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Stratigraphic Relationships of Cretaceous and Early Tertiary Rocks of a Part of Northwestern San Juan Basin

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BALTZ — TERTIARY ROCKS OF SAN JUAN BASIN

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STRATIGRAPHIC RELATIONSHIPS
OF CRETACEOUS AND EARLY TERTIARY ROCKS
OF A PART OF NORTHWESTERN SAN JUAN BASIN

By

Elmer H. Baltz, Jr.

A Thesis
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ABSTRACT

The Bridge Timber Mountain area in south-central La Plata County, southwestern Colorado lies mostly in the northwestern part of the Central San Juan Basin but contains a segment of the bounding Hogback "monocline" and Four-Corners platform.

The area contains rocks of late Cretaceous through early Eocene age, as well as Pliocene, Pleistocene, and Recent terrace and pediment gravels. The Pictured Cliffs sandstone of late Montana age is the latest marine formation present. Retreat of the Cretaceous seas from the area marked the beginning of Laramide orogenic activity and the earliest stages of deformation which produced the modern San Juan Basin. The Fruitland formation and Kirtland shale were deposited in brackish water and on coastal plains left by the retreating Cretaceous sea. Beds of the Farmington sandstone member and upper shale member of the Kirtland shale show evidence of a new source of sediments to the north or northeast distinct from the southwestern source area of older Cretaceous rocks. The McDermott "formation", composed mainly of volcanic debris, is considered to be a local lower member of the Animas formation. Beds of the upper member of the Animas formation of Cretaceous and Paleocene age are considered to extend entirely across the area and into New Mexico. Overstep of higher sandstone and shale

beds of the upper member across lower conglomeratic beds shows that folding on the Hogback "monocline" began during deposition of the upper member. Beds of the upper member of the Animas formation grade laterally southward into Paleocene beds of the Nacimiento formation, but upper Nacimiento beds overstep folded beds of the Animas formation on the Hogback "monocline" at the north end of Bridge Timber Mountain. The San José formation of Paleocene and Eocene age is conformable with the Nacimiento formation except at the north end of Bridge Timber Mountain where upper San José beds overstep all older tilted beds down to the Fruitland formation. The heavy sandstone facies of the Nacimiento and San José formations are correlated with similar facies of these formations on the east side of the San Juan Basin. Folding along the borders of the Central Basin was completed prior to deposition of the youngest San José beds, and they were probably widely distributed outside of the Central Basin in Eocene time. In Pliocene time, the San Juan region was beveled by the San Juan peneplain. Rejuvenation of the San Juan Mountains in late Pliocene time caused erosion in the mountains and deposition of the Bridgetimber gravel in the San Juan Basin. Uplift in Pleistocene time caused large-scale erosion in the Bridge Timber Mountain area and gravel-covered terraces represent the various stages of uplift and erosion.

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The stratigraphic relationships of uppermost Cretaceous and lower Tertiary rocks in the Bridge Timber Mountain area are similar to recently described relationships of equivalent rocks in other parts of the San Juan Basin. The southwestern lobe of the Pictured Cliffs sandstone was derived from older Cretaceous source areas to the southwest and deposited in the seaway which was retreating northeastward. The northeast lobe was derived from Cretaceous sediments eroded from the flanks of the rising San Juan dome and Sangre de Cristo upwarp and deposited in an arm of the sea which was isolated by uplift of the mountain masses. This arm of the sea was forced to retreat to the southeast as sediments of the Fruitland, Kirtland, Animas, and Ojo Alamo formations were deposited in the basin. The Animas formation which was derived from highlands to the northeast spread progressively to the southwest and interfingered with lesser amounts of Fruitland and Kirtland sediments derived from the southwest. In latest Cretaceous or earliest Paleocene time folding began along the Hogback "monocline" in northern and western San Juan Basin and sediments were eroded from the uplifted platforms around the margin of the Central Basin and redeposited within the Central Basin. These sediments of the Nacimiento and San José formations interfingered with coarse sandstone and conglomerate facies which were derived from

the northeast and deposited in the structurally deepest part of the Central Basin. Domal uplift in the Nacimiento and Jemez uplifts probably began in late Paleocene or early Eocene time. Folding along the borders of the Central Basin was essentially completed near the end of middle Wasatch time and the San José formation blanketed most of the area of the present San Juan Basin. Middle and late Tertiary sediments were probably deposited in the San Juan Basin and later eroded. Late Tertiary or Quaternary orogenic activities modified the structure of the southeastern part of the San Juan Basin causing thrusting along the west border of the Nacimiento uplift and normal faulting farther to the south.

INTRODUCTION

Purpose

The stratigraphy of Upper Cretaceous and Tertiary rocks of the San Juan Basin of northwestern New Mexico and southwestern Colorado has been the subject of study by geologists and paleontologists for many years. A large body of literature has accumulated in which there seems to be general agreement about the age and distribution of the major stratigraphic units. However, there is sharp disagreement among many workers as to the detailed relationships of some of the formations. The stratigraphy of the alternating wedges of marine and nonmarine sediments which comprise the greatest bulk of Upper Cretaceous rocks in the San Juan Basin is fairly well understood because of the occurrence of considerable amounts of coal, petroleum, and natural gas in these rocks which has given the necessary economic inducement for their study. The lack of mineral resources in the uppermost Cretaceous and Tertiary rocks of the Basin has made their study mainly of scientific interest and there is as yet no complete understanding of the relationships and distribution of the formations from one side of the Basin to the other. The writer believes that an eventual understanding of the stratigraphy of these rocks will not only be of scientific interest, but also will have

considerable economic value in interpretation of geophysical data in the search for oil and gas.

The area of this report contains exposures which are perhaps more significant than any others occurring around the rim of the Central San Juan Basin, for it is here that the overstepping relationships of the lower Tertiary rocks can be clearly seen. These relationships provide the necessary information for dating the stages of folding of the Hogback "monocline" along the western and northern boundaries of the Central Basin. Field work for this report was more detailed than that done for earlier regional studies which have dealt with the area, and new evidence has been obtained which provides the basis for new interpretations of stratigraphic relationships.

Geography

Location and accessibility

The mapped area of this report is in the south-central portion of La Plata County, southwestern Colorado. The eastern boundary is the Animas River; the southern boundary is the New Mexico-Colorado state line; the western boundary is approximately the eastern edge of Red Mesa which lies east of La Plata River; the northern boundary is the base of Hogback Mountain south of Durango, Colorado. The mapped area contains approximately 196 square miles.

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Geography

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The eastern half of the area is accessible from a graded county road which follows the west bank of Animas River from Durango to Bondad where it joins U. S. Highway 550 and continues south in the Animas Valley. The eastern slopes of Bridge Timber Mountain may be reached from the county road by several roads shown on the map, but these roads are passable only by Jeep or pickup truck. The northeastern corner of the area is approximately 2 miles south of Durango; the southeastern corner is about 15 miles northeast of Aztec, New Mexico on U. S. Highway 550.

The western border of the area is accessible from the graded Long Hollow road which joins U. S. Highway 160 to the north about 2 miles west of Durango and joins Colorado Highway 140 to the southwest in the valley of the La Plata River about 1½ miles north of the Colorado-New Mexico state line. The roads leading into the area east of Long Hollow road are passable in fair weather but become slick and gullied during wet periods. It is about 23 miles from Farmington, New Mexico north on New Mexico Highway 17 along the La Plata River to the southwestern corner of the area.

Physiography

Nearly all the San Juan Basin, including the area of this report, lies within the Navajo section of the Colorado Plateaus province (Fenneman and Johnson, 1946), a region of young plateaus with moderate to strong relief. The

predominant feature of erosion is the stripping of nearly horizontal sedimentary beds to leave outlying mesas and buttes. Locally the major streams have incised themselves into the soft Cretaceous and Tertiary rocks forming fairly deep, steep-walled canyons.

There are four relatively distinct topographic divisions in the mapped area. The most prominent feature is Bridge Timber Mountain (or Basin Mountain) which rises more than 1,000 feet above the surrounding countryside to an elevation of 8,270 feet. It is a north-south trending ridge lying near the center and extending across approximately three-quarters of the length of the area. There are remnants of two distinct erosion surfaces preserved on top of the mountain, the northernmost and highest of which is flat and gravel-capped. East of Bridge Timber Mountain is a well-dissected "badlands" terrain with elevations of 6,000 to 7,000 feet. The higher elevations are capped by remnants of terrace gravel to the north and by resistant sandstone beds to the south. West of Bridge Timber Mountain is a similar area of dissected badlands with elevations ranging from 6,000 to 7,000 feet. There are remnants of a gravel-covered terrace which was probably once coextensive with Red Mesa to the west. Near the western boundary of the mapped area is the north-northeast trending band of parallel hogback ridges and valleys which are a part of the

great Hogback "monocline". The westernmost and highest of these ridges, locally known as Rocky Ridge, ranges from 6,600 to 8,000 feet in elevation. Just north of the State line are three promontories on Rocky Ridge which are known as the Cinder Buttes. The hogback ridges pass under and around the north end of Bridge Timber Mountain and trend in an eastward direction along the northern boundary of the mapped area where they attain an elevation of more than 8,000 feet.

Bridge Timber Mountain forms the drainage divide between the Animas and La Plata Rivers. The east flank of the mountain is drained by intermittent streams which empty to the east into the Animas River, the only permanent stream of the mapped area. The valley of the southward-flowing Animas River is 150 to 700 feet deep and constricts to form a canyon near the State line. The area west of Bridge Timber Mountain is drained by tributaries of McDermott Arroyo which empties to the south and southwest into La Plata River approximately 7 miles south of the State line. Most of the intermittent streams draining into McDermott Arroyo were at one time consequent upon the old southwestward-sloping, gravel-covered Red Mesa surface. Several subsequent streams have cut valleys into the shaly beds between ridges of the Hogback "monocline".

Climate and vegetation

The climate of the area is typical of that of higher elevations in the semiarid southwestern United States. Summers are short and pleasantly cool and winters are cold. Average annual precipitation at Durango is about 20 inches and becomes progressively less to the south. Average precipitation in the mapped area is about 17 inches per year. Much of the rain and snowfall is due to storms which form around and spread outward from the San Juan and La Plata Mountains to the north.

There is considerable variety in vegetation throughout the area. The valleys and low-level areas are covered by grass, various herbs, yucca, and sagebrush. The terrace remnants are covered by dense stands of pinon pine and juniper. There are a few fields which have been cleared for farming and occasional east-west strips of charred stumps left by fires which are swept across the land in an eastward direction by the prevailing westerly wind. The pinon-juniper forests merge upward on the slopes of Bridge Timber Mountain into large stands of ponderosa or western yellow pine which clothe the upper slopes and top of the mountain and the higher portions of the Hogback.

Inhabitants and Industry

The only inhabitants of the area live in the valley of

Animas River on farms and ranches. The principal occupations are sheep and cattle raising and both dry and irrigated farming. Pinto beans and alfalfa are the important crops but some corn, oats, and vegetables are raised. The Ute Indians graze sheep on much of the area west of Bridge Timber Mountain.

The ponderosa pines on the north end of Bridge Timber Mountain have been the source of lumber for many years, and a small sawmill is operated sporadically in Sawmill Creek canyon.

Coal has been mined from the lower part of the Fruitland formation in numerous places along Rocky Ridge and Hogback Mountain on the north edge of the area, but at present none of these mines is in operation.

Previous Work

Few detailed geologic reports concerning this area have been published. Reeside (1924) mapped and described the area in his regional study of the Upper Cretaceous and Tertiary formations of the western San Juan Basin and this work has become the more or less standard reference for geologists in the region. The northernmost portion of the area was mapped and described by Zapp (1949). The physiography and Quaternary geology of the San Juan Mountains and adjoining areas have been discussed by Atwood and

Mather (1932).

Present Work

Field work

The area included in this report is part of a larger area in which the writer worked as a member of a field party of the U. S. Geological Survey during the months of June-November, 1951. The area east of Bridge Timber Mountain was examined and mapped in detail on aerial photographs by the writer. The area west of Bridge Timber Mountain was mapped by Harley Barnes and the writer.

Compilation of map

The geologic map (Fig. 7) was compiled by the writer from aerial photographs at the scale of 1:48,000. Horizontal control was obtained by location on the photographs of several triangulation stations which are shown on the map. Geodetic positions of these stations, Fort Lewis (not on map), Carbon, La Plata, and Line, were obtained from descriptions of first-order triangulation furnished by the U. S. Coast and Geodetic Survey. Data were transferred from the photographs to the projection sheet by means of the Kail plotter. The land grid was projected on the basis of a few located section corners, roads, and planimetric maps of the La Plata Conservation District prepared by the U. S. Soil Conservation Service.

Methods (1957). [illegible]

Present Work

Field Work

The [illegible] in [illegible] area in which the writer was a [illegible] party of the [illegible] June–November, 1951. [illegible] tain was [illegible] by the [illegible] mapped by [illegible] for the writer.

Compilation of Map

[illegible] from [illegible] of several [illegible] map. [illegible] [illegible] U. S. [illegible] from [illegible] [illegible] a few [illegible] of the [illegible] [illegible]

Acknowledgments

The writer is indebted to the U. S. Geological Survey for permission to use much of the field data included in this report, and to Harley Barnes who was in charge of the party in which the writer worked. Typing of manuscript and drafting of illustrations was done by Diana H. Baltz.

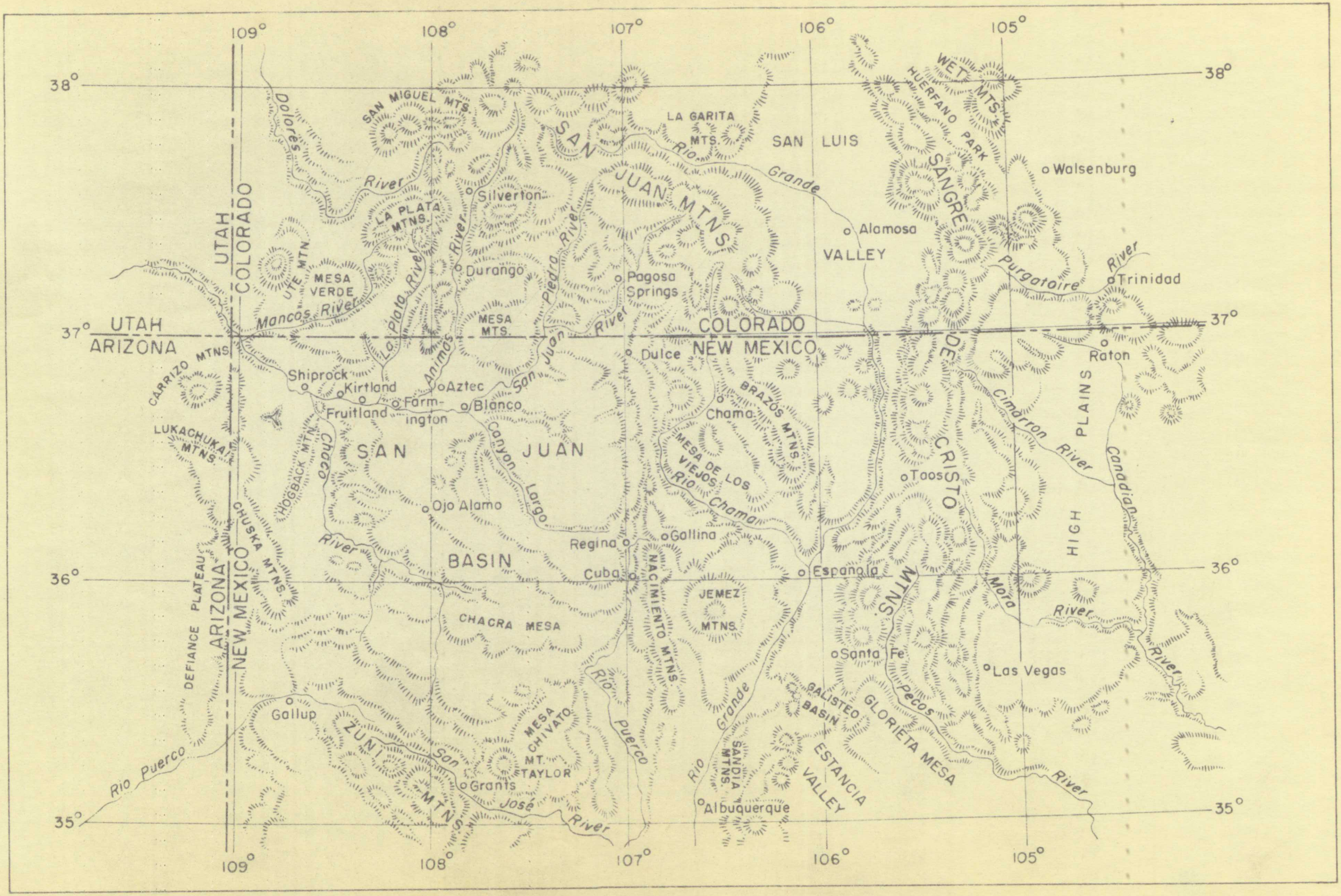

Figure 1. Geographic index map of parts of northern New Mexico and southern Colorado.

GENERAL DESCRIPTION OF THE SAN JUAN BASIN

The structure and stratigraphy of the San Juan Basin have been discussed in detail in other publications;[1] thus only a short summary is presented here for convenience of the reader. Figure 1, p. 14, shows the principal geographic features of the San Juan Basin and surrounding region in northern New Mexico and southern Colorado.

Structure

The San Juan Basin of northwestern New Mexico and southwestern Colorado is a large shallow structural basin most of which is drained by the San Juan River and its tributaries. Maximum east-west width of the Basin proper is approximately 135 miles and the north-south length is approximately 180 miles. The major structural elements have been named and described by Kelley (1950, pp. 101-104; 1951, pp. 124-128), and are shown in Figure 2, p. 16.

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[1]For descriptions of the southern part of the San Juan Basin, _see_ Sears (1934); Hunt (1936); Dane (1936); Sears, Hunt, and Hendricks (1941); Pike (1947); Guidebook of the New Mexico Geological Society (1951). For descriptions of the western part of the Basin, _see_ Gregory (1917); Guidebook of the New Mexico Geological Society (1951). For descriptions of the eastern part, _see_ Dane (1936), (1946), (1948); Wood and Northrop (1946); Pike (1947); Simpson (1948); Guidebook of the New Mexico Geological Society (1950); Colbert, _et al_. (1950). For descriptions of the central and northern parts, _see_ Bauer (1916); Reeside (1924); Pike (1947); Wood, Kelley, and MacAlpin (1948); Zapp (1949); Guidebook of the New Mexico Geological Society (1950).

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The San Juan Basin of northwestern New Mexico and southwestern Colorado is a large shallow structural basin most of which is drained by the San Juan River and its tributaries. Maximum east-west width of the basin proper is approximately 125 miles and its north-south length is approximately 150 miles. The major structural elements have been named and described by Kelley (1950, pp. 101-108; 1951, pp. 124-131), and are shown in Figure 3, p. 17.

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[1]For descriptions of the western part of the San Juan Basin, see Harris (1954); Hunt (1956); Kane (1951); Kelley, Hunt, and Hendricks (1941); Lee (1912); Guidebook of the New Mexico Geological Society (1951). For descriptions of the western part of the basin, see Gregory (1917); Guidebook of the [illegible] Geological Society (1951). For descriptions of the eastern part, see [illegible] (1960); Dane (1948); Wood and Northrop (1946); [illegible] (1949); [illegible] (1943); Guidebook of the Four Corners Geological Society (1952); Gilbert, et al. (1957). For descriptions of the central and northern parts, see Barnes (1953); Reeside (1924); [illegible] (1947); Wood, Kelley, and MacAlpin (1948); [illegible] (1957); Guidebook of the New Mexico Geological Society (1951).

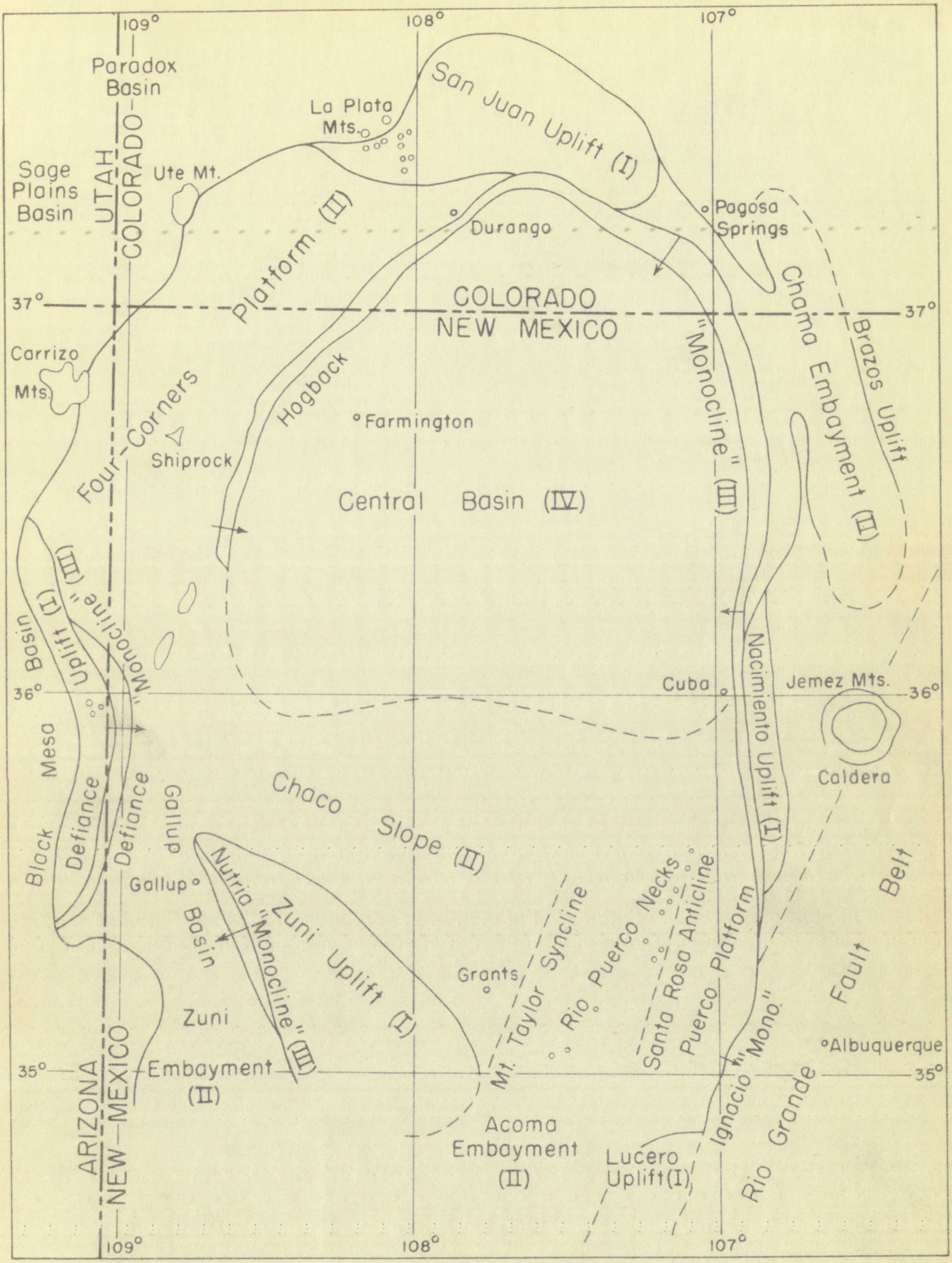

Figure 2. Structural elements of the San Juan Basin.
After Kelley (1951, p. 125).

