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Geology of the Nutria Monocline, McKinley County, New Mexico

R. John Edmonds

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GEOLOGY OF THE NUTRIA MONOCLINE,
McKINLEY COUNTY, NEW MEXICO

By

R. John Edmonds

A Thesis
Submitted in Partial Fulfillment of the
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MASTER OF SCIENCE

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ABSTRACT

The Nutria monocline forms the northwestern boundary of the Zuni uplift in McKinley County, New Mexico. The sedimentary rocks that are exposed along the monocline range in age from Permian to Cretaceous and rest on granite of probable Precambrian age. The Jurassic Todilto limestone, which is present north of the mapped area, pinches out in a southerly direction. South of this pinch-out the massive sandstone of the Entrada formation joins the main body of the Zuni sandstone. Only the even-bedded, silty sandstone that has previously been considered to be the middle member of the Entrada is regarded as Entrada in this report.

The west-facing Nutria monocline extends southward from the vicinity of Gallup, to a point 3 miles southeast of Upper Nutria where it flattens and disappears. The monocline consists of an upper anticlinal bend, a lower synclinal bend, and a steep middle limb common to both flexures. The dip reverses locally, both above the head and below the foot of the monocline. The monoclinal symmetry is broken by the Stinking Springs thrust from a point in sec. 31, T. 13 N., R. 16 W., to the northern boundary of the area. The McGaffey fault zone roughly parallels the monocline and lies about 4 miles east of it. Other smaller faults and folds are found within the area.

The Nutria monocline forms the northeastern boundary of the Zuni uplift in McKinley County, New Mexico. The sedimentary rocks that are exposed along the monocline range in age from Permian to Cretaceous and rest on granite of probable Precambrian age. The Todilto limestone, which is present north of the mapped area, pinches out in a southerly direction. South of this pinch-out the [illegible] sandstone of the Entrada formation joins the main body of the Zuni sandstone. Only the even-bedded, silty sandstone that has previously been considered to be the middle member of the Entrada is regarded as Entrada in this report.

The west-facing Nutria monocline extends southward from the vicinity of Gallup, to a point 3 miles southeast of Upper Nutria where it flattens and disappears. The monocline consists of an upper anticlinal bend, a lower synclinal bend, and a steep middle limb between the bends. [illegible] reverses locally, both above and below the limb of the monocline. The monocline's trend [illegible] is broken by the Stinking Springs thrust from a point in sec. [illegible], T. [illegible] N., R. 16 W., to the northern boundary of the area. The [illegible] fault zone roughly parallels the monocline and lies about [illegible] miles east of it. Small [illegible] within the area.

The Nutria monocline appears to have been formed by tangential compressive forces. The monocline cannot be dated accurately with respect to the Zuni uplift. Any interpretation of the forces involved in the formation of the uplift is somewhat tenuous. However, it seems most probable that the primary movement of the Zuni Mountain mass was a complex, rotational movement caused by a nonuniform couple. This couple probably acted over a larger area than that of the uplift itself.

Although coal and uranium are present within the mapped area, no mining is being carried on at this time. Parts of the area serve as recharge for the ground-water supplies in surrounding areas.

INTRODUCTION

Location and Accessibility

The area studied for this report includes about 65 square miles lying along the western flank of the Zuni Mountains (Fig. 1). At the north it lies between 108°30' and approximately 108°37' west longitude, and at the southern border between 108°30' and approximately 108°33'. It lies roughly between latitudes 35°12' and 35°25' north. The mapped area extends for 16 miles in a northerly direction. Its maximum width is about 7 miles near the northern edge. The width decreases southward to the southern boundary where it is only about 2 miles.

About 9 square miles of the area are included in the Zuni Indian Reservation, 8 square miles are within the boundaries of Fort Wingate Military Reservation, and another 23 square miles are private land. The remainder of the area is in the Cibola National Forest.

The accessibility of the area is reasonably good. The area may be reached from the north by way of New Mexico Road 400, which is paved as far south as McGaffey. New Mexico Road 32, a paved, north-south highway, lies about 10 miles west of the area. New Mexico Road 53, a paved, east-west highway, lies about 5 miles south of the area. An improved dirt road runs from a point about 9 miles south

INTRODUCTION

Location and accessibility

The area studied for this paper includes about 36 square miles lying along the western flank of the Zuni Mountains (Fig. 1). At the north it lies between 108°30' and approximately 108°57' west longitude, and at the southern border between 108°30' and approximately 108°33'. It lies roughly between latitudes 35°12' and 35°23' north. The mapped area extends for 10 miles in a northerly direction. Its maximum width is about 7 miles near the northern edge. The width decreases southward to the southern boundary where it is only about 2 miles.

About 9 square miles of the area are included in the Zuni Indian Reservation, 2 square miles are within the boundaries of Fort Wingate Military Reservation, and about 23 square miles are private land. The remainder of the area is in the Cibola National Forest.

The accessibility of the area is reasonably good. The area may be reached from the north by way of New Mexico Road 602, which is paved as far [illegible] New Mexico Road [illegible], a gravel, north-south highway, lies about 10 miles west of the area. New Mexico Road 53, an east-west highway, lies about [illegible] miles south of the area. An improved dirt road runs from a point [illegible]

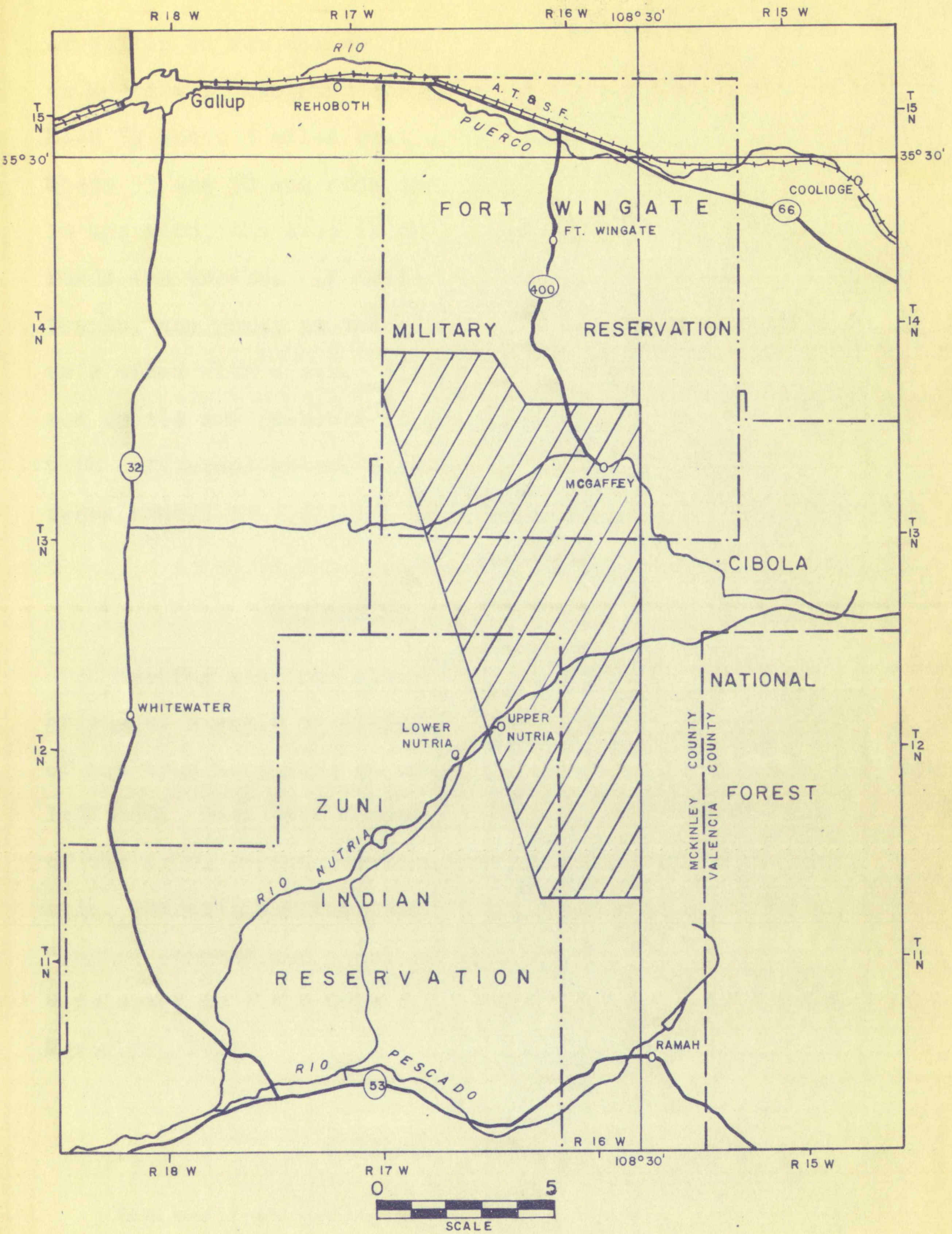

Figure 1. Index map showing the location of the area.

of Gallup on New Mexico Road 32, eastward through the area to McGaffey. Another improved dirt road joins New Mexico Road 53 about 3 miles east of the junction of New Mexico Roads 53 and 32 and runs northeastward to Upper Nutria. In addition, the area is crossed by numerous unimproved dirt roads and trails. If maximum use is made of the roads and trails, any point in the area can be approached as closely as 2 miles with a car. Although the unimproved dirt roads and trails are passable in dry weather to a passenger vehicle with sufficient ground clearance, a jeep or pickup truck is recommended.

Methods of Investigation

Mapping was done along the monocline on aerial photographs at a scale of 1:15,840. Notations throughout the rest of the area were made on aerial photographs at a scale of 1:31,680. Data were compiled on planimetric quadrangle maps of the U. S. Forest Service at a scale of 2 inches equals 1 mile. Stratigraphic sections were measured by means of a Brunton compass and steel tape. Approximately 5½ weeks were spent in field work during September, October, and November, 1960.

Previous Work

The earliest geologic reports of the Zuni Mountain area are those of men who were associated with various exploratory expeditions between 1853 and 1880. The first

of Gallup on New Mexico Road 32, northeast through the area to McGaffey. Another improved dirt road joins New Mexico Road 53 about 3 miles east of the junction of New Mexico Roads 53 and 32 and runs northeastward to [illegible]. In addition, the area is crossed by numerous unimproved dirt roads and trails. If maximum use is made of the roads and trails, any point in the area can be approached by as close as 2 miles with a car. Although the majority of dirt roads and trails are passable in dry weather to a passenger vehicle with sufficient ground clearance, a jeep or pickup truck is recommended.

Methods of Investigation

Mapping was done almost entirely on aerial photographs at a scale of 1:15,840. Traverses throughout the rest of the area were made on aerial photographs at a scale of 1:31,680. Data were compiled on planimetric base maps of the U. S. Forest Service at a scale of 2 inches equals 1 mile. Stratigraphic sections were measured by means of a Brunton compass and steel tape. Approximately [illegible] weeks were spent in field work during September, October, and November, 1960.

Previous Work

The earliest geologic reports of the [illegible] area are those of men who were associated with various exploratory expeditions between [illegible]

of these was by Marcou (1856, p. 147-149), who traveled through the area in 1853. Brief descriptions of the area were given by Newberry in 1861 (p. 94-96), and Gilbert in 1875 (p. 542-567). Dutton (1885, p. 113-163) reported at some length on the geology of the Zuni Mountain area, and named the Zuni and Wingate sandstones for exposures north of Fort Wingate. He also described the Nutria monocline, which he considered to be a tilted block bounded by two faults.

Sears in 1925 was primarily concerned with the Gallup-Zuni Coal basin, but briefly discussed the adjoining Zuni Mountains. Darton (1928, p. 137-155) described the general geology of the Zuni Mountain area. Sears, et al. (1929) described the geology from Gallup eastward to Mount Taylor. In 1936 Baker, Dane, and Reeside discussed the Jurassic rocks of the Colorado Plateau and reinterpreted the section at Fort Wingate (p. 44). The depositional relationships of the Cretaceous rocks of northwestern New Mexico were discussed by Sears, et al. (1941) and Pike (1947). In 1947 Baker, Dane, and Reeside re-examined their earlier interpretation of the Fort Wingate section and correlated Dutton's Wingate with the Entrada formation of Utah.

Geologists were especially active in the area during the 1950's. Rapaport, Hadfield, and Olson (1952) described the Jurassic rocks of the Zuni Mountains. Gilkey (1953) studied the fracture patterns of the Zuni Mountains and

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concluded that the uplift was formed primarily by vertical forces. Smith mapped the Thoreau, Inscription Rock, and Foster Canyon quadrangles to the east of the area covered in this report in 1954, 1958, and 1959 respectively. Kelley (1955a) discussed monoclines, among them the Nutria monocline. He also discussed (1955b, p. 30-34 and 63-64) the tectonics of the Colorado Plateau including the possible origins of the Zuni uplift. Freeman and Hilpert (1956) described the Morrison stratigraphy of the northeastern flank of the uplift. Harshbarger, Repenning, and Irwin (1957) discussed the Jurassic stratigraphy of the Navajo Country including the Zuni Mountains. In 1957, O'Sullivan and Beaumont published a geologic map of the western part of the San Juan basin, which included the northernmost parts of the Zuni Mountains and the Nutria monocline. In the same year, Dane and Bachman published a geologic map of northwestern New Mexico which included the Zuni Mountains. In 1960 Kelley and Clinton discussed the fracture patterns and tectonics of the Colorado Plateau, and the possible origins of the Zuni Mountains (p. 44-48).

Present Work

An attempt has been made in this report to map and describe the structure of the Nutria monocline in somewhat more detail than has been done before, with the hope of determining what type of forces caused its formation. An attempt

has been made also to determine how the Nutria monocline is related to the Zuni uplift and how their modes of formation are related. Although the primary interest of the writer was the determination of the structure along the Nutria monocline, a secondary emphasis was placed on stratigraphy, particularly the Jurassic section.

Acknowledgments

Thanks should go to Mr. William Seager, who so helpfully criticized portions of this report, and to the Zuni Indians, who gave the writer permission to do field work on their tribal lands. Thanks for the use of Survey equipment for map-making should go to Mr. Charles B. Read of the U. S. Geological Survey. The writer extends his appreciation to Herbert Taylor of Gallup, who flew the writer over the area and helped in measuring the stratigraphic sections. The New Mexico Geological Society provided funds for the aerial photographs for this study. A special note of gratitude should go to Dr. Vincent C. Kelley, who suggested this problem and willingly gave up much of his time in the discussion of various aspects of the report.

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GEOGRAPHY

The elevation of the area ranges from a little less than 6800 feet near Upper Nutria to 8280 feet about 1 mile east of Little Bear Spring. The hogback along the western border of the area rises almost 400 feet above the valleys that parallel it on either side. West of the area the landscape is dissected, with an elevation of about 7400 feet along the flat-topped drainage divides. East of the hogback, the surface rises toward the center of the Zuni Mountains to as much as 8000 feet. Slopes east of the hogback are gentle at the higher elevations, but along the hogback the slopes range up to 40°. East of Upper Nutria the Rio Nutria has cut a steep-walled canyon nearly 200 feet deep.

All the streams in the area drain westward into the Little Colorado River. North of a line running roughly from Little Bear Spring to McGaffey, the drainage is westward and northward into the Rio Puerco of the West, but south of this line the drainage is southwestward into the Zuni River. The Rio Nutria flows constantly above the reservoir at Upper Nutria and is the only permanent stream in the report area. All other drainage is by arroyos that run only after rainfall.

Rainfall in the Zuni Mountains varies directly with the elevation and ranges from less than 14 inches at Upper Nutria to a little over 18 inches at McGaffey, where the

GEOGRAPHY

The elevation of the area ranges from a little less than 6800 feet near Upper Nutria to 7250 feet about 2 miles east of Little Bear Spring. The hogback along the eastern border of the area rises almost 200 feet above the valleys that parallel it on either side. West of the area the landscape is dissected, with an elevation of about 7100 feet along the flat-topped drainage divides. East of the hogback, the surface rises toward the center of the Zuni Mountains to as much as 8000 feet. Slopes west of the hogback are gentle at the higher elevations, but along the hogback the slopes range up to 40°. East of Upper Nutria the Rio Nutria has cut a steep-walled canyon nearly 200 feet deep.

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Rainfall in the Zuni Mountains varies directly with the elevation and ranges from less than 14 inches at Upper Nutria to a little over 18 inches at McGaffey, where the

U.S. Weather Bureau maintains a recording station. The average annual temperature at McGaffey is 43.6°. The January average is 22.2° and the July average is 64.8°. The temperature at McGaffey is characterized by great daily variation, often exceeding 50°. Precipitation occurs during two periods of the year, during August usually as cloudbursts and heavy showers, and during winter and early spring from more general storms. Snowfall during the winter amounts to 70 inches. Precipitation is sparse or absent from mid-May to mid-July and again from September through November.

The area has three vegetation zones that are dependent upon elevation (Williams, Anderson, and Crezee, 1960). The lowest occurs only along the southwestern edge of the area and in the valley east of the hogback. The vegetation of this zone consist of grass and low-growing weeds. Above this is a zone consisting mainly of pinon pine and juniper. This zone covers most of the southern half of the area and extends northward along the western side of the hogback. At the higher elevations, and covering most of the northern half of the area, is a zone of Ponderosa pine and scrub oak. This zone contains a few natural grassy areas, and spruce, fir, and quaking aspen occur in some of the more sheltered canyons. These vegetation zones commonly grade into one another, and plants of all three zones may be found within a few feet.

A great variety of animal life is found within the area. Deer, bobcats, porcupines, and coyotes are the principal abundant large animals. Elk, bears, and mountain lions are only rarely encountered. Rabbits, squirrels, and other smaller animals are also abundant. Bird life is plentiful and ranges from waterfowl, wild turkeys, and large birds of prey to the smaller songbirds. Trout have been introduced in the reservoir at McGaffey, and bass in the reservoir near Upper Nutria. The Rio Nutria contains two native species of fish, at least one of which is unique to its waters (Koster, 1961, oral communication).

Cattle raising is the chief industry of the area. Sheep are raised by the Zuni Indians, and small-scale lumbering is carried on at the higher elevations. Much recreational use is made of the National Forest lands. Prior to 1935, large-scale lumbering operations were carried on in the area, but the addition of much of this land to the National Forest has greatly reduced the size of this industry.

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STRATIGRAPHY

General Aspects

The exposed sedimentary section in the report area consists of approximately 5200 feet of rocks resting on a basement of Precambrian granite. The sedimentary rocks range in age from Permian to Cretaceous. Some unconsolidated sediments of Recent derivation locally overlie the older formations. A few scattered beds of Pennsylvanian age were mapped by Smith, et al. (1959a), east of the area. Although beds of possible Pennsylvanian age may be present within the area, the writer did not see any. The sedimentary rocks are predominantly clastic. Less than 250 feet of carbonate rocks occur throughout the section, mostly in the Permian San Andres limestone. The aggregate thickness of sandstone in the area is almost equal to that of the finer clastics. Due to their greater resistance to weathering and erosion, the sandstones are much better exposed than are the fine-grained clastics. The resistant sandstone strata control much of the topography, and the finer sediments are poorly exposed either in slopes or valleys.

Precambrian

A small outcrop of granite is present in the northeastern corner of the area, between the McGaffey fault zone and the eastern edge of the map (Fig. 2). Although

STRATIGRAPHY

General Statement

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Precambrian

A small outcrop of granite is present in the northeastern corner of the area, between the Montosa fault zone and the eastern edge of the map (Fig. 2). Although

this granite may be dated as only pre-Permian or possibly pre-Pennsylvanian, it is similar in lithology to other granites in the Southwest that are known to be Precambrian (Smith, 1957, p. 54).

The Precambrian is almost entirely a pink, medium-grained gneissic granite that weathers a pale pink to brown. It consists mainly of pink orthoclase and quartz with minor amounts of biotite and mafic minerals. Locally, it is cut by irregular quartz veins. The granite produces low rounded hills and gentle slopes where exposed, but is commonly covered by alluvium. The Abo formation rises above the granite on the west and thinly covers it a short distance to the southeast (Smith, et al., 1959a). Thus, the surface of the Precambrian may correspond very nearly to the surface on which the Abo was deposited in early Permian time.

Permian Rocks

The Permian section of the western Zuni Mountains may be divided into four formations which are equivalent to the Permian formations of central New Mexico. They are the Abo, Yeso, Glorieta, and San Andres. The Permian section is bright red in the lower part but becomes dull gray and brown near the top. The total thickness of the Permian rocks in the area is slightly more than 1000 feet.

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Of this, approximately 140 feet is limestone, 560 feet is sandstone, and about 300 feet is siltstone and mudstone. No evaporites were seen in the Permian outcrops. The Permian rocks of the Zuni Mountains appear to be the result of sedimentation on a stable shelf.

Abo Formation

The Abo formation was named by Lee in 1909 (p. 12) for exposures at the southern end of the Manzano Mountains in Socorro County, New Mexico. Read (1961, oral communication) has measured a thickness of 290 feet at McGaffey and of 790 feet at Cottonwood Canyon, east of the area. However, thickness variations were not observable because of limited outcrops and faulting.

The Abo formation is exposed east of McGaffey along the Precambrian core of the Zuni uplift. It forms a low, rounded ridge immediately west of the broad central valley of the uplift. Some of the more resistant sandstone units form low cuestas, which provide small topographic breaks within the slopes that characterize the Abo formation as a whole.

The formation rests unconformably on the Precambrian granite, or locally on Pennsylvanian beds. The contact has at least 15 feet of local relief. The lower portion of the Abo is locally very coarse arkose. Upward the formation is predominantly thin-bedded (see appendix), red, red-brown, and white sandstone. The sandstone is slightly micaceous, poorly sorted, fine- to coarse-grained and silty. It is locally cross-bedded and arkosic.

of this, approximately 140 feet is limestone, 320 feet is sandstone, and about 300 feet is siltstone and mudstone. No evaporites were seen in the Permian outcrops. The Permian rocks of the Zuni Mountains appear to be the result of sedimentation on a stable shelf.

Abo Formation

The Abo formation was named by Lee in 1909 (p. 12) for exposures at the southern end of the Manzano Mountains in Socorro County, New Mexico. Read (1951, oral communication) has measured a thickness of 820 feet at McGaffey and of 790 feet at Cottonwood Canyon, west of the area. However, thickness variations were not observable because of limited outcrops and faulting.

The Abo formation is exposed east of McGaffey along the Precambrian core of the Zuni uplift. It forms a low, rounded ridge immediately west of the broad central valley of the uplift. Some of the more resistant sandstone units form low cuestas, which provide small topographic breaks in the slopes that characterize the Abo formation as a whole.

