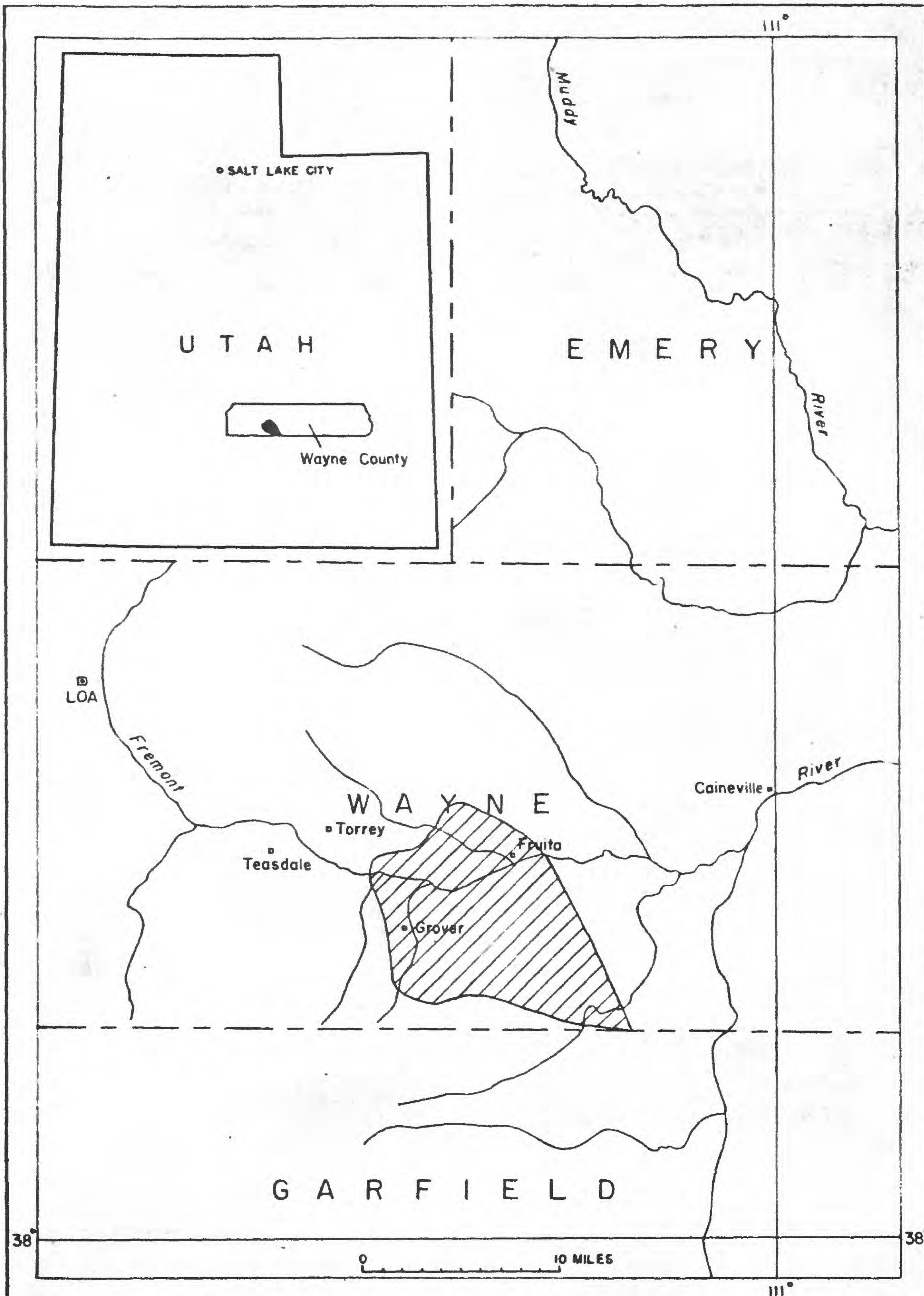


FIGURE 1—Index map showing location of the Miners Mountain area, Wayne County, Utah (shaded area)

PURPOSE AND SCOPE OF REPORT

The purpose of this report is to describe the stratigraphic and structural features in an area that is a part of a larger region being studied on the Colorado Plateaus. The geologic studies program is being conducted by the U. S. Geological Survey on behalf of the Raw Materials Division of the U. S. Atomic Energy Commission.

Previous investigations in the area have been of a reconnaissance nature only. The objectives of the work were to study in detail the geologic structure and the distribution, thickness, and lithology of the sedimentary rocks to obtain possible new data that would aid in interpretation of sedimentary processes and structural relations.

FIELD WORK

Approximately six months during the summers of 1951 and 1952 were spent doing field work in the area. Most of the work was done by the writer.

A base map was prepared from a triangulation net established from a measured baseline. Horizontal and vertical primary control was obtained with an explorer's alidade and plane table. From the location of section corners, the positions of the townships established by the General Land Office were determined. The geology and culture were mapped first on Soil Conservation Service aerial photographs, and then were transferred to the base map by sketching between located points that were determined by the three-point method or by two-point intersections. Altitudes used to construct the structure contour map were obtained by vertical-angle measurements from Coast and Geodetic Survey bench marks. The triangulation mapping was supplemented in several places by stadia traverses. Stratigraphic sections were measured in the field by alidade and plane table, tape, and hand level.

Mapping of the area was done on a scale of one inch to about one mile (1:62,500), but the map accompanying this report has been enlarged to the scale of two inches to one mile (1:31,680).

PREVIOUS WORK

This discussion of previous work in the area is in part a condensation of the discussion of scientific exploration and surveys in the vicinity of the Miners Mountain area as compiled by Gregory and Anderson (1939, pp. 1832-1834). For more detailed information concerning the early work done in this region, the reader is referred to the original sources.

Thompson (1875), Chief Geographer of the Powell Survey, outlined and named many of the principal physiographic features during the first scientific traverse of this region. Howell (1875), who did the first geologic work in the region, described and measured the stratigraphy along the Fremont River. He also made note of the salient structural features. While en route to the Henry Mountains, Gilbert (1877) observed the structure and stratigraphy in the region and confirmed many of the observations of Thompson and Howell. While studying the geology of the High Plateaus which are immediately west of the area, Dutton (1880) briefly described the stratigraphy and physiography in this vicinity. In 1918, Gregory and Moore (1931) examined the geology in the Miners Mountain area in connection with their work on the Circle Cliffs region. Dake (1919; 1920) outlined the stratigraphic sequence in the area and related it to the rest of the Colorado Plateaus. After the Capitol Reef National Monument was established, Gregory and Anderson (1939) published a brief geographic and geologic sketch of the area based on observations made in 1918 and brief surveys in 1935 and 1937. Hunt, et al (in press) briefly discusses that part of the Capitol Reef south of the Fremont River and includes Capitol Reef on his geologic map of the Henry Mountains region.

During the past six decades, this region has been mapped at different times by the Geological Survey, General Land Office, Forest Service, and the National Park Service. The Coast and Geodetic Survey made an altitude traverse through the area in 1934. Most maps of the Miners Mountain area are old and of a small scale.

AKNOWLEDGMENTS

The writer expresses his appreciation to J. F. Smith, Jr., under whose supervision the field work was done, and who made many helpful suggestions during the field and office work. His constructive criticisms of the manuscript were invaluable. The helpful cooperation and assistance in the field work by E. N. Hinrichs and L.C. Huff is gratefully acknowledged. Special thanks are due Professor W.W. Longley of the University of Colorado who reviewed the manuscript and gave freely of his time and assistance. The writer also wishes to express his appreciation to the many people who gave encouragement and assistance which facilitated the progress of this report.

GEOGRAPHY

Topography of the Miners Mountain area is typical of that of much of the Colorado Plateaus. The area is characterized by cliffs and deep canyons. Miners Mountain, a gentle, fairly broad, and flat-topped domal feature is greatly dissected to canyons on all sides except the west. Flanking the mountain on the northeast and east is Capitol Reef, an unscalable cliff towering 800 to 1,000 feet above the valley floor. The southwest part of the area is the lower slope of Boulder Mountain. (See fig. 2.)

FIGURE 2 - Panorama view of the Miners Mountain area.

Shows the broad, gentle domal-shaped Miners Mountain in the center; Capitol Reef cliffs on the left; Boulder Mountain right background.

The total relief within the area is about 3,100 feet. Altitudes range from about 5,400 feet at Fruita to about 8,500 feet on the side of Boulder Mountain. The highest altitude of Miners Mountain is about 7,900 feet.

Pleasant Creek, Carcass Creek, Fish Creek, Sulphur Creek, and the Fremont River are perennial streams. All other streams are intermittent and have water only during times of excessive rain. Most streams (fig. 3), perennial or intermittent, are in deep incised meanders. All streams are tributary to the Fremont River either within or immediately east of the area.

The climate is semiarid. Vegetation is scanty except on the top of Miners Mountain and the side of Boulder Mountain. On Miners Mountain the vegetation consists mostly of pinyon pine and juniper, whereas on the side of Boulder Mountain it consists mostly of yellow pine, fir, and aspen.

The Miners Mountain area may be reached either from the east or west by Utah State Highway No. 24. The western part also is accessible by Utah State Highway Nos. 117 and 237 and by a U. S. Forest Service road. The few other roads within the area are recommended for jeep travel only; there are no marked trails.

Habitants of the area live at the few scattered ranches or within the communities of Grover and Fruita.

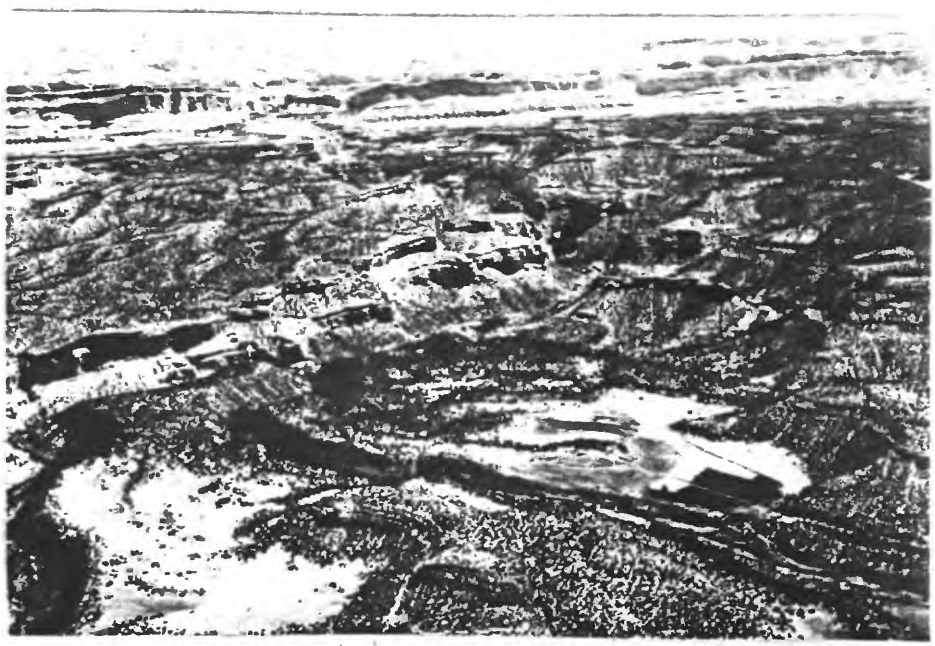


FIGURE 3 - Aerial view northeast along the Fremont River gorge in the Miners Mountain area.

Shows the deep, incised river gorge cutting through Miners Mountain in the center, and the Capitol Reef in the background. Junction of Fremont River and Carcass Creek in foreground.

STRATIGRAPHY

GENERAL FEATURES

Discussion of the sedimentary rocks is limited primarily to those of Permian, Triassic, and Jurassic ages. See figure 4 for the exposed stratigraphic section in the Miners Mountain area. Only brief mention is made of Quaternary deposits. The aggregate thickness of the exposed stratigraphic section totals more than 3,500 feet.

Bedrock exposures are excellent and formation contacts easily traced. Sandstone is the dominant rock type in the area. Next in order of decreasing abundance are siltstone, mudstone, limestone, and gypsum. The sedimentary rocks represent marine, brackish-water, fresh-water, and wind-blown deposits.

A noted feature of the stratigraphic sequence is that the attitude of a formation is generally accordant with the underlying and overlying formations even where there is indication of long time lapses and radical changes in conditions of sedimentation.

In general lithologic features, origin, stratigraphic sequence, and age, the Triassic and Jurassic formations are comparable with corresponding units in other parts of the Colorado Plateaus, but these generalizations can not be made for the Permian formations throughout the Plateaus.

Age	Group and formation
Quaternary	Undifferentiated deposits
Jurassic	San Rafael group
Upper Jurassic series	Carmel formation
Jurassic (?)	Unconformity
	Glen Canyon group
	Navajo sandstone
	Kayenta formation
	Wingate sandstone
Triassic	Unconformity
Upper Triassic series	Chinle formation
	Upper part
	Lower part
	Shinarump conglomerate
	Unconformity
Lower Triassic series	Moenkopi formation
	Upper part
	Lower part
	Unconformity
Permian	Kaibab limestone
	Coconino sandstone

FIGURE 4 - Stratigraphic section in the Miners Mountain area, Wayne County, Utah

PERMIAN SYSTEM

Coconino sandstone

The Coconino sandstone crops out in the Fremont River and Pleasant Creek gorges and in most of the canyons on the east side of Miners Mountain. The Coconino is a resistant formation exposed in steep to vertical walls and massive rounded ledges. Weathering along vertical joints has caused vertical walls in places (fig. 5).

