GEOLOGY OF BEAR CREEK CANYON

ARIZONA - NEW MEXICO

by

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Panoramic View of Bear Creek Canyon Area, Looking West

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures

Table

Plates

Frontispiece

INTRODUCTION

Location and Accessibility

Bear Creek Canyon lies on the northeast flank of the Chuska Mountains, on the boundary line between New Mexico and Arizona. The center of the area is approximately at the point where parallel 36° 30' intersects the state line, about 35 miles south of the Four Corners monument (see index map, Figure 1).

The area encompasses the adjoining portions of Townships 35, 36, and 37 North, Ranges 30 and 31 East, Arizona (Gila and Salt River Base and Meridian), and Townships 26 and 27 North, Ranges 20 and 21 West, New Mexico Base and Meridian. It is bounded on the west by the Chuska Mountains, on the south by the divide between Bear Creek and Sanostee Creek, and on the east by the west side of Beautiful Mountain. The total area under consideration is about fifty square miles.

Bear Creek Canyon may be reached by traveling south from Shiprock, New Mexico over U. S. Highway 666 to its junction with the graveled Red Rock Highway, a distance of about seven miles. From this point it is twenty-one miles to Red Rock Trading Post. The graded dirt road leading southward from the trading post to Lukachukai, nineteen miles distant, enters the Bear Creek Canyon area about five miles south of Red Rock Trading Post. An emergency landing strip, suitable for light planes, is located about one and one half miles north of Red Rock Trading Post.

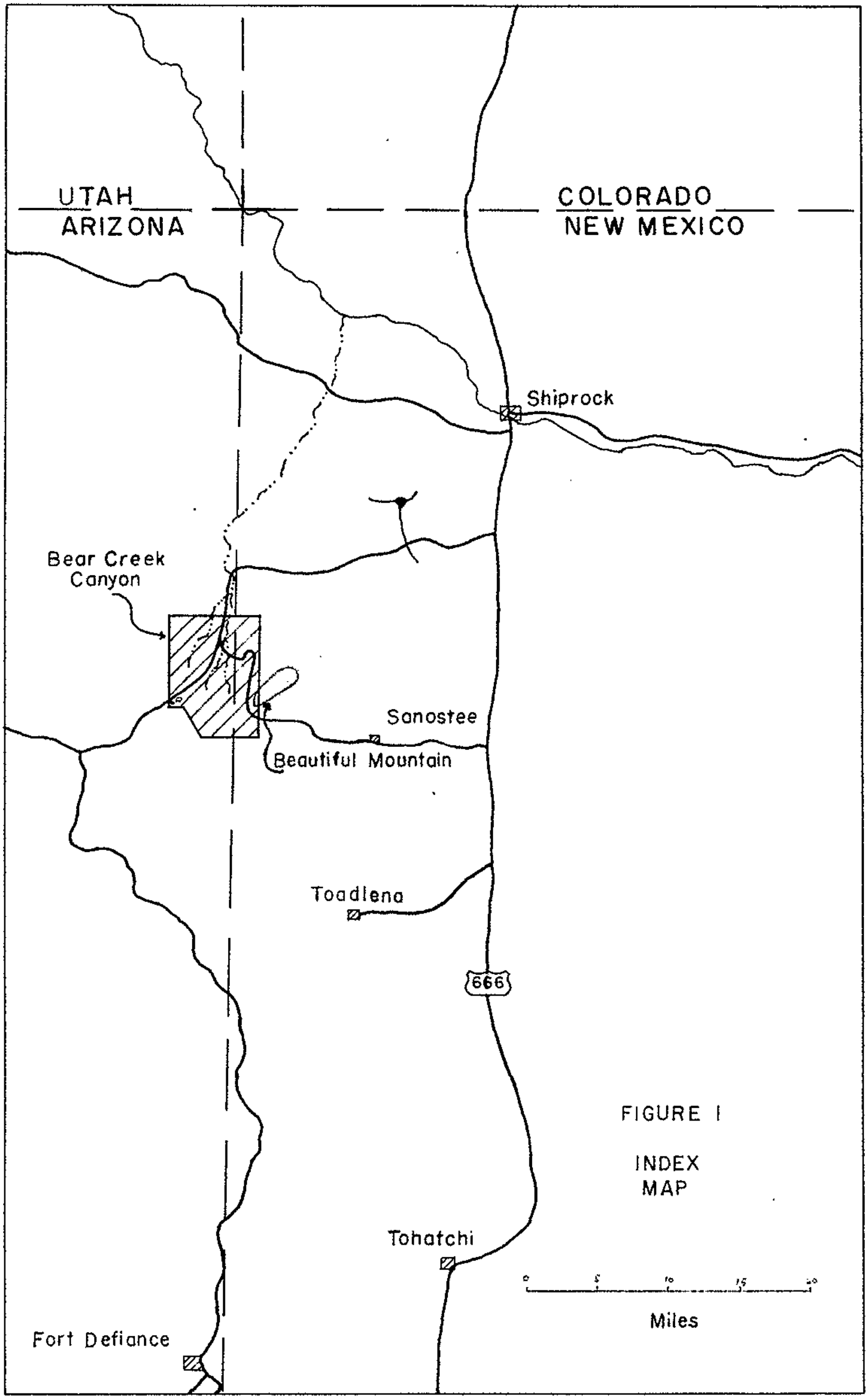

UTAH
ARIZONA
COLORADO
NEW MEXICO
Shiprock
Bear Creek Canyon
Sanostee
Beautiful Mountain
Toadlena
666
FIGURE I
INDEX MAP
Tohatchi
Miles
Fort Defiance

FIGURE I

The entire area lies within the bounds of the Navajo Indian Reservation. The land is administered by the Navajo Tribal Council, with headquarters at Window Rock, Arizona. This body must approve all claims, mineral and oil and gas leases, as well as all prospecting permits issued on Tribal lands.

Field Work

The field work on which this paper is based was done during the summer of 1954, while the author was engaged in field exploration for the Atomic Energy Commission. A total of twenty-one days was spent in the area. The purpose of the investigation was to map and describe the geology of Bear Creek Canyon.

Field mapping was done partly on aerial photographs at scales of 1:20,000 and 1:28,000, and partly on planimetric base maps at a scale of one inch to one-quarter mile obtained from the U. S. Forest Service office at Fort Defiance, Arizona.

Stratigraphic sections were measured with a Locke level, gross relationships noted, and samples collected for later inspection in the laboratory. Dips, strikes, and directional readings were made with a Brunton compass. A number of scattered elevations were determined by means of a pair of survey altimeters.

Photo Coverage

Aerial photographs on three scales are available for the area. Photographs at the scale of 1:28,000 were made for the U. S. Soil

Conservation Service in 1934; photographs at the scale of 1:20,000 were made for the U. S. Geological Survey in 1952; and low-level photography covering the southern half of Bear Creek Canyon only at the scale of 1:12,000 was flown for the U. S. Forest Service in 1950.

Fifteen-minute quadrangle mosaics which include Bear Creek Canyon are obtainable from the U. S. Soil Conservation Service. These mosaics were used in compiling the geologic map which accompanies this paper. A list of the photos and mosaics which cover the area is included in the appendix.

Previous Geologic Work

No known previous work has dealt directly with the geology of Bear Creek Canyon. Much has been written concerning the Colorado Plateau in general, and papers by Gregory (1916, 1917), Williams (1936), Imlay (1949), Wright and Becker (1951) and Craig et al (1951) deal with portions of the Plateau which include Bear Creek Canyon. However, none of these contain any direct reference to the area. Baker, Dane, and Reeside (1936) refer to a section measured "a few miles south of Red Rock Trading Post", which is presumably in Bear Creek Canyon.

A report of vertebrate fossils found some years ago in the Chuska sandstone near the western edge of the area by Dr. F. B. Loomis of Amherst College has not been verified. Repeated efforts to locate both the fossils and the locality have been unrewarding, and no reference to the specimens is to be found in the literature. (Harshbarger, personal communication)

GEOGRAPHY

Physiography and Topography

Bear Creek Canyon lies within the Navajo Section of the Colorado Plateau physiographic province as defined by Fenneman (1931). Within the Navajo Section, the Bear Creek Canyon area includes parts of the Chuska Mountains and Red Rock Valley provinces as defined by Gregory (1916).

The elevation of the lowest point, near the northern boundary of the area, is approximately 6,000 feet above sea level. The highest point is Roof Butte, a volcanic neck in the southwest corner of the mapped area, which rises to 9,575 feet above sea level. The maximum elevation along the divide near the southern border of the area is about 7,500 feet. The plateau-like top of Beautiful Mountain stands about 9,000 feet above sea level.

The overall drainage pattern is a combination of trellis and dendritic types, controlled in part by the geologic structure and in part by the differential resistance to weathering exhibited by the various rock units.

Topography of the southern half or Chuska Mountains portion of the area is typical of the dissected uplift or canyon lands of the Colorado Plateau province. Bear Creek and its tributaries have carved the land surface into steep-walled canyons and long, moderately steep back slopes which conform generally to the eastward dip of the beds. Numerous small erosional remnants stand up as buttes on the dip slopes.

Steep wooded slopes characterize the higher elevations, underlain on the eastern side of the area by the Mancos shale, and on the western and southern sides by the Chuska sandstone.

Bear Creek, the master stream, flows northward near the eastern edge of the area, following in general the strike of the beds. In its upper reaches it cuts into the upper portion of the Entrada sandstone, but throughout most of its course it flows through the lower members of the Morrison formation. The major tributaries trend either nearly parallel or nearly perpendicular to the main stream, depending on the nature of the underlying strata, local structure, and fracture pattern.

The northern portion of the area, within Gregory's Red Rock Valley province (1916), is a broad, gently northward sloping alluvial plain. Little bedrock crops out upon it excepting along the eastern edge where an escarpment of Morrison strata capped by Dakota sandstone is present. A few other low erosional remnants also stand above the general level of the plain.

Upon emerging from the canyons to the south, the main washes continue northward across the plain. These washes and their smaller tributaries dissect the plain so that travel by vehicle is somewhat restricted.

Throughout most of their courses Bear Creek and its tributaries are intermittent streams, flowing only in the spring of the year and during times of sudden storms. A few seeps and small springs are located in the upper reaches of these washes, generally at the base of the Chuska sandstone, and these may produce a small flow the year round. Along the road near the west side of the area these small flows are utilized by the Navajos for stock and domestic water supply.

Climate and Vegetation

The climate of the Colorado Plateau in general is semi-arid to arid. The predominant type of precipitation is the summer thunderstorm; gentle, soaking showers are unusual. During the winter, snow falls in the higher elevations and in some areas may account for most of the annual precipitation.

The major amount of precipitation is probably provided by the late summer thunderstorms, although several inches of snowfall can be expected throughout the area during the winter months. Weather Bureau records for the station at Shiprock, New Mexico, elevation, 4,945 feet, over the last thirty-year period show a normal precipitation of about eight inches per year, about half of which occurs during the months of July, August, September, and October. Precipitation in the Bear Creek Canyon area may be as much as twice this amount due to the higher elevation.

Prevailing winds are from the west, and, due to the shelter provided by the Chuska Mountains, high winds in the area are not common. The winds tend to be gusty both in the canyons and on the plain, and "dust devils" are frequently seen on the plain during the summer.

The local climate of any particular area is controlled more by its elevation above sea level than by its position in latitude and longitude.