The formation rests unconformably on the Precambrian granite, or locally on Pennsylvanian beds. The contact has at least 15 feet of local relief. The lower portion of the Abo is locally very coarse arkose. Upward the formation is predominantly thin-bedded (see appendix), red, red-brown, and white sandstone. The sandstone is slightly micaceous, poorly sorted, fine- to coarse-grained and silty. It is locally cross-bedded and arkosic.

The Abo formation is a continental deposit resting on, and in great part derived from, the Precambrian. It is possibly a piedmont deposit. In the report area it apparently has been deposited over a Pennsylvanian or early Permian positive area of low relief which had received little, if any, Pennsylvanian covering.

Yeso Formation

The Yeso formation was named by Lee (1909, p. 12) for exposures east of Socorro, New Mexico. The formation in the Zuni Mountains has been divided into two members by Read (1961, oral communication), which he correlated with the Meseta Blanca sandstone, and the San Ysidro member of Northrop and Wood (1946). Smith (1954, p. 54) has divided the Yeso formation into four members in the Zuni Mountains, the upper three of which are equivalent to the San Ysidro member as designated by Read. No attempt was made to divide the Yeso formation into members in the course of the mapping for this report.

Read (1961, oral communication) has measured 305 feet of Yeso beds at McGaffey and has noted slight thinning to the east. No thickness variation of the Yeso can be observed in the area because of limited outcrops, but a general thickening appears toward the southwest (Foster, 1957, p. 67). The Yeso formation is exposed along the eastern side of the hogback in the McGaffey fault zone and in a small area in Grasshopper Canyon, where the axis of

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the anticlinal bend of the Nutria monocline has been deeply cut by erosion. The lower half of the Yeso is not exposed in Grasshopper Canyon. Faulting may have removed a portion of the lower Yeso in the McGaffey fault zone. In both of these locations the Yeso is steeply dipping and forms a slope that is protected by the more resistant Glorieta sandstone above. Exposures are fair to poor in these areas because of partial coverage by talus derived from the Glorieta sandstone.

The Yeso formation rests conformably on the Abo below. At the base of the Yeso, 80 feet or more (Anonymous, 1959, p. 64) of cross-bedded, fine-grained, orange to orange-brown sandstone form the Meseta Blanca member. Above this the Yeso consists of a medium-grained, buff to brown sandstone interbedded with very thin bedded to medium-bedded, orange to orange-brown siltstone. Near the middle of the formation are three or more thin-bedded, dense crystalline, gray limestone beds. Each limestone is about 10 feet thick. The upper part of the Yeso formation consists of buff to brown sandstone interbedded with very thin bedded to medium-bedded, bright orange-brown siltstone. The sandstone content of the formation increases upward.

The Yeso formation is probably a marine deposit. Its greatest thickness in west-central New Mexico is in the Quemado-Cuchillo trough, which lies southwest of the Zuni Mountains (Foster, 1957, p. 67). The increase in sandstone upward in the Yeso indicates the growing dominance of a near-shore environment and a possible retreat of the

the anticlinal bend of the [illegible] had been deeply cut by erosion. The lower half of the Yeso is not exposed in Grasshopper Canyon. Faulting may have removed a portion of the lower Yeso in the [illegible] fault zone. In most of these locations the Yeso is [illegible] and forms a slope that is protected by the more resistant Glorieta sandstone above. Exposures are relatively poor in these areas because of partial covering by talus derived from the Glorieta sandstone.

The Yeso formation [illegible] on the [illegible]. At the base of the Yeso, 58 feet [illegible] (Longgood, 1950, p. 64) of cross-bedded, fine-grained, [illegible] to orange-brown sandstone form the Meseta Blanca member. Above this the Yeso consists of a medium-grained, [illegible] to brown sandstone interbedded with very thin-bedded to medium-bedded, orange to orange-brown siltstone. Near the middle of the formation are three or more thin-bedded, dense crystalline, gray limestone beds. Each limestone is about 11 feet thick. The upper part of the Yeso formation consists of buff to brown sandstone interbedded with very thin-bedded to medium-bedded, bright orange-brown siltstone. The sandstone content of the Formation increases upward.

The Yeso Formation is probably a shallow deposit. Its greatest thickness in east-central New Mexico is in the [illegible] trough, which lies southwest of the [illegible] Mountains (Foster, 1959, p. 57). The increase in sandstone upward in the Yeso indicates the growing dominance of a near-shore environment and a possible retreat of the

sea; although the lack of continental sediments, or of a noticeable unconformity, would seem to indicate that the sea did not withdraw completely.

Glorieta Sandstone

The Glorieta sandstone was named for exposures on Glorieta Mesa in Santa Fe County, New Mexico by C. R. Keyes (1915, p. 257). A thickness of 300 feet was measured at McGaffey by Read (1961, oral communication). The Glorieta is a hard and resistant, cliff-forming sandstone. It apparently has a fairly uniform thickness throughout the area. Long, uniform dip slopes occur on the Glorieta in some places. The Glorieta is exposed along the crest of anticline A-1 between McGaffey and Stinking Springs, with an area of exposure of about 6 square miles. Dips are generally gentle in this area, although they steepen near the Nutria monocline. In many places soil has been stripped from the surface of the Glorieta and the land surface may follow the exposed bedding surfaces for several hundred feet. The Glorieta is exposed along several steep-walled canyons in the central part of the area, including the spectacular Nutria Canyon. The Glorieta sandstone also forms the crest of the hogback along the McGaffey fault zone.

The Glorieta sandstone is conformable on, and gradational with the underlying Yeso formation. This contact

sea; although the lack of continental sediments, or of any noticeable unconformity, would seem to indicate that the sea did not withdraw completely.

Glorieta Sandstone

The Glorieta sandstone was named for exposures at Glorieta Mesa in Santa Fe County, New Mexico by K. H. Keyes (1915, p. 257). A thickness of 200 feet was measured at McGaffey by Read (1951, oral communication). The Glorieta is a hard and resistant, cliff-forming sandstone. It apparently has a fairly uniform thickness throughout the area. Long, uniform dip slopes occur on the Glorieta in some places. The Glorieta is exposed along the crest of anticline A-1 between McGaffey and Thirty Springs, with an area of exposure of about 5 square miles. Dips are generally gentle in this area, although they steepen near the Nutria monocline. In many places soil has been stripped from the surface of the Glorieta and the land surface may follow the exposed bedding surface for several hundred feet. The Glorieta is exposed along several steep-walled canyons in the central part of the area, including the spectacular Nutria Canyon. The Glorieta sandstone also forms the crest of the hogback along the McGaffey fault zone.

The Glorieta sandstone is conformable and gradational with the underlying Yeso formation. This contact

is somewhat arbitrarily placed where the sandstone of typical Glorieta lithology predominates over the interbedded orange siltstone of the Yeso. The Glorieta is a massive pure quartzose, white to buff sandstone that weathers orange, brown, and gray. Crossbedded layers may alternate with even-bedded layers, particularly in the middle portion. It is fine- to medium-grained, very well sorted, and slightly micaceous, with occasional limonite nodules up to one-half inch in diameter. These nodules possibly account for the buff or brown color on the weathered surface. The Glorieta becomes somewhat harder and better cemented upwards.

The Glorieta may be a marine sandstone deposited as near-shore and bar sediment. The extreme purity and sorting indicate much winnowing, possibly due to wave-action, and deposition in shallow water. The configuration of the bars of the Glorieta may have exerted some controls upon the evaporitic Permian sediments to the southeast (Read, 1961, oral communication). However, the excellent sorting and rounding may indicate an eolian origin.

San Andres Limestone

The San Andres limestone was named for exposures in the northern San Andres Mountains of New Mexico by Lee (1909, p. 23). The San Andres is made up of three units,

is somewhat arbitrarily placed where the sandstone of typical Glorieta lithology predominates over the irregular-bedded orange siltstone of the Yeso. The Glorieta is a massive pure quartzose, white to buff sandstone that weathers orange, brown, and gray. Cross-bedded layers may alternate with even-bedded layers, particularly in the middle portion. It is fine- to medium-grained, very well sorted, and slightly siliceous, with occasional limonite nodules up to one-half inch in diameter. These nodules possibly account for the light brown color on the weathered surface. The Glorieta becomes somewhat denser and better cemented upward.

The Glorieta may be a marine sandstone deposited as near-shore and bar sediments. Uniformity of grain size and sorting indicate much winnowing, possibly due to wave action, and deposition in shallow water. The restriction of the bars of the Glorieta may have exerted some control upon the evaporitic Permian sediments of the southeast (Read, 1951, oral communication). However, the excellent sorting and rounding may indicate an eolian origin.

San Andres Limestone

The San Andres limestone was named for exposures in the northern San Andres Mountains of New Mexico by Lee (1909, p. 23). The San Andres is made up of three units,

a lower fossiliferous limestone, a medial sandstone, and an abundantly fossiliferous upper limestone. The thickness of the San Andres limestone in the area is extremely variable. Pre-Chinle erosion has removed a part, and locally all, of the San Andres over most of the area. However, the San Andres has a maximum thickness of slightly more than 100 feet and probably was at least that thick over all the report area at the conclusion of its deposition.

The San Andres is very resistant under the present semiarid weathering conditions and forms long and gentle dip-slopes throughout much of the area. Along the Nutria monocline, the dips steepen to as much as 60°. The resulting dip-slope extends from the higher elevation east of the monocline down to the level of the Chinle strike valley. Exposures are poor to excellent, depending on the amount of Chinle sediment on the surface of the San Andres. Although nearly 20 square miles of the area are mapped as San Andres limestone, much of the outcrop appears to consist of a very thin residual veneer of Chinle sediment. However, knobs of San Andres control the level of the land surface in this area, and the Chinle lies in the solution swales of the limestone.

The San Andres limestone appears to be conformable with the underlying Glorieta sandstone. The lower limestone bed is 25 to 30 feet thick. It is finely crystalline, fossiliferous, and gray, weathering gray to red-brown with

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The San Andres limestone appears to be conformable with the underlying Glorieta sandstone. The lower limestone bed is 25 to 30 feet thick. It is finely crystalline, fossiliferous, and gray, weathering gray to yellowish brown.

abundant solution cavities on the weathered surface. Some edgewise conglomerate is present locally at the base. The most abundant fossils are pelecypods, gastropods, cephalopods, and brachiopods. A sandstone bed about 20 feet thick overlies the lower limestone. This sandstone is somewhat softer than the limestone and is similar to the Glorieta in lithology. Above this sandstone lies a bed of hard, massive, finely to coarsely crystalline, gray to pink limestone that weathers gray and has many solution cavities on its surface. This bed may be as much as 60 to 65 feet thick but is commonly less owing to the karst surface developed on it. It is abundantly fossiliferous, with the fossils tending to weather more rapidly than the limestone. The fossils appear to be marine. Brachiopods, pelecypods, gastropods, and cephalopods predominate. Much of the limestone of this upper bed has been altered to a very coarsely crystalline calcite. Many fossils are selectively replaced by this material.

The limestone beds of the San Andres formation seem to indicate a period of deposition that lacked appreciable clastic sediment in the area. The source areas of the Yeso and Glorieta formations had probably been reduced to a low level by San Andres time. Although the sea receded somewhat during the deposition of the Glorieta, the lack of an appreciable unconformity at the Glorieta-San Andres contact and the intertonguing relationship of these two formations

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in the southeastern part of the Zuni Mountains (Anonymous, 1959, p. 63) suggests that the sea did not withdraw completely. Smith (1957, p. 55) believed that the San Andres represented the deposits of a shallow shelf which connected the Permian seas of West Texas with the Cordilleran geosyncline.

Triassic Rocks

The Triassic sediments along the Nutria monocline may be assigned to two formations, Chinle and overlying Wingate. The Triassic rocks of the area are a bright red and orange sequence of clastics. Their total thickness may be as much as 2000 feet, although accurate measurements were unavailable. Of this a maximum of 600 feet is sandstone and nearly all the rest is siltstone or claystone. Limestone may be present locally in minor amounts.

Chinle Formation

The Chinle formation was originally named by Gregory (1917, p. 42) for exposures in northeastern Arizona. Along the Nutria monocline the Chinle formation is divisible into three members that cannot be readily correlated with Gregory's four-fold division (Smith, 1957, p. 56). This three-fold division of the Chinle is believed to be the most natural in this area and is used in this report. The lower member is composed of fine-grained sandstone, siltstone, and shale; the middle member is composed of sandstone

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and conglomerate; and the upper member consists of tuffaceous shale, siltstone, and a few sandstone beds. The beds of all three members are lenticular and exhibit lateral variation within short distances.

The Shinarump conglomerate occurs only as channel-filling deposits in the Zuni Mountains and not as a mappable member of the Chinle formation (Cooley, 1959, p. 69). Beds that have been mapped as Moenkopi by previous workers are thought to be somewhat younger than the type Moenkopi and were described as upper Moenkopi(?) by Cooley (1959, p. 68-69). Because the upper Moenkopi(?) is of very irregular thickness, its occurrence is doubtful over much of the mapped area, and this interval has been included with the lower Chinle formation in this report.

The lower member ranges from 300 to 500 feet in thickness within the area (Smith, 1957, p. 56). This variation is due to the extensive karst surface and irregular thickness of the underlying San Andres limestone. The middle member ranges from 110 to 200 feet in the Zuni Mountains (Smith, 1957, p. 56), although it is not completely exposed anywhere within the mapped area. Owing to the lenticularity of the channel-type deposits of this member, irregular thicknesses are the rule. The upper member is by far the thickest of the three. Smith (1957, p. 56) has found a thickness of 1400 feet along the southwestern side of the Zuni Mountains. Due to the fact that some of the formation

and conglomerate; and the upper member consists of bentonitic shale, siltstone, and a few sandstone beds. The beds of all three members are lenticular and exhibit lateral variation within short distances.

The Shinarump conglomerate occurs only as channel-filling deposits in the Zuni Mountains and not as a separate member of the Chinle formation (Cooley, 1959, p. 69). Beds that have been mapped as Moenkopi by previous workers are thought to be somewhat younger than the type Moenkopi and were described as upper Moenkopi(?) by Cooley (1959, p. 68-69). Because the upper Moenkopi(?) is of very irregular thickness, its occurrence is doubtful over much of the mapped area, and this interval has been included with the lower Chinle formation in this report.

The lower member ranges from 300 to 520 feet in thickness within the area (Smith, 1957, p. 56). This variation is due to the extensive karst surface and irregular thickness of the underlying San Andres limestone. The middle member ranges from 110 to 300 feet in the Zuni Mountains (Smith, 1957, p. 56), although it is not completely exposed anywhere within the mapped area. Owing to the lenticularity of the channel-type deposits of this member, irregular thicknesses are the rule. The upper member is by far the thickest of the three. Smith (1957, p. 55) has found a thickness of 1400 feet along the northeastern side of the Zuni Mountains. Due to the fact that none of the formation

has been omitted by faulting over much of the report area, thickness determinations were impossible.

With the exception of the middle sandstone member, the Chinle formation is a weak slope-and-valley former throughout the area. The Chinle forms a well-defined strike valley immediately east of the hogback along the Nutria monocline. The outcrop and the strike valley widen in the southern part of the area where the dips are less steep. The lower and upper members are very weak and easily eroded, but in some places the middle member caps mesas or forms cuestas. Slumping commonly is present where the lower member is near or at the surface. The middle member frequently exhibits erratic dips where flowage has occurred in the underlying lower member.

The lower member rests on the San Andres limestone with marked unconformity. A karst surface with an average relief of about 25 feet was developed on the San Andres prior to the deposition of the Chinle. Locally, the entire San Andres has been removed by pre-Chinle erosion and the Chinle rests directly on the Glorieta sandstone. The contact between the San Andres and the Chinle was selected as the general level of the tops of the knobs of San Andres limestone that were left after the pre-Chinle erosion. Thus, large areas of surficial lower Chinle is included on the map (Fig. 2) with the San Andres as pockets filling the karst surface on the limestone. A more detailed map would show a good many of

these pockets, but much time would be consumed in detailing the smaller pockets of Chinle that do not show up readily on aerial photographs. Because the land surface closely follows the contact selected by the writer, a vertical change in its selection of a few feet might move its position laterally for more than a mile.

The basal part of the lower member consists of gray and tan sandstone. This sandstone is fine- to coarse-grained, even-bedded and cross-bedded, generally thin-bedded and micaceous. Interbedded with the sandstone is some red, green, gray, and tan siltstone. Occasional lenses of chert pebble conglomerate are also found in the lower part of this member. Although the base of the lower member usually consists of sandstone, locally the sandstone is of minor importance or absent, and the siltstone rests directly on the San Andres limestone. Upward the lower member becomes fine-grained, with red, white, purple, gray and tan tuffaceous and bentonitic siltstone and claystone predominating. Weathering of the siltstone and claystone units is extremely rapid, and weathered material commonly conceals the bedding. Although the upper part of this member is predominantly fine-grained, local lenticular, cross-bedded, tan sandstone and chert pebble conglomerate beds may be found. Isolated chert pebbles may be found throughout this member.

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The base of the middle member of the Chinle is chosen where the first continuous sandstone is encountered above the siltstone and claystone beds of the lower member. The middle member commonly consists of fine- to coarse-grained, poorly sorted to well sorted, micaceous, cross-bedded, tan and gray sandstone and chert pebble conglomerate beds. These are interbedded with thin red and gray siltstone units. A few calcareous zones and sandy limestone conglomerates are present. The sandstone units may be thin-bedded to massive but are not commonly more than 20 feet thick. Beds of this member are somewhat lenticular and commonly display rapid lateral changes of grain size. Petrified wood is common in parts of this member, and a few pelecypods were found, particularly in the calcareous units.

The upper member of the Chinle is conformable with the middle member. The contact is usually gradational. This member consists of variegated tuffaceous and bentonitic siltstone and claystone, with occasional cross-bedded, tuffaceous, tan sandstone. The upper part of this member is slightly calcareous with a lenticular zone of limy nodules near the top. However, this zone of limestone nodules was not observed to form a bed of limestone anywhere within the report area. Petrified wood occurs locally in the lower half of this member. Owing to the extreme softness of this member, it is very poorly exposed. The beds are usually very lenticular.

The base of the middle member of the Chinle is drawn where the first conglomerate bed is encountered above the siltstone and claystone of the lower member. The middle member commonly consists of fine- to coarse-grained, poorly sorted to well sorted, micaceous, cross-bedded, tan and gray sandstone and quartz pebble conglomerate beds. These are interbedded with red and gray siltstone units. A few calcareous zones and many limestone conglomerates are present. The sandstone units may be thick-bedded to massive but are not commonly more than 20 feet thick. Units of this member are somewhat lenticular and commonly display rapid lateral changes in grain size. Petrified wood is common in parts of this member, and a few pelecypods were found, particularly in the calcareous units.

The upper member of the Chinle is conformable with the middle member. The contact is usually gradational. This member consists of variegated but mostly red calcareous siltstone and claystone with occasional interbedded tuffaceous, tan sandstone. The upper part of this member is slightly calcareous with a lenticular zone of limestone nodules near the top. However, this zone of limestone nodules was not observed to form a bed of limestone anywhere within the report area. Petrified wood occurs locally in the lower half of this member. Owing to the extreme softness of this member, it is very poorly exposed. The beds are usually very lenticular.

The Chinle formation was deposited as a thick blanket on a plain of low relief that sloped to the west (Parker, 1957, p. 74). The sea lay far to the west, in Nevada and California. Cross-bedding studies in the middle member and some of the sandstone beds of the upper member reveal that drainage was northward, thus indicating that the Mogollon highland to the south was contributing sediment to the Chinle (Cooley, 1959, p. 71). The presence of petrified wood and reptile remains (Gregory, 1917, p. 47) within the Chinle could indicate a warm and somewhat moist climate. Streams meandered across the area, and the presence of limestone in the middle member may indicate that lacustrine conditions were locally present at times.

Wingate Formation

The Wingate formation was originally named by Dutton (1885, p. 137) for the orange-red cliffs that form the northern side of the Rio Puerco Valley at Fort Wingate. He included all the sediments between the limestone in the upper Chinle and the Todilto limestone in the Wingate formation. However, this writer has followed the recommendation of Harshbarger, Repenning, and Irwin (1957, p. 8) and included only the lower portion of that interval, along with the Chinle "A" of Gregory, in the Wingate formation.

The Wingate formation consists of two members, the lower Rock Point member, mainly of siltstone, and

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The Wingate formation consists of two members, the lower Rock Point member, mainly of siltstone, and

the upper Lukachukai member, which is mainly sandstone and conglomerate. The Lukachukai is the only member present north of the mapped area. It thins southward along the monocline and pinches out immediately south of the mapped area. The Rock Point member is not exposed north of Little Bear Spring but thickens southeastward along the strike in the mapped area. No attempt was made to separate these members on the map (Fig. 2).

The Wingate formation is poorly exposed along the base of the eastern side of the hogback. Nowhere along the monocline is all of the Wingate exposed, although a nearly complete exposure is afforded near Little Bear Spring. The lower part of the formation is nearly always covered by alluvium.

The contact of the Rock Point member with the underlying Chinle formation is gradational, where exposed. The Rock Point consists of bright orange-red siltstone and some interbedded sandstone. These are thin- and even-bedded. The Rock Point member tends to be very soft and friable throughout its limited exposures along the monocline. The Rock Point is 31 feet thick near Little Bear Spring, and does not appear to exceed 60 feet anywhere along the monocline, although accurate thicknesses were unavailable because of the very poor exposures.

The contact between the Rock Point member and the overlying Lukachukai member is marked by an orange-brown, silty, chert pebble conglomerate. This is about 3 feet

the upper Lukachukai member, which is mainly sandstone and conglomerate. The Lukachukai is the only member present north of the mapped area. It thins southward along the monocline and pinches out immediately south of the mapped area. The Rock Point member is not exposed north of Little Bear Spring but thickens southeastward along the strike in the mapped area. No attempt was made to separate these members on the map (Fig. 2).

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The contact between the Rock Point member and the overlying Lukachukai member is marked by an orange-brown silty, chert pebble conglomerate. This is about 2 feet

thick and is deposited on a scoured surface with about 6 inches of relief. A few siltstone beds occur in the lower 25 feet of the Lukachukai member, and indicate a probable intertonguing relationship with the Rock Point, as noted by Harshbarger, Repenning, and Irwin (1957, p. 7). The Lukachukai is predominantly massive, cross-bedded, well sorted, fine- to medium-grained, orange-brown sandstone. A few lenses of conglomerate are found in scoured surfaces of the lower half of the formation. These contain rounded chert and jasper pebbles with sparse limestone and quartzite fragments. Locally, the conglomerate may be very coarse, with rounded cobbles up to 5 inches in the longest dimension. The sandstone of the Lukachukai contains calcareous zones, and thin veinlets of white calcareous sandstone are common along the joints. The Lukachukai member of the Wingate thins from a maximum of 113 feet near Little Bear Spring to probably less than 50 feet at the southern edge of the mapped area.