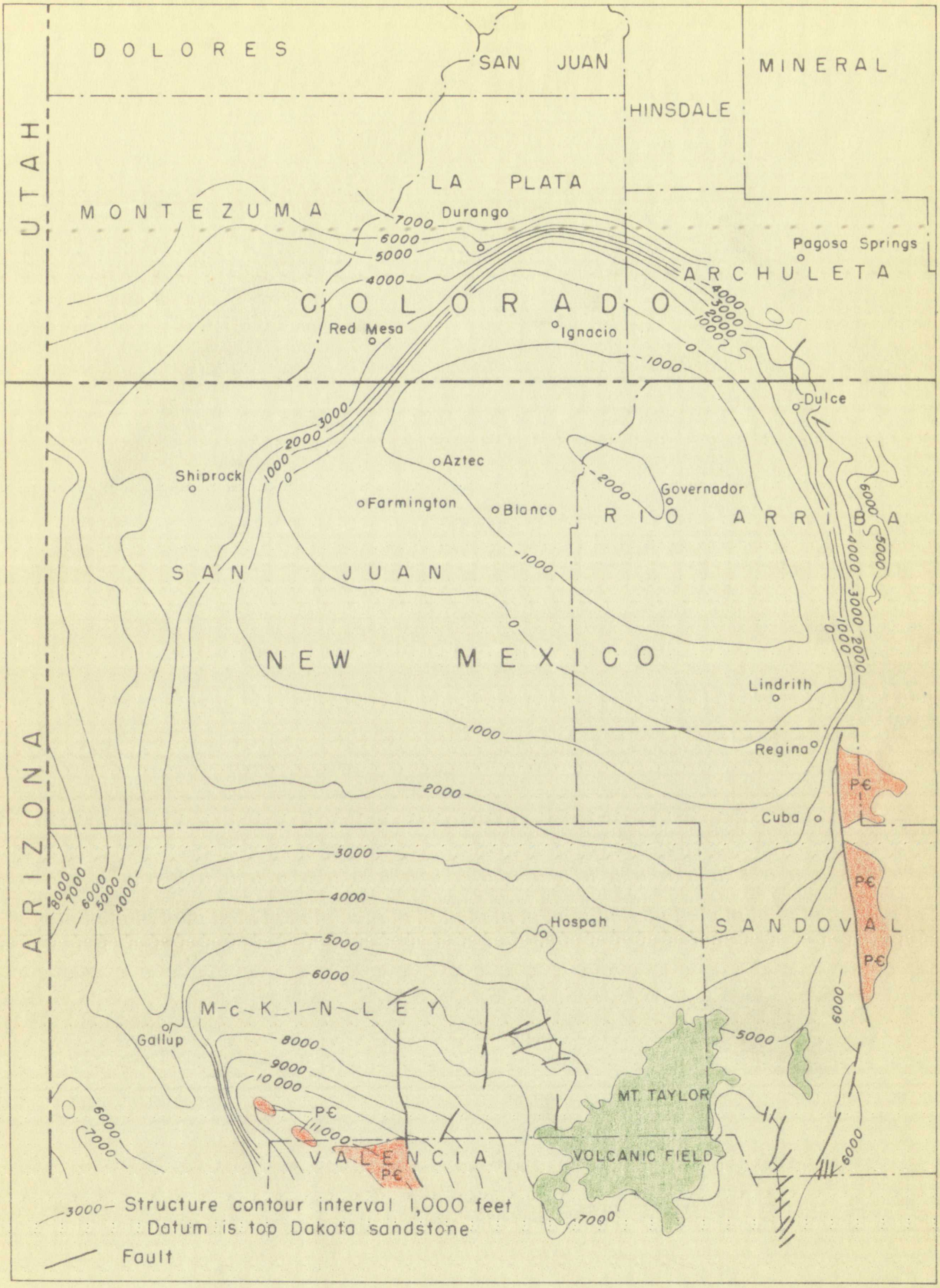

Figure 3. Structure contour map of the San Juan Basin. Modified from Silver (1950).

The San Juan Basin may be described as a "basin within a basin". The Central Basin, which is bounded on east, north, and west sides by the Hogback "monocline", is almost entirely enclosed by gently inward-dipping platforms or slopes. According to Kelley (1951, p. 130), "Viewed broadly the basin is a downwarp resulting from the upward bulge and outward spread of (bordering) uplifts which were active recurrently throughout Cenozoic time." Almost all the latest Cretaceous and early Tertiary rocks with which this paper is concerned are restricted in occurrence to the Central Basin.

The area of this report lies mainly within the northwestern part of the Central Basin but includes along its western and northern boundaries a segment of the Hogback "monocline" and a narrow strip of the Four Corners structural platform.

Stratigraphy

The surface rocks of the San Juan Basin range in age from late Cretaceous through late Tertiary. There are extensive exposures of Paleocene and lower Eocene rocks in the Central Basin. There are small patches of middle (?) Tertiary rocks along the western boundary of the San Juan Basin and middle to late Tertiary volcanic rocks in the Mount Taylor-Mesa Chivato area in the southeastern part of

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ERA	Period	SOUTH Zuni Mts.		NORTH San Juan Mts.	
MESOZOIC	Jurassic				
		Morrison fm.		Morrison fm.	
		San Rafael gp.	Todilto ls.	Wanakah fm.	
			Entrada ss.	Entrada ss.	
			Carmel fm.		
		Glen Canyon gp.	Wingate ss.		
	Triassic	Chinle sh.		Dolores fm.	Chinle sh.
		Shinarump ss.			Shinarump ss.
		Moenkopi fm. (?)		Dolores fm.	Moenkopi fm. (?)
PALEOZOIC	Permian				
		San Andres fm.	Ls. memb.	Cutler fm.	
			Glorieta ss.		
		Yeso fm.			
		Abo fm.		?	
	Pennsylvanian	Locally present (Madera ls.)		Rico fm.	
				?	
				Hermosa fm.	
				Molas fm.	
	Mississippian				
				Leadville ls.	
	Devonian			Ouray ls.	
				Elbert fm.	
	Silurian				
	Ordovician				
	Cambrian			Ignacio quartzite	
Precambrian		Granite, gneiss, schist		Granite, gneiss, schist	

Table I. Nomenclature of outcropping Paleozoic, Triassic, and Jurassic rocks south and north of the San Juan Basin.

the Basin. Paleozoic, Triassic, and Jurassic rocks crop out in various localities around the margins of the Basin and are known to underlie it. The nomenclature of the Paleozoic, Triassic, and Jurassic rocks is summarized in Table 1, p. 19.

In late Cretaceous time the San Juan Basin was the site of extensive marine and nonmarine sedimentation. The sediments were derived from highlands to the west and southwest in Arizona and spread northeastward into a major epicontinental sea which extended far to the east across the present Rocky Mountains and Great Plains. The essential relationship of the sediments deposited in the area of the present San Juan Basin is an intertonguing of continental sandstone, shale and coal beds from the southwest with marine shale and sandstone beds from the northeast. In general, Upper Cretaceous rocks of the San Juan Basin record (1) major transgression of the late Cretaceous sea across the region from northeast to southwest; (2) major regression of the sea across most of the area of the San Juan Basin; (3) major transgression of the sea across the region: (4) final regression of the late Cretaceous sea from the region. The nomenclature and stratigraphic relationships of the rocks deposited during these phases is shown in Figure 4, p. 21.

The uppermost Cretaceous and lower Tertiary rocks were deposited under diverse conditions which reflect the stages in formation of the present San Juan Basin.

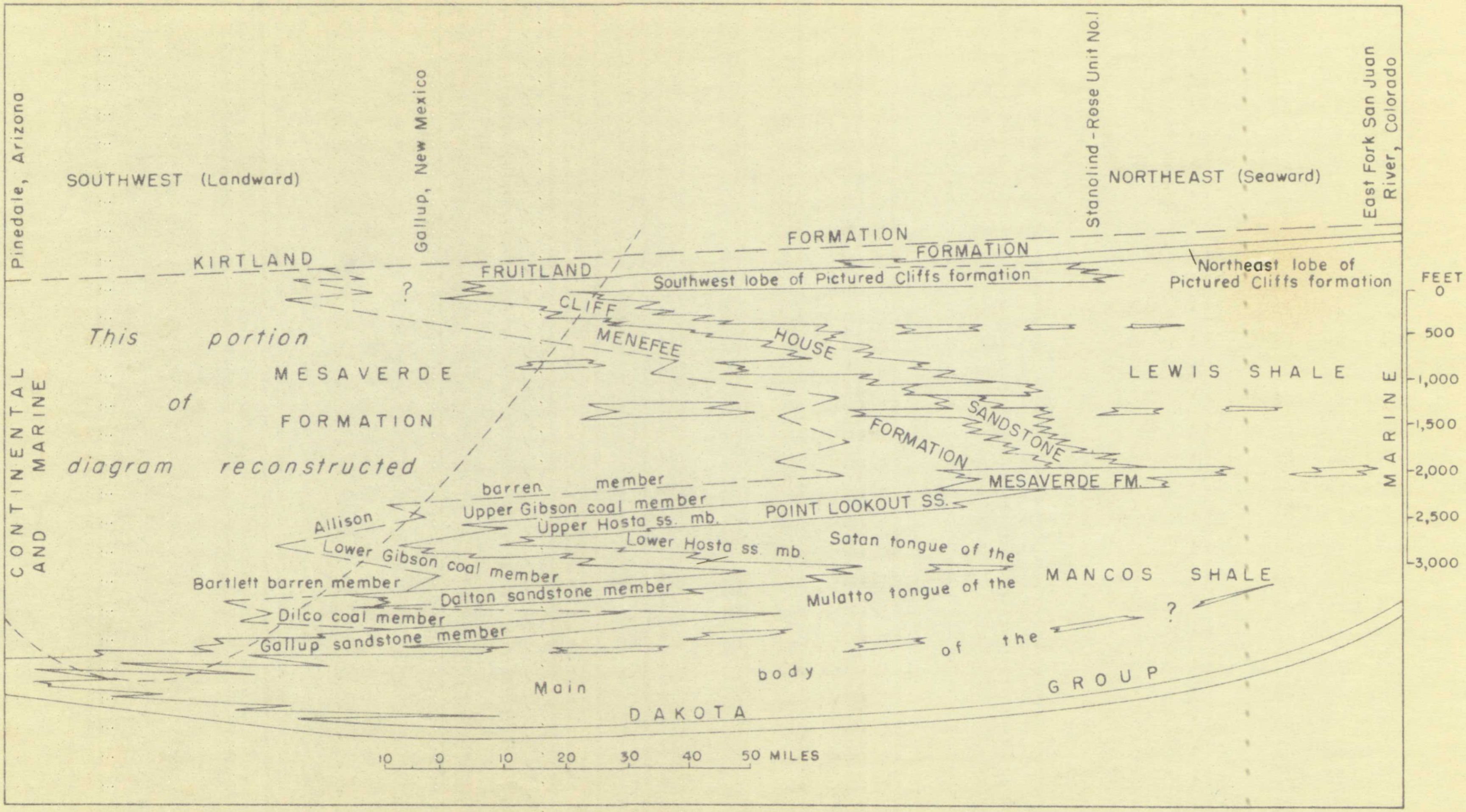

Figure 4. Diagram showing the stratigraphic relationships of Upper Cretaceous rocks in the San Juan Basin, New Mexico and Colorado. After Silver (1951, p. 110).

STRATIGRAPHY OF THE BRIDGE TIMBER MOUNTAIN AREA

General Statement

The final retreat of late Cretaceous seas from the region of the San Juan Basin marks the beginning of Laramide orogenic activity in the region. For this reason, the oldest formation considered in detail in this paper is the Pictured Cliffs sandstone which was deposited during the final regression of the late Cretaceous sea. Older rocks of northwestern San Juan Basin have been discussed by Zapp (1949).

Pictured Cliffs Sandstone

Type locality and distribution

The Pictured Cliffs sandstone was first named and described by Holmes (1877, pl. 35, p. 248). The name was applied to the massive ledges of marine sandstone exposed north of San Juan River 1 mile west of Fruitland, New Mexico. The name was applied because of the interesting petroglyphs which were carved by prehistoric Indians in the relatively soft cliffs near the type locality. Reeside (1924, p. 18) redefined the formation to include the massive ledges of Holmes and the interbedded shale and sandstone beneath them.

The Pictured Cliffs sandstone is confined in occurrence to the San Juan Basin where it outcrops in a continuous

STRATIGRAPHY OF THE AZTEC-FARMINGTON AREA

General Statement

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Pictured Cliffs Sandstone

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The Pictured Cliffs sandstone was first named and described by Holmes (1877, pl. 30, p. 248). The name was applied to the massive ledges of marine sandstone exposed north of the San Juan River, 1 mile west of Fruitland, New Mexico. The name was applied because of the interesting pictographs which were carved by prehistoric Indians in the relatively soft sandstone at the type locality. Reeside (1924, p. 18) redefined the formation to include the massive ledges of Holmes and the intertonguing shale and sandstone beneath them.

The Pictured Cliffs sandstone is continuous in outcrop around the San Juan Basin and its outcrops form a continuous

narrow band around the north, west, and south sides of the Central Basin. About 6 miles southeast of Dulce, New Mexico the Pictured Cliffs grades laterally southward into the underlying Lewis shale and is not present along the eastern edge of the Basin (Dane, 1946). About 6 miles southwest of Cuba, New Mexico the Pictured Cliffs sandstone of the southern part of the Basin grades northward into the Lewis shale (idem).

In the western part of the area of this report the Pictured Cliffs sandstone forms a prominent northeastward-trending hogback, Rocky Ridge, which extends from the Cinder Buttes near the State line to the north end of Bridge Timber Mountain. From here the Pictured Cliffs hogback extends eastward toward Animas River forming the caprock of a prominent north-facing erosional escarpment.

Lithology

The lower one-third of the Pictured Cliffs sandstone is composed of thin, grayish-orange and light olive-gray, very fine grained sandstone, interbedded with subordinate amounts of gray shale and siltstone. The upper two-thirds of the formation is composed of dark yellowish-orange and light gray, medium- to thick-bedded, ledge-forming sandstone. The ferruginous and calcareous sandstone is composed of clean, well-sorted, fine- to medium-grained, subangular to subrounded quartz sand. Sandstone beds in the lower unit are generally parallel-bedded, but the thick sandstone of

the upper unit is generally irregularly bedded and occasionally cross-bedded. Concave cross-lamination is common in most beds. Rounded, cellular, and cavernous weathering are characteristic; irregularly rounded dark brown ferruginous concretions and casts of *Halymenites* are numerous.

The physical characteristics of the Pictured Cliffs sandstone and the marine fossils contained in it indicate that the sediments are littoral deposits formed during the final regression of late Cretaceous seas from this area.

Relation to adjacent formations

The contact of the Pictured Cliffs sandstone with the underlying Lewis shale is conformable and transitional by intertonguing. The lower unit of the Pictured Cliffs, consisting of thin, interbedded sandstone, siltstone, and shale, is the zone of intertonguing. The base of the Pictured Cliffs has been arbitrarily mapped as the lowest point where sandstone predominates over shale in the transitional zone, in accordance with the redefinition of the formation by Reeside (1924, p. 19). Intertonguing with the Lewis shale causes the base of the Pictured Cliffs to rise stratigraphically to the northeast.

The contact with the overlying Fruitland formation is transitional but generally sharp. In most places the cliff-forming sandstone of the upper unit is immediately overlain by carbonaceous shale, sandstone, or coal of the Fruitland

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formation, and the base of this carbonaceous material marks the top of the Pictured Cliffs sandstone. There is large-scale intertonguing between the two formations along Rocky Ridge. At locality 4, 2½ miles southwest of Bridge Timber Mountain, the top of the Pictured Cliffs sandstone rises 65 feet, stratigraphically because of intertonguing with the Fruitland formation. To the southwest this tongue of the Pictured Cliffs or another tongue in similar stratigraphic position is 20 feet thick at locality 5. By intertonguing with the Fruitland formation the top of the Pictured Cliffs rises stratigraphically to the northeast.

Thickness

The thickness of the formation is variable across the area due to the arbitrary placing of the lower contact and intertonguing with adjacent formations. Near the State line the Pictured Cliffs is about 285 feet thick, decreasing northward to 215 feet at locality 5. At locality 4 it is about 280 feet thick due to the wedge-out of the Fruitland tongue which intervenes to the south between the main body of Pictured Cliffs sandstone and the Pictured Cliffs tongue. From Bridge Timber Mountain the thickness decreases northeastward toward Animas River and in Sec. 4, N. T. 34 N., R. 9 W., outside the area, the Pictured Cliffs is 215 feet thick (Zapp, 1949).

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Thickness

The thickness of the formation is variable across the area due to the arbitrary placing of the lower contact and intertonguing with adjacent formations. Near the State line the Pictured Cliffs is about 235 feet thick, decreasing northward to 215 feet at locality 3. At locality 4 it is about 280 feet thick due to the wedge-out of the Fruitland tongue which intervenes to the south between the main body of Pictured Cliffs sandstone and the Pictured Cliffs tongue. From Bridge Timber Mountain the thickness decreases northeastward toward Animas River and in Sec. 4, T. 34 N., R. 9 W., outside the area, the Pictured Cliffs is 215 feet thick (Zapp, 1949).

Age and correlation

According to Reeside (1924, p. 19; 1944), the Pictured Cliffs contains a littoral marine fauna of late, but not latest, Montana age with a probable age equivalence to the upper part of the Pierre shale in eastern Colorado. The fossils which are the basis for this age determination were collected in the northwest corner of the Basin. It has been shown that the Pictured Cliffs rises stratigraphically to the northeast by intertonguing with the Fruitland formation and is thus younger to the northeast. The easternmost exposures of the formation may be equivalent in age to the Fox Hills sandstone of the region east of the Rocky Mountains. Lee (1917, pp. 219-220) considered that the uppermost Cretaceous rocks west of the Rocky Mountains were once coextensive with the Cretaceous rocks in the Great Plains region and correlated the Pictured Cliffs sandstone with the Trinidad sandstone and the Fox Hills sandstone (see also Pike, 1947, pl. 12). The age relationships of the Pictured Cliffs within the San Juan Basin favor this interpretation as far as age equivalence is concerned, but the evidence of lateral gradation into the Lewis shale along the eastern edge of the Basin, as shown by Dane (1946), may indicate that the Pictured Cliffs was never continuously distributed across the mountains to the east.

Age and correlation

According to Reeside (1924, p. 10; 1944), the Pictured Cliffs contains a distinctive fauna of late, but not latest, Montana age which is probably the equivalent to the upper part of the Pierre shale in eastern Colorado. The fossils which are the basis for this age determination were collected in the northwest corner of the basin. It has been shown that the Pictured Cliffs rises stratigraphically to the northeast by intertonguing with the Fruitland formation and is thus younger to the northeast. The easternmost exposures of the formation may be equivalent in age to the Fox Hills sandstone of the region east of the Rocky Mountains. Lee (1917, pp. [illegible]) considered that the uppermost Cretaceous rocks west of the Rocky Mountains were once continuous with the Cretaceous rocks in the Great Plains region and correlated the Pictured Cliffs sandstone with the Trinidad sandstone and the Fox Hills formation (see Dane and others, 1937, pl. [illegible]). The [illegible] intertonguing of the Pictured Cliffs within the [illegible] as an age equivalence [illegible], and the evidence of [illegible] gradation into the [illegible] along the [illegible] edge of the basin, as [illegible] by Dane ([illegible]), may indicate that the Pictured Cliffs was never continuous [illegible] mountains in the east.

Fruitland Formation

Type locality and distribution

The Fruitland formation was named and described by Bauer (1916, p. 274) from exposures near the town of Fruitland, New Mexico on the San Juan River. The formation as described contains the lower coal-bearing sandstone and shale beds of the "Laramie formation" of Holmes (1877, p. 224), Shaler (1907, p. 376), and Gardner (1909, p. 338). The outcrop pattern of the Fruitland formation in San Juan Basin is similar to that of the underlying Pictured Cliffs sandstone. It is present as a band around the rim of the Central Basin except for the eastern rim of the Basin. In the area southeast of Dulce, New Mexico the Fruitland formation and overlying Kirtland shale pass by lateral gradation southward into the Lewis shale. Similarly, southwest of Cuba, New Mexico, the undifferentiated Fruitland-Kirtland sequence grades northward into Lewis lithology (Dane, 1946).

In the mapped area of this report the Fruitland formation is exposed as a series of low ridges and intervening shallow valleys on the backslope of the Pictured Cliffs hogback. The outcrop is continuous from the Cinder Buttes, at the southwest corner of the area around the north end of Bridge Timber Mountain to the Animas River.

Lithology

The Fruitland formation is composed of varying proportions of interbedded sandstone, shale, and coal. The basal part of the formation is composed of a sequence of coal, carbonaceous shale, and thin lenses of sandstone and siltstone, locally known as the "Carbonero bed". This carbonaceous zone is continuous across the entire area except where locally interrupted and raised stratigraphically by intertonguing with the Pictured Cliffs sandstone. Above the lower carbonaceous sequence the Fruitland is composed of shale and interbedded lenticular coal beds and medium- to thick-bedded sandstone.

Sandstone beds of the Fruitland formation are gray, brown, and olive in color and fine- to medium-grained. Angular to subrounded quartz grains are the most common mineral constituent with small amounts of feldspar and ferromagnesian minerals also present. The beds are fairly well indurated and form good ledges. Calcium carbonate, silica, and limonite are the principal cementing agents. Bedding is medium to thick, with cross-bedding and cross-lamination common. Many of the sandstone beds may be seen to grade laterally and vertically into siltstone and shale. There is an over-all gradation from grayish-orange, fairly pure quartzose sandstone of Pictured Cliffs type in the lower part of the Fruitland formation to pale olive, chloritic,

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feldspathic sandstone in the upper part of the formation.