Elevations in the area considered here range from about 6,000 to 9,000 feet above sea level, thus including parts of the Upper Sonoran (4,000-7,500 feet), Transition (7,000-8,500 feet), and Canadian (8,000-9,500 feet) zones as defined by Merriam. Most of the area is divided between the Upper Sonoran and Transition zones.

Vegetation characteristic of the several life zones is present. Sagebrush, Mormon tea, prickly pear cactus and several types of grasses are common in the Sonoran zone, and some scattered piñon and juniper trees and clumps of oak brush are also present. A few cottonwood trees grow in the bottoms of the canyons in the southern portion of the area where sufficient moisture exists. Plants of Astragalus and clumps of rice-grass were infrequently noted along the canyons.

Juniper, Ponderosa pine and oak brush are common in the Transition zone. Thistle and lupine were noted, as well as numerous unidentified types of small plants and grasses.

The Canadian zone is represented by juniper, pine and spruce in some quantity, and many smaller shrubs and weeds are present also.

Except for the herds of Navajo sheep which graze in the area, animal life is rather scarce. A few rabbits were seen, and one rattlesnake was killed in the area during the course of the field work.

Culture and Population

The few permanent residents of the area are Navajo Indians, whose main occupations are sheep raising and working their small farms.

The few small farms are located along the road near the base of the mountain in the southwestern and western portion of the area. Here a small supply of water is available the year round for stock and domestic supply. The spring runoff is caught in two "tanks" and is used for irrigation of the fields, by means of a series of ditches. Indian corn and watermelons are the main crops. Sheep are grazed throughout the area.

The Navajo women supplement the family income by weaving rugs or "blankets" as they are popularly called, which are traded or sold at the Red Rock store or the stores in Shiprock.

In the late summer and early fall the women and children may be seen gathering piñon nuts for sale to the trader. The usual price paid by the traders for these nuts is fifteen cents per pound.

A small amount of mining has been undertaken in the area. Several claims have been staked for uranium, and some small test pits have been dug. A few of these claims were worked intermittently during the summer of 1954 and then abandoned.

Cars and pickup trucks are commonly seen in the area, but the main transportation within the area mapped is still the horse and wagon, horseback, or on foot. Sheep trails and wagon tracks, some of which can be negotiated by jeep, run part way through the area in a southerly direction parallel to the main drainage. East-west roads and trails exist in the northern half of the area, but due to the rugged topography, only a few foot trails cross the southern portion.

REGIONAL GEOLOGY

Geologic Setting

The rocks of Bear Creek Canyon are predominantly sedimentary. A single lava flow caps Beautiful Mountain, and two small intrusive bodies lie in the southwest corner of the mapped area. Neither the extrusive nor the intrusives was studied in detail.

An eastward-dipping monocline trends generally northwest through the area, casting the pre-Tertiary strata into a broad fold which has been truncated by a post-Cretaceous erosion surface. Upon this surface lies the late Tertiary Chuska sandstone.

Strata belonging to the Triassic, Jurassic, Cretaceous, and Tertiary systems are present. The Triassic, Jurassic, and Tertiary rocks are dominantly non-marine and marginal-marine; only the Jurassic Carmel formation is considered to be truly marine in origin. The Cretaceous is represented mainly by the thick marine shales of the Mancos formation.

Among the non-marine sediments, material of fluvial and aeolian origin is predominant. Some lacustrine deposits are present, but these are less common than the deposits formed in channels, on flood plains, and accumulated by wind action.

A single thin limestone unit, the Todilto limestone of Jurassic age, is present in the section. This crops out in numerous places and is a valuable marker bed in correlating from place to place, and useful in separating some of the sandstone units having nearly identical lithologies.

As shown by Table I, the section in Bear Creek Canyon includes, in ascending order, the Chinle and Wingate formations of Triassic age, the Carmel, Entrada, Todilto, Summerville, Bluff, and Morrison formations of Jurassic age, and the Dakota and Mancos formations as well as the Gallup sandstone member of the Mesa Verde formation, all of Cretaceous age. The Tertiary period is represented by a single formation, the Chuska of Pliocene(?) age, and the igneous rocks which are all considered to be post-Chuska (Williams, 1936).

A major angular unconformity occurs between the Chuska and the underlying beds. This represents the time interval between the uplifting of the Defiance Monocline and the deposition of the Chuska sandstone, during which a considerable thickness of sediments of Triassic, Jurassic, and Cretaceous ages was removed by erosion.

The structure of the area is fairly simple. The eastward-facing Defiance Monocline trends northwesterly across it, and both the eastern and western limits of the structure are exhibited within the area mapped. Between these two limits the dips range from six to eighteen degrees, the steeper dips being toward the northern end of the area. No reversal of dip was found; the dips east and west of the fold are all northeasterly to east, but less than those of the fold itself.

The monocline extends both north and south from Bear Creek Canyon. To the south it forms the steep eastern escarpment of the Chuska Mountains, passing southwestward beneath the Chuska sandstone near Washington Pass and then continuing southward to the vicinity of Lupton, Arizona.

TABLE I

GENERALIZED STRATIGRAPHIC SECTION - BEAR CREEK CANYON

System	Series	Group and Formation		Thickness (feet)	Remarks
Tertiary	Pliocene(?)	Chuska sandstone		700	Sandstone, white, friable, with some silica cement. Some bentonite and sandy clay, particularly toward the base. Overlies the other formations unconformably
				Unconformity	
Cretaceous	Upper Cretaceous	Mesa Verde fm. Gallup ss. member		120	Sandstone, light yellow-orange, fine to medium-grained. Forms massive cliff
		Mancos shale		1,000	Shale and claystone, gray to dark gray. Upper and lower units separated by Gallup ss.
		Dakota sandstone		175	Sandstone, light yellow, conglomeratic; cemented by silica. Some thin beds of shale and thin coal seams.
				Unconformity	
Jurassic	Upper Jurassic	Morrison formation	Brushy Basin member	58-144	Bentonite, blue-gray, sandy. Intertongues with unit below.
			Westwater Canyon member	157	Sandstone, light yellow to light gray, friable. Some beds of sandy bentonite.
			Recapture member	511	Sandstone, light red to light gray, friable. Some mudstone. Unit contains U_3O_8
			Salt Wash member	75	Sandstone, light gray, calcareous with thin red and gray mudstone seams.
		San Rafael Group	Bluff sandstone	65	Sandstone, light pink to yellow, aeolian cross-bedding.
			Summerville formation	120	Sandstone, banded, light to dark red-orange. Contains barite zone.
			Todilto limestone	8	Limestone, dense, light gray, some white siltstone beds.
			Entrada sandstone	65	Sandstone, red-orange, fine-grained.
			Carmel formation	22	Sandstone, dark red, earthy, silty. Marine origin.
Triassic	Upper Triassic	Glen Canyon Group	Wingate formation	686	Divided into two units: upper unit, light red sandstone of aeolian origin; lower unit, darker red and silty sandstone of sub-aqueous origin. Some intertonguing of units.
		Chinle formation		275	Siltstones, red-brown, some limestone ledges and nodules

Northward the monocline is represented by a series of low cuestas which extend irregularly as far as the San Juan River.

Correlation with Other Areas

Strata of Triassic, Jurassic, and Cretaceous age are exposed over a wide area of the Colorado Plateau. The areal relations of a number of the units have been worked out fairly well, while others await further study to determine their detailed relationships. Gregory's study of the Navajo Country (1917) has provided the gross relationships upon which many later workers have based their studies.

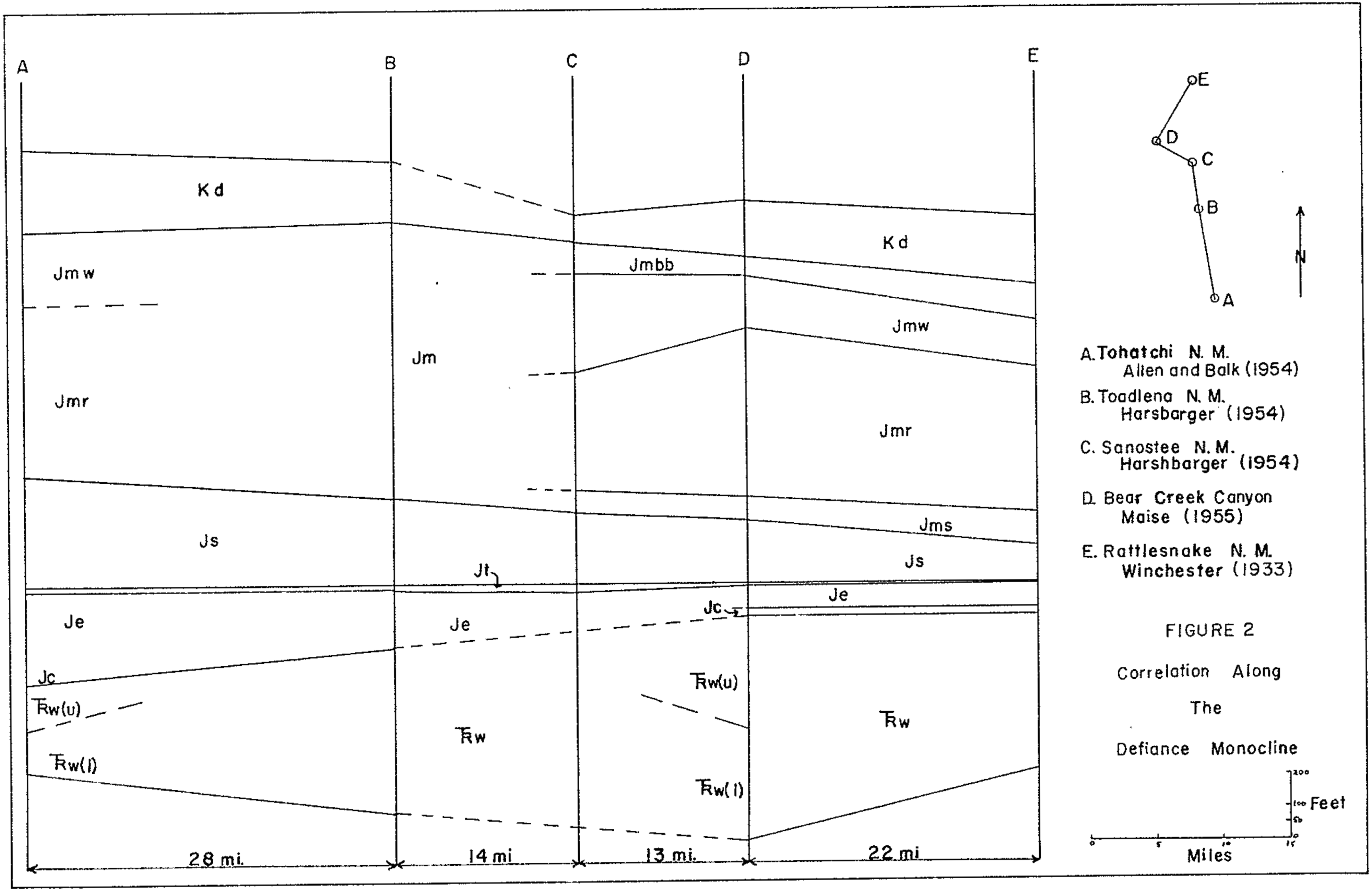
Detailed studies of several nearby areas have been published in recent years. The Fort Defiance-Tohatchi area has been reported on by Allen and Balk (1954), Harshbarger (1954) reports on the general geology of the Chuska Mountains, and a map by Beaumont (1954) presents the geology of the Beautiful Mountain Anticline. Wright and Becker (1951) discuss the correlation of the Jurassic formations along the Defiance Uplift, and papers by Wright (1954), Repenning (1954), Repenning and Irwin (1954), and Silver and Allen (1954) discuss the Tertiary strata of the Chuska Mountains and related areas.