The Rock Point member is thought to have been deposited in a shallow basin that was centered in east-central Arizona and deepened to the south (Harshbarger, Repenning, and Irwin, 1957, p. 23). However, Cooley (1959, p. 72) believed that the Rock Point member is lacustrine. In any event, the Rock Point member is a quiet-water deposit that marked the first downwarping of the basin that was to become the site of deposition of the Glen Canyon group. The Zuni Mountain area is thought to be very near the eastern edge of the Rock Point basin, for the Rock Point member thins eastward in this area, and pre-Lukachukai erosion appears to be of a very minor nature.

thick and is deposited on a scoured surface with about 1 [illegible] inches of relief. A few siltstone beds occur in the lower [illegible] feet of the Lukachukai member, and indicate a possible inter-tonguing relationship with the Rock Point, as noted by Harsh-barger, Repenning, and Irwin (1957, p. [illegible]). The Lukachukai is predominantly massive, cross-bedded, well-sorted, fine- to medium-grained, orange-brown sandstone. A few lenses of con-glomerate are found in scoured surfaces of the lower unit of the formation. These contain rounded chert and jasper pebbles with sparse limestone and quartzite fragments. Locally, the conglomerate may be very coarse, with pebbles [illegible] up to 5 inches in the longest dimension. The sandstone of the Lukachukai contains calcareous zones, and [illegible] of white calcareous sandstone are common along the joints. The Lukachukai member of the Wingate ranges from a maximum of [illegible] feet near Little Bear Spring [illegible] to [illegible] feet at the southern edge of the mapped area.

The Rock Point member [illegible] have been deposited in a shallow basin that was centered in [illegible] Arizona and deepened to the south (Harshbarger, Repenning, and Irwin, 1957, p. 23). However, Cooley ([illegible], p. [illegible]) believes that the Rock Point member is [illegible] the Rock Point member is a quiet-water deposit that [illegible] formed contem-[illegible] warping of the basin that [illegible] of the Glen Canyon group. [illegible] to be very near the eastern edge of the Rock Point basin, for the Rock Point member [illegible] in this area, and pre-Lukachukai [illegible] appears to [illegible] nature.

The Lukachukai is an eolian sandstone (Stewart, et al., 1957, p. 350) that formed as dune sand around the borders of the Rock Point basin. As the water retreated westward in an oscillatory manner, sand dunes spread across the basin, interfingering with the last stages of the Rock Point (Harshbarger, Repenning, and Irwin, 1957, p. 23). Thus, the basal Lukachukai in the Zuni Mountains is probably older than the same horizon to the west. The lenticular conglomerate probably represents stream channels draining into the Rock Point basin.

Jurassic Rocks

The Jurassic section in the area may be divided into three formations, Entrada, Zuni, and Morrison. The Jurassic rocks are brightly colored and form massive cliffs along the Nutria monocline. They are more than 700 feet thick within the area and all but about 120 feet is eolian sandstone. Locally, as much as 60 feet is claystone or siltstone. Non-eolian sandstone beds make up the remainder of the section. The Todilto limestone and the lower member of the Thoreau formation which are present near Fort Wingate pinch out southward and were not observed in the mapped area.

Entrada Formation

The Entrada formation was originally named in 1928 by Gilluly and Reeside for exposures in San Rafael Swell in

southern Utah. The silty interval below the cliff-forming sandstone at Fort Wingate was assigned to the middle member of the Entrada formation by Harshbarger, Repenning, and Irwin (1957, p. 37). The cliff-forming sandstone at Fort Wingate, heretofore regarded as Entrada, was found by this writer to be continuous with the Zuni sandstone in the area, and is discussed as a part of that formation in this report.

The Entrada formation is a thin unit that lies at or near the base of the east hogback of the Nutria monocline. Thicknesses range from 12 feet at the northern boundary of the report area to a feather edge a short distance north of Upper Nutria.

The Entrada lies on the Wingate formation with slight unconformity. The contact has a maximum observed relief of about 6 inches in the report area. Nowhere were any conglomeratic materials associated with this contact, although some reworked sand, apparently from the Wingate, was observed in the lower 2 feet of the formation. The Entrada formation consists of comparatively homogeneous even-bedded, bright reddish-orange, very fine grained and silty sandstone. The formation exhibits little lithologic variation either laterally or vertically, except for the few larger sand grains incorporated at the base. The contact with the overlying Zuni sandstone appears to be either conformable or gradational everywhere.

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The Entrada formation represents an advance of the sea from the northwest. The even bedding and good sorting indicate that is was probably deposited in a shallow-water, near-shore environment (Harshbarger, Repenning, and Irwin, 1957, p. 44). The absence of an unconformity at the top of the Entrada probably indicates that this is the depositional edge of the formation. Although the Entrada rests on a slight unconformity, it is not at all certain what length of time is represented by this hiatus. It is possible that this break represents the entire upper part of the Glen Canyon group farther west. However, as water advanced over the Wingate sand dunes, it would tend to level their undulatory surface. Because transgressing seas leveling an unconsolidated dune would produce exactly the same effect regardless of the age of the dune, this unconformity may be merely a depositional break and, thus, represents practically no time. Thus, the Wingate sandstone may represent, in part, much younger units than does the Wingate to the west.

Zuni Sandstone

The Zuni sandstone was first described by Dutton in 1885 (p. 137) for the exposures in the cliffs north of Fort Wingate. It thickens southward from the northern edge of the report area along the monocline. Although no thicknesses were measured south of a point 3 miles southeast of Upper Nutria, the Zuni must thin farther to the southeast

The Entrada formation [illegible] sediments of the sea from the northeast. The even bedding and good sorting indicate that it was probably deposited in a quiet-water, near-shore environment (Harshbarger, Repenning, and Irwin, 1957, p. 46). The absence of an unconformity at the top of the Wingate probably indicates that it is the depositional edge of the formation. Although the Entrada marks such a slight unconformity, it is not at all certain what length of time is represented by this hiatus. It is possible that this break represents the entire upper part of the Glen Canyon group farther west. However, as water advanced over the Wingate sand dunes, it would tend to level their undulatory surface. Because transgressing seas leveling an unconsolidated dune would produce exactly the same effect regardless of the age of the dune, this unconformity may be merely a depositional break and, thus, represents practically no time. Thus, the Wingate sandstone may represent, in part, much younger units than does the Wingate to the west.

Zuni Sandstone

The Zuni sandstone was first described by Dutton in 1885 (p. 137) for the exposures in the cliffs north of Fort Wingate. It extends southward from the northern edge of the report area along the [illegible]. Although no thicknesses were measured [illegible] of [illegible] [illegible] [illegible] of Upper Entrada, the [illegible] [illegible] [illegible] the southeast

as a thickness of approximately 200 feet is reported at El Morro, 11 miles southeast of Ramah (Smith, 1959, p. 76). The formation appears to be of intermediate thickness east of Ramah. The Zuni sandstone was measured near Little Bear Spring, where it is 598 feet thick. The formation is 735 feet thick in sec. 6, T. 12 N., R. 16 W., 3 miles north of Nutria. A thickness of 783 feet was observed in sec. 28, T. 12 N., R. 16 W. The change in the direction of thinning may be explained by the removal of progressively older sediments southward by pre-Dakota(?) erosion, combined with the inclusion of more Morrison-equivalent sands in the Zuni to the south.

The Zuni sandstone forms a colorful red, orange, and white slope along the eastern side of the east hogback along the monocline. It is generally well exposed throughout its length, but some areas may be covered by Dakota(?) talus, and the base of the formation is locally obscured by alluvium. The outcrop produces a slope that is convex upward and averages about 25°.

The contact of the Zuni sandstone with the underlying silty sandstone of the Entrada is gradational or conformable wherever it was observed. South of the depositional pinch-out of the Entrada, the Zuni rests directly on the Wingate formation. Although an unconformity is present between the Entrada and the Wingate, none can be detected between the Zuni and the Wingate where the Entrada is absent. Where the Entrada formation is present, the upper 50 feet or so

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of the Wingate consists of a sandstone that is very similar, if not identical, in lithology to the Zuni sandstone. South of the Entrada pinch-out, the contact between the Wingate and the Zuni is placed at the highest conglomerate of the Wingate, a horizon which appears as much as 50 feet below the Entrada to the north.

The Zuni sandstone consists of massive, extensively cross-laminated, friable, red, red-orange, and white beds. It is very well sorted throughout, with fine- to medium-sized grains. These grains are almost entirely quartz and range from subangular to well rounded. At least 75 percent of the grains are frosted. The grain size is comparatively uniform throughout the lower three-quarters of the formation, but increases irregularly to coarse sand size, accompanied by increasing angularity, in the upper one-quarter. Horizontal bedding planes are uncommon or almost entirely lacking in the Zuni, and in a small zone near the top of the formation, bedding of any sort is absent. The cement of the Zuni sandstone is irregularly calcareous, with calcareous zones occasionally occurring along foreset beds and sometimes cutting across all bedding. Calcareous material has apparently been introduced along irregular fractures resulting in the formation of veinlets of calcareous sandstone throughout the entire formation. These veinlets tend to weather in relief.

of the Wingate consists of a sandstone that is very similar, if not identical, in lithology to the Zuni sandstone. North of the Entrada pinch-out, the contact between the Wingate and the Zuni is placed at the highest conspicuous bench of the Wingate, a horizon which appears as much as 50 feet below the Entrada to the north.

The Zuni sandstone consists of massive, structureless cross-laminated, friable, red, red-orange, and white beds. It is very well-sorted throughout, with fine- to medium-sized grains. These grains are almost entirely quartz and range from subangular to well rounded. At least 75 percent of the grains are frosted. The grain size is comparatively uniform throughout the lower three-quarters of the formation, but increases irregularly to coarse sand size, accompanied by increasing angularity, in the upper one-quarter. Horizontal bedding planes are uncommon or almost entirely lacking in the Zuni, and in a small zone near the top of the formation, bedding of any sort is absent. The cement of the Zuni sandstone is irregularly calcareous, with calcareous zones occasionally occurring along foreset beds and sometimes cutting across all bedding. Calcareous material has apparently been introduced along irregular fractures resulting in the formation of veinlets of calcareous sandstone throughout the entire formation. These veinlets tend to weather in relief.

The color of the Zuni sandstone is apparently secondary and is the result of coatings of hematite on the surface of some of the sand grains. Other grains adjacent to these coated grains have been stained a light orange, and grains at a greater distance from the coated grains remain white. The lower part of the formation is a uniform reddish orange color. This reddish orange portion of the Zuni amounts to two-thirds of the formation at the northern boundary of the mapped area and one-third of it at the southern boundary. The coloration is caused by a fairly uniform spacing of the hematitic coatings. Above this is a comparatively light-colored zone in which the coatings are much less common. In the southern part of the area, the contact between these two zones is a fairly sharp, slightly undulating line on the outcrop surface (Fig. 3), which has previously been selected as the contact between the Entrada formation and the Zuni sandstone (Smith, et al., 1959b, p. 47). Cross-laminations do not cross this color change. North of sec. 28, T. 12 N., R. 16 W. the change becomes gradational, and the dividing line, where it is present at all, is intermittent both horizontally and vertically and is much less sharp. Above the light-colored zone, the Zuni is mottled and banded with deep red and pure white areas. The red is the result of a concentration of hematitic coatings, and the white is due to the absence of such coatings. These red and white areas are irregular in occurrence and do not appear to be related to the bedding.

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Figure 3. Abrupt color change in the Zuni sandstone.

The contact between the red and white mottling and the light-colored zone below is as completely irregular as the red and white colors themselves.

The Zuni sandstone is considered to be an eolian sand because of its high degree of frosting and excellent sorting. It was deposited along the southern and western sides of the San Rafael basin and the north slope of the Mogollon highland (Harshbarger, Repenning, and Irwin, 1957, p. 50). The Zuni sand dunes were active during the deposition of the Entrada, Todilto, and lower Thoreau formations, and at least the lower part of the Morrison formation, for the Zuni is seen to grade into, or intertongue with, all of these. During times when the San Rafael basin was dry, the dunes advanced northward across the basin. The climate during the deposition of the Zuni sandstone must have been extremely dry to account for the widespread deposition of large sand dunes of long duration.

Because of the lack of observed angularity in the contact between the Wingate and the Entrada, and because the upper eolian sands of the Wingate may be continuous with the Zuni dunes in this area, the possibility that at least a part of the Wingate sand is associated with the San Rafael group should not be overlooked. However, it is also possible that pre-existing Wingate dunes were reworked during San Rafael time, in which case, the reworked material may be logically considered as a part of the Zuni

and contact between the [illegible] and the
[illegible]
[illegible]

The fault contacts [illegible]
[illegible] section.
It was [illegible] along the southern [illegible] of
the San Rafael basin and the south slope of the [illegible]
district [illegible]
[illegible] during the deposition of
the [illegible] formation, [illegible]
[illegible] formation, [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
large [illegible] location.

Because of the lack of [illegible] in the
contact between the [illegible] and the [illegible], and because
the upper [illegible]
[illegible] in this area, [illegible]
[illegible] with the
[illegible]
[illegible] possible that [illegible]
[illegible]
[illegible]

sandstone, and only those sands that were separated from the Zuni by the Entrada could be considered as Wingate.

The change in color on the outcrop that was mentioned previously is believed to be the result of a zone of water saturation associated with the Todilto basin. As the Todilto waters advanced over the sloping, dune-covered surface of the Mogollon highland, they tended to rework and level the undulating dune surface (Ash, 1958, p. 18). However, a water table would be present in the dunes beyond the margins of the basin at approximately the same level as the water in the basin (Fig. 4). Because the wind cannot move wet sand nearly as easily as dry sand, the top of this water table would be a stabilized surface over which the remaining dry sand could freely move. Hence, no cross-laminations are observed to cross the line of color change in the Zuni sandstone. In the basin, but nearer to shore than where the limestone was being deposited, wave-action would constantly rework the sand, while additional sand would be blown in from the shore. Thus, no sharp change could be seen between the shore area and the area of limestone deposition. The waters are postulated to have contained some iron and to have deposited some of it in the sand. The fact that color is spread more or less evenly throughout the sand below the color change is also indicative of a comparatively stationary depositional agent such as would be found beneath a water table. The sand that was above the zone of saturation received no such even coloration.

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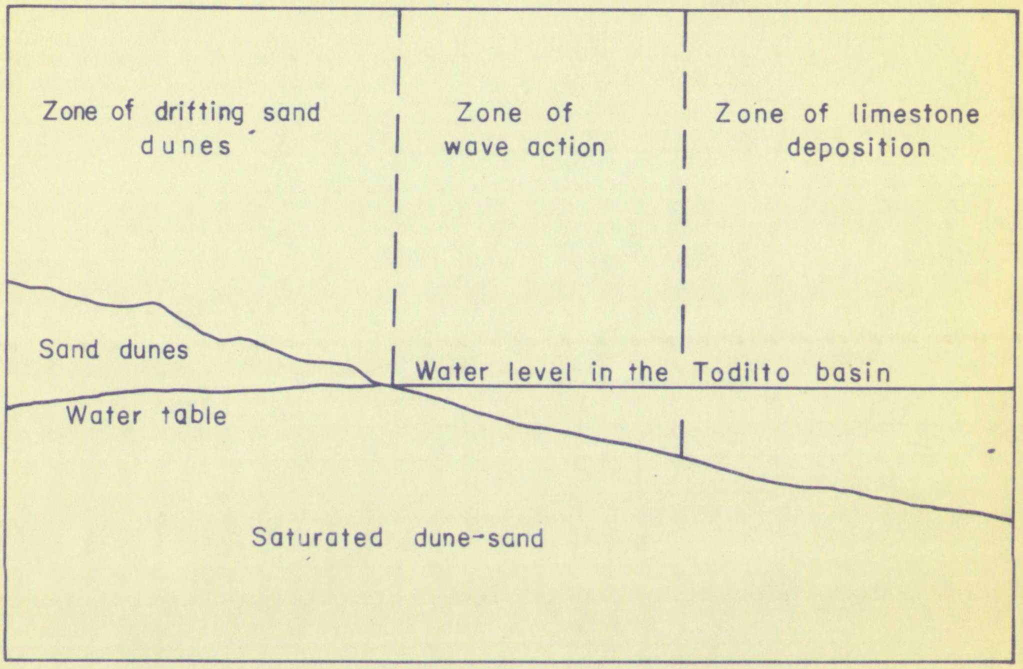

Figure 4. Relationship of the water table in the Zuni dune-sand to the water in the Todilto basin.

Morrison Formation

The Morrison formation was first described by Cross in 1894 (p. 2) near the town of Morrison in eastern Colorado. Along the north flank of the Zuni Mountains, the Morrison has been divided into three members (Rapaport, et al., 1952, p. 14), but because of the thinning of the formation in a southerly direction, and because of the complexly intergradational relationship of the beds, no attempt has been made in this report to subdivide the formation. The Morrison is a comparatively weak formation occurring along the crest of the east hogback of the Nutria monocline. It is generally poorly exposed, owing to its softness and the fact that it is ordinarily covered by talus from the Dakota(?) sandstone.

The Morrison thins slightly to the south along the Nutria monocline, and pinches out shortly south of Upper Nutria. A thickness of 116 feet was measured near Little Bear Spring, and the formation had only thinned to 109 feet in sec. 6, T. 12 N., R. 16 W., 3 miles north of its southernmost exposure. This rather sudden termination of the Morrison can best be explained by gradation into the Zuni sandstone rather than by pre-Dakota(?) erosion.

The contact of the Morrison formation with the underlying Zuni sandstone is gradational everywhere within the report area. Selection of a contact is arbitrary. The Morrison consists of thin-bedded to massive, poorly sorted, coarse-grained, white, purple, and red sandstone, interbedded with variegated siltstone and claystone. The order

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The Morrison thins slightly to the south along the Nutria monocline, and pinches out shortly south of Upper Nutria. A thickness of 115 feet was measured near Little Bear Spring, and the formation had only thinned to 103 feet in sec. 6, T. 12 N., R. 16 W., 3 miles north of its southernmost exposure. This rather sudden termination of the Morrison can best be explained by gradation into the Zuni sandstone rather than by pre-Dakota(?) erosion.

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in which these are encountered in various exposures is not predictable, because the beds are lenticular and grade into each other very rapidly, both vertically and along the strike.

The Morrison is considered to be an alluvial deposit formed on a gentle northward-sloping surface, which, in the mapped area, consisted of dune sand. The streams that fed the area flowed to the north off the Mogollon highland through the active dunes of the Zuni (Harshbarger, Repenning, and Irwin, 1957, p. 55). The lateral, gradational relationship between the Morrison sediments and the Zuni sandstone suggests that the dunes were being actively reworked, if not actually being deposited, during the interval of time represented by the Morrison in this area. Pre-Dakota(?) erosion has removed any evidence that might have existed to indicate that the Morrison later covered all the dunes in this area.

Correlation of Some of the Triassic and Jurassic Rocks

The Upper Triassic and the Jurassic rocks have been the subject of more controversy in the geologic literature of this area than any in the entire section. The difficulty arose because a number of tenuous lithologic correlations had been attempted between this and other distant areas, thus giving rise to a nomenclature that is more difficult to understand than the rocks themselves.

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Dutton (1885, p. 137) divided the Jurassic section at Fort Wingate into two sandstones, the lower Wingate sand,

stone, and the upper Zuni sandstone, separated by a thin limestone bed. He believed that the Wingate sandstone was equivalent to the sandstone in the Vermillion Cliffs in Utah. Other workers followed this erroneous correlation, which later complicated the nomenclature. Gregory (1917, p. 55) raised the limestone to formational status, calling it the Todilto formation. Baker, Dane, and Reeside (1936, p. 44) correlated the lower part of Dutton's Zuni sandstone with the Wanakah formation and the upper part with the Morrison formation. In 1947 (p. 1668), they correlated the massive, cliff-forming Wingate sandstone of Dutton with the Entrada formation of the San Rafael group, and recommended the abandonment of Fort Wingate as the type locality. Harshbarger, Repenning, and Irwin (1957, p. 8), however, thought that the lowermost part of Dutton's Wingate correlated with the Wingate formation as used farther west, and was of Triassic age. They assigned the Chinle "A" of Gregory to the Wingate as the Rock Point member (1957, p. 5). They also assigned the silty sandstone between their Wingate formation and the cliff-forming Entrada formation to the middle member of the Entrada (1957, p. 37). This writer believes that because the length of time represented by the unconformity between the Entrada and the Wingate formations is unknown in this area, at least a part of the Wingate may be younger than the same formation to the west or vice versa.

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In 1954, Smith (p. 14) designated the rocks between the Todilto limestone and the Morrison formation as the Thoreau formation. He divided the Thoreau formation into two members, an upper sandstone and a lower silty sandstone (Fig. 5). This same interval was assigned to two different formations by Harshbarger, Repenning, and Irwin (1957, p. 42). They correlated the lower Thoreau of Smith with the Summerville formation of the San Rafael group and interpreted the cross-bedded, eolian upper Thoreau to be a tongue of the Cow Springs sandstone (Fig. 5). This writer believes that the terminology of Smith is to be preferred because of the great distance to the type locality of the Summerville. The name "upper Thoreau" has precedence over "Cow Springs."

The lower Thoreau formation and the Todilto limestone pinch out a short distance south of Fort Wingate and are not found within the mapped area. The upper cliff-forming part of the Entrada formation joins the upper Thoreau formation to form one unit, the Zuni sandstone. Thus, the cliff-forming part of the Entrada and the upper Thoreau formations near Fort Wingate are actually tongues of the Zuni sandstone (Fig. 5).

Cretaceous Rocks

The Cretaceous section along the Nutria monocline is readily divisible into four formations, Dakota(?), Mancos, Gallup, and Crevasse Canyon. All these beds are related

In 1951, Smith (p. 11) recognized the units between the Todilto limestone and the Morrison formation as the Thoreau formation. He divided the Thoreau formation into two members, an upper sandstone and a lower silty sandstone (Fig. 5). This same interval was included in two different formations by Harshbarger, Repenning, and Irwin (1957, p. 44). They correlated the lower Thoreau interval with the Summerville formation of the San Rafael group and interpreted the cross-bedded, eolian upper Thoreau to be a tongue of the Cow Springs sandstone (Fig. 5). The writer believes that the terminology of Smith is to be preferred because of the great distance to the type locality of the Summerville. The name "upper Thoreau" has precedence over "Cow Springs".

The lower Thoreau formation and the Todilto limestone pinch out a short distance south of Fort Wingate and are not found within the mapped area. The upper cliff-forming part of the Entrada formation joins the upper Thoreau formation to form one unit, the Zuni sandstone. Thus, the cliff-forming part of the Entrada and the upper Thoreau formations near Fort Wingate are actually tongues of the Zuni sandstone (Fig. 5).