The less resistant parts of the formation are composed of dark gray to black carbonaceous shale and thin coal and pale olive to greenish-gray, chloritic, micaceous, sandy shale. There are numerous thin concretionary ferruginous siltstone lenses associated with the carbonaceous beds.

The Fruitland formation was deposited on the plains left by the last retreat of late Cretaceous seas from the region. The lower beds were deposited in lagoonal and swamp areas adjacent to the sea as indicated by the thick carbonaceous sequence and the intertonguing relationships with the Pictured Cliffs sandstone. The upper beds represent fluviatile deposits laid down by streams after the sea had retreated to the northeast. There are abundant silicified and carbonized logs and leaf impressions at various localities as well as remains of terrestrial reptiles which indicate the continental origin of these beds.

Relation to adjacent formations

The Fruitland formation is conformable with the underlying Pictured Cliffs sandstone and the overlying Kirtland shale. The lower contact has been discussed on page 24. The contact with the Kirtland shale is conformable and gradational and has been chosen and mapped arbitrarily. In this report all coal beds more than 1 foot thick and the associated shale and resistant sandstone are considered as

feldspathic sandstone in the upper part of the formation.

The less resistant parts of the formation are composed of dark gray to black carbonaceous shale and thin coal and pale olive to greenish-gray, chloritic, siliceous, sandy shale. There are numerous thin generally ferruginous siltstone lenses associated with the carbonaceous beds.

The Fruitland Formation was deposited on the plains left by the last retreat of late Cretaceous seas from the region. The lower beds were deposited in lagoonal and swamp areas adjacent to the sea as indicated by the thick carbonaceous sequence and the interfingering relationship with the Pictured Cliffs sandstone. The upper beds represent alluvial deposits laid down by streams after the sea had retreated to the northeast. There are abundant silicified and carbonized logs and leaf impressions at various localities as well as remains of terrestrial reptiles which indicate the continental origin of these beds.

<u>Relation to adjacent formations</u>

The Fruitland Formation is conformable with the underlying Pictured Cliffs sandstone and the overlying Kirtland shale. The lower contact has been discussed on page 26. The contact with the Kirtland shale is conformable and gradational and has been chosen and mapped arbitrarily. In this report all coal beds more than 1 foot thick and the associated shale and resistant sandstone are considered as

being in the Fruitland formation. The upper contact is generally the top of the uppermost ledge-forming sandstone beneath nonresistant beds of the Kirtland shale, but the stratigraphic position of this contact varies somewhat due to lenticularity of the sediments.

Thickness

Thickness of the Fruitland formation across the area is variable due to the intertonguing of the lower beds with the Pictured Cliffs sandstone and the arbitrary placing of the upper contact. It is about 510 feet thick at locality 5 and about 520 feet thick at locality 2 north of Bridge Timber Mountain. Eastward it appears to thin to an average of about 300 feet in the Durango area (Zapp, 1949).

Age and correlation

The lithologic similarity of the Fruitland formation and Kirtland shale is further accentuated by the floral and faunal similarities of the two, thus they have generally been considered together in various paleontological interpretations of their ages. Reptilian faunas of the Fruitland, Kirtland, and Ojo Alamo formations studied by Gilmore (1916, p. 281; 1919, p. 8) are said to indicate conclusively that these formations are of Montana age and older than the Lance or Laramie formations. The nonmarine invertebrates, according to Stanton (1916, p. 310), indicate that the

Fruitland, Kirtland, and Ojo Alamo formations are equivalent to everything from Fox Hills to Lance, inclusive. Knowlton (1916, p. 331) stated that the flora of the Fruitland and Kirtland formations is of Montana age. Reeside (1944) considered the Fruitland and Kirtland formations as time equivalents of the Fox Hills sandstone of the Great Plains and they are considered as such in this paper (Table 2, p. 79).

Kirtland Shale

Type locality and distribution

The Kirtland shale was named by Bauer (1916, p. 274) from exposures which occur along San Juan River between the towns of Kirtland and Farmington, New Mexico. The formation was subdivided by Bauer into a lower shale unit, a thick sandy part named the Farmington sandstone member, and an upper shale.

The Kirtland shale has similar distribution to the underlying Fruitland formation in the San Juan Basin. It crops out around the north, west, and south sides of the Central Basin but is not present along the east side. According to Wood, Kelley, and MacAlpin (1948) the undifferentiated Fruitland-Kirtland formations thin rapidly to the east from Yellowjacket Creek in western Archuleta County, Colorado, by intertonguing with the overlying Animas formation. The Kirtland shale on the south edge of the Basin

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Kirtland Shale

<u>Type locality and distribution</u>

The Kirtland shale was named by Bauer (1916, p. 274) from exposures which occur along the San Juan River between the towns of Kirtland and Farmington, New Mexico. The formation was subdivided by Bauer into a lower shale unit, a thick sandy part named the Farmington sandstone member, and an upper shale.

The Kirtland shale has similar distribution to the underlying Fruitland formation in the San Juan Basin. It crops out around the north, west, and south sides of the Central Basin [illegible] sides. According to Wood, Kellogg, and MacAlpin (1948) the undifferentiated Fruitland-Kirtland formations thin rapidly to the east from Yellowjacket Creek in western Archuleta County, Colorado, by intertonguing with the overlying Animas formation. The Kirtland shale on the south edge of the Basin

thins to the east (Dane, 1936, p. 115) and grades laterally into the Lewis shale southwest of Cuba, New Mexico (Dane, 1946).

In the area of this report the Kirtland shale is exposed in a band parallel to, and southeast of, the outcrop belt of the Fruitland formation. Exposures are continuous across the area except where overstepped[1] by Tertiary sediments at the north end of Bridge Timber Mountain. The outcrop band includes two valley-forming sequences separated by a middle ridge-forming sequence, reflecting the three members of the Kirtland formation.

Lithology

The Kirtland shale is composed of interbedded sandstone, shale and siltstone. Three members of variable thickness and lithology have been mapped. The lower shale member is composed of olive to medium gray, sandy and silty clay shale which contains occasional lenses of soft, olive-gray, fine-grained sandstone. There are thin carbonaceous shale lenses and conspicuous amounts of silicified wood at various horizons.

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[1]The term "overstep" is used in this paper to denote the stratigraphic and structural relationships at the north end of Bridge Timber Mountain which have been called "angular unconformities" and "overlap" by previous authors. According to Swain (1949, p. 635) "Overstep . . [is] . . the regular truncation of older units of a complete sedimentary sequence by one or more later units of the sequence".

The sandstone beds in this member are similar in most respects to those of the Fruitland formation but are thinner and generally softer, lacking topographic expression.

The Farmington sandstone member, the middle unit of the Kirtland shale, is a sequence of ledge-forming sandstone lenses separated by shale and sandy, silty shale. The number, thickness, and stratigraphic position of these beds vary throughout the area because of their lenticularity. The sandstone beds of the Farmington member are pale olive, dusky yellow, and grayish-orange in color. They are composed of fine- to medium-grained angular to subrounded quartz grains with abundant feldspar, mica flakes, and some ferromagnesian minerals. Bedding is thick to massive; cross-bedding and cross-lamination are characteristic. The interbedded shale and sandy shale are similar to that of the lower member except for a more pronounced greenish or olive color.

The upper shale member is composed of shale, interbedded thin, poorly indurated sandstone, and thick friable sandstone which occurs near the top of the member. The shale is generally similar to that of the lower member and the sandstone, similar to that of the Farmington member. Throughout the area the highest beds of the upper shale member are composed of light yellowish-white sandstone which locally forms ridges or slopes depending on the degree of induration. In general, the sandstone beds seem to be lens-shaped but overlap

of the lenses causes the lithologic zone to persist across the area. The sandstone contains fine- to coarse-grained angular quartz and some weathered feldspar. Discontinuous lenses of well-rounded quartzite and chalcedony pebbles and cobbles as large as 6 inches in diameter occur in the highest lenses of the Kirtland from the State line north at least as far as locality 5. The base of the sandstone unit is almost always concealed in the valley formed by the underlying shale but where seen is apparently gradational into the shale beneath. In the vicinity of locality 5, several thin lenses of purple shale are interbedded in the sandstone. This shale is identical with shale of the lowest beds of the overlying Animas formation. Immediately west of locality 6, beds below the sandstone unit are composed of variegated maroon, purple, yellow, and gray shale, a condition not observed elsewhere in the area. Reeside (1924, p. 57) considered the sandstone and its included pebbles to be a part of the McDermott "formation". However, in the section measured on Animas River, Reeside (<u>op</u>. <u>cit</u>., p. 56) excluded the sandstone from the McDermott and considered it to be in the upper member of the Kirtland shale apparently because of the lack of pebbles in the unit at this locality. In some respects the lithology of the sandstone unit is similar to both overlying and underlying rocks. The coarse angular grit and the pebbles are not present in any of the

of the lenses causes the lithologic zone to persist across the area. The sandstone contains fine- to coarse-grained angular quartz and some weathered feldspar. Discontinuous lenses of well-rounded quartzites and chalcedony pebbles and cobbles as large as 6 inches in diameter occur in the highest lenses of the Kirtland from the State line north at least as far as locality 5. The base of the sandstone unit is almost always concealed in the valley formed by the underlying shale but where seen is apparently gradational into the shale beneath. In the vicinity of locality 5, several thin lenses of purple shale are interbedded in the sandstone. This shale is identical with shale of the lowest beds of the overlying Animas formation. Immediately west of locality 6, beds below the sandstone unit are composed of variegated maroon, purple, yellow, and grayish shale, a condition not observed elsewhere in the area. Reeside (1924, p. 57) considered the sandstone and its included pebbles to be a part of the McDermott "formation". However, in the section measured on Animas River, Reeside (op. cit., p. 56) excluded the sandstone from the McDermott and considered it to be in the upper member of the Kirtland shale apparently because of the lack of pebbles in the unit at this locality. In some respects the lithology of the sandstone unit is similar to both overlying and underlying rocks. The coarse angular grit and the pebbles are not present in any of the

underlying Cretaceous rocks above the Dakota sandstone and are identical with much of the coarse material in the overlying Animas formation. However, the largest bulk of the sandstone is lithologically similar to the Farmington sandstone and differs from the overlying Animas formation in color and lack of volcanic material. For this reason the unit has been included in the Kirtland shale in this paper.

The Kirtland shale was deposited under fluviatile conditions similar to those that accompanied the deposition of the Fruitland formation. Larger quantities of feldspar, ferromagnesian minerals, and coarse clastic material in the Farmington sandstone and in the upper shale member indicate the presence of a new source of sediments distinct from the older Cretaceous sources. This is the earliest direct evidence of Laramide orogenic events within this area.

Relation to adjacent formations

The Kirtland shale is conformable with the underlying Fruitland formation and the overlying Animas formation. The lower contact has been discussed on page 29. The contact with the Animas formation is sharp because of the presence of purple and maroon lithic tuffs in the lower part of the Animas. Locally, these tuffs lie on the uppermost sand unit of the Kirtland shale with erosional contact, but the contact is usually entirely conformable. In the

vicinity of localities 5 and 6 the presence of purple shale in or below the yellow sandstone probably, but not conclusively, indicates an intertonguing contact.

Thickness

The Kirtland shale is about 1,065 feet thick at the Colorado-New Mexico boundary (Reeside, 1924, p. 22), about 1,125 feet thick at locality 5, and about 1,200 feet thick in the Durango area (Zapp, 1949). At locality 5 the lower shale member is 325 feet thick, the Farmington sandstone member is 345 feet thick, and the upper shale member is 455 feet thick.

Age and correlation

The age of the Kirtland shale has been discussed previously (p. 30).

Animas Formation

Type locality and distribution

Above the Kirtland shale lies a sequence of purple and olive-drab rocks containing much andesitic debris which was first described by Cross (1892, pp. 25-27) without application of a specific name. In 1896, Cross described the rocks in greater detail and named them the "Animas River beds" from exposures on Animas River south of Durango, Colorado (Emmons, Cross, and Eldridge, 1896, p. 27; also

Cross, 1899, p. 4). A stratigraphic section measured on Florida River by Gardner was included in two papers by Lee (1912, pp. 584-587; 1917, pp. 185-186) and the andesitic beds were referred to as the Animas formation.

Reeside (1924, pp. 24, 25, 32) subdivided the sequence into the lower McDermott formation and the upper Animas formation, postulating an angular and erosional unconformity between the two formations.

For reasons to be discussed later in this paper, it is proposed to return to the older definition of Cross and Gardner and consider the entire sequence of andesitic sediments as the Animas formation. The McDermott is considered to be a member of the Animas formation, locally present, and distinguishable from the main body of the Animas mainly by color.

The Animas formation is confined to the northeastern half of the San Juan Basin. On the east side of the Basin, Dane (1946) has shown that beds of the Animas formation grade laterally to the south into beds of the Nacimiento formation. He has arbitrarily restricted the name Animas formation to beds north of Canyoncito de las Yeguas (or Yegua), approximately 10 miles north of Gallina, New Mexico. The Animas formation crops out nearly continuously around the northern edge of the Central San Juan Basin in Colorado. In the northwestern part of the Basin the upper member of

the Animas formation has not been recognized south of the Colorado-New Mexico state line, but the McDermott member is said to be present along the west side of the Central Basin to a locality some miles south of Ojo Alamo, New Mexico (Reeside, 1924, p. 24).

In the northeast corner of the area of this report the Animas formation, including the McDermott member, is exposed in a wide band of fairly resistant ridges and intervening valleys from Animas Valley west to the foot of Bridge Timber Mountain where it is concealed by the overstep of younger formations. Southwest of Bridge Timber Mountain the Animas forms a continuous band of poorly exposed ridges and valleys east of Rocky Ridge.

Lithology

The Animas formation is composed of interbedded breccia, boulder conglomerate, tuffaceous sandstone, shale, and lithic tuff. Two members have been mapped, the lower or McDermott member, and the upper member. Difference in color was the main criterion used in mapping as the two members are generally conformable with each other and have similar compositions.

The McDermott member is composed of interbedded, very coarse breccia, volcanic conglomerate, coarse tuffaceous sandstone, shale, and thick beds of massive, fine- to coarse-grained tuff. The sediments are predominantly

the Abiquiu Formation has not been recognized south of the Colorado-New Mexico state line, but the Tinemont [illegible] is said to be present along the west side of the [illegible] basin to a locality some miles south of [illegible], New Mexico (Reeside, 1924, [illegible]).

In the northeastern portion of the area of this report the Animas Formation, including the [illegible] member, is exposed in a wide band of gently [illegible] [illegible] [illegible] valleys [illegible] valley east to the foot of Bridge Timber Mountain where it is [illegible] by the [illegible] step of younger formations. [illegible] of Bridge Timber Mountain the Animas forms a [illegible] band of [illegible] [illegible] ridges and valleys east of [illegible] Ridge.

Lithology

The Animas Formation is composed of [illegible] breccia, boulder conglomerate, tuffaceous sandstone, shale, and [illegible] tuff. Two members have been recognized, the lower or [illegible] member, and the upper member. Differences in color and the main criterion used in separating the two members are generally conformable with each other and have similar compositions.

The [illegible] member is composed of [illegible], very coarse breccia, volcanic conglomerate, [illegible] tuffaceous sandstone, shale, and thin [illegible] of [illegible], [illegible] coarse-grained tuff. The [illegible] are [illegible]

reddish-brown to purple in color but include some yellow and green beds. Most of the material in the beds is relatively unweathered andesitic debris, but there are subordinate amounts of quartz, quartzite, and chert. The lowest tuff beds of the McDermott member usually contain irregular lenses of well-rounded quartz, quartzite, and chert pebbles similar to those occurring in the upper shale member of the Kirtland formation. On Animas River, the McDermott member contains angular andesite boulders up to 4 feet in diameter in the lower beds and large andesite cobbles and pebbles in the upper beds. Across the area coarseness of the material decreases to the southwest and the andesitic constituents become more highly weathered. South of locality 5 the McDermott member thins considerably and becomes highly irregular in lithology. In Secs. 29 and 32, T. 33 N., R. 11 W., purple conglomeratic tuff and shale beds of the McDermott member were found to be discontinuous because of intertonguing with the upper member of the Animas formation. Evidence of probable intertonguing with the underlying Kirtland shale in this vicinity has been discussed previously (pp. 35-36). In the southwestern part of the area near McDermott Arroyo (locality 7) the member consists mainly of variegated purple and gray shale with lesser amounts of coarse-grained sandstone containing weathered andesite pebbles. The sandstone is predominantly quartzose with matrix of fine andesitic

reddish brown or purple is common but include pale olive and green types. Most of the material in the unit is relatively unweathered andesite detritus, but there are subordinate amounts of chert, quartzite, and granite. The lowest tuff beds of the McDermott member usually contain irregular lenses of well-rounded quartz, quartzite, and chert pebbles similar to those occurring in the upper shale member of the Kirtland formation. On Animas River, the lowermost member contains rounded andesite boulders up to 4 feet in diameter in the lower beds and large andesite cobbles and pebbles in the upper beds. Across the area coarseness of the material decreases to the southeast and the andesite constituents become more highly weathered. South of locality 5 the McDermott member thins considerably and becomes highly irregular in lithology. In secs. 29 and 32, T. 33 N., R. 12 W., purple conglomeratic tuff and shale beds of the McDermott member were found to be discontinuous because of intertonguing with the upper member of the Kirtland formation. Evidence of probable intertonguing with the underlying Farmington shale in this vicinity has been presented previously (pp. 35-36). In the southeastern part of the area near the mouth of Arroyo (locality 7) the member consists of variegated purple and gray shale with lenses of coarse-grained sandstone containing andesite and scattered pebbles. The sandstone is predominantly andesite with a little of the andesite

material and resembles the uppermost sandstone of the Kirtland formation.

Along the band of outcrop from locality 5 northeastward to Animas River, the contact of the McDermott member with the upper member of the Animas formation is conformable and gradational, and intertonguing relationships are observable in several localities. The "angularity" between the members on Animas River south of Durango, Colorado (Reeside, 1924, pp. 25, 33) is an optical illusion due to rapid steepening of dip in the McDermott beds where they outcrop slightly to the north of the upper Animas beds. Tracing of individual beds along the outcrop immediately west of Animas River has shown that purple beds of the McDermott member interfinger with greenish conglomerate beds of the upper Animas. Zapp (1949) found that the McDermott thins northeastward from Animas River by intertonguing with the upper member of the Animas formation and is completely replaced by greenish beds in the vicinity of the Florida-Los Piños drainage divide.

Southwest of locality 5 the rapid and irregular thinning of the McDermott member appears to have been caused by both depositional thinning and erosion. The base of the McDermott probably rises stratigraphically to the southwest by intertonguing with the upper Kirtland sandstone. The upper contact of the McDermott member is in many places definitely erosional and is overlain by conglomeratic channel

material and [illegible] of uppermost members of the Kirk-land Formation.

Along the band of outcrop from locality 2 northeastward to Animas River, the contact of the McDermott member with the upper member of the Animas Formation appears to be gradational, and interfingering relationships are observed in several localities. The contact [illegible] between the members on Animas River south of Durango, [illegible] (Reeside, 1924, pp. 25, 31) [illegible] of dip in the [illegible] beds [illegible] the north of the upper Animas beds. [illegible] of individual beds along the outcrop immediately west of Animas River has shown that [illegible] of the McDermott [illegible] interfingers with greenish sandstones [illegible] of the upper Animas. [illegible] (1949) found that the McDermott [illegible] northeastward from Animas River by interfingering with the upper member of the Animas Formation and is completely replaced by greenish beds in the vicinity of the Florida-Los Pinos drainage [illegible].

Northwest of locality 3 the abrupt and irregular thinning of the McDermott member appears to have been caused by both depositional thinning and erosion. The base of the McDermott probably rises stratigraphically to the [illegible] by interfingering with the upper Kirtland sandstone. The upper surface of the McDermott, however, is in many places definitely erosional and is overlain by conglomeratic sandstone

deposits of the upper member of the Animas formation. The notable disintegration of andesitic material of the McDermott member and rapid reduction in grain size south of locality 5 are interpreted as being the result of a post-depositional period of weathering and erosion. Intertonguing of the McDermott member and the upper member of the Animas formation in Secs. 29 and 32, T. 33 N., R. 11 W. is thus most likely due to reworking and redeposition of McDermott sediments at the time sediments of the upper member were being deposited.

The upper member of the Animas formation consists of a persistent ridge-forming conglomeratic sequence and an overlying thick sand and shale sequence which forms minor ledges and intervening slopes and valleys. The characteristic colors of the upper member are olive, brown, various shades of gray, and occasionally, purple and red.

The conglomeratic sequence of the upper member is composed of thick interbedded conglomeratic tuff, shale, sandstone, and thick- to massive-bedded cobble and boulder conglomerate. Thin carbonaceous to coaly shale beds are locally present and carbonized and silicified logs are common. In the northern half of the area the boulders, cobbles, pebbles, and matrix in the conglomeratic sequence are mainly weathered andesite, but there are considerable quantities of quartz, quartzite, chert, granite, and weathered

deposits of the upper member of the Animas formation. The notable disturbance [illegible] of the McDermott member and [illegible] relocation [illegible] south of locality [illegible] interpreted as being the result of a post-depositional period of [illegible] and erosion. [illegible] of the McDermott [illegible] where the upper member of the Animas formation is [illegible] 25, T. [illegible] R. [illegible] is thus most likely due to [illegible] redeposition of McDermott sediments at the time [illegible] were being deposited.

The upper member of the Animas formation is a series of persistent ridge-forming conglomeratic sequence and [illegible] underlying thick sand and shale sequence which forms minor ledges and intervening slopes and valleys. The characteristic colors of the upper member are olive, brown, various shades of gray, and occasionally, purple and red.

The conglomeratic sequence of the upper member is composed of thick, interbedded conglomeratic sand, silty sandstone, and thin- to massive-bedded cobble and boulder conglomerate. Thin dark carbonaceous shale beds are locally present and carbonized and silicified logs are common. In the northern half of the area the boulders, cobbles, pebbles, and matrix in the conglomeratic sequence are mainly weathered andesite, and there are occasional particles of quartz, quartzite, chert, granite, and weathered

coarse-grained porphyritic igneous rocks.

The sand and shale sequence of the upper member is composed of thick sandy, tuffaceous shale with interbedded thin to thick, cross-bedded tuffaceous sandstone. The sand is usually coarse-grained and angular and many beds are granule or pebble conglomerates. Higher beds contain more highly weathered and finer-grained sediments, with quartz becoming the predominant mineral constituent of the higher sandstone beds.