Winchester (1933) presents a discussion of the geology of the Rattlesnake and Tocito domes, including the sample log of a well drilled to a depth of 6,771 feet on the Rattlesnake structure. Much detailed work has been done by geologists of the Atomic Energy Commission and the U. S. Geological Survey in the Four Corners area in connection with the search for uranium deposits.

Correlation of the sections of some of these nearby localities with that measured in Bear Creek Canyon is presented in Figure 2. The interpretation of the Rattlesnake well log is by the present author.

In general, the rock units of Bear Creek Canyon are lithologically similar to those commonly found throughout the eastern portion of the Navajo Reservation. By reference to Plate II it will be noted that the nomenclature for the Mesozoic rocks of the southern portion of the Colorado Plateau is rather confused. This is due to the complex relationships brought about by dominantly continental sedimentation such as intertonguing, restricted depositional areas, mixed sub-aqueous and sub-aerial deposition, general lack of fossils, erosional unconformities, and dissection of the entire region making it impossible to walk out many of the beds from place to place.

The nomenclature used in this paper is essentially that used by Harshbarger (1954) for the eastern flank of the Chuska Mountains, modified somewhat to conform with the usage of the Atomic Energy Commission geologists currently working in nearby areas.



A
B
C
D
E
Kd
Jmw
Jm
Jmbb
Jmr
Jms
Js
Jt
Je
Jc
Ŧ̄Rw(u)
Ŧ̄Rw
Ŧ̄Rw(l)
28 mi.
14 mi
13 mi.
22 mi
N
A. Tohatchi N. M.
Allen and Balk (1954)
B. Toadlena N. M.
Harsbarger (1954)
C. Sanostee N. M.
Harshbarger (1954)
D. Bear Creek Canyon
Maise (1955)
E. Rattlesnake N. M.
Winchester (1933)
FIGURE 2
Correlation Along
The
Defiance Monocline
Feet
Miles

FIGURE 2

STRATIGRAPHY

Triassic System

Chinle formation

The Chinle formation of Triassic age is the lowest formation present in the Bear Creek Canyon area. An incomplete section of the formation, 259 feet thick, was measured near the western edge of the area mapped.

The Chinle consists predominantly of a series of slightly calcareous siltstones, alternating with a few thin ($<$0.5 feet) bands of thin-bedded calcareous and non-calcareous fissile shales. The siltstones commonly contain some subangular to subrounded grains of fine iron-stained quartz sand, and some of the siltstones are bentonitic. The dominant color of the siltstone units is light to dark red-brown, although some red-gray and gray zones were noted. The shales are mainly red-brown, although near the top of the formation a single bed of purple shale, 0.5 feet thick, was found.

Numerous small gray spots, 1 cm. or less in diameter, occur throughout the siltstones. Origin of these spots is not known, but they may represent local reduction or "bleaching" of the iron coloration of the sediment by small grains of pyrite dissolving in groundwater to form sulphuric acid.

Some zones of individual limestone nodules were noted, and several more or less continuous ledges of nodular limestone up to eighteen inches thick occur interbedded with the siltstones. These ledges are visible in the photograph, Figure 3. They probably represent fresh-water lime deposits formed in shallow, ephemeral lakes which occurred from time to time on the Chinle flood plains.

The Chinle formation outcrops as a moderately steep, hard slope broken by thin ledges and typically covered by a thin veneer of loose, weathered material, making climbing somewhat hazardous.

The portion of the Chinle here described is correlated with the Chinle "B" of Gregory (1917). The lithology as measured seems quite similar to that described by Gregory, and the appearance of the exposures corresponds closely to that pictured by him in Plate XA, page 47 (1917). This correlation is also indicated by the stratigraphic position, directly below the Wingate.

No fossils were found in the formation, with the exception of a few small pieces of petrified wood found loose on the slopes. All are silicified; the wood is of the yellow and black variety and some pieces contain small cavities partially filled with quartz crystals.

The Chinle formation is generally considered to have been deposited on a series of flood plains, in part fluviatile and in part lacustrine, and in a climate which was tropical or sub-tropical (McKee, 1951). The Bear Creek Canyon exposures lead the present author to concur with this view, particularly with respect to the flood plain origin.

Wingate sandstone

The Wingate sandstone as exposed in Bear Creek Canyon is made up of two units, an upper sandy unit and a lower silty unit. A total of 686 feet of Wingate was measured, of which 341.5 feet were assigned to the lower unit, and 344.5 feet were assigned to the upper unit.

The lower Wingate as recognized here consists of a number of ledges of very fine-grained to silty, red to dark red quartz sandstone. The red color is due to a stain of iron oxide on the individual grains. A few accessories such as garnet and mica are present in minor amounts. The ledges range in thickness from a few feet up to about twenty-five feet, and are separated from each other by somewhat thinner zones of red siltstone, or by bedding planes. Erosion along the siltstone zones and bedding planes has caused the sand units to weather out in a series of large steps up the sides of some of the mesas.

The upper Wingate is composed of several massive, cross-bedded sand units separated by thin zones of silty sandstone. The massive sands are light tan to light red and the silty units have a darker red color. Large scale tangential crossbedding noted in these sands indicates an aeolian origin, in the manner of dune sands. Numerous angular unconformities exist between superimposed sets of crossbeds.

The material composing the upper Wingate is almost entirely quartz sand with a few accessories similar to those found in the lower unit. The sand grains are individually coated with an iron oxide stain which imparts the red color to the rock units. The grains are loosely cemented together by calcite.

Some intertonguing of the upper and lower units is evident in the outcrops; therefore, the thicknesses assigned each unit are somewhat arbitrary. The contact was chosen at the point at which the sandy units appear to become dominant over the silty units. If continuous outcrops were available over a larger area, the intertonguing relationship would probably be more pronounced. Several of the thicker sand units near the top of the lower unit may in reality be tongues of the upper unit. One such relationship is illustrated in the photograph, Figure 4.

Deposits of this nature probably reflect an environment which alternated between shallow water and aeolian, becoming more aeolian toward the end of Wingate time. Several directional readings taken on sets of crossbeds in the upper portion of the formation indicate that the material was deposited by winds from the west and southwest, and presumably the source of the material was also in that direction.

At the top of the Wingate, just below the overlying Carmel formation, is a two-foot thick zone of hard, fine-grained, light gray, structureless sandstone. This may represent a reworking of the uppermost Wingate sands by the encroaching sea in which the Carmel was deposited.

The division and age assignment of the Wingate used here corresponds to that used by Harshbarger (1954) in the area immediately to the south, along the east front of the Chuska Mountains.

The Wingate sandstone is the only representative of the Glen Canyon Group present in Bear Creek Canyon. However, the general section for the Four Corners area shows two units, the Kayenta formation and the Navajo sandstone, overlying the Wingate and making up the remainder of the Glen Canyon Group.

The explanation for this omission of beds is to be found in a paper by Wright and Becker (1951). They report that the Kayenta and Navajo strata, as well as the Wingate sandstone, are truncated by the unconformity at the base of the Carmel formation. The attitude of the beds is such that the Kayenta and Navajo are cut out in the vicinity of Cove Mesa, about fifteen miles northwest of Bear Creek Canyon. In addition, they found that the Kayenta formation thins somewhat by interfingering with the underlying Wingate sandstone as well as by truncation. Thus the Glen Canyon Group at Bear Creek Canyon consists only of the Wingate, underlying the unconformity at the base of the Carmel formation.

Jurassic System

Carmel formation

The Carmel formation crops out immediately above the Wingate sandstone, and is the lowest of the beds here assigned to the Jurassic San Rafael Group.

Figure 3. Typical Chinle slope showing the limestone ledges. Most of the outcrop is composed of siltstones.

Figure 4. Chinle (Trc), lower Wingate (Trw(l)), and upper Wingate (Trw(u). Note intertonguing of lower and upper Wingate.

The Carmel is about twenty-two feet thick and composed of a dark red sandy siltstone of marine origin. It is easily recognized on outcrop by its dark red, earthy appearance. The rock is fairly well consolidated, some beds more than others, but as a whole it weathers more rapidly than the underlying Wingate and forms a retreating escarpment above the Wingate cliff. The formation is characterized by thin, parallel bedding.

Since Bear Creek Canyon lies near the eastern edge of the Carmel (Lower Callovian) basin as depicted by Imlay (1949), the Carmel of the area may represent shallow-water deposition on a shelf or coastal plain. No fossils were found in the Carmel, but it has been correlated with marine deposits to the north and west (Imlay, 1949) and so is considered to be marine in origin.

Source of the sediment for the Carmel deposits is not known. Smith (1951) suggests that the seaway was restricted by movements on the southern and western Navajo Highland and by the partial rejuvenation of the Uncompahgre Uplift to the north and east, but intimates that neither of these elements was able to supply sediment at that time. The fineness of the material suggests that the major source was probably quite distant. Some rounded quartz grains similar to those of the Wingate are present, suggesting that there may have been low, local prominances of that formation which were eroded as the Carmel was laid down.

Entrada sandstone

In Bear Creek Canyon the Entrada formation is 65 feet thick, and represents the sandy facies of that formation as described by Imlay (1949). It overlies the Carmel formation with apparent conformity throughout the area.

The Entrada sandstone is composed of fine-grained, fairly well-sorted quartz sand. A few grains of garnet and chert are present as accessories. The sand is red-orange, due to a stain of iron oxide on the individual grains, which are loosely cemented by calcite. The grains are generally sub-rounded, with some few individuals well rounded and frosted.

The Entrada is somewhat crossbedded, but generally the bedding is thin and parallel. This association may represent reworking of an originally aeolian sand by oscillatory bodies of shallow water. No fossils were found in the Entrada, and the mineralogy does not indicate whether the waters were fresh or saline.

The sandy facies of the Entrada grades westward into a red, earthy facies which contains beds of salt and gypsum, indicating the presence of a body or bodies of saline water (Imlay, 1949). Fluctuations in the water level could provide opportunity for reworking the Entrada sands of Bear Creek Canyon. The intervening land surface was probably one of low relief, making possible widespread fluctuations of the strandline with only relatively small changes in the level of the water.

The Entrada of Bear Creek Canyon may then be interpreted as being a continental or littoral deposit, probably marginal to a large body of saline water similar to the Great Salt Lake of today. The main mode of deposition of the sand was by wind action with subsequent reworking by water destroying most of the dune structures.

The source area of the sand which makes up the Entrada has been postulated by Smith (1951) to be the uplifted older sediments of the Navajo Highland to the southwest. Smith considers that the Navajo Highland rose and began to contribute sediments to the Jurassic Basin at this time and continued as a strong source of material throughout the remainder of the Jurassic.

Todilto limestone

The Todilto limestone conformably overlies the Entrada sandstone throughout Bear Creek Canyon. Where measured, the total thickness of the Todilto is eight feet, and this is thought to represent the maximum thickness of the formation in the area.