Cretaceous Rocks

The Cretaceous section along the Nutria monocline is readily divisible into four formations, Dakota(?), Mancos, Gallup, and Crevasse Canyon. All these beds are gently

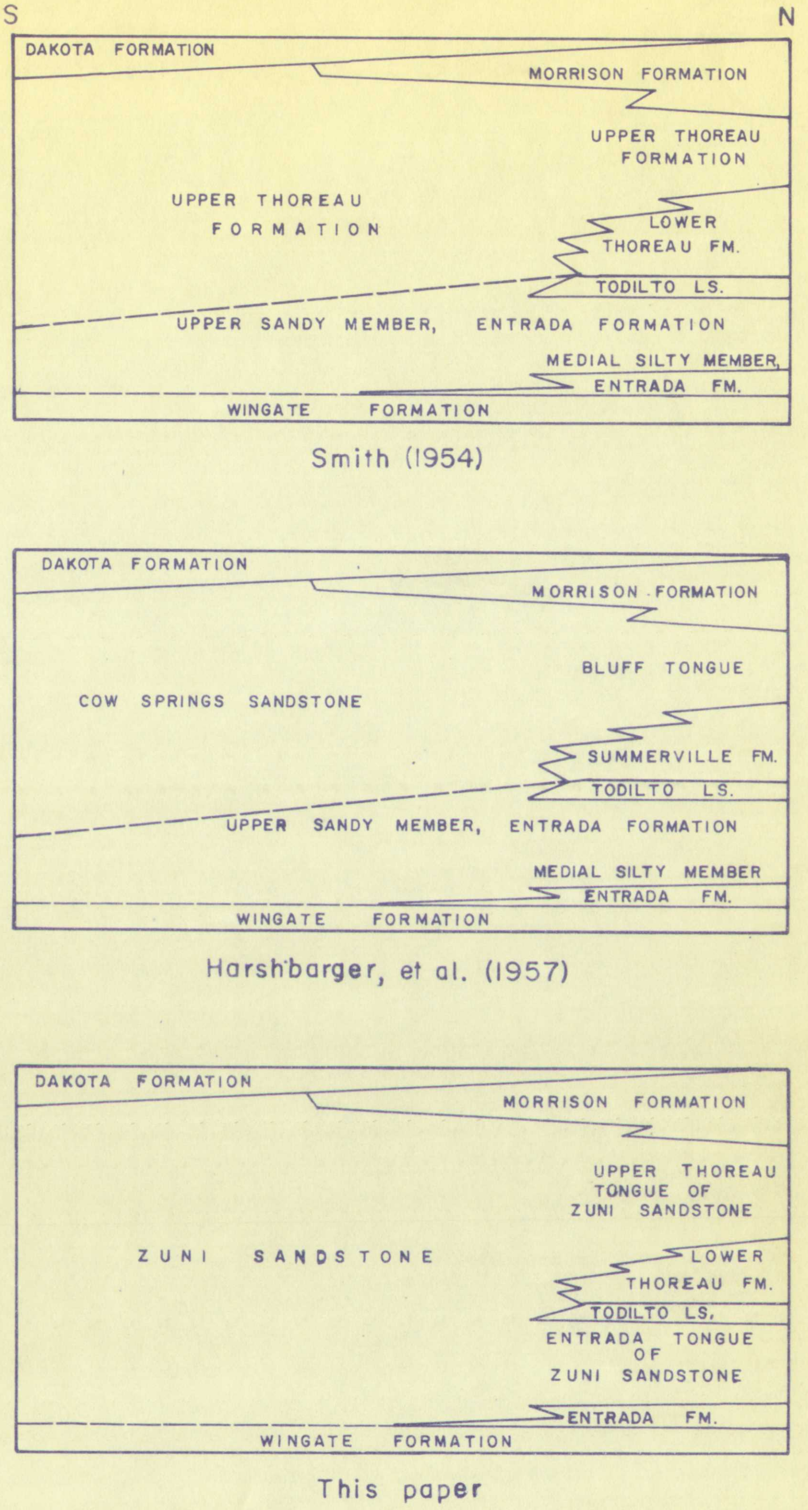

Figure 5. Stratigraphic diagrams showing suggested nomenclature and intertonguing relations of the Jurassic rocks from Fort Wingate to the vicinity of Ramah.

to a single major cycle of marine transgression and regression with several minor fluctuations. Intertonguing of the marine and nonmarine deposits is present on a large scale (Pike, 1947, p. 13). The Cretaceous rocks are almost entirely clastic and present a very drab appearance in the outcrop. The total thickness of the Cretaceous sediments in the mapped area is indeterminable because of Tertiary and Recent erosion, but a thickness of at least 1400 feet appears to be present in the northwestern corner.

Dakota(?) Sandstone

The Dakota sandstone was first described by Meek and Hayden (p. 419) in 1862 for exposures near the town of Dakota in Nebraska. The exact relationship of the Dakota(?) in the Zuni Mountains to the type Dakota is not fully known, so the basal sandstone of the Cretaceous in the report area has been designated Dakota(?) after Smith (1954, p. 18). The Dakota(?) sandstone of the Zuni Mountains is taken to be of early(?) and late Cretaceous age (Dane and Bachman, 1957, p. 98).

Along the Nutria monocline the Dakota(?) varies in thickness irregularly from less than 30 feet to approximately 130 feet within the mapped area. It is resistant and forms the crest of the east hogback along the monocline.

to a single major cycle of marine transgression and regression with several minor fluctuations. Interfingering of the marine and nonmarine deposits is present on a large scale (Pike, 1947, p. 47). The Cretaceous rocks are almost entirely clastic and present a very typical appearance in the outcrop. The total thickness of the Cretaceous sediments in the mapped area is indeterminable because of Tertiary and Recent erosion, but a thickness of at least 450 feet appears to be present in the northwestern corner.

Dakota(?) Sandstone

The Dakota sandstone was first described by Meek and Hayden (p. 419) in 1862 for exposures near the town of Dakota in Nebraska. The exact relationship of the Dakota(?) in the Zuni Mountains to the type Dakota is not fully known, so the basal sandstone of the Cretaceous in the mapped area has been designated Dakota(?) as by Smith (1954, p. 13). The Dakota(?) sandstone of the Zuni Mountains is believed to be of early(?) and late Cretaceous age (Dane and Bachman, 1957, p. 98).

Along the Nutria monocline the Dakota(?) ranges in thickness irregularly from less than 50 feet to approximately 130 feet within the mapped area. It is resistant and forms the crest of the main hogback along the monocline.

The Dakota(?) is well exposed. Its upper surface forms a steep dip slope that extends for a considerable distance below the crest of the hogback on the west side.

The Dakota(?) sandstone rests with marked unconformity on the Morrison formation in the northern two-thirds of the report area and on the Zuni sandstone in the southern one-third. Locally, the relief of this unconformity is about 5 feet, but undoubtedly is much greater when measured over a distance of several miles. The basal beds of the Dakota(?) are medium-grained sandstone and coarse conglomerate. Locally, a black and brown shale with interbedded coal rests directly on the Jurassic rocks. Uranium has been mined from this basal shaly interval where it rests on the Morrison to the north of the mapped area. Moderate radioactivity has been noted from a basal shale near Little Bear Spring (Taylor, 1961, oral communication).

The Dakota(?) commonly consists of fine- to coarse-grained, thin-bedded to massive, even- and cross-bedded, micaceous, buff to tan, orange, and brown sandstone that weathers to a gray or brown. There are sparse dark-red hematitic stains on the bedding surfaces. Interbedded with the sandstone is fissile black, brown, and gray shale with a few lenticular coal seams. The grain size decreases from the base to the top, and the sorting improves upward within the formation. The Dakota(?) is predominantly sandstone; but because the beds have a tendency to be lenticular, the number of sandstone beds may vary from place to place. The Dakota is well cemented with

The Dakota(?) is well exposed. Its upper surface forms a steep dip slope that extends for a considerable distance below the crest of the hogback on the east side.

The Dakota(?) sandstone rests with erosional unconformity on the Morrison formation in the northern two-thirds of the report area and on the Entrada sandstone in the southern one-third. Locally, the relief of this unconformity is about 15 feet, but undoubtedly is much greater when measured over a distance of several miles. The basal beds of the Dakota(?) are medium-grained sandstone and coarse conglomerate. Locally, a black and brown shale with interbedded coal rests directly on the Jurassic rocks. Uranite has been mined from this basal shaly interval where it rests on the Morrison to the north of the mapped area. Anomalous radioactivity has been noted from a basal shale near Little Bear Spring (Taylor, 1961, oral communication).

The Dakota(?) commonly consists of fine- to coarse-grained, thin-bedded to massive, even- and cross-bedded, micaceous, buff to tan, or a light gray sandstone that weathers to a gray or brown. Some are mostly dark-red hematitic staining on the bedding surfaces. Interbedded with the sandstone is fissile black, brown, and gray shale with a few lenticular coal seams. The grain size decreases from the base to the top, and the bedding tends to thin upward within the formation. The Dakota(?) is predominantly sandstone; but because the beds have a tendency to be lenticular, the number of sandstone beds may vary from place to place. The Dakota is well cemented with

siliceous and, locally, calcareous material. The Dakota(?) becomes more even-bedded upward. Many beds show evidence of ripple-marking in the upper part of the formation.

The Dakota(?) sandstone is regarded as the basal transgressive unit of an advancing Cretaceous sea. The sea transgressed from the northeast over a northeastward tilted and subsiding landmass compsed of exposed Jurassic rocks. Thus, the Dakota(?) becomes younger toward the southwest. The Dakota(?) was deposited over progressively older rocks to the southwest, but because the exposures along the Nutria monocline form an acute angle with the postulated shoreline, this relationship is not as apparent as it might be elsewhere (Pike, 1947, p. 93). A few tongues of sandstone in the lower part of the Mancos shale appear to join the Dakota(?), thus, indicating a fluctuating advance of the sea. The irregular variations in the thickness of the Dakota(?) sandstone are probably due to local variations in the pre-Dakota(?) erosion surface near and along the shoreline. The base of the formation, thus, represents fluvial and coastal-plain environments, but the upper portion is indicative of a littoral environment associated with further advance of the sea.

Mancos Shale

The Mancos shale was first described by Cross in 1899 near the town of Mancos, Colorado. Within the mapped area

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The Dakota(?) sandstone is regarded as the basal transgressive unit of an advancing Cretaceous sea. The sea transgressed from the northeast over a northeastward-tilted and subsiding landmass composed of exposed Jurassic rocks. Thus, the Dakota(?) becomes younger toward the southwest. The Dakota(?) was deposited over progressively older rocks to the southwest, but because the exposures along the Nutria monocline form an acute angle with the postulated shoreline, this relationship is not as apparent as it might be elsewhere (Pike, 1947, p. 93). A few tongues of sandstone in the lower part of the Mancos shale appear to join the Dakota(?), thus, indicating a fluctuating advance of the sea. The irregular variations in the thickness of the Dakota(?) sandstone are probably due to local variations in the pre-Dakota(?) erosion surface near and along the shoreline. The base of the formation, then, represents fluvial and coastal-plain environments, but the upper portion is indicative of a littoral environment associated with further advance of the sea.

Mancos Shale

The Mancos shale was first described by Cross in 1899 near the town of Mancos, Colorado. Within the mapped area

the Mancos is probably of Greenhorn and Carlile age (Dane, Bachman, and Reeside, 1957, p. 111). It is primarily a body of gray shale with some interbedded sandstone. The Mancos shale thins southward along the Nutria monocline as a result of intertonguing with the overlying Gallup sandstone. Thicknesses range from slightly more than 700 feet at the northern boundary of the area to about 450 feet near the southern edge (Dane, Bachman, and Reeside, 1957, p. 102-103).

The Mancos shale forms a strike valley between the two hogbacks along the Nutria monocline. The Mancos is poorly exposed over much of its extent along this strike valley, due to the extreme softness of the shale and the weathered condition of the outcrop. Dips are in excess of 65° along most of the outcrop, although at the southern edge of the mapped area the dip flattens, and the Mancos is poorly exposed on the eastward-facing, steep slope of the Gallup sandstone cuestas.

The Mancos is, in the main, a body of dark-gray, fissile shale. A few sandstone beds occur within the shale. These are probably related to either the transgressive or regressive fluctuations of the late Cretaceous Sea. Calcareous zones are locally present but do not form continuous limestone beds. Calcareous concretions and septaria are abundant in places. Some horizons of the Mancos are abundantly fossiliferous. Pelecypods appear to be the most abundant forms.

the Mancos is probably of Turonian and Coniacian age (Dane, Bachman, and Reeside, 1957, p. [illegible]). It is primarily a body of gray shale with some interbedded sandstone. The Mancos shale thins southward along the Nacimiento uplift as a result of intertonguing with the overlying Gallup Sandstone. Thicknesses range from slightly more than 700 feet at the northern boundary of the area to about [illegible] feet near the southern edge (Dane, Bachman, and Reeside, 1957, p. [illegible]).

The Mancos shale forms a strike valley between the two hogbacks along the Nacimiento uplift. The Mancos is poorly exposed over much of its extent along this strike valley, due to the extreme softness of the shale and the weathered condition of the bedrock. Alluvium and talus cover it along most of the outcrop, although at the southern edge of the mapped area the dip flattens, and the Mancos is mainly exposed on the eastward-facing, steep slope of the Gallup sandstone cuestas.

The Mancos is, in the main, a soft, dark-gray, fissile shale. A few sandstone beds occur within the shale. These are probably related to either the transgressive or regressive fluctuations of the Late Cretaceous sea. Calcareous zones are locally present but do not form continuous limestone beds. Calcareous concretions and septaria are abundant in places. Some horizons of the Mancos are abundantly fossiliferous. Pelecypods appear to be the most abundant forms.

The Mancos shale was deposited during an advance and retreat of the sea in late Cretaceous time (Pike, 1947, p. 92). The sea advanced from the northeast over a gently sloping to nearly level landmass. Deposition of clastic sediment appears to have been almost continuous in the area during the period of marine inundation. The lack of limestone within the Mancos may indicate that this area was never far enough offshore to permit the clearing of the water sufficiently to allow limestone deposition, as has been reported to the northeast (Dane, Bachman, and Reeside, 1957, p. 97).

Gallup Sandstone

Sears described the continental deposits above the Mancos shale and assigned them to the Mesaverde formation. He named the basal sandstone the Gallup member for exposures along the Nutria monocline east of Gallup, New Mexico (1925, p. 17). The Mesaverde has since been elevated to group status. The Gallup is probably of latest Carlile to earliest Niobrara age (Dane, Bachman, and Reeside, 1957, p. 112). It consists of three massive sandstone beds and interbedded shale in the northern portion of the mapped area, and of five major sandstone beds with interbedded shale from the vicinity of Upper Nutria southward. The Gallup thickens southward by intertonguing with the Mancos shale. A thickness of 250 feet

The Mancos shale was deposited during an advance and retreat of the sea in late Cretaceous time (Pike, 1947, p. 92). The sea advanced from the northeast over a gently sloping to nearly level landmass. Deposition of clastic sediment appears to have been almost continuous in the area during the period of marine inundation. The lack of limestone within the Mancos may indicate that this area was never far enough offshore to permit the clearing of the water sufficiently to allow limestone deposition, as has been reported to the northeast (Dane, Wanek, and Reeside, 1957, p. 97).

Gallup Sandstone

Sears described the coal-bearing deposits above the Mancos shale and assigned them to the Mesaverde formation. He named the basal sandstone the Gallup member for exposures along the Nutria monocline east of Gallup, New Mexico (1925, p. 17). The Mesaverde has since been elevated to group status. The Gallup is probably of latest Carlile to earliest Niobrara age (Dane, Bachman, and Reeside, 1957, p. 182). It consists of three massive sandstone beds and interbedded shale in the northern portion of the mapped area, and of five major sandstone beds with interbedded shale from the vicinity of upper Nutria southward. The Gallup thickens southward by intertonguing with the Mancos shale. A thickness of 250 feet

was reported from the type locality north of the mapped area, and a thickness of 500 feet was observed at New Mexico Road 53 near Pescado (Dane, Bachman, and Reeside, 1957, p. 99-108). The contact with the underlying Mancos shale was somewhat arbitrarily placed by the writer at the base of the lowest of five major sandstone beds south of Upper Nutria, and at the base of the lowest of the three major sandstone beds elsewhere. Thus, the thickness of the Gallup decreases rather suddenly a short distance north of Upper Nutria as the lower two sandstone beds pinch out in the main body of the Mancos shale.

The resistant sandstone ledges of the Gallup form the western hogback of the Nutria monocline. The formation is well exposed along the monocline except for an interval of about 2 miles north of Upper Nutria, where it is largely covered by alluvium. Dips are steeper than 70° from the northern edge of the report area to approximately 2 miles southeast of Upper Nutria, where the monocline flattens and the Gallup forms a series of westward-sloping cuestas.

The three sandstone beds of the Gallup in the northern part of the mapped area occur as the upper units south of Upper Nutria. The lower of the other two tongues of the Gallup exposed in the southern part of the area is a massive, micaceous, well sorted, fine- to medium-grained, pink sandstone. The upper of these two tongues is massive, slightly micaceous, well sorted, fine-grained, buff to light tan

was reported from the type locality north of Gallup and a thickness of 50½ feet was observed at New Mexico Route 32 near Pescado (Dane, Bachman, and Reeside, 1957, p. [illegible]). The contact with the underlying Mancos shale was somewhat arbitrarily placed by the writer at the base of the lowest of five major sandstone beds south of Upper Nutria, and at the base of the lowest of the three major sandstone beds elsewhere. Thus, the thickness of the Gallup decreases rather suddenly a short distance north of Upper Nutria as the lower two sandstone beds pinch out in the main body of the Mancos shale.

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The three sandstone beds of the Gallup in the northern part of the mapped area occur as the [illegible] south of Upper Nutria. The lower of the other two tongues of the Gallup exposed in the northern part of the area is a massive, micaceous, well-sorted, fine- to medium-grained, [illegible] stone. The upper of these two tongues is massive, slightly micaceous, well-sorted, fine-grained, buff to [illegible]

sandstone, weathering brown. Shark teeth were found in this unit. Between these units, and between them and the upper three sandstones of the Gallup, is a dark-gray shale of typical Mancos lithology.

The lowermost unit of the main part of the Gallup is a massive, soft and friable, well-sorted, fine-grained, orange-brown sandstone. Above this lies a zone of soft gray shale and interbedded, lenticular sandstone that becomes darker and more carbonaceous toward the top. A few thin seams of coal were found in the upper part of this interval. The middle sandstone of the main portion of the Gallup is a medium-bedded to massive, micaceous, medium-grained, buff sandstone. Above this is a soft, red-brown shale containing a few lenticular sandstone beds. This interval also contains a few plant stems. The upper ledge of the Gallup is a massive, cross-bedded, poorly sorted, coarse-grained, arkosic, light-gray sandstone, weathering red-brown. The quartz grains in this unit may be as large as granule size in a matrix of medium sand. The grains are clear and angular. Cross-bedding and the grain size increase upward in the Gallup sandstone, but sorting decreases toward the top of the formation.

The Gallup sandstone is a regressive deposit associated with the oscillatory retreat of the Mancos sea. The basal sandstones represent littoral deposits, and the upper sandstones and carbonaceous shales represent fluvial and coastal plain deposits. The marine shales intertonguing

sandstone, weathering brown. Plant casts were found in this unit. Between these units, and between them and the upper three sandstones of the Gallup, is a dark-gray shale of typical Mancos lithology.

The lowermost unit of the main part of the Gallup is a massive, soft and friable, well-sorted, fine-grained, orange-brown sandstone. Above this lies a zone of dark-gray shale and interbedded, lenticular siltstone that becomes siltier and more carbonaceous toward the top. A few thin seams of coal were found in the upper part of this interval. The middle sandstone of the main portion of the Gallup is a medium-bedded to massive, moderately medium-grained, soft sandstone. Above this is a soft, red-brown shale containing a few lenticular sandstone beds. This interval also contains a few plant stems. The upper ledge of the Gallup is a massive, cross-bedded, poorly sorted, coarse-grained, arkosic, light-gray sandstone, weathering red-brown. The quartz grains in this unit are as large as granule size in a matrix of medium sand. The grains are clear and angular. Cross-bedding and the grain size increase upward in the Gallup sandstone, but sorting decreases toward the top of the formation.

The Gallup sandstone is a regressive deposit associated with the oscillatory retreat of the Mancos sea. The basal sandstones represent littoral deposits, and the upper sandstones and carbonaceous shales represent fluvial and coastal plain deposits. The marine shales interfingering

with the basal sandstones were deposited during temporary readvances of the sea. Thus, the Gallup forms the geologic mirror image of the Dakota(?) as it records a change from marine to continental environment. The relationship between the Mancos shale and the Gallup sandstone was admirably worked out by Pike (1947), who maintained that the advance and retreat of the Upper Cretaceous sea could be best explained by a basin subsiding at a constant rate with variation in the amount of available detritus determining the position and movement of the strand line.

Crevasse Canyon Formation

The Crevasse Canyon formation of the Mesaverde group was named by Allen and Balk in 1954 (p. 91) for exposures located near Crevasse Canyon in San Juan County, New Mexico. The Crevasse Canyon was designated as the interval between the Gallup and Point Lookout sandstones (Foster, 1957, p. 70). The Point Lookout sandstone is not present in the Zuni Mountain area so the Menefee formation, which overlies the Point Lookout to the north, rests directly on the Crevasse Canyon. Both the Crevasse Canyon and the Menefee consist of interbedded sandstone and shale and a few coal beds. In the absence of the Point Lookout sandstone, the contact between the Crevasse Canyon and the Menefee formations is difficult to place. A small area in the northwestern corner of the report area contains beds that may be assign-

with the basal sandstone was deposited during temporary readvances of the sea. Thus, the Gallup forms the regressive mirror image of the Dakota(?) in it records a change from marine to continental environment. The relationship between the Mancos shale and the Gallup sandstone was admirably worked out by Pike (1947). He maintained that the advance and retreat of the Upper Cretaceous sea could be best explained by a basin subsiding at a constant rate with variation in the amount of available detritus determining the position and movement of the strand line.

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able to the lower Menefee, but these have been included with the Crevasse Canyon for mapping purposes.

Sears (1925, p. 18) measured about 800 feet of beds that have since been assigned to the Crevasse Canyon formation. Because the mapped area does not cover the full stratigraphic range of the Crevasse Canyon, except in the northwest corner, and because the upper beds of the formation have been removed by erosion in a southerly direction, the variation in thickness of the formation could not be ascertained within the report area.

