4-7-1958

Geology of the Northern End of San Pedro Mountain, Rio Arriba and Sandoval Counties, New Mexico

Osler C. Hutson

AN PEDRO
MOUNTAIN

HUTSON

GEOLOGY OF THE NORTHERN END OF SAN PEDRO MOUNTAIN, RIO ARRIBA AND SANDOVAL COUNTIES, NEW MEXICO

By

Osler C. Hutson

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Geology

The University of New Mexico

1958

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

E. F. Castetter
DEAN

April 7, 1958
DATE

Thesis committee

Wolfgang E. Elston
CHAIRMAN

J. Paul Fitzsimmons

Roger Y. Anderson

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirement for the degree of

[illegible]

Thesis committee

CONTENTS

Page

ILLUSTRATIONS

ABSTRACT

The San Pedro Mountain area of north-central New Mexico is made up of 12,000 feet of Mississippian to Recent sediments resting on Precambrian granite gneiss. Strata of Cambrian through Devonian age are missing. If these rocks were deposited they were removed prior to deposition of the Mississippian rocks. Mississippian carbonates are present where they have been structurally preserved in synclines and down-faulted blocks; for the most part they were removed by pre-Pennsylvanian erosion. Pennsylvanian rocks consist of fossiliferous limestone alternating with soft shale and arkose beds. The Permian system is represented by red-brown, feldspathic conglomeratic sandstone and red shale of the Cutler formation. The Triassic Chinle formation has been mapped as three units, the Agua Zarca sandstone and Salitral shale, the Poleo sandstone lentil, and the upper Chinle shale member. The Jurassic system is composed of 1100 feet of sandstone and shale divided by a thin sequence of evaporites. These rocks are represented by the Entrada sandstone, the Todilto limestone and gypsum, and the Morrison formation. Alternating marine shale and sandstone with lesser amounts of continental sediments record the transgressions and regressions of the Upper Cretaceous sea. These beds are represented by the Dakota sandstone, Mancos shale, the Mesaverde group, and the Ojo Alamo sandstone. The Nacimiento formation and the San Jose formation of Paleocene and Eocene age, respectively, are the youngest formations mapped within the area, other than Quaternary alluvium.

Structural development of the area took place in three stages. First, minor uplift and depression of the San Juan Basin, due to early

Laramide movement, resulted in radial folding along the Nacimiento-San Pedro Mountain front. Deposition of the Ojo Alamo sandstone was affected by this folding as revealed by thickening in the synclines and thinning on the anticlines. Second, absence of the lower Paleocene beds suggests continued uplift. Uplift and contemporaneous downwarping of the San Juan Basin resulted in an asymmetrical fold in the San Pedro Mountain area. Third, continued deformation of this fold in late Paleocene or early Eocene time, developed a steep limb inclined to the west and resulted in the Nacimiento-San Pedro high-angle reverse fault along the west flank of San Pedro Mountain.

Previous reports have described repetition of Pennsylvanian strata, which supposedly resulted from low-angle overthrusting. The Pennsylvanian beds, however, were found to be in a normal sequence.

A gas discovery by the Magnolia Oil Company (sec. 24, T. 24 N., R. 1 W.) has stimulated interest in the oil and gas possibilities of the eastern flank of the San Juan Basin. The most important producing horizons of the San Juan Basin crop out along the west flank of San Pedro Mountain; preservation of petroleum in these formations is unlikely. The entrapment of oil and gas in the Pennsylvanian rocks along the Nacimiento-San Pedro fault is possible, but drilling tests of Pennsylvanian strata in structures along the eastern flank of the San Juan Basin have been negative.

Laramide movement, resulted in radial folding along the Nacimiento-San Pedro Mountain front. Deposition of the Ojo Alamo Sandstone was affected by this folding as revealed by thickening in the synclines and thinning on the anticlines. Second, absence of the lower Paleocene beds suggests continued uplift. Uplift and contemporaneous downwarping of the San Juan Basin resulted in an asymmetrical fold in the San Pedro Mountain area. Third, continued deformation of this fold in late Paleocene or early Eocene time, developed a steep limb inclined to the east and resulted in the Nacimiento-San Pedro high-angle reverse fault along the west flank of San Pedro Mountain.

Previous reports have described [illegible] Pennsylvanian [illegible] which supposedly resulted from low-angle overthrusting. The Pennsylvanian beds, however, were found to be in normal sequence.

A gas discovery by the [illegible] (sec. [illegible], T. [illegible] N., R. 1 W.) has stimulated interest in the oil and gas possibilities of the eastern flank of the San Juan Basin. The gas and oil producing horizons of the San Juan Basin crop out along the west flank of San Pedro Mountain; preservation of petroleum in these formations is unlikely. The occurrence of oil and gas in the Pennsylvanian rocks along the Nacimiento-San Pedro fault is possible, but drilling tests of Pennsylvanian targets in structural along the eastern flank of the San Juan Basin have been negative.

INTRODUCTION

Geography

The area of this report comprises 50 square miles along the northern end of the Nacimiento-San Pedro uplift in Sandoval and Rio Arriba Counties, New Mexico (Fig. 1). It is divided by the New Mexico Principal Meridian and is mainly within T. 23 N., R. 1 E., and R. 1 W.

New Mexico highway 96 provides accessibility, and traverses the area from northeast to southwest. This road connects the towns of Regina, Gallina, and Capulin, and joins New Mexico highway 112 in sec. 21, T. 23 N., R. 1 W. These roads may become impassable after torrential summer rains. Numerous other unimproved roads provide access to ranches, lumber camps, and mining properties. Nevertheless, much of the area cannot be reached except on foot.

Concentration of population is in the towns along highway 96. Most of the residents are engaged in the lumber industry, though ranching and farming also contribute substantially to the economic well-being of the area.

The topography of the area is rugged. A panoramic glance at the area shows gently dipping beds rising from the San Juan Basin to the northwest, and merging into a jumbled mass of steeply dipping hogbacks, overturned beds, and fault scarps along the Nacimiento-San Pedro fault front. The topographic ruggedness is attributed mainly to differential erosion of steeply inclined strata of variable resistance. The erosive agents are undoubtedly aided to a large extent by weakening of rocks along fault and fracture planes. The western and northwestern parts of the area

INTRODUCTION

Geography

The area of this report comprises 20 square miles along the northern end of the Nacimiento-San Pedro uplift in Sandoval and Rio Arriba Counties, New Mexico (Fig. 1). It is divided by the New Mexico Principal Meridian and is mainly within [illegible].

New Mexico Highway [illegible] crosses the area from northeast to southwest. This road connects the towns of [illegible], Gallina, and Capulin, and joins New Mexico Highway [illegible] R. 1 W. These roads are passable in [illegible] weather. Numerous other unimproved roads provide access to [illegible] and mining properties. Nevertheless, much of the area is [illegible] except on foot.

Concentration of population is in the towns along [illegible]. Most of the residents are engaged in the lumber industry; [illegible] and farming also contribute [illegible] of the area.

The topography of the [illegible] area shows gently dipping beds [illegible] to the northwest, and merging into a [illegible] and overturned beds, and fault scarps along the [illegible] fault front. The topographic ruggedness is attributed mainly to differential erosion of steeply inclined strata [illegible]. The erosion agents are undoubtedly aided to a large extent by weathering [illegible] along fault and fracture planes. The [illegible] of the area

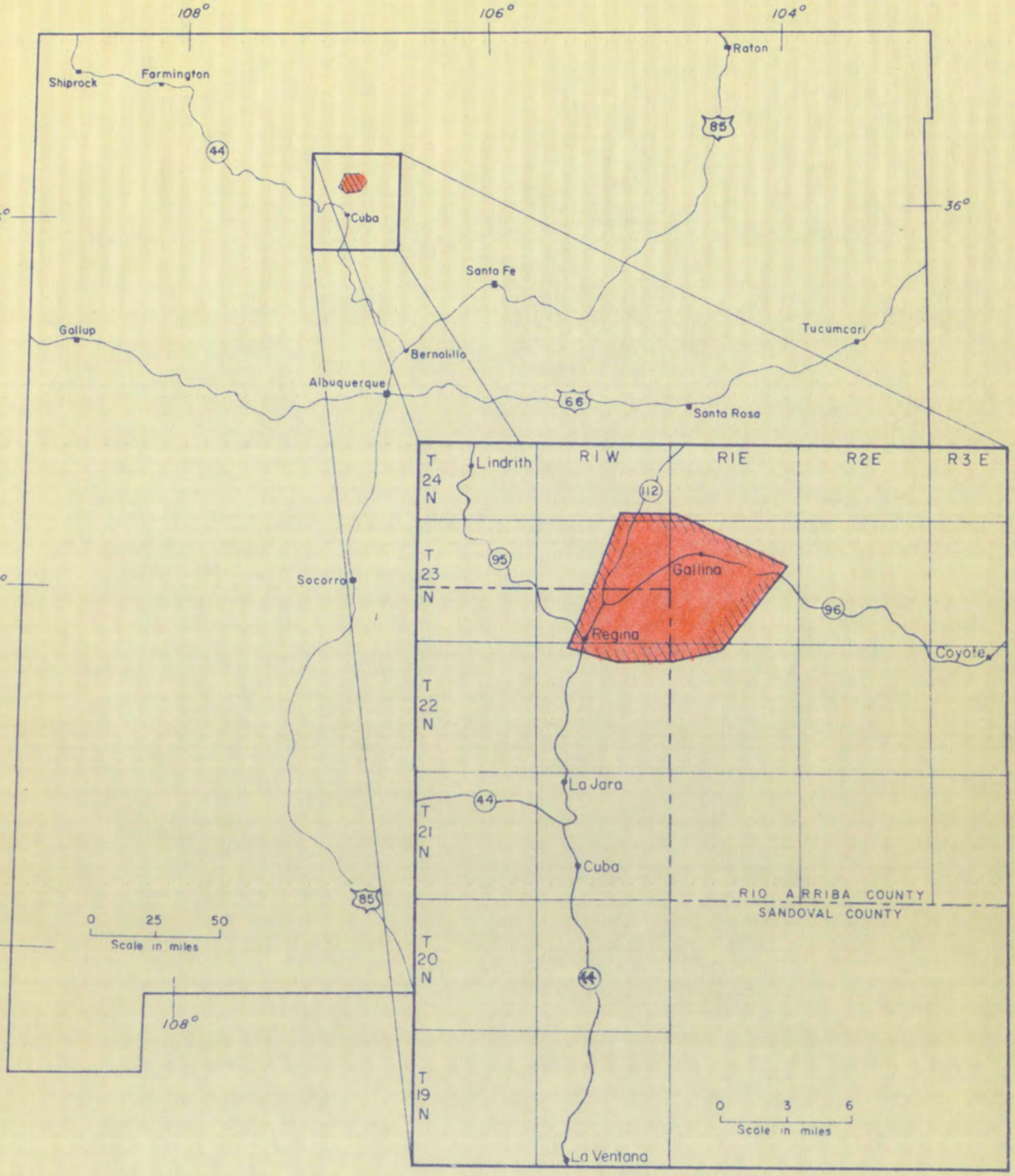


Figure 1.- Index map showing area of study in red.

are part of the San Juan Basin. They are characterized by beds of shallow dip, and are not as rugged as the southeastern and central parts.

The area is bordered on the west by the Continental Divide. Elevations vary from 7300 feet at Gallina to approximately 9500 feet to the south. San Pedro Mountain peak, three miles south of the area of this report, reaches an elevation of 10,577 feet. The area is considered semi-arid and shows considerable climatic variation. Most of the precipitation is during July and August, although winter snows are common. The mean average rainfall at Regina is 18 inches, relatively high as compared to the average annual rainfall of nearby areas. This is undoubtedly due to the proximity of the mountains.

The area is drained by the Rio Gallina and San Jose creek and their dendritic tributaries. The Rio Gallina flows northward and is a tributary of the Rio Chama, while San Jose creek drains the western side of the San Pedro Mountain and flows southward into the Rio Puerco near Cuba.

Three ecologic communities are evident in the area. The lowermost is the Upper Sonoran zone, characterized by pinon, pine, and juniper, with abundant greasewood in dry, sheltered valleys. This zone merges with the Transition zone at 7000 foot elevation. The Transition zone, characterized by ponderosa pine, extends upward to elevations between 8500 and 9000 feet, where the pine mingles with the spruce and fir of the Canadian zone. Where logging operations have removed the primary growth, and in places where there is an abundance of young evergreens, dense growth of aspen are common.

Previous Work

The first noteworthy geologic study of this area was included in the report of Darton (1928, p. 155-178). This report contained a discussion on are part of the San Juan Basin. They are [illegible] by [illegible] dip, and are not as rugged as the [illegible] parts.

The area is bounded on the west by the [illegible]. Elevations vary from 7300 feet [illegible] to approximately [illegible] feet to the south. San Pedro Mountain peak, the highest point in the area of this report, reaches an elevation of 10,5?? feet. The area is considered semi-arid and shows considerable climatic variation. Most of the precipitation is during July and August, although winter snows are [illegible]. The mean average rainfall at Regina is 23 inches, which is high compared to the average annual rainfall of nearby areas. This is attributed to the proximity of the mountains.

The area is drained by the [illegible] and its numerous small dendritic tributaries. [illegible] drains the northwestern part of the Rio Chama, while San Jose Creek drains the [illegible] San Pedro Mountain and flows southward into the Rio Puerco [illegible].

Three ecologic communities are evident in the area. The lowest is the Upper Sonoran zone, characterized by pinon pine and juniper, with abundant greasewood in dry washes and valleys. This area merges with the Transition zone at 7000 feet elevation. The Transition zone, characterized by ponderosa pine, extends upward on slopes between [illegible] and [illegible] feet, where the pine mingles with the [illegible] of the Canadian zone. Where logging operations have removed the primary growth, and in [illegible], there is an abundance of young ponderosa, dense growth of [illegible]

Previous Work

The first noteworthy geologic study of this area was included in the report of Darton (1928, p. [illegible]). [illegible] the stratigraphy and structure of the Nacimiento-San Pedro uplift and the Chama embayment. Renick (1931) discussed the geology and ground water of western Sandoval County. His interpretation of the faulting on the northern end of San Pedro Mountain as bedding thrusts and overthrusts is of unusual interest. Northrop and Wood (1946) termed these structures imbricate thrusting. More recent works including this area are by Dane (1946), who discussed the stratigraphic relations of the Eocene, Paleocene, and latest Cretaceous formations; and Northrop and Wood (1946), who were concerned with oil and gas possibilities, structure, and stratigraphy.