The Todilto is composed of several layers of hard, dense, light gray limestone separated by thin beds of white, limey siltstone. The limestone contains some sand grains, and small quartz pebbles are occasionally found in it. Locally the formation contains masses of coarse-grained, white, recrystallized limestone somewhat less than one foot in maximum diameter. Fractures in the dense light gray limestone are commonly filled with hard, white limestone probably precipitated from ground water.

The thin siltstone beds which occur between the layers of limestone weather easily, leaving a series of separate and distinct limestone ledges at the outcrops as illustrated in Figure 5. Some of the limestone layers were found to be ripple marked.

Numerous small folds were found in the Todilto; these folds range in amplitude from a few inches to three feet, from a few feet to forty feet in length, and up to six or eight feet across. There does not appear to be any particular frequency to the occurrence of these folds. However, none were found at outcrops which dipped less than about six degrees. Axial plunge of the folds corresponds in general with the direction of dip of the beds.

Many such folds have been found to contain uranium minerals at Grants, New Mexico, and small amounts of uranium have been found in similar folds in the Todilto a few miles south of Bear Creek Canyon. However, no uranium minerals were found in the folds examined by the author in Bear Creek Canyon.

Due to its resistance to erosion, its continuity, and its color and lithologic differences from the sediments above and below, the Todilto makes an excellent marker bed throughout the area.

The Todilto limestone is generally considered to be of fresh water lacustrine or shallow marine origin. No fossils have been found in it by the author, but dinosaur tracks were found in it at two locations by Gregory (1917), and non-marine ostracodes have

Figure 5. Outcrop of Todilto limestone showing uneven limestone beds separated by beds of siltstone. Entrada sandstone below.

Figure 6. Aerial view of Bear Creek Canyon, looking south. Beautiful Mountain on the left and Defiance Monocline on the right.

been reported from the Todilto by Swain (1946). Correlation of the occurrence at Bear Creek Canyon with the type section at Todilto Park, New Mexico, 40 miles due south of Bear Creek Canyon, is made on the basis of lithologic similarity and stratigraphic position.

Summerville formation

The Summerville formation is consistent in thickness throughout Bear Creek Canyon, and where measured it has a thickness of 120 feet. In this area the formation is primarily fine to very fine sandstone containing a minor amount of silt. It has the typical color banding characteristic of the formation elsewhere, bands of dark red-orange alternate with lighter red-orange or buff colored sandstone. The upper 90 feet of the formation form a sheer cliff in which some of the color bands weather irregularly into slight prominence. The lower 30 feet of the formation form a steeply rounded slope, the upper part of which carries a band of light orange sandstone containing numerous nodules of crystalline barite.

The barite zone is about eight feet thick and is found wherever the lower part of the Summerville crops out. The barite itself occurs in concretionary masses up to four inches in diameter. The nodules are more resistant to weathering than the enclosing sandstone, and frequently stand out in relief on the sandstone slope. Where the nodules have broken loose and been concentrated by the action of running water several pounds may be collected in a few minutes. Small fragments of the barite are found in the alluvium below its outcrop source.

The barite nodules are considered to have grown in place, possibly from connate waters high in barium, or possibly from barium-rich ground water moving through the sediment after deposition.

The barite zone of the Summerville extends southward, and is found on some of the central mesas in the Sanostee Wash drainage. Here the barite occurs in larger masses, up to a foot across and several pounds in weight.

The Summerville of Bear Creek Canyon belongs to the "sandy facies" of the formation as set up by Wright and Becker (1951). Its origin is probably that of a predominantly aeolian beach sand which accumulated along the margin of a series of playa lakes, and which was occasionally inundated by the lake waters.

No fossils were found in the formation. Correlation is based on lithologic similarity and stratigraphic position to units referred to the Summerville in nearby areas. No direct correlation of any of the units referred to as Summerville in the Four Corners area of New Mexico and Arizona has been established with the type section of the Summerville in the San Rafael Swell, due to erosion and lack of fossils.

Bluff sandstone

A zone of light pink to yellow sandstone, about 65 feet thick, conformably overlying the Summerville formation but lacking the banding of that formation, is here assigned to the Bluff sandstone.

The Bluff is a fairly massive sandstone containing some large-scale tangential cross-bedding. It is fine-grained and somewhat friable. In most places within the Bear Creek Canyon area it is light red to pink in color, but along the west branch of Bear Creek the entire unit abruptly becomes bright yellow for a distance of about 3,000 feet along the outcrop. The explanation for this color change is not known, but may be due to differential movement of ground water through the unit. The color in all cases is due to iron staining of the individual sand grains. The cross-bedding in the unit suggests an aeolian origin for the formation.

The Bluff sandstone does not exhibit the fluviatile sedimentary characteristics which are typical of the lower Morrison formation; therefore,it is considered to be pre-Morrison in age. Since the base of the Morrison formation is generally considered to be the top of the San Rafael Group, the Bluff becomes the uppermost representative of the San Rafael Group in Bear Creek Canyon.

An alternate correlation is that this unit may represent a tongue of the Wanakah formation of southern Colorado as interpreted by Read et al (1949), but no attempt was made to establish a correlation in that direction. Beaumont (1954) uses the term Wanakah to include sandstone units found in the Sanostee Day School water well which are probably equivalent to both the Summerville and Bluff units as used in this paper, and lists the Todilto as a basal member of the Wanakah.

Morrison formation

The Morrison formation consists of four members in the Four Corners area, all of which are recognized in Bear Creek Canyon. The total thickness of the formation at this point is 887 feet. The individual members are described separately as follows:

Salt Wash sandstone member

The Salt Wash sandstone member of the Morrison formation overlies the Bluff sandstone unconformably. Some channeling of the Salt Wash into the Bluff was noted. The contact between the Salt Wash and the Bluff represents a change from dominantly marginal-aqueous and aeolian deposits to deposits laid down by streams on a broad, featureless plain.

The Salt Wash sandstone is about 75 feet thick in Bear Creek Canyon. It is composed of alternating beds of calcareous sandstone and red or gray siltstone or mudstone. The units are broadly lenticular and show the effects of scour and fill type of deposition.

The sandstone is fine to medium-grained, generally light gray to white in color;but some of the ledges are light pink, the individual grains being stained with iron oxide. Patches of yellow were occasionally noted, also due to iron staining of the grains. Some carbonaceous trash is present in the sandstone units. No large pieces of woody remains were found; the material consisted entirely of macerated plant matter. The cementing material is calcite.

The majority of the fine material interbedded with the sandstones is classified as mudstone. It occurs both as distinct beds and as chunks or galls within the sandstones, and may be red-brown, light gray-green, or gray in color.

In other areas of the Colorado Plateau the Salt Wash is the main source of uranium ore, but no uranium mineralization was found in the Salt Wash of Bear Creek Canyon. However, numerous outcrops exist in the central portion of the area, and these should be prospected more closely before the area is condemned as worthless. A few occurrences of rice grass and Astragalus were noted in crossing areas underlain by Salt Wash. The presence of these plants indicates minute amounts of selenium in the soil, and the uranium-vanadium deposits of the Colorado Plateau are known to contain traces of this element. These plants have been used in other areas to locate mineralization in commercial quantities.

<u>Recapture member</u>

The Recapture member in Bear Creek Canyon makes up the major portion of the Morrison formation present. It is 511 feet thick where measured and forms a series of steep cliffs topped by a steep, easily weathered slope.

The lower, cliff-forming member is 130 feet thick and consists of thin-bedded to massive, light tan to dark red sandstone. The sandstone is fine-grained, and the color is due to iron stain on the individual grains. A few thin friable sandstone units and dark red mudstones form short slopes in this portion of the member. The cementing agent is calcite.

The upper portion of the Recapture member is 381 feet thick and consists mainly of soft, friable sandstone units with some intercalated beds of siltstone, mudstone, and bentonite. Some of the sandstone contains a silty matrix.

The sandstones are fine to medium in grain size and are fairly well sorted. Red, gray, yellow, and tan, in the lighter shades, are the predominant colors. Crossbedding, both fluviatile and aeolian, occurs on a wide variety of scales. Most of the units are broadly lenticular in form.

The siltstone and mudstone units make up a minor portion of the upper Recapture. They are commonly red to red-brown with some gray bentonite streaks.

Several horizons in the upper Recapture contain limestone nodules imbedded in red-purple to green silty sandstone or sandy siltstone, which may represent ancient buried soil profiles. The lime nodules are coarsely crystalline and up to one foot in longest dimension, and appear to have grown in place. They are roughly spheroidal in shape and may have formed from a zone of caliche in an ancient soil horizon.

Uranium mineralization occurs in places near the base of the upper Recapture, in association with gray sandstone and red and gray mudstone or mudstone galls. These occurrences are discussed more fully under the heading of Economic Geology.

Westwater Canyon member

The Westwater Canyon member of the Morrison formation directly overlies the Recapture. The contact between the two is difficult to place due to their similarity. Possibly both members should be considered as a single sandstone facies, but the occurrence of uranium deposits in the lower member makes the distinction useful.

The Westwater Canyon member as recognized here is characterized by somewhat coarser sand and thicker units than the Recapture, as well as by the predominant yellow color. The Westwater contains distinct beds of impure bentonite while the Recapture has none, and limestone nodules such as occur in the Recapture were not found in the Westwater. On the basis of these criteria, 157 feet of the Morrison interval is here assigned to the Westwater Canyon member.

The contact between the two members is picked at the base of a fourteen-foot unit of light yellow-gray, friable sandstone which overlies a five-foot thick red and green-gray silty sandstone containing limestone nodules. The contact appears to be conformable; however, if the lower bed represents the remains of a soil profile, then it is probable that an erosion surface exists between the two units.

The manner of origin of the Westwater Canyon member is in doubt. It is only slightly channeled, and no great amount of tangential cross-bedding is exhibited in the exposures. It is probably due primarily to aeolian deposition, with intermittent reworking by streams, plus some lacustrine phases represented by the bentonitic claystone units.

The coarseness of the sand suggests a nearby source. Craig et al (1951) recognize a thick (plus 300 feet) section of conglomeratic sandstone in the upper Morrison interval southward near Tohatchi, New Mexico, so possibly the source was in this direction. No conglomerate lenses were found in the section measured by the author.

Brushy Basin member

The Brushy Basin member of the Morrison formation overlies the Westwater Canyon member with apparent conformity in some parts of Bear Creek Canyon, but in overall aspect the two members have been found to intertongue and replace each other to some extent. Along the east rim of Bear Creek Canyon the relationship is such that about 20 feet of sands assignable to the Westwater Canyon member overlie a 37-foot unit of bentonite assigned to the Brushy Basin member. For purposes of measurement these sands were included with the Brushy Basin.

The Brushy Basin member is made up primarily of somewhat sandy bentonite, with some bentonitic sandstone and a few highly silicified layers included in the bentonite beds. The thickness of the member is not constant over the area. At the rim of Bear Creek Canyon, 58 feet of sandstone and bentonite are assigned to this unit, although the sands are considered to be tongues of the underlying Westwater Canyon member. In a section measured 75 yards due east of the hairpin turn on the road along the west side of Beautiful Mountain, 144 feet of bentonite are assigned to the Brushy Basin member, and no intertonguing relations are recognized. This difference in thickness is due to an erosional unconformity between the Brushy Basin and the overlying Dakota sandstone of Cretaceous age.