The Crevasse Canyon formation is primarily exposed as flat-lying beds to the west of the hogbacks of the Nutria monocline, although the lower part of the formation is caught up in the monoclinal folding in the northern part of the report area. Dissection of the flat-lying beds west of the monocline has produced mesas and ledges capped by the resistant, lenticular sandstones, and slopes formed by the softer shales and coals of the formation. Many canyons and valleys cut through the more resistant beds and produce a rugged terrain. Where the Crevasse Canyon dips steeply, thin hogbacks of sandstone rise almost vertically out of the softer materials to heights of 100 feet or more.

The Crevasse Canyon formation is apparently conformable with the Gallup sandstone below. The base of the Crevasse Canyon is marked by a soft shaly interval up to 200 feet

able to the lower [illegible], but these have been included with the Crevasse Canyon for mapping purposes.

Sears (1925, p. 12) measured about 690 feet of beds that have since been assigned to the Crevasse Canyon Formation. Because the mapped area does not cover the full stratigraphic range of the Crevasse Canyon, except in the northeast corner, and because the upper beds of the Formation have been removed by erosion in a southerly direction, the variation in thickness of the Formation could not be ascertained within the report area.

The Crevasse Canyon Formation is primarily exposed as flat-lying beds to the west of the hogbacks of the Hogback monocline, although the lower part of the Formation is caught up in the monoclinal folding in the northern part of the report area. Dissection of the flat-lying beds west of the monocline has produced mesas and ledges capped by the resistant, lenticular sandstones, and slopes formed by the softer shales and coals of the Formation. Many canyons and valleys cut through the more resistant beds and produce rugged terrain. Where the Crevasse Canyon dips steeply, thin hogbacks of sandstone rise almost vertically out of the softer materials to heights of 250 feet or more.

The Crevasse Canyon Formation is apparently unconformable with the Gallup Sandstone below. The base of the Crevasse Canyon is marked by a soft shale interval up to 200 feet

thick. This interval contains black and brown, fissile shale, gray and brown siltstone, and occasional coal beds. Some lenticular, thin- to medium-bedded, well sorted to poorly sorted, fine- and coarse-grained, tan, buff, orange, and red-brown sandstones are also present in this interval. Locally, dark-red staining appears on the bedding surfaces of these lenticular sandstone beds. The lithology is much the same upward, in the middle part of the formation. However, the sandstone beds become more massive and less lenticular, more numerous and thicker, and the shale beds become less numerous and less carbonaceous. The upper part of the formation is much the same as the lower, with a return of a greater proportion of softer units and carbonaceous zones. This part of the Crevasse Canyon does not appear to contain quite as much coal as does the basal part. Plant stems can be found throughout the formation, although they are particularly abundant near the coal horizons.

The Crevasse Canyon formation was apparently deposited on a low floodplain after the retreat of the Mancos sea. Abundant and lenticular sandstone beds would seem to indicate the presence of many streams with varying channels. The abundant plant remains may indicate a moist and probably mild climate with swampy conditions locally predominating. The shoreline lay to the northeast and trended in a northwesterly direction. It retreated to the northeast (Pike, 1947, p. 94). Thus, the source area for the Crevasse Canyon sediments lay somewhere to the southwest.

thick. This interval contains black carbonaceous, fissile shale, grey and brown siltstone, and occasional coal beds. Some lenticular, thin- to medium-bedded, well sorted to poorly sorted, fine- and coarse-grained, tan, buff, grey, and red-brown sandstones are also present in this interval. Locally, dark-red staining appears on the bedding surfaces of these lenticular sandstone beds. The lithology is much the same upward, in the middle part of the formation. However, the sandstone beds become more massive and less lenticular, more numerous and thicker, and the shale beds become less numerous and less carbonaceous. The upper part of the formation is much the same as the lower, with return of a greater proportion of softer, silty and carbonaceous zones. This part of the Crevasse Canyon does not appear to contain quite as much coal as does the lower part. Plant stems can be found throughout the formation, although they are particularly abundant near the coal horizons.

The Crevasse Canyon Formation was apparently deposited on a low floodplain after the retreat of the Mancos sea. Abundant and lenticular sandstone beds would seem to indicate the presence of many streams with varying discharge. The abundant plant remains may indicate a moist and probably mild climate with swampy conditions locally predominant. The shoreline lay to the northeast and trended in a northwesterly direction (Pike, 1947, p. 94). Thus, the source area for the Crevasse Canyon sediments lay somewhere to the southwest.

Cenozoic Rocks

The Cenozoic rocks of the report area are confined to alluvial deposits of Recent origin. No consolidated deposits younger than Cretaceous were found within the area. The alluvium occurs primarily in the wider, and more gently sloping valleys. Some of it occurs as fans against a few of the slopes. The grain size of this alluvium is quite variable and is dependent both upon the gradient of the depositing stream and the rocks from which it was derived. Alluvium is actually much more widespread than is shown on the geologic map (Fig. 2) but was only mapped where it was rather extensive or thoroughly covered the underlying bedrock.

Cenozoic Rocks

The Cenozoic rocks of the map area are confined to alluvial deposits of Recent origin. No Tertiary deposits younger than Cretaceous were found within the area. The alluvium occurs primarily in the valleys and more gently sloping valleys. Some of it occurs as fans against a few of the slopes. The grain size of this alluvium is variable and is dependent both upon the gradient of the depositing stream and the rocks from which they are derived. Alluvium is actually much more widespread than is shown on the geologic map (Fig. 2) but was only mapped where it was rather extensive or thoroughly covered the underlying bedrock.

STRUCTURE

General Setting

The Nutria monocline forms the boundary between the Zuni Mountains on the east and the Gallup sag on the west. The Zuni Mountains are considered to be the local southern boundary of the San Juan basin (Fig. 6). West of the mountains, the Gallup sag forms a southern extension of the basin, and on the east the Acoma embayment forms another southern extension (Kelley, 1951, p. 124).

The Zuni Mountains are an oval, doubly plunging uplift. The primary axis of the mountains trends northwesterly and is composed of several small, northerly trending anticlines arranged in echelon along its trace (Kelley, 1955b, p. 28). Dips are usually gentle on the northern and eastern sides and along the southwestern margin, but are steeper along the monocline on the western and northwestern sides. South of Ramah, the western margin of the Zuni uplift swings more to the southeast, as the steep dips along the monocline flatten. Faulting has obscured the symmetry of the uplift. The southeastern end has been downfaulted and is hidden beneath Recent lava flows. Faults tend to be arranged radially to the uplift along the gently dipping northern and eastern sides and longitudinal along the southwestern flank. The radial faults average about 3-6 miles in length and generally have a displacement of less than 600

STRUCTURE

General Setting

The Nutria monocline forms the boundary between the Zuni Mountains on the east and the Gallup [illegible] on the west. The Zuni Mountains are considered to be the [illegible] southern boundary of the San Juan basin (Fig. [illegible]). West of the mountains, the Gallup [illegible] forms a southern extension of the basin, and on the east the [illegible] forms another southern extension (Kelley, [illegible], p. [illegible]).

The Zuni Mountains are an oval, doubly plunging uplift. The primary axis of the mountains trends northwesterly and is composed of several small, [illegible] anticlines arranged in echelon along the trend (Darton, 1928, p. [illegible]). Dips are usually gentle on the northern and eastern sides and along the southwestern margin, but are steeper along the monocline on the western and northwestern [illegible]. [illegible] of Ramah, the western margin of the Zuni uplift [illegible] to the southeast, as the steep dips along the monocline flatten. Faulting has obscured the [illegible] of the uplift. The southeastern end has been downfaulted and [illegible] beneath Recent lava flows. Faults tend to be arranged radially to the uplift along the [illegible] and eastern [illegible] along the southwestern flank. The radial faults average about [illegible] in length and generally [illegible] displacement [illegible]

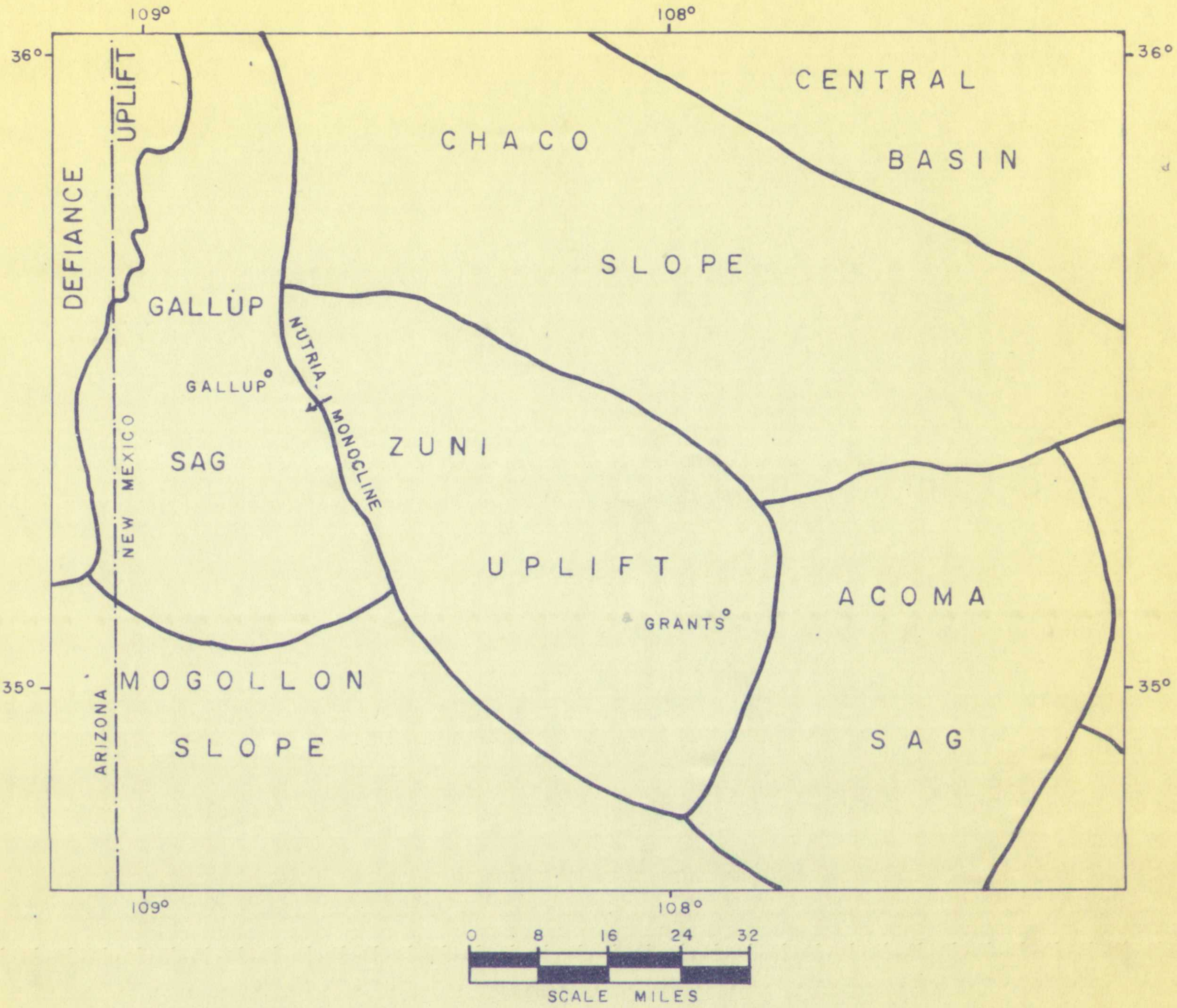

Figure 6. Index map showing the tectonic divisions of the southern San Juan Basin. (After Kelley, 1957)

feet, with the downthrow side usually to the east. The longitudinal faults are somewhat longer, averaging about 10 miles in length, with small throws of generally less than 200 feet. They are usually downthrown on the northern and northeastern sides (Smith, 1957, p. 60). No longitudinal faults of the type described by Smith are found along the western flank north of Nutria.

The Gallup sag is a flat-bottomed, structural trough lying between the Defiance uplift on the west and the Zuni uplift on the east (Kelley, 1957, p. 46). The border between the Gallup sag and the Zuni uplift is sharp along the Nutria monocline, but becomes gradual where the monocline dies out a few miles south of Nutria. The Gallup sag is gently warped by a number of north-northwesterly trending anticlines and synclines (Sears, 1925, p. 21). The floor of the sag slopes gently to the north at a rate of about 60 feet per mile. It is nearly 30 miles wide in the vicinity of Zuni Pueblo, but narrows to less than 10 miles north of Gallup, because of a northward convergence of the Zuni and Defiance uplifts (Kelley, 1957, p. 46).

Folds

Nutria Monocline

The Nutria monocline forms the western boundary of the Zuni uplift and is the most striking feature of the area. The monocline conforms to the definition of Kelley (1955a,

feet, with the downthrown side usually to the east. The longitudinal faults are somewhat longer, extending about [illegible] miles in length, with small throws of generally less than 200 feet. They are usually downthrown on the southern and northeastern sides (Smith, 1957, p. 60). No longitudinal faults of the type described by Smith are found along the western flank north of Nutria.

The Gallup sag is a flat-bottomed, structural trough lying between the Defiance uplift on the west and the Zuni uplift on the east (Kelley, 1951, p. [illegible]). The boundary between the Gallup sag and the Zuni uplift is sharp along the Nutria monocline, but becomes gradual where the monocline dies out a few miles south of Nutria. The Gallup sag is gently warped by a number of north-northwesterly trending anticlines and synclines (Sears, 1925, p. 24). The axes of the folds plunge gently to the north at a rate of about 50 feet per mile. The sag is nearly 30 miles wide in the vicinity of Gallup, but narrows to less than 20 miles north of Gallup, because of northward convergence of the Zuni and Defiance uplifts (Kelley, 1951, p. [illegible]).

Folds

Nutria Monocline

The Nutria monocline forms the western boundary of the Zuni uplift and is the major folding feature of the area. The monocline conforms to the definition of Kelley (1955a,

p. 801), who said, "A monocline is a double bend involving local steepening in otherwise less steeply inclined layers." As such, the monocline consists of an anticlinal bend, a synclinal bend, and a steep middle limb common to both flexures.

The Nutria monocline faces to the west, hence, the synclinal bend lies west of the anticlinal bend.

The Nutria monocline extends from the northern end of the Zuni uplift, a few miles north of Gallup, southeastward to sec. 33, T. 12 N., R. 16 W. South of this point beds flatten and have a fairly uniform dip off the flank of the uplift, with no pronounced bends (Fig. 7). At the southern end of the monocline, the dips steepen rather abruptly to the north, going from 25° to 70° in less than a mile. Thus, the southern end of the monocline forms a moderately sharp twist in the rocks along the flank of the Zuni uplift. The dip on the steep limb remains fairly constant to the north and averages about 70° to a point north of Little Bear Spring. Dips of 80° and more are found for 1 1/2 miles north of Little Bear Spring. The dips flatten from this area northward to 40°-60° east of Gallup, and north of the area. Nowhere within the area were any beds found that were overturned along the steep limb of the monocline itself.

The anticlinal and synclinal bends of the Nutria monocline roughly parallel each other, although a slight divergence to the north was noted. The axes average about

p. 801), who said, "A monocline is a unilateral flexure involving local steepening in otherwise less steeply inclined strata." As such, the monocline contains an anticlinal bend, a synclinal bend, and a steep middle limb or step of the flexure.

The Nutria monocline faces to the east, hence, the synclinal bend lies east of the anticlinal bend.

The Nutria monocline extends from the northern end of the Zuni uplift, a few miles north of Gallup, south [illegible] to sec. 33, T. 12 N., R. 16 W. South of this point beds flatten and have a fairly uniform dip off the flank of the uplift, with no pronounced step (Fig. 7). At the northern end of the monocline, the dips steepen rather abruptly to the north, going from 25° to 70° in less than a mile. Thus, the southern end of the monocline marks the [illegible] twist in the rocks along the flank of the Zuni uplift. The dip on the steep limb generally [illegible] to the north and averages about 70° to a point [illegible] west of [illegible]. Dips of 60° and more are found [illegible] 1/2 mile north of [illegible] Bear Springs. The [illegible] [illegible] [illegible] 40°-60° east of Gallup, and northward [illegible]. However within the area were any [illegible] [illegible] found along the steep limb of the monocline [illegible].

The anticlinal and synclinal bends of the Nutria monocline roughly parallel each other, although a slight divergence to the north [illegible] noted. The axes [illegible] show

Figure 7. Southern end of the Nutria monocline showing the uniform dips off the Zuni uplift farther to the southeast.

4000 feet apart, although an eastward bowing of the anticlinal axis in the vicinity of Stinking Spring locally doubles the separation. The axial planes of both flexures are inclined about 45° to the northeast. The synclinal bend is generally sharper than the anticlinal bend, and locally the change from steep to flat-lying beds takes place within 200 feet. The beds below the foot of the monocline dip gently to the southwest away from the synclinal flexure. However, in the northern half of the area, the beds dip southwestward for a distance of less than a mile before passing into a flat-bottomed syncline. This syncline is west of the foot of the monocline and was not mapped for this report. The rocks above the head of the monocline also dip southwestward, so the monocline may be called a normal one that is not opposed to the regional dip (Kelley, 1955a, p. 795). However, this dip can be considered regional only to the extent that it forms the west flank of the Zuni uplift, because other structural modifications, which will be discussed later, locally alter the direction of dip above the head of the monocline.

Formations from the Crevasse Canyon to the Yeso are included in the flexure at the surface. The trace of the anticlinal bend is found in the outcrop belts of the lower Chinle, San Andres, Glorieta, and Yeso formations, depending on the depth of erosion from place to place. The axial trace of the synclinal bend occurs everywhere in beds of

the Crevasse Canyon formation, although progressively younger horizons are included in the flexure toward the north. This is probably indicative of a very slight northward plunge of the monocline.

The upper part of the steep limb of the Nutria monocline is broken by faults in sec. 17, 20, and 21, T. 12 N., R. 16 W., and from sec. 31, T. 13 N., R. 16 W. to sec. 35, T. 14 N., R. 17 W. In these areas, it is impossible to determine how much of the total deformation is due to faulting and how much is a result of the monoclinal deformation. However, northeast of Upper Nutria, where faulting is absent, a structural relief of 4600 feet is attributed to the monoclinal deformation alone. The maximum structural relief, owing both to monoclinal deformation and faulting, is about 5800 feet approximately 1 mile north of Little Bear Spring. North of Little Bear Spring the structural relief gradually diminishes until the northern end of the monocline is reached.

The trace of the Nutria monocline consists of three straight segments each trending approximately N. 35° W. Each of these segments is about 3 miles long. They are connected to one another by reverse S curves which trend somewhat more northerly. The straight segments are offset from each other about 1 mile and form a right echelon. The southernmost of the two curving segments lies immediately north of Upper Nutria and is about 3 miles long. The northern curving segment is immediately north of Little Bear Spring and is only about 1 mile long. It curves much more

the Crevasse Canyon Formation, [illegible] horizons are [illegible] toward the [illegible] is probably indicative of a very slight northward plunge of the monocline.

The upper part of the [illegible] of the [illegible] monocline is broken by faults in secs. 17, 20, and 21, T. 17 N., R. 16 W., and from sec. 31, T. 17 N., R. 16 W. to sec. [illegible], T. [illegible] N., R. 17 W. In these areas, it is impossible to determine how much of the total deformation is due to faulting and how much is a result of the monoclinal deformation. However, southeast of Upper Nutria, where faulting is absent, a structural relief of 4600 feet is attributed to the monoclinal deformation alone. The maximum structural relief, adding both the monoclinal deformation and faulting, is about [illegible] feet approximately 1 mile north of Little Bear Spring. North of Little Bear Spring the structural relief gradually diminishes until the northern end of the monocline is reached.

The trace of the Nutria monocline consists of three straight segments each trending approximately [illegible]. Each of these segments is about [illegible] miles long. They are connected to one another by reverse S curves which trend somewhat more northerly. The straight segments are offset from each other about 1 mile and [illegible]. The southernmost of the two curving segments lies immediately north of Upper Nutria and is about [illegible] miles long. The northern curving segment lies immediately north of Little Bear Spring and is only about 2 mile long. [illegible]

sharply than does the southern segment. Other offset straight segments of the monoclinal trace appear north of the mapped area.

Other Folds

Between the upper anticlinal flexure of the Nutria monocline and the eastern edge of the area lie three small anticlines and a syncline. These have been designated A-1, A-2, A-3, and S-1 (Fig. 2). They occur in an area of gently dipping beds. Deformation associated with these features is of much less magnitude than either that of the monocline or the faults above the head of the monocline.

The westernmost of these is anticline A-1, which follows a somewhat irregular course from sec. 35, T. 14 N., R. 17 W. to sec. 30, T. 13 N., R. 16 W. The axial trace of this anticline roughly follows the trace of the Nutria monocline and is about 5 miles long. It might be considered to be the crest of the moncline but is treated separately here, because it is present for such a comparatively short distance. Anticline A-1 plunges less than 5° toward the south and dies out at its northern extremity. The southwestern limb of anticline A-1 forms the upper level of the anticlinal bend of the monocline. The northeastern limb of this anticline is 2-4 miles wide and dips at about 6° into the McGaffey fault zone, or syncline S-1, on the northeast. Anticline A-1 is a comparatively broad, gentle fold

with the dips of both limbs less than 10°.

Another of these anticlines, anticline A-2, is found in secs. 27, 34, and 35, T. 13 N., R. 16 W. This anticline is about 2 miles long and follows a roughly arcuate northwesterly course that closely parallels the McGaffey fault zone. Anticline A-2 lies slightly less than 1 mile west of the McGaffey fault zone and crosses the upper reaches of Nutria Canyon at nearly right angles. It plunges less than 5° northward and appears to form a simple echelon with anticline A-1. Dips are on the order of 5° or 6° in both limbs. The eastern flank dips gently toward the McGaffey fault zone, and the western flank passes into the Nutria monocline about 3 miles down-dip. Anticline A-2 appears to be upright.

A third anticline, A-3, crosses the northeastern corner of the area in an arcuate, northerly-trending course. Only the western limb is exposed to any extent within the report area. Although Precambrian rocks are exposed along the trace of this anticline, the structural relief along the western flank appears to be small compared with the uplift associated with the McGaffey fault zone. Dips up to 15° have been measured along the western flank of anticline A-3. Anticline A-3 plunges less than 5° northward producing a definite nose. Not much can be observed of this anticline because of its small exposure within the report area. The eastern limb appears to extend for several miles down-dip,

with the dips on both flanks [illegible] than 10°.

Another of these anticlines, anticline A-2, is found in secs. 27, 34, and 35, T. 11 N., R. 18 W. This anticline is about 2 miles long and follows a roughly arcuate northwesterly course that closely parallels the McGaffey fault zone. Anticline A-2 lies slightly less than 1 mile west of the McGaffey fault zone and crosses the upper reaches of Nutria Canyon at nearly right angles. It plunges less than 5° northward and appears to form a single echelon with anticline A-1. Dips are on the order of 5° to 6° in both limbs. The eastern flank dips gently toward the McGaffey fault zone, and the western flank passes into the Nutria monocline about 3 miles down-dip. Anticline A-2 appears to be upright.