Purpose and Method of Investigation

The structural complexity of this area provided the initial stimulus for this study. With encouragement from Dr. Vincent C. Kelley, the study of this area was undertaken as a master's thesis project. The field work necessary to the project was begun in February, 1957 and completed during the summer of 1957.

Mapping was accomplished with the aid of aerial photographs scaled two inches equals one mile. Data were transferred from photographs to a U. S. Soil Conservation Service planimetric map. Stratigraphic sections were measured with Brunton compass and a 50-foot steel tape.

Acknowledgments

The writer wishes to acknowledge the aid and guidance of Dr. Vincent C. Kelley and Dr. Wolfgang E. Elston of the University of New Mexico and Mr. Frank A. Packard of the Humble Oil & Refining Company. The assistance of Mr. Douglas W. Kirkland, who aided in field work, is also gratefully acknowledged.

the stratigraphy and structure of the [illegible] and the Chama embayment. Renick (19[illegible]) discussed the geology and ground water of western Sandoval County. His interpretation of the faulting on the northern end of San Pedro Mountain as bounding [illegible] overthrusts is of unusual interest. Northrop and Wood (194[illegible]) termed these structures imbricate thrusting. More recent works including this area are by Dane (194[illegible]) who discussed the stratigraphy of [illegible] the Eocene, Paleocene, and Late Cretaceous formations, and [illegible] and Wood (1945), who were concerned with oil and gas possibilities, structure, and stratigraphy.

Purpose and Method of Investigation

The structural complexity of this area provided the initial stimulus for this study. With encouragement from Dr. Vincent C. Kelley, the study of this area was undertaken as a master's thesis project. The field work necessary to the project was begun in February, [illegible] and completed during the summer of [illegible].

Mapping was accomplished on [illegible] aerial photographs at a scale of two inches equals one mile. Data were transferred from photographs to U. S. Soil Conservation Service planimetric maps. Stratigraphic sections were measured with Brunton compass and a [illegible] staff.

Acknowledgments

The writer wishes to acknowledge the aid and guidance of Dr. Vincent C. Kelley and Dr. [illegible] of the University of New Mexico and Mr. Frank [illegible] of the Humble Oil & Refining Company. The assistance of Mr. [illegible] is also gratefully acknowledged.

STRATIGRAPHY

General Features

Sedimentary rocks exposed along the northern flank of San Pedro Mountain include representatives of all geologic periods from Mississippian to Recent.

The sedimentary sequence is approximately 11,600 feet thick, measured from the top of the Precambrian to the base of the San Jose formation. Rocks of marine origin comprise over one-third of the total. The Cretaceous marine section is dominantly clastic; the Pennsylvanian and Mississippian rocks are mainly carbonates. Continental deposits are characterized by their content of claystone, mudstone, coal, and petrified wood. Information related to the rocks exposed in the area of this report is summarized in Table I.

Terminology of stratigraphic units incorporated into this project agree with those employed by the U. S. Geologic Survey (Dane and Bachman, 1957).

Precambrian Era

Precambrian rocks are exposed along the Nacimiento-San Pedro fault and on San Pedro Mountain. Exposures were observed in sec. 1, T. 22 N., R. 1 W. and secs. 5 and 6, T. 22 N., R. 1 E.

In general, the Precambrian terrane stands high and is irregular and rugged. The dominant rock type is a pink, coarse-grained granite gneiss. In the NW$\frac{1}{4}$ sec. 36, T. 23 N., R. 1 W., small exposures of Precambrian greenstone were observed below faulted Mississippian rocks.

STRATIGRAPHY

General Statement

Sedimentary rocks exposed along the [illegible] San Pedro Mountain include representatives of [illegible] from Mississippian to Recent.

The sedimentary sequence is approximately [illegible] feet thick, measured from the top of the Precambrian to the base of the [illegible] Formation. Rocks of marine and [illegible] of the [illegible]. The Cretaceous marine section [illegible] and Mississippian rocks are mainly carbonates. [illegible] are characterized by their content of [illegible] wood. Information related to the [illegible] is summarized in Table II.

Terminology of stratigraphic units [illegible] agree with those employed by the U. S. Geological Survey ([illegible] 1957).

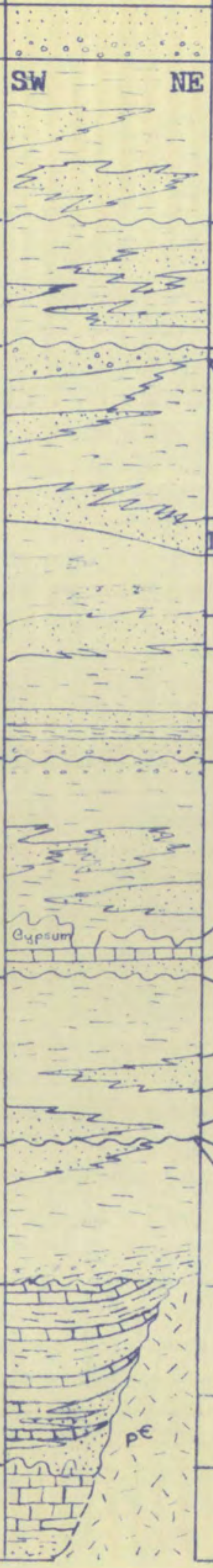
Precambrian

Precambrian rocks are exposed along the [illegible] and on San Pedro Mountain. [illegible] R. 1 W. and secs. [illegible] and [illegible]

In general, the Precambrian [illegible] and rugged. The dominant rock [illegible] gneiss. In the [illegible] sec. 35, T. 12 N., R. [illegible] Precambrian greenstone are observed [illegible]

TABLE I

COLUMNAR SECTION OF THE SAN PEDRO MOUNTAIN AREA



Age		Section	Formation	Thickness (feet)
CENOZOIC	Recent		Alluvium and gravels	
CENOZOIC	Eocene		San Jose	2,000 +
			Disconformity (?)	
CENOZOIC	Paleocene		Nacimiento	800 +
			Disconformity (?)	
MESOZOIC	Upper Cretaceous		Ojo Alamo sandstone	30
			Fruitland, Kirtland & Pictured Cliffs	Absent
			Lewis shale	1,850
			La Ventana tongue (Cliff House)	40 - 70
			Menefee	480
			Point Lookout sandstone	130
			Mancos shale	2,190
			Dakota sandstone	199
			Unconformity	
MESOZOIC	Jurassic		Morrison	790
			Unconformity	
			Todilto	55 - 80
			Entrada sandstone	235 ?
			Disconformity (?)	
MESOZOIC	Triassic		Chinle shale	579 ?
			Poleo ss. lentil	75
			Salitral shale	20 - 30
			Agua Zarca ss.	0 - 4
			Disconformity	
PALEOZOIC	Permian		Yeso	?
			Cutler	2,150
			Unconformity	
PALEOZOIC	Pennsylvanian		Madera	1,890
			Sandia (?)	
			Unconformity	
PALEOZOIC	Mississippian		Arroyo Penasco	70 ?
			Nonconformity	
Precambrian				

Mississippian System

Arroyo Penasco formation

Exposures of Mississippian rocks are found in sec. 36, T. 23 N., R. 1 W., about 3 miles east of Regina. The Mississippian outcrops are faulted and densely covered with vegetation. No accurate measurement was possible, but the thickness is estimated to be 70 feet.

The base of the Arroyo Penasco formation rests nonconformably on Precambrian granite gneiss. It consists of 3 feet of tan, medium to coarse grained, slightly conglomeratic sandstone which grades upward into 12 feet of shale alternating with 3- to 6- inch beds of gray limestone. Overlying this unit is about 25 feet of light brown to tan, dense, fine-crystalline limestone in beds 6 inches to 3 feet thick. This limestone has a petroliferous odor when freshly broken. This unit is a distinguishing feature of the Mississippian rocks in the San Pedro Mountain area. The uppermost unit consists of 30 - 35 feet of a light gray, very dense, fine-crystalline limestone with small amounts of white chert.

Prior to the discovery of Mississippian fossils in the northern part of New Mexico, it was commonly thought that the Mississippian sea had advanced only to the central part of the state. More recent work has shown that strata of Mississippian age once probably covered a great part of north-central New Mexico, but that erosion has removed most of them (Fitzsimmons, et al., 1956). The remaining Mississippian rocks in the San Pedro Mountain area are preserved in down faulted blocks.

The name Arroyo Penasco was derived from a stream on the western flank of the Nacimiento Mountains (Armstrong, 1955, p. 3).

Arroyo Penasco Formation

Exposures of Mississippian rocks are found in sec. 26, T. [illegible] N., R. 1 W., about 5 miles east of Regina. The Mississippian sediments are faulted and densely covered with vegetation. No accurate measurement was possible, but the thickness is estimated to be 50 feet.

The base of the Arroyo Penasco Formation rests unconformably on Precambrian granite gneiss. It consists of [illegible] feet of brown, quartzitic, coarse grained, slightly conglomeratic sandstone which grades upward into 12 feet of shale alternating with thin beds of gray limestone. Overlying this unit is about 25 feet of light brown to gray dense, fine-crystalline limestone in beds [illegible] inches to 3 feet thick. The limestone has a petroliferous odor when freshly broken. This odor is a distinguishing feature of the Mississippian rocks in the San Pedro Mountain area. The uppermost unit consists of 10 - 15 feet of a light gray, very dense, fine-crystalline limestone with small amounts of green chert.

Prior to the discovery of Mississippian rocks in the north-central area of New Mexico, it was generally thought that the Mississippian seas had advanced only to the central part of the state. More recent work has shown that strata of Mississippian age once probably covered the major part of north-central New Mexico, but that erosion has removed most of them (Fitzsimmons, et al., 1950). The remaining Mississippian rocks in the San Pedro Mountain area are preserved in down faulted blocks.

The name Arroyo Penasco was derived from exposures on the western flank of the Nacimiento Mountains (Armstrong, 1955, p. [illegible]).

Pennsylvanian System

Magdalena group

Approximately 1890 feet of Pennsylvanian marine limestone, shale, and arkose lie unconformably on Mississippian rocks. The thickness is only an estimate, as faulting may have repeated some of the section. A similar thickness, 1864 feet, was found in a well drilled on the nearby Gallina Mountain anticline, SW$\frac{1}{4}$ sec. 20, T. 26 N., R. 2 E. (Lookingbill, 1953, p. 12).

To a large extent vegetation, soil cover, and faulting have obscured the Pennsylvanian outcrops. Therefore, the beds were mapped as one unit, the Magdalena group. In the NE$\frac{1}{4}$ sec. 36, T. 23 N., R. 1 W., the upper 700 feet of the Magdalena group is fairly well exposed and is equivalent to the upper arkosic member of the Madera formation described by Northrop and Wood (1946). These beds consist of soft, gray, purple, greenish, and red-brown, fossiliferous shale, alternating with fossiliferous, gray and light gray, fine to medium-crystalline limestone beds 1- to 9- feet thick.

Northrop and Wood (1946) mapped the Magdalena group as the Sandia and Madera formations. The Sandia formation was subdivided into a lower limestone and an upper clastic member, the Madera formation into a lower gray limestone and an upper arkosic member. Paleontological evidence has since proved the lower limestone member of the Sandia formation to be of Mississippian age (Fitzsimmons, et al., 1956). The upper clastic member of the Sandia formation is Morrow to Lampasas in age and the conformably overlying Madera formation is Lampasas to Virgil (Northrop and Wood, 1946).

Permian System

Cutler formation

The Permian "red beds" of the San Pedro Mountain area were mapped as the Cutler formation (undifferentiated). The aggregate thickness is about 2150 feet. The Cutler formation, which strikes generally east-west, is exposed in a broad band in the central part of the area. Except for a few conglomeratic zones in the lower third of the formation, it is readily eroded.

The base of the Cutler formation is poorly exposed. Although the formation appears to be generally conformable and gradational with the underlying Magdalena group (Northrop and Wood, 1946), there is some local divergence of beds at or near the contact with the Pennsylvanian rocks. In the SW$\frac{1}{4}$ sec. 30, T. 23 N., R. 1 E., an angular unconformity exists within the lower part of the Cutler formation. The exact stratigraphic position of this unconformity is indeterminable because of dense vegetation and soil cover. The Magdalena beds dip 30° N., while the overlying Cutler rocks dip 14° N. (Fig. 2). This unconformity is not surprising as it is believed that the San Pedro-Nacimiento Mountains were tectonically active during Pennsylvanian and probably early Permian time.

The lower part of the Cutler formation is composed of alternating beds of feldspathic, crossbedded sandstone and conglomerate and shale. The sandstone is brown and red-brown, fine to coarse grained, angular to subrounded, and locally calcareous. The conglomerate consists of brown and red-brown particles ranging from granule to cobble sizes. The shale

Cutler Formation

The Permian [illegible] rocks [illegible] were mapped as the Cutler Formation (undifferentiated). The [illegible] thickness is about 1200 feet. The Cutler Formation, [illegible] generally east-west, is exposed in a [illegible] band in the central part of the area. Except for a few [illegible] of the formation, it is [illegible].

The base of the Cutler Formation [illegible] the formation appears to be [illegible] the underlying Hermosa group (Fortune [illegible]). There is some local divergence of bedding [illegible] contact with the Hermosa rocks. In the [illegible] exists within the lower [illegible] of the Cutler Formation. The [illegible] stratigraphic position of this [illegible] of dense vegetation and [illegible]. The [illegible] while the overlying Cutler [illegible] is not surprising as it is believed that the Uncompahgre [illegible] Mountains were [illegible] early Permian time.