The bentonites are dominantly gray and green-gray, although some have a bluish cast while other beds are pink to red or light purple. Fine to medium-sized quartz grains are common in the bentonite beds. Layers of hard, silicified material occur within the beds of bentonite. These layers are very fine-grained and appear to be silicified bentonite. They are commonly up to eight inches thick.

Judging from the predominance of bentonite in the member, the greater amount of material was supplied by vulcanism. The area of vulcanism is not known, but it may have been in the Sierra Nevada ranges which were being actively uplifted at the time of Brushy Basin deposition, and which orogenic movement was accompanied by much volcanic activity.

If this be the case, probably the bentonites of Bear Creek Canyon were mainly wind-transported and deposited in shallow waters or on a flood plain. Possibly some of the material was moved in by streams, to account for the admixing of sand grains in the finer material.

Cretaceous System

All Cretaceous strata in Bear Creek Canyon are thought to be upper Cretaceous. No lower Cretaceous beds are recognized.

Dakota formation

The Dakota formation is separated from the underlying Morrison formation by an erosional unconformity. The Dakota of the Colorado Plateau is generally considered to be upper Cretaceous in age, so the unconformity represents all of lower Cretaceous time. During this time it is likely that much material was removed from the top of the Morrison formation, as well as any lower Cretaceous material which may have been deposited.

No complete section of the Dakota formation was measured in the area. Partial sections were measured at three locations. On the basis of these sections, the Dakota is known to be composed of fine to medium quartz sand, firmly cemented by silica. It is divided into a number of units, some of which appear lenticular, and contain pebbles of quartz and chert. In some places the rock is a conglomerate. Fragments of red and green chert are common accessories.

Thin beds of clay, shale, and impure coal are found interstratified with the thicker sandstone units. The shales are black, carbonaceous, and siliceous. The coal is similar but with more organic matter. Both the shale and coal beds are quite fissile.

The lower 25 to 50 feet of the Dakota appear coarser and more siliceous than the upper portions, and it is these lower units which form the capping rim along the eastern edge of Bear Creek Canyon. The total thickness of the Dakota is estimated to be 175 feet.

Mancos shale

Two divisions of the Mancos shale are recognized in the area, the lower Mancos and the upper Mancos. These are separated by a tongue of sandstone formerly known as the Tocito sand lentil of the Mancos, but now referred to as the Gallup sandstone member of the Mesa Verde formation.

The Mancos shale was not measured, but the part below the Gallup sandstone is estimated to be 700 feet thick. This lower unit is composed of gray to dark gray fissile shale and claystone. No fossils were collected from it, although a few specimens of *Gryphea* were noted on the slopes.

Only a small outcrop of material assigned to the upper Mancos lies within the mapped area, and this was not inspected due to difficulty in reaching it. This portion of the formation has been largely cut out by the Chuska sandstone of Tertiary age which rests unconformably across it. According to Harshbarger (1954), "The upper part is grayish-brown sandy fissile claystone and siltstone, having an average thickness of 950 feet." No more than two or three hundred feet of the unit occurs in Bear Creek Canyon.

The Mancos is generally thought to represent deposits of the late Cretaceous sea which covered most of the Western Interior area.

Since completion of the field work, Jones (personal communication) has called the following occurrence to the attention of the writer. Jones, of the University of Utah, reports collecting a sample of cream-colored marl from an outcrop along the road near the southwest tip of Beautiful Mountain, which he found to contain a foraminiferal faunule of "definite upper Cretaceous age". He identified specimens of Ramulina, Haplophragmoides glabra, Pseudotextularia varians, and Gumbelitria cretacea, as well as several other genera of foraminifera, some ostracodes, and some fish teeth. Jones also notes that the fauna is "as a whole somewhat dwarfed".

The zone from which these were collected lies "below the Tertiary sandstone and marly bentonites".

The relationship of this outcrop to the beds lithologically considered to be Chuska (Tertiary) by the present writer, or those recently assigned to the new Deza formation (pre-Chuska Tertiary) by Wright (1954) is not known. On the basis of the lithology as described by Jones, the outcrop is tentatively considered to be in the strata included in the basal portion of the Chuska by the present author and also in the beds assigned by Wright to the Deza formation. If this is true, a problem is raised which needs to be given careful consideration in the field and in the laboratory.

Mesa Verde formation

The sole representative of the Mesa Verde formation in the Bear Creek Canyon area is a thin sandstone unit assigned by Pike (1947) to the Gallup sandstone member of the Mesa Verde. This unit had previously been known as the Tocito sandstone lentil of the Mancos shale, named for its outcroppings near the Tocito store, about fifteen miles southeast of Bear Creek Canyon.

Where measured, along the south side of Beautiful Mountain, this unit is about 120 feet thick and composed of fine to medium light yellow-orange sandstone. It is thin-bedded and forms a massive-appearing vertical cliff. It is moderately well cemented by calcite.

The unit occurs on the west side of Beautiful Mountain, where it crops out for a short distance before it is cut off by the unconformably overlying Chuska sandstone.

The Gallup sandstone represents a littoral deposit laid down by a regressive seaway and is a part of the general pattern of transgression and regression exhibited by the Mancos-Mesa Verde sequence of deposits throughout this portion of the Colorado Plateau (Silver, 1951).

Tertiary System

Chuska sandstone

The Chuska sandstone occurs in the higher elevations throughout the area. It lies on a surface of erosional unconformity which truncates all the older rocks of the area. No section was measured through the Chuska, but it is estimated to be about 800-900 feet thick.

The Chuska is a fine to medium-grained, well sorted white sandstone. It is commonly friable, although portions of it are well cemented by silica. It is generally massive and exhibits some large scale cross-bedding indicating an aeolian origin. Its lower portion contains thin bands of light tan bentonite and beds of sandy clays possibly correlative to the Deza formation of Wright (1954).

Some parts of the formation are sufficiently well cemented to form resistant caps on the higher elevations and to break out as shingle on the moderately steep slopes. Source of the silica cement may be from the volcanics which intrude the sandstone along the ridge of the Chuska Mountains.

The exact age of the Chuska sandstone is in doubt. No fossils were found in it by the author, and with the exception of a few undiagnostic ostracodes found near its base (Harshbarger, personal communication), no authenticated fossil localities are known to him.

A report of vertebrate fossils found in the Chuska near the western edge of the mapped area by the late Dr. F. B. Loomis of Amherst College a number of years ago has not been verified. Repeated investigations by various personnel have failed to locate either the fossils or the locality, and there is no known reference to the material in the literature.

The Chuska sandstone has been correlated with the Bidahochi lake beds (Wright, 1954) which have been determined to be Pliocene in age on the basis of vertebrate fossils found in them. Although there is no direct connection between the two formations due to erosion, they appear to rest on remnants of the same erosion surface, and they have somewhat similar lithologies. The age of the Chuska is therefore presently considered to be Pliocene(?).

IGNEOUS ROCKS

Intrusive rocks

Two small intrusive igneous masses occur near the southwest corner of the area. The easternmost one, Roof Butte, is the site of a Forest Service lookout station. The other is unnamed. These two necks stand up about 800 feet above the general level of the Chuska Mountains and form prominent landmarks.

Neither of these necks was examined in detail. However, they probably correspond in general to the descriptions given by Williams (1936) for a number of other plugs along the crest of the Chuska Mountains. According to Williams, the Chuska Mountains volcanics intrude the Chuska sandstone and are made up of minnette containing xenoliths of the underlying sediments as well as some pieces of granite and diorite, presumably from a deep-seated source. Thumb Rock, a small cylindrical neck about two miles north of the mapped area, was found by Williams to contain xenoliths of garnetiferous granite, diorite, and marble as well as numerous inclusions of sandstone and shale.

Extrusive rocks

A single occurrence of extrusive rock is found in the area. It is a thick columnar lava flow which caps Beautiful Mountain, on the east side of the area. The thickness of this flow was not measured directly but barometer readings taken by the author along the south side of the mountain just east of Bear Creek Canyon indicate a thickness of about 325 feet.

The flow is composed of a black, dense, finely crystalline material which may be described as basalt. The rock is quite brittle and on fracturing presents a columnar appearance. A view of the flow is presented in Figure 7.

Source of the lava is not definitely knowr. However, two small necks stand up as pinnacles near the southeast edge of Beautiful Mountain, and these presumably supplied the flow material.

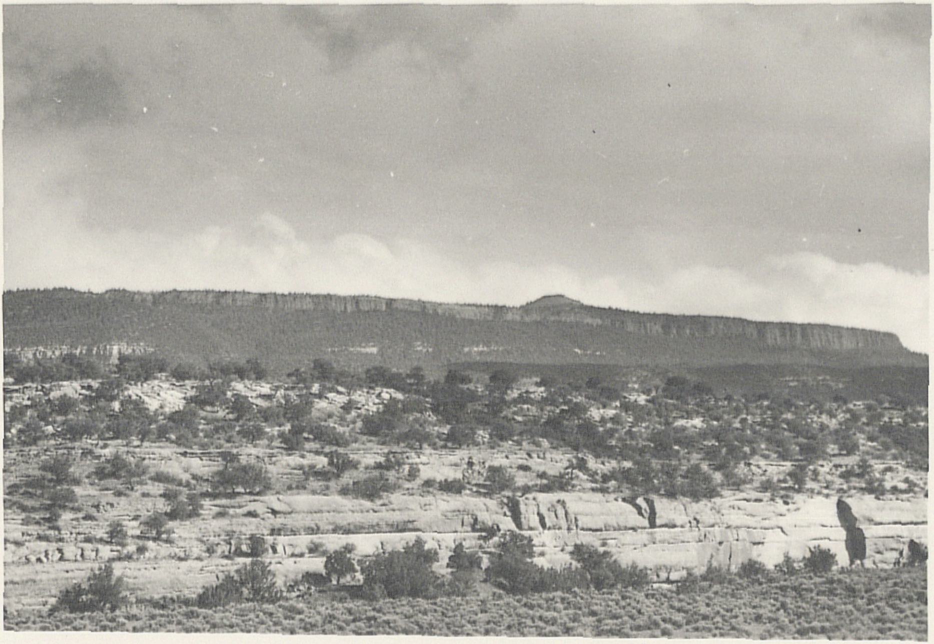


Figure 7. Beautiful Mountain lava flow on the skyline. Note the columnar jointing. Salt Wash and Bluff sandstones in foreground.

STRUCTURE

Defiance Monocline

The Defiance Monocline is a sinuous, eastward-dipping structure which extends for over one hundred miles along the border of Arizona and New Mexico, from near Gallup, New Mexico, to the San Juan River. It forms the east flank of the Defiance Uplift, an asymmetrical anticlinal structure which dips more steeply to the east than to the west. A general view of the structure is presented in figure 6.

The core of the Defiance Uplift is composed of Precambrian rocks, which are exposed in two places south of Bear Creek Canyon. At Bonito Canyon, near Fort Defiance, the Precambrian rock is a dense, blue quartzite which exhibits ripple marks and mud cracks on the bedding planes. At Hunters Point, a few miles farther south, the Precambrian is a dark metamorphic complex containing thin stringers of specular hematite. At both locations the Precambrian is overlain unconformably by the Permian DeChelly sandstone.

The portion of the Defiance Monocline which passes through Bear Creek Canyon is represented on the map, plate I, by two trend lines indicating the approximate eastern and western limits of the monocline. Between these limits the dips range from six to eighteen degrees, while beyond the limits the dips range from two to six degrees. Total vertical displacement is about 700 feet.