The Coconino is a very fine- to fine-grained, massive, cross-bedded sandstone; it is calcareous and slightly friable. Weathering and erosion emphasize the large sweeping cross-beds. Large vertical joints are characteristic of the formation in places. The formation is white to buff and in many places is stained black by desert varnish.

The sandstone consists mostly of well-sorted sub-angular to sub-rounded quartz grains cemented by lime carbonate and some clay. Many grains are frosted, but they appear to be fairly clean. A few grains are yellow from limonite stain.

Some limonite stained spots, whose centers are commonly pods of pyrite and/or marcasite, are in the upper part of the formation. Also, in these upper beds were found some chert and calcite nodules.

FIGURE 5 - Coconino sandstone in the Fremont River gorge.

Shows steep walls along the vertical joints. KC, Coconino sandstone and Kaibab limestone; Si, "Sinbad limestone member" of the Moenkopi formation.

The thickest section of Coconino in this area is in the Fremont River gorge and is estimated to be more than 800 feet. The section in Pleasant Creek gorge may be of comparable thickness. A reported thickness of about 1,250 feet of sandstone was assigned to the Coconino in the dry hole in sec. 17, T. 36 S., R. 6 E. which was drilled by Pacific Western Oil Corporation. The thicknesses of the Coconino in this area are believed to be greater than those in the Circle Cliffs or the San Rafael Swell. If the sandstone in the Miners Mountain area is correctly assigned to the Coconino, the thicknesses do not conform to the southward and westward thinning of the Coconino suggested by others (Gilluly and Reeside, 1928, p. 63; Baker, 1945, pp. 52-53).

The base of the Coconino sandstone is not exposed in the area. In all places observed, the contact of the Coconino with the overlying Kaibab limestone appeared to be conformable and gradational. The upper contact was placed arbitrarily at the top of the large-scale cross-bedding. Alternating thin even beds, some showing small-scale cross-bedding were above this contact, but they were limy and were therefore included in the lower part of the Kaibab. If all cross-bedded strata were included as part of the Coconino, the contact with the Kaibab would be 20 to 30 feet above the one chosen.

Deposition of the Coconino sandstone in the Grand Canyon region, Arizona (type section), is believed to be mostly eolian (McKee, 1933, 1934, 1940, and 1945; Reiche, 1938). Because of the large-scale sweeping cross-bedding exhibited in the Coconino, eolian deposition is indicated in the Miners Mountain area. Climatic conditions during this time were probably semiarid to arid. Reiche (1938) and McKee (1940) believe the sediments came from the north.

The tentative age assigned the Coconino in the type section is probably Middle Permian. This age is based on paleontological evidence from the underlying Hermit shale (McKee, 1934) and the overlying Kaibab limestone (McKee, 1938). Because of the great thickness of the Coconino in the Miners Mountain area, the formation may span a greater geologic age and possibly be equivalent to most or all of the Permian section to the south in Arizona. Gilluly and Reeside (1928, p. 63) had this same conclusion with respect to the Coconino in the San Rafael Swell.

The Coconino sandstone in this area is correlated with the Coconino in both the San Rafael Swell and Circle Cliffs and is thought to be of the same lithologic unit. As previously stated, the thicknesses between the three different localities do not agree with respect to the postulated southward thinning of the Coconino. McKee (1934) does not believe the Utah "Coconino" can be directly correlated to the Arizona "Coconino". He states that the latter disappears near the Utah-Arizona state line. Gregory and Moore (1931, p. 45) also suggest that the Utah "Coconino" and the Arizona "Coconino" might not be the same formations.

Kaibab limestone

Exposures of the Kaibab limestone are found in the same canyons as those of the underlying Coconino sandstone, but the Kaibab exposures are more extensive. The Kaibab also is a resistant formation characterized by massive rounded ledges with some intervening more gentle slopes. The following section of the Kaibab limestone, which was measured on Pleasant Creek, illustrates the lithology of the formation.

Section of the Kaibab limestone on Pleasant Creek in sec. 30, T. 30 S., R. 7 E.
(Measured by R. G. Luedke)

Moenkopi formation

Unconformity

Kaibab limestone

		Feet
1.	Sandstone, white to yellowish-gray, limy, fine-grained, thick-bedded; contains abundant chert geodes and stringers, and iron concretions	86
2.	Sandstone, yellowish-gray, limy, fine-grained, thin- to thick-bedded, fossiliferous; contains a few chert geodes and stringers, and a few thin dense limestone and chalk beds	128
3.	Coquina, buff, sandy, fossiliferous	1
4.	Sandstone, light-gray, limy, fine-grained. .	4
		219

Coconino sandstone

The Kaibab is a thin- to thick-bedded calcareous siltstone and sandstone and sandy limestone. Some of the lower beds have small-scale cross-beds. Many beds are friable. The formation is white to gray, but in many places is stained black by desert varnish. In general, the Kaibab is more white than the underlying Coconino.

Sandstones of the Kaibab are very fine-grained and consist of well-sorted, sub-angular to sub-rounded quartz grains. The grains average between 0.125 and 0.062 mm in diameter. Some grains are frosted. Cementing material is predominantly calcium carbonate, although there is some clay and siliceous cement.

A few limonite stains similar to those in the upper part of the Coconino are in the lower part of the Kaibab. The upper part of the Kaibab has a great concentration of chert geodes and nodules and chert stringers as much as 6 inches thick. Most chert geodes are white and are filled with quartz and calcite crystals. A few geodes are filled with a thick, tar-like petroliferous material. The dense chert stringers are white, gray, and blue. All chert in the upper part of the formation is resistant to weathering, and as a result, weathered surfaces are rough and irregular. At a few places on the east side of Miners Mountain, the upper 50 feet of beds are dark gray because of impregnated petroliferous material.

Thickness of the Kaibab limestone in the area ranges from 155 feet at the north to 219 feet at the south. These figures indicate a southward thickening of the Kaibab in the area. The thickness in the Miners Mountain area is greater than in either the San Rafael Swell or the Circle Cliffs. In the San Rafael Swell, Gilluly and Reeside (1928, p. 64) and Gilluly (1929. p. 82) obtained thicknesses ranging from a vanishing point to 85 feet for the Kaibab; also at the south end of the Swell, Hunt, et al (in press) measured a thickness of 94 feet. Gregory and Moore (1931, p. 41) had a maximum thickness of 163 feet for the Kaibab in the Circle Cliffs. There appears to be substantiating evidence for an overall southward thickening of the Kaibab limestone (McKee, 1938), but with an apparent local thinning in the region of the Circle Cliffs. Many writers have suggested lateral gradation between the Kaibab and Coconino as a possible explanation for the northward thinning of the Kaibab. As suggested by Longwell, et al (1923), the northward thinning of the Kaibab may be due to beveling of the surface during the erosional interval between Paleozoic and Mesozoic times.

The first published paper about the pre-Triassic unconformity in the Colorado Plateaus province was written by Dake (1920). He examined the pre-Triassic unconformity along the Fremont River, but his observations were incorrect because of misinterpretation of the local stratigraphic section. Within the Miners Mountain area, the Permian-Triassic contact, where not covered by talus, is distinctive in change of color, lithology, and physiographic expression. At no place in the area were beds of the Kaibab observed to be beveled by beds of the Moenkopi formation. Near the junction of Carcass Creek and the Fremont River, the Moenkopi formation contains a basal conglomerate as much as 15 feet thick. The conglomerate is composed of angular chert fragments and chert geodes in a matrix of white, very fine-grained, calcareous sandstone. The chert presumably was derived from the underlying Kaibab. A similar lense of basal conglomerate was found on the east side of Miners Mountain in sec. 34, T. 29 S., R. 6 E., but the matrix was a light-red sandstone instead of white sandstone. In many canyons on the east side of Miners Mountain, the lower unit of the Lower Moenkopi formation was noted to thicken and thin locally. Whether this thickness difference was due to erosion or non-deposition is not known. Although local evidence for a pre-Triassic unconformity in the Miners Mountain area is not conclusive, the unconformity recognized in surrounding regions undoubtedly extends through this area.

The Kaibab is locally fossiliferous. Fauna collected were brachiopods, bryozoa, crinoid stems, and pelecypods (?). On the basis of similar fossils from the Grand Canyon region, Arizona, McKee (1938, p. 217) concluded the age of the Kaibab limestone to be Middle Permian.

It long has been recognized that the Kaibab limestone was deposited by invading marine water from the west and southwest. McKee (1938, p. 142) feels that the types of fauna found in the Kaibab in this area indicate that the beds were deposited in open-sea water.

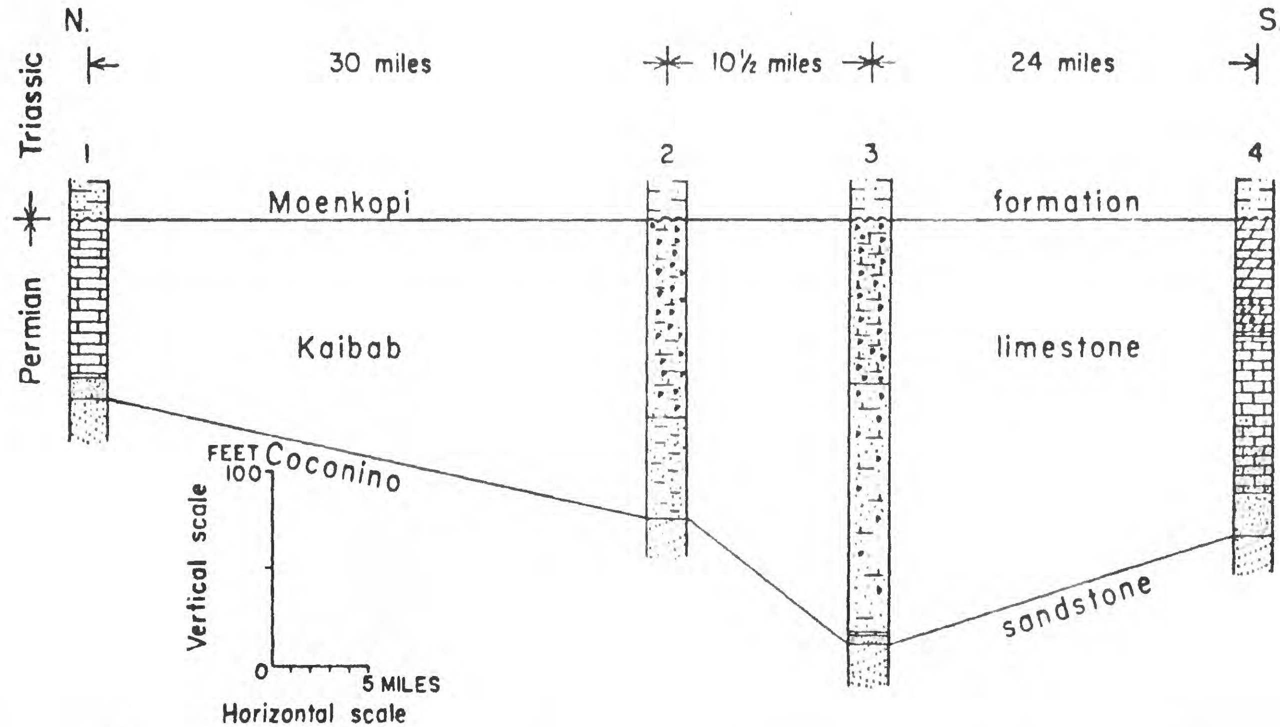
The Kaibab limestone in the Miners Mountain area is correlated with the Kaibab in both the San Rafael Swell and Circle Cliffs. (See fig. 6.)

TRIASSIC SYSTEM

Lower Triassic Series

Moenkopi formation

Exposures of the Moenkopi formation are widespread throughout the Miners Mountain area and are conspicuous because of the predominant red color and many forms of physiographic expression. As shown on plate 1, the formation was mapped as two units: 1) a Lower Moenkopi, and 2) an Upper Moenkopi. Both the lower and upper parts of the Moenkopi may be subdivided further into two units each. The following section is representative of the Moenkopi formation in the Miners Mountain area.