A third anticline, A-3, crosses the northeastern corner of the area in an arcuate, northwest-trending course. Only the western limb is exposed to any extent within the report area. Although Precambrian rocks are exposed along the trace of this anticline, the structural relief along the western flank appears to be small compared with the relief associated with the McGaffey fault zone. Dips up to 15° have been measured along the western flank of anticline A-3. Anticline A-3 plunges less than 5° northward and shows a definite nose. Not much can be observed directly of it because of its small exposure within the report area. The eastern limb appears to extend for several miles northeastward.

and may even form the eastern flank of the Zuni Mountains (Smith, et al., 1959a). The axial plane of anticline A-3 appears to be very steep to vertical.

Syncline S-1 extends from about one-third of a mile due north of McGaffey to beyond the northern edge of the area. It is apparently related to the passage of the McGaffey fault zone northward into a fold. The axial trace trends nearly due north. It is asymmetrical with the eastern limb inclined up to 55° and the western limb about 6° to the crest of anticline A-1. The syncline plunges less than 10° northward, and the axial plane dips about 65° to the east.

Faults

Stinking Springs Thrust

The Stinking Springs thrust is one of the major features associated with the Nutria monocline. This fault closely follows the trace of the monocline for about 5 miles. The fault trace follows a somewhat sinuous course, striking about N. 30° W. from sec. 31, T. 13 N., R. 16 W., to a point about 1 mile north of Little Bear Spring. From there it swings northeastward and strikes about N. 18° E. to the northern edge of the area. Owing to poor exposures and to a lack of topographic control, the dip of the fault cannot be accurately determined. However, it appears to dip between 30° and 60° to the northeast. No evidence of the

and may even form the eastern flank of the ... Mountains (Smith, et al., 1959). The axial plane of ... appears to be very steep to vertical.

Syncline S-1 extends from about one-third of a mile ... north of McCaffey to beyond the northern edge of the area. It is apparently related to the passage of the McCaffey fault zone northward into a fold. The axial trace trends nearly due north. It is asymmetrical with the eastern limb dipping up to 55° and the western limb about 5° to the crest anticline A-1. The syncline plunges less than 10° northward, and the axial plane dips about 67° to the east.

Faults

Stinking Springs Thrust

The Stinking Springs thrust is one of the major features associated with the ... zone. ... closely follows the trace of the ... for about ... miles. The fault trace follows a somewhat sinuous course, ... about N. 30° W. from sec. ..., T. ..., R. ... W., to a point about 1 mile north of Little ... where it swings northeastward and strikes about N. 10° E. to the northern edge of the area. ... a lack of topographic control, the dip of the fault cannot be accurately determined. However, it appears to dip between 30° and 60° to the northeast. No evidence of the

fault can be found on the 30°-slope of the east side of the hogback along Grasshopper Canyon, so the fault must be somewhat steeper than this slope. However, the amount of curving of the fault trace across this canyon would seem to preclude a dip in excess of 60°.

The axis of the anticlinal flexure of the monocline is apparently recessed to the east in the vicinity of Stinking Springs. Near Little Bear Spring the axis is offset to the right. This may indicate that the attitude of the fault surface of the Stinking Springs thrust varies somewhat along the strike. The attitude of the fault surface would be steeper than the axis of the anticlinal bend where that axis is recessed to the east. Where the anticlinal axis is recessed to the west, the fault surface would have to be somewhat flatter than the fold axis.

The Stinking Springs thrust is upthrown on the northeastern side. South of sec. 35, T. 14 N., R. 17 W. the thrust cuts the upper part of the steep limb of the monocline below the anticlinal bend. North of this point it lies above the head of the monocline. The thrust thus appears to descend slightly to the south along the monocline. The stratigraphic throw of the fault increases northward along the strike from the southern end to a maximum in Grasshopper Canyon, where the lower Chinle rests against the upper part of the Zuni sandstone. The throw diminishes northward from Grasshopper Canyon for about 1 mile, where in the vicinity of Stinking Springs the fault is inferred

fault can be found on the 30°-slope of the west side of the hogback along Grasshopper Canyon, as the fault must be somewhat steeper than this slope. However, the arcuate outcropping of the fault trace across this narrow ridge seems to indicate a dip in excess of 60°.

The axis of the anticlinal flexure of the monocline is apparently recessed to the [illegible] in the vicinity of Stinking Springs. Near Little Bear Spring the axis is offset to the right. This may indicate that the [illegible] of the fault surface of the Stinking Springs thrust varies somewhat along the strike. The [illegible] would be steeper than the axis of the anticlinal bend where that axis is recessed to the east. Where the anticlinal axis is recessed to the west, the fault surface would have to be somewhat flatter than the fold axis.

The Stinking Springs thrust is upthrown on the north-eastern side. South of sec. 15, T. 11 N., R. 27 E., the thrust cuts the upper part of the steep limb of the mono-cline below the anticlinal bend. North of this point it lies above the bend of the monocline. The thrust plane appears to descend steadily to the south along the monocline. The stratigraphic throw of the fault increases southward along the strike from the northern end and its maximum is at Grasshopper Canyon, where [illegible] against the upper part of the [illegible] sandstone. The throw diminishes northward from Grasshopper Canyon [illegible], and in the vicinity of Stinking Springs the fault is inferred

by the absence of a part of the upper Chinle. Steep overturning of middle and lower Chinle beds was noted on the upthrown side of the fault at this locality. The displacement along the fault increases from Stinking Springs to a maximum about 1 mile north of Little Bear Spring, where a small portion of the lower Chinle is faulted against the Dakota(?) sandstone. As the fault trace swings northeastward, the displacement diminishes, and the fault dies out somewhere north of the area in Fort Wingate Military Reservation.

Although it is impossible to separate the throw of the fault from the deformation associated with the monocline without an accurate knowledge of the attitude of the thrust, a maximum stratigraphic separation in excess of 2000 feet is probably present north of Little Bear Spring.

Within the thrust sheet of the Stinking Springs thrust are three small faults that are oriented approximately at right angles to the thrust itself. These are labeled F-1, F-2, and F-3, respectively, on the map (Fig. 2). They are probably all of a pivotal type, with movement dying out away from the plane of the thrust.

The northernmost of these, fault F-1, lies east of Stinking Springs. It strikes approximately N. 20° E. and is probably not over 1500 feet long. It is downthrown to the south where overturned beds of the middle member of the Chinle have been brought into fault contact with overturned beds of the lower member. Fault F-1 is probably vertical, although it is not exposed well enough to observe its

by the absence of a part of the upper Chinle. [illegible] turning of middle and lower Chinle beds is [illegible] on the upthrown side of the fault at this locality. The displacement along the fault increases from [illegible] Springs to a maximum about 1 mile north of Little Bear Spring, where a small portion of the lower Chinle is faulted against Dakota(?) sandstone. [illegible] the fault [illegible] northward, the displacement diminishes, and the fault [illegible] north of the area in [illegible].

Although it is impossible to estimate the throw of the fault from the deformation associated with the [illegible] without an accurate knowledge of the [illegible] of the [illegible], a maximum stratigraphic separation [illegible] feet is probably present north of Little Bear Spring.

Within the thrust sheet of the [illegible] thrust are three small faults that [illegible] right angles to the thrust [illegible] F-1, F-2, and F-3, respectively, [illegible]. They are probably all of a [illegible] type [illegible] away from the plane of the thrust.

The northernmost of these, fault F-1, [illegible] of Stinking Springs. It [illegible] and is probably not over 1500 feet [illegible]. It is [illegible] to the south where [illegible] beds of the [illegible] Chinle have been brought into fault contact with [illegible] beds of the lower member. Fault F-2 is [illegible] although it is not [illegible] enough to [illegible] it.

attitude directly. The throw is probably at least 200 feet near the thrust, for no middle Chinle beds appear north of the fault. The displacement dies out rapidly northeastward along the strike. Fault F-1 was not observed to cut the San Andres limestone at this locality.

Faults F-2 and F-3 form the boundaries of a small horst along the upthrown side of the Stinking Springs thrust in Grasshopper Canyon. Fault F-2, the northern fault of this pair, is downthrown to the north, and F-3 is downthrown to the south. Neither the attitude of F-2 or F-3 was determined. Both faults strike about N. 65° E. The Yeso formation is exposed along the anticlinal crest of the monocline where it crosses the horst. The bounding faults, F-2 and F-3, die out 2000 to 3000 feet from the thrust. Movement along these faults was greatest near the thrust, where the Glorieta sandstone within the horst is faulted against the San Andres limestone and the lower Chinle, both to the north and the south. Movement along these bounding faults is about 200 to 300 feet near the thrust, diminishing away from it. Although the bounding faults of this horst cut the anticlinal flexure of the Nutria monocline, no displacement is apparent. This might indicate that the movement of the horst, along faults F-2 and F-3, was more or less parallel to the dip of the axial plane.

South of this horst, two small high-angle reverse faults occur in the thrust sheet. These two faults converge slightly to the south and both are cut off at their north

attitude directly. [illegible] near the thrust, [illegible] the fault. The [illegible] along the strike. Fault F-4 was [illegible] San Andres limestone at this locality.

Faults F-2 and F-3 form the boundaries of a small horst along the upthrown side of the [illegible] Grasshopper Canyon. Fault F-2, the northern fault of this pair, is downthrown to the north, and F-3 is downthrown to the south. Neither the attitude of F-2 nor F-3 was determined. Both faults strike about N. 65° E. The Yeso formation is exposed along the anticlinal crest of the monocline where it crosses the horst. The bounding faults, F-2 and F-3, die out 2000 to 3000 feet from the thrust. Movement along these faults was greatest near the thrust, where the Glorieta sandstone within the horst is faulted against the San Andres limestone and the [illegible], both to the north and the south. Movement along these bounding faults is about 200 to 300 feet near the thrust, diminishing away from it. Although the bounding faults of this horst cut the anticlinal flexure of the Nutria monocline, no displacement is apparent. This might indicate that the movement of the horst, along faults F-2 and F-3, was more or less parallel to the dip of the fault plane.

South of this horst, [illegible] high-angle reverse faults occur in the [illegible] sheet. These faults [illegible] slightly to the south and northward [illegible]

ends by fault F-3. Fault F-4 strikes N. 31° W. and dips 81° northeast. The trace of fault F-5 is buried beneath a talus slope and is largely inferred. Its strike is approximately N. 18° W. and its dip is assumed to be similar to that of F-4. The block included between faults F-4 and F-5 is tilted to the east from about 15° to more than 50°. The tilting increases northward to a maximum along the northern edge of the block. Thus, movement along faults F-4 and F-5 is greatest where they terminate against F-3 and dies out to the south within 3400 feet. Because this tilted block lies along the anticlinal axis of the monocline, the symmetry of the anticlinal flexure is destroyed at this point.

McGaffey Fault Zone

The McGaffey fault zone lies roughly east and south of the village of McGaffey. The fault zone trends N. 10° E. at its northern end, about 1 mile north of McGaffey. Southward it follows an arcuate trend, bending progressively more to the east, until it strikes approximately N. 30° W. at the eastern edge of the area in sec. 26, T. 13 N., R. 16 W.

The McGaffey fault zone is composed of two faults that have essentially parallel traces and are both upthrown on the eastern side. The western fault, F-6, appears to be a high-angle reverse fault. One plane of movement associated with this fault less than 1 mile south of McGaffey has a strike of N. 8° E. and a dip of 86° E. Although all the movement of the fault probably has not occurred entirely

ends by faults. [illegible] and dips [illegible] northeast. The [illegible] of fault F-3 is [illegible] along and is [illegible]. Its strike [illegible] N. 18° W. and the [illegible] appears to be similar to that of F-4. The block included between faults F-3 and F-4 [illegible] to the east from about 45° to more than [illegible]. The [illegible] increases northward to a maximum along the northern edge of the block. Thus, movement along faults F-3 and F-4 is greatest where they [illegible] against F-5 and dies out to the south within 3,000 feet. Because [illegible] along the anticlinal axis of [illegible], the [illegible] of the anticlinal flexure is [illegible].

McGaffey Fault Zone

The McGaffey fault zone lies roughly east and [illegible] of the village of McGaffey. The fault zone trends N. 10° W. at its northern end, about 1 mile north of McGaffey. Southward it follows an arcuate trend, bending progressively more to the east, until it strikes approximately N. [illegible] W. at the eastern edge of the area in sec. [illegible], T. [illegible] N., R. 16 W.

The McGaffey fault zone is composed of two faults that have essentially parallel traces and are both upthrown on the eastern side. The western fault, F-6, appears to be a high-angle reverse fault. The plane of movement associated with this fault zone [illegible] strike of N. [illegible] W. and a dip [illegible]. [illegible] movement of the fault [illegible]

along this one surface, it is likely that this plane represents one of a series of parallel or subparallel surfaces that constitute the fault zone. Although no overturning was seen along fault F-6, beds on the upthrown side commonly dip steeply to the west, in many places as much as 85°. Along fault F-6 the Glorieta sandstone has been faulted against the lower Chinle. This fault extends at least as far as 1 mile north of McGaffey, and may extend to the northern edge of the area. Fault F-6 continues south and east for 5 miles to the eastern edge of the mapped area, and has been mapped 4 miles farther to the southeast by Smith, et al. (1959a).

Fault F-7 lies roughly parallel to fault F-6 and about 1100 feet to the east. Along this fault beds of the Abo formation are brought into contact with Yeso beds. Fault F-7 dies out somewhat less than 1 mile south of McGaffey. At the eastern edge of the area the Abo formation is missing and the Precambrian is in fault contact with the Yeso along fault F-7. The attitude of fault F-7 could not be determined, but it is most probably a high-angle reverse fault similar to F-6. Faults F-7 and F-6 may join at depth.

The fault slice between the two faults is inclined steeply to the west. Much of the structural relief of the McGaffey fault zone is due to this tilting (Fig. 8). The total displacement across the zone is in excess of 600 feet, although lack of topographic control prevented accurate measurement. The McGaffey fault zone gradually passes into a fold near the northern edge of the area.

along this one surface, it is likely that this plane repre-
sents one of a series of parallel or subparallel surfaces
that constitute the fault zone. Although no [illegible] was
seen along fault F-6, beds on the upthrown side generally dip
steeply to the west, in many places as much as 60°. Along
fault F-6 the [illegible] sandstone has been faulted against
the lower Chinle. This fault extends at least as far as a
mile north of McGaffey, and may extend to the northern edge
of the area. Fault F-6 continues south and east for [illegible] miles
to the eastern edge of the mapped area, and has been mapped
4 miles farther to the southeast by Smith, et al. (1959).

Fault F-7 lies roughly parallel to fault F-6 and about
1100 feet to the east. Along this fault beds of the [illegible]
formation are brought into contact with [illegible]. Fault
F-7 dies out somewhere less than 1 mile north of McGaffey.
At the eastern edge of the area the [illegible] formation
and the Precambrian [illegible] are in fault contact with [illegible] along
fault F-7. The attitude of fault [illegible] is not [illegible],
but it is most probably a high-angle reverse fault similar
to F-6. Faults F-7 and F-6 may join at depth.

The fault slice between the [illegible] dips
steeply to the west. [illegible] relief of the
McGaffey fault zone is [illegible] (fig. [illegible]). The
total displacement across this zone is probably [illegible] feet,
although lack of topographic control prevented accurate
measurement. The McGaffey faults are probably related to
a fold near the [illegible] edge of the area.

Figure 8. Hogback of Glorieta sandstone between faults F-6 and F-7 along the McGaffey fault zone south of McGaffey.

Other Faults

Fault F-11 runs from a point in sec. 17, T. 12 N., R. 16 W., about 1 mile east of Upper Nutria, southeastward for about 2 1/2 miles to a point in sec. 28, T. 12 N., R. 16 W., where it is cut off by fault F-8. Fault F-11 strikes N. 30° W. and follows closely the trace of the Nutria monocline. It lies in the Chinle formation, and, because the fault closely follows the strike of the soft Chinle, it is poorly exposed. The attitude of the fault could not be determined. Fault F-11 is upthrown to the east and the lower Chinle is brought into contact with the upper part of the upper member. The throw is on the order of 1000 feet. The displacement is greatest at its southern termination and gradually dies out to the north. Although fault F-11 lies in approximately the same relative position to the monocline as does the Stinking Springs thrust, no evidence was found to indicate that the two are continuous. Fault F-11 appears to be steeper than the Stinking Springs thrust and may be a normal fault.

The Dan Valley fault is one of a series of subparallel faults that trend obliquely across the Zuni Mountains to the south and east of the mapped area. It was mapped by Smith (1958) and extends into the area of this report before ending in the Box S fault zone in sec. 27, T. 12 N., R. 16 W. East of the area the Dan Valley fault splits into two branches, and extends northwestward into the area as such. The northern

branch strikes N. 60° W. and the southern branch strikes N. 70° W. Both branches of the fault are downthrown on the northeastern side, toward the core of the Zuni uplift. Along the Dan Valley fault the lower member of the Chinle has been faulted against the middle member with a probable displacement of slightly less than 300 feet. Both branches of the fault form northeastward-facing scarps.

In the vicinity of the ruined buildings of the Box S Ranch, and between the Dan Valley fault and fault F-11 lies a complex zone of small faults. Owing to the soft, irregular beds of the Chinle formation, the exact location of a particular fault is very difficult to determine. Dips are highly variable, both because of faulting and slumping. The Box S fault zone is upthrown to the north, although the direction of displacement along individual faults is difficult or impossible to determine. Fault F-8 trends easterly and is downthrown on the south. This fault may have a component of left movement associated with it in addition to the dip slip.

Fault F-9 lies roughly 4000 feet southwest of the Dan Valley fault and strikes N. 46° W. It strikes northwestward from the eastern edge of the mapped area in sec. 35, T. 12 N., R. 16 W., to where it disappears under the valley fill west of the Box S ranch. Fault F-9 is upthrown on the northeastern side, where the middle Chinle is brought against the lower portion of the upper member. The throw along fault F-9 is probably between 100 and 200 feet. The block between fault F-9 and the Dan Valley fault to the northeast is thus a small

branch strikes N. 60° E. and the [illegible] strikes N. 70° W. Both branches of the fault are upthrown on the northeastern side, toward the [illegible]. Along the Dan Valley fault the lower member of the Chinle has been faulted against the middle member with a probable displacement of slightly less than 100 feet. [illegible] of the fault form northeastward-facing scarps.

In the vicinity of the [illegible] of the [illegible] Ranch, and between the Dan Valley fault and fault F-11 lies a complex zone of small faults. [illegible] beds of the Chinle formation, the exact location of a particular fault is very difficult to determine. [illegible] variable, both because of faulting and slumping. The Box S fault zone is upthrown to the south, although the direction of displacement along individual faults is difficult or impossible to determine. Fault F-8 trends easterly and is downthrown on the south. This fault may have a component of left movement associated with it in addition to the [illegible].

Fault F-9 lies roughly 1000 feet southwest of the Dan Valley fault and strikes N. 40° W. It extends northwestward from the eastern edge of the mapped area in sec. 35, T. 42 N., R. 15 W., to where it disappears under the valley fill [illegible] of the Box S ranch. Fault F-9 is upthrown on the northeastern side, where the middle Chinle is brought against the lower portion of the upper member. Displacement along fault F-9 is probably between 100 and 200 feet. The block between fault F-9 and the Dan Valley fault is tilted [illegible] and forms a small

horst. The middle Chinle strata which occupy the surface of this horst are very complexly contorted. It is not known if this is the result of many small tectonic folds and faults or is the product of slumping. Fault F-9 may extend for a distance beneath the alluvium to the northwest, and may even cross the valley entirely and terminate against fault F-8 on the north side. Fault F-9 might thus be the offset end of fault F-11, although the evidence is inconclusive.

Fault F-10 cuts the steep limb of the Nutria monocline in secs. 33 and 34, T. 12 N., R. 16 W. This fault is about 1 mile long and follows an arcuate course which is convex southward. Fault F-10 is pivotal with the beds on the north side dipping about 5° more steeply than those on the south. The movement appears to be entirely rotational and is counterclockwise in which the beds across the fault appear to have moved counterclockwise to the observer.

The Little Bear fault occurs at Little Bear Spring, and is the only fault in the area that was observed to cut through the entire monocline. It strikes N. 63° E. and is about 4000 feet long. Movements along this fault appears to be mostly dextral, for the eastward dipping Stinking Springs thrust is displaced nearly as much and in the same direction, as the westward-dipping beds. The displacement along the Little Bear fault is about 200 feet. This fault cuts all the beds exposed along the monocline at this locality from the Glorieta sandstone to the Crevasse Canyon formation.

horst. The middle Chinle [illegible] of this horst are very irregularly [illegible]. [illegible] this is the result of many small [illegible] faults and [illegible] or is the product of slumping. Fault F-9 may extend for a distance beneath the alluvium to the northwest, [illegible] cross the valley [illegible] and terminate against fault F-8 on the north side. Fault F-9 [illegible] fault F-11, although the evidence is inconclusive.

Fault F-10 cuts the steep limb of the [illegible] monocline in secs. 33 and 34, T. 12 N., R. 16 W. This fault is about [illegible] mile long and follows an arcuate course which is convex south-ward. Fault F-10 is pivotal with the [illegible] dipping about 5° more steeply than those on the [illegible]. The movement appears to be [illegible] clockwise in which the beds across the fault [illegible] moved counterclockwise to the observer.

The Little Bear fault occurs at Little Bear Spring, and is the only fault in the area that was observed to [illegible] the entire monocline. Its strike is N. [illegible] and [illegible] about 1,400 feet long. Movement along this fault appears to be [illegible] dextral, for the eastward dipping [illegible] is displaced nearly as much and in the same direction as the westward-dipping beds. The displacement along the Little Bear fault is about 200 feet. This fault [illegible] exposed along the monocline [illegible] sandstone to the [illegible] Formation.

Slumping

Slumping has occurred in the Chinle formation in many places where it is comparatively gently dipping and forms low hills. This is particularly noticeable in secs. 16 and 17, T. 12 N., R. 16 W. The slumping, where observed, is related to the failure of the upper part of the lower member under the force of gravity. This part of the Chinle is somewhat bentonitic and may be plastic when wet.

The sandstone beds of the lower Chinle, as well as the sandstones of the middle member, rest on the softer material and are dependent upon it for support. These sandstone beds have failed when the lower, bentonitic shale has been removed by flowage. The sandstone beds are thus cut by a number of small surficial faults. They dip in various directions quite chaotically. Locally, the blocks have rotated as they moved and commonly dip into the side of hills.