The conglomeratic sequence is apparently persistent across the area, cropping out in a narrow band from Animas River to Bridge Timber Mountain, and southwest of Bridge Timber Mountain to the State line. Reeside (1924, p. 33) has said that the Animas formation wedges out to the south in the northwestern part of T. 32 N., R. 11 W. However, it was found that the coarse conglomerate, shale, and sandstone in the upper part of the McDermott "formation" at the type locality in McDermott Arroyo (locality 7; Reeside, 1924, p. 57) could be traced northward with some certainty into the conglomeratic sequence of the upper member of the Animas formation. For this reason these beds have been mapped as part of the upper member.[1] In the gravel-capped hills north

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[1]The typical section of the McDermott defined by Reeside (1924, p. 57) in the SW$\frac{1}{4}$ NW$\frac{1}{4}$, Sec. 19, T. 32 N., R. 11 W. is subdivided in this report as follows: the lowest 95 feet

of McDermott Arroyo (Secs. 5, 8, and 9, T. 32 N., R. 11 W.) and near the south end of Coyote Gulch, poorly exposed beds above the McDermott member are composed of olive-colored, coarse-grained, tuffaceous sandstone, containing pebbles of quartzite and rotten andesite; yellowish-olive, coarse-grained sandstone; and thick olive- to somber-hued shale. These beds were considered by Reeside (op. cit., p. 57) as part of the Torrejon formation, but they are lithologically more similar to the sand and shale sequence of the upper member of the Animas formation and are so designated in this paper.

The upper member of the Animas formation exhibits a southwestward gradation from coarse to finer, more highly weathered, better-sorted materials. Sandstone and conglomerate beds in the upper member in the vicinity of McDermott Arroyo are composed mainly of chatter-marked quartz, quartzite, and chert, ranging from fine-grained sand to pebbles and cobbles of 6-inch diameter embedded in andesitic matrix. Reeside (op. cit., p. 29) has noted the similarity of these conglomeratic materials to those found in the Ojo Alamo sandstone to the south in New Mexico.

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of pebble-bearing sandstone and sandy shale is part of the Kirtland shale, the overlying 127 feet of purplish beds is the McDermott member of the Animas formation, and the top 106 feet of shale, coarse-grained sandstone, and coarse conglomerate is included in the upper member of the Animas formation.

The section of the McDermott member exposed on Animas River (locality 1) is considered more typical of the McDermott member as described in this paper.

of McDermott arroyo (sec. 5, 8, and 9, T. 32 N., R. 9 W.) and near the south end of Barker Dome, which, poorly exposed beds above the McDermott member are composed of olive-colored, coarse-grained, feldspathic sandstone, containing pebbles of quartzite and rotten andesite; yellowish-olive, medium-grained sandstone; and thin layers of copper-bearing shale. These beds were considered by Reeside (op. cit., p. 47) as part of the McDermott formation, but they are lithologically more similar to the sand and shale sequence of the upper member of the Animas formation and are so designated in this paper.

The upper member of the Animas formation exhibits a southwestward gradation from coarse to finer, more intensively weathered, better-sorted materials. Sandstone and conglomerate beds in the upper member in the vicinity of McDermott Arroyo are composed mainly of andesite, quartz, quartzite, and chert, ranging from fine-grained sand to pebbles and cobbles of 6-inch diameter embedded in an andesitic matrix. Reeside (op. cit., p. 50) has noted the similarity of these conglomeratic materials to those found in the Ojo Alamo sandstone to the south in New Mexico.

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of pebble-bearing sandstone and shale is part of the Kirtland shale, the overlying 157 feet of purplish beds is the McDermott member of the Animas formation, and the top 105 feet of pebble, coarse-grained sandstone, and conglomerate is included in the upper member of the Animas formation.

The section of the McDermott member exposed on Animas River (locality 1) is considered more typical of the McDermott member as described in this report.

The Animas formation was deposited under differing conditions throughout the area of this report. The McDermott member was apparently deposited by streams flowing from volcanic highlands north or northwest of Durango, as shown by the thickening and coarsening of materials in that direction (Zapp, 1949). The source of sediments of the conglomeratic phase of the upper member was to the east or northeast of the site of the present San Juan Basin (Zapp, 1949; Wood, Kelley, and MacAlpin, 1948; Dane, 1946). The writer interprets the conglomerate as being stream-borne pediment gravel deposited on a surface of little relief. During transport of this gravel a considerable amount of weathering and sorting would occur and silt, clay, and finer quartzose material would precede the coarse materials. Thus much of the material included in the upper member of the Kirtland formation is probably genetically related to sediment of the Animas formation to the east. The observed weathering and sorting phenomena within the upper member of the Animas formation in the mapped area have already been described.

Wood, Kelley, and MacAlpin (1948), and Zapp (1949) have mentioned that the source of some of the Animas material was probably to the west or northwest of the present outcrops. On the boundary between Secs. 15 and 22, S. T. 34 N., R. 10 W., gently dipping beds of shale and sandstone of the upper member were observed to overstep more steeply dipping and

The Galisteo formation apparently was deposited under differing conditions throughout the area of this report. The [illegible] member was apparently deposited by streams flowing from volcanic highlands north or northwest of Durango, as shown by the thickening and coarsening of materials in that direction (Zapp, 1949). The source of sediments of the conglomeratic phases of the upper member was to the west or northeast of the site of the present San Juan basin (Zapp, 1949; Wood, Kelley, and MacAlpin, 1948; [illegible], 1948). He interprets the [illegible] as being stream-deposited sediment gravel deposited on a surface of [illegible] relief. During transport of this gravel a considerable amount of weathering and sorting would occur and silt, clay, and finer quartzose material would separate the coarse materials. Thus much of the material included in the upper member of the [illegible] Formation is probably genetically related to sediment of the [illegible] Formation to the west. The observed weathering and sorting phenomena within the upper member of the [illegible] formation in the mapped area have already been described.

Wood, Kelley, and MacAlpin (1948), and Zapp (1949) have mentioned that the source of some of the [illegible] materials was probably to the west or northwest of the present outcrops. On the boundary between secs. 11 and 12, T. [illegible] N., R. 10 W., gently dipping beds of shale and sandstone of the upper member were observed to [illegible] more steeply dipping and

stratigraphically lower beds of Animas conglomerate. The overstep shows that folding on the borders of the Central San Juan Basin in this area began shortly after the deposition of the conglomeratic sequence of the upper member of the Animas formation. This relationship indicates that much of the material of the finer-grained sequence of the upper member within the Basin was probably derived from weathering and erosion of the conglomeratic beds of the upper member on the uplifted platform outside the Hogback fold.

Relation to adjacent formations

The conformable contact of the Animas formation with the underlying Kirtland shale has been discussed on page 35.

Predominantly olive-colored shale and coarse resistant sandstone beds of the Animas formation are succeeded by somber gray shale and light gray to brown, friable sandstone of the Nacimiento formation. Color contrast, degree of induration, and coarseness of sediments were the main criteria used to separate the formations in mapping.

In the area between Indian Creek and Sawmill Canyon, northeast of Bridge Timber Mountain, gently dipping beds of the Nacimiento were seen to overstep more steeply dipping beds of the Animas formation. To the south, sediments of the two formations become parallel. Good exposures in the

stratigraphically lower than Animas conglomerate. The overlap shows that folding on the borders of the Central San Juan Basin in Colorado began shortly after the deposition of the conglomeratic sequence at the upper part of the Animas formation. This relationship indicates that much of the material of the fine-grained sequence of the upper member within the basin was probably derived from weathering and erosion of the conglomeratic beds of the upper member on the flanks of the anticlinal fold.

<u>Relation to adjacent formations</u>

The conformable contact of the Animas formation with the underlying Kirtland shale has been discussed on page 33.

Predominantly olive-colored muds and sandy residual sandstone beds of the Animas formation are succeeded by somber gray shale and pinkish gray to brown, friable sandstone of the Nacimiento formation. Color contrast, degree of induration, and character of sediments were the main criteria used to separate the formations in mapping.

In the area between Indian Creek and Cowhill Canyon, northeast of Chimney Rock Mountain, gradational beds of the Nacimiento were seen to intertongue with steeply dipping beds of the Animas formation. To the south, sediments of the two formations become similar. Sand appears to play

west bank of Animas River (Secs. 25, 26, 35, and 36, S. T. 34 N., R. 10 W.) and near the mouth of Posta Canyon reveal a transitional contact of the Animas and Nacimiento formations. The contact in this area is actually a zone of interfingering somber shale, olive and yellowish sandstone and shale, and fine conglomerate beds. The zone varies in thickness but may be as much as 50 feet thick in some localities. The stratigraphic position of the zone of interfingering appears to become progressively lower to the south and passes out of the area to the east in Sec. 12, T. 33 N., R. 10 W.

West and southwest of Bridge Timber Mountain the upper contact of the Animas formation is difficult to trace because of poor exposures. However, at various localities the color contrast with the overlying Nacimiento formation which was noted on Animas River serves as a guide for separating the formations. At the north end of Bridge Timber Mountain the Animas formation is concealed by overstepping beds of younger formations. In the hills north of McDermott Arroyo the contact of the Nacimiento and Animas formations is transitional. South of McDermott Arroyo the contact is concealed by alluvium and is only approximately located.

Thickness

At locality 7 near the State line the McDermott member

west bend of Animas River (secs. 21, 28, 29, and 32, T. 34 N., R. 10 W.) and near the mouth of Texas Canyon reveal a transitional contact of the Animas and McDermott formations. The contact in this area is defined by a zone of interfingering somber purple, olive and yellowish sandstone and shale, and fine conglomerate beds. The zone ranges in thickness but may be as much as 50 feet thick in some localities. The stratigraphic position of the zone of interfingering appears to become progressively lower to the south and passes out of the area to the east (in sec. 17, T. 33 N., R. 10 W.).

West and southwest of Bridge Timber Mountain the upper contact of the Animas formation is difficult to trace because of poor exposures. However, at various localities the color contrast with the overlying [illegible] formation which was noted on Animas River served as a guide for separating the formations. At the north end of Bridge Timber Mountain the Animas formation is concealed by overlapping beds of younger formations. On Shy Hills north of [illegible] the contact of the [illegible] and Animas formations [illegible]. South of McDermott Arroyo the contact is concealed by [illegible] wide and is only approximately located.

Thickness

At locality 7 near the [illegible] the McDermott member

is 127 feet thick and the conglomerate sequence of the upper member is at least 106 feet thick. Beds above the conglomerate are not exposed and no measurement of the upper sequence is possible. To the north near locality 6 the McDermott member is replaced by intertonguing with the upper member which is estimated to be about 450 feet thick. At locality 5 the McDermott member is about 290 feet thick and the upper member is too poorly exposed to be measured. On Animas River the McDermott member is 256 feet thick and the upper member is 1,110 feet thick (Reeside, 1924, p. 56).

The considerable thinning of the upper member of the Animas formation from Animas River to the southwest is probably mostly due to lateral gradation of Animas lithology into Nacimiento lithology as described on pages 45-46 of this paper. A similar relationship on the east side of San Juan Basin has been described by Dane (1946).

Age and correlation

The Animas formation is considered to be late Cretaceous and Paleocene in age. The McDermott member contains a fairly well known dinosaur and turtle fauna which has been described and discussed by Gilmore (1916, p. 280; 1919, p.8) as part of the Kirtland fauna. The evidence presented by the dinosaur remains indicates that the McDermott beds (considered as part of the Kirtland by Gilmore) in New Mexico

is 127 feet thick and. ... conglomerate sequence of the upper member is at least 100 feet thick. Beds above the conglomerate are not exposed and no measurement of the upper sequence is possible. To the south near locality 6 the McDermott member is replaced by intertonguing with the upper member which is estimated to be about 600 feet thick. At locality 6 the McDermott member is about 290 feet thick and the upper member is too poorly exposed to be measured. On Animas River the McDermott member is [illegible] feet thick (Reeside, 1924) and the upper member is 1,2[illegible] feet thick (Reeside, 1924, p. 26).

The considerable thinning of the upper member of the Animas Formation from Animas River to the southeast is probably mostly due to lateral gradation of Animas lithology into Nacimiento lithology as described on pages 45-48 of this paper. A similar relationship on the west side of the San Juan Basin has been described by Dane (1946).

Age and correlation

The Animas Formation is considered to be Late Cretaceous and Paleocene in age. The McDermott member contains a fairly well known dinosaur and turtle fauna which has been described and discussed by Gilmore (1916, p. 280; 1919, p. [illegible]) as part of the Kirtland fauna. The evidence presented by the dinosaur remains indicates that the McDermott member (considered as part of the Kirtland by Gilmore), is Late Creta-

are of Montana age (Gilmore, 1919, p. 8). In discussion of the flora of the McDermott, Knowlton (1924, p. 77) stated that the plants favor placing the McDermott in the Cretaceous. However, the evidence is not entirely conclusive because of the presence of several species which seem to indicate Tertiary age. Intertonguing of the upper member of the Animas with the McDermott member and the Kirtland-Fruitland formations to the northeast of Animas River indicates that the lower part of the upper member is probably late Montana or Laramie in age. Inclusion of conglomerate beds bearing dinosaur and turtle bones in the upper member at locality 7 near McDermott Arroyo indicates Cretaceous age of at least the lowest beds of the upper member in this vicinity. Plant fossils collected from the upper member in the area between Animas River and Pagosa Junction indicate Tertiary age (Knowlton, 1924, p. 71). On the east side of the San Juan Basin turtle bones collected near the top of the Animas were identified by Gilmore (Dane, 1946) as probably being of Paleocene (Torrejon) age.

The Animas formation, considered as a whole, is probably correlative in age with at least part of the Pierre shale, Fox Hills sandstone, Laramie, and Arapahoe formations, and the Denver formation in the Denver Basin (modified from Reeside, 1944) and with part of the Pierre shale, Trinidad sandstone, Vermejo formation, Raton formation, and part of

are of Montanan age ([illegible], 1925, p. 8). In discussion of the flora of the [illegible], Knowlton (1924, p. 77) stated that the plants were indicating the [illegible] is the Cretaceous. However, the evidence is not entirely conclusive because of the presence of several species which seem to indicate Tertiary age. The correlating of the upper member of the Anthus with the [illegible] member and the Kirtland-Fruitland formations (Dorf) in [illegible] of [illegible] River indicate that the lower part of the upper member is probably late Montana in age. The inclusion of conglomerate beds bearing abundant [illegible] cobbles in the upper member at locality [illegible] near [illegible] Creek indicates Cretaceous age of at least the lowest beds of the upper member in the vicinity. Plant fossils collected from the upper member in the area between Antelope Valley and [illegible] Canyon indicate Tertiary age (Knowlton, 1924, p. 77). On the east side of the San [illegible] Creek, forms collected near the top of the Anthus were identified by [illegible] (Dorf, 1940) as probably being of Paleocene ([illegible]) age.

The Anthus formation, considered as a whole, is apparently correlative in age with at least part of the [illegible] shale, Fox Hills sandstone, [illegible] formation, and the [illegible] formation in the [illegible] Basin (modified from [illegible], 1944) and with most of the [illegible] shale, [illegible] sandstone, [illegible] formation, [illegible] formation, and part of

the Poison Canyon formation in the Raton Mesa region east of the Rocky Mountains.

Nacimiento Formation

Type locality and distribution

The Nacimiento formation was first described and named the "Puerco Marls" by Cope (1875, pp. 1008-1017) from unfossiliferous exposures of these beds on Puerco River in the vicinity of Cuba, New Mexico. Paleocene fossils were later found farther to the west in the San Juan Basin in beds believed to be equivalent to those on Puerco River (Cope, 1885). Matthew (1897, p. 260) separated the Puerco fauna (originally described by Cope) into two distinct faunas, supposedly separated by a hiatus. He named the beds containing the older fauna the Puerco formation, and those containing the younger fauna the Torrejon formation. Later Gardner (1910, p. 714) proposed that the two formations be included in the Nacimiento group and this terminology was generally accepted. Dane (1946) used the term Nacimiento formation without specifically proposing that these rocks should be lowered from the status of group to formation. Simpson (1948, pp. 272-273) agreed with this usage, pointing out that the supposed boundary between the Puerco and Torrejon formations has never been mapped. He proposed that Puerco and Torrejon be considered only as names of faunal zones in the

the Polson Canyon Formation in the [illegible] region [illegible] of the [illegible].

Nacimiento Formation

__Type locality and distribution__

The Nacimiento formation (more [illegible]) was named the "Puerco marls" by Cope (Wheeler, 1875, pp. 1008-1017) from exposures [illegible] along the Puerco River in the vicinity of [illegible]. [illegible] fossils were later found farther to the [illegible] beds believed to be equivalent to those on Puerco River (Cope, 1885). Matthew (1897, p. 259) separated the Puerco beds (originally described by Cope) into two divisions, apparently separated by [illegible]. He named the beds containing the older fauna the Puerco formation, and those containing the younger fauna the Torrejon formation. Later Gardner (1910, p. 713) proposed that the two formations be included in the Nacimiento group and this terminology was generally accepted. [illegible] (1948) used the term Nacimiento formation without specifically [illegible] that name which should be lowered from the status of group to formation. Simpson (1948, pp. 272-273) agreed [illegible] this usage, pointing out that the supposed boundary between the Puerco and Torrejon formations has never been mapped. He proposed that Puerco and Torrejon be considered only as names of faunal zones in the

Nacimiento formation.

In this paper the writer uses the terminology proposed by Simpson, and beds formerly called Puerco and Torrejon formations in the area of this report are designated the Nacimiento formation.

The Nacimiento formation is exposed in the southeastern, southern, and western portions of the Central San Juan Basin. Around the northern and northeastern margins of the Basin much of the stratigraphic interval of the Nacimiento formation is represented by rocks of the upper member of the Animas formation. Lateral gradation of Nacimiento rocks into Animas rocks has been mentioned (page 37).

In the mapped area of this report the Nacimiento formation is fairly well exposed in the canyon lands between Animas River and Bridge Timber Mountain. Exposures are continuous from the northeast corner of the area to the New Mexico-Colorado state line. Southwest of Bridge Timber Mountain, Nacimiento rocks are exposed over much of T. 32 N., R. 11 W. but are very poorly exposed to the north and were not differentiated from the overlying San José formation in this vicinity.

Lithology

The Nacimiento formation presents two considerably different sedimentary facies in exposures east of Bridge

Nacimiento Formation.

In this paper the writer uses the terminology proposed by Simpson, and b.g. formerly called Puerco and Torrejon formations in the area of this report are designated the Nacimiento Formation.

The Nacimiento Formation is exposed in the southeastern, southern, and western portions of the central San Juan Basin. Around the northern and northeastern margins of the basin much of the stratigraphic interval of the Nacimiento Formation is represented by rocks of the upper portion of the Animas Formation. Lateral gradation of Nacimiento rocks into Animas rocks has been postulated (page 37).

In the mapped area of this report the Nacimiento Formation is fairly well exposed in the canyon lands between Animas River and Bridge Timber Mountain. Exposures are continuous from the northwest corner of the area to the New Mexico-Colorado state line. Northeast of Bridge Timber Mountain, Nacimiento rocks are exposed over much of T. 32 N., R. 11 W., but are only poorly exposed to the north and were not differentiated from the overlying San Jose Formation in this vicinity.

Lithology

The Nacimiento Formation presents two considerably different sedimentary facies in exposures east of Bridge

Timber Mountain. North of Round Mountain (in T. 33 N., R. 10 W.) the Nacimiento is composed mainly of soft, somber gray shale; soft, cross-bedded, yellow, greenish-gray and tan, generally fine-grained, well-sorted quartz sandstone; and occasional variegated red, white, and gray shale, especially near the top of the formation. The lower beds are similar to the uppermost beds of the Animas formation and grade laterally into those beds except on the ridges between Indian Creek and Sawmill Canyon northeast of Bridge Timber Mountain where successively younger beds of the Nacimiento overstep older beds to the north and finally overstep steeply dipping beds of the Animas formation.

South of Round Mountain the upper part of the Nacimiento formation contains many beds of coarse-grained, heavy-bedded, resistant sandstone with interbedded gray, purple, red, and white shale and soft sandstone. This cliff-forming sequence is well exposed in the narrow canyon of Animas River south of Bondad. The sandstone is generally yellowish-gray to brown and contains fine- to very coarse-grained, subangular to subrounded quartz as the principal mineral constituent. There is some weathered pink feldspar, and pebbles of quartz, quartzite, and chert are very common in most beds. The sandstone is medium- to massive-bedded and generally cross-laminated and cross-bedded. Individual beds were found to thin and lense out to the north into the finer-grained shaly

Timber Mountain, north of Round Mountain (in T. 33 N., R. 10 W.) the [illegible] is composed mostly of marl, [illegible] gray [illegible] beds, cross-bedded, yellow, granite-gray and tan, generally fine-grained, well-bedded [illegible] and occasional [illegible] and wedges, and grey-[illegible] especially near the top of the formation. The lower beds are similar to the uppermost beds of the [illegible] formation and grade laterally into those beds exposed on the [illegible] Indian Creek and [illegible] north [illegible] of [illegible] Mountain where successively younger beds of the formation overlap older beds to the north and finally overlap steeply dipping beds of the [illegible] formation.

South of Round Mountain the upper part of the [illegible] formation contains many beds of [illegible], [illegible], resistant sandstone with [illegible] gray, purple, red, and white [illegible]. This [illegible] is well exposed in the upper [illegible] of [illegible] of Round [illegible]. The sandstone is generally yellowish-gray to brown and contains [illegible] of very coarse-grained, subangular to subrounded grains as the principal mineral constituents. There is [illegible] quartz, feldspar, and pebbles of quartz, quartzite, and chert are very common in some beds. [illegible] in [illegible] laminated and cross-bedded. Individual beds were [illegible] [illegible] [illegible] [illegible]

sequence of the Nacimiento, with successively higher beds persisting farther to the north than lower beds. The uppermost resistant sandstone beds lense out on the north slope of Round Mountain. The interbedded shale intervals are traceable into similar beds in the shaly sequence to the north.

Southwest of Bridge Timber Mountain the heavy sandstone facies is exposed southeast of McDermott Arroyo in T. 32 N., R. 11 W., and the shaly facies is poorly exposed to the northwest. In this area the heavy sandstone beds lense out to the north, northwest, and west as they approach the Hogback fold.

It is of interest to note that shale beds in both shaly facies and heavy sandstone facies show a progressive color change from stratigraphically lower to higher beds. The lower beds are greenish-gray and somber gray, higher beds are predominantly somber gray, and upper beds are variegated wine-red, purple, and gray.