1. Boulder Canyon, San Rafael Swell (C. B. Hunt, U.S.G.S. Prof. Paper, in preparation)
2. 3 miles west of Fruita on Sulphur Creek
3. 2 miles west of the Capitol Reef on Pleasant Creek
4. The Peaks, Circle Cliffs (Gregory and Moore, U.S.G.S. Prof. Paper 164)

FIGURE 6 —Sections showing lateral variations of the Kaibab limestone between the San Rafael Swell, Miners Mountain area, and Circle Cliffs

Section of the Moenkopi formation three-quarters of a mile south of Fruita

(Measured by R. G. Luedke)

Chinle formation

Unconformity

Moenkopi formation

	Feet
Upper part	
1. Mudstone and siltstone, variegated, thin-bedded, gypsiferous	40
2. Mudstone and siltstone, reddish-brown, thin-bedded; contains much gypsum and selenite; weathers as soft slopes and fluted walls . .	385
3. Siltstone, reddish-brown, thin- to medium-bedded, micaceous, ripple-marked	46
4. Siltstone, yellow, thick-bedded, calcareous, ripple-marked, cross-bedded, micaceous, petroliferous	37
5. Siltstone, reddish-brown, thin-bedded, ripple-marked, calcareous	74
6. Siltstone, yellow, thick-bedded, ripple-marked, cross-bedded, micaceous, petroliferous . . .	23
7. Siltstone, reddish-brown, thick-bedded, ripple-marked, cross-bedded, micaceous . . .	57
8. Siltstone, reddish-brown and yellow, thin-bedded, ripple-marked	93
9. Siltstone, yellow, thick-bedded, calcareous, ledge-former	2
10. Siltstone, reddish-brown, thin-bedded, weathers as slope	9
11. Siltstone, yellow, thin-bedded, calcareous, weathers as slope	6
Lower part	
12. Sinbad limestone member (?)	
a. Sandstone, yellow, fine-grained, thick-bedded, very calcareous, ripple-marked; contains calcite geodes	30
b. Limestone, yellow to gray, dense, thin- to medium-bedded	10
c. Sandstone, yellow, fine-grained, thick-bedded, ripple-marked, very calcareous .	7
d. Limestone, yellow to gray, silty, thin- to medium-bedded; contains some clay pellets	8
e. Sandstone, yellow, fine-grained, thick-bedded, ripple-marked, very calcareous; contains some interbedded gray mudstone	53

		Feet
13.	Siltstone, yellow, thin-bedded, calcareous; manganese speckled; weathers as a slope	18
14.	Siltstone, reddish-brown, thin-bedded, ripple-marked, gypsiferous; weathers as a slope	57
15.	Siltstone, yellow, thin-bedded, calcareous; weathers as a slope	11
		968

Unconformity

Kaibab limestone

The lower unit of the lower part of the Moenkopi formation is thin-bedded, ripple-marked, calcareous siltstone with interbedded thin layers of gypsum. A few thin coquinite beds were found in this unit at the south end of Miners Mountain. Some cherty conglomeratic beds are at the base of this unit in two different localities on Miners Mountain. The siltstones are dominantly brownish-red except at the base where they are yellow for an average thickness of about 5 feet. In sec. 20, T. 30 S., R. 6 E., all siltstone in the unit is a yellowish-gray. The thickness varies throughout the area, but averages about 75 feet. In general, this unit thins to the south. (See pl. 2.) This unit is exposed in steep slopes because it is overlain everywhere by resistant beds. The contact with the overlying unit is conformable.

Sandstone and limestone strata comprise the upper unit of the lower part of the Moenkopi which is widespread and is the surface rock of Miners Mountain. Tentatively, the unit is called the Sinbad limestone member of the Moenkopi formation. This name was given to a similar series of beds in the San Rafael Swell by Gilluly and Reeside (1928, p. 65).

The beds are dominantly yellow, thick-bedded calcareous sandstone and arenaceous limestone with some interbedded lenses of green and red mudstone and siltstone. The sandstone is very fine-grained. Everywhere observed, this unit contained within the upper half, two, in places three, thin-bedded, dense, grey fossiliferous limestone layers each of which had an average thickness of 10 feet. Collected fauna were gastropods, pelecypods, and cephalopods. Throughout the area, the limestone layers are at the same approximate stratigraphic position.

This unit has an average thickness of about 100 feet. The Sinbad limestone member (?) thins both to the north and the south as shown on plate 2. The northward thinning is gradual, but that to the south is rapid. Gregory and Moore (1931) reported no beds comparable to the "Sinbad limestone" in the Circle Cliffs. According to J. H. Stewart (personal communication), the "Sinbad" is found in the northern end of the Circle Cliffs, but is absent in the middle of the Circle Cliffs.

This unit is everywhere a cliff-former. The contact of the Sinbad limestone member (?) with the overlying unit is sharp, but apparently is everywhere conformable.

The lower unit of the Upper Moenkopi is composed of lenticular, brownish-red siltstone and very fine-grained sandstone. Most beds are only slightly calcareous and are very micaceous. Ripple marks and mud cracks are common. The unit is thin- to thick-bedded, but most beds are found to consist of thin laminae. Both torrential and tangential cross-bedding are exhibited in many of the beds and excellent scour and fill structures (fig. 7) are present. At a few places on the east side of Miners Mountain, some of the lower beds of this unit are a dark gray because of saturation with petroliferous material. At least two distinct kinds of fossil vertebrate tracks were found in beds near the top of the unit. This unit has a fairly constant thickness of about 350 feet throughout the area.

This unit weathers and erodes into characteristic blocky, massive ledges (fig. 8) with small intervening slopes. All washes and canyons in this unit are narrow and deep.

The contact between this and the overlying unit is gradational.

The upper unit of the upper part of the Moenkopi formation consists of alternating very thin, even-bedded mudstone, shale, and siltstone. The beds are chiefly brownish-red. Many thin white seams of selenite are parallel to and cross-cut the bedding, and many thin layers of pinkish-orange rock gypsum are parallel to the bedding. At a few localities, salt casts and oscillation-type ripple marks were found. The unit weathers into rounded "badland-type" hills and slopes or to form fluted walls where it is overlain by a resistant bed. (See fig. 9.)

FIGURE 7 - Scour and fill structures in the Moenkopi formation.

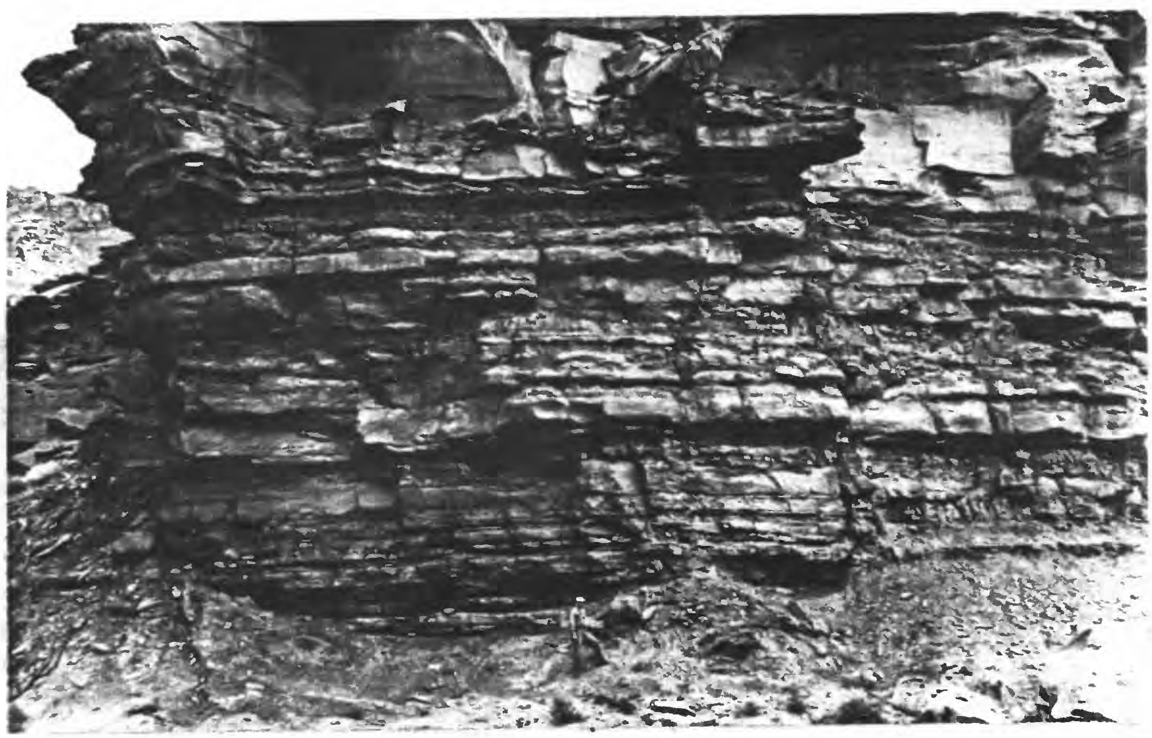


FIGURE 8 - Characteristic weathering into blocky, massive ledges of the lower part of the upper Moenkopi formation.

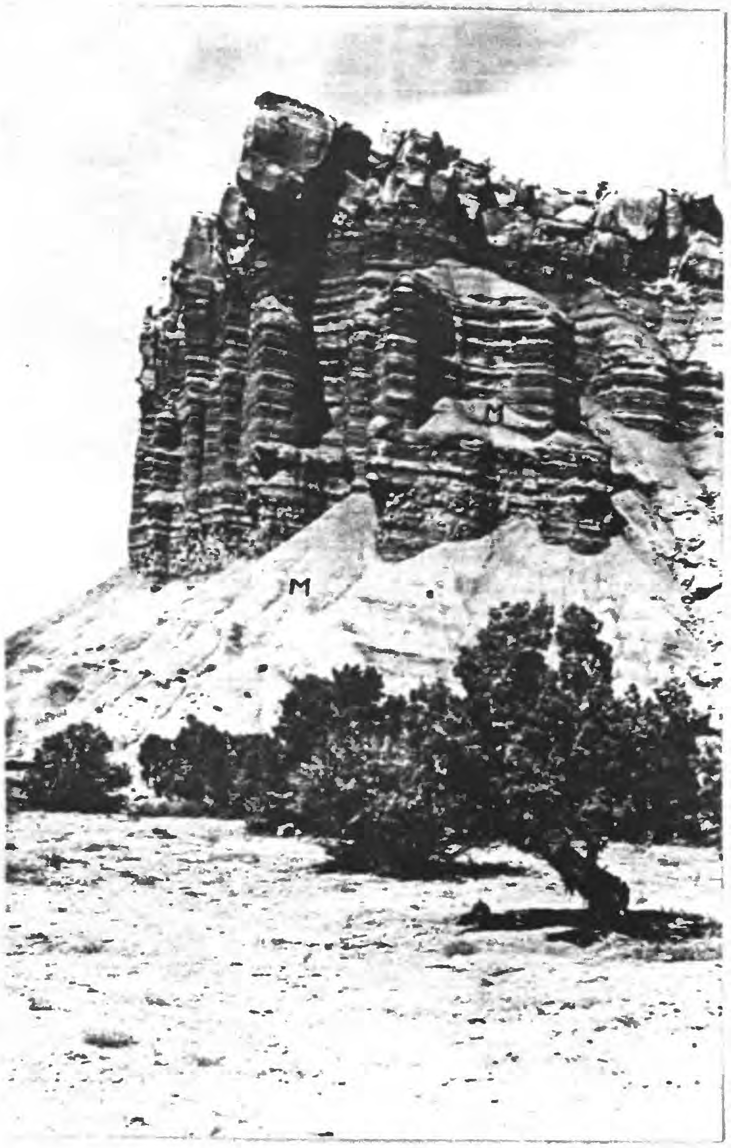


FIGURE 9 - Fluted walls of the Moenkopi formation overlain by cliff-forming Shinarump conglomerate near Capitol Wash.

S, Shinarump conglomerate; M, Moenkopi formation.

The upper contact of the Moenkopi formation is an erosional unconformity and is marked by a change in both lithology and color. On the north side of Grand Wash, a scour or channel has been cut into the uppermost beds to a depth of about 10 feet. At several places between Grand Wash and Capitol Wash, a slight beveling of the uppermost beds was noted.

Where overlain by the Shinarump conglomerate, the uppermost beds of the Moenkopi formation are bleached yellow through a zone ranging from 6 inches to 8 feet in thickness. Where the Shinarump is absent and the Moenkopi is overlain by the Chinle formation, the uppermost beds are commonly variegated. At one place near Pleasant Creek, the variegated rather than the bleached beds were found underlying the Shinarump. At two different localities along Capitol Reef, the top of the Moenkopi is marked by one-half inch to 6 inch thick layer of red chert or jasper which tentatively is included within the Moenkopi formation.

The Moenkopi formation in the Miners Mountain area is thicker than most other areas on the Colorado Plateaus; in the vicinity of Miners Mountain, it ranges from 766 to 968 feet in thickness. As shown on plate 2, the formation thins both to the north and south of this area. Differences in thickness between this area and the San Rafael Swell to the north may be attributed in part to post-Moenkopi erosion. Thickness of the Moenkopi to the south in the Circle Cliffs is notably thinner. The difference in thickness may be explained in at least three possible ways: 1) absence of the "Sinbad limestone member", 2) post-Moenkopi erosion, and 3) non-deposition.