As the limits of the monocline are traced through the Bear Creek

Canyon area they converge and veer northward. In the southern part of the area they are nearly three miles apart and in the northern portion they approach within three quarters of a mile of each other.

The easterly dip steepens as the width of the monocline decreases, ranging from six degrees in the wide southern portion to eighteen degrees where it narrows toward the north.

The sharpest fold of the monocline known to the author is at Hunters Point, about sixty-three miles south of Bear Creek Canyon. Here the strata change in dip from nearly horizontal to nearly vertical within about one hundred yards.

The Defiance Monocline is one of several similar structures on the Colorado Plateau; others include the Comb Ridge Monocline, the Kaibab Monocline, and the Waterpocket Fold. The nearby Hogback Monocline is thought to be a branch of the Defiance Monocline, as is the Lukachukai Monocline. Origin of these relatively sharp, asymmetrical folds in the sediments is thought to be due to faults in the basement complex which flex but do not break through the overlying sediments. The sediments were simply draped over the edge of the faulted blocks.

Neither the age nor the exact nature of these faults is definitely known. The general consensus of opinion is that most of the movement took place during the Laramide orogeny, a time of crustal unrest in areas surrounding the Colorado Plateau. However, there is some evidence to indicate that the plane or zone of fault movement existed before the Laramide, and that there may have been some slight displacement occurring from time to time during the Triassic and Jurassic.

In the Bear Creek Canyon area the youngest strata affected by the folding are of upper Cretaceous age. An erosional unconformity cuts across the fold, truncating all the beds from the upper Cretaceous to the upper Triassic. This erosion surface is overlain by the Pliocene(?) Chuska sandstone, thus dating the development of the monocline as post-Cretaceous and pre-Chuska. Allowing a period of time for the stripping away of about two thousand feet of sediment before the deposition of the Chuska, the uplifting of the monocline falls within the range of the Laramide orogeny.

From investigations of the Salt Wash member of the Morrison formation in the Lukachukai Mountains, Stokes (1954) postulates that minor movement took place along the Lukachukai Monocline during Salt Wash time. This is based on observations of rather consistent changes in direction of the Salt Wash stream channels as they approach the site of the monocline. The channels curve noticeably from a northeastward direction to eastward or slightly southeastward, as if to avoid an area of high ground where the monocline now stands.

Movement of this nature is contemporaneous with and may be related to the Nevadan orogeny which was taking place west of the Colorado Plateau at that time. Considering the intense folding that was characteristic of the Nevadan, it is not unreasonable to suspect that some pressure was exerted on the Plateau from the west, and some reverse fault movement might be expected, as a means of relieving the pressure.

Eardley (1951) has characterized the Colorado Plateau as a "knot" in the center of the general deformation of the Laramide orogeny, resisting compressional forces from all sides. On the basis of such a concept, it is the opinion of the author that any movement along fault planes on the Plateau during that time would have to show reverse movement. This movement might be of the ramp type as suggested by Eardley (1951) or possibly of the high angle, "trapdoor" type proposed by Blackstone (1940) as the cause of the monoclines in the Pryor Mountains of Montana. In the Pryor Mountains the thrust in the Precambrian basement has broken through the overlying sediments in places and is exposed to study, a situation which does not exist along the Defiance Monocline. However, greater vertical displacement and steeper dips exist in unbroken strata in the Pyrors than on the Defiance structure, indicating the mechanical possibility of the trapdoor type fault along the Defiance Monocline. A thorough study of the joint patterns along the Defiance Monocline might lead to a more definite interpretation of the underlying structure.

Minor Structure

A single small normal fault was observed cutting some of the lime beds in the Chinle formation. A displacement of about two and one half feet was noted, and the fault plane dips eastward at about ten degrees. Two or three other features thought to be faults were examined, but they appeared to be landslide phenomena in the soft sandstones.

Somewhat over one hundred joint planes were measured for direction with the Brunton compass. These were measured primarily in the outcrops of the Todilto limestone, although some fifteen or twenty were measured in the Wingate sandstone. Prominent joints were not common in the other formations in the section. The dominant direction of joints in both the Todilto and Wingate was found to range between 50 and 80 degrees east of north. Other directions which occurred frequently were between 10 and 50 degrees west of north, and nearly due east.

A number of small folds were measured in the Todilto limestone. The largest folds measured were about eight feet across and up to forty feet long, with an amplitude of three feet. The average fold, however, is about half this size. The axial trend of these folds is generally in the direction of dip of the formation, and they were not found to occur at outcrops where the dip of the Todilto was less than six degrees. The majority of the folds located along the rims, where a complete cross section was visible, did not affect the entire thickness of the formation. Generally only the top few layers were disturbed, to a thickness of perhaps three feet at the most.

Small fractures were commonly observed on the folds, both parallel and perpendicular to the fold axes. These fractures probably resulted from stresses at the time of folding, or if the material was deformed plastically under pressure of overlying sediments, they may have resulted from release of pressure as the sediments were later eroded.

The folding was not observed to affect either the overlying or underlying sandstones, and slickensides are common on the faces of the individual limestone beds as well as on the fracture surfaces. This also might indicate lateral compression under confining loads, which was not translated into the resultant structure until the load was removed.

A thorough study of the direction of alignment of the slickensides on beds or minor folds, coupled with careful observations on the folds, fractures, and bedding displacement, might lead to interesting conclusions as to the forces involved in the movement, and possibly their relation to the deformation of the Defiance Monocline as a whole.

GEOLOGIC HISTORY

The geologic history of Bear Creek Canyon, as read from the deposits, is fairly simple and directly related to the history of the Colorado Plateau within which it lies.

The major event in the history of the area is the deformation which took place some time after the deposition of the upper Cretaceous strata, at which time the Defiance Monocline developed on the site of the old Defiance Highland of Paleozoic time. This renewed movement probably took place during the Laramide time, when the Colorado Plateau as a whole is considered to have been slightly deformed.

The Defiance Highland had a relatively uneventful existence before the Permian. It remained out of water throughout most of the Paleozoic era, standing as an island of Precambrian rock amid the shallow seas which inundated the Colorado Plateau region almost constantly throughout the Paleozoic.

Some parts of the highland were covered from time to time and accumulated comparatively thin layers of marine sediments, but the northeastern tip of the highland, where Bear Creek Canyon now lies, appears to have remained above water until some time in the Permian, when the sea finally covered the area to a depth of less than one thousand feet (Eardley, 1951, Plates 2 through 9).

The beginning of the Mesozoic era marked the beginning of dominantly continental sedimentation on the Plateau in general. Shallow water deposits gave way to flood plain deposits; these were followed by aeolian sediments, and finally fluviatile and lacustrine material was laid down at the close of the era. The visible record in Bear Creek Canyon begins with the upper Triassic, represented by the Chinle formation. The upper Triassic Chinle formation was deposited in a quiet environment of flood plain or lacustrine sedimentation, with no nearby land masses to contribute coarse sediments. Fossil fern material suggests a fairly humid climate at the time. The Triassic period came to a close with the deposition of the Wingate sandstone, marking a change from shallow water deposition to dominantly aeolian environment as the end of the period was approached.

The beginning of the Jurassic was marked by the incursion of a shallow body of marine water in which the Carmel was deposited. Again the land relief was low, judging from the lack of coarse material in the section, although locally there may have been some islands of Wingate protruding above the surface of the water.

At the end of Carmel time the seas withdrew and the deposits become predominantly those of the wind. The Entrada was formed as an area of sand marginal to an area of saline waters to the north and west. Periodic variations in the level of these waters caused them to fluctuate across the Bear Creek Canyon area occasionally and destroy the windblown structure of the Entrada to a great extent.

During this time the Navajo Highland to the southwest had risen and was contributing sediment to the Jurassic Basin.

By the commencement of Todilto time the source for the sand had either been removed or perhaps the wind action had diminished since the Todilto is nearly pure limestone deposited in a widespread shallow lake. Bear Creek Canyon lies near the western and northern limits of that body of water.

The Summerville formation represents the renewal of aeolian deposition, this time along the margins of a series of playa lakes which reworked the littoral sediments from time to time. Aeolian deposition eventually dominated, and the Bluff sandstone was not disturbed by flooding.

The beginning of Morrison time represents a major change in the type of deposition. Fluvial sediments become dominant, and rapid changes from torrential to quiet water deposits are characteristic, particularly in the lower Morrison. The upper Morrison is somewhat more quietly deposited, reflecting an increase in lake sediments. Fluviatile material is still predominant, although not so much as in the lower portion. The composition of the lower Morrison clays indicates that some volcanic activity was going on at that time. However, no great amount of vulcanism is recorded until the advent of upper Morrison time, during which great volumes of volcanic ash were deposited over wide areas.

The upper Morrison sediments were more quietly deposited than those of the lower Morrison, reflecting an increase in lake sediments or perhaps a widespread valley flat environment. Channel-type deposits persist, but are not as dominant as in the lower Morrison.

At the close of the Morrison time an extensive period of erosion set in. Whether any deposits were laid down and then later removed during this time is not known, since no evidence of such deposits was observed. The hiatus represented by this erosion is thought to include all of lower Cretaceous time.

Following this interval, deposition continued with the accumulation of the Dakota sandstone. This again appears to be a fluviatile deposit, consisting of coarse sands and conglomerates, indicative of a nearby uplift.

Following this phase and continuing to the end of the Cretaceous, the marine invasion of the Mancos sea from the northeast deposited thick gray and black shales over the area. Some transgression and regression of the sea is recorded in the occurrence of the Gallup member of the Mesa Verde formation, a littoral sand within the dominantly shale deposits.

At the close of deposition of the Mancos-Mesa Verde sequence the sediments were folded to form the Defiance Monocline and related structures. This movement is probably related to the general disturbances of the Laramide orogeny which surrounded the Colorado

Plateau (Eardley, 1951), as discussed in a preceding section.

A period of erosion then commenced, during which time large volumes of sediments were removed from the Cretaceous deposits, and the underlying rocks, down to the Triassic Chinle formation, which were involved in the folding, were partially removed. An essentially level plain was developed, with a low dip to the southwest.

By Pliocene time erosion of this surface was essentially complete, and a lake had formed in the basin to the southwest. The Chuska sandstone probably originated as a marginal area of shore sands and dunes around the edge of this lake, covering the erosional surface with up to about a thousand feet of clean, white sand. Some volcanic activity, possibly local, contributed ash beds to the sandstone.

After the deposition of the Chuska, the entire plateau was elevated to initiate the canyon cutting cycle, and at about the same time the volcanics of the Chuska Mountains were emplaced. This event is dated as Pleistocene or very late Pliocene (Eardley, 1951).

Dissection of the Bear Creek Canyon area has been controlled primarily by the structure and assisted by the variable nature of the formations. After once cutting through the soft Chuska sandstone, the master stream sought out the weak strata of the Morrison formation and followed them downward, removing large amounts of material in the process. Upon reaching the more resistant formations it seems to have been controlled by fractures and joints in picking its course. A second large drainage to the west has followed the general strike of the structure through the Chinle beds.

ECONOMIC GEOLOGY

Uranium

Several occurrences of carnotite-type mineralization have been discovered in Bear Creek Canyon, and on the strength of these occurrences, a number of claims for uranium have been staked. The mineralization occurs in the upper portion of the Recapture member of the Morrison formation, associated with red and gray mudstone layers and enclosed in light gray arkosic sandstone. The sandstone is quite friable, being only loosely cemented by calcite. Some clay matrix is present in the sandstone, and an unknown vanadium mineral of the roscoelite type also occurs with the uranium.