It was found by rapid reconnaissance and examination of aerial photos that the heavy sandstone facies dies out to the south in New Mexico, presumably in a manner similar to the northward wedge-out in Colorado. Thus, in the northern part of T. 31 N., R. 11 W. and in the eastern and southeastern part of T. 32 N., R. 12 W. the interval of the heavy sandstones is replaced to the south by thick shale and thin soft sandstone.

sequence of the [illegible], with successively higher beds persisting farther to the north than lower ones. The upper-most resistant sandstone beds [illegible] out on the north flank of Round Mountain. The interbedded shale intervals are traceable into similar beds in the shaly sequence to the north.

Southwest of [illegible] the heavy sandstone facies is exposed southeast of [illegible] in T. 32 N., R. 11 W., and the shaly facies is poorly exposed to the northwest. In this area the heavy sandstone beds taper out to the north, northwest, and east as they approach the [illegible] fold.

It is of interest to note that shale beds in both shaly facies and heavy sandstone facies show a progressive color change from stratigraphically lower to higher beds. The lower beds are greenish-gray and yellow-gray; higher beds are predominantly somber gray, and upper beds are variegated wine-red, purple, and gray.

It was found by rapid reconnaissance and examination of aerial photos that the heavy sandstone facies dies out to the south in [illegible] section, apparently in a manner similar to the northward wedge-out just described. Thus, in the northern part of T. 31 N., R. 11 W., and in the western and southeastern part of T. 32 N., R. 10 W., the interval of the heavy sandstone is replaced to the south by shale and thin, soft sandstone.

Nacimiento sediments must have been derived from several sources. The lowest beds are composed of weathered and sorted Animas sediments which are equivalent to coarser Animas sediments in areas to the northeast. Gray and greenish-colored sediments in the main part of the formation are weathered equivalents of sediments in the shaly sequence of the upper member of the Animas formation. Red and purple shale beds of the upper part of the Nacimiento formation exposed near the upper end of Posta Canyon contain large quantities of siliceous pebbles identical with those found in the McDermott member of the Animas formation. Some of the shale and sandstone may have been derived from the uplift and erosion of Montana and Colorado rocks on the flanks of the San Juan dome which appears to have been gently uparched in latest Cretaceous and early Tertiary time (Atwood and Mather, 1932, p. 15). Sediments of the shaly facies are probably channel and floodplain deposits of meandering streams. Occasional swamp or lake conditions are indicated by lenticular lignitic beds. Turtle, crocodile, and fish remains found in similar beds in other parts of the Basin (Gilmore, 1919, p. 9) tend to confirm this interpretation of the physical evidence.

The heavy sandstone beds south of Round Mountain contain considerable quantities of siliceous pebbles and feldspathic material of a type not characteristic of sediment

composing the better-sorted, finer-grained sandstone of the shaly facies. The heavy sandstone beds have better-defined contacts with the interbedded shale than beds of sandstone in the shaly facies which in many places grade both laterally and vertically into shale. The shaly units of the heavy sandstone facies appear to be mainly continuous from the shaly facies north of Round Mountain to a similar sequence some miles south in New Mexico. Thus, the heavy sandstone beds are lenses in this area, being enclosed by shale to the north, west, and south. The difference in composition from that of surrounding sediments and the lenticularity and other bedding characteristics of the heavy sandstones indicate that the source of these sediments was probably to the east or northeast of the area of this report.

The heavy sandstone facies was deposited in the structurally lowest part of the Central Basin (compare described lateral extent of facies with structure-contour map, Figure 3, page 17), by relatively competent streams. Large quantities of soft material easily eroded from the surrounding platform must have been carried into the Basin from all sides and restricted deposition of the heavy sandstone near the edges of the Basin.

Relation to adjacent formations

The generally conformable and gradational contact of the

composing the cutline-sorted, finer-grained sediments of the shaly facies. The heavy sandstone beds have better-defined contacts with the interbedded shale than beds of sandstone in the shaly facies which in many places grade both laterally and vertically into shale. The shaly units of the heavy sandstone facies appear to be notably continuous from the shaly facies north of Pease Mountain to a point near the point where noted in the section. Thus, the heavy sandstone beds are largely in the central part, enclosed by shale to the north, west, and south. The difference in composition shows that of sedimentary structure and the lenticularity and other bedding characteristics of the heavy sandstone, indicate that the source of these sediments was probably to the east or northeast of the area of this report.

The heavy sandstone facies was deposited in the structurally lowest part of the Central basin (central described lateral extent of facies with structure-contour map, Figure 5, page 17), by relatively competent streams. Large quantities of sand-sized detrital material from the surrounding terrane must have been carried into the basin from all sides and restricted deposition of the heavy sandstone near the edges of the basin.

Relation to pattern of deposition

The general sedimentary and depositional conditions of the

Nacimiento formation with the underlying Animas formation has been described on page 45 and 46.

Above the Nacimiento formation is a sequence of variegated shale and sandstone which is called the San José formation in this paper. Near the head of Sawmill Canyon, northeast of Bridge Timber Mountain, beds of the San José formation overstep more steeply dipping beds of the Nacimiento and underlying formations. This same relationship was observed immediately southwest of Bridge Timber Mountain, but extensive gravel and soil cover made it impossible to map a contact between the formations farther south. Exposures east of Bridge Timber Mountain show that the contact is entirely conformable and gradational south of the area of overstep. Near the State line the heavy sandstone facies of the Nacimiento formation is similar to overlying heavy sandstone beds in the San José formation. The contact between the formations in this area was arbitrarily chosen as the base of a thick cliff-forming sandstone "zone" which appears to have more lateral persistence than underlying sandstone lenses. The base of the sandstone is at approximately the same stratigraphic horizon as the contact between the "Torrejon" and "Wasatch" formations of Reeside (1924, p. 46). Placing of the contact at this position is justified as Torrejon fossils were found 115 feet below the same horizon a few miles to the south near Cedar Hill, New Mexico

Sandstone formation [illegible] the underlying [illegible] formation has been described on page 47 and 48.

Above the [illegible] formation is a sequence of variegated shale and sandstone which is called the [illegible] formation in this paper. [illegible] the head of [illegible], northeast of Bridger [illegible] however, beds of the [illegible] formation overstep [illegible] beds of the [illegible] and underlying [illegible]. [illegible] relationship was observed [illegible] of the [illegible] but [illegible] to make a contact between the formations farther north. [illegible] east of Bridger [illegible] that the contact is entirely conformable and gradational [illegible] of the area of overstep. Near the [illegible] the heavy sandstone ledges of the [illegible] formation is similar to overlying heavy-sandstone beds in the [illegible] formation. The contact between the formations in this area was arbitrarily chosen as the base of a [illegible] "zone" which appears to have more lateral persistence than underlying sandstone lenses. The base of the [illegible] is approximately the same stratigraphic horizon as the contact between the "[illegible]" and "[illegible]" [illegible] (1924, p. 40). [illegible] of the contact of [illegible] identified as [illegible] feet below the same horizon a few miles to the [illegible]

(Reeside, 1924, pp. 57-58). Beds above the contact were followed to the northeast by Reeside (1924, p. 45) into lower beds of the San José (Wasatch) formation cropping out in the H-D Hills. Here the beds contain the Tiffany fauna. On the north slope of Round Mountain the sandstone wedges out and poor exposures made it impossible to trace a logical contact to the north across an area of several miles. In the upper drainage of Posta Canyon a gradational contact was mapped between variegated shale and soft, finely conglomeratic sandstone of the San José, and more somber-hued shale and soft lenticular sandstone of the Nacimiento. This contact is at approximately the same stratigraphic horizon as the contact farther south.

The base of the cliff-forming sandstone "zone" on Animas River was followed on aerial photographs to the southwest in New Mexico and northward into the area east of McDermott Arroyo. The contact between the Nacimiento and San José formations in this vicinity is at about the same stratigraphic horizon as on Animas River. In Sec. 31, T. 33 N., R. 10 W. the sandstone wedges out and the formations were not differentiated to the north and west.

Thickness

A section of the Nacimiento formation measured by Reeside (1924, p. 58) about 2 miles south of the State line

(Reeside, 1956, pp. 57-58). Later, Dane [illegible] the contact [illegible] was fol-
lowed to the northeast by [illegible] (1958, p. 46) [illegible] lower
beds of the San Jose [illegible] formation cropping out in the
[illegible] Hills. Here the [illegible] the [illegible] On the
north slope of [illegible] Mountain the sandstone wedges out and
poor exposures make it impossible to trace a logical contact
to the north across an area of several miles. In the upper
drainage of [illegible] Canyon a [illegible] contact exists
between variegated shales [illegible] of the
stone of the San Jose, and more [illegible] shale and soft
lenticular sandstones of the Nacimiento. This contact is at
approximately the same stratigraphic horizon as the contact
farther south.

The base of the cliff-forming [illegible] on Animas
River was followed on aerial photographs to the southwest in
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Arroyo. The contact between the Nacimiento and San Jose
formations in this vicinity is at about the same stratigraphic
horizon as on Animas River. In sec. 11, T. [illegible] N., R. 10 W.
the sandstone wedges out and the formations were not differ-
entiated to the north and west.

Thickness

A section of the [illegible] formation measured by [illegible]
side (1936, p. 58) [illegible] miles south of the State line

(Pruett pasture, T. 32 N., R. 12 W.) is 1,450 feet thick. This section probably contains beds which would more properly be placed in the Animas formation if exposures were better, and the thickness is thus considered somewhat excessive. The Nacimiento formation thins to the northeast by lateral transition of lower beds into beds of Animas lithology and by overstep of younger beds on older beds. Thickness is estimated to be about 350 feet immediately northeast of Round Mountain (Secs. 11, 14, and 22, T. 33 N., R. 10 W.). At all localities the Nacimiento formation thins toward ridges of the Hogback "monocline" and is cut out completely by overstep of the San José formation at the north end of Bridge Timber Mountain. In the northwestern part of the San Juan Basin the Nacimiento seems to have been deposited entirely within the boundaries of the Central Basin.

Age and correlation

The Nacimiento formation is considered to be lower and middle Paleocene in age. Fossils of middle Paleocene (Torrejon) age have been found in upper beds of the Nacimiento just south of the State line in Animas Valley (Reeside, 1924, p. 37). No fossils of lower Paleocene (Puerco) age have been found in the northwestern part of the Basin but this time interval is probably represented, as the lower beds of the Nacimiento grade laterally into beds of the Animas formation.

(Pruett pasture, T. 32 N., R. 10 W.) 1,450 feet thick. This section probably contains beds which would more properly be placed in the Animas formation if exposures were better, and the thickness is thus considered somewhat excessive. The Nacimiento formation thins to the northeast by lateral transition of lower beds into beds of Animas lithology and by overlap of younger beds on older beds. Thickness is estimated to be about 350 feet immediately northwest of Round Mountain (secs. 12, 13, and 24, T. 32 N., R. 10 W.). At all localities the [illegible] toward ridges of the [illegible] "smoothed" and is cut out completely by overlap of the San Jose formation at the north end of [illegible] Mountain. In the northwestern part of the San Juan Basin the Nacimiento seems to have been deposited entirely within the boundaries of the Central Basin.

Age and correlation

The Nacimiento formation is considered to be lower and middle Paleocene in age. Fossils of middle Paleocene (Torrejon) age have been found in upper beds of the Nacimiento just north of the [illegible] in [illegible] Valley (Reeside, 1924, p. 37). No fossils of lower Paleocene (Puerco) age have been found in the northwestern part of the basin but this time interval is probably represented, as the lower beds of the Nacimiento grade laterally into beds of the Animas formation.

Roland W. Brown (1943, p. 76) stated that the mammal-ring (upper) portions of the Denver formation and Dawson ose of the Denver Basin are of Puercan Paleocene age and rrelative with the lower part of the Fort Union sequence in the northern Great Plains. Brown (op. cit., p. 83) mentions the probability that the Raton formation of southern Colorado and New Mexico is both Cretaceous and Paleocene in age and parts of it are thus assumed by the present writer to be time equivalents of both Animas and Nacimiento formations of San Juan Basin. According to Wood and Johnson (1952) the Raton and overlying Poison Canyon formation of Paleocene and Eocene age intertongue in the Raton Mesa region. Thus probably all of Paleocene time is represented in rocks of the Raton region which contain age equivalents of all of the Nacimiento formation and the overlying Tiffany beds of the San José formation.

San José Formation

Type locality and distribution

Eocene fossils of the San Juan Basin were first discovered by E. D. Cope in the vicinity of Yegua (Lleguas) Canyon northeast of Gallina, New Mexico. He recognized the similarity of the fauna to that of the Wasatch beds of Wyoming and applied the name "Wahsatch" formation to the sequence of sandstone and variegated shale which form the

Roland W. Brown (1949, p. 76) stated that the mammal-bearing (upper) portions of the Denver formation and Dawson arkose of the Denver Basin are of Paleocene age and correlative with the lower part of the Fort Union sequence in the northern Great Plains. Brown (op. cit., p. 85) mentions the probability that the Raton formation of southern Colorado and New Mexico is both Cretaceous and Paleocene in age and parts of it are thus assumed by the present writer to be time equivalents of both Animas and Nacimiento formations of San Juan Basin. According to Wood and Johnson (1948) the Raton and overlying Poison Canyon formation of Paleocene and Eocene age intertongue in the Raton Mesa region. Thus probably all of Paleocene time is represented in rocks of the Raton region which contain age equivalents of all of the Nacimiento formation and the overlying Tiffany beds of the San Jose formation.

San Jose Formation

Type locality and distribution

Eocene fossils of the San Juan Basin were first discovered by E. D. Cope in the vicinity of Regina (Gallegos) Canyon northeast of Gallina, New Mexico. He recognized the similarity of the fauna to that of Wasatch beds of Wyoming and applied the name "Wasatch" formation to the sequence of sandstone and variegated shale which form the

youngest rocks of the San Juan Basin (Cope, 1875). This terminology (Wasatch formation) was generally accepted and perpetuated by later workers although several revisions of nomenclature were proposed.[1]

Recently, Simpson (1948, p. 280) proposed that the term "Wasatch" be discarded and the name San José formation be applied to these sediments, stating that they were deposited in an entirely different sedimentary basin from that of the type Wasatch in Wyoming and that the age spans, though overlapping, were not the same for the two formations (op. cit., p. 277). The type locality of the San José formation was designated as the badlands area in the upper drainage of San José Creek northwest of Regina, New Mexico.

In the type region the San José consists of three major lithologic facies which intergrade but are dissimilar in typical development. In the vicinity of Yegua Canyon most of the San José is composed of thick, heavy-bedded, conglomeratic sandstone and intercalated thin clay and silt beds. The heavy sandstone beds grade laterally into predominantly clay facies to the north and to the south. There are two distinguishable clay facies within the type region. These are the Almagre and Largo beds which contain the Almagre and Largo faunas described by Granger (1914). The

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[1]For a history of the terminology, see Simpson (1948, pp. 269-271, 273-276).

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In the type region the San Jose consists of three major lithologic facies which intergrade but are dissimilar in typical development. In the vicinity of Regina Canyon most of the San Jose is composed of thick, heavy-bedded, conglomeratic sandstone and interbedded thin clay and silt beds. The heavy sandstone beds grade laterally into predominantly clay facies to the north and to the south. There are two distinguishable clay facies within the type region. These are the Almagre and Largo beds which contain the Almagre and Largo faunas described by Granger (1914). The

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[1] For a history of the terminology, see Simpson (1948, pp. 266-271, 273-276).

Almagre facies occurs to the south of the Yegua Canyon facies and grades northward into it. The lower beds of the Largo facies grade into the upper Yegua Canyon sandstone beds and upper beds of the Largo form the stratigraphically highest part of the San José formation in the type region.

In the northern part of San Juan Basin in Colorado the lowest beds of the San José formation contain a late Paleocene fauna transitional in age between the Torrejon and Almagre faunas. Beds containing the fossils were described by Granger (1917, p. 829) as the "Tiffany beds", a predominantly clay facies overlain by heavy-bedded sandstone, but no specific upper or lower stratigraphic limits were given. According to Simpson (op. cit., p. 377) lateral equivalents of the Tiffany beds are not present at the type locality of the San José formation, having been overstepped by younger beds farther north. However, Dane (1946) indicated the possibility that they are present but unrecognized because of the lack of fossils in lower beds of the San José in the southern part of the Basin.

In general, the San José formation occupies an elliptically shaped area to the north and east of the middle of the Central Basin. This area extends from Cuba, New Mexico at the southeast to Bridge Timber Mountain at the northwest. In the area of this report, beds of the San José formation

Almagre facies occurs to the south of the Largo [illegible] facies and grades northward into it. The lower beds of the Largo facies grade into the upper [illegible] sandstone beds and upper beds of the Largo form the stratigraphically highest part of the San Jose Formation in the type region.

In the northern part of the San Juan Basin in Colorado the lowest beds of the San Jose Formation contain a late Paleocene fauna, [illegible] in age between the Torrejon and Almagre faunas. [illegible] fossils were described by Granger (1917, p. [illegible]) as the "Tiffany beds", a predominantly clay facies overlain by interbedded sandstone, but no specific upper or lower stratigraphic limits were given. According to Simpson (op. cit., p. 377) lateral equivalents of the Tiffany beds are not present at the type locality of the San Jose Formation, having been overlapped by younger beds farther north. However, [illegible] ([illegible]) indicated the possibility that they are present but unrecognized because of the lack of fossils in lower beds of the San Jose in the southern part of the basin.

In general, the San Jose Formation occupies an elliptically shaped area to the north and east of the middle of the Central Basin. This area extends from Cuba, New Mexico at the southeast to [illegible] Mountain at the northwest. In the area of [illegible], beds of the San Jose Formation

are exposed on Bridge Timber Mountain and as capping rocks of the high mesa land to the south.

Lithology

The San José formation is, in many respects, lithologically similar to the upper part of the underlying Nacimiento formation in the area of this report. There are three fairly well defined sedimentary facies exposed on east and west slopes of Bridge Timber Mountain.

Near the north end of Bridge Timber Mountain the lower one-half, approximately, of the San José formation is composed of variegated white, purple, green, and maroon shale; interbedded, friable, yellow, white, and brown, lenticular, cross-bedded sandstone; and a few beds of thin gray and white silicified tuff. The whole unit characteristically weathers to shaly slopes. Upper beds of the unit are composed mainly of maroon-colored shale which contains notable quantities of siliceous pebbles like those occurring in the McDermott member of the Animas formation.

In the southern part of the mapped area the lower two-thirds of the San José formation is composed of thick, heavy-bedded, cliff-forming sandstone and thinner beds of gray, red, and green shale and friable, lenticular sandstone. The heavy sandstone is grayish-yellow, fine-grained to granulitic, and contains quartz, jasper, and chert pebbles. Higher

are exposed on Bridge Timber Mountain and on nearby peaks of the high mesa land to the south.

Lithology

The San José Formation is, in many respects, lithologically similar to the upper part of the underlying Nacimiento formation in the area of this report. There are three fairly well defined sedimentary facies exposed along the west slopes of Bridge Timber Mountain.

Near the north end of Bridge Timber Mountain the lower one-half, approximately, of the San José Formation is composed of variegated white, purple, green, and maroon shale; interbedded, friable, yellow, white, and brown, lenticular, cross-bedded sandstones; and a few beds of thin gray and white silicified tuff. The whole group is massive and relatively weathers to shaly slopes. Upper beds of the unit are composed mainly of maroon-colored shale which contains small quantities of siliceous pebbles like those occurring in the McDermott member of the Animas formation.

In the southern part of the mapped area the lower two-thirds of the San José Formation is composed of thick, heavy-bedded, cliff-forming sandstone and few thin beds of gray, red, and green shale and friable, lenticular sandstone. The heavy sandstone is gray-to-yellow, fine-grained to granulitic, and contains quartz, jasper, and chert pebbles. Quartz

sandstone beds are somewhat finer-grained than lower beds. Bedding is medium to massive, cross-laminated, and cross-bedded.

Beds of the heavy sandstone facies lense out to the north into the lower shale facies in a manner similar to that of the underlying heavy sandstone facies of the Nacimiento formation. Successively higher sandstone beds persist farther to the north than the beds beneath them. Contact "a" is the base of a thick double-ledged sandstone which is stratigraphically the highest and most persistent bed of the heavy sandstone facies. Exposures on east and west sides of Bridge Timber Mountain show that the heavy sandstone beds beneath contact "a" lose their topographic expression north of the latitude of Round Mountain.

Above the heavy sandstone facies is a sequence of interbedded shale and soft sandstone beds which are the stratigraphically highest rocks of the San José formation in the area. At the north end of Bridge Timber Mountain this upper shale facies is about 400 feet thick, being preserved from erosion by the overlying Bridgetimber gravel. Farther south there are only thin erosional remnants of the upper shale facies along the top of Bridge Timber Mountain. Where exposed, beds of the upper shale facies are generally similar to those of the lower shale facies, except for a predominance of red- and purple-colored shale in the upper

sandstone beds are somewhat finer-grained than lower beds. Bedding is medium to massive, cross-laminated, and cross-bedded.

Each of the heavy sandstone facies tongue out to the north into the lower shale facies in a manner similar to that of the underlying heavy sandstone facies of the [illegible] Formation. Successively higher sandstone beds persist further to the north than the beds beneath them. Contact "a" is the base of a thick double-ledged sandstone which is stratigraphically the highest and most persistent bed of the heavy sandstone facies. Exposures on both [illegible] sides of [illegible] Ridge [illegible] show that the heavy sandstone beds beneath contact "a" lose their tongue-like [illegible] north of the latitude of [illegible].

Above the heavy sandstone facies is a sequence of interbedded shale and thin sandstone beds which are the stratigraphically highest rocks of the [illegible] Formation in the area. At the north end of [illegible] Ridge [illegible] Mountain this upper shale facies is about 300 feet thick, being preserved from erosion by the overlying [illegible] gravel. Further south there are only thin erosional remnants of the upper shale facies along the top of [illegible] Ridge [illegible]. Where exposed, beds of the upper shale facies are generally similar to those of the lower shale facies, except for a predominance of red- and purple-colored shale in the upper

facies.