Depositional environment of the Moenkopi is believed to have varied during Lower Triassic time. The lowest unit probably represents lagoonal or marginal shallow-water deposition as indicated by the gypsum, ripple marks, and oxidation of the beds. Following this, the area was inundated by a sea probably from the west and northwest, and the beds of the Sinbad limestone member (?) were deposited. As the sea retreated, marginal shallow-water deposition is indicated, but this was succeeded by material suggestive of continental environment. Evidences of continental deposition are micaceous beds, torrential cross-bedding, irregular lenticular bedding, and scour and fill structures. In part, these beds may have been deposited on a flood-plain adjacent to a sea, but the material of the beds was transported and deposited by fluviatile action. The beds of the uppermost unit again represent a slight advance of the sea to give marginal marine or lagoonal deposition as indicated by the presence of oscillation-type ripple marks, salt casts, and great amount of gypsum. Deposition of the Moenkopi formation was followed by a period of erosion, perhaps the Middle Triassic (?).

Most of the depositional environment was marine. This same conclusion was reached by Gilluly (1929, p. 86) for the Moenkopi in the San Rafael Swell. Climate of the Lower Triassic time was probably semiarid to arid.

Upper Triassic Series

Shinarump conglomerate

The Shinarump conglomerate is exposed along the Capitol Reef and on the southwest side of Miners Mountain area. Along the Reef, the Shinarump crops out as a cliff, whereas on the southwest side of the mapped area, the steeply dipping Shinarump forms ridges. In this paper, the Shinarump conglomerate is defined as the massive sandstone underlying the Chinle formation. The following measured section is typical of the Shinarump in the Miners Mountain area.

Section of the Shinarump conglomerate three-quarters of a mile north of Pleasant Creek

(Measured by R. G. Luedke)

Chinle formation

Shinarump conglomerate

	Feet
1. Sandstone, greenish-gray and red, fine-grained, thin-bedded, cross-bedded, micaceous	14
2. Sandstone, white to gray, medium-grained, thin- to thick-bedded, cross-bedded, iron stained; contains much fossil wood near base; has some interstitial clay . . .	28
	42

Unconformity

Moenkopi formation

In the Miners Mountain area, the Shinarump conglomerate consists of a friable, lenticular, cross-bedded, massive sandstone with small interbedded lenses of green and gray mudstone. Cross-bedding is of the festoon type. The formation is white to buff except where stained by desert varnish or by wash from the overlying formation. At a few places, large amounts of limonite cement have stained the beds a deep yellow. This coloring is commonly prominent on the upper surface of the sandstone; the iron stain is heavy enough in places to form a crust on this surface. At several places along the Reef, the Shinarump has a basal layer of green and white clay as much as a foot thick; the layer contains selenite seams and thin stringers of sandstone. The Shinarump contains an abundant amount of fossil twigs, logs, and leaves, most of which is silicified, although some is carbonized. Clay pellets, 1 to 2 inches in diameter, are scattered sparingly throughout the formation. Very few quartz, quartzite, and chert pebbles were found; the maximum pebble diameter observed was one-quarter inch.

The Shinarump has been defined as a conglomerate, but in the Miners Mountain area it is a medium- to coarse-grained sandstone. The sand grains are predominantly quartz with minor amounts of chert and feldspar, chiefly microcline. A few quartz grains are frosted but most are clear. In thin-section, some of the quartz grains show secondary silica growth. The grains are angular to subrounded and most grains range in diameter between 0.50 and 0.125 mm. Cementing material is mostly clay with minor amounts of iron and calcium carbonate.

Thickness of the Shinarump in the Miners Mountain area ranges from a vanishing point to 60 feet. When the Shinarump is compared with the same formation in the San Rafael Swell and the Circle Cliffs (pl. 2), no significant differences can be noted except that the thickness may vary slightly and that the sandstones might be somewhat more conglomeratic in those two areas.

The Shinarump appears to be gradational with the overlying Chinle formation. At many places, lithologic contrast between the two formations is distinct. At other places, the Shinarump sandstone grades upward into similar sandstone and sandy mudstone of the Chinle (fig. 10). Lateral gradation is also evident in the area. Along the Reef about one and one-half miles south of Pleasant Creek, a tongue of sandstone splits from the main ledge and grades laterally northward into typical Chinle sandy mudstones. The tongue of sandstone wedges out about 30 feet above the base of the mudstones in a distance of 1,000 feet. The boundary between formations is difficult to pick at these places. Where the Chinle is resting directly on the Moenkopi, the lack of Shinarump may be due to lateral gradation into Chinle beds. This explanation could account for the irregularity of exposures of Shinarump in the Miners Mountain area. Evidence presented here further substantiates the general opinion of geologists familiar with Plateau stratigraphy; the Shinarump is a basal conglomerate or sandstone of the Chinle formation.

FIGURE 10 - Gradational contact of the Shinarump conglomerate and the Chinle formation.

Shows gradation from Shinarump sandstone to Chinle sandstone and sandy mudstone. M, Moenkopi formation; S, Shinarump conglomerate; C, Chinle formation.

In general, Shinarump sediments are believed to be fluviatile deposits as is indicated by lensing, irregular bedding, cross-bedding, coarse sediments, and large amounts of fossil wood. The source of the sediments is presumably to the south and southeast as indicated by slight thickening and a greater amount of coarser materials in that direction. Because of the reasonably uniform thickness and persistence of the formation throughout the Colorado Plateaus, some geologists believe the Shinarump to be a piedmont-type deposit. Stokes (1950) believes the Shinarump to be a pediment-type deposit. One of the problems of the depositional conditions of the Shinarump is whether erosion of the upper surface of the Moenkopi and deposition of the Shinarump were two separate distinct episodes or whether the streams which eroded the upper surface also deposited the Shinarump at the same time. Stokes (1950, p. 94) prefers the former idea.

Stratigraphically the Shinarump is between the Lower Triassic Moenkopi formation and the Upper Triassic Chinle formation. The lower boundary of the Shinarump is marked by an erosional unconformity. Because of the Shinarump's affinities to the Chinle formation, it seems likely that the Shinarump conglomerate, as the Chinle formation, is Upper Triassic.

Chinle formation

The Chinle formation is exposed continuously along the base of the Capitol Reef cliff and at scattered outcrops on the southwest side of Miners Mountain. Along the Reef, physiographic expression of the Chinle is characterized by long, steep slopes broken by low steps (fig. 11). These slopes are strewn with rock debris which falls from the cliffs above. At a few places where the Chinle is exposed over wider areas or on broad benches of Shinarump, the beds are eroded to a "badland-type" topography. On the southwest side of the area, the Chinle underlies a narrow strike valley.

The Chinle formation was mapped as a lower and upper part. Following is a representative section of the Chinle formation in the Miners Mountain area.

Section of the Chinle formation three-quarters of a mile north of Pleasant Creek

(Measured by R. G. Luedke)

Wingate sandstone

Unconformity

Chinle formation

		Feet
1.	Mudstone, variegated, very calcareous; contains several mottled conglomeratic limestones with clay pellets in beds 1/2 to 2 feet thick; weathers as a slope broken by several steps	150
2.	Sandstone, pale red, fine-grained, cross-bedded, thin-bedded, calcareous; conglomeratic at base with flattened clay and lime pellets; contains a few inter-bedded mudstone lenses; weathers a dominant ledge throughout area	36
3.	Mudstone, variegated, sandy; contains many thin lenses of fine-grained sandstone and conglomerate which are cross-bedded	141
4.	Mudstone, light-olive gray, sandy, gypsiferous; contains a few thin-bedded, cross-bedded, micaceous sandstone lenses; possibly contains volcanic ash; weathers as a slope	98
5.	Mudstone, reddish-brown, sandy near base; weathers as a slope	22
		447

Shinarump conglomerate

FIGURE 11 - The Castle in the Capitol Reef National Monument.

Shows the Chinle formation, divided by a prominent sandstone ledge, overlying the Moenkopi formation and underlying the Wingate sandstone. M, Moenkopi formation; C, Chinle formation; W, Wingate sandstone.

The rocks of the lower Chinle consist of sandy mudstone with many interbedded lenses of sandstone and a few lenses of shale. Bedding is obscure in most exposures. On the basis of color only, the lower Chinle could be divided roughly into two units. The lower one-half is dominantly gray to greenish-gray whereas the upper one-half is dominantly red to brownish-red. Throughout the area, the range of colors remains about the same although the color of individual beds may vary considerably along strike. A few individual beds are variegated in shades of red, maroon, purple, yellow, green, and gray. In some places, the mudstones weather to form a hard crust while in other places, they weather to form a very soft, fluffy surface. The soft condition may be due to the presence of volcanic ash and swelling clays. Gregory and Moore (1931, p. 57) describe swelling clays from the Chinle formation in the Circle Cliffs. Waters and Granger (1953, p. 6) report that the lower beds of the Chinle formation contain a large amount of pumice and volcanic glass shards completely altered to montmorillonite. The entire section of mudstone is only slightly calcareous. Silicified and a little carbonized wood is abundant in the lower Chinle.

The lower one-half of the lower Chinle contains a great amount of slightly calcareous sandstone. The sandstone near the base of the formation is coarse and more like the sandstone of the underlying Shinarump. Sandstones higher in the section are more fine-grained and are locally micaceous and ripple-marked, cross-bedded, thin-bedded, and extremely lenticular. Usually, no lens is more than 5 feet thick; they are discontinuous along strike and occur at different levels. A weathered surface on the sandstone is dark-brown whereas a fresh surface is light-brown or speckled brown. Some sandstone lenses have been noted to dip as much as 30 degrees greater than the present dip of bedding. Intra-formation slumping during or shortly after the deposition may be a possible explanation for this unusual feature.

Along the Reef, a continuous ledge or cliff of irregularly bedded, lenticular sandstone marks the top of the lower Chinle. This sandstone forms a prominent break in the slope and remains at approximately the same horizon throughout the exposure of the Chinle formation. Much of the sandstone, which is slightly to moderately calcareous, is cross-bedded. The quartz and chert sand grains are sub-angular to sub-rounded and average between 0.50 and 0.125 mm in diameter. Interbedded with the sandstone are lenses of mudstone and conglomerate, which consists chiefly of limestone and claystone pellets. Fresh surfaces of this sandstone are light-brown to light-red whereas the weathered surface is dark-brown. Throughout the area, this sandstone ledge ranges from 20 to 40 feet in thickness. The contact between the lower and upper Chinle arbitrarily was put at the top of the sandstone. On the southwest side of the area, this sandstone is not exposed because of faulting.

The lower Chinle of the Miners Mountain area is believed to correspond with Divisions C and D of the Chinle in the Navajo country of Arizona (Gregory, 1917, p. 43).

The upper Chinle in the area consists of calcareous mudstone and limestone and weathers to form a hard crusted slope, broken by several small steps which are formed by beds of dense limestone ranging from a few inches to 2 or 3 feet in thickness. The limestone beds are discontinuous along strike and vary in number from one place to another. Some sandy mudstone is near the base of the upper Chinle. Conglomerate lenses consisting of claystone and limestone pellets in a limy siltstone matrix are exposed in places near the top of the Chinle formation. At one locality along the Reef, about 1 mile north of Capitol Wash fossil teeth were found in the conglomerate. The upper Chinle is dominantly grayish-green; the limestone beds are mottled green and lavender. The upper Chinle in the Miners Mountain area probably corresponds to Gregory's Division B (1917, p. 42) of the Chinle formation in Arizona.

At one locality north of the town of Fruita, the uppermost 20 feet of the upper Chinle consists of purplish, unevenly bedded, cross-bedded, coarse-grained sandstone. The length of outcrop of this sandstone is about 300 feet and the maximum thickness is about 20 feet. Sand grains are coarser than those in the overlying Wingate sandstone. Whether this sandstone grades laterally into the calcareous mudstones of the upper Chinle or represents a scour and fill structure in the mudstones has not been determined. Possibly this sandstone may correspond in part to Division A of the Chinle in Arizona (Gregory, 1917, p. 42).

Along Capitol Reef, the total thickness of the Chinle formation ranges from 447 to 475 feet. The lower Chinle increases slightly in thickness to the south and the upper Chinle thins slightly in that direction. The overall thickness of the Chinle formation is relatively uniform throughout the area.

As previously mentioned, the contact of the Chinle with the underlying Shinarump is gradational, but the contact with the overlying Wingate sandstone is a sharp lithologic boundary and is believed to represent an unconformity in this area. One mile north of Capitol Wash, the uppermost beds of the Chinle are beveled by the Wingate, but at most places the contact appears conformable. At many places along the Chinle-Wingate contact, ancient mud cracks filled by Wingate sandstone, penetrate the Chinle to a depth of 1 foot.

As shown on plate 2, the Chinle formation of this area is correlated with the Chinle in the San Rafael Swell and the Circle Cliffs. From the description of the Chinle in the Circle Cliffs by Gregory and Moore (1931), the formation compares lithologically and differs only slightly in thickness from the Chinle in this area. A marked difference in both lithology and thickness is exhibited in the Chinle in the San Rafael Swell from that in the Miners Mountain area. The Chinle in the Swell is a sandy shale and sandstone and is much thinner. The thinness of the Chinle in some northern parts of the Colorado Plateaus has been suggested to be due in part to pre-Jurassic erosion.

The Chinle formation is of continental origin and may be a flood-plain deposit (Gilluly and Reeside, 1928, p. 63). Fluviatile conditions are indicated by the sandstones in the lower part of the formation with the finer sediments possibly representing deposition farther out in the basin. Baker (1945, p. 63) suggested that the variegated clays and muds may be due in part to lacustrine deposition. The limestone beds also could be due in part to lacustrine deposition. A possible northern source for the sediments was suggested by Gilluly and Reeside (1928, p. 68), but the Chinle formation probably had several sources of direction for the sediments.