The lower part of the Cutler Formation [illegible] beds of feldspathic, [illegible] sandstone [illegible]. The sandstone is brown [illegible] subrounded, and [illegible] and red-brown [illegible]

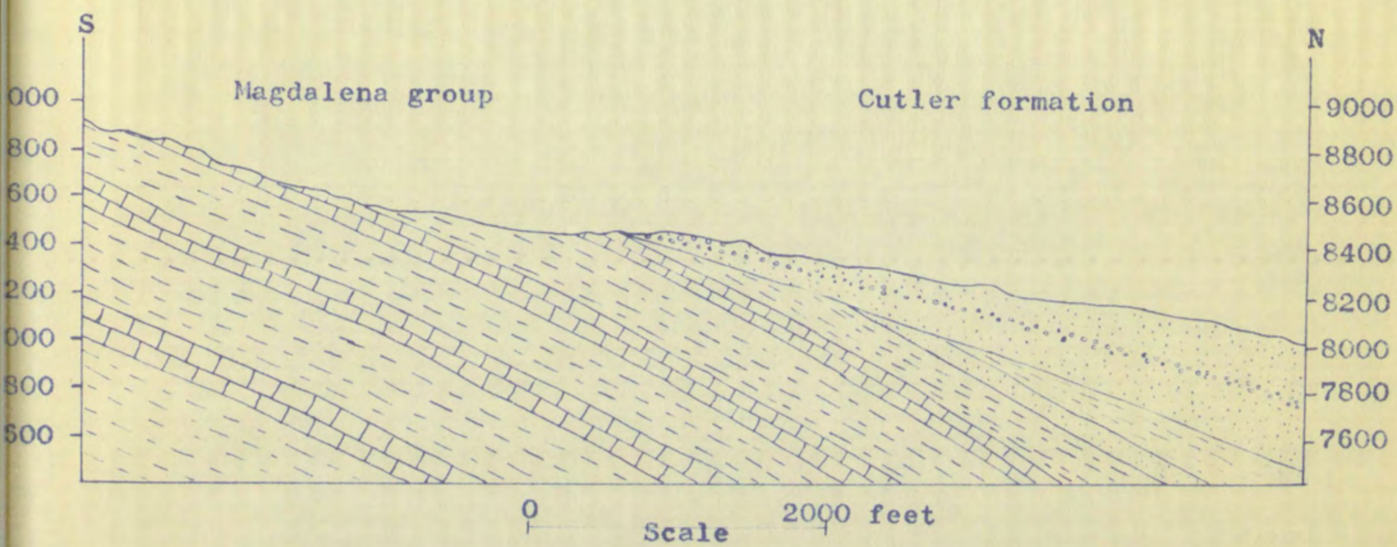


Figure 2. Cross section showing angular unconformity within lower part of the Cutler formation (SE¼ sec. 25, T. 23 N., R. 1 W.).

is red, red-brown and purplish, soft, and slope-forming. About 750 feet of upper Cutler beds are exposed along a scarp two miles south of Gallina (Pl. 1B). Most of the rocks exposed in this scarp are soft, slope-forming, red, red-brown, and purplish shale and siltstone. About 200 feet below the upper contact are massive 20- to 30- foot ledges of red, fine grained, calcareous sandstone, capped by a soft and friable, white, fine-grained sandstone. This white sandstone may be equivalent to the lower part of the Yeso formation, which is mappable about 15 miles south of this area. This scarp is capped by the Poleo sandstone lentil of Upper Triassic age.

South of Cuba, three formational units are recognized in the Permian system. They were mapped by Northrop and Wood (1946) as the Abo, the Yeso, and the San Andres formations. North of latitude 36° N. the Permian rocks are called the Cutler formation and are equivalent to the Abo formation and possibly the lower part of the Yeso formation. Pre-Triassic erosion has removed the upper part of the Yeso formation.

Triassic System

For mapping purposes the Upper Triassic is divided into three units: (1) the Agua Zarca sandstone and Salitral shale members, (2) the Poleo sandstone lentil, and (3) the Chinle shale member.

Lower Triassic rocks are believed to be absent in the San Pedro Mountain area. Momper (1957) suggests that the Agua Zarca sandstone and Salitral shale tongue are age equivalents of the Lower Triassic Moenkopi formation of Arizona. This correlation was suggested despite recovery of Upper Triassic vertebrate remains below the Poleo sandstone is red, red-brown and purplish. About 40 feet of upper Cutler beds are exposed along a stream two miles south of Gallina (Pl. 13). Most of the rocks exposed in this locality are soft, slope-forming, red, red-brown, and purplish shale and siltstone. About 200 feet below the upper contact are massive 20- to 30-foot ledges of red, fine grained, calcareous sandstone, capped by a soft, ... white, fine-grained sandstone. ... to the lower part of the Yeso Formation which ... south of this area. ... is a member of the Chinle Formation of Upper Triassic age.

South of this area Permian rocks are ... in the Permian system. They are ... the Abo (?) ... the Yeso, and the San Andres Formation ... Permian rocks are called the Cutler ... Abo Formation and possibly the lower part of the Yeso Formation. Pre-Triassic erosion has removed the upper part of the Yeso Formation.

Triassic System

For mapping purposes the Upper Triassic is divided into three units: (1) the Agua Zarca sandstone and Salitral shale members, (2) the Poleo sandstone lentil, and (3) the Petrified Forest member.

Lower Triassic rocks are ... in the ... Mountain area. Harper (1935) suggests that the Agua Zarca sandstone and Salitral shale ... of the Moenkopi Formation of Arizona. This correlation ... recovery of Upper Triassic vertebrate remains ...

lentil (Baker and Reeside, 1929, p. 1428). In this study, the rocks are considered to be Upper Triassic, in agreement with the work of Northrop and Wood (1946) and Reeside, et al (1957).

Agua Zarca sandstone and Salitral shale members. Rapid northward thinning of the Agua Zarca sandstone along the Nacimiento-San Pedro highland has been reported by Northrop and Wood (1946). Lookingbill (1953) postulated that the Salitral shale pinches out, and that the Agua Zarca sandstone merges with the Poleo sandstone lentil in the Gallina area, 20 miles north of San Pedro Mountain.

In the area of this study the occurrence of a pebble conglomerate was noted 20 to 30 feet below the base of the massive Poleo sandstone. The conglomerate is greenish and contains rounded quartz pebbles in a matrix of coarse, friable sandstone. It is not resistant to erosion and varies in thickness from 0 to 4 feet. It is overlain by 20 feet of soft, slope-forming, purplish, reddish-brown, and greenish shale.

The writer believes that the conglomerate is the wedge-edge remnant of the Agua Zarca sandstone which thickens to the south, and that the overlying shale is the edge of the Salitral shale, which pinches out to the north-northwest of this area.

Poleo sandstone lentil. The Poleo sandstone lentil is exposed as a broad northward dipping scarp about 1 mile south of Gallina (Pl. 1B). It consists of 75 feet of interbedded conglomerate and sandstone. The lower fourth of the member is dominantly conglomeratic, but there are conglomeratic lenses throughout the unit. The pebbles are well rounded quartz, chalcedony, and limestone fragments averaging ½ inch in diameter.

lentil (Baker and Reeside, 1929, p. [illegible]), the [illegible] are considered to be Upper Triassic, in agreement with the work of Northrop and Wood (1946) and Reeside, et al (1957).

Agua Zarca sandstone and Salitral shale members. Local northward thinning of the Agua Zarca sandstone along the Nacimiento-San Pedro highland has been reported by Northrop and Wood (1946). Wood and [illegible] (1953) postulated that the Salitral shale pinches out, and that the Agua Zarca sandstone merges with the Poleo sandstone lentil in the Gallina area, 20 miles north of San Pedro Mountain.

In the area of this study the occurrence of a conglomerate lentil was noted 20 to 30 feet below the base of the massive Poleo sandstone. The conglomerate is greenish and contains rounded quartz pebbles in a matrix of coarse, friable sandstone. It is [illegible] and varies in thickness from 0 to 4 feet. It is [illegible] soft, slope-forming, purplish, reddish-brown, and green shales.

The writer believes that the conglomerate is the feather-edge remnant of the Agua Zarca sandstone which thickens to the south, and that the overlying shale is the edge of the Salitral shale which pinches out to the north-northwest of this area.

Poleo sandstone lentil. The Poleo sandstone lentil is exposed in a broad northward dipping scarp about a mile south of Regina (Pl. [illegible]). It consists of 75 feet of interbedded conglomerates and sandstone. The lower fourth of the member is dominantly conglomeratic, but there are conglomeratic lenses throughout the unit. The pebbles are well-rounded quartz, chalcedony, and limestone fragments averaging [illegible]

A. Air view (toward the north) of Upper Cretaceous rocks (secs. 11 and 12, T. 23 N., R. 1 W.). Foreground is the Dakota sandstone. The broad valley is in Mancos shale, with the Carlile shale member forming a low ridge in the valley. On the skyline (left center) is the San Jose formation. Right center is the west flank of the French Mesa anticline.

B. Air view (north) of the Poleo scarp. The scarp (foreground) is capped by the Poleo sandstone lentil. Exposed in the scarp are 750 feet of upper Cutler beds. Right center is the west side of the French Mesa anticline.

Buff and gray, calcareous, medium grained, subangular to subrounded sandstone is the predominant rock type of the member. Near the top of the Poleo sandstone lentil is a very calcareous, medium grained, subrounded sandstone 3 to 5 feet thick, characterized by a weathered surface with a dark brown color and a rough appearance.

Chinle shale member. The contact of the Poleo sandstone with the overlying Chinle shale is conformable. The Chinle shale member contains variegated clay, shale, and thin limestone and sandstone stringers. The Nacimiento-San Pedro fault follows the Chinle outcrop in most of the area. The thickest section, which is largely covered with alluvium, forms the valley in which the town of Gallina is located.

The thickness of the Chinle shale member could not be measured because of faulting, but it is 579 feet thick in the Gallina area according to Lookingbill (1953). The lower part of the formation is exposed at the base of the Poleo scarp and consist of 3- to 6- foot beds of red and purple, moderately hard siltstone and sandstone. These beds grade upward into softer red, green, and maroon shales alternating with 2- to 6- inch beds of limestone and lenticular siltstone and sandstone.

Jurassic System

Approximately 1100 feet of continental and evaporite deposits overlie the Chinle formation. These rocks have been assigned to the Jurassic system. They were subdivided and mapped in this area as the Entrada sandstone, the Todilto formation, and the Morrison formation (Pl. 2B).

Buff and grayish-green, medium-grained, [illegible] quartzose sandstone of the [illegible] the [illegible] of the Poleo sandstone member is a very calcareous, [illegible] unrounded sandstone 3 to 5 feet thick. [illegible] surface with a dark brown color and a rough [illegible] texture.

Chinle shale member. The contact of the Poleo sandstone with the overlying Chinle shale member [illegible]. The Chinle is a shale member of variegated, sandy, shale, and thin limestone and [illegible] Nacimiento-San Pedro [illegible] the [illegible] of the area. The thickest section, which [illegible] forms the valley in which the town of Gallina is [illegible].

The thickness of the Chinle shale member could not be measured because of faulting, but [illegible] 300 feet [illegible] according to [illegible] (1933). The lower part of the formation is exposed at the base of the [illegible] and [illegible] of red and purple, [illegible] sandstone and [illegible] grade upward into [illegible] 2- to 6- inch beds of limestone and [illegible] conglomerate.

[illegible] system

Approximately 1400 feet of [illegible] overlie the Chinle formation. These [illegible] have been assigned to the Jurassic system. They are [illegible] in ascending order, the Entrada sandstone, the Todilto formation, and the Morrison formation (Pl. 13).

Entrada sandstone

Exposures of the Entrada sandstone are poor in this area because of faulting. North of Gallina, on the southern end of the French Mesa anticline, part of the Entrada is exposed in a sheer cliff. The colors of the Entrada are distinctive soft reds, whites, and yellows.

The Entrada is composed of fine grained, subangular to subrounded, friable, calcareous sandstone. Thickness of the Entrada sandstone could not be measured in this area. In the French Mesa area, which borders the San Pedro Mountain area on the north, it is approximately 235 feet (Fitter, 1958).

Channeling of the Entrada sandstone into the underlying Chinle shale was noted by Darton (1928, p. 167), and thinning of the Chinle shale to the east and the south, towards Coyote, suggests pre-Entrada erosion (Lookingbill, 1953, p. 32).

Todilto formation

A laminated limestone lies conformably on the Entrada sandstone and grades transitionally into an overlying massive gypsum bed. These units together constitute the Todilto formation.

The limestone ranges from 5 to 10 feet thick in this area. It is gray, platy and has a fetid odor when broken. The gypsum ranges in thickness from 50 to 75 feet and is relatively pure. It is best exposed just north and south of Gallina. In most places the gypsum has been weathered to form a gray, puffy, soft soil cover, known as gypsite. The gypsum shows considerable variation in thickness and is locally absent in the French Mesa area (Fitter, 1958). Erosion following

Entrada Sandstone

Exposures of the Entrada sandstone [illegible] poor in [illegible] because of faulting. Most of [illegible] on [illegible] of the French Mesa anticline [illegible] part of [illegible] the [illegible] cliff. The colors of the Entrada are [illegible] and yellows.

The Entrada is composed of fine grained, [illegible] rounded, friable, [illegible]. [illegible] the Entrada sandstone could not be [illegible]. In the French Mesa [illegible] which borders the [illegible] to the north, it is approximately [illegible] feet (Mattsey, 1957).

Thinning of [illegible] shale was noted by Barton ([illegible], p. [illegible]), and thinning [illegible] shale to the east and [illegible] erosion (Lookingbill, [illegible], p. 32).

Todilto Formation

A laminated [illegible] limestone [illegible] and grades transitionally [illegible]. These units together constitute the Todilto formation.

The limestone ranges from [illegible] gray, platy and has a fetid odor [illegible] thickness from [illegible] just north and south of [illegible] weathered [illegible] gray, [illegible] The gypsum shows considerable [illegible] absent in the French Mesa area ([illegible], [illegible]). [illegible] deposition of the gypsum has been postulated as the most probable reason for varying thicknesses of the formation in New Mexico (Lookingbill, 1953, p. 35).

The marine or nonmarine origin of the Todilto formation is controversial; a recent study of this problem suggests a nonmarine origin (Kirkland, 1958).

Morrison formation

The Morrison formation includes a sequence of continental deposits lying unconformably above the Todilto gypsum and below the basal conglomerate of the Dakota sandstone. The total thickness, measured in the NE$\frac{1}{4}$ sec. 24, T. 23 N., R. 1 W., is 790 feet. The Morrison formation crops out along the west and north sides of the San Pedro Mountain and is abruptly cut out by the San Pedro-Nacimiento fault west of Gallina.

The members of the Morrison formation described by Lookingbill (1953, p. 38) in the Gallina Mountains area are easily recognizable in the San Pedro Mountain area. They are the buff sandstone member, the green claystone member, and the conglomerate member. The contacts between the members are gradational and characterized by interfingering.

Buff sandstone member. A predominantly massive, white to buff, fine- to very fine-grained sandstone, about 375 feet thick, is referred to as the buff sandstone member. In the upper part of the member the massive sandstone is thin bedded, and alternates with lenses of cocoa-brown claystone and shale. Locally, the lower massive sandstone unit forms deposition of the gypsum has been postulated as the most plausible reason for varying thickness of the formation in the area ([illegible], 1953, p. 35).