Rocks of the San José formation in the vicinity of Bridge Timber Mountain are similar to those of the type section in the eastern part of the San Juan Basin. Beds of the heavy sandstone facies were traced southeastward on aerial photographs to the lower reaches of Canyon Largo east of the town of Blanco, New Mexico. Simpson (1948, p. 368) has observed heavy sandstone beds in the vicinity of Canyon Largo which he believes to be equivalent in part to sandstones of the Yegua Canyon facies. On the basis of these observations the present writer believes that the heavy sandstone facies exposed on Animas River in the Bridge Timber Mountain area correlates generally with the Yegua Canyon facies. The upper shale facies of the San José formation on Bridge Timber Mountain is probably correlative with part of the Largo facies of the type section. Some of the beds of the lower shale facies are undoubtedly equivalent to the Tiffany beds of Granger which are exposed in the Mesa Mountains and the H-D Hills to the east. South of Bridge Timber Mountain only the heavy sandstone beds of the San José formation are preserved and beds which would presumably be equivalent to the Almagre facies have been removed by erosion.

Three general depositional environments have been suggested by Simpson (op. cit., pp. 381-382) for the three

facies.

Rocks of the San Jose Formation in the vicinity of Bridge Timber Mountain are similar to those of the type section in the eastern part of the San Juan Basin. Some of the heavy sandstone ledges were traced southeastward on aerial photographs to the lower reaches of Canyon Largo east of the town of Blanco, New Mexico. Simpson (1948, p. 368) has observed heavy sandstone beds in the vicinity of Canyon Largo which he believes to be equivalent in part to sandstones of the Cuba Mesa Member. On the basis of these observations the present writer believes that the heavy sandstone facies exposed on [illegible] in the Bridge Timber Mountain area correlates generally with the Largo Canyon facies. The upper shale facies of the San Jose Formation on Bridge Timber Mountain is probably correlative with part of the Largo facies of the type section. Some of the beds of the lower shale facies are probably equivalent to the [illegible] beds of Granger which are exposed in the Nacimiento Mountains and the [illegible] to the east. South of Bridge Timber Mountain only the heavy sandstone beds of the San Jose Formation are preserved and beds which would presumably be equivalent to the Almagre facies have been removed by erosion.

These general depositional relationships have been suggested by Simpson (op. cit., pp. 361-369) [illegible]

facies of the San José formation. Beds of the Almagre facies, which are pale (gray or drab) may have accumulated in swampy lowlands whereas red beds of the Largo facies represent drier, less-wooded, savannah conditions. Lenticular channel sandstones of both facies were deposited in slow-moving streams. The faunal groups more common in the Almagre are mainly aquatic or swamp-dwelling types. <u>Meniscotherium</u>, which is characteristic of the Largo facies, is believed to have been a savannah-dweller. The heavy sandstones of the Yegua Canyon facies have yielded few fossils, but remains of turtles and scraps of the amblypod <u>Coryphodon</u> are said to indicate that the sandstones are stream deposits. The wide distribution of coarse conglomeratic material in the beds indicates large streams of considerable competency.

Rocks of the San José formation are obviously composed of at least second-cycle sediments eroded from the rising highlands around the San Juan Basin. Much of the red material may have been derived from Jurassic, Triassic, or Permian red beds exposed by stripping of overlying sediments from the highlands.

<u>Relation to adjacent formations</u>

The conformable and gradational contact of the San José formation with the underlying Nacimiento formation has been discussed on page 55. Near the north end of Bridge Timber

facies of the San Jose Formation. Much of the Almagre facies, which are pale gray or drab, may have accumulated in swampy lowlands whereas red beds of the Largo facies represent drier, better-drained, savannah conditions. Point-bar and channel sandstones of both facies were deposited in slow-moving streams. The faunal groups more common in the Almagre are mainly aquatic or swamp-dwelling types. Coryphodon, which is characteristic of the Largo facies, is believed to have been a swamp-dweller. The heavy sandstones of the Regina (Cuba Mesa?) have yielded few fossils, but remains of turtles and stems of the amblypod Coryphodon are said to indicate that the sandstones are stream deposits. The wide distribution of coarse conglomeratic material in the beds indicates large streams of considerable competency.

Rocks of the San Jose Formation are obviously composed of at least second-cycle sediments derived from the rising highlands around the San Juan Basin. Much of the red material may have been derived from Mesozoic, Triassic, or Permian red beds exposed by stripping of overlying sediments from the highlands.

<u>Relation to adjacent formations</u>

The conformable and gradational contact of the San Jose Formation with the underlying Nacimiento Formation has been discussed on page 8b. Near the north end of Gallina Arch

Mountain higher beds of the San José formation overstep lower, more steeply dipping beds of the same formation and underlying strata from the Nacimiento formation to the lower member of the Kirtland shale. The area of overstep is poorly exposed, but near the northeast foot of Bridge Timber Mountain, gently dipping sandstone and tuff beds of the lower shale facies may be seen resting on steeply dipping McDermott beds, and red shale may be seen overstepping the Farmington sandstone. At locality 3, to the southwest, a series of similarly overstepping beds is exposed in a large erosional scar. The Kirtland shale dips about 23 degrees and successively overstepping beds have dips that decrease upward so that tuff beds of the lower shale facies dip about 8 degrees and the "a" sandstone dips only about 4 degrees. This series of beds shows that folding along the Hogback "monocline" was taking place during deposition of most of the San José formation. Beds of the upper shale facies at one time must have completely overstepped the Hogback and extended for an unknown distance outside of the Central Basin.

The top of the San José formation appears to have been eroded everywhere. On the highest part of Bridge Timber Mountain the San José is overlain unconformably by the Bridgetimber gravel. Elsewhere in the area no younger beds are preserved except for thin deposits of Quaternary gravel and alluvium.

Honaker Ridge, beds of the [illegible] formation overstep [illegible] more steeply dipping beds of the [illegible] formation and underlying strata from the [illegible] formation to the lower member of the [illegible] shales. The area [illegible], however, is poorly exposed, but near the northeast foot of Bridge Timber Mountain, gently dipping sandstone and tuff beds of the lower shale facies may be seen resting on steeply dipping basement beds, and the latter may be seen overstepping the [illegible] sandstone. At [illegible] the southeast, a series of similarly overstepping beds [illegible] exposed in a large erosional scarp. [illegible] about 40 degrees and successively overstepping beds lying [illegible] at successive [illegible] tuff beds of the lower shale facies dip about 8 degrees and the "a" sandstone dips only about 4 degrees. This series of beds shows that folding along the [illegible] "anticline" was taking place during deposition of most of the [illegible] formation. Beds of the upper shale facies [illegible] have [illegible] overstepped the [illegible] and extended for an unknown distance out [illegible] of the Central Basin.

The top of the [illegible] formation appears to have been eroded everywhere. On the highest part of Bridge Timber Mountain the [illegible] is overlain unconformably by [illegible] Bridgetimber gravel. Elsewhere in the area no younger beds are preserved except for thin deposits of Quaternary gravel and alluvium.

Thickness

The San José formation is estimated to be about 1,100 feet thick near the head of Posta Canyon (Sec. 31 , S. T. 34 N., R. 11 W.). The lower 700 feet, approximately, is composed of beds of the lower shale facies (including the "a" sandstone), and the upper 400 feet is composed of beds of the upper shale facies. The heavy sandstone facies occupies the same stratigraphic interval as the lower shale facies and is estimated to be approximately 700 feet thick in Secs. 8, 9, and 10, T. 32 N., R. 10 W.

Age and correlation

The San José formation is considered to be of late Paleocene and early Eocene age. Beds of the lower shale facies in the area of this report are correlative with the Tiffany beds to the east which contain a fauna now considered to be late Paleocene in age (Simpson, 1948, p. 378). No fossils have been reported from strata above the Tiffany beds in the northern part of the San Juan Basin. However, the probable correlation of the heavy sandstone facies and upper shale facies with the Yegua Canyon and Largo facies, respectively, of the type area indicates that the beds are of early Eocene (Wasatchian) age.

The Tiffany fauna is slightly older than the Clark Fork fauna of Wyoming and the same age as the Silver Coulee of

Wyoming (op. cit., p. 383). Unfossiliferous beds above those containing the Tiffany fauna are probably of Clark Fork age as there is no perceptible evidence of unconformity between the Tiffany beds and overlying sediments. The Almagre fauna is similar to the Gray Bull fauna, and that of the Largo is similar to the Lysite of Wyoming (idem).

According to Wood and Johnson (1952) the Poison Canyon formation of southeastern Colorado was deposited through most of Paleocene time and some of the beds of this formation are probably equivalent in age to the Tiffany beds. The Cuchara formation of early and middle Wasatch (early Eocene) age is probably generally equivalent to the Almagre and Largo facies of the San José formation.

Bridgetimber Gravel

Type locality and distribution

The highest part of Bridge Timber Mountain is capped by a thick deposit of pebble, cobble, and boulder gravel named the Bridgetimber gravel by Atwood and Mather (1932, p. 89). This gravel was deposited on an erosion surface preserved at the top of Bridge Timber Mountain which is probably a remnant of the once widespread San Juan peneplain. Similar deposits occur at the top of the Mesa Mountains to the east of the mapped area, on the La Plata Mountains and neighboring uplands, and on Mesa Verde to the

Wyoming (Ibid., p. 135). [illegible] were [illegible] those containing the [illegible] fauna [illegible] of Black Fork are as there is no perceptible evidence of unconformity between the Tiffany beds and overlying sediments. The Almagre fauna is similar to the Gray Bull fauna, and that of the Largo is similar to the Lysite of Wyoming (Idem).

According to Wood and Johnson (1948) the [illegible] Canyon Formation of [illegible] Colorado was deposited through most of Paleocene time and none of the beds of this formation are probably equivalent in age to the Tiffany beds. The Cuchara Formation of early and middle Wasatch (early Eocene) age is probably generally equivalent to the Almagre and Largo faunas of the San Jose Formation.

Pleistocene(?) gravel

<u>Type locality and classification</u>

The highest part of [illegible] is capped by a thick deposit of cobble, pebble, and boulder gravel named the [illegible] gravel by Atwood and Mather (1932, p. 89). This gravel was deposited on an erosion surface preserved at the top of [illegible] Mountain which is probably a remnant of the once extensive San Juan peneplain. Similar deposits occur at the top of the [illegible] mountains to the [illegible] of the mapped area, on the [illegible] mountains and [illegible], and at some [illegible] to the

west, indicating a former widespread distribution of the formation.

Lithology

The Bridgetimber gravel is composed of very fine to coarse-grained sand, pebbles, cobbles, and boulders as large as 3 feet in diameter--all somewhat water-worn and only slightly consolidated. The coarser sediments are composed of sandstone, limestone, chert, and quartz fragments; schist and quartzite; granite, diorite, and rhyolite, and other volcanic rocks. Many of the cobbles and boulders are recognizable as being similar to sedimentary, metamorphic, and igneous rocks cropping out in the San Juan and La Plata Mountains which were undoubtedly the source of the sediments.

Thickness

Atwood and Mather (*op. cit.*, p. 90) have given the thickness of the Bridgetimber gravel as about 20 feet on Bridge Timber Mountain, but the writer estimates that the deposit is at least 100 feet thick.

Age and correlation

The age of the Bridgetimber gravel is uncertain as no fossils have been found. It is preglacial and may be as old as Pliocene (*op. cit.*, p. 92). According to Kelley and Silver (1952, p. 114, Fig. 14) the Bridgetimber is late

west, indicating a former widespread distribution of the formation.

Lithology

The Bridgetimber gravel is composed of very fine to coarse-grained sand, pebbles, cobbles, and boulders as large as 3 feet in diameter—all [illegible] and only slightly cemented. The [illegible] are composed of quartzite, limestone, [illegible], schist and quartzites, granite, diorite, and rhyolite, and other volcanic rocks. Some of the pebbles and boulders are recognizable as being similar to sedimentary, metamorphic, and igneous rocks occurring within and near the [illegible] Mountains which were [illegible] the source of the sediments.

Thickness

Atwood and Mather (op. cit., p. 96) have given the thickness of the Bridgetimber gravel as about 20 feet at Bridge Timber Mountain, but the writer estimates that the deposit is at least 100 feet thick.

Age and Correlation

The age of the Bridgetimber gravel is uncertain as no fossils have been found. It is preglacial and may be as old as Pliocene (op. cit., p. 96). According to [illegible] and Silver (195[illegible], p. [illegible], Fig. [illegible]), the Bridgetimber is [illegible]

Pliocene, correlative with part of the Santa Fe formation and Hinsdale volcanics in north-central New Mexico and the youngest part of the Ogallala formation in the Raton basin east of the Sangre de Cristo Mountains.

Quaternary Deposits

Quaternary gravel and alluvial deposits occur on three erosion surfaces at different elevations on both sides of Bridge Timber Mountain. The author did not attempt to differentiate the deposits except as high-level and low-level deposits. Recent alluvium in stream valleys has been shown on the map as "Qal" and all other higher-level gravel deposits as "Qg". Pleistocene deposits of the entire San Juan region (including the area of this report) have been discussed in considerable detail by Atwood and Mather (*op. cit.*, pp. 101-167).

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Quaternary Deposits

Quaternary gravel and alluvial deposits occur on many erosion surfaces at different elevations on both sides of Bridge Timber Mountain. The writer did not attempt to differentiate the deposits except as high-level and low-level deposits. Recent alluvium in stream valleys has been shown on the map as "Qal" and all other higher-level gravel deposits as "Qg". Pleistocene deposits of the entire San Juan region (including the area of this report) have been discussed in considerable detail by Atwood and Mather (*op. cit.*, pp. 101-157).

DEPOSITIONAL HISTORY OF THE BRIDGE TIMBER MOUNTAIN AREA

Late in Montana time Cretaceous seas retreated to the northeast across the northwestern part of the San Juan Basin. During this final retreat of the seas from the area, beach and off-shore sands of the Pictured Cliffs sandstone were deposited above the Lewis shale as a series of imbricated lenses, stratigraphically higher to the northeast. Coal, shale, and sandstone of the Fruitland formation and the lower part of the Kirtland shale were deposited in coastal swamps and on gently northeastward-dipping coastal plains left by the retreating sea. At least one minor reversal of the general retreat of the sea is represented by intertonguing of the Pictured Cliffs and Fruitland formations. Character of sediments and intertonguing relationships indicate that the source of sediments of the Pictured Cliffs, Fruitland, and lower Kirtland in the area of this report was to the southwest, presumably the Arizona highlands which supplied older Cretaceous sediments of the San Juan Basin.

The presence of feldspar, chloritic material, mica, and various heavy minerals in the fluviatile beds of the Farmington sandstone and upper shale member of the Kirtland formation indicates a new source of sediments for the region. Much of the sedimentary material of the Farmington

DESCRIPTIVE HISTORY OF THE [illegible]

[illegible] the [illegible] was [illegible] to the northeast [illegible] the [illegible] part of [illegible] During this final retreat of the sea from the area, beach and off-shore zones of the Pictured Cliffs sandstone were deposited upon the [illegible] and series of [illegible] lenses, stratigraphically superior [illegible] shale, and [illegible] of [illegible] lower part of the [illegible] were deposited in [illegible] swamps and [illegible] left by the retreating sea. [illegible] the general retreat of the [illegible] by intertonguing of the Pictured Cliffs and [illegible] formations. Character of sediments and [illegible] of [illegible] Fruitland, and lower [illegible] in the area of [illegible] was to [illegible] which supplied [illegible] sediments of the [illegible] Basin.

The presence of [illegible] and various heavy minerals in the [illegible] part of the Fruitland [illegible] and [illegible] Formation indicate a new source of sediments [illegible] sion. Most of the sedimentary material of the [illegible]

sandstone and the upper shale member is similar to that of older beds, and a probable interfingering of materials from at least two and possibly three sources is indicated.

It appears likely that the present structure of the northwestern San Juan Basin began to form as early as the time of deposition of the Farmington sandstone and upper member of the Kirtland shale. Zapp (1949) has noted the slight suggestion of southeastward thickening of the Kirtland shale along Florida River. Atwood and Mather (1932, pp. 15-16) have postulated that the San Juan dome to the north was being uplifted at this time. This uplift may have supplied sediments to the area of the present San Juan Basin and probably began to define the platform area north and west of the present Hogback "monocline". Wood, Kelley, and MacAlpin (1948) have mentioned the probability of intertonguing of the Animas formation with the Fruitland-Kirtland sequence in Archuleta County to the northeast, and the feldspathic and ferromagnesian materials in the Kirtland may represent the earliest spread of fine-grained weathered Animas detritus as far to the southwest as the Bridge Timber Mountain area.

As uplift and volcanism continued in the region to the north and northeast of the present San Juan Basin, weathered and sorted coarse sediments of the Animas formation spread to the south and west in latest Cretaceous (probably Laramie)

sandstone and the upper shale member is similar to that of older beds, and a probable intermingling of materials from at least two and possibly three sources is indicated.

It appears likely that the present structure of the northwestern San Juan Basin began to form as early as the time of deposition of the Farmington sandstone and upper member of the Kirtland shale. [illegible] has noted the slight suggestion of southeastward thickening of the Kirtland shale along the Animas River. Atwood and Mather (1932, p. 10-15) have postulated that the San Juan dome to the north was being uplifted at this time. This uplift may have supplied sediments to the area of the present San Juan basin and probably began to define the position area north and west of the present Hogback "monocline". Wood, Kelley, and MacAlpin (1948) have mentioned the possibility of intertonguing of the Animas formation with the Fruitland-Kirtland sequence in Archuleta County to the northeast, and the feldspathic and ferromagnesian materials in the Kirtland may represent the earliest spread of fine-grained weathered Animas detritus as far to the southwest as the Bridge Timber Mountain area.

As uplift and volcanism continued in the region to the north and northeast of the present San Juan Basin, weathered and eroded coarse sediments of the Animas formation were carried to the south and west in latest Cretaceous (probably Lancian)

time as fans and pediment gravels. The first of these coarse sediments to reach the area of this report is represented by the lenticular, coarse-grained, pebble-bearing sandstone at the top of the Kirtland shale. This "siliceous pebble zone" (of the McDermott formation of Reeside and Zapp) was traced eastward from Animas River by Zapp (1949) into the base of the Animas formation on the Florida-Los Piños drainage divide.

As the coarse sandstone was being deposited, local volcanism occurred and pyroclastic and water-borne andesitic material of the McDermott member of the Animas formation was deposited. The volcano (or volcanoes) furnishing this material must have been fairly near the present area of outcrop of the McDermott member as indicated by the large angular boulders and coarse breccia exposed near Animas River. Coarseness, angularity, and relative freshness of the material, as well as torrential bedding indicate a rapid rate of accumulation of McDermott sediments. The direction of thickening and coarsening of the McDermott member strongly suggests that the volcano (volcanoes) furnishing the sediments was to the north or northwest of Durango, quite possibly in the vicinity of the La Plata Mountains. The laccolithic intrusions which domed the La Platas can be dated only as late Cretaceous or Tertiary (Eckel, et al., 1949, p. 42), but the magma which formed

time as lavas and pyroclastic material. The first of these coarse sediments to reach the area of this report is represented by the lenticular, coarse-grained, pebble-bearing sandstone at the top of the Kirtland shale. This "siliceous pebble zone" (of the McDermott formation of Reeside and Baker) was traced westward from Animas River by Dane (1946) into the base of the Animas formation on the Florida-Los Pinos drainage divide.

As the coarse sandstone was being deposited, local volcanism occurred and pyroclastic and water-borne andesitic material of the McDermott member of the Animas formation was deposited. The volcano (or volcanoes) furnishing this material must have been fairly near the present area of outcrop of the McDermott member as indicated by the large angular boulders and cobbles of andesite exposed near Animas River. Coarseness, angularity, and relatively fresh state of the material, as well as torrential bedding indicate a rapid rate of accumulation of volcanic sediments. The direction of thickening and coarsening of the McDermott member strongly suggests that the volcano (volcanoes) furnishing the sediments was to the north or northwest of Durango, quite possibly in the vicinity of the La Plata Mountains. The laccolithic intrusion which domed the La Platas can be dated only as late Cretaceous or Tertiary (Cross, et al., 1899, p. [illegible]), but the magma which formed

the monzonite-diorite intrusive rocks could have been the source of "andesitic" volcanic rocks. As beds of the McDermott member were laid down by streams flowing into the area from the north or northwest they interfingered along their eastern and southeastern margins with coarse volcanic fragments and eroded sedimentary material of the upper member of the Animas formation, probably temporarily restricting the southwestward spread of this material in the northwestern part of the San Juan Basin. Well-indurated resistant tuff and interbedded conglomerate beds which characterize the McDermott member on Animas River are not found south of McDermott Arroyo in the southwestern part of the mapped area. The rapid thinning of the McDermott south of locality 5 is interpreted as being the result of both depositional thinning to the south and post-depositional weathering and erosion, with subsequent deposition of decomposed McDermott material as red and purple clay for many miles to the south in New Mexico. In a sense, these clays might well be considered part of the Kirtland shale as originally described by Bauer (1916, p. 275).

After deposition of the McDermott member, conglomeratic beds of the upper member of the Animas formation containing much andesitic debris were deposited across the area. During transport of these sediments considerable weathering and sorting occurred and the conglomeratic beds of the upper

the monzonite-diorite intrusive epoch could have been the source of "andesitic" volcanic rocks. As none of the McDermott member were laid down as streams flowing into the area from the north or northwest they interfingered along their eastern and southwestern margin with coarse volcanic fragments and eroded sedimentary material of the upper member of the Animas formation, probably temporarily restricting the southwestward spread of this material in the northwestern part of the area [illegible] and interbedded conglomerate of the pyroclastics of the McDermott member of Animas River are not found south of McDermott outcrops in the southwestern part of the mapped area. The rapid thinning of the McDermott member of locality 3 is interpreted as being the result of both depositional thinning to the south and post-depositional weathering and erosion, with subsequent deposition of decomposed McDermott material as red and purple clay for many miles to the south in New Mexico. In a sense, these upper units will be considered part of the Kirtland shale as originally described by Bauer (1916, p. 275).

After deposition of the McDermott member, conglomeratic beds of the upper member of the Animas formation containing much andesitic debris were deposited across the area. Brief transport of these sediments permitted little weathering and sorting occurred and the conglomeratic beds of the upper

member are thinner and contain more pure quartz sandstone and gray shale and fewer highly weathered andesite pebbles in the southwestern part of the area. Sediments of the upper member of the Kirtland shale and the Animas formation near McDermott Arroyo are very similar in lithology to the Ojo Alamo sandstone, and the writer is of the opinion that the Ojo Alamo in New Mexico is probably a highly weathered and sorted facies of the Animas formation.