JURASSIC (?) SYSTEM

Glen Canyon Group

Wingate sandstone

Exposures of the Wingate sandstone, the lowest formation of the Glen Canyon group, form the cliff proper of the Capitol Reef. The outcrop forms a nearly vertical wall, approximately 300 feet high, which can be crossed only in the few canyons cutting through the Reef. Where the Wingate is not overlain by the Kayenta formation, weathering along closely spaced vertical joints results in many round-topped pinnacles or "needles". On the southwest side of Miners Mountain, steeply dipping Wingate crops out as many narrow hogbacks with serrate crests.

The Wingate consists of large-scale tangentially cross-bedded, massive sandstone. Horizontal bedding is not conspicuous except at a few places near the bottom of the formation where the bedding is thick and can not be traced along strike for more than a few hundred feet. Everywhere along the Reef, the Wingate is characterized by large vertical joints most of which traverse the entire thickness of the formation. (See fig. 12.) On the face of the cliff, there appear to be many conchoidal-like fractures of the magnitude of 30 feet or more. The Wingate is predominantly reddish-brown but in a few places is yellow. Locally, the surface of the cliff has been stained bluish-black by desert varnish or by dark-red wash from the overlying Kayenta. Along the Reef in the southern end of the area, several lenses of dense, unfossiliferous, gray to tan, slightly sandy limestone were observed in the Wingate. Estimated thickness of the limestone lenses is 3 to 5 feet with the length estimated to be 100 to 200 feet.

The Wingate consists of a nearly homogeneous very fine- to fine-grained sandstone. Clean quartz grains which are slightly frosted and are cemented by lime and silica, make up the sandstone. The grains average in diameter between 0.02 and 0.125 mm, and are sub-angular to sub-rounded. Several thin stringers of coarse sand grains are found at the base of the sandstone and are characteristic of the sandstone over a large area.

FIGURE 12 - Cliff of massive Wingate sandstone with characteristic vertical joints.

M, Moenkopi formation; C, Chinle formation; W, Wingate sandstone; K, Kayenta formation

The thickness of the Wingate appears to be fairly constant along the Reef in the Miners Mountain area. The average thickness is 320 feet, although a thickness of 360 feet was measured in two places. Inconsistency of the thickness is due in part to the difficulty in selecting the precise boundary between the Wingate and Kayenta at most localities along the Reef; commonly this contact is near the top of the cliff and is inaccessible.

The upper contact of the Wingate is gradational with the Kayenta (fig. 13) except on Pleasant Creek where the contact appears to be clearly defined. Difficulty was encountered in selecting the contact because of lithologic similarity between the two formations and inaccessibility of the outcrop. Therefore, the contact was arbitrarily placed at the lowest thin horizontal bedding. At most places, this even bedding was distinguishable, but it did not continue at exactly the same horizon along the outcrop.

Little, if any, difference in lithology, texture, structure, and physiographic expression occurs within the Wingate sandstone in the San Rafael Swell, the Miners Mountain area, and the Circle Cliffs. (See pl. 3.)

FIGURE 13 - Gradational contact between the Wingate sandstone and Kayenta formation.

C, Chinle formation; W. Wingate sandstone; K, Kayenta formation; N, Navajo sandstone.

Because of the homogeneous, tangentially cross-bedded sandstone, the Wingate is believed to represent an eolian deposit. Possibly near the top and bottom of the formation, the eolian sediments may have been slightly reworked by streams. The limestone lenses are presumably of fresh-water origin and represent playa-like basins of deposition in the dune areas. Gilluly and Reeside (1928, p. 70) suggest that the deposition of the limestone in playa basins might have been during periods of high groundwater level. The main source of the sediments for the Wingate was believed by Baker, et al (1936, p. 44) to be from the southeast.

Climatic conditions during the time of deposition of the Wingate were probably semiarid to arid.

The age of the Wingate has been discussed comprehensively in the literature, particularly by Baker, et al (1936). On the basis of meager fossil evidence and stratigraphic position between the Chinle and Kayenta formations, the Wingate has been assigned tentatively to the Jurassic. In a more recent article, Imlay (1952, p. 964) suggests that the age of the Wingate may prove to be Triassic.

<u>Kayenta formation</u>

The Kayenta, the middle formation of the Glen Canyon group, crops out along the top of the Capitol Reef and on the southwest side of Miners Mountain. At most localities along the Reef, the more resistant lower part of the Kayenta forms a cap over the underlying friable Wingate sandstone. (See Fig. 14.) The less resistant upper part of the Kayenta erodes back from the top of the cliff to form many broad benches and platforms which extend to the base of the overlying Navajo sandstone cliffs. On the southwest side of the area, the Kayenta formation forms ledges and in places, crops out in a series of irregular, narrow hogbacks.

The Kayenta formation consists of thin- to thick-bedded, irregularly stratified sandstones (fig. 15) interbedded with lesser amounts of mudstone and mud, silt, and lime pellet conglomerate. Some beds are lenticular, and others are truncated and have channel or scour and fill structures. Cross-bedding is common in many of the sandstone beds. The formation is predominantly brownish-red, but locally, some beds are yellow and green. The following stratigraphic section is considered typical of the Kayenta formation in the Miners Mountain area.

Section of the Kayenta formation in Grand Wash
(Measured by J. F. Smith, Jr.)

Navajo sandstone

Kayenta formation	Feet
1. Sandstone, yellow to gray, fine-grained, thick-bedded, some cross-bedding; contains some clay pebbles and clay lenses	67
2. Sandstone, pale orange to pale red, thin- to thick-bedded; contains some conglomerate beds of clay and silt pebbles in a sandstone matrix; some cross-bedding and scour and fill structures; weathers as massive ledges . . .	54
3. Sandstone, yellow to red, fine-grained, some cross-bedding, thick-bedded; weathers as massive ledges	125
	246

Wingate sandstone

The friable and loosely compacted sandstone is fine- to medium-grained, micaceous, and calcareous. Most of the sand grains appear to be quartz and are frosted and fairly well sorted. The grains are sub-angular to sub-rounded and average between 0.25 and 0.125 mm in diameter. In the lower part of the Kayenta, the cementing material is primarily siliceous; in the upper part, it is primarily calcareous. In general, the lithology of the lower part of the Kayenta is like the Wingate whereas the upper part is more like the Navajo except for the conglomerate. Little difference in the lithology of the formation exists between the San Rafael Swell, the Miners Mountain area, and the Circle Cliffs.

FIGURE 14 - Aerial view northwest along the top of the Capitol Reef.

Shows the broad benches and platforms of the Kayenta formation and the lower resistant beds capping the more underlying friable Wingate. C, Chinle formation; W, Wingate sandstone; K, Kayenta formation; N. Navajo sandstone.

FIGURE 15 - Kayenta formation exposed on Pleasant Creek.

Shows the thin- to thick-bedded, irregularly stratified sandstones and the clearly defined lower contact. W, Wingate sandstone; K, Kayenta formation; N, Navajo sandstone.

Throughout the Miners Mountain area, the thickness of 246 feet for the Kayenta formation appears to be fairly constant. On plate 3, the thickness of the representative section for the San Rafael Swell is 322 feet and the thickness for the representative section in the Circle Cliffs is 287 feet (Hunt, et al, in press). Both Gilluly (1929, p. 95) and Gregory and Moore (1931, p. 64) give slightly less thicknesses for the Kayenta in the San Rafael Swell and the Circle Cliffs respectively. The differences in thickness may be accounted for, in part, by the necessarily arbitrary selection of the contacts of the Kayenta formation.

As previously stated, the Wingate-Kayenta contact is gradational. The contact of the Kayenta with the overlying Navajo sandstone also is gradational. In most places, the contact was inaccessible, but where observed, it appeared to be transitional through a zone of about 40 to 50 feet. This zone is a gradual change in lithology and bedding between the two formations. The boundary arbitrarily was selected to include all distinct horizontal bedding in the Kayenta. (See fig. 16.)

Types of sediments and bedding indicate that the Kayenta probably was deposited on flood-plains where conditions alternated between still and rapid moving waters (Baker, et al, 1936, p. 61). No definite sources are known for the sediments.

Tentatively, the age of the Kayenta formation is Jurassic, the same as the underlying Wingate sandstone.

FIGURE 16 - Contact between the Kayenta formation and the Navajo sandstone.

Shows the gradational boundary; contact picked to include all distinct bedding in the Kayenta. K, Kayenta formation; N, Navajo sandstone.

Navajo sandstone

The Navajo sandstone is the upper formation of the Glen Canyon group. Within the Miners Mountain area, exposures of the Navajo are limited to two localities on the Reef and to several isolated localities on the southwest side of the area. Extensive outcrops of the Navajo are along the top and east sides of the Capitol Reef, but those outcrops were not included within the mapped area. As seen in figure 17, the Navajo along the Reef weathers as huge rounded knobs or domes and rounded elongate knobs which are accentuated by sharp, deep crevices eroded along joints. At a few places on top of the Reef, isolated caps of the overlying Carmel formation cause the Navajo sandstone to stand out as flat-topped pinnacles. On the southwest side of the area where the Navajo is overlain by the Carmel, the sandstone weathers to steep, rounded cliffs. (See fig. 18.) A short distance west and south of Grover, there are erosional outliers of Navajo sandstone. Because the Navajo erodes easily, many outcrops are surrounded and partly covered by dune sands.

The Navajo is a white to buff, friable, massive, cross-bedded sandstone. The cross-bedding is on a large scale and truncation at many angles of one set of cross-beds by another set is characteristic of the formation (fig. 19).

FIGURE 17 - Characteristic weathering of Navajo sandstone into huge rounded knobs and domes.

FIGURE 18 - View of the southwest part of the Miners Mountain area (looking southeast).

Shows the Navajo sandstone cliffs overlain by the Carmel formation. At left (background) is Miners Mountain; at right (background) is the lower northeast slope of Boulder Mountain. Quaternary deposits make up most of center. Moenkopi formation exposed left (center) and in foreground. Photograph by L. C. Huff.

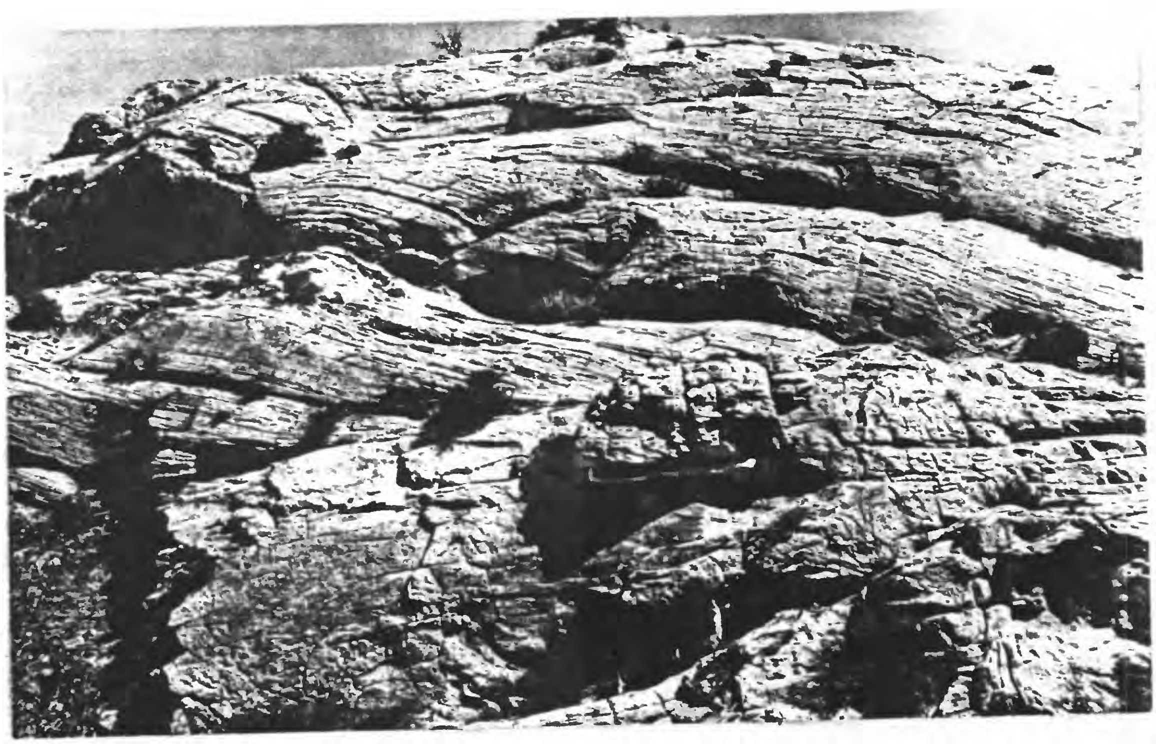


FIGURE 19 - Truncated sets of cross-bedding in the Navajo sandstone.