The marine or nonmarine origin of the Todilto has long been controversial. A recent study of this unit suggests a [illegible] origin (Kirkland, 1959).

Morrison Formation

The Morrison formation designation is here given to continental deposits lying conformably above the Todilto gypsum and below the basal conglomerate of the Dakota formation. The total thickness, measured in the NE 1/4 sec. 26, T. 22 N., R. 1 W., is 790 feet. The Morrison formation crops out along the east and north sides of the San Pedro Mountain and is structurally cut off on the west by the Nacimiento fault west of Regina.

The members of the Morrison formation described by [illegible] (1953, p. 36) in the [illegible] area are not recognizable in the San Pedro Mountain area. Except for the basal sandstone member, the green claystone member, and the [illegible], the contacts between the members are gradational and [illegible].

Buff sandstone member: A predominantly buff, [illegible], fine- to very fine-grained sandstone, about 150 feet thick, is referred to as the buff sandstone member. In the upper part of this member the sandstone is thin bedded and alternates with thin beds of red-brown claystone and shale (Fig. 11). [illegible] pedestal rocks, and in some cases is capped by a remnant of a thin brown calcareous sandstone.

Green claystone member. The green claystone member is composed chiefly of green claystone and shale, 270 feet thick. About 85 feet from the base occurs 17 feet of light brown to buff, fine- to medium-grained sandstone. Overlying the sandstone is soft, slope-forming green shale with interbedded sandstone lenses which make up the remainder of the member.

Conglomerate member. About 122 feet of massive, buff conglomerate and coarse-grained sandstone make up the conglomerate member. The lower conglomerate beds are 62 feet thick and are overlain by 37 feet of green shale with smaller amounts of sandstone. This in turn is overlain by buff sandstone and conglomerate alternating with thin shale beds. The conglomerate contains rounded quartz, chalcedony, and jasper pebbles, up to 2 inches in diameter, in a matrix of coarse grained, subangular sandstone.

The conglomerate member crops out as a steeply dipping hogback along the west side of San Pedro Mountain. It appears to thin to the north and is absent southwest of Gallina, perhaps due to pre-Dakota erosion (Lookingbill, 1953, p. 43). Beds equivalent to the conglomerate member grade laterally into sandstone to the south (Swift, 1956, p. 24).

Swift (1956, p. 42) suggested that the conglomerate member may be Lower Cretaceous, equivalent to the Burro Canyon formation of Colorado. He named the conglomerate member Deadmans Peak formation, from excellent exposures near Dead Mans Peak in the Gallina Mountains.

pedestal rocks, and the conglomerate is capped by a resistant [illegible] brown calcareous sandstone.

<u>Green claystone member</u>. The green claystone member is a variable sequence of green claystone and shale 40 feet thick. [illegible] the base occurs 17 feet of light brown to buff, fine- to medium-grained sandstone. Overlying the sandstone is [illegible] greenish gray shale with interbedded sandstone lenses [illegible] the remainder of the member.

<u>Conglomerate member</u>. About 150 feet of massive buff conglomerate and coarse-grained sandstone make up the conglomerate member. The lower conglomerate beds are [illegible] thick and are overlain by 35 feet of green shale with smaller amounts of sandstone. This in turn is overlain by buff sandstone and conglomerate alternating with thin shale beds. The conglomerate contains rounded quartz, chert, [illegible] pebbles up to 2 inches in diameter, in a matrix of [illegible] sandstone.

The conglomerate member forms a steep ridge [illegible] along the west side of [illegible]. It appears to thin to the north and is absent southwest of [illegible], perhaps due to pre-Dakota erosion ([illegible], 1953, p. 43). Beds equivalent to the conglomerate member grade laterally into [illegible] to the south ([illegible], p. 41).

Swift ([illegible], p. [illegible]) suggested that the [illegible] be Lower Cretaceous, equivalent to the [illegible] formation of [illegible]. He named the conglomerate member [illegible] from exposures near [illegible] in the [illegible].

Cretaceous System

The Cretaceous system includes mainly marine rocks, about 4900 feet thick. They crop out in a wide band of alternating resistant sandstone ridges and nonresistant shale valleys, parallel to the western flank of the north trending San Pedro highland (Pl. 1A). To the north, the strike turns northeasterly forming the San Pedro Nose and a broad open syncline (Fig. 3).

The Cretaceous formations include the Dakota sandstone, Mancos shale, Point Lookout sandstone, Menefee formation, La Ventana tongue of the Cliff House formation, Lewis shale, and Ojo Alamo sandstone. All are of Upper Cretaceous age.

Dakota sandstone

The name Dakota has been applied to the lower, massive sandstone and conglomerate beds of the Upper Cretaceous series in the San Pedro Mountain area.

The Dakota section is divided into three units. The lower, about 31 feet thick, is a resistant, white to buff, argillaceous, fine to medium grained sandstone, conglomeratic at the base. The conglomerate is 8 feet thick, with clay nodules, quartz, and quartzite pebbles up to 3 inches in diameter. The middle unit contains 151 feet of nonresistant, dark gray, carbonaceous, blocky shale, interbedded with nonresistant, white, buff, and light gray, fine- and medium-grained sandstone. The upper unit is composed of light gray and buff, fine grained, friable, slightly argillaceous, massive-bedded sandstone, 17 feet thick.

Cretaceous System

The Cretaceous system includes [illegible] about [illegible] feet thick. They crop out in a wide band of [illegible] sandstone ridges and [illegible] of the [illegible] western flank of the [illegible] (Pl. [illegible]). To the north, the [illegible] and a broad open syncline (Fig. [illegible]).

The Cretaceous formations [illegible] are the Dakota sandstone, Mancos shale, Point Lookout sandstone, Menefee formation, [illegible] the Cliff House formation, Lewis shale, and [illegible] are of Upper Cretaceous age.

Dakota sandstone

The name Dakota has been applied [illegible] sandstone and conglomerate beds of the [illegible] Mountain area.

The Dakota sandstone is [illegible] 31 feet thick, is a [illegible] medium grained [illegible] is 8 feet [illegible] 3 inches in diameter. The [illegible] dark gray, carbonaceous, [illegible] shale, [illegible] white, buff, and light gray, [illegible] upper unit is composed of light gray and buff, fine grained, [illegible] slightly argillaceous, [illegible] 17 feet thick.

Mancos shale

The Mancos shale is an olive-green, drab, and gray, sandy, calcareous, marine shale, approximately 2190 feet thick in the area studied. It can be subdivided into three mappable units: the Lower Mancos shale member, the Carlile shale member, and the Upper Mancos shale member. To the north and northwest Dane et al. (1948) subdivided the Mancos shale into the following: Graneros shale member, Greenhorn limestone member, Carlile shale member, Niobrara calcareous shale member, and Upper shale member. The only units of Dane's subdivision which are recognizable in this area are the Carlile shale and possibly the Greenhorn limestone which is mapped within the Lower Mancos member.

Lower Mancos shale member. Resting conformably on the Dakota sandstone, and consisting primarily of dark gray, thinly bedded, arenaceous, calcareous shale, is the Lower Mancos shale member. In the lower part of the member thin beds of limestone, 2 to 6 inches thick, alternate with dark gray, calcareous shale. Very fine-grained sandy zones intermingle with shale through the upper part of the member. Beds of septarian concretions are found in the upper one-fourth of the member.

Carlile shale member. Rocks referred to as the Carlile shale member are equivalent to only the upper part of the Carlile member, as defined by Dane et al. (1948). The Carlile shale member of this report was mapped primarily on its topographic expression; it forms low hogbacks in the middle of the Mancos shale. Dane included the zone of septarian concretions which were mapped as part of the Lower Mancos shale member in this report. This member consists of 150 feet of thin, platy, Mancos shale

The Mancos shale, as far as [illegible] exposed [illegible] area, is a [illegible] calcareous, marine shale, exposed [illegible] studied. It can be subdivided into [illegible] Mancos shale member, the [illegible] member, and the [illegible] shale member. [illegible] (19[illegible]) [illegible] the Mancos shale into [illegible] Mancos shale member, [illegible] limestone member, Carlile [illegible] member, and Upper shale member. The only units of [illegible] which are recognizable in the area are the [illegible] and the Greenhorn limestone which [illegible].

Lower Mancos shale member. [illegible] and consisting primarily of [illegible] calcareous shale. [illegible] of the member [illegible] with dark gray, calcareous shales. [illegible] intermingle [illegible] septarian concretions are found in the upper [illegible] of the member.

Carlile shale member. [illegible] are equivalent [illegible] by Dane et al. (19[illegible]). [illegible] mapped [illegible] in the middle of the [illegible] concretions which [illegible] in this report. This member [illegible].

calcareous, gray, very finely sandy siltstone and silty, very fine-grained, calcareous sandstone.

Upper Mancos member. The Upper Mancos member is predominantly composed of gray and drab, calcareous, sandy shale and thin stringers of limestone. The shale becomes increasingly sandy in the upper one-third of the member, and sandy zones increase in number and thickness.

Mesaverde group

On the eastern side of the San Juan Basin, the Mesaverde group was divided by Dane et al. (1948) into three members: the Hosta sandstone member, the Allison and Gibson member (undifferentiated), and the La Ventana sandstone member. Beaumont et al. (1956, p. 2149), suggested that the Mesaverde formation be raised to group status, equivalent to the Mesaverde group on the western side of the San Juan Basin, and renamed the members as follows: Point Lookout sandstone, Menefee formation, and La Ventana tongue of the Cliff House formation. Though the relations of the lithologic units on the eastern and western sides of the San Juan Basin have become generally known and accepted, it is evident that the dual systems of nomenclature now employed should be reconciled and standardized.

The Mesaverde group varies in thickness from 650 feet to over 700 feet in the area covered by this report.

Point Lookout sandstone. The Point Lookout sandstone gradationally overlies the Mancos shale and forms low hogbacks through most of the area of this report. It consists of 130 feet of sandstone, massive, calcareous, gray, very finely sandy siltstone and [illegible] fine grained, calcareous sandstone.

Upper Mancos member. The Upper Mancos shale is predominantly composed of gray and dark, calcareous, sandy shale and thin lenses of limestone. The shale becomes increasingly sandy in the upper one-third of the member, and sandy zones [illegible] thickness.

Mesaverde group

On the eastern side of the San Juan Basin, the Mesaverde group was divided by Dane et al. (1937) into three members: the lower sandstone member, the [illegible] member (middle member) and the La Ventana sandstone member. Beaumont et al. ([illegible], p. [illegible]) suggested that the Mesaverde formation be raised to group status, equivalent to the Mesaverde group on the western side of the San Juan Basin, and renamed the members as follows: Point Lookout sandstone, Menefee formation, and La Ventana tongue of the Cliff House sandstone. Though the relations of the lithologic units on the eastern and western sides of the San Juan Basin have been [illegible], it is evident that the dual systems of nomenclature [illegible] be reconciled and standardized.

The Mesaverde group ranges in thickness from [illegible] feet to 700 feet in the area covered by this report.

Point Lookout sandstone. The Point Lookout sandstone [illegible] overlies the Mancos shale and [illegible] area of this report. It consists of [illegible] feet of sandstone, [illegible] white, buff, and light gray, fine to coarse grained, slightly argillaceous, micaceous, and friable with some crossbedding. Alternating with the sandstone, especially in the lower part of the formation, are small amounts of dark gray, fissile, calcareous shale.

Menefee formation. In conformable contact with the Point Lookout sandstone are the continental deposits of the Menefee formation. It is composed of 480 feet of slope-forming, friable, light gray, silty sandstone, interbedded with carbonaceous shale and lignitic shale. Near the top of the formation are small lenticular beds of subbituminous coal.

La Ventana sandstone tongue. The La Ventana sandstone tongue conformably overlies the Menefee formation. It is composed of 40 to 70 feet of massive, cliff forming, light gray and buff, fine to medium grained, well sorted sandstone. Variation in thickness seems to be due to interfingering of the La Ventana sandstone tongue into the overlying Lewis shale.

Lewis shale

The Lewis shale is composed of 1850 feet of soft, dark gray and drab, sandy, marine shale, and calcareous, iron-stained, concretionary beds. About 600 feet from the lower contact there are several beds of very tight, hard, sandy, fossiliferous siltstone, 6" inches to 3" feet thick. The Lewis shale intertongues with the underlying La Ventana sandstone tongue.

white, buff, and light gray. Some of the sandstone is slightly argillaceous, micaceous, and feldspathic, with carbonaceous streaks. Alternating with the sandstone, especially in the lower part of the formation, are small lenses of dark gray, fissile calcareous shale.

Menefee formation. In conformable contact with the Point Lookout sandstone are the continental deposits of the Menefee formation. It is composed of 450 feet of slope-forming, lenticular, light gray, silty sandstone, interbedded with carbonaceous shale and lignitic coal. Near the top of the formation are small lenticular beds of subbituminous coal.

La Ventana sandstone tongue. The La Ventana sandstone tongue conformably overlies the Menefee formation. It is composed of 40 to 90 feet of massive, cliff forming, light gray and buff, fine to medium grained, well sorted sandstone. Variation in thickness is due to the interfingering of the La Ventana tongue with the overlying Lewis shale.

Lewis shale

The Lewis shale is composed of 1,300 feet of soft, dark gray and drab, sandy, marine shale, and calcareous, iron-stained, concretionary beds. About 600 feet from the lower contact there are several beds of very tight, limy, sandy, fossiliferous limestone from 2 to 3 feet thick. The Lewis shale intertongues with the underlying La Ventana sandstone tongue.

The Pictured Cliffs formation, an important oil- and gas-producing formation in the San Juan Basin pinches out southwest of Cuba in T. 20 N., R. 2 W. and is not present in this area. The overlying Fruitland and Kirtland formations become indistinguishable northeast of T. 19 N., R. 2 W. and were mapped by Dane (1946) as the Kirtland formation up to T. 21 N., R. 1 W. In the area of this report the Kirtland is indistinguishable from the Lewis shale, and could not be mapped separately. In the northwestern part of the French Mesa area, in T. 25 N., R. 1 E., the Pictured Cliffs, the Fruitland, and the Kirtland formations are again distinguishable and mappable units. The stratigraphic relations of these formations in the San Pedro Mountain area indicate that deposition took place in an embayment of the Cretaceous sea both from the southwest and from the north and northeast (Dane, 1946).

Ojo Alamo formation

The Ojo Alamo sandstone lies conformably on the Lewis shale (Dane, 1946). The best exposure of the Ojo Alamo sandstone is in the SW$\frac{1}{4}$ sec. 11, T. 23 N., R. 1 W. It forms a steeply dipping hogback, revealing 25 feet of conglomeratic, buff to light gray, medium to coarse grained sandstone, containing siliceous pebbles and much petrified wood.