In the area of this report, the earliest folding of the Hogback "monocline" for which there is direct evidence occurred after deposition of the conglomeratic phase of the upper member of the Animas formation. As the structural platform outside the Hogback was uplifted, conglomeratic sediments of the upper member of the Animas were eroded from the platform area and redeposited within the Basin as finer-grained, sandy, shaly beds of the upper member of the Animas formation and their lateral equivalents--the somber shale and soft sandstone of the Nacimiento formation. Progressive folding, erosion, and basin filling caused the finer-grained Animas and later Nacimiento sediments to overstep tilted beds of conglomerate near the Hogback. Meanwhile, deposition was continuous within the Basin. During deposition of the somber shale of the Nacimiento formation in early and middle Paleocene time, considerable quantities of coarse detritus were carried from the east

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In the area of this report, the earliest folding of the Hogback "monocline" for which there is direct evidence occurred after deposition of the conglomeratic beds of the upper member of the Animas formation. As the structural platform outside the basin was uplifted, coarse [illegible] sediments of the upper member of the Animas were eroded from the platform area and redeposited within the basin as finer-grained, sandy, shaly beds of the upper member of the Animas formation and their lateral equivalents—the [illegible] shale and part of the [illegible] formation. Progressive folding, erosion, and basin filling caused the finer-grained Animas and later Paleocene sediments to overlap tilted beds of conglomerate near the hogback. Meanwhile, deposition was continuous within the basin. During deposition of the lower [illegible] of the Nacimiento formation in early and middle Paleocene time, considerable quantities of [illegible] were carried from the east

or northeast by large streams into the depositional center of the Central Basin to the south of the Bridge Timber Mountain area in New Mexico. The coarse, conglomeratic sand, later indurated to form the heavy sandstone facies of the Nacimiento formation, intertongued with sediments being carried into the Basin from the surrounding platforms. As basinal filling progressed, beds of the heavy sandstone facies were deposited over wider areas and progressively overlapped (not overstepped) older beds toward the Hogback.

Late in the depositional history of the Nacimiento formation (late middle Paleocene), beds of the McDermott member of the Animas formation on the platform area were uncovered by erosion which was probably the result of more vigorous orogenic activity in the surrounding region. The deposition of considerable quantities of purple and red shale and soft sandstone in the Basin marks the transition from the Nacimiento formation to the lower shale facies (Tiffany beds) of the San José formation. Deposition of the heavy sandstone facies was continuous from middle Paleocene through early Eocene time. Most of the soft sandstone of the shale facies of the Nacimiento and San José formations contains sediments identical with those of Fruitland, Pictured Cliffs, Lewis, and Mesaverde rocks and was probably derived from those formations which were exposed on the San Juan dome to the north and northeast. Streams

or deposited by large streams into the depositional basin of the Central Basin to the south of the present Nacimiento mountain area in New Mexico. These coarse, conglomeratic sands, later indurated to form the heavy sandstone ledges of the Nacimiento formation, interfingered with sediments being carried into the basin from the surrounding platforms. As basinal filling progressed, tongues of the heavy sandstone facies were deposited over wider areas and progressively overlapped (not overstepped) older beds toward the platform.

Late in the depositional history of the Nacimiento formation (late middle Paleocene), beds of the uppermost member of the Animas formation on the platform area were uncovered by erosion which was probably the result of more vigorous orogenic activity in the surrounding region. The deposition of considerable quantities of purple and red [illegible] and soft sandstone in the Chaco marks the transition from the Nacimiento formation to the lower Wasatch Regina (Tiffany beds) of the San Jose formation. Deposition of the heavy sandstone facies was continuous from middle Paleocene through early Eocene time. Many of the soft sandstone of the upper part of the Nacimiento and San Jose formations contains [illegible] identical with those of Fruitland, Pictured Cliffs, Lewis, and Mesaverde rocks and was probably derived from those formations which were exposed on the San Juan dome to the north and northeast. [illegible]

flowing southward from the dome transported these finer sediments and also eroded and moved Animas material from the platform area into the Central Basin, thus causing the mingled types of sediments in the shaly facies of the Nacimiento and San José formations. The thin acidic tuffs of the San José formation give evidence of volcanic activity in the region during early Eocene time.

Folding of the Hogback "monocline" in the northwestern San Juan Basin was probably essentially completed at the end of deposition of the lower shaly facies (Tiffany beds) of the San José formation (late Paleocene or early Eocene). The "a" sandstone which oversteps all older beds down to the lower member of the Kirtland shale on the north end of Bridge Timber Mountain is overlain conformably by beds of the upper shale (Largo) facies. The "a" sandstone and the upper shale facies have southeastward dips of 3 to 5 degrees at the north end of Bridge Timber Mountain but tilting of these beds probably occurred later than early Eocene time.

The upper part of the San José formation undoubtedly was deposited on the surrounding structural platform beyond the Hogback "monocline", but the original areal extent of these sediments is unknown. The Blanco Basin formation of Cross and Larsen (1935, pp. 48-50) which crops out on the southern slopes of the San Juan Mountains northeast of Pagosa Springs shows many lithologic similarities to the

flowing northward from the [illegible] transported these finer sediments and also eroded and moved andesitic material from the platform area into the central basin, thus accounting for the mingled types of sediments in the early facies of the [illegible] [illegible] and San Jose formations. The [illegible] of the San Jose Formation give evidence of volcanic activity in the region during early Eocene time.

Folding of the [illegible] "geosyncline" in the southwestern San [illegible] [illegible] probably completed at the end of deposition of the [illegible] facies (filling beds) of the San Jose Formation (late Paleocene or early Eocene). The "a" sandstone which overlaps all older beds down to the lower member of the [illegible] shale in the north end of Bridge [illegible] Mountain is overlain conformably by beds of the upper shale (Lange) facies. The "a" sandstone and the upper shale facies have southeastward dips of [illegible] degrees at the north end of Bridge [illegible] Mountain but tilting of these beds probably occurred later than early Eocene time.

The upper part of the San Jose Formation apparently was deposited on the surrounding structural platforms beyond the borders of the "geosyncline", but the original areal extent of these sediments is unknown. The [illegible] [illegible] [illegible] of Cronk and [illegible] (1937, pp. 45-50) which crops out on the southern slopes of the [illegible] Mountains northwest of [illegible] [illegible] [illegible] [illegible] to the

coarser-grained beds of the San José formation. Cross and Larsen (<u>op</u>. <u>cit</u>., p. 50) tentatively classified the Blanco Basin as Oligocene in age but admitted that it may be as old as Eocene. The Blanco Basin overlies the Mancos shale with angular unconformity as would be expected if it were correlative with the upper beds of the San José formation which at one time presumably overlapped successively older beds to the north. Thus it is possible that the Blanco Basin formation is correlative with the upper part of the San José formation or slightly younger rocks belonging to the same sedimentary cycle which have been eroded from the San Juan Basin. The conglomeratic beds of the Blanco Basin formation may represent a coarse facies of the San José formation or younger rocks deposited nearer the source areas of earlier San José sediments.

History of the Bridge Timber Mountain area is unknown from early Eocene time to late Pliocene time as rocks representing this time interval were either not deposited in the San Juan Basin or, more probably, were deposited and later eroded. It is probable that middle Tertiary volcanic activity in the San Juan Mountains caused large quantities of volcanic material to be deposited in the area. According to Atwood and Mather (<u>op</u>. <u>cit</u>., p. 25) the entire San Juan region was uplifted and peneplained in late Pliocene time with subsequent removal of rocks younger than the San José

coarser-grained beds of the San Jose formation. Cross and Larsen (op. cit., p. 29) tentatively classified the Blanco Basin as Oligocene in age but mentioned that it may be as old as Eocene. The Blanco Basin rests over [illegible] the older rocks with angular unconformity as would be expected if it were correlative with the upper beds of the San Jose formation which at the time were being folded and successively older beds to the north. Thus it is possible that the Blanco Basin formation is correlative with the upper part of the San Jose formation or slightly younger rocks belonging to the same sedimentary cycle which have been eroded from the San Juan Basin. The conglomeratic beds of the Blanco Basin formation may represent a coarse facies of the San Jose formation or younger rocks deposited nearer the source areas of the older San Jose sediments.

History of the Bridge Timber Mountain area is unknown from early Eocene time to late Pliocene time as rocks representing this time interval were either not deposited in the San Juan Basin or, more probably, were deposited and later eroded. It is probable that middle Tertiary volcanic activity in the San Juan Mountains caused large quantities of volcanic material to be deposited in the area. According to Atwood and Mather (op. cit., p. 28) the entire San Juan region was uplifted and peneplaned in late Pliocene time with subsequent [illegible] uplift [illegible] the [illegible]

formation. The Bridgetimber gravel of late Pliocene or earliest Pleistocene age was deposited upon the San Juan peneplain as the result of renewed uplift and erosion in the San Juan Mountains. The history of Quaternary uplift and erosion has been described by Atwood and Mather (1932) and will not be discussed in this paper.

Stratigraphic relationships of sedimentary rocks of the Bridge Timber Mountain area are shown in Figure 6 (in pocket).

formation. The Bridge Timber gravel of late Pliocene or earliest Pleistocene age was deposited upon the then peneplain as the result of renewed uplift and erosion in the San Juan Mountains. The history of intermittent uplift and erosion has been described by Atwood and Mather (1932) and will not be discussed in this paper.

Stratigraphic relationships of sedimentary rocks of the Bridge Timber Mountain area are shown in Figure [illegible] (in pocket).

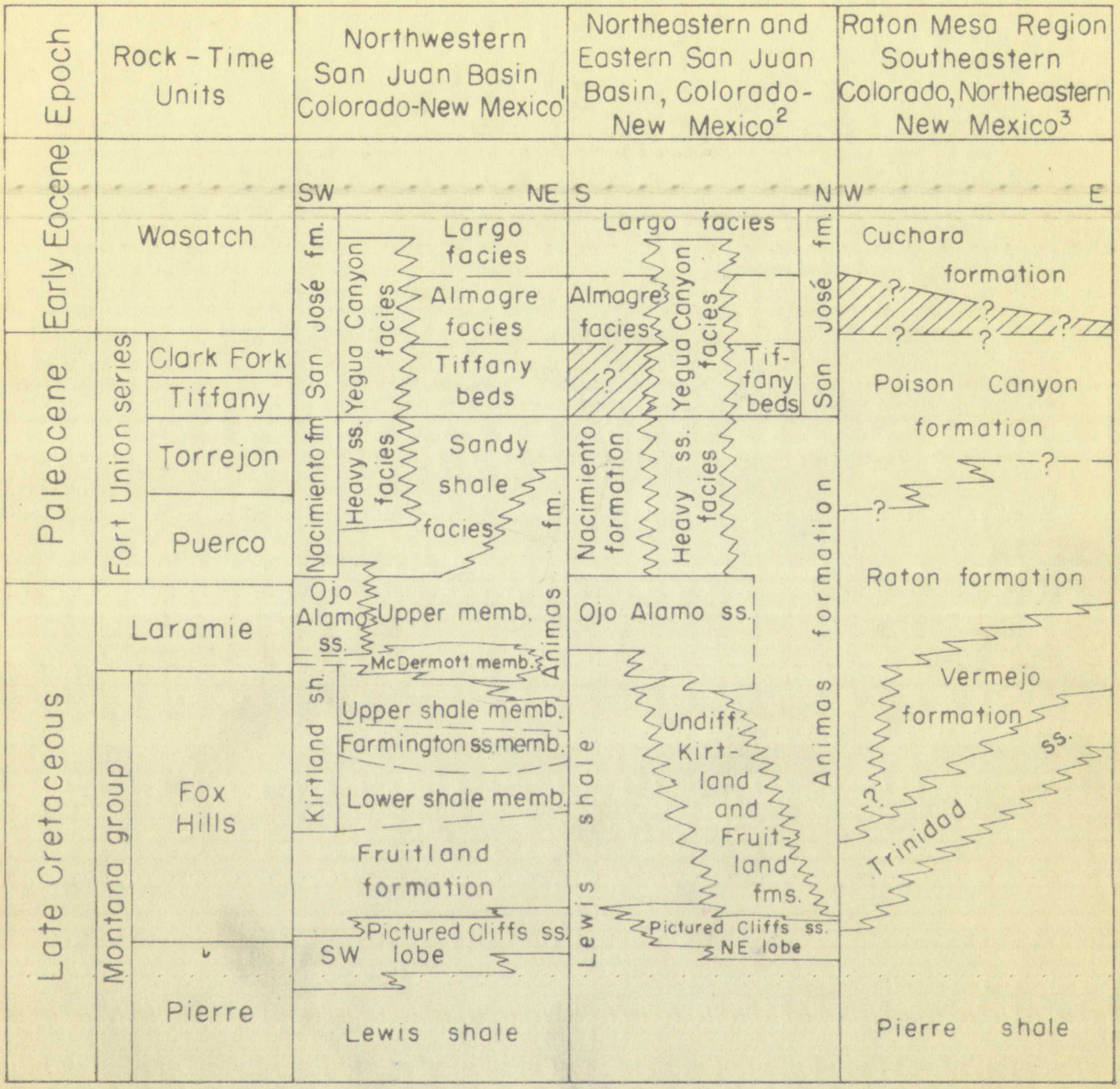

Table 2. Nomenclature and correlation of latest Cretaceous and early Tertiary rocks of parts of the San Juan Basin.

[1] This paper.
[2] After Simpson (1948), and slightly modified from Dane (1946).
[3] After Wood and Johnson (1952).

LATE CRETACEOUS AND TERTIARY DEPOSITIONAL HISTORY OF THE SAN JUAN BASIN

Stratigraphic relationships of Upper Cretaceous and lower Tertiary rocks in the northwestern part of the San Juan Basin compare closely with relationships of similar rocks in other parts of the Basin as reported in various recent publications. It appears that sufficient detailed information is available to interpret a general history of the late Cretaceous and Tertiary stages of development of the present San Juan Basin.

The structural development of the San Juan Basin as shown by the deposition of sediments within the Basin began as early as Pennsylvanian and Permian time. At that time, the Zuni, Defiance, San Juan (Uncompahgre) and Nacimiento positive areas which form the present boundaries roughly outlined a shallow depositional basin similar in outline to the present San Juan Basin but probably of much larger areal extent (see Read and Wood, 1947, especially Fig. 2, p. 226). During Triassic and Jurassic time the region of the San Juan Basin was part of a larger area which received sediments from the Uncompahgre highland to the northeast and the Navajo highland to the southwest of the present Basin. There is some evidence of recurrent uplift on the Zuni and Defiance positive areas during this time (Kelley, 1951, p. 129), but it is doubtful whether the San Juan

[illegible]

Stratigraphic relationships of Upper Cretaceous and lower Tertiary rocks in the [illegible] part of the San Juan Basin compare closely with relationships of similar rocks in other parts of the Basin as reported in various recent publications. [illegible] information is available to [illegible] of the late Cretaceous and [illegible] of the present [illegible].

The structural development of the San Juan Basin as shown by the position of sediments within the basin began as early as [illegible] time. At that time, the Zuni, Defiance, [illegible] positive areas [illegible] the general [illegible] position of a shallow [illegible] basin, similar in outline to the present San Juan Basin but probably of much larger areal extent (see [illegible], 1955; especially fig. 2, p. 220). The [illegible] that [illegible] the San Juan Basin was part of a larger zone which received sediments from the [illegible] to the [illegible] and the [illegible] the [illegible] west of the present Basin. There is [illegible] on the Zuni and Defiance [illegible] (Kelley, 1951, p. [illegible]), but it is [illegible]

Basin as a structural unit was also a distinct depositional basin during most of Mesozoic time.

During early Upper Cretaceous time epeirogenic seas transgressed across the region from the northeast. The area of the San Juan Basin was generally depressed and received sediments from mountainous regions to the southwest and west. The history of transgression and regression of the Cretaceous seas across the area of the San Juan Basin is well known.[1] Silver (1951, p. 110) has shown the northeastward thinning of the thick marine shale sequence (Mancos and Lewis) which separates the early marine transgressive Dakota sandstone from the latest marine regressive Pictured Cliffs sandstone (Fig. 4, p. 21 of this paper). This convergence indicates that uplift occurred to the northeast during the latest phases of marine sedimentation in the San Juan Basin. Silver (1950, p. 112) has described two "lobes" of the Pictured Cliffs sandstone--an older southwestern lobe, and a younger northeastern lobe which overlaps the southwestern lobe in the Durango area. These lobes correspond with the two phases of the Pictured Cliffs described by Dane (1946) which grade from both north and south into the Lewis shale on the eastern side of the Basin. Dane, however, considered the

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[1]For more complete discussions of Triassic and Jurassic and Cretaceous stratigraphy and structural evolution, <u>see</u> New Mexico Geol. Soc. Guidebooks of the San Juan Basin for 1950 and 1951. Also, <u>see</u> pp. 18-20 of this report.

basin as a structural unit was less distinct or significant basin during most of Mesozoic time.

During early Upper Cretaceous time spreading of seas transgressed across the region from the northeast. The area of the San Juan Basin was generally depressed and received sediments from uplifted regions to the southwest and west. The history of transgression and regression of the Cretaceous seas across the area of the San Juan Basin is well known.[1] Silver (1951, p. 110) has shown the most landward tonguing of the thick marine Mancos shale (Mancos and Lewis) which separates the early marine transgressive Dakota sandstone from the latest marine regressive Pictured Cliffs sandstone (Fig. 4, p. 24 of this report). This convergence indicated that uplift occurred to the southwest during the latest phase of marine sedimentation in the San Juan Basin. Silver (1950, p. 110) has described the "Pictured Cliffs" of the Pictured Cliffs sandstone as northeastward trending, the northeastern lobe which entered the northeastern lobe in the Durango area. These later correspond with the two phases of the Pictured Cliffs described by Dane (1948) which grade from both north and south into the Lewis shale on the eastern side of the basin. Dane, however, considered the

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[1]The more complete discussions of Cretaceous and Tertiary and literature is summarized in structural relations, in New Mexico Geol. Soc. Guidebook of the San Juan Basin, 1950 and 1951, and the ... of this report.

northeastern lobe to be the older one.

During recent stratigraphic studies in the Raton Mesa region of Colorado and New Mexico, Wood and Johnson (1952) have found that epeirogenic uplift in the Sangre de Cristo Mountains began in late Montana time and was reflected in marine sediments of the Pierre shale and Trinidad sandstone, and the nonmarine Vermejo formation. According to Burbank and Goddard (1937, p. 933) the area of the present-day San Luis Valley was a part of this original crustal fold of the Sangre de Cristo Mountains and the bordering domal uplift of the San Juan Mountains. As the early San Juan-Sangre de Cristo folds were uplifted they must have slowly risen above the Cretaceous seas and formed the northeast flank of a large sedimentary basin. The sea in this basin was restricted to the southwest, northwest, north, and northeast by rising landmasses but probably connected to the southeast around the edge of the rising Rocky Mountains with the retreating Cretaceous sea of the Midcontinent. The Chama embayment of the present San Juan Basin was undoubtedly a part of this basin as was the area of the present Jemez-Nacimiento uplift. It is probable that the area of the present Galisteo Basin to the southeast was also part of the depositional basin. The northwest-trending axis of the basin was probably parallel to the present structural axis of the San Juan Basin but farther to the

northeast. A paleogeographic map of the early stage of development of the late Montana basin is shown in Figure 5, page 84.

The southwestern lobe of the Pictured Cliffs sandstone, the Fruitland formation, and the lower part of the Kirtland shale were derived from source areas to the southwest, possibly in part from the flanks of the Zuni and Defiance uplifts which may have been rising at this time (Kelley, 1951, p. 129). The northeast lobe of the Pictured Cliffs and the Fruitland formation on the north and northeast sides of the San Juan Basin were composed of sediments eroded from the flanks of the rising San Juan-Sangre de Cristo upwarps. These sediments were spread to the south and southwest into the semi-isolated arm of the sea, forcing it to retreat to the southeast.

Near the end of Cretaceous time accelerated orogenic activity and attendant volcanism in the mountains to the north and northeast caused large amounts of detritus to be poured into the earlier-formed basin. Thrusting in the Sangre de Cristo Mountains probably began in the vicinity of the present San Luis Valley near the end of Montana time. Burbank and Goddard (1927, p. 971) picture the early stages of deformation as having been produced by sheets of granite thrust out to the east from the Sierra Blanca massif and overriding, crumpling, and imbricating the

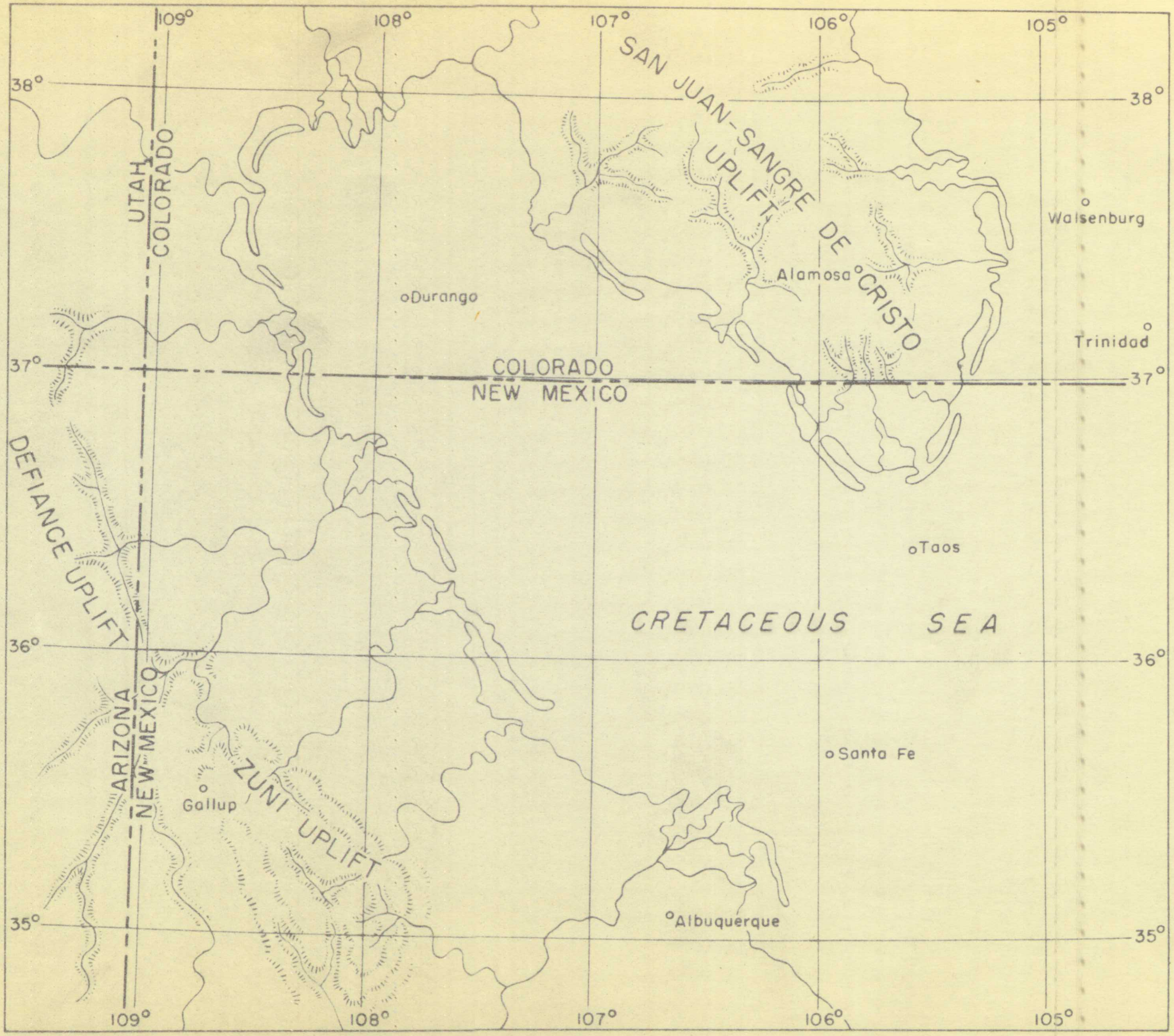

Figure 5. Paleogeographic map of parts of northern New Mexico and southern Colorado in late Montana (Pictured Cliffs-early Trinidad) time.

sedimentary blanket in front of them. Erosion of these sheets of basement rock probably accounts for the sudden appearance of Precambrian detritus in lower beds of the Animas formation and the Ratón formation. Recurrent episodes of thrusting in the Southern Rocky Mountains must have supplied sediments of the coarse-grained facies of the Nacimiento and San José formations in the San Juan Basin.