The Navajo is a homogeneous, medium-grained quartz sandstone with the sand grains sub-angular to rounded and ranging from 0.125 to 0.25 mm in diameter. All of the grains are frosted; a few grains show what appear to be wind-worn facets. Most of the cementing material is calcium carbonate.

At one locality on the northeast side of Boulder Mountain a sandy limestone lens was observed near the top of the Navajo. Also on Boulder Mountain, the upper 3 to 5 feet of the Navajo is light-tan to orange, is not cross-bedded, is similar in composition and texture to the beds below, and appears to be Navajo sandstone that has been reworked by water. Locally, yellow limonitic stained spots which are 3 to 4 feet in diameter are found in the formation.

A thickness of the Navajo sandstone was not measured. Gregory and Anderson (1939, p. 1840) estimated the thickness of the Navajo in Capitol Wash to be 1,050 feet, but as shown on plate 3, the writer estimated the thickness of the Navajo to be about 750 feet. This estimation was based on the comparison of known thicknesses of the Navajo both to the north and the south of the area, and on the knowledge that the Navajo thickens to the southwest. The Navajo sandstone may be thicker on Boulder Mountain than along the Reef.

The Navajo sandstone of this area is correlated with the similar unit in the San Rafael Swell and the Circle Cliffs. Lithology, texture, and topographic expression of the sandstone shows no marked differences throughout the entire region. The reworked zone at the top of the Navajo possibly corresponds in part to the Temple Cap member of the Navajo sandstone in the Zion Park region (Gregory, 1950, p. 89).

The contact of the Navajo sandstone with the overlying Carmel formation is a sharp lithologic boundary. Also, the Navajo is separated from the Carmel by an unconformity, but probably no important period of erosion occurred prior to the deposition of the Carmel. The reworked zone at the top of the Navajo may represent the first advance of the sea that deposited the Carmel.

The Navajo sandstone has long been considered as an eolian deposit. "Dreikanters" (Gilluly, 1929, p. 98) and wind-worn pebbles from many localities indicate this type of environment. Baker (1945, p. 69) suggests that the thin limestone lenses probably imply deposition in ephemeral lakes. From the kind of deposition, semiarid to arid climatic conditions probably prevailed during that time. The source of the sediments was primarily from the southwest.

The Navajo sandstone was assigned tentatively to the Jurassic system by Baker, et al (1936, pp. 55-58). Imlay (1952, p. 964) states that the age of the Navajo is probably Lower Jurassic.

JURASSIC SYSTEM

Upper Jurassic Series

San Rafael Group

Carmel formation

The Carmel formation is the lowest unit of the San Rafael group, and is the only formation of the group exposed in the Miners Mountain area. Exposures, as soft slopes with intervening small cliffs, are only on the southwest side of the area (fig. 20). The basal resistant beds of the Carmel form a cap on the underlying Navajo sandstone.

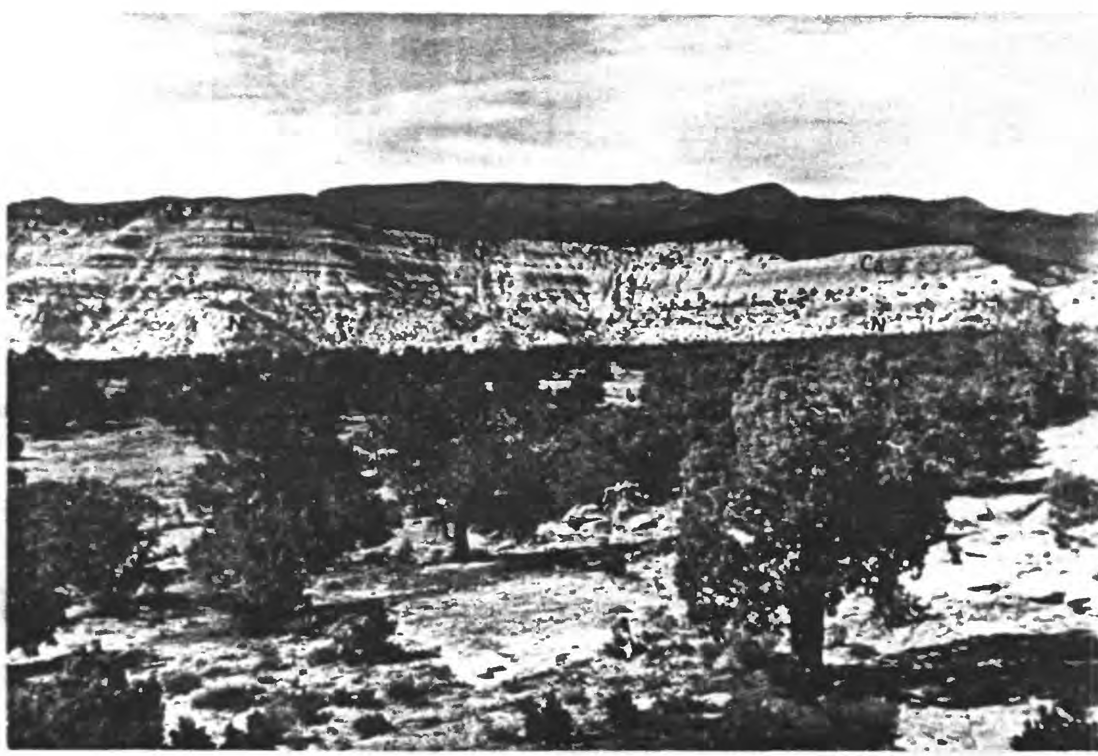


FIGURE 20 - Outcrop of the Carmel formation on the southwest side of area.

Shows soft slopes with intervening cliffs. Boulder Mountain is background. N, Navajo sandstone; Ca, Carmel formation.

The Carmel formation consists of interbedded shale, siltstone, fine-grained sandstone, gypsum, and fossiliferous limestone, the latter occurring near the base of the formation. Except for the massive beds of gypsum, the formation is composed of thin, even beds. White, sugary gypsum beds range from a few inches to more than 40 feet in thickness. Beds are white, gray, yellow, buff, and red to give the formation an overall banded appearance. Hunt, et al (in press) described the Carmel east of the area as similar lithologically, but said the beds are predominantly red. Collected fossils from the limestones were gastropods, pelecypods, crinoid stems, and echinoid spines.

An estimated 300 to 400 feet of Carmel is exposed in the area, and in an incomplete section measured about 10 miles west of the area, more than 900 feet is exposed. Near Pleasant Creek on the east side of the Capitol Reef, the Carmel is 336 feet thick (Hunt, et al, in press). Hence, the Carmel thickens from east to west.

Lithology, structure, and fossils of the formation probably indicate deposition as a marginal marine facies. According to Imlay (1952, pp. 963-964), the beds exposed in the area, which are the lower part of the formation, are probably of Middle Jurassic age.

QUATERNARY SYSTEM

Within the Miners Mountain area, all deposits of Quaternary age were mapped as one unit. The deposits have been differentiated into separate types, but more field work is needed to determine their age and physiographic relations.

The Quaternary deposits consist of sands, gravels, boulder accumulations, and bedrock debris. Material in many of the deposits is well consolidated.

The deposits are of both Pleistocene and Recent ages. Alluvium is found only along the major perennial streams. Colluvium deposits are extensive and are found on canyon sides and bottoms throughout the area. Some landslide deposits occur along the base of the Capitol Reef cliffs. At several localities on the east side of Miners Mountain, terrace or bench gravels (fig. 21) are found on at least three different levels. Gravels covering pediment surfaces are on the northeast flank of Boulder Mountain. On the west side of the area, the large expanse of Quaternary deposits consists chiefly of slide, slump, and glacial material. Gould (1939) reported that undoubted glacial deposits did not occur below the altitude of 8,950 feet. R. F. Flint and C. S. Denny (personal communication) believe glacial material is found at lower altitudes and comprises most of the material in the vicinity of Grover.

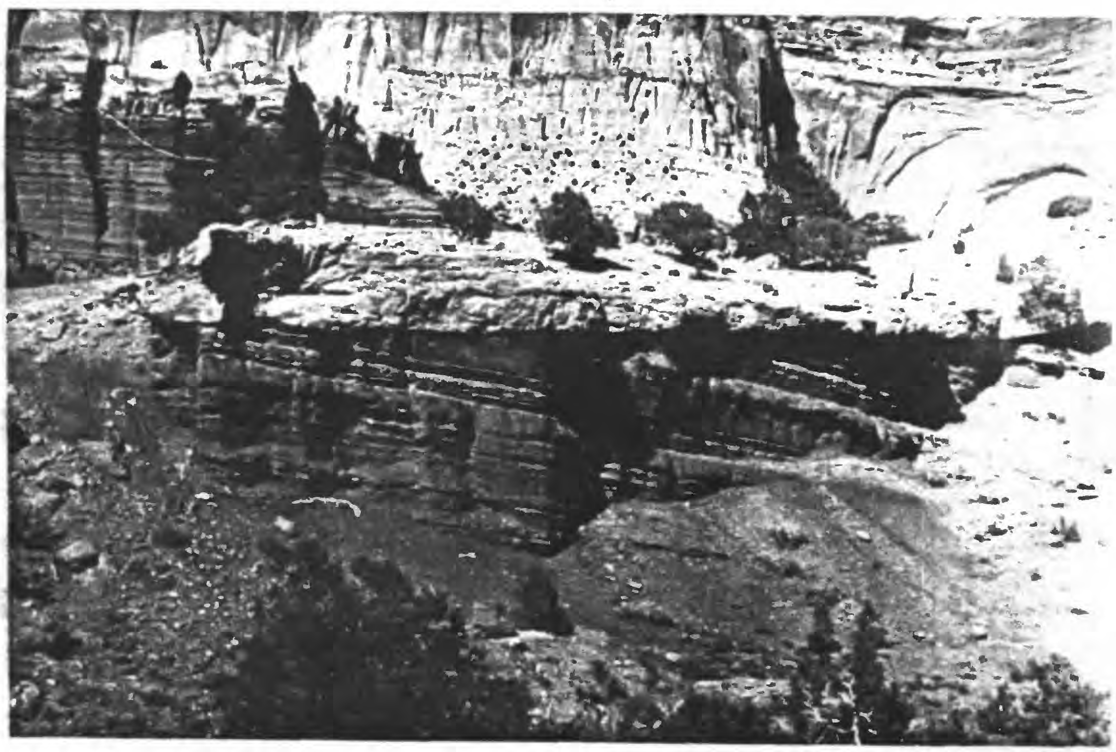


FIGURE 21 - Consolidated terrace or bench gravel, which truncates the Moenkopi formation, on the east side of Miners Mountain.

STRUCTURE

GENERAL FEATURES

The rocks of the Miners Mountain area are folded into a large anticlinal upwarp which is modified by a few minor folds and is cut by several faults. The limits of the upwarp are defined by the Capitol Reef on the north and east sides and by the Teasdale fault on the south and southwest sides. The west and northwest limits of the upwarp are difficult to define because of the gentle northwesterly dip of the strata in that part.

The Miners Mountain area, the San Rafael Swell to the northeast, and the Circle Cliffs upwarp to the southeast are structurally similar in some respects and dissimilar in others. (See fig. 22.) The three upwarps form a broad arc around the west side of the Henry Mountains basin; axes of the Circle Cliffs and Miners Mountain folds trend northwest and the axis of the San Rafael Swell upwarp trends northeast. Steep, east-dipping monoclines form the boundaries between the upwarped areas and the basin. The Miners Mountain area differs from the San Rafael Swell and Circle Cliffs in asymmetry of the upwarps; the fold in this area has a steep-dipping west flank whereas the folds in the Swell and Circle Cliffs have a steep-dipping east flank. The upwarp of this area is much smaller in size than those of the San Rafael Swell and Circle Cliffs.