In sec. 21, T. 12 N., R. 16 W., a block of middle Chinle sandstone has moved a considerable distance downhill. This block, and similar smaller blocks, are lying in the bottom of a canyon 200 feet below and 500 feet away from the nearest outcrop of the middle Chinle. They dip 50°-60° and are lined up along the stream course, thus, giving the appearance of a hogback along a fold.

Slumping

Slumping has occurred in the Chinle formation in those places where it is comparatively gently dipping and forms low hills. This is particularly noticeable in secs. 16 and 17, T. 12 N., R. 26 W. The slumping, where observed, is related to the failure of the upper part of the lower member under the force of gravity. This part of the Chinle is somewhat bentonitic and may be plastic when wet.

The sandstone beds of the lower Chinle, as well as the sandstones of the middle member, rest on the softer material and are dependent upon it for support. These sandstone beds have failed when the lower, bentonitic shale has been removed by flowage. The sandstone beds are displaced by a number of small surficial faults. They dip in various directions quite chaotically. Locally, the blocks have rotated as they moved and commonly dip toward the side of hills.

In sec. 23, T. 12 N., R. 26 W., a block of the middle sandstone has moved a considerable distance downhill. This block, and similar smaller blocks, are lying in the bottom of a canyon 200 feet below and 500 feet away from the nearest outcrop of the middle Chinle. They dip 20°-30° and are lined up along the stream course, having the appearance of a hogback along a fold.

Joints

The joints of the Zuni Mountains were studied in some detail by Gilkey (1953). Kelley and Clinton (1960) have also discussed the joint pattern of the Zuni Mountains. Gilkey (1953, p. 18) found the dominant set of joints in the uplift to trend roughly parallel to the long dimension of the uplift. Kelley and Clinton (1960, p. 45) found the joints to be transverse to the long dimension of the uplift, especially near its ends. Gilkey used a method somewhat akin to statistical analysis in describing the joints. He measured all the joints in a small area and plotted the mean direction of each set in that area on his map. Kelley and Clinton made use of aerial photographs and plotted the pronounced lineations. It is not surprising that these methods of description have yielded different results. Joints approximately paralleling the strike of a formation are easily overlooked on aerial photographs, and a point sample is dependent upon significant spacing of the sampling for accuracy.

This writer found that above the head of the monocline, the primary set of joints trended N. 40°-60° E., and secondary joints seemed to follow roughly the strike of the beds. Jointing is extremely variable along the steep limb of the monocline. The primary joints may parallel the strike of the monocline or they may cut across the strike at any angle up to and including perpendicular. The joints exposed along the steep limb of the monocline frequently are seen to curve

Joints

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through as much as 35° in a distance of less than 300 feet. The joint planes along the steep limb are commonly slickensided, as are the bedding surfaces. The joints above the head of the monocline were observed primarily in the Glorieta sandstone, but those along the steep limb were seen in formations from the Wingate to the lower part of the Crevasse Canyon. The diversity of the joint orientation along the monocline makes interpretation difficult. The value of the joints in the interpretation of the process of monoclinal deformation is doubtful.

Synthesis

Monoclines have traditionally been considered to have been formed as drape features located over deep-seated normal faults. Baker (1935, p. 1502) postulated that compressive forces were chiefly responsible for monocline formation. Kelley (1955a, p. 802) favored a compressive origin for the monoclines, although he did not completely rule out vertical forces in their formation. He considered the evidence somewhat inconclusive and felt that mechanics of deformation might vary greatly from one monocline to another. Because the Nutria monocline was the only one studied for this report, no attempt has been made to extend the mechanics of this monocline to other parts of the Colorado Plateau. Although the various theories concerning monocline formation were kept in mind, an attempt was made to determine the origin

through as much as 15° in a distance of less than 300 feet. The joint planes along the [illegible] are smoothly slicken-sided, as are the bedding surfaces. The joints above the head of the monoclines were observed [illegible] in the Glorieta sandstone, but those along the steep limb were seen in formations from the Wingate to the lower part of the [illegible] Canyon. The diversity of the joint orientation along the monocline makes interpretation difficult. The value of the joints in the interpretation of the process of monoclinal deformation is doubtful.

Synthesis

Monoclines have traditionally been considered to have been formed as drape features localized by [illegible] normal faults. Baker (1935, p. 1492) suggested that compressive forces were chiefly responsible for monocline formation. Kelley (1955a, p. 802) favored a compressive origin for the monoclines, although he did not completely rule out vertical forces in their formation. He considered the evidence somewhat inconclusive and felt that mechanics of deformation might vary greatly from one monocline to another. Because the [illegible] monocline was the only one studied in this report, no attempt has been made to extend the mechanics of this monocline to other parts of the Colorado Plateau. Although the various theories concerning monocline formation were kept in mind, an attempt was made to determine the origin

of the Nutria monocline by analysis of the structures found in the field. Because the Nutria monocline forms the northwestern boundary of the Zuni uplift, the possible origins of the uplift had to be considered when postulating the formation of the monocline.

Accurate dating of the Nutria monocline is not possible, but it is similar to others in the Colorado Plateau of known Laramide age (Kelley, 1955a, p. 797). No evidence for or against more than one major period of deformation in the formation of the Zuni uplift was found.

One of the unsolved questions in the formation of the Nutria monocline is the orientation of the primary forces. Is the monocline the result primarily of vertical or horizontal (compressive) forces? This writer favors the compressive forces in the formation of the monocline.

Vertical movement along the monocline has been interpreted as the result of movement along a basement fault that does not reach the surface. However, vertical movement along a buckle in the basement rocks might also result in a similar feature without a fault actually being present (Kelley, 1955a, p. 798). Vertical movement in the basement would require that the veneer of sedimentary rocks be draped over the zone of movement in much the same manner as one table cloth covering two tables of slightly different heights. Such draping would seem to require that both bends of the resulting flexure would be of about the same curvature or intensity. If one bend was sharper than the other, it

of the Nutria monocline by analysis of the structures found in the field. Because the Nutria monocline forms the south-western boundary of the Zuni uplift, the possible [illegible] of the uplift had to be considered when postulating the formation of the monocline.

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would probably be the upper one where the change from the well supported sediments of the rising block to the somewhat less well supported sediments overlying the subsiding block occurs. However, the lower synclinal bend is sharper along the Nutria monocline.

As movement progressed along a basement fault or buckle, the overlying strata would be rotated progressively into closer alignment with the axis of maximum deformation. The end result of this rotation would be parallelism with this plane. Thus, the draped strata would not be rotated through an angle greater than the initial angle between the sedimentary rocks with the axis of maximum deformation. Further rotation of the beds would result in a complex crumpling that was not found along the Nutria monocline. It is probable that tangency is never attained in nature, and that a small angle always exists between the draped beds and the axis of maximum deformation. Dips in excess of 85° to the southwest were noted along the Nutria monocline. This would seem to indicate that the plane of deformation does not dip any less steeply than 85° to the southwest and probably does not have a southwesterly component of dip at all. Thus, the Nutria monocline is probably not located over a deep-seated normal fault with any appreciable inclination to the southwest. Any horizontal tension accompanied by vertical movement would require that a fault surface would dip away from the side of upward movement.

would probably be the upper one where the plastic [illegible] well supported sediments of the [illegible] to the [illegible]. Less well supported sediments overlying the monoclines [illegible] occurs. However, the lower amplitude [illegible] the Nutria monocline.

As movement progressed along a basement fault or buckle, the overlying strata would be rotated progressively into closer alignment with the axis of maximum deformation. The end result of this rotation would be parallelism with this plane. Thus, the upper strata would not be rotated through an angle greater than the initial angle between the sedimentary rocks with the axis of maximum deformation. Further rotation of the beds would result in a [illegible] that was not found along the Nutria monocline. It is probable that [illegible] is never [illegible], and that a small angle always exists between the [illegible] and the axis of maximum deformation. [illegible] in excess of [illegible] to the southwest were noted along the Nutria monocline. This would seem to indicate that the plane of [illegible] does not dip any less steeply than [illegible] to the [illegible] and probably does not have a southwesterly component of dip at all. Thus, the Nutria monocline is [illegible] located over a deep-seated normal fault with [illegible] inclination to the southwest. Any [illegible] upthrust [illegible] vertical movement would require that a fault surface would dip away from the [illegible] of [illegible].

Draping of sedimentary strata over a basement fault or buckle along which there had been vertical movement would require that the sedimentary rocks be stretched. Sedimentary rocks that originally occupied a given horizontal distance before flexure would have to cover that same horizontal distance plus the distance necessary to cover the vertical movement. Thus, the beds that formerly occupied, when horizontal, the base of a right triangle, must occupy its hypotenuse after the flexure. Along section C-C' (Fig. 2), the beds of the Nutria monocline would have to lengthen about 3700 feet in order to compensate for the vertical rise. It is very unlikely that rocks, with their low tensile strength, would be able to lengthen this much within the width of the monocline without some extensional faulting parallel to the strike of the monocline. No faults of this type were found along the Nutria monocline, with the possible exception of fault F-11. Fault F-11 extends for only about 2 miles at the southern end of the monocline, and its attitude cannot be accurately determined.

If the Nutria monocline has been formed by compression, the steep limb of the monocline would have originally taken up a greater horizontal distance than it does now. Thus, the beds along section C-C' would have occupied 3700 feet more distance horizontally than they do now. No faults are required if the beds were rotated into their present position by a compressive force.

Draping of sedimentary strata over a basement fault or buckle along which there had been vertical movement would require that the sedimentary rocks be stretched. Sedimentary rocks that originally occupied a given horizontal distance before flexure would have to cover that same horizontal distance plus the distance necessary to cover the vertical movement. Thus, the beds that formerly occupied, when horizontal, the base of a right triangle, might occupy its hypotenuse after the flexure. Along section G-G' (Pl. 2), the beds of the Nutria monocline would have had to lengthen about 3700 feet in order to compensate for the vertical rise. It is very unlikely that rocks, with their low tensile strength, would be able to lengthen this much within the width of the monocline without some extensional faulting parallel to the strike of the monocline. No faults of this type were found along the Nutria monocline, with the possible exception of fault F-11. Fault F-11 extends for only about 2 miles at the southern end of the monocline, and its attitude cannot be accurately determined.

If the Nutria monocline has been formed by compression, the steep limb of the monocline would have originally taken up a greater horizontal distance than it does now. Thus, the beds along section G-G' would have occupied 3700 feet more distance horizontally than they do now. No faults are required if the beds were rotated into their present position by a compressive force.

The fact that the steep limb of the Nutria monocline is cut by the Stinking Springs thrust is indicative of compression. The monocline is not due to drag along this fault, for the fault does not extend the full length of the monocline.

Although a synclinal bend that is sharper than the anticlinal bend is not likely if vertical movement is involved, a more sharply flexed synclinal bend is not incompatible with a compressive origin. The sedimentary strata might be progressively peeled back when one block of basement rock over-rode another.

It is not possible to determine if the Stinking Springs thrust existed as a normal fault before the formation of the Nutria monocline. If it did exist when monocline formation was begun, the initial movement in response to the compressive forces would probably not have been along the fault. The first movement would probably have been a rotation of the beds and the fault plane into a gentle monocline. As the fault became more nearly aligned with the axis of deformation, relief would have been along the fault in addition to further rotation. This hypothesis of formation has been discussed by Kelley (1955a, p. 798). However, it is not necessary for the Stinking Springs thrust to have formed prior to the beginning of the monocline. As compressive forces built up, the sedimentary rocks began to rotate into the form of a monocline. When the stress had reached a certain level, the steep limb of the monocline gave way with the formation of the thrust. Further deformation would have been both along the fault and by continued intensification of the monoclinal fold.

The fact that the steep limb of the Natrona monocline is cut by the Stinking Springs thrust is indicative of compression. The monocline is not due to drag along this fault, for the fault does not extend the full length of the monocline.

Although a synclinal bend that is sharper than the anticlinal bend is not likely if vertical movement is involved, a more sharply flexed synclinal bend is not incompatible with a compressive origin. The sedimentary strata might be progressively peeled back when one block of basement rock overrides another.

It is not possible to determine if the Stinking Springs thrust existed as a normal fault before the formation of the Natrona monocline. If it did exist when monocline formation was begun, the initial movement in response to the compressive forces would probably not have been along the fault. The first movement would probably have been a rotation of the beds and the fault plane into a gentle monocline. As the fault became more nearly aligned with the axis of deformation, relief would have been along the fault in addition to further rotation. This hypothesis of formation has been discussed by Kelley (1955a, p. 796). However, it is not necessary for the Stinking Springs thrust to have formed prior to the beginning of the monocline. As compressive forces built up, the sedimentary rocks began to rotate into the form of a monocline. When the stress had reached a certain level, the steep limb of the monocline gave way with the formation of the thrust. Further deformation would have been both along the fault and by continued intensification of the monoclinal fold.

It is not possible to determine from examination of the monocline itself if deformation occurred over a thrust fault or a buckle in the basement rocks. The presence of a thrust fault at the surface might point to a thrust at depth rather than a fold in the basement. However, it is also possible that because lithostatic pressure would have been greater on the more deeply buried basement rocks, relief of compressive stress would have been by plastic flow at depth. Thus, the Stinking Springs thrust may die out at depth and pass into a fold.

The offset, short straight segments of the monocline may be indicative of en echelon structures at depth. However, the monocline is continuous at the surface, and this possibility is not provable from the pattern of the monoclinal trace alone.

The McGaffey fault zone, which roughly parallels the trend of the Nutria monocline, appears to be the result of compressive forces inasmuch as it is a reverse fault. Because of this parallelism, it probably was formed by the same compressive forces responsible for the Nutria monocline. Relief of stress along the McGaffey fault zone thus appears to be complimentary to the deformation of the monocline.

Inasmuch as the Nutria monocline forms the northwestern boundary of the Zuni uplift, a consideration of the forces that formed the monocline and its surrounding structures must take into account, at least in a general way, the

forces responsible for the uplift as a whole. The uplift has been reported as being strongly asymmetrical to the southwest (Smith, 1957, p. 59). Although dips along the southern half of the southwest flank are 10° to 15° steeper than along the northern and eastern sides of the uplift, the noticeable asymmetry is due to the intense deformation along the Nutria monocline.

Because the Nutria monocline forms the western flank of the Zuni uplift, it has been considered to have been formed at about the same time and by the same forces that formed the uplift. Although this is probably the most likely sequence of events, it is not demonstrable from field relationships alone. It is not likely that the monocline was formed before the uplift. If it had been, the entire uplift of the mountains would not be almost entirely along the monocline as it is now, but would extend beyond the monocline with strata dipping away from the core above the head and below the foot. For an appreciable distance along the Nutria monocline, the dip reverses above the head and becomes practically horizontal below the foot.

As was mentioned previously, it is not possible to determine whether the monocline was formed during or after the uplift. If it was formed during the course of the uplift, the forces that caused the uplift must have caused the monocline. However, if the monocline formed after the uplift as a peeling back of already-dipping strata, forces quite different in orientation from those that caused the uplift might be expected. If the monocline actually had

forces responsible [illegible]

has been reported [illegible] strong [illegible] to the southwest (Smith, 1957, p. [illegible]). Although dips along the southern half of the [illegible] 10° to 15° [illegible] than along the northern and eastern sides of the uplift, the noticeable asymmetry is due to the intense deformation along the Nutria monocline.

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been formed after the Zuni uplift, there is no way of determining whether any appreciable period of time passed between the formation of the uplift and the monocline. However, in the absence of any evidence indicative of a long break between the two events, it must be regarded as being more likely that monocline formation would have begun, in this case, soon after the formation of the uplift.

Gilkey (1953, p. 20) believed that the Zuni uplift was caused by primarily vertical forces. He regarded it as a horst draped with sedimentary rocks. Kelley and Clinton (1960, p. 47) disagreed with Gilkey's interpretation of the joints and believed that it was unlikely that the uplift was a horst covered by sediments. They considered a vertical origin for the Zuni uplift was possible, if unlikely. However, the throw on the Dan Valley fault and similar faults in the southwestern and south-central part of the uplift is downward towards the core of the uplift. This direction of throw is not compatible with an origin of the uplift due to vertical forces, nor is the sharp compressive flexure of the Nutria monocline. However, a vertical origin is not impossible if both the faults of the southern and western portions and the monocline were formed after the formation of the uplift. However, even disregarding the faults and the monocline, the slight asymmetry of the uplift would seem to point to some other type of origin.

been formed after the uplift, there is no way of determining whether any appreciable period of time passed between the formation of the uplift and the monocline. However, in the absence of any evidence indicative of a long break between the two events, it must be regarded as being more likely that monocline formation would have begun, in this case, soon after the formation of the uplift.

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Smith (1957, p.60) thought that compressive forces oriented N. 60° E. could account for both the Zuni uplift and the Nutria monocline. Kelley and Clinton (1960, p. 48) pointed out that the throws on the faults were not compatible with this interpretation unless they were of a later age. It appears unlikely that effects of intense compression would be found only on the northwestern side of the uplift if it was caused by compressive forces. Evidence for compression should be found along most of the western flank of the mountains instead of only along the northern portion. Formation of the uplift by direct compression might be possible if the faults of the southwestern side and possibly the monocline are regarded as being somewhat later in origin than the uplift.

In order for the monocline to have been formed at the same time as the uplift, a more complex set of forces is required. Kelley (1955a, p. 799) has postulated a rotational movement of the Zuni Mountain mass. It appears that a simple rotational movement would require that there be compressive features on diagonally opposing corners of the uplift and tensional features on the other two corners. In the Zuni uplift the Nutria monocline forms a compressional feature along the northwestern flank and the faults of the southwestern part trend diagonally across the uplift (Smith, 1958), and could have provided the necessary tensional relief. However, compressional features were not found along the southeastern border of the uplift (Smith, 1957, p. 60), nor are the faults found along the northeastern side of the

Smith (1957, p.60) mapped [illegible] oriented N. 60° E. [illegible] and the Nutria monocline. [illegible] (1940, p. [illegible]) pointed out that [illegible] with this interpretation [illegible] appears unlikely [illegible] found only on the [illegible] caused by compressive [illegible] be found along [illegible] instead of only along [illegible] uplift by direct [illegible] of the southwestern side [illegible] regarded as being [illegible].

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uplift the type that would be expected after a simple rotational movement of the Zuni uplift. A simple horizontal rotation of the Zuni uplift seems somewhat unlikely.

An accurate interpretation of the forces involved in the formation of the Zuni uplift necessitates the determination of the relative ages of the Nutria monocline and the Dan Valley fault with respect to the uplift and to each other. A complex movement of the Zuni uplift area would be required if the monocline and the Dan Valley fault are approximately the same age as the uplift. Such a movement might be a complex, counterclockwise rotation of the Zuni uplift about a point. A movement of this type might have been caused by a non-uniform couple acting upon the uplift area. The lack of intense compressive features other than the monocline may indicate that such a couple was acting over a larger area than the Zuni uplift itself. The plane of the couple would probably have been tilted slightly to the south or southeast, and the effective forces may have increased in intensity to the northwest. If such forces acted on the area, the arching of the Zuni uplift and its rotation would have begun almost simultaneously. As the rotation of the uplift continued, failure would have begun by upward rotation along a zone of weakness represented by the Nutria monocline-Dan Valley fault trend. Thus, the Box S fault zone could represent the hinge area along this plane of weakness. The Nutria monocline-Dan Valley fault trend

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tional movement of the Zuni uplift. A slight [illegible]
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approximately follows the zero isopach line of the Pennsylvanian rocks shown by Kottlowski (1959, Fig. 1), and may represent a pre-existing line of weakness associated with the border of the Pennsylvanian Zuni uplift, which lay to the southwest of the present Zuni Mountains.

If the Nutria monocline is definitely younger than the Zuni uplift, such a complex rotation would not have been necessary. The uplift could be formed first by either vertical or compressive forces. A later simple rotation of the uplift could be responsible for the formation of the monocline, and possibly the Dan Valley fault trend. However, the Dan Valley fault and associated faults may be somewhat younger than the other features of the uplift, in which case they may represent a relaxation of forces. Additional studies in other parts of the Zuni uplift and along the Nutria monocline may further clarify the mechanics of uplift.

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ECONOMIC GEOLOGY

General Features

No deposits of commercial value have ever been worked within the area mapped for this report. Although both coal and uranium have b een mined within 10 miles of the area, no commercially exploitable deposits have been found within it. Probably the most important use of the geologic features of this area is as a recharge area for ground-water supplies of the surrounding areas.

Coal

Sears, in 1925, made a rather thorough survey of the coal resources of the Gallup-Zuni basin (Gallup sag). He described coal of commercial importance in the Dilco Coal member and the Gibson Coal member of what is now the Crevasse Canyon formation. Coal seams of lesser importance were also described in the Gallup sandstone and the Dakota(?) sandstone. Miningwas most active from the 1880's until the 1920's. The coal was principally used as fuel on the Santa Fe Railroad. When the railroad's demand for coal slackened, mining activity declined. Today coal mining is carried on at one mine, the Robert's mine, about 3 miles north of the area. Lenticular coal beds are present in the Crevasse Canyon formation west of the Nutria monocline. The lenticu-

larity of the beds and the low grade of the coal combined with the poor coal market at the present time make these deposits unattractive. However, an increased demand for coal might stimulate further interest in these deposits.

Ground Water

The area is important for recharge of the ground-water supplies on the northern and northwestern sides of the Zuni uplift. The extensive outcrops of San Andres limestone and Glorieta sandstone that are found above the head of the monocline dip north and east. Artesian flow is found down-dip from the mapped area at the Fort Wingate School and northward across the Rio Puerco Valley. Along the monocline itself, the upturned beds of the Dakota(?) sandstone, the Zuni sandstone, and the Wingate formation provide access for water into these formations. Artesian conditions might be expected from these beds in the Gallup-Zuni basin to the west. Due to the steep dips along the monocline, the recharge area is small. Total flow from these formations might be expected to be less than that of the Permian strata to the north of the uplift. Several small springs along the Nutria monocline and the McGaffey fault zone provide local watering for livestock.

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Uranium

No uranium mining has been done within the area. However, uranium has been mined from the Morrison and Mancos formations along the monocline north of the area. The Morrison is the only formation within the area that might contain a deposit of appreciable size. Although it pinches out southward along the monocline, uranium deposits may be present, where it is present, in the northern half of the area. Radioactivity has been reported in the Morrison north of Stinking Springs (Taylor, 1961, oral communication), and a few claims have been staked in that locality. The ore does not crop out at the surface, and the level of radioactivity would indicate that it is probably of a low grade. If the demand for uranium increases, this deposit may prove workable.