The oldest sediments of the Animas formation were probably deposited in a marine environment as they appear to intertongue with the Lewis shale on the east side of San Juan Basin and contain casts of the marine fossil Halymenites (Dane, 1946). As beds of the Animas formation were spread to the southwest they forced the withdrawal of the seaway to the southeast. Animas sediments intertongued in the north with Fruitland and Kirtland sediments which were still being supplied from the west and southwest and probably the north.

The thickest development of the Farmington sandstone member of the Kirtland shale is in the area between San Juan River and the New Mexico-Colorado state line (Reeside, 1924, p. 22). From this area the member thins to the south by lateral gradation of lower beds into upper beds of the lower shale member of the Kirtland formation (idem). The Farmington wedges out south of Ojo Alamo and is not present along

sedimentary [illegible] [illegible] by [illegible]. [illegible] of these miofossils of [illegible] [illegible] [illegible] [illegible] the [illegible] [illegible] of [illegible] deposition beginning in upper part of the [illegible] formation and the [illegible] [illegible] [illegible] a [illegible] of [illegible] in the [illegible] [illegible] must have supplied sediments to the coarse-grained facies of the [illegible] and [illegible] formations in the [illegible] basin.

The [illegible] sediments of the [illegible] formation were probably deposited in a [illegible] environment as they appear to interfinger with the [illegible] [illegible] on the east side of [illegible] Basin, and [illegible] [illegible] of the [illegible] *[illegible]* ([illegible], [illegible]). As beds of the [illegible] formation were spread to the southwest [illegible] toward the [illegible] of the [illegible] in the southwest, [illegible] [illegible] [illegible] in the north [illegible] [illegible] and [illegible] sediments were still being supplied [illegible] [illegible] and southwest [illegible] [illegible] the north.

The [illegible] [illegible] of the [illegible] [illegible] member of [illegible] [illegible] is [illegible] [illegible] between [illegible] River and the [illegible] [illegible] ([illegible], [illegible], p. [illegible]). From this area the [illegible] [illegible] in the [illegible] [illegible] lateral gradation of [illegible] beds into upper beds of the lower [illegible] member of the [illegible] formation (*[illegible]*). The [illegible] [illegible] and [illegible] the [illegible] and is not [illegible] along

the southern and eastern margins of the Central Basin. On the northern rim of the Basin, the Farmington sandstone appears to interfinger with Animas-type sediments and wedges out to the east in the vicinity of Yellowjacket Creek in western Archuleta County (G. H. Wood, personal communication). These relationships and the observed differences in lithology between the Farmington sandstone and underlying rocks indicate that Farmington sediments were derived from the San Juan uplift and spread to the south into a shallow basin forming near the center of the present San Juan Basin. As Farmington sediments were deposited they mingled with sediments similar to those of the lower Kirtland derived from the west and south.

During and following deposition of the Farmington sandstone, weathered and sorted detritus of the Animas formation was spread across much of the area of the Central Basin and deposited as beds of the upper member of the Kirtland shale in the northwestern part of the Basin and as the Animas formation in the eastern and southeastern part of the Basin. This material probably interfingered with lesser amounts of finer sand and shale still being supplied from the southwest. The wide areal distribution of sediments from the north and northeast at this time probably represents filling of the Animas basin and uplift on the northeastern flank of the basin and neighboring highlands.

the southern and western margins of the [illegible] basin. On the northern rim of the basin, the [illegible] sandstone appears to intertongue with [illegible]-type sediments and to [illegible] out to the east in the vicinity of [illegible] Creek in western [illegible] County (G. H. [illegible], personal communication). These relationships and the abrupt differences in lithology between the [illegible] and the underlying rocks indicate that [illegible] sand were derived from the [illegible] uplift and spread to the south [illegible] basin, forming near the center of [illegible]. In [illegible]-ton sediments were deposited they mingled with sediments similar to those of the lower [illegible] derived from the east and south.

During the following deposition of the [illegible] sandstones, westward and upward [illegible] of the [illegible] Formation was spread across much of [illegible] of the [illegible] deposited in both of the upper member of the [illegible] in the northeastern part of the basin and of the [illegible] Formation in the western and southwestern part of the basin. This material probably intertongues with [illegible] amounts of fine-grained and [illegible] being supplied from the southwest. The wide areal distribution of sediments from the north and northeast [illegible] provenance [illegible] of the [illegible] basin and [illegible] the sediments to which of the basin [illegible].

Late in Cretaceous (probably Laramie) time, local volcanic activity in the San Juan uplift resulted in deposition of the McDermott member of the Animas formation in the northwestern part of the San Juan Basin. As this material was deposited it interfingered with Animas detritus being supplied from the northeast and temporarily restricted the deposition of this material in the northwestern part of the Basin. During this period there was weathering and erosion of McDermott beds to the west and the resulting fine volcanic material and clay was deposited to the south over about the same area as that of the Farmington sandstone. At the time of McDermott volcanism, weathered and sorted Animas material was spreading far to the southwest of the source areas and was deposited as beds of the Ojo Alamo sandstone. Ojo Alamo sediments probably interfingered with material being supplied from the southern (Zuni) and western (Defiance) highlands. Dane (1936, p. 119) has described the interbedding of Kirtland and Ojo Alamo rocks on the south side of the Central Basin and the probable northward gradation of the Ojo Alamo into beds of Animas lithology on the eastern side of the Basin (Dane, 1946). The southwestward gradation of Animas beds into beds lithologically similar to those of the Ojo Alamo in the northwestern part of the San Juan Basin has been described in the present paper. Dane (1936, p. 121) has

Late Cretaceous (probably [illegible]) time. Local volcanic activity in the [illegible] area resulted in deposition of the volcanic member of the [illegible] Formation in the northeastern part of the [illegible] area. The [illegible] material was deposited in interfingered with [illegible] detritus being supplied from the mainland, and temporarily restricted the deposition of this material in the northwestern part of the basin. During this period there was weathering and erosion of volcanic beds to [illegible] the result in [illegible] volcanic material [illegible] to the north over about the same time as that of the [illegible] [illegible]. [illegible] the time of [illegible] volcanism, weathered and [illegible] other materials were [illegible] the southwest of the [illegible] area [illegible] deposition in beds of the [illegible] sequence. [illegible] sediments probably interfingered with material being supplied from the southern (east) and western (inferred) highlands. [illegible] has mentioned the intermediating of [illegible] rocks on the north side of the [illegible] and the [illegible] [illegible] of the [illegible] late beds at [illegible] the western side of [illegible] ([illegible]). The [illegible] formation of [illegible] beds [illegible] similar to those of the [illegible] in the [illegible] [illegible] described in the [illegible] ([illegible]) and

attributed the southwestward thinning of the McDermott in New Mexico to depositional thinning rather than erosional truncation as described by Reeside (1924, p. 26). This view is consistent with observations by the present writer in the Bridge Timber Mountain area.

At this point it is appropriate to note that the interpretations of stratigraphic relationships of Cretaceous rocks of the San Juan Basin as presented by Silver (1950, p. 112; 1951, p. 116) are not in agreement with the views expressed in this paper. The Kirtland basin of Silver (1950, p. 119) is said to have developed following deposition of the Pictured Cliffs sandstone and Fruitland formation. The axis of this basin was somewhere to the west of the present area of outcrop of the Kirtland formation and the eastward thinning of the Kirtland is said to be due to depositional thinning upon the east flank of the Kirtland basin. According to Silver (1950, p. 112; 1951, p. 116), the Animas formation overlies the Kirtland formation disconformably due to post-Kirtland erosion, but this disconformity is obscured by reworking of Kirtland and Fruitland beds during deposition of the Animas formation.

The evidence of intertonguing of Animas sediments with Lewis, Pictured Cliffs, Fruitland, and Kirtland formations as presented by Dane (1946) and Wood, Kelley, and MacAlpin (1948) seems fairly conclusive. According to G. H. Wood

attributed the southeastward dipping, of the sediments in northwestern New Mexico to depositional thinning rather than erosional truncation as advocated by Reeside (1924, p. 20). This view is consistent with observations by the present writer in the Bridge Timber Mountain area.

At this point it is appropriate to note that the interpretations of the tectonic relationships of Cretaceous rocks of the San Juan Basin as presented by Silver (1950, p. 113; 1951, p. 115) are in general accord with the views expressed in this paper. The Fruitland Hogback [illegible] (p. 115) is said to have developed during deposition of the Pictured Cliffs sandstone and Fruitland formation. The axis of this basin was somewhere to the west of the present area of outcrop of the Fruitland formation and the eastward thinning of the Fruitland is said to be due to depositional thinning upon the east flank of the Fruitland basin. According to Silver (1950, p. 115; 1951, p. 116), the Animas formation overlies the Kirtland formation unconformably due to post-Kirtland erosion, but this unconformity is obscured by thickening of Kirtland sediments deposited during deposition of the Animas formation.

The evidence of intertonguing of marine sediments with Lewis, Pictured Cliffs, Fruitland, and Kirtland formations as presented by Reeside (1924) and Dane, Bachman, and Reeside (1948) seems fairly conclusive. [illegible] According to [illegible]

(personal communication), at various places in Archuleta County, Colorado there are coal beds which are persistent through the zone of interfingering of Fruitland and Animas formations. It is difficult to conceive a mechanism of deposition whereby coal beds could have been eroded before, or during, deposition of the Animas and redeposited in such manner as to be laterally continuous with coal beds in the Fruitland formation. The interfingering of upper Animas and McDermott sediments described by Zapp (1949) east of Durango was further substantiated by observations on Animas River in the area of this report. The presence of coarse detritus in the upper Kirtland similar to that of the Animas formation and the probable intertonguing of the McDermott member of the Animas formation with the upper Kirtland in the area of this report are in complete accord with the concept of intertonguing sediments derived from northeastern and southwestern source areas. According to C. H. Dane (personal communication), remains of large sauropod dinosaurs have been found in the Ojo Alamo sandstone (see Gilmore, 1922) and the presence of these types suggests that the Ojo Alamo was deposited in low areas which may have been near the Cretaceous seaway. This is not in agreement with the concept of the relatively high eastern flank of the Kirtland basin of Silver. The writer concludes that the basin in which the Kirtland shale was deposited was the same as that in

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which the Animas formation was deposited, and that the axis of this basin was either in the vicinity of the present structural axis of the Central San Juan Basin or to the northeast of this area.

According to Reeside (1924, p. 30), the greatest thickness (400 feet) of the Ojo Alamo sandstone is in the triangular area between San Juan and Animas Rivers. This is in the vicinity of the structurally deepest part of the present San Juan Basin and probably indicates that the Basin was beginning to assume its modern aspects during deposition of the Ojo Alamo. Evidence has already been presented which indicates that the conglomeratic phase of the upper member of the Animas formation is the stratigraphic equivalent of part of the Ojo Alamo sandstone in northwestern San Juan Basin. After deposition of this phase of the Animas formation and corresponding beds of the Ojo Alamo, folding began along the Hogback "monocline" in western and northern San Juan Basin. Kelley (1951, pp. 129-130) has described the concept of expanding mobile rims which encroached upon the Basin from the surrounding highlands, causing uplift of the platforms and folding of the "monoclines" during downwarp of the Central Basin.

During the folding of the Hogback in latest Cretaceous or early Paleocene time, sediments on the platforms were eroded and carried into the newly defined Central Basin from

which the Animas Formation was deposited, and that the axis of this basin was at that time in the vicinity of the present structural axis of the Central San Juan Basin, or to the northeast of that area.

According to Reeside (1924, p. 3?), [illegible] maximum thickness (400 feet) of the Ojo Alamo sandstone is in the triangular area between San Juan and Animas Rivers. This is in the vicinity of the structurally deepest part of the present San Juan Basin and probably indicates that the basin was beginning to assume its modern aspect during deposition of the Ojo Alamo. Evidence has already been presented which indicates that the conglomeratic facies of the upper member of the Animas Formation is the stratigraphic equivalent of part of the Ojo Alamo sandstone in the New Mexico San Juan Basin. After deposition of this phase of the Animas Formation and contemporaneous beds of the Ojo Alamo, folding began along the Hogback monocline in western and northern San Juan Basin. Kelley (1951, pp. 126-130) has described the concept of expanding basin [illegible] sedimentation encroached upon the basin from the margins of highlands, causing uplift of the platforms and folding of the monoclines or margins adjacent of the Central Basin.

During the folding of the Hogback in latest Cretaceous or early Paleocene time, sediments in the platforms were eroded and [illegible] into the newly defined Central Basin from

the north, west, and south by streams with centripetal drainage. In the north and northwest the thick beds of the shaly sequence of the upper Animas were deposited and these sediments, by lateral gradation to the south, became beds of the Nacimiento formation. Probably the Nacimiento to the south is composed mainly of sediments derived from uplift and erosion of Cretaceous beds on the Four-Corners platform to the west and the Chaco slope to the south with a resultant interfingering of materials from several sources near the center of the Basin. The "monocline" on the east side of the Basin had not begun to form and upper Animas and Nacimiento sediments were probably deposited across the entire area from the northeastern highlands to the Chaco slope.

The lower Nacimiento (Puerco) beds were said by Reeside (op. cit., p. 43) to be distinctly younger than the Ojo Alamo sandstone as shown by the erosional unconformity between them. However, Dane (1946) reported that there was no evidence of erosional unconformity on the eastern side of the San Juan Basin and no evidence of unconformity was observed between lower Animas (thus, Ojo Alamo) and Nacimiento beds in the area of this report except, of course, near the Hogback "monocline". The evidence of erosional unconformity and thinning of Nacimiento beds on the south side of the Central Basin is fairly clear and

the north, west, and probably already were obstructed

drainage. In the [illegible] portion [illegible] the [illegible] of the

early sequence of the upper [illegible] were deposited [illegible]

sediments, by lateral [illegible] to the south, became [illegible]

of the [illegible] formation. Probably the sediments to

the south are composed mainly of sediments [illegible] from

uplift and erosion of [illegible] beds on the [illegible]

platform to the west and the [illegible] to the [illegible]

a [illegible] several

sources near the center of the basin. The "[illegible]" on

the west side of the basin had not begun to [illegible] upon

[illegible] and [illegible] the sediments were probably deposited

across the entire area from the [illegible] to

the [illegible].

The lower [illegible] beds were said to [illegible]

side (op. cit., p. 83) to be [illegible] the

Ojo Alamo sandstone as shown by the [illegible]

between them. However, [illegible] (1956) reported that there

was no evidence of erosional unconformity on the western

side of the San Juan basin and no evidence of unconformity

was observed between lower [illegible] (Ojo Alamo) and

[illegible] beds in the area of this report except, of

course, near the [illegible] channel [illegible]. The evidence of

erosional unconformity [illegible] of [illegible]

the south side of the [illegible] basin [illegible]

would logically be expected. As uplift occurred around the margins of the Central Basin, earlier-deposited beds were eroded and redeposited toward the central part of the Basin. Beds of the heavy sandstone facies were deposited in the deepest part of the Basin from northwest to southeast and appear to be genetically related to upper Animas beds in the eastern part of the San Juan Basin (Dane, 1946). These beds intertongue with detritus that was supplied from the margins of the Basin.

Sediments of the San José formation reflect continuation of the same conditions which prevailed during deposition of the Nacimiento-upper Animas sequence. The Yegua Canyon sandstone facies was deposited in the deepest part of the Central Basin and was probably derived from the same sources in the north and northeast as were the sediments of the heavy sandstone facies of the Nacimiento. The San José and Nacimiento formations are probably unconformable on the southern, western, and northern rims of the Central Basin but entirely conformable within the Basin. Strong uplift in the highlands to the north and northeast in late Paleocene and early Eocene time is indicated by the abrupt overstepping relationships of the San José formation in the northern part of the Basin. The predominance of red clay beds in the San José formation is probably due mainly to the exposure and erosion of Jurassic, Triassic, and Permian

"redbeds" in the highlands and subsequent deposition in the San Juan Basin of sediments derived from these sources. Folding on the Hogback "monocline" in the west and north appears to have been essentially completed before the deposition of the latest San José sediments and it is likely that the entire San Juan Basin was blanketed by these beds in middle or late Eocene time.

The Nacimiento-Jemez uplift and the structurally related Archuleta anticlinorium on the east side of the San Juan Basin may have begun to form in late Paleocene or early Eocene time as broad domal features. Sediments derived from these sources would not be notably different from those being deposited in the Basin which were derived from other sources. Angular unconformities resulting from this early uplift may have been present to the east where early Tertiary rocks are not preserved today. Wood and Northrop (1946) found no evidence of overstepping relations between Nacimiento and San José beds along the west front of the Nacimiento uplift but Simpson (1948, p. 376) has mentioned the possibility of slight discordance in the vicinity of Cuba Mesa. The top of the Nacimiento Mountains is truncated by a mature erosion surface which is at least pre-Abiquiu (Oligocene) in age. The Brazos uplift to the northeast of the Chama embayment has a similar surface overlain by conglomerate of the El Rito formation which is considered as being of Eocene

[illegible] in [illegible] [illegible] in the same [illegible] of sediments derived from these sources. [illegible] of the [illegible] in the [illegible] appears to have been [illegible] completed before the deposition of the [illegible] and it is likely that the entire [illegible] by these beds in middle or late Eocene time.

The [illegible] [illegible]

being deposited in the [illegible] which were derived from other sources. [illegible] [illegible] early [illegible] may have been present in the [illegible] early [illegible] are not preserved [illegible] [illegible] (1960) found no evidence of [illegible] relations between [illegible] [illegible] along the west front of the [illegible] but [illegible] (1968, p. 270) has mentioned the possibility of slight [illegible] in the vicinity of [illegible]. The top of the [illegible] is [illegible] by a [illegible] surface [illegible] at [illegible] (Oligocene) [illegible] the [illegible] uplift to the [illegible] of the [illegible] [illegible] and a similar [illegible] [illegible] [illegible] of the [illegible] Formation, which is considered as being of [illegible]

age by Kelley and Silver (1952, p. 114, Fig. 4) and correlated with the San José formation. Thrusting on the west front of the Nacimiento uplift probably did not develop until late Tertiary time (Kelley, 1951, p. 129), at about the time when rifting occurred in the Rio Grande fault belt to the southeast.

PRINCIPAL CONCLUSIONS

The principal conclusions presented in this paper are summarized as follows:

1. Sediments of the Pictured Cliffs sandstone and younger Cretaceous and Tertiary formations were deposited in a large southeast-trending basin formed by Laramide uplift of the San Juan-Sangre de Cristo Mountains. The northeast flank of this basin was modified repeatedly during latest Cretaceous and early Tertiary time by encroachment of the highlands upon the basin. Middle and late Tertiary orogenic events related to rifting in the Rio Grande and San Luis Valleys produced the present eastern structural limits of the San Juan Basin and destroyed the southeastern part of the older basin.

2. The San Juan-Sangre de Cristo uplifts were the dominant sources of sediments deposited in the area of the present San Juan Basin in latest Cretaceous and early Tertiary time. The Zuni and Defiance uplifts to the southwest supplied lesser amounts of sediments. Unconformities between the Animas, Nacimiento, and San José formations on the margins of the Central Basin reflect several stages of uplift and erosion in the bordering highlands.

3. Facies of the upper Animas, Nacimiento, and San José formations reflect the structure of the Central Basin.

PRINCIPAL CONCLUSIONS

The principal conclusions presented in this paper are summarized as follows:

1. Sediments of the Richard [illegible] evidence that younger Cretaceous and Tertiary formations were deposited in a large southeast-trending basin formed by the uplift of the San Juan-Sangre de Cristo Mountains. The northeast flank of this basin was modified repeatedly during latest Cretaceous and early Tertiary time by encroachment of the highlands upon the basin. Middle and late Tertiary orogenic events related to rifting in the Rio Grande and San Luis valleys produced the present eastern structural limits of the San Juan Basin and destroyed the southeastern part of the older basin.

2. The San Juan-Sangre de Cristo Mountains were the dominant sources of sediments deposited in the area of the present San Juan Basin in latest Cretaceous and early Tertiary time. The Zuni and Defiance uplifts to the southwest supplied lesser amounts of sediments. Unconformities between the Animas, Nacimiento, and San Jose Formations on the margins of the Central Basin reflect [illegible] stages of uplift and erosion in the bordering highlands.

3. [illegible] of the [illegible] Animas, Nacimiento, and San Jose Formations reflect the structure of the Central Basin.

The coarse-grained heavy sandstone facies were deposited in the structurally deepest part of the Central Basin and interfinger with shaly facies deposited nearer the northwestern, western, and southern margins of the Central Basin.

4. Sediments within the Central Basin were deposited almost continuously through late Cretaceous, Paleocene, and early Eocene time. The only significant unconformities occur near the margins of the Central Basin.

The [illegible] facies were deposited in the structurally deepest part of the Central Basin and interfinger with [illegible] deposited across the north-western, western, and southern margins of the Central Basin.

4. Sediments within the Central Basin were deposited almost continuously through late Cretaceous, Paleocene, and early Eocene time. The only significant unconformities occur near the margins of the Central Basin.

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