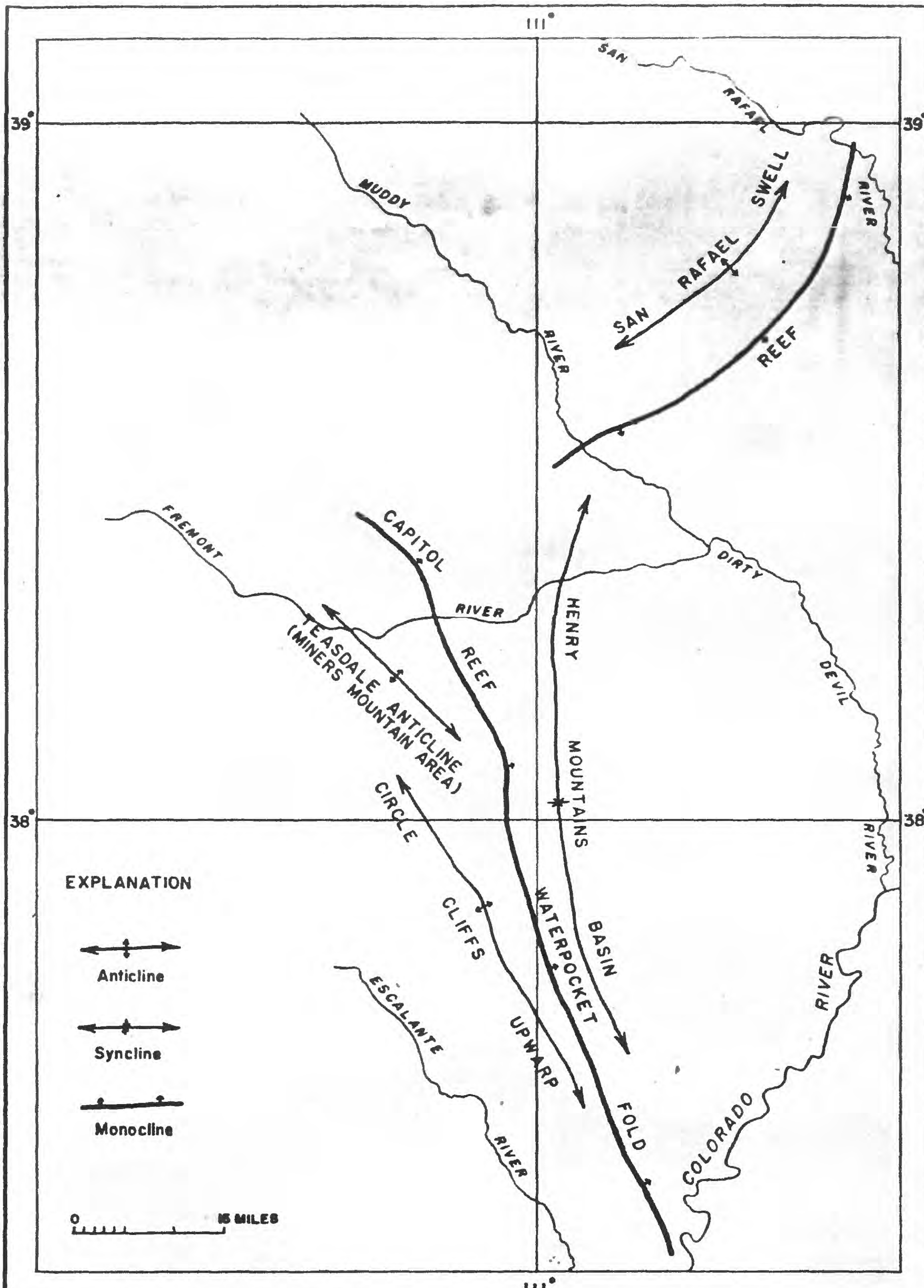


FIGURE 22—Index map showing the monocline and fold axes of the San Rafael Swell, Miners Mountain area, Circle Cliffs, and Henry Mountains region, Utah

In many places, the rocks of the area are broken by normal faults, most of which are vertical, have small displacements, have no definite structural trend, and apparently had dip slip movement. Drag along the faults is negligible, and where present, is only on the downthrown side as shown in figure 23.

Joints are prominent in some of the rocks throughout the area, particularly in the Moenkopi formation on the upwarp and in the Wingate and Navajo sandstones along the Capitol Reef.

METHODS OF REPRESENTING STRUCTURE

The structural attitudes of the strata in the Miners Mountain area are shown on plate 4 which gives the location of the faults and the attitude of the Sinbad limestone member (?) of the Moenkopi formation by contours. Strike and dip symbols on plate 1 also show the attitudes of the beds. Structure contour lines are drawn on the top of the lower part of the Moenkopi formation. This datum plane was used because of its widespread exposure.

Surface positions of the faults, with the downthrown and upthrown sides indicated, are shown on plates 1 and 4.

The cross section on plate 1 shows the attitude of the strata and the surface profile of the area.

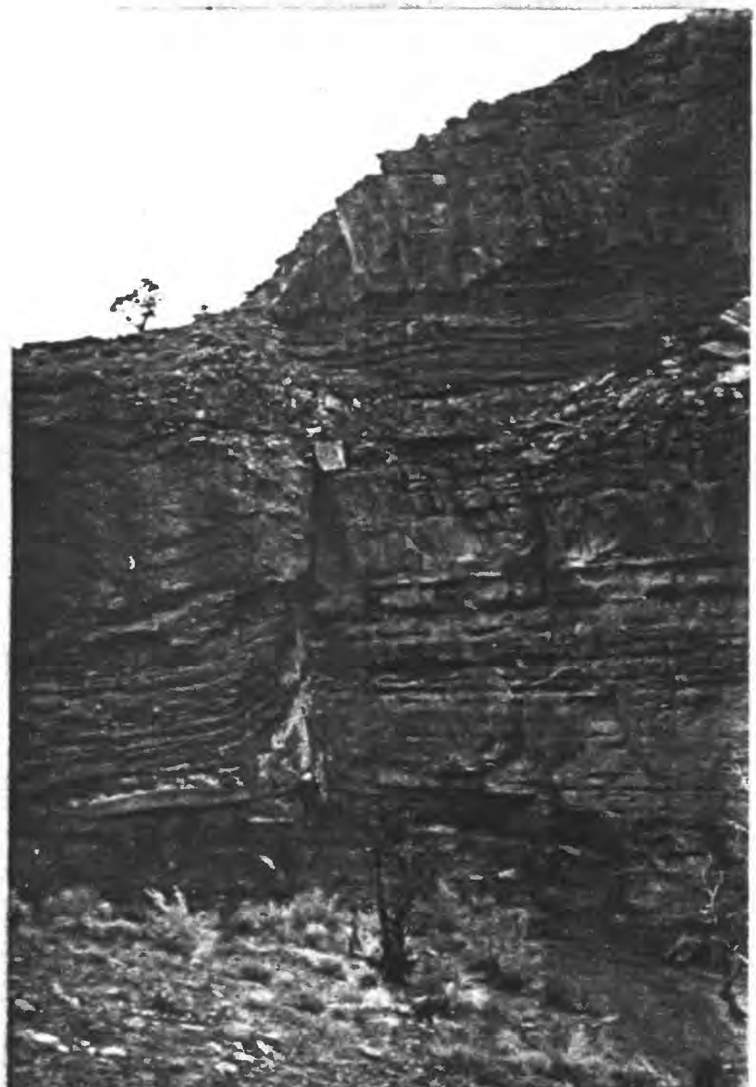


FIGURE 23 - A fault, typical of those in the Miners Mountain area, showing drag on the downthrown side.

FOLDS

Teasdale Anticline

The major fold in the Miners Mountain area was called the Red Gate Flexure by Gilbert (1877) and the Miners Mountain Swell by Gregory and Moore (1931), but in a symposium volume on the oil and gas possibilities of Utah, it is called the Teasdale anticline. All but the southern end of the anticline is in the mapped area.

The Miners Mountain structure is an anticline about 14 miles long and 3 to 6 miles wide. As shown on plate 4, the double-plunging Teasdale anticline trends about N. 35° W. and is asymmetric with the steeper flank on the west. The axis is not sinuous, but is slightly convex toward the east. The eastern flank has dips of 8° to 12°, whereas the western flank has dips ranging from 20° to 50°. Towards the northern end of the fold, the dips of both flanks decrease to about 3° to 5°. The anticline has closure of 1,000 feet or more. Short distances east and west of the Miners Mountain area, the steeply dipping strata abruptly assume nearly flat attitudes. The structural relief between the axis of the Henry Mountains synclinal basin and the axis of the Teasdale anticline is estimated to be about 7,000 feet.

The fold is broad and gently rounded on the northern end, but is narrow and sharply rounded on the southern end. The asymmetry of the fold changes along strike from south to north. Because the Teasdale fault that flanks the southwest side of the anticline has caused more abrupt warping, the southern end is extremely asymmetric with a steeply dipping west flank. Northward along the anticline, the dips on the west flank decrease until at the northern end, the strata have relatively low dips. At the northern end, the writer believes the anticline there becomes asymmetrically similar to other upwarps, such as the San Rafael Swell and Circle Cliffs upwarps, in that dips on west flanks are gentle and those on east flanks steep.

Several subordinate folds are superimposed on the Teasdale anticline, but they probably represent minor adjustments during the time of folding. (See pl. 4.) On the eastern flank are a small syncline and anticline whose axes trend about N. 50° W. and may be a reflection of the large fault a short distance to the northwest. Near the south end, a shallow subsidiary flexure or transverse fold forms a shallow depression across the anticline at a right angle to the crest. On the northern end, the anticline has two small warps or structural noses superimposed upon it, one on each side of the crest. At several localities along the eastern flank, small drag folds (fig. 24) plunge in the same direction as the anticline.

FIGURE 24 - Plunging drag fold in thin beds of the Moenkopi formation on the east flank of the Teasdale anticline.

The anticline is broken by many normal faults, but with the exception of the group of nearly parallel faults at the south end, none appear to have a definite common structural trend.

The oldest rocks exposed in the area, the Coconino sandstone and the Kaibab limestone, are found only in the canyons cut deep into the anticline. The most widespread formation throughout the area is the Moenkopi of which the Sinbad limestone member (?) is the surface rock of much of the Teasdale anticline. The younger rocks from the Moenkopi to the Carmel crop out along the flanks of the upwarp.

The regional structural relationships of the Teasdale anticline to the San Rafael Swell and Circle Cliffs upwarps was discussed previously. As a further note, Gregory and Moore (1931, p. 120) mention a shallow sag along the axis between the high points of this area and the Circle Cliffs. The writer believes that instead of both upwarps having the same axis, they have separate axes and are en echelon. Baker (1935, p. 1481) also recognized this echelon arrangement.

Capitol Reef Monoclines

Capitol Reef is the name for the northern part of the Waterpocket Fold (fig. 25) which is one of the dominant monoclines of the Colorado Plateaus. This northwest-trending monocline may be traced from the Colorado River to Thousand Lake Mountain, a distance of nearly 80 miles (Gregory and Moore, 1931, p. 119). North of the Fremont River, the monocline bends sharply to trend west-northwest towards Thousand Lake Mountain. The Waterpocket Fold-Capitol Reef actually is not a monocline but is the eastern flank of the Teasdale anticline and the Circle Cliffs upwarp.

The Capitol Reef monocline marks the northeast and east boundaries of the Miners Mountain area. Along the east side of the area, the strata in the monocline have an average dip of 8° to 12°, but the amount of dip decreases to about 5° along the northeast side and increases southward along the fold.

Capitol Reef is a long, high escarpment with a very ragged, irregular top. The prominent cliff-forming rocks are the sandstones of the Wingate, Kayenta, and Navajo formations. Incompetent beds of the Chinle and Moenkopi formations on the west side and the Carmel formation on the east side form strike valleys. (See fig. 26.) Along the east side, the lower resistant beds of the Carmel form large cusp-shaped prominences.

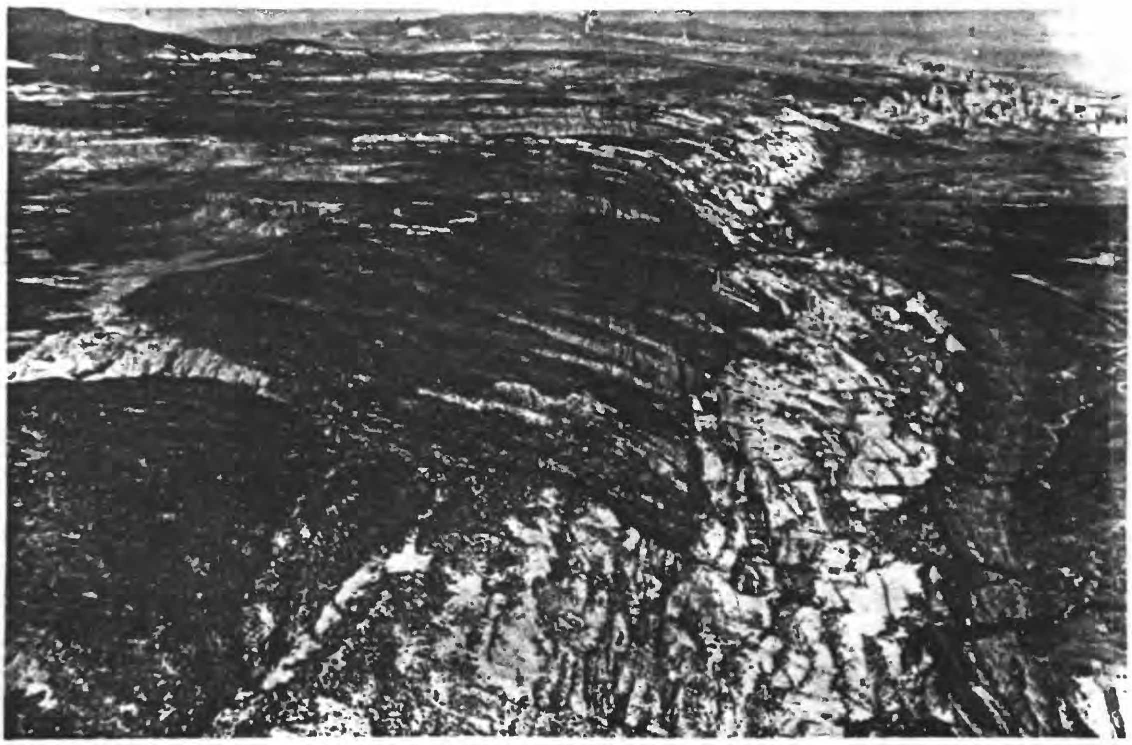


FIGURE 25 - Aerial view northwest along the Waterpocket Fold - Capitol Reef.