The occurrences are irregular and do not seem to follow any general pattern. The most highly mineralized portions of the formation seem to be the gray sands directly in contact with the gray mudstones, the mineralization occurring both in the sandstone and in the mudstone. The mudstone underlies the sandstone, and probably represents a permeability barrier to the passage of mineralized solutions. No carbon was observed in connection with the deposits.

Work on these claims has been limited to some rim stripping and a little open-pit mining. Some small tonnages of low-grade ore have been removed. Operations were suspended near the end of the summer of 1954.

Similar occurrences of uranium are present along the Sanostee

Wash drainage immediately to the south of Bear Creek Canyon. One of these, the South Peak mine, has been in operation at least since 1952 and has produced more than 1,000 tons of ore-grade material.

Uranium mineralization also occurs in the Salt Wash member of the Morrison formation along Sanostee Wash, but no mineralization has been found in this member in Bear Creek Canyon. The strata of Bear Creek Canyon appear to be equally favorable for the occurrence of uranium, and some few so-called indicator plants have been found growing on the outcrop areas, indicating that at least traces of the element may be present. The Salt Wash crops out over considerable area in the central portion of Bear Creek Canyon, and should be prospected more thoroughly.

Fairly extensive outcrops of Todilto limestone are present in the area, but no mineralization has been found in them. Small amounts of uranium have been found in the Todilto a few miles south of Bear Creek Canyon, and this formation also warrants further examination.

Coal

The Dakota sandstone contains at least one coal seam of minable thickness. However, the seam is quite shaley and probably of little economic importance. The bed is about four feet thick and one hundred feet long at the outcrop marked on the map. It pinches to the north and south, and possibly has no great extent back from the face. Similar occurrences of coally material are known in the Dakota above Sanostee

Wash, but as yet no use has been made of any of these.

Bentonite

Several beds of light gray bentonite occur in the Brushy Basin member of the Morrison formation. These beds pinch and swell throughout the area along the rims; the thickest one measured was 94 feet. However, the beds are not pure bentonite, containing a fair amount of sand and probably other clay minerals. The beds are overlain by the Dakota sandstone, and any fairly extensive utilization of the material would have to be by underground methods.

Barite

Crystalline barite is found as scattered concretionary nodules in a sandstone zone of the lower portion of the Summerville formation. These nodules weather out and are concentrated in the nearby stream beds, where they may be easily collected.

Although no great quantity of the material is available, it could perhaps be utilized as mineral specimens, if collected and sold through nearby traders along the tourist routes.

Oil Possibilities

No surface evidence of oil occurrence was found during the investigation.

Oil is known to occur in several of the formations in nearby areas, however. Near Sanostee Day School a water well produces small globules of oil, presumably from the Wingate sandstone. The well is drilled on a small structure, the Beautiful Mountain Anticline.

Oil occurs in the Dakota formation at the Rattlesnake field, 25 miles northeast of Bear Creek Canyon. The major production from the Rattlesnake field is from the Pennsylvanian Hermosa formation, on a small anticlinal structure.

Eardley (1951, plate 8) depicts somewhat less than one thousand feet of Pennsylvanian sediments abutting against a highland of Precambrian rock in the region of Bear Creek Canyon. If this is the case, then the monocline at this point may have deformed the Pennsylvanian strata sufficiently to form a trap in which oil and gas could accumulate. No test of this structure has been made, and no outcrops of the Hermosa occur near the Chuska Mountains to be available for study.

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APPENDIX A

Aerial Photo Coverage of Bear Creek Canyon

Aerial photography covering the area of Bear Creek Canyon is presently available on three scales. A set of photographs at a scale of approximately 1:28,000 is available from the U. S. Department of Agriculture, Soil Conservation Service, Washington, D. C. These were flown in 1934 by Fairchild Aerial Surveys, Incorporated.

In 1952 a set of photos at the scale of 1:20,000 was flown for the U. S. Geological Survey.

In 1950 the U. S. Forest Service had aerial photos made of the timbered areas of the Defiance Uplift at a scale of 1:12,000. These were made by K. B. Wood and Associates, Inc., of Portland, Oregon. Copies of these photos may be obtained from K. B. Wood, price sixty cents for each nine by nine inch contact print ordered. These photos cover only the southern portion of the area of Bear Creek Canyon, since the northern portion is not timbered.

Numbers of the individual photographs in each set are given below:

1:28,000	1:20,000	1:12,000 Flight	1:12,000 Photo No.
5246 - 5251		C-15	67-75
5368 - 5370	GS-WH: (13-212)-(13-217)	C-16	1 - 11
5834 - 5837	(14-4) -(14-9)	C-17	1 - 9
5882 - 5885	(14-159)-(14-164)	C-18	1 - 7
5889 - 5893		C-19	1 - 7
5937 - 5940		C-20	1 - 7
8299 - 8303		C-21	1 - 8
		C-22	1 - 5

In addition, aerial mosaics have been constructed by the Soil Conservation Service which cover the Bear Creek Canyon area. These were made from the 1:28,000 scale photographs and further reduced to an approximate scale of one inch to one mile. Portions of Bear Creek Canyon lie in two of the fifteen minute quadrangles, Arizona 40 (Navajo 34) and Arizona 60 (Navajo 51). These quadrangle mosaics are available from the U. S. Department of Agriculture, Soil Conservation Service, Washington, D. C.

Planimetric base maps for the southern portion of Bear Creek Canyon were made by K. B. Wood and Associates, Inc. from the 1:12,000 scale photographs. These maps are at the scale of approximately four inches to the mile, and cover only the wooded portion of the area.

APPENDIX B

Measured Stratigraphic Section - Bear Creek Canyon

Base of section at base of first prominent ridge east of road eight miles south of Red Rock Trading Post. Direction approximately due east.

Cretaceous

Dakota Sandstone	Feet
Sandstone, light gray to tan, very siliceous. Upper portion contains pebbles up to 1/2 inch in diameter	10.0
Bentonite, gray-brown, sandy..........................	5.0
Sandstone, light gray, siliceous, massive Contains some pebbles. Forms cliff.................	30.0
Total Dakota Measured	45.0

Jurassic

Morrison formation

Brushy Basin Member	
Sandstone, light yellow gray. Upper portion contains some bentonite beds with thin silicified layers. Crossbedded and channeled near base. Probably tongue of Westwater Canyon member	20.5
Bentonite, tan, red, and green-gray, sandy	37.5
Total Brushy Basin member	58.0

Westwater Canyon Member	
Sandstone, yellow gray to light pink. Massive, some portions silty	31.0
Sandstone, light red-brown, silty.......................	4.0
Sandstone, light yellow-gray. Some lenses of red-brown silty sandstone. Thin-bedded, forms cliff	27.5

Claystone, purple-gray, bentonitic	16.5
Sandstone, alternating dark yellow and light yellow-gray beds. Massive, friable, contains some silt	21.0
Sandstone, light gray to light yellow-gray. Massive, friable. Contains some lenses of pink, yellow, and brown silty sandstone. Some siltstone splits near center of unit	45.0
Sandstone, red to pink-gray, silty	3.0
Sandstone, light yellow-gray, friable	9.0
Total Westwater Canyon member	157.0

Recapture Member

Sandstone, red and green-gray. Contains some siltstone beds and limestone nodules	3.0
Sandstone, light yellow-gray. Massive, friable.	15.0
Sandstone, tan to red. Fine-grained	3.0
Sandstone, light tan to light yellow. Friable, some red siltstone splits	62.0
Siltstone, gray and red. Contains some light pink, friable sandstone	3.0
Sandstone, light yellow-gray. Friable	30.0
Sandstone, light pink to tan. Some red and gray mudstone and siltstone splits near center of unit	47.0
Sandstone, light pink-gray, friable. Some red mudstone seams	13.0
Sandstone, red and green-gray. Contains some red siltstone and red mud galls	5.0
Sandstone, light pink-gray. Friable. Bedding thin and even	25.0

Sandstone, mottled red, green-gray, and gray. Ore bearing	20.0
Siltstone, red-brown. Contains interbedded light gray sandstone	5.5
Sandstone, red to tan. Forms slope	19.5
Sandstone, light gray-pink. Local siltstone splits. Friable, thin-bedded, contains some $CaCO_3$ cement	16.0
Siltstone, dark brown. Contains some gray spots	4.0
Sandstone, light gray-white. Forms ledge	1.0
Sandstone, light red-brown. Friable, silty	11.0
Sandstone, tan to yellow	8.0
Siltstone, red	1.0
Sandstone, mottled red and gray	4.0
Sandstone, tan to gray	5.0
Siltstone and sandstone, dark red to purple to gray. Friable, forms slope	10.0
Sandstone, light tan. Forms cliff. 0.5 ft. of red mudstone at base	15.5
Sandstone, dark red to tan. Silty, forms slope	6.5
Sandstone, light tan to gray. Forms low cliff	8.0
Sandstone, light gray to dark red. Friable, silty. Very fine-grained	6.0
Sandstone, tan to gray. Forms low cliff	9.0
Mudstone, red-brown. Contains some gray spots	5.0
Sandstone, light gray to red-brown, mottled and banded	10.0
Sandstone, tan to gray. Thin-bedded with shallow cross-bedding. Forms massive-appearing cliff	60.0
Total Recapture member	511.0

Salt Wash Member

Sandstone and mudstone, red. Thin, alternating beds, somewhat channeled. Sandstone fine to very fine-grained, poorly cemented	2.0
Sandstone, light gray-white. Thin-bedded, with thin seams of limey sandstone. Lower ten feet forms cliff, upper portion forms steep slope	28.0
Sandstone, dark red, fine to medium-grained, some silty matrix. Forms slope	7.0
Sandstone, light gray, massive. Forms cliff	21.5
Mudstone, gray, with interbedded light gray sandstone	1.5
Sandstone, light gray-white. Massive, contains some mudstone splits	15.0
Sandstone and mudstone, light gray to light green. Altërnating beds, some channeling within the unit	20.0
Total Salt Wash member	75.0
Total Morrison formation	801.0'

Bluff Sandstone

Sandstone, light tan to gray. Some $CaCO_3$. Massive, some fine cross-bedding	5.0
Sandstone, light yellow to yellow. Some thin cross beds, tangential type, separated by local unconformities	5.0
Sandstone, tan to pink	5.0
Sandstone, bright yellow to light tan. Massive, friable, forms soft cliff	15.0
Sandstone, light tan	6.5
Sandstone, light yellow-gray. Contains some thin $CaCO_3$ concretionary zones	13.5
Sandstone, light brown-gray. Forms slope	15.0
Total Bluff sandstone	65.0

Summerville formation

Sandstone, light to dark brown and gray in alternating bands	40.0
Sandstone, dark brown to brown. Earthy, weathered exposures, forms slope	15.0
Sandstone, red and white. Banded, friable	2.0
Sandstone, light red. Some gray spots and some $CaCO_3$ concretions. Contains nodules of crystalline barite	8.0
Sandstone, tan to red-brown. Massive	20.0
Sandstone, dark red-gray. Mottled	0.5
Sandstone, tan to light red	2.5
Sandstone, mottled red-gray	2.0
Total Summerville formation	90.0