Oil and Gas

No drilling for oil or gas has been attempted within the area. Pennsylvanian strata, productive in the Four Corners area, are absent in this area in any appreciable amount. The Cretaceous beds are steeply dipping and exposed along the monocline. Any hydrocarbons that may have been present in them could have easily escaped updip. However, the Permian beds of the area may constitute potential reservoir rocks. The San Andres limestone, the Glorieta sandstone, and the Yeso formation are all marine, and as has

been noted in the case of ground water, are suitable for the transport and storage of fluids. Although these beds were subjected to erosion during early Triassic time, the area of erosion was small (McKee, et al., 1956). Hydrocarbons may have migrated into this area from uneroded areas after these units were sealed by the impermeable Chinle formation. A trap may exist beneath the Stinking Springs thrust within these Permian beds. If hydrocarbons have been preserved within the Permian rocks, entrapment may be expected to occur where the line of intersection of the fault surface and the San Andres-Chinle contact is highest. The fault surface of the Stinking Springs thrust descends slightly to the south so that fluids would move upward beneath this surface until stopped by some impermeable obstruction. Such an obstruction may exist where the Little Bear fault cuts the thrust. Thus, if a trap exists, it would probably be found in the northwestern quarter of sec. 12, T. 13 N., R. 17 W. Permian strata might be expected at 2000-2500 feet below the surface. A more accurate location of this structure is not possible without better knowledge of the thickness of the Chinle formation in the area and more precise information about the dip of the fault surface in this locality.

CONCLUSIONS

The observations made during the course of this report permit only a few definite conclusions to be drawn. It is believed that the Nutria monocline was formed by compressive forces. It was not possible to date the monocline definitely with respect to the Zuni uplift, although it may be said that the monocline is not older than the uplift. It would be expected that a sharp flexure of this type that forms one flank of an uplift would be of the same age as the uplift, but this cannot be positively demonstrated in the case of the Nutria monocline. Similarly, the origins of the uplift itself have not been positively established. The possible modes of formation are dependent upon the order of formation of the various individual structures on the Zuni uplift itself.

It was discovered that all the Jurassic formations present north of the report area either pinch out to the south, or grade into the Zuni sandstone in a southerly direction. Thus, the Jurassic section in the southern part of the area is represented by a single eolian sandstone, the Zuni sandstone.

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APPENDIX

Explanation of Bedding Terms

Massive ----------------------	over 3 feet
Medium-bedded ----------------	1 to 3 feet
Thin-bedded ------------------	1 inch to 1 foot
Very thin bedded -------------	1/2 inch to 1 inch
Fissile ----------------------	less than 1/2 inch

Measured Sections I

Sec. 11, T. 13 N., R. 17 W.

No.		Thickness Unit	Cumulative
	(Mancos shale above)		
	Top of Dakota sandstone		
33	SANDSTONE: massive; cross-bedded; tan; hematite stain on bedding surfaces; micaceous; medium-grained; well sorted -	16	996
32	SHALE: black and brown; carbonaceous; some thin coal --------------------------	15	980
31	SANDSTONE: massive; cross-bedded; tan; hematite stain on bedding surfaces; micaceous; medium-grained; well sorted -	54	965
30	SHALE, CLAYSTONE, AND SANDSTONE: interbedded; shale, fissile, brown; sandstone, thin-bedded, brown, micaceous, fine-grained -------------------	8	911
29	SANDSTONE: medium-bedded to massive; dark orange-brown; weathered light brown; medium-to coarse-grained; poorly sorted; subangular grains --------------	7	903
28	SHALE: fissile; black, brown and gray with lenticular coal beds --------------	16	896

No.		Thickness Unit	Cumulative
27	SANDSTONE: massive; cross-bedded; tan; weathered buff; calcareous; micaceous; medium- to coarse-grained; poorly sorted; subangular grains ------	8	880
26	CONGLOMERATE: brown; medium to coarse sand matrix with rounded chert pebbles and angular quartz granules; very poorly sorted --------------------------	3	872
	Total Dakota:	127	
	Top of Morrison formation		
25	SANDSTONE: massive; white to purple; very friable; coarse-grained; subangular grains ------------------------	19	869
24	CLAYSTONE AND SILTSTONE: interbedded; variegated ----------------------------	23	850
23	SANDSTONE: thin-bedded; light brown; coarse-grained; poorly sorted ---------	5	827
22	CLAYSTONE AND SILTSTONE: red and green; very soft; sandy ----------------------	25	822
21	SANDSTONE, CLAYSTONE, AND SILTSTONE: interbedded; sandstone red and white, coarse-grained, poorly sorted, silty; claystone green; mostly covered -------	44	797
	Total Morrison:	116	
	Top of Zuni sandstone		
20	SANDSTONE: massive; red; slightly micaceous; medium-grained; rounded grains; well sorted; contains a few nodules of calcareous sandstone -------	54	753
19	COVERED: ----------------------------	17	699
18	SANDSTONE: massive; cross-laminated; red and white; very friable; medium-grained; well rounded grains; well sorted; contains a few nodules of calcareous sandstone ----------------	28	682
17	COVERED: ----------------------------	92	654

No.		Thickness Unit	Cumulative
16	SANDSTONE: massive; cross-laminated; red and white mottled; fine- to medium-grained; rounded grains; well sorted; contains irregular masses of calcareous sandstone ------------------	37	562
15	SANDSTONE: thin-bedded; white; very calcareous; fine-grained --------------	7	525
14	COVERED: --------------------------------	15	518
13	SANDSTONE: cross-laminated; red and white; red sandstone weathers brown; white sandstone very calcareous; fine-grained; well sorted ------------------	2	503
12	SANDSTONE: massive; cross-laminated; orange and white; weathers brown; fine- to medium-grained; well sorted --------	12	501
11	COVERED: --------------------------------	8	489
10	SANDSTONE: massive; cross-laminated; orange-brown; weathered brown; fine- to medium-grained; well sorted; contains a few foreset beds of white, very calcareous sandstone -------------	118	481
9	SANDSTONE: massive; red; fine-grained; silty ----------------------------------	5	363
8	SANDSTONE: massive; white; fine-grained ----------------------------------	4	358
7	SANDSTONE: massive; cross-laminated; orange to orange-brown; weathered light gray-brown to orange-brown; fine- to medium-grained; well sorted; contains a few calcareous zones ----------------	209	354
	Total Zuni:	598	
	Top of Entrada formation		
6	SANDSTONE: thin-bedded; even-bedded; bright red-orange; very friable; very fine grained and silty ----------------	11	155
	Total Entrada:	11	

No.		Thickness Unit	Cumulative
	Top of Wingate formation		
5	SANDSTONE: massive; cross-bedded; white to brown; calcareous; very friable; medium- to coarse-grained; subrounded to subangular grains -------	23	144
4	SANDSTONE: massive; cross-laminated; orange; friable; medium-grained; well rounded grains -----------------------	77	121
3	CONGLOMERATE: orange-brown; coarse sand matrix with chert and quartzite pebbles; well rounded grains; very poorly sorted ------------------------	1	44
2	SANDSTONE: medium-bedded; cross-bedded; orange; weathered orange-brown; medium- to fine-grained; poorly sorted -	12	43
1	SILTSTONE: orange-brown; mostly covered --------------------------------	31	31
	Total Wingate:	144	
	(Chinle formation below)		

Measured Section II

Sec. 6, T. 12 N., R. 16 W. and
Sec. 1, T. 12 N., R. 17 W.

No.		Thickness Unit	Cumulative
	(Mancos shale above)		
	Top of Dakota sandstone		
28	SANDSTONE: massive; cross-bedded; tan to buff; weathered tan; micaceous; medium- to coarse-grained; subrounded to subangular grains ------------------	38	1058
27	SANDSTONE: massive; cross-bedded; orange; weathered orange-brown; micaceous; fine- to medium-grained; well sorted --------------------------	13	1020

No.		Thickness Unit	Cumulative
26	SANDSTONE AND SHALE: interbedded; sandstone, even-bedded, buff to tan, weathered tan, micaceous, fine- to medium-grained; shale, brown and black, carbonaceous --------------------	14	1007
25	SANDSTONE: massive; cross-bedded; orange; weathered orange-brown; micaceous; fine- to medium-grained; well sorted -------------------------	13	993
24	SANDSTONE AND SHALE: interbedded; sandstone thin-bedded, gray and brown, weathered brown, micaceous, silty, fine-grained, poorly sorted; shale carbonaceous -------------------------	7	980
23	SANDSTONE: massive; cross-bedded; brown; contains limonite nodules that weather in relief; red and yellow staining on fresh surfaces; fine-grained ------------------------------	8	973
22	SANDSTONE AND SHALE: interbedded; sandstone thin-bedded, gray and brown, weathered brown, red and yellow staining on fresh surfaces, micaceous, slightly silty, fine-grained, poorly sorted; shale, black, carbonaceous ----	4	965
21	SANDSTONE: massive; brown, weathered orange-brown; fine- to medium-grained; subrounded grains --------------------	7	961
	Total Dakota:	104	
	Top of Morrison formation		
20	SHALE: gray, brown and black; carbonaceous -------------------------	12	954
19	COVERED: ------------------------------	22	942
18	CLAYSTONE AND SANDSTONE: interbedded; claystone black to brown; sandstone tan, micaceous, fine-grained ----------	10	920
17	CLAYSTONE: gray, red, green, and brown; very soft ---------------------	32	910

No.		Thickness Unit	Cumulative
16	SILTSTONE: red and brown; slightly sandy ----------------------------------	6	878
15	SANDSTONE: thin-bedded; gray-green; silty; medium-grained; poorly sorted; soft ----------------------------------	6	872
14	SANDSTONE: bright red; very friable; medium-grained; well sorted; very soft ----------------------------------	21	866
	Total Morrison:	109	
	Top of Zuni sandstone		
13	SANDSTONE: massive; cross-laminated; red and white; very friable; micaceous; coarse- and medium-grained; subangular grains ----------------------	183	845
12	SANDSTONE: nonbedded; white; weathered light-gray; medium-grained; subangular to subrounded grains; contains nodules of calcareous sandstone that weather in relief ---------------------------	17	662
11	SANDSTONE: massive; cross-laminated; red and white; medium-grained; subangular grains -----------------------	105	645
10	SANDSTONE: massive; cross-laminated; red and white; weathered red or gray; slightly calcareous; medium-grained; subangular to subrounded grains -------	87	540
9	SANDSTONE: massive; cross-laminated; light-brown; weathered tan; calcareous; fine- to medium-grained; subrounded grains --------------------------------	23	453
	COVERED: ----------------------------	35	430
8	SANDSTONE: massive; cross-laminated; orange-brown; weathered gray to tan; very friable; calcareous; fine- to medium-grained; subrounded grains; well sorted --------------------------	39	395

No.		Thickness Unit	Cumulative
7	SANDSTONE: massive; cross-laminated; orange-brown; weathered gray to tan; fine- to medium-grained; well rounded grains; well sorted -------------------	233	356
	Total Zuni:	722	
	Top of Entrada formation		
6	SANDSTONE: even-bedded; bright orange; silty; very fine-grained ------	3	123
	Total Entrada:	3	
	Top of Wingate formation		
5	SANDSTONE: thin- to medium-bedded; even-bedded; white; weathered gray; friable; medium-grained; well rounded grains; well sorted -------------------	6	120
4	SANDSTONE: massive; cross-laminated; orange-brown; weathered light orange-brown; medium-grained; well rounded grains; well sorted -------------------	32	114
3	COVERED: ---------------------------------	40	82
2	SANDSTONE: medium-bedded; cross-bedded; red-brown; weathered brown; contains a few chart pebbles and granules; silty to conglomeratic; grain size changes rapidly laterally --------	24	42
1	CONGLOMERATE: massive; cross-bedded; red-brown; weathered brown; contains quartzite and banded chert pebbles; matrix of medium to coarse sand -------	18	18
	Total Wingate measured:	120	

(Base of Wingate not exposed)

Measured Section III

Sec. 28, T. 12 N., R. 16 W.

No.		Thickness Unit	Cumulative
	(Dakota sandstone above)		
	Top of Zuni sandstone		
6	SANDSTONE: massive; cross-bedded; red-brown; weathered brown; medium-grained; well sorted; top 30 feet bleached white ------------------------	94	787
5	SANDSTONE: massive; nonbedded; red; medium-grained; well sorted -----------	57	693
4	SANDSTONE: red; very soft; very friable; medium- to coarse-grained; subangular grains; mostly covered -----	46	636
3	SANDSTONE: massive; cross-laminated; red and white; fine- to medium-grained; contains a few calcareous zones -------	238	590
2	SANDSTONE: massive; cross-laminated; red-orange and white; calcareous along foreset beds; fine- to medium-grained -	18	352
1	SANDSTONE: massive; cross-laminated; red-orange; weathered gray to tan; calcareous in places; fine- to medium-grained; subrounded grains; well sorted --------------------------------	334	334
	Total Zuni:	787	
	(Wingate formation below)		

REFERENCES CITED

Allen, J. E., and Balk, Robert, 1954, Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Inst. of Min. and Tech., State Bur. of Mines and Min. Res. Bull. 36, 192 p.

Anonymous, 1959, Stratigraphy of the outcropping Permian rocks in the southern part of the San Juan Basin, New Mexico; in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. 63-65.

Ash, H. O., 1958, The Jurassic Todilto formation of New Mexico: Univ. of New Mexico, unpublished master's thesis, 63 p.

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

Baker, A. A., Dane, C. H., and Reeside, J. B., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico and Colorado: U. S. Geol. Survey Prof. Paper 183, 66 p.

----- 1947, Revised correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 9, p. 1664-1668.

Cooley, M. E., 1959, Triassic stratigraphy in the state line region of west-central New Mexico and east-central Arizona; in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. 66-73.

Cross, Whitman, 1894, Pikes Peak, Colorado: U. S. Geol. Survey, Geol. Atlas, folio 7, 5 p.

----- 1899, Description of the Telluride quadrangle (Colorado): U. S. Geol. Survey Atlas, Telluride folio 57, 18 p.

Dane, C. H., and Bachman, G. O., 1957. The Dakota sandstone and Mancos shale in the Gallup area; in Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 95-98.

----- 1957, Preliminary Geologic map of the northwestern part of New Mexico: U. S. Geol. Survey, Misc. Geol. Inv. Map I-224.

Dane, C. H., Bachman, G. O., and Reeside, J. B., 1957, The Gallup sandstone, its age and stratigraphic relationships south and east of the type locality; in Guidebook of the Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 99-113.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, 356 p.

Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau: U. S. Geol. Survey, 6th Ann. Rept., p. 105-198.

Foster, R. W., 1957, Stratigraphy of west-central New Mexico; <u>in</u> Guidebook of the Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 62-72.

Freeman, V. L., and Hilpert, L. S., 1956, Stratigraphy of the Morrison formation in part of northwestern New Mexico: U. S. Geol. Survey Bull. 1030-J, p. 309-334.

Gilbert, G. K., 1875, Report on the geology of portions of New Mexico and Arizona: U. S. Geol. Survey W. 100th Mer. (Wheeler), v. 3, p. 503-567.

Gilkey, A. K., 1953, Fracture pattern of the Zuni uplift: U. S. Atomic Energy Comm. RME-3050, Tech., Inf. Service, Oak Ridge, Tenn., 35 p.

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

Gregory, H. E., 1917, Geology of the Navajo Country: U. S. Geol. Survey Prof. Paper 93, 161 p.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U. S. Geol. Survey Prof. Paper 291, 74 p.

Foster, R. W., 1957, Stratigraphy of west-central New Mexico: in Guidebook of the Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 62-72.

Freeman, V. L., and Hilpert, L. S., 1956, Stratigraphy of the Morrison formation in part of northwestern New Mexico: U. S. Geol. Survey Bull. 1030-J, p. 309-334.

Gilbert, G. K., 1875, Report on the geology of portions of New Mexico and Arizona: U. S. Geol. Survey W. 100th Mer. (Wheeler), v. 3, p. 503-567.

Gilkey, A. K., 1953, Fracture pattern of the Zuni uplift: U. S. Atomic Energy Comm. RME-3050, Tech., Inf. Service, Oak Ridge, Tenn., 39 p.

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

Gregory, H. E., 1917, Geology of the Navajo Country: U. S. Geol. Survey Prof. Paper 93, 161 p.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U. S. Geol. Survey Prof. Paper 291, 74 p.

Kelley, V. C., 1951, Tectonics of the San Juan Basin; in Guidebook of the geology of the south and west sides of the San Juan Basin, New Mexico and Arizona: New Mexico Geol. Soc., 2nd Field Conf., p. 124-131.

----- 1955a, Monoclines of the Colorado Plateau: Geol. Soc. America Bull., v. 66, p. 789-804.

----- 1955b, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: Univ. of New Mexico Pub. in Geol. no. 5, 120 p.

----- 1957, Tectonics of the San Juan Basin and surrounding areas; in Guidebook of the geology of the southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 44-52.

Kelley, V. C., and Clinton, N. J., 1960, Fracture systems and tectonic elements of the Colorado Plateau: Univ. of New Mexico Pub. in Geol. no. 6, 104 p.

Keyes, C. R., 1915, Foundation of exact geological correlation, Iowa Acad. Sci. Proc., v. 22, p. 249-267.

Kottlowski, F. E., 1959, Pennsylvanian rocks on the north-east edge of the Datil Plateau; in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. 57-62.

Lee, W. T., 1909, Stratigraphy of the Manzano Group: U. S. Geol. Survey Bull. 289, p. 1-40.

Marcou, Jules, 1856, Resume of a geological reconnaissance extending from Napoleon, at the junction of the Arkansas with the Mississippi, to the Pueblo de Los Angeles in California: U. S. Pacific R. R. Expl., v. 3, pt. 4, p. 165-171.

McKee, E. D., and others, 1959 Paleotectonic maps, Triassic system: U. S. Geol. Survey, Misc. Geol. Inv. Map 1-300.

Meek, F. B., and Hayden, F. V., 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska Territory, with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Phila. Proc. 1861, p. 415-447.

Newberry, J. S., 1861, Geological report, in Ives, J. C., Report upon the Colorado River of the West: U. S. 36th Cong. 1st sess., Sen. Ex. Doc. and House Ex. Doc. 90, pt. 3, 154 p.

Northrop, S. A., and Wood, G. H., 1946, Geology of Nacimiento Mountains, San Pedro Mountain and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 57.

O'Sullivan, R. S., and Beaumont, E. C., 1957, Preliminary geologic map of western San Juan Basin, San Juan and McKinley Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inv. Map OM-190.

Marcou, Jules, 1856, Resume of a geological reconnaissance extending from Napoleon, at the junction of the Arkansas with the Mississippi, to the Pueblo de los Angeles in California: U. S. Pacific R. R. Expl., v. 3, pt. 4, p. 165-171.

McKee, E. D., and others, 1959, Paleotectonic maps, Triassic system: U. S. Geol. Survey, Misc. Geol. Inv. Map I-300.

Meek, F. B., and Hayden, F. V., 1861, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska Territory, with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Philadelphia Proc. 1861, p. 415-447.

Newberry, J. S., 1861, Geological report, in Ives, J. C., Report upon the Colorado River of the West: U. S. 36th Cong., 1st sess., Sen. Ex. Doc. and House Ex. Doc. 90, pt. 3, 154 p.

Northrop, S. A., and Wood, G. H., 1946, Geology of Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 57.

O'Sullivan, R. B., and Beaumont, E. C., 1957, Preliminary geologic map of western San Juan Basin, San Juan and McKinley Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Map OM-190.

Parker, J. W., 1957, Nacimiento Mountains-history and relation to the San Juan Basin; in Guidebook of the Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 73-76.

Pike, W. S., Jr., 1947. Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. America Mem. 24, 103 p.

Rapaport, Irving, Hadfield, J. P., and Olson, R. H., 1952, Jurassic rocks of the Zuni uplift, New Mexico: U. S. Atomic Energy Comm. RMO-642, 47 p.

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni basin, New Mexico: U. S. Geol. Survey Bull. 767, 52 p.

Sears, J. D., Hunt, C. B., and Hendricks, T. A., 1941, Transgressive and regressive Cretaceous deposits in southern San Juan Basin, New Mexico: U. S. Geol. Survey Prof. Paper 193-F, p. 101-121.

Smith, C. T., 1954, Geology of the Thoreau Quadrangle, McKinley and Valencia Counties, New Mexico: New Mexico Inst. of Min. and Tech., State Bur. of Mines and Min. Res. Bull. 31, 36 p.

Smith, C. T., 1957, Geology of the Zuni Mountains, Valencia and McKinley Counties, New Mexico; in Guidebook of the Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. 53-61.

----- 1958, Geologic map of Inscription Rock fifteen-minute quadrangle: New Mexico Inst. of Min. and Tech., State Bur. of Mines and Min. Res. Geol. Map 4.

----- 1959, Jurassic rocks of the Zuni Mountains; in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. 74-80.

Smith, C. T., and others, 1959a, Geologic map of Foster Canyon quadrangle, Valencia and McKinley Counties, New Mexico: New Mexico Inst. of Min. and Tech., State Bur. of Mines and Min. Res. Geol. Map 9.

Smith, C. T., Foster, R. W., and Ostrander, Robert, 1959b, Supplementary road log, Ramah to McGaffey, via Ruin Canyon and Page; in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. 47-51.

Stewart, J. H., Poole, F. G., and Wilson, R. F., 1957, Triassic studies; in Geologic inv. of radioactive deposits: Semiannual Progress Rept., Dec. 1, 1956 to May 31, 1957: U. S. Geol. Survey TEI-690, Book 2, p. 341-351.

REFERENCES CITED - Continued

Smith, C. T., 1957, Geology of the Zuni Mountains, Valencia and McKinley Counties, New Mexico: in Guidebook of the Geology of southwestern San Juan Basin: Four Corners Geol. Soc., 2nd Field Conf., p. [illegible].

----- 1958, Geologic map of Inscription Rock [illegible] quadrangle: New Mexico Inst. of Min. and Tech., State Bur. of Mines and Min. Res. Geol. Map [illegible].

----- 1959, [illegible] rocks of the Zuni Mountains: in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. [illegible].

Smith, C. T., and others, 1959, Geologic map of Foster Canyon quadrangle, Valencia and McKinley Counties, New Mexico: New Mexico Inst. of Min. and Tech., State Bureau Mines and Min. Res. Geol. Map [illegible].

Smith, C. T., Budding, A. J., and [illegible], Robert, 1959, Supplementary road log, Ramah to Zuni, via Galestina Canyon and Pescado: in Guidebook of West-central New Mexico: New Mexico Geol. Soc., 10th Field Conf., p. 47-51.

Stewart, J. H., Poole, F. G., and Wilson, R. F., 1959, Triassic [illegible] uraniferous deposits: [illegible] Geol. Soc. [illegible] May 31, 1957 [illegible] p. 341-351.

Williams, J. A., Anderson, T. C., and Crezee, D. B., 1960, Soil-management report for the Zuni Mountains area of Cibola National Forest, Region 3: U. S. Forest Service, unpublished report.

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