Shows the arched beds of the monocline. At left (center) is the Circle Cliffs; left (background) is Boulder Mountain; center (background) is Teasdale anticline; right (center) is Henry Mountains synclinal basin; center (on horizon) is Thousand Lake Mountain.

FIGURE 26 - View of the west side of part of the Capitol Reef cliffs.

M, Moenkopi formation; S, Shinarump conglomerate; C, Chinle formation; W, Wingate sandstone; K, Kayenta formation; N, Navajo sandstone.

Baker (1935, pp. 1501-1504) and Spieker (1946, p. 155) independently arrived at the same structural interpretation of the monoclines. They believe the monoclincal structures are a result of deep-seated compressive forces which produced steep overthrusts in the underlying basement. The thrusts failed to penetrate to the surface, but are represented there by strong asymmetrical upwarps. Baker (1935, pp. 1501-1502) does not believe the regional upwarps can be fully explained if they were formed by vertical movement over deep-seated normal faults.

FAULTS

Teasdale Fault

The Teasdale fault trends about N. 45° W. across the southwestern part of the Miners Mountain area. Of the approximately 6 miles of the fault that crosses the area, more than 3 miles are covered by Quaternary deposits. The fault may be traced for several miles in either direction outside of the area.

The Teasdale fault is actually a zone which consists of two dominant faults. They are typical normal, dip-slip faults with the southwest sides downthrown. At the few localities where the fault planes could be observed, they were vertical. Beds in and adjacent to the fault zone have dips ranging from 20° through vertical to 75° overturned. More faults are probably within the zone but they were impossible to detect because of similar lithology and lack of marker beds in the strata involved in the faulting. Also, for the same reasons, it was impossible to determine the thickness of beds cut out by the faulting. About 3 miles southeast of Grover, the Teasdale fault has a probable maximum displacement of more than 200 feet. Lower Moenkopi beds are at the same level as uppermost Navajo beds across the fault, although parts of all intervening formations are present in the fault zone. Because of the complexity, size, and amount of displacement, the fault zone is believed to be a definite reflection of disturbance of the basement.

Along the fault zone are several small transverse faults near which dips of the beds are steepened. The greatest number of transverse faults occur in the competent Shinarump conglomerate (pl. 1), but they do not intersect the margins of the fault zone. On all transverse faults the east sides are upthrown and dip-slip movement occurred along a vertical fault plane. Several small antithetic faults with only a few inches displacement were observed in the beds on the downthrown side of the northwest-trending fault zone. Both the antithetic and transverse faults probably represent minor readjustments of the beds within the fault zone.

Along the fault zone and irregular, discontinuous narrow strike ridges and valleys are in a topographic low, which is the boundary between Boulder Mountain on the southwest and Miners Mountain on the south southeast.

Other Faults

With the exception of the Teasdale fault, trends of the faults in the Miners Mountain area range from about N. 80° W. to about N. 65° E., but have no dominant structural trend; west or south sides are upthrown along most of the faults. The faults are all normal and had dip-slip movement. Throw of the faults range from a few feet to about 200 feet, but most average about 45 feet. Most of the fault planes are nearly vertical to vertical. The faults in the area are not extensive and can be traced only short distances.

The largest fault of this group is the Y-shaped fault that can be traced about 4 miles on the side of Miners Mountain. The stem of the Y trends about N. 30° W., and the two forks trend about N. and N. 70° W. A maximum throw of 175 feet occurs near the split and decreases along the fault in both directions. The east trending fork has a maximum throw of about 40 feet. The fault plane is vertical everywhere observed. Topographically, this fault is manifested in a partly eroded scarp along the mountain top. The fault is not believed to be a reflection of rupturing of basement rocks, but is a superficial readjustment of the rocks at the time of folding.

The second-largest fault of this group is the one which trends about N. 80° W. across the northern end of the area. This fault may be traced westward outside of the area, but the east end dies out in a group of strong west-trending joints. In the area, the maximum throw is about 170 feet but decreases to the east and west. The fault plane is vertical with the Shinarump faulted against the uppermost beds of the lower part of the Chinle formation. (See fig. 27.)

The zone of faults in sec. 7, T. 29 S., R. 6 E. can be traced for about one mile and has a maximum throw of about 50 feet. The zone is slightly sinuous, but trends nearly north. The fault planes dip from 80° E. to vertical.

The group of four nearly parallel faults in sec. 14, T. 30° S., R. 6 E. are believed to be related to the shallow transverse fold that crosses the Teasdale anticline and the rupturing represents minor adjustment within the transverse fold. These faults are vertical and maximum throw along any one of them is not more than 20 to 30 feet.

The remainder of the faults have small displacements and apparently have no significant relationship to the geologic structure of the Miners Mountain area.

FIGURE 27 - View of the west end of the large fault in the northern part of the area.

Shows vertical fault with left side downthrown. M, Moenkopi formation; S, Shinarump conglomerate; C, Chinle formation.

JOINTS

Within the Miners Mountain area, joints are prominent in the more competent beds, such as the Coconino, Shinarump, Wingate, and Navajo sandstones and the Sinbad limestone member (?) of the Moenkopi formation. Dips of joints range from 70° to vertical; the vertical dips are more prevalent. Insufficient joints were measured on Miners Mountain to establish a definite pattern, but those measured have random orientations and apparently do not reflect the structure of the double-plunging Teasdale anticline. A prominent set of joints along the crest of Capitol Reef trends approximately N. 20° W. In the northern part of the area, another set of prominent joints trends approximately N. 70° W. At the bend of the monoclinal fold, the joints do not curve but one set intersects the other set at a sharp angle. The joints on Capitol Reef are accentuated by erosion to form long, narrow gorges. Joints measured in the Shinarump trend approximately N. 20° W. Joints in the Coconino trend generally north.

AGES OF DEFORMATION

The rocks of the Colorado Plateaus probably were affected by several periods of deformation (Baker, 1935). In some regions there was deformation during Paleozoic time, but the Miners Mountain area is not believed to have been affected. The intervals represented by unconformities in Paleozoic and Mesozoic sediments probably were not associated with profound folding, although locally, slight angular discordances are between formations. Probably, relatively stable conditions prevailed in this area to the end of Cretaceous deposition.

The major orogenic movement is believed to be late Upper Cretaceous to early Tertiary. At that time, the strata were folded and then beveled by erosion prior to the deposition of sediments of early Tertiary age. Gregory and Moore (1931, pp. 116-122) describe the Eocene Wasatch formation as lying unconformably on truncated strata ranging in age from late Cretaceous to Jurassic (?) along the south sides of the Aquarius, Paunsaugunt, and Table Cliffs Plateaus and Boulder Mountain. Dutton (1880, pp. 280-281) described Eocene beds deposited over the beveled Waterpocket Fold near Thousand Lake Mountain. Spieker (1946, pp. 149-156) has shown that several periods of deformation occurred in central Utah, and suggests that possibly some folding on the Colorado Plateaus might have occurred in Upper Cretaceous time between middle and late Montana times. However, he strongly favors the possibility that most of the folding occurred during his pre-Flagstaff epoch which he dates as Paleocene. In most respects, the structure of the Miners Mountain area is analogous to the other major upwarps and folds of the Colorado Plateaus; therefore, the same age is inferred for this area.

Apparently, the major folding of the Plateaus was the result of one dominant orogenic movement. Hunt, et al (in press) stated that there is no evidence of more than one time of movement along the Waterpocket Fold and Capitol Reef. As support for their statement, Babenroth and Strahler (1945, pp. 148-149) believe the East Kaibab monocline of Utah and Arizona, which is similar to the Waterpocket Fold, also had only one major period of folding.

During the late Cretaceous-early Tertiary period of regional deformation, most of the smaller structural features also were formed (Baker, 1945, p. 105). Hunt, et al (in press) believe that most of the faulting and jointing also occurred during this time, although some later faulting did occur intermittently throughout Tertiary time.

Undoubtedly, the Miners Mountain area was affected by epeirogenic uplift during Tertiary time. Hunt, et al (in press) state that epeirogenic uplift occurred in the interval of late Eocene to early Miocene, at which time the entire Colorado Plateaus was elevated. They also suggest that the Plateaus probably was raised intermittently through Tertiary and perhaps much of Quaternary times.

BIBLIOGRAPHY

1. Babenroth, D. L., and Strahler, A. N., 1945, Geomorphology and structure of the East Kaibab monocline, Arizona and Utah: Geol. Soc. America Bull., vol. 56, pp. 107-150.

2. Baker, A. A., 1935, Geologic structure of southeastern Utah: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 1472-1507.

3. __________, 1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U. S. Geol. Survey Bull. 951.

4. Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 183.

5. Baker, A. A., and Reeside, J. B., Jr., 1929, Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1413-1448.

6. Crickmay, C. H., 1931, Jurassic history of North America - its bearing on the development of continental structure: Am. Philos. Soc. Proc., vol. 70, pp. 1-102.

7. Dake, C. L., 1919, Horizon of marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 636-646.

8. __________, 1920, The pre-Moenkopi unconformity of the Colorado Plateau: Jour. Geology, vol. 28, pp. 61-74.

9. Dutton, C. E., 1880, Geology of the High Plateaus of Utah: U. S. Geog. and Geol. Survey Rocky Mtn. Region.

10. Eardley, A. J., 1951, Structural Geology of North America; Harper and Brothers, pp. 393-409.

11. Fenneman, N. M., 1931, Physiography of Western United States: McGraw-Hill, pp. 274-325.

12. Gilbert, G. K., 1877, Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Survey of the Rocky Mtn. Region.

13. Gilliland, W. N., 1951, Geology of the Gunnison quadrangle, Utah: Univ. of Nebraska Studies, n. ser., no. 8, pp. 1-101.

14. Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806-C, pp. 69-130.

15. Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150-D, pp. 61-110.

16. Gould, L. M., 1939, Glacial geology of Boulder Mountain, Utah: Geol. Soc. America Bull., vol. 50, pp. 1371-1380.

17. Gregory, H. E., 1913, The Shinarump conglomerate: Am. Jour. Sci., 4th ser., vol. 35, pp. 424-438.

18. ___________, 1917, Geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93.

19. ___________, 1950, Geology and geography of the Zion Park region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 220.

20. ___________, 1951, The geology and geography of the Paunsaugunt region, Utah: U. S. Geol. Survey Prof. Paper 226.

21. Gregory, H. E., and Anderson, J. C., 1939, Geographic and geologic sketch of the Capitol Reef region, Utah: Geol. Soc. America Bull., vol. 50, pp. 1827-1850.

22. Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits region, Utah and Arizona: U. S. Geol. Survey Prof. Paper 164.

23. Howell, E. E., 1875, Report on the geology of Utah, Nevada, Arizona, and New Mexico examined in the years 1872 and 1873: in Wheeler, G. M., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, Geology.

24. Hunt, C. B., Averitt, Paul, and Miller, R. L., in press, Geology and geography of the Henry Mountains region, Utah: U. S. Geol. Survey Prof. Paper.

25. Imlay, R. W., 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., vol. 63, pp. 953-992.

26. Longwell, C. R., et al, 1923, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132-A, pp. 1-23.

27. McKee, E. D., 1933, Some stratigraphic principles illustrated by Paleozoic deposits of northern Arizona: Am. Jour. Sci., 5th ser., vol. 26, pp. 101-108.

28. ___________, 1934, The Coconino sandstone - its history and origin: Carnegie Inst. Washington Pub., no. 440, pp. 77-115.

29. ___________, 1938, Environment and history of the Toroweap and Kaibab formations of northern Arizona and southern Utah: Carnegie Inst. Washington Pub., no. 192.

30. ___________, 1940, Three types of cross-lamination in Paleozoic rocks of northern Arizona: Am. Jour. Sci., vol. 238, pp. 811-824.

31. ___________, 1945, Small-scale structures in the Coconino sandstone of northern Arizona: Jour. Geology, vol. 53, pp. 313-325.

32. ___________, 1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., vol. 62, pp. 481-506.

33. Noble, L. F., 1928, A section of the Kaibab limestone in Kaibab Gulch, Utah: U. S. Geol. Survey Prof. Paper 150-C, pp. 41-46.

34. Reiche, Parry, 1938, An analysis of cross-lamination - the Coconino sandstone: Jour. Geology, vol. 46, pp. 905-932.

35. Spieker, E. M., 1946, Late Mesozoic and Early Cenozoic history of central Utah: U. S. Geol. Survey Prof. Paper 205-D, pp. 117-161.

36. Stokes, M. L., 1950, Pediment concept applied to Shinarump and similar conglomerates: Geol. Soc. America Bull., vol. 62, pp. 953-992.

37. Thompson, A. H., 1875, Report of a trip to the mouth of the Dirty Devil River, in Powell, J. W.: Exploration of the Colorado River of the West.

38. Utah Geol. and Miner. Survey, 1949, The oil and gas possibilities of Utah, (symposium volume), pp. 284-287.

39. Waters, A. C., and Granger, H. C., 1953, Volcanic debris in uraniferous sandstones, and its possible bearing on the origin and precipitation of uranium: U. S. Geol. Survey Circular 244.