The Ojo Alamo sandstone was observed to thicken and thin along the Nacimiento-San Pedro Mountain front (Packard, F. A., Humble Oil & Refining Company, oral communications). This variation in thickness is thought to be due to folds developing along the margin of the San

The Pictured Cliffs formation, an important gas-producing formation in the San Juan Basin, pinches out northeast of Cuba in T. 20 N., R. 2 W., and is not present in this area. The overlying Fruitland and Kirtland formations [illegible] northeast of T. 19 N., R. 2 W., and are mapped by Dane (1946) as the Kirtland formation up to T. 21 N., R. 1 W. In the area of this report the Kirtland and [illegible] could not be mapped separately. In the [illegible] French Mesa area, in T. 2? N., R. 1 E., [illegible] Pictured Cliffs, Fruitland, and the Kirtland formations are [illegible] mappable units. The stratigraphic relationships of these formations in the San Pedro Mountain area indicate [illegible] embayment of the Cretaceous sea [illegible] north and northeast (Dane, 1946).

Ojo Alamo Formation

The Ojo Alamo sandstone [illegible] (Dane, 1945). The best exposure of the Ojo Alamo [illegible] SW¼ sec. 11, T. 2? N., R. 1 W. [illegible] revealing 25 feet of conglomeratic [illegible] course grained sandstone [illegible] petrified wood.

The Ojo Alamo sandstone [illegible] the Nacimiento-San Pedro [illegible] Refining Company [illegible]. This [illegible] is thought to be due to folds [illegible]

Juan Basin previous to Ojo Alamo deposition. The Ojo Alamo formation thins noticeably to the north from the San Pedro Mountain area and is thought by Dane (1946) to be equivalent to a sandstone about 100 feet above the base of the Animas formation in the French Mesa area, sec. 17, T. 25 N., R. 1 E. The Animas formation is equivalent to the Ojo Alamo and Nacimiento formations of the San Pedro Mountain area (Dane, 1946).

Tertiary System

Nacimiento formation

The Nacimiento formation of Paleocene age is covered in practically all of the area of this report. The only exposures are in the south center of sec. 34, T. 23 N., R. 1 W. According to Dane (1946) there is a notable hiatus between the Nacimiento formation and the underlying Cretaceous rocks on the south side of the San Juan Basin. The thickness of the Nacimiento formation is approximately 800 feet in the San Pedro Mountain area. It consists of banded, light and dark gray clay, with lesser amounts of light gray, fine-grained sandstone. West of Cuba, 12 miles south of this area, the Nacimiento formation contains a few discontinuous coal seams that range from 1 to 10 inches in thickness. The Nacimiento formation changes to a coarse grained, yellowish sandstone in T. 24 N., R. 1 E. and grades northward into the Animas formation in the French Mesa area.

San Jose formation

The San Jose formation, formerly called Wasatch, is of Eocene age and is the youngest formation mapped in the San Pedro Mountain area

Juan Basin previous to the Alamo deposition. The Ojo Alamo formation thins noticeably to the north of the San Pedro Mountains. It is thought by Dane (1946) to be equivalent to a sandstone about 100 feet above the base of the Animas formation in the French Mesa area, sec. 17, T. 25 N., R. 2 E. The Animas formation is thought to be the [illegible] Alamo and Nacimiento formations of the San Juan Basin area (Dane, 1946).

Tertiary System

Nacimiento formation

The Nacimiento formation of Paleocene age is exposed over practically all of the area of this report. The only [illegible] is in the south center of sec. 34, T. 19 N., R. 1 W. According to Dane (1946) there is a [illegible] between the [illegible] formation [illegible] the underlying [illegible] [illegible]. The thickness of the Nacimiento formation is approximately 500 feet in the San Pedro Mountain area. [illegible] clay, with lesser amounts of [illegible]. [illegible] of Cuba, 12 miles south [illegible] a few [illegible]. The Nacimiento formation [illegible] in T. 24 N., R. 1 E. [illegible] the French Mesa area.

San Jose formation

The San Jose formation, formerly called Wasatch, is of Eocene age and is the youngest formation exposed in the [illegible] other than Quaternary deposits. It is believed to be preceded by a hiatus representing late Paleocene time. An erosional break was observed by Simpson (1948, p. 376) between the Nacimiento formation and the massive, commonly conglomeratic sandstone of the San Jose formation on Cuba Mesa, 12 miles to the south. There seems to be a slight angular unconformity, although the discordance in dip is so small, and true bedding planes are so hard to determine, that this is uncertain.

The thickness of the San Jose formation in the San Pedro Mountain area is more than 1000 feet, probably over 2000 feet (Dane, 1946). Exposures along the western side of the area consist of gray and tan conglomerate, sandstone, and siltstone, and purplish banded clay and shale.

The San Jose formation is divided into the basal conglomeratic Cuba Mesa sandstone (Koogle, 1955) and two "clay facies", the Almagre and Largo beds (Granger, 1914; Simpson, 1948). Dane (1946) stated that on the southeastern side of the San Juan Basin the age of the lower 500 feet of the San Jose formation is undetermined, implying that the Cuba Mesa sandstone may be of Paleocene age. Koogle (1955) found the Cuba Mesa sandstone to be vertical or overturned in the vicinity of La Jara along the Nacimiento-San Pedro Mountain front. The Almagre beds, of Eocene age (Simpson, 1948, p. 363), unconformably overlie the Cuba Mesa sandstone. Similar overstepping relationships have been found on the northwestern side of the San Juan Basin near Bridgetimber Mountain southwest of Durango, Colorado (Baltz, 1953, fig. 6).

other than Quaternary deposits. This is believed to be caused by a hiatus representing late Paleocene time. A gradational contact was observed by Simpson (1948, p. 274) between the Nacimiento Formation and the massive, commonly conglomeratic sandstone of the San Jose Formation on Cuba Mesa, 12 miles to the south. There seems to be a slight angular unconformity, although the discordance in dip is so small, and true bedding planes are so hard to distinguish, that this is uncertain.

The thickness of the San Jose Formation in the San Pedro Mountain area is more than 1000 feet, probably over 1400 feet (Dane, 1946). Exposures along the western side of the area consist of gray and tan conglomerate, sandstone, and siltstone, and purple, brown and gray shale.

The San Jose Formation is divided into the basal conglomeratic Cuba Mesa sandstone (Baltz, 1967) and San Jose [illegible] and Largo beds (Granger, 1914; Simpson, 1948). Dane (1946) states that on the southeastern side of the San Juan Basin the age of the upper 600 feet of the San Jose Formation is Eocene [illegible], implying that the Cuba Mesa sandstone may be of Paleocene age. [illegible] found the Cuba Mesa sandstone to be [illegible] in the vicinity of [illegible] along the Nacimiento-San Pedro Mountain area. The [illegible] Eocene age (Simpson, 1948, p. [illegible]), [illegible] the Cuba Mesa sandstone. Similar overlapping relationships have been found on the northwestern side of the San Juan Basin near [illegible] Mountain southwest of Durango, Colorado (Barnes 1953, fig. [illegible]).

The San Jose formation was named by Simpson (1948, p. 280) from the San Jose valley in northwestern Sandoval County, T. 23 N., R. 1 W.

Quaternary System

Terrace gravels

Terrace gravels in the San Pedro Mountain area consists principally of well rounded granite gneiss cobbles with lesser amounts of limestone debris. A pediment surface was observed in sec. 11, T. 22 N., R. 1 W. (Fig. 5). It slopes westward from the San Pedro highland at about two degrees and is from 40 to 60 feet higher than the surrounding area. Smooth, well rounded cobbles of granite gneiss and limestone cover the surface of the pediment. Only a few remnants of the pediment are left in the San Pedro Mountain area, as general regional uplift of the San Juan Basin has resulted in degradation of the pediment surface.

Alluvium and colluvium

Stream deposits are found in most of the valleys, particularly those underlain by the Lewis, Mancos, and Chinle shales. The alluvium is mostly silt and sand, but particles range from clay to boulder sizes. The thickest alluvium deposits were noted in the northern part of the area where the Rio Gallina has cut through 30 feet of alluvial fill above Mancos shale.

Landslide material may be found locally at the bases of steep slopes along the Nacimiento-San Pedro fault. It is composed mainly of talus debris from the Precambrian granite gneiss.

The San Jose formation was named by Simpson (1948, p. [illegible]) from the San Jose valley in northwestern Sandoval County, T. [illegible] N., R. 1 W.

Quaternary System

Terrace gravels

Terrace gravels in the San Pedro Mountains area consist principally of well rounded granite gravels with a lesser amount of limestone debris. A pediment surface was mapped in sec. [illegible], T. 22 N., R. 1 W. (Fig. 5). It slopes west and from the San Pedro highland at about two degrees and is from 40 to 50 feet higher than the surrounding area. Mostly well rounded cobbles of granite, gneiss, and limestone cover the surface of the pediment. Only a few remnants of this pediment are left in the San Pedro Mountains area, suggesting that uplift of the San Juan Basin has resulted in dissection of the pediment surface.

Alluvium and colluvium

Stream deposits are found in most of the valleys, particularly in those underlain by the Lewis, Menefee, and Mancos shales. The alluvium is mostly silt and sand, but locally it contains [illegible] boulders. The thickest alluvium deposits were found in the northern part of the area where the [illegible] well [illegible] 30 feet of alluvium before entering Mancos shale.

Landslide material may be found locally at the bases of steep slopes along the Nacimiento-San Pedro fault. It is composed mainly of talus debris from the Precambrian granite and gneiss.

STRUCTURE

Regional Setting

A relatively narrow belt of north-northwesterly trending folds extends for 150 miles along the eastern and northeastern flank of the San Juan Basin (Fig. 3). These structural features are part of the Southern Rocky Mountain province and lie between the Great Plains on the east and the Colorado Plateau on the west (Fenneman, 1931, p. 92). The southern half of this belt is characterized by sharp, asymmetrical, northerly aligned, plunging folds. The northern part is made up of sharp domical folds aligned in a north-northwesterly direction (Dane, 1948). This line of positive features is divided into three tectonic divisions by Kelley (1957, p. 45). From north to south these are: (1) the Archuleta arch, (2) the French Mesa-Gallina uplift, and (3) the Nacimiento-San Pedro uplift.

The Archuleta arch forms a low structural divide between the San Juan Basin on the west and the narrow downwarp of the Chama embayment on the east (Fig. 3). It is about 75 miles long and 6 to 16 miles wide (Kelley, 1957, p. 47) and becomes part of the San Juan dome in southern Colorado. It is modified by numerous short folds and faults.

The French Mesa-Gallina division is relatively small, about 24 miles long and 4 to 6 miles wide. This tectonic belt is composed of three anticlines. The southernmost is the French Mesa anticline, an asymmetrical fold inclined to the west. The two northern structures, the Rio Gallina and Gallina anticlines are asymmetrical to the east, opposite to the French Mesa anticline.

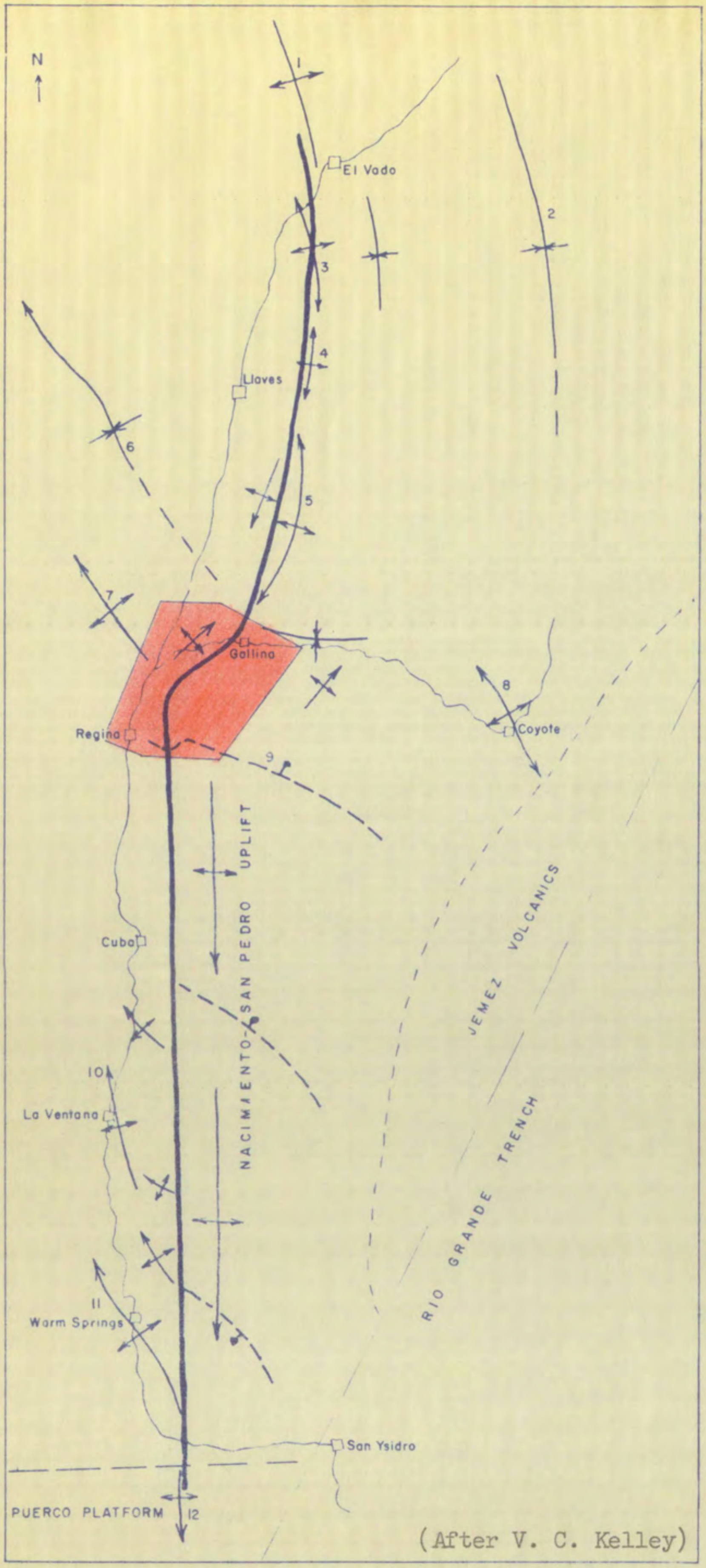
STRUCTURE

Regional Setting

A relatively narrow belt of [illegible] northwesterly-trending [illegible] extends for 190 miles along the eastern and [illegible] of the San Juan Basin (Fig. 2). The [illegible] lateral margin of the Southern Rocky Mountain [illegible] and [illegible] between the [illegible] on the east and the Colorado Plateaus on the west (Kelley, 1955, p. 22). The southern half of this belt is [illegible] (Fig. 2) [illegible] northerly [illegible] of [illegible] folds. The northern part is made up of sharp domical folds [illegible] in a north-[illegible] en echelon (Kelley, 1948). This zone of [illegible] has been divided into [illegible] divisions by Kelley (1955, p. 45). From north to south these are: (1) the Archuleta arch, (2) the French Mesa-Gallina uplift, and (3) the Nacimiento-San Pedro uplifts.

The Archuleta arch forms [illegible] the boundary between the San Juan Basin on the west and the [illegible] on the east (Fig. 3). This [illegible] (Kelley, 1955, p. 47) [illegible] the San Juan [illegible] in southern Colorado. It is modified by numerous [illegible].

The French Mesa-Gallina uplift is [illegible] miles long and 4 to [illegible] miles wide. [illegible] three anticlines. The [illegible] asymmetrical [illegible] to the [illegible], whereas the Rio Gallina and Gallina anticlines are asymmetrical to the east, opposite to the French Mesa anticline.



1. ARCHULETA ARCH
2. CHAMA EMBAYMENT
3. GALLINA ANTICLINE
4. RIO GALLINA ANTICLINE
5. FRENCH MESA ANTICLINE
6. AXIS OF SAN JUAN BASIN
7. SAN PEDRO NOSE
8. COYOTE ANTICLINE
9. THE SAN PEDRO MTN FAULT
10. LA VENTANA ANTICLINE
11. RIO SALADO ANTICLINE
12. TIERRA AMARILLA ANTICLINE

EXPLANATION

Axis of anticline

Axis of syncline

Nacimiento-San Pedro reverse fault

Normal fault

0 4 8 16 Miles

Scale in miles

Figure.-3. Regional structures on the eastern flank of the San Juan Basin. Area of study in red.

East of the Archuleta and French Mesa-Gallina uplifts is the Chama embayment, an area of low dips, generally in the form of an elongated, north-northwesterly trending shallow trough.

The Nacimiento-San Pedro uplift,. is about 50 miles long and 8 to 10 miles wide (Kelley, 1957, p. 47). It borders the Jemez structural bench and the Rio Grande depression to the east and the Puerco Platform to the south (Fig. 3). It is terminated on the west by the Nacimiento-San Pedro fault, which trends almost due north for the full length of the mountain range. The beds on the downthrown side of the fault front are for the most part vertical, and in a number of places they are overturned.

In its present configuration, the Nacimiento-San Pedro uplift takes the form of two large Precambrian blocks upthrust from the east against sediments of Mississippian to Cretaceous age to the west. East of Cuba, in Senorita Canyon, the northernmost block is faulted and rotated downward so that some of the sediments in the uplift are preserved and exposed at a fairly low level (Packard, F. A., Humble Oil & Refining Company, oral communications). This block, San Pedro Mountain, is terminated on the north by the San Pedro Mountain fault (Fig. 3). Precambrian rocks are faulted against Mississippian and Pennsylvanian rocks.

The area of this report is part of the Nacimiento-San Pedro uplift. It lies on the northwestern flank of this structure, between the San Pedro Mountain and the southern end of the French Mesa anticline.

East of the [illegible] and [illegible]-[illegible] uplift is the Chamuma embayment, an area of low dips, generally in the form of an elongated, north-northwest-trending [illegible].

The Nacimiento-San Pedro uplift is about 50 miles long and 8 to 10 miles wide (Kelley, 1955, [illegible]). It is bordered by the structural bench and the Rio Grande depression on the east and the Puerco Platform to the south (Fig. 3). [illegible] the Nacimiento-San Pedro uplift, which trends [illegible] the full length of the mountain range. The beds on the [illegible] the fault front are for the most part [illegible] they are overturned.

In its present configuration, the Nacimiento-San Pedro uplift takes the form of two large [illegible] faulted against sediments of [illegible] Cuba, in Senorito Canyon, the [illegible] downward so that some of the sediments in the uplift [illegible] exposed at a fairly low level (Renick, [illegible] Company, oral communication). [illegible] nated on the north by the San [illegible] fault (Fig. 3). [illegible] rocks are faulted against [illegible].

The area of this report is west of the Nacimiento-San Pedro uplift. It lies on the [illegible] western flank of this [illegible], between the San Pedro Mountain and the [illegible] of the [illegible].

Local Structure

Folds

The area of this report consists of the northern and western flanks of a broad, asymmetrical fold inclined to the west, and broken along the western flank by a high angle reverse fault. The beds along the west flank dip steeply and are overturned in several places. In the northern part of the area, the steeply dipping beds make a broad turn to the northeast, forming the San Pedro nose (Pl. 2B). To the south, the transverse San Pedro Mountain fault forms the northern end of San Pedro Mountain (Fig. 3).

A small northeasterly plunging anticlinal nose is located in sec. 7, T. 23 N., R. 1 E. This structure is slightly asymmetrical to the southeast and the closure is probably less than 50 feet. It is thought to have formed as a result of northwesterly - southeasterly compressive stresses which resulted from the rupture of the Nacimiento-San Pedro high angle reverse fault (Fig. 5, Cross section A-A').

Faults

Nacimiento-San Pedro fault. The Nacimiento-San Pedro fault zone, named by Renick (1931, p. 71), is approximately 70 miles long. It extends from the southern end of the Nacimiento Mountains, in the Tierra Amarilla anticline, northward through the French Mesa-Gallina uplifts (Fig. 3). Along the Nacimiento-San Pedro uplift, it is an eastward-dipping high-angle fault. Northward the throw of the fault decreases, and at

A. View of the Todilto gypsum repeated by faulting. The fault is just back of the first white ridge. The Conglomerate member of the Morrison formation forms the hogback behind the massive gypsum beds.

B. Air view (toward the north) off the northern end of San Pedro Mountain. Foreground is the Poleo scarp. The white ridge (right center) is the Todilto gypsum, underlying the Morrison formation. The broad valley is cut in the Mancos shale. The hogback (center) is the Mesaverde group which outlines the west flank of the French Mesa anticline (upper right).

the northern end of the French Mesa anticline the angle of the fault appears to be nearly vertical (Fitter, 1958). In the Gallina anticline the fault plane reverses its dip from east to west. The relative displacement is also reversed, the upthrust being from the west (Lookingbill, 1953, p. 67).

A number of small anticlines and synclines developed along the southern part of this fault zone. Their axes tend to swing away from the fault and plunge northwest into the San Juan Basin (Fig. 3). Kelley (1955, p. 66) suggested the possibility that they were formed by right lateral movement along the southern part of the Nacimiento-San Pedro fault.

The Nacimiento-San Pedro fault runs north from the south central part of the San Pedro Mountain area. It turns northeastward in sec. 24, T. 23 N., R. 1 W. and continues in this direction for three miles, to just southwest of Gallina. At this point it turns to the north, cutting the French Mesa anticline (Fig. 5). The fault apparently follows zones of weak rocks. It follows the upper Chinle shale around the San Pedro nose (Fig. 5, Cross sections A-A' through D-D'). Southwest of Gallina, where the fault changes strike, it cuts across Jurassic beds and follows the upper shale beds of the Morrison formation to the southern end of the French Mesa anticline.

The angle of the fault is difficult to determine but in the SW$\frac{1}{4}$ sec. 36, T. 23 N., R. 1 W., the conglomerate member of the Morrison formation is within 600 feet of the upfaulted Precambrian block. The Morrison beds dip 84° W., suggesting that the fault plane at this point the northern end of the [illegible] [illegible] the [illegible] of the fault appears to be nearly vertical ([illegible], [illegible]). In the [illegible] the fault plane reverses its dip from east to west. The relative displacement is also reversed, the upthrown block being from the west ([illegible], 1953, p. [illegible]).

[illegible] of small anticlines and synclines have formed along the southern part of this fault zone. These axes tend to strike away from the fault and plunge [illegible] into the San [illegible] (Fig. [illegible]). [illegible] (1955, p. [illegible]) suggested the possibility that they were formed by [illegible] lateral movement along the southern part of the [illegible]-San Pedro fault.

The [illegible]-to-San Pedro fault [illegible] from the south-central part of the San Pedro [illegible] area. It [illegible] in [illegible] T. 23 N., R. 1 W. and [illegible] in [illegible] direction [illegible] miles, to just south-east of [illegible], at which point it turns to the [illegible], [illegible] the French Mesa anticline (Fig. [illegible]). The fault [illegible] of weak rocks. It follows the [illegible] of the San Pedro nose (Fig. [illegible], cross sections [illegible]). [illegible] where the fault changes strike, it cuts across [illegible] beds and follows the upper shale beds of the Morrison Formation on the [illegible] of the French Mesa anticline.

The [illegible] of the fault is difficult to determine but in the [illegible] sec. 35, T. 23 N., R. 1 W., the [illegible] member of the Morrison Formation is within [illegible] feet of the [illegible] Cretaceous [illegible]. The Morrison beds dip [illegible] W., [illegible] that the fault [illegible] at [illegible] is almost vertical. The best exposure of the fault is in sec. 24, T. 23 N., R. 1 W. (Fig. 4). The dip of the fault at this point is approximately 83° SE., and the stratigraphic displacement is over 900 feet.

The displacement of the fault increases to the south. In sec. 18, T. 23 N., R. 1 E. the Chinle shale is upthrust against Jurassic beds, indicating a relatively small displacement at this point. Following the Nacimiento-San Pedro fault to the south, older beds are progressively upthrust, until in sec. 36, T. 23 N., R. 1 W., Precambrian lies directly against Jurassic. The stratigraphic throw at this point is approximately 5000 feet.

San Pedro Mountain fault. The northern end of San Pedro Mountain is truncated by the San Pedro Mountain fault; it is an oblique-slip fault and trends west, transverse to the axis of the mountain. In the SW$\frac{1}{4}$ sec. 1, T. 22 N., R. 1 W., the plane of the San Pedro Mountain fault dips 63° NE.

The San Pedro Mountain fault can be followed for approximately 12 miles, disappearing to the west under soil and alluvium cover about 2 miles west of San Pedro Mountain in sec. 34, T. 23 N., R. 1 W. The relationship of the San Pedro Mountain fault to the Nacimiento-San Pedro fault is problematical. In sec. 1, T. 22 N., R. 1 W., where these faults meet, dense vegetation and soil cover prevented mapping.

Minor faults. There are numerous small cross faults in the area. Most are of minor importance with displacements ranging from 10 to 80 feet.

is almost vertical. The best exposure of the fault is in sec. 24, T. 23 N., R. 1 W. (Fig. 4). The dip of the fault at this point is approximately 63° SE., and the stratigraphic displacement is over 700 feet.

The displacement of the fault increases to the south. In sec. 18, T. 23 N., R. 1 W., the Clifty shale is brought against [illegible] beds, indicating a relatively small displacement at this point. Following the Nacimiento-San Pedro fault to the south, younger beds are progressively cut out, until in sec. 30, T. 23 N., R. 1 W., the [illegible] lies directly against Triassic. The stratigraphic throw at this point is approximately 3000 feet.

San Pedro Mountain fault. The northern end of San Pedro Mountain is truncated by the San Pedro Mountain fault, which is an oblique-slip fault and trends west, transverse to the axis of the mountain. In the NW¼ sec. 1, T. [illegible] N., R. 1 W., the plane of the San Pedro Mountain fault dips 63° NE.

The San Pedro Mountain fault can be followed for approximately [illegible] miles, disappearing to the west under alluvial cover about 2 miles west of San Pedro Mountain in sec. 24, T. 23 N., R. 1 W. The relationship of the San Pedro Mountain fault to the Nacimiento-San Pedro fault is problematical. In sec. [illegible], T. 22 N., R. 1 W., where these faults meet, dense vegetation and soil cover prevent mapping.

Minor faults. There are numerous small cross faults in the area. Most are of minor importance with displacements ranging from 10 to 50 feet.

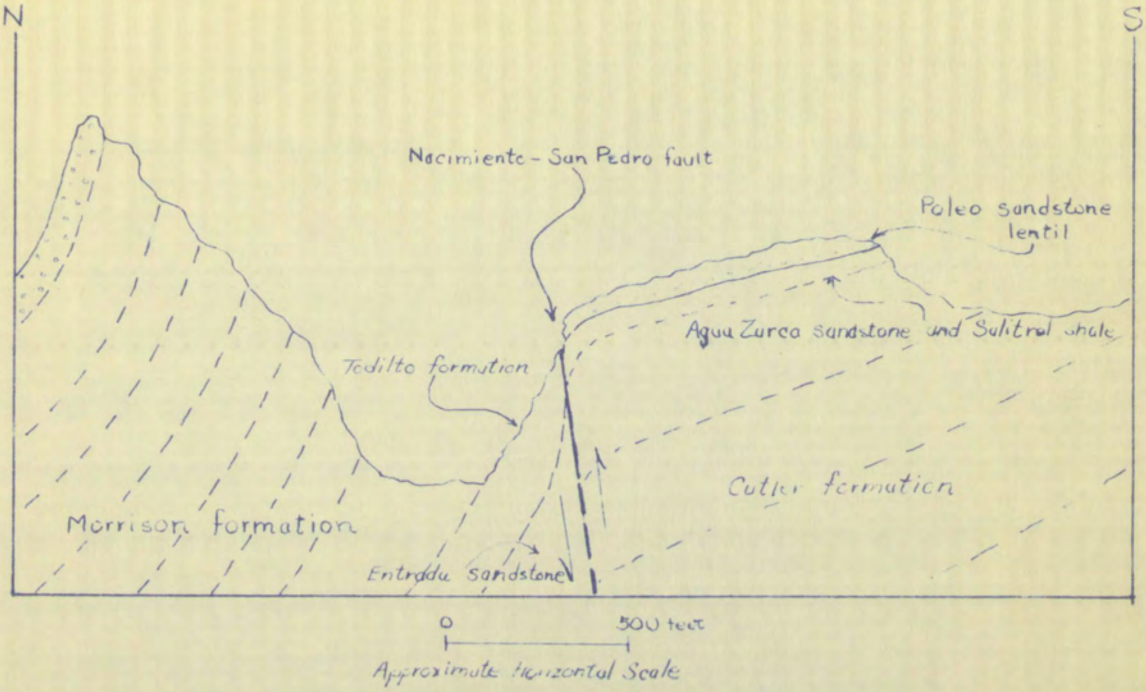


Figure 4. Cross sectional sketch showing relationship of beds along the Nacimiento-San Pedro fault in the NE¼ sec. 24, T. 23 N., R. 1 W. Angle of the fault is approximately 83° SE. Stratigraphic throw at this point is over 900 feet.

These faults are mostly due to folding and adjustment of the weaker sedimentary rocks after the rupture of the Nacimiento-San Pedro fault and the San Pedro Mountain fault.

Structural Development

Stages of development of the San Pedro Mountain area are shown in Figure 6.

The first stage of development probably began in late Cretaceous time. Gradual downwarping of the San Juan Basin area, contemporaneous with uplift in the San Pedro Mountain area is postulated. The Ojo Alamo sandstone thickens in the synclines and thins on the anticlines located along the front of the Nacimiento-San Pedro Mountains, suggesting structural movement previous to deposition of the Ojo Alamo sandstone.

The second stage of development shows continued uplift of the San Pedro Mountain area and continued downwarping of the San Juan Basin resulting in an asymmetrical fold inclined to the west. Dane (1946) saw the Paleocene Nacimiento formation lying unconformably on the Ojo Alamo sandstone in the southern part of the basin. Simpson (1948) postulated uplift in late Paleocene, as shown by the erosion or nondeposition of these beds in the vicinity of Cuba.

The third stage of development represents a steep asymmetrical fold, possibly slightly overturned, with the San Pedro-Nacimiento fault breaking along the western flank, resulting in older beds sliding on the Chinle shale. The fault follows this relatively weak stratigraphic horizon through the area, cutting out the Chinle shale completely in places (Fig. 5, Cross sections A-A' through D-D').

These faults are mostly due to gliding and adjustment of the weaker sedimentary rocks after the uplifts of the [illegible] and the San Pedro Mountain fault.

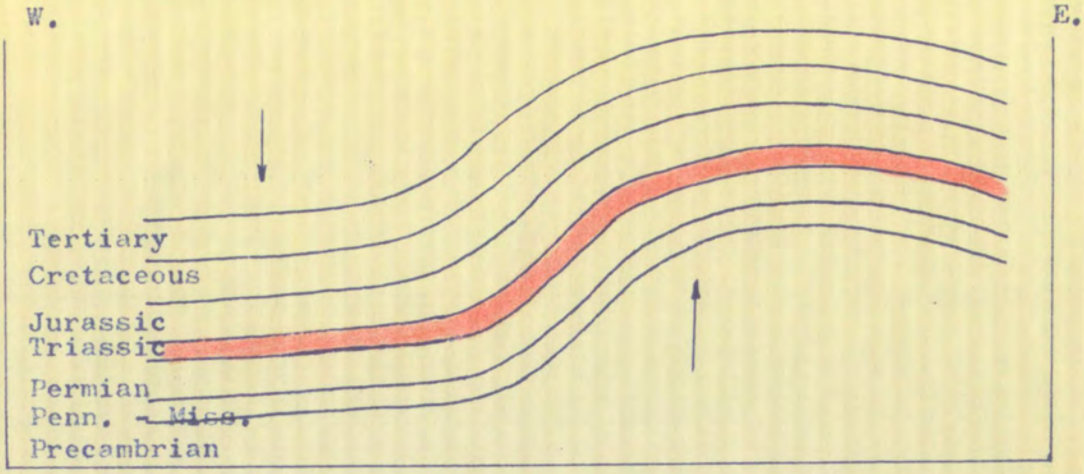
Structural Development

Stages of development of the San Pedro Mountain area are shown in Figure 5.

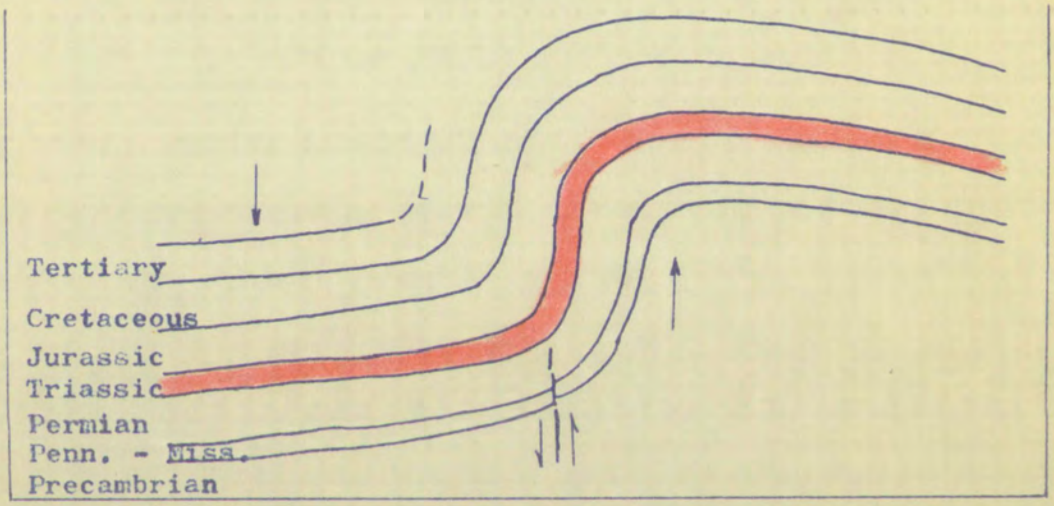
The first stage of development probably began in late Cretaceous time. Gradual downwarping of the San Juan Basin area, contemporaneous with uplift in the San Pedro Mountain area, is postulated. The Ojo Alamo sandstone thickens in the synclines and thins on the anticlines located along the front of the Nacimiento-San Pedro Mountains, suggesting structural movement previous to deposition of the Ojo Alamo sandstone.

The second stage of development shows continued uplift of the San Pedro Mountain area and continued downwarping of the San Juan Basin resulting in an asymmetrical fold inclined to the west. Dane (1946) shows the Paleocene Nacimiento formation lying unconformably on the Ojo Alamo sandstone in the southern part of the basin. Simpson (1948) postulated uplift in late Paleocene, followed by the erosion or nondeposition of these beds in the vicinity of Cuba.

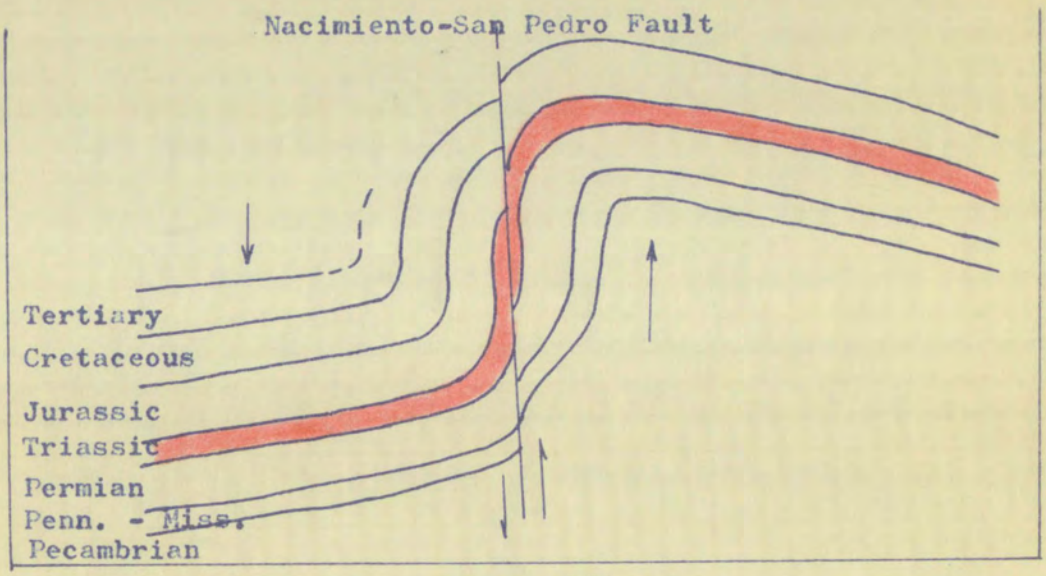
The third stage of development represents a steep asymmetrical fold, possibly slightly overturned, with the San Pedro-Nacimiento fault breaking along the eastern flank, [illegible] older beds riding on the Chinle shale. The fault follows this relatively weak stratigraphic horizon through the shale, cutting out the Chinle shale completely in places (Fig. 5, cross sections A-A' through D-D').



STAGE I



STAGE II



STAGE III

Figure 6. Possible stages in the development of San Pedro Mountain.

Precambrian particles are not angular and brecciated, but for the most part are relatively smooth. This suggests that they were transported off San Pedro Mountain by flash floods and or possibly as colluvial deposits. A cross section (Fig. 2) shows the writer's findings of alternating beds rather than the previously described low angle thrusting.

Conclusions

In the vicinity of La Jara the Cuba Mesa sandstone of the lower San Jose formation is found to be vertical to overturned and is unconformably overlain by the Almagre beds (Koogle, 1955). Dane (1946) stated that the age of the lower San Jose formation is unknown and may be of Paleocene age. Coupled with paleontological evidence, which has dated the Almagre beds as Eocene (Simpson, 1948, p. 363), it is thought that the major folding and faulting occurred in early Eocene or possibly entirely in late Paleocene.

All evidence obtained in the San Pedro Mountain area, that might give clues as to the direction of the forces applied in the deformation of the area, indicates more of a vertical component of force rather than previously described horizontal compressive forces.

The major faults of the area, the Nacimiento-San Pedro fault and the San Pedro Mountain fault, are high angle, indicating vertical movement in the development of the area. No low angle or thrust faulting was found or any other evidence that would indicate that the main tectonic stresses were not vertical. These findings concur with recent studies along the southern and southwestern part of the San Juan Basin.

Precambrian particles are not angular and rectangular, but for the most part are relatively small. This suggests that they were brought in off San Pedro Mountain by [illegible] [illegible] [illegible] [illegible] deposits. A cross section (Fig. [illegible]) shows the writer's findings of alternating beds rather than [illegible] [illegible] [illegible] thrusting.

Conclusions

In the vicinity of La Jara the [illegible] [illegible] of the [illegible] San Jose formation is found to be vertical or overturned and is unconformably overlain by the [illegible] [illegible] (Fig. [illegible]). Dane (1946) stated that the age of the [illegible] San Jose formation is Eocene and may be of Paleocene age. [illegible] with [illegible] [illegible] who dated the [illegible] [illegible] as Eocene ([illegible] [illegible], [illegible]). [illegible] that the major folding and faulting occurred in early Eocene or possibly entirely in late Paleocene.

No evidence observed in the San Pedro Mountain area that might give clues as to the direction of the forces [illegible] in the deformation of the area, indicates more of vertical movement in [illegible] rather than previously described horizontal compressive forces.

The major faults of the [illegible] of [illegible] San Pedro [illegible] [illegible] the San Pedro Mountain fault, are high angle, which [illegible] vertical movement in the development of the area. No low angle thrusting [illegible] was found or any other evidence that would indicate that the main tectonic stresses were not vertical. These [illegible] [illegible] [illegible] [illegible] along the southern and southwestern part of the San Juan Basin.

Duschatko (1953) and Gilkey (1953), from studies of fracture patterns in the Lucero and Zuni uplifts have found the tectonic forces in these areas to be primarily vertical.

GEOLOGIC HISTORY

Data on the geologic history of the Precambrian are inadequate for interpretations other than generalizations. The San Pedro-Nacimiento Mountain area was probably part of a great geosyncline during a portion of Precambrian time (Beaumont and Read, 1950, p. 49). This regional sag became the resting place for thousands of feet of sediment which flooded in from the bordering highlands and were later compacted and folded. Large volumes of granitic material were later emplaced (Parker, 1957, p. 73). When crustal stability had finally been attained, the Precambrian region was levelled to a peneplain above which rose occasional monadnocks (Northrop, 1950, p. 40).

A sedimentary hiatus from Precambrian to mid-Mississippian time makes reconstruction of early Paleozoic history inconclusive. It is possible that strata belonging to the Cambrian, Ordovician, Silurian, and Devonian systems may have been deposited; but if so, they were stripped prior to deposition of the Mississippian rocks. The general movement of the area in the Paleozoic was positive; this ancestral positive feature is called the Penasco highland or arch (Parker, 1957, p. 73).

In middle Mississippian time seas from the south, and possibly from the north, encroached onto the Penasco highland. During this inundation the Arroyo Penasco sediments, and possibly other Mississippian rocks, were deposited. Late Mississippian and early Pennsylvanian movement resulted in uplift of the area and erosion of Mississippian rocks. As a result, Arroyo Penasco sediments are preserved only in synclines and in down-faulted blocks (Fitzsimmons, et al., 1956).

GEOLOGIC HISTORY

Data on the geologic history of the Precambrian are inadequate for interpretations other than generalizations. The San [illegible] Mountain area was probably part of a [illegible] during [illegible] portion of Precambrian time ([illegible] and [illegible], 1970, p. [illegible]). [illegible] became the resting place for thousands of feet of sediments [illegible] in from the bordering highlands and [illegible]. Large volumes of [illegible] materials were later [illegible] ([illegible], 197[illegible], p. 73). When crustal [illegible] began [illegible] the region was [illegible] (Northrop, 1959, p. 40).

A sedimentary record from [illegible] makes reconstruction of early Paleozoic history [illegible] possible that strata belonging to the Cambrian, Ordovician, Silurian, and Devonian systems may have been deposited, but if so, they were stripped prior to deposition of the Mississippian rocks. The [illegible] of the area in the Paleozoic was [illegible] called the Pedernal [illegible] ([illegible], 19[illegible], p. [illegible]).

In middle Mississippian time, seas from the south, and [illegible] from the north, encroached onto the [illegible]. [illegible] this inundation the Arroyo Penasco sediments, and possibly [illegible] Mississippian rocks, were deposited. [illegible] Mississippian and early Pennsylvanian movement resulted in uplift of the area and erosion of Mississippian rocks. As a result, Arroyo Penasco sediments are preserved only in synclines and in down-faulted blocks ([illegible], et al., 19[illegible]).

In early Pennsylvanian time the seas again encroached upon the positive mass. They did not fully inundate the area, for it was not until Permian time that the Precambrian ridge was completely covered. Permian beds are in direct contact with the Precambrian rocks on the west flank of San Pedro Mountain (Northrop and Wood, 1946).

Oscillations of the Pennsylvanian and early Permian shorelines are recorded in the alternating layers of limestone and clastic sediments. Tectonic activity is indicated by an angular unconformity in the lower part of the Permian beds (Fig. 2). A flood of clastic sediments, probably derived from the active Ancestral Rocky Mountains of Colorado, is represented by the terrestrial red beds of the Cutler formation. Continental conditions were firmly established during Permian time.

Local uplifts in Triassic time resulted in the deposition of Upper Triassic sediments unconformably upon the Cutler formation. The northward thinning Agua Zarca sandstone and the southward thinning Poleo sandstone lentil apparently indicate their derivation from separate uplifts. The Chinle shale is the product of fluviatile and floodplain conditions which existed on a vast plain, dipping gently westward toward a Triassic sea in Nevada (McKee, 1951, p. 91 and Parker, 1957, p. 74).

Regional upwarping in early Jurassic time resulted in erosion as evidenced by channeling into the underlying Chinle shale (Darton, 1928, p. 167). This was followed in the Upper Jurassic by desert conditions during which the eolian Entrada sandstone blanketed the region. After deposition of the Entrada sandstone, lacustrine conditions possibly

In early Pennsylvanian time the area again emerged as a positive mass. They did not [illegible] sediments [illegible] until Permian time [illegible] the [illegible] completely covered. Permian beds are in direct contact with the Precambrian rocks on the west flank of San Pedro Mountain (Northrop and Wood, 1946).

Oscillations of the Pennsylvanian and early Permian shorelines are recorded in the alternating layers of limestone and clastic sediments. Tectonic activity is indicated by an angular unconformity in the lower part of the Permian beds (Fig. [illegible]). A flood of clastic sediments, probably derived from the [illegible] of Colorado, is represented by the [illegible] red beds of the Cutler formation. Continental conditions were firmly established during Permian time.

Local uplifts in Triassic time [illegible] the deposition of the Upper Triassic sediments [illegible] upon the Cutler formation. The northward thinning [illegible] sandstone [illegible] the [illegible] sandstone [illegible] apparently [illegible] their [illegible] uplifts. The Chinle shale [illegible] conditions which existed [illegible] a Triassic sea in Nevada ([illegible], 1953, [illegible]; and [illegible], 1951, [illegible]).

Regional upwarping in early Jurassic time [illegible] is evidenced by channeling into the underlying Chinle shale ([illegible], 19[illegible], p. 159). This was followed by the [illegible] during which the [illegible] of the region. After deposition of the Entrada sandstone, [illegible] conditions [illegible] existed, in which the Todilto limestone and gypsum were deposited (Kirkland, 1958). The Todilto gypsum was subjected to erosion for a short period, as indicated by its absence in the French Mesa area (Fitter, 1958) and the Gallina Mountains area (Lookingbill, 1953, p. 34), then covered by the Morrison formation which was deposited in a fluvial and lacustrine environment (Swift, 1956, p. 36). The source of the Morrison sediments is believed to have been south and east of the present San Juan Basin (Silver, 1948, p. 68-81) and partially from the Ancestral Rockies of Colorado (Swift, op. cit., p. 37).

During early Cretaceous time the San Pedro-Nacimiento Mountain area underwent erosion. Early Cretaceous sediments are possibly represented by the discontinuous conglomerate and shale at the top of the Morrison formation. Late Cretaceous time began with a period of fluctuating shorelines and swamp conditions represented by the Dakota formation. Subsidence resulted in deposition of the marine Mancos shale, in which periodic oscillations occurred with deposition of the Gallup sands to the southwest, before the sea finally withdrew in Point Lookout time. A period of continental deposition, represented by the Menefee formation, existed prior to the last transgression of the Upper Cretaceous sea. This transgression is recorded by the La Ventana tongue and the Lewis shale. As the sea withdrew the regressive Pictured Cliffs and the Fruitland formations were deposited in its wake. A northeast trending embayment in the San Pedro Mountain area resulted in continued deposition of Lewis shale and nondeposition of the Pictured Cliffs and Fruitland formations. Uplift to the southeast supplied the sediments for the Ojo Alamo conglomeratic sandstone and possibly resulted in the withdrawal of the Cretaceous sea.

existed, in which the Todilto limestone and gypsum were deposited (Kirkland, 1958). The Todilto evaporites [illegible] erosion for a short period, as indicated by its absence in the [illegible] area (Ritter, 1958) and the [illegible] Mountains area ([illegible], p. 74). [illegible] then covered by the Morrison Formation which was deposited in a fluvial and lacustrine environment (Craig, 1956, p. 15). The source of the Morrison sediments is believed to have been southwest of the present San Juan Basin (Silver, 1948, p. 58-61) and partly from the Ancestral Rockies of Colorado (Smith, op. cit., p. 7).

During early Cretaceous time the San Pedro-Nacimiento area underwent erosion. Early Cretaceous sediments are possibly represented by the discontinuous conglomerate and shale at the top of the Morrison Formation. Late Cretaceous time began with a period of fluctuating shorelines and swamp conditions represented by the Dakota Formation. [illegible] as a result of [illegible] in which periodic [illegible] with [illegible] sands to the southwest, before the sea finally [illegible] time. A period of [illegible], represented by the Mancos Formation, existed prior to the last transgression of the Upper Cretaceous sea. This transgression is represented by the [illegible] Lewis Shale. As the sea withdrew [illegible] the Pictured Cliffs and Fruitland Formations were deposited in [illegible] embayment in the [illegible] of Lewis Shale and [illegible] the Pictured Cliffs and Fruitland formations. [illegible] the sediments of the Ojo Alamo conglomeratic sandstone and [illegible] in the [illegible] of the Cretaceous sea.

As uplift continued, continental and fluviatile sediments of the Nacimiento formation were deposited on a broad south-sloping plain. Later uplift to the southeast resulted in erosion or nondeposition of the late Paleocene beds. This uplift supplied the sediments for the basal conglomerates of the San Jose formation (Simpson, 1948, p. 377), and may have been the initial stage of folding of the San Pedro-Nacimiento Mountains. The major folding and faulting of the Nacimiento-San Pedro Mountains occurred in late Paleocene or early Eocene time, as evidenced by an angular unconformity occurring in the lower San Jose formation (Koogle, 1955).

Broad pediment surfaces formed along the west flank of the San Pedro Mountain. Regional upwarp of the San Juan Basin caused Tertiary deposition to cease and recent erosion has resulted in removal of most of the later Tertiary beds and Quaternary gravels.

ECONOMIC GEOLOGY

Oil and Gas

Discovery of gas in the Magnolia No. 1 - Henry Schmitz well (sec. 24, T. 24 N., R. 1 W.) in 1954 has stimulated interest along the eastern flank of the San Juan Basin. This well, about one mile northwest of the San Pedro Mountain area, produces gas from the lower part of the Paleocene Nacimiento formation. The steeply dipping beds of the Nacimiento formation crop out one mile west of the well, suggesting a porosity trap in the sands. The Lindrith and Gavilan fields, 12 miles northwest of the area of this report, produce gas and oil from the Pictured Cliffs formation and the Dakota sandstone of Upper Cretaceous age. No gas or oil wells have been drilled in the area covered by this report.

Some of the most important producing horizons of the San Juan Basin are present in the San Pedro Mountain area. They are the Mesaverde group, the Mancos shale, and the Dakota sandstone. All of these strata dip steeply and are exposed along the western flank of the San Pedro-Nacimiento Mountain front. Preservation of petroleum that may formerly have been present in these rocks is unlikely.

Possibly oil and gas may have been trapped along the west side of the San Pedro-Nacimiento fault in the Mississippian and Pennsylvanian rocks. The Mississippian rocks, once probably a good source rock, as indicated by their petroliferous odor, were subjected to subaerial erosion and removed for the most part prior to deposition of the Pennsylvanian strata. The petroleum, if once present, would probably have escaped.

ECONOMIC GEOLOGY

Oil and Gas

Discovery of gas in the Magnolia No. 1 - Navajo tract (sec. 24, T. 24 N., R. 1 W.) in 1940 has not aroused interest in the eastern flank of the San Juan Basin. This well, [illegible] the northwest of the San Pedro Mountain area, produces gas from the upper part of the Paleozoic sedimentary column. The steeply dipping beds of the Nacimiento Formation crop out one mile west of the well, suggesting a possible trap in the vicinity. The [illegible] Fields, 12 miles northwest of the edge of this map, produce gas and oil from the Pictured Cliffs Formation and the [illegible] of Upper Cretaceous age. No gas or oil wells have been drilled in the area covered by this report.

Some of the most important producing horizons of the San Juan Basin are present in the San Pedro Mountain area. They are the Mesaverde group, the Mancos shale, and the Dakota sandstone. All of these strata dip steeply and are exposed along the eastern flank of the [illegible] Nacimiento Mountain front. Presumably, [illegible] have been present in these strata [illegible].

Possibly oil and gas may have been trapped along the west side of the San Pedro-Nacimiento [illegible] in [illegible] rocks. The Mississippian rocks, quite probably good source rocks as indicated by their petroliferous odor, were subjected to considerable erosion and removal of the [illegible] prior to deposition of the Pennsylvanian strata. The [illegible] have escaped.

The highly fossiliferous limestone of the Pennsylvanian system is considered favorable for oil and gas production. A well drilled by the Skelly Oil Company in sec. 36, T. 24 N., R. 1 E., penetrated these rocks on the French Mesa anticline to the north and had shows of oil and gas in two zones.

Dakota production might be expected from the small northeasterly plunging anticlinal nose in sec. 7, T. 23 N., R. 1 E. if this fold developed before the rupture of the Nacimiento-San Pedro fault. However, if this structure was caused by compressive forces resulting from the Nacimiento-San Pedro reverse fault (Fig. 5, Cross section A-A'), then it is later than the initial uplift of the San Pedro Mountain. In this case, any petroleum would have migrated up dip and escaped before the reverse faulting could have created a satisfactory trap.

Mr. Raymond Reed of Regina drilled a 100 foot water well in the west center sec. 23, T. 23 N., R. 1 W. The well was drilled in steeply dipping beds (70° W.) of the Lewis shale 500 feet above the lower contact of the formation. No water was encountered, but oil was bailed from the hole. The lower part of the Lewis shale includes beds of very tight sandy siltstone 2 to 3 feet thick. It is possible that these beds may become productive laterally, where development of a sand facies might increase porosity and permeability. However in the immediate area, the tightness of these sandy siltstone beds makes production from them unlikely.

Coal

Small mining operations north of San Pedro Mountain, in the French Mesa area, and south, in the La Ventana area, produce coal from the

Menefee formation. The higher grade coal appears in thin, discontinuous lenses in the upper third of the formation. In the San Pedro Mountain area this zone contains low grade, subbituminous coal and dark brown, carbonaceous shale. A small operation in the NW$\frac{1}{4}$ sec. 23, T. 23 N., R. 1 W., was abandoned after producing insignificant amounts of coal. Since the coal deposits of this area are characteristically of low grade and insignificant quantity, mining possibilities are considered poor.

Gypsum

Large quantities of gypsum are exposed in the SW$\frac{1}{4}$ sec. 24, T. 23 N., R. 1 W. (Pl. 2A), and north and southwest of Gallina (Pl. 1B, 2B). The gypsum is in the upper member of the Todilto formation, of late Jurassic age. The surface of the exposures is weathered to a soft, earthy soil called gypsite. Beneath the gypsite cover the gypsum is relatively pure, and is probably of commercial quality. However, with large quantities of gypsum occurring throughout the State, it is doubtful that the relatively inaccessible deposits in the San Pedro Mountain area have commercial value.

Uranium and Copper

Uranium has been found in the coals of the Mesaverde group, the Dakota sandstone, the Morrison, Chinle, and Cutler formations, but no major discoveries have yet been made. Numerous claims have been staked throughout the area but very little assessment work has been done. One small mine was started in sec. 19, T. 23 N., R. 1 E. by the Slatex Company of Texas, but according to Mr. Jim Powell of Warm Springs only a few truck loads were hauled from the area.

Menefee formation. The thickest [illegible] coal [illegible] appears in [illegible] discontinuous lenses in the [illegible] half of the formation in the San Pedro Mountain area but [illegible] complete [illegible] of [illegible] coal and dark brown, carbonaceous shale. A small open pit [illegible] of the NW¼ sec. 21, T. 23 N., R. 1 E., was abandoned after producing insignificant amounts of coal. Since the [illegible] of this area are characteristically of low grade and has difficult access, mining possibilities are considered poor.

Gypsum

Large quantities of gypsum are exposed in sec. [illegible], T. 23 N., R. 1 W. (Pl. [illegible]), at northwest end of [illegible] (Pl. 18, 23). The gypsum is in the upper member of the Todilto formation, of Late Jurassic age. The surface of the deposit is weathered to a soft earthy [illegible] cover the gypsum is relatively pure, and is probably of good quality. However, with larger and more accessible deposits throughout the State, it is doubtful that the relatively inaccessible deposits in the San Pedro Mountains are of much commercial value.

Uranium and Copper

Uranium has been found in the [illegible] of the [illegible] Dakota sandstone, the Morrison, Todilto, and Entrada formations, but no major discoveries have been made. Prospect pits have been excavated throughout the area but with little [illegible] mineralization. One small mine was [illegible] in sec. [illegible], T. [illegible] N., R. [illegible] E. by [illegible] Company of Texas, [illegible] only a few truck loads were hauled from the area.

No major copper discoveries have been made in the area of this report, but considerable prospecting has been done in the Permian "red beds". In the course of copper exploration a number of roads were bulldozed through the dense vegetation and rugged topography along the outcrop of the Cutler formation. Most of the mineralization is in small veinlets of azurite and malachite in the conglomeratic sandstone in the lower Permian beds. The mineralization is in discontinuous lenses, which makes mining of the low grade ore difficult or impossible.

APPENDIX

APPENDIX

Descriptive Stratigraphic Sections

Mesaverde group, Section No. 1
SW$\frac{1}{4}$ Sec. 14, T. 23 N., R. 1 W.

No.	Description	Thickness (feet)
	(Lewis shale above)	
	Top of Mesaverde group	
	La Ventana tongue	
11.	SANDSTONE: light gray and buff, fine to medium grained, subrounded, well sorted, thin to massive bedded; upper 10 feet interbedded with dark gray shale................	40
	Menefee formation	
10.	SANDSTONE: light gray, fine to medium grained, subangular to subrounded, friable, slightly calcareous, slope former..