Todilto limestone

Limestone, light to dark gray. Dense. Many individual beds up to 0.5 feet thick, separated by thinner zones of silt	8.0
Total Todilto limestone	8.0

Entrada sandstone

Sandstone, light gray-purple. Very fine, silty. Bedding contorted. $CaCO_3$ cement	2.0
Sandstone, dark tan to red. Massive, some irregular bedding, forms cliff	63.0
Total Entrada sandstone	65.0

Carmel formation

Sandstone, dark red. Thin-bedded to massive. Silty, earthy appearing on outcrop	22.5
Total Carmel formation	22.5

Wingate Sandstone

Upper Wingate Sandstone

Sandstone, light gray. Very fine-grained, well sorted. Well cemented by $CaCO_3$. Forms resistant cap to Wingate sandstone	2.5
Sandstone, tan to red. Massive, very little bedding	19.5
Sandstone, light tan. Steep, irregular tangential crossbedding. Forms steep, rounded slope	87.0
Sandstone, light tan to tan-red. Contains large tangential crossbedding locally	98.0
Sandstone, light red-tan. Massive, no true bedding apparent. Forms cliff	33.0
Sandstone, light red to red. Thin-bedded, silty, Tongue of lower Wingate	37.0
Sandstone, light tan. Contains large tangential crossbedding. Forms cliff	30.0
Sandstone, red. Silty. Cuts across crossbedding unconformably. Probably a tongue of the lower Wingate	2.5
Sandstone, tan to light red. Contains giant tangential crossbedding. Forms cliff continuous with unit below	21.5
Sandstone, red. Massive, forms cliff	13.5
Total Upper Wingate	344.5

Lower Wingate Sandstone

Sandstone, red. Thin-bedded to massive	26.5
Sandstone, red. Thin-bedded and shaley. Silty	16.0
Sandstone, light red-brown. Massive, forms broken slope	18.0
Sandstone, dark red to red-brown. Very fine-grained, sorting good. Massive. Lower 20 feet forms steep cliff	72.0

Siltstone, dark red. Sandy	3.0
Sandstone, light red-brown, Very fine-grained, sorting good. Massive	29.5
Sandstone, red-brown, Silty, fissile. Weathers easily, forms rough slope	52.5
Sandstone, light red-brown	5.0
Sandstone, dark red, silty	1.0
Sandstone, light red-brown. Fine to very fine-grained, sorting good. Contains a few light gray spots. Massive. Lower 10 feet forms cliff	54.0
Sandstone, light gray-brown, mottled. Very fine-grained, sorting good. This unit is a channel sand, 5 feet thick at the center. Lower 2 feet thin-bedded, upper 3 feet massive. Minor amount of siltstone at base	5.0
Sandstone, red-brown to brown. Thin-bedded, some siltstone splits in lower 2 feet.	30.0
Sandstone, red-brown. Lower 14 feet massive, middle portion thin-bedded with some siltstone and upper 17 feet massive, fine-grained	39.0
Total Lower Wingate	341.5
Total Wingate Sandstone	686.0

Chinle formation

Shale, purple. Fissile and limey. Contains a number of light gray spots	1.5
Siltstone, gray. Forms ledge and grades into sandstone unit below	4.5
Sandstone, light pinkish brown. Fine to very fine, sorting good. Some small gray spots	11.0
Siltstone, pink-gray. Hard	10.5
Sandstone, brown to red-brown. Fine-grained, sorting good. Thin-bedded. Some silt matrix and some gray spots	17.5

Lime Pebble Conglomerate, green-gray	2.5
Shale, purple	0.5
Sandstone, red-brown. Fine-grained, sorting fair. Arkosic with some muscovite flakes. Several stringers of pebbles up to one inch in diameter..................................	15.5
Mudstone, purple-gray. Bentonitic	5.0
Sandstone and siltstone, red-gray to gray. Sandstone fine-grained, poorly sorted, arkosic. Siltstone speckled, hard, compact. Contains pebbles.....	11.0
Sandstone, red-brown. Silty. Contains small light gray spots	11.5
Siltstone, purple-gray to gray, compact..................	3.0
Lime Pebble Conglomerate, red-gray. Silty................	10.0
Shale, red to red-brown. Calcareous	25.0
Shale, red. Silty, calcareous. Some small light gray spots....................................	1.5
Lime Pebble Conglomerate, dark red-brown and green-gray. Mottled	10.5
Siltstone, red-brown. Shaley, soft. Forms slope. A few pieces of black and yellow silicified wood on surface of outcrop	21.5
Sandstone, red-brown. Silty. Forms ledge	2.5
Siltstone, dark red to red. Sandy. Some small gray spots and lime nodules. Contains two red and gray calcareous ledges, each 0.5 feet thick, 7.5 and 13 feet from base of unit respectively	14.5
Siltstone, red. Sandy. Forms slope......................	8.0
Sandstone, red. Silty. Forms ledge	5.0

Lime Pebble Conglomerate, light brown-gray. Silty, some small gray spots. Forms gentle to steep, rounded slope	67.5
Total exposed thickness, Chinle formation	259.0
Total thickness of Measured Section, Bear Creek Canyon	2,041.5

GEOLOGIC MAP AND SECTIONS
BEAR CREEK CANYON
ARIZONA - NEW MEXICO

PLATE I

Gregory 1917 U. S. Geol. Survey Prof. Paper 93	Gregory 1932 U. S. Geol. Survey Prof. Paper 188	Goldman and Spencer 1942 A.A.P.G. Vol. 26	Stokes 1944 G.S.A. Bull. Vol. 55	Baker, Dane, and Reeside 1947 A.A.P.G. Vol. 31	Gregory 1950 U. S. Geol. Survey Prof. Paper 220	Hoover 1950 New Mexico Geol. Soc. Guidebook No. 1	Stokes 1951 U. S. Geol. Survey Circular 111	Wright and Becker 1951 A.A.P.G. Vol. 35	Allen and Balk 1954 New Mexico Bur. Mines Bull. 36	Beaumont 1954 U. S. Geol. Survey Oil and Gas Prelim. Map OM 147	Harshbarger 1954 U. S. Geol. Survey Circular 308	Maise 1955 This Paper
Chuska sandstone Tohachi Shale Eocene (?) U. Cretaceous Post Mesa Verde rocks Mesa Verde formation	Not Present	Not Studied	Not Studied	Not Studied	Wasatch formation Eocene U. Cretaceous Kaiparowits formation Straight Cliffs and Wahweap formations	Not Studied	Not Present	Not Studied	Chuska sandstone Pliocene (?) U. Cretaceous Tohatchi formation Menefee formation Point Lookout sandstone Crevasse Canyon formation	Not Present Tocito sandstone lentil of Mancos shale	Not Present Upper Mancos shale Gallup sandstone member Mesa Verde formation	Chuska sandstone Pliocene (?) U. Cretaceous Upper Mancos shale Gallup sandstone member Mesa Verde formation
Mancos shale	Mancos shale		U. Cretaceous		Tropic formation		Mancos shale		Gallup sandstone Mancos shale	Mancos shale	Mancos shale	Lower Mancos shale
Dakota sandstone U. Cretaceous Jurassic (?)	Dakota (?) sandstone Cretaceous U. Jurassic		L. Cretaceous (?) Dakota sandstone Cedar Mt. ss. Buckhorn cong. L. Cretaceous (?) Jurassic	Dakota (?) sandstone Cretaceous Jurassic	Dakota (?) sandstone U. Cretaceous U. Jurassic	Dakota sandstone U. Cretaceous Jurassic	Dakota sandstone Cretaceous Jurassic	Dakota sandstone L. Cretaceous U. Jurassic	Dakota (?) sandstone U. Cretaceous U. Jurassic	Dakota sandstone Cretaceous Jurassic	Dakota sandstone Cretaceous Jurassic	Dakota sandstone U. Cretaceous Jurassic
McElmo formation Jurassic (?)	Morrison formation: Brushy Basin shale memb. Westwater Canyon shale memb. Recapture shale member Bluff sandstone member	Morrison formation: Junction Creek sandstone Wanakeh Marl member Bilk Creek sandstone member Pony Express limestone member	Morrison formation: Brushy Basin shale memb. Westwater Canyon shale memb. Recapture Creek shale memb. Salt Wash sandstone member	Morrison formation	Windsor formation	Morrison formation: Brushy Basin shale Salt Wash sandstone	Morrison formation: Brushy Basin shale memb. Westwater Canyon ss. memb. Recapture shale member Salt Wash sandstone member	Morrison formation: Sandstone facies Grit facies Sandstone facies	Morrison formation: Westwater Canyon sandstone member Recapture shale member	Morrison formation	Morrison formation: Brushy Basin member Westwater member Recapture member Salt Wash sandstone member	Morrison formation: Brushy Basin member Westwater member Recapture member Salt Wash sandstone member
La Plata Group: Jurassic Navajo sandstone Todilto formation	San Rafael Group: Summerville formation Entrada formation Carmel (?) formation U. Jurassic	Entrada sandstone	San Rafael Group: Summerville formation Curtis formation Bluff sandstone Todilto limestone	San Rafael Group: Wanakah formation Todilto memb. Wanakah fm. Entrada formation Carmel formation Jurassic	San Rafael Group: Curtis formation Entrada sandstone Carmel formation U. Jurassic	San Rafael Group: Summerville formation Bluff ss. memb. Entrada Red Mesa formation Entrada sandstone Carmel formation	San Rafael Group: Bluff sandstone Summerville sandstone Todilto limestone Entrada sandstone Carmel shale Jr.	San Rafael Group: Summerville formation Entrada sandstone Carmel formation U. Jurassic	San Rafael Group: Summerville formation Todilto limestone Entrada sandstone Carmel formation U. Jurassic	San Rafael Group: Wanakah formation Todilto member Wanakah fm. Entrada sandstone Carmel formation Jurassic	San Rafael Group: Summerville formation Todilto limestone Entrada sandstone Jurassic	San Rafael Group: Bluff sandstone Summerville formation Todilto limestone Entrada sandstone Carmel formation Jr.
Wingate sandstone Jurassic	Glen Canyon Group: Jurassic (?) Navajo ss. Kayenta formation Wingate sandstone Jurassic (?)	Not Studied	Glen Canyon Group Undiff.	Glen Canyon Group: Jurassic (?) Navajo ss. Kayenta formation Wingate sandstone Jurassic (?)	Glen Canyon Group: Jurassic (?) Navajo sandstone Kayenta formation	Glen Canyon Group: Navajo sandstone Kayenta formation Wingate sandstone Jurassic	Glen Canyon Group: Jurassic (?) Sandstone Undiff. Jurassic (?)	Glen Canyon Group: Jurassic (?) Wingate sandstone Jurassic (?)	Glen Canyon Group: L. Jurassic Wingate sandstone L. Jurassic	Jurassic (?) Glen Canyon Group Undiff. Jurassic (?)	Glen Canyon Group: Triassic Wingate sandstone	Glen Canyon Group: Triassic Wingate sandstone
Triassic Chinle formation	Triassic Chinle formation		Not Studied	Triassic Chinle formation	Wingate sandstone Jurassic (?) Triassic Chinle formation	U. Triassic Chinle formation	Triassic Chinle red beds	Triassic Chinle formation	Triassic Chinle formation	Triassic Chinle formation	Chinle formation	Chinle formation

Nomenclature Comparison-Colorado Plateau

Exact Correlation Not Implied

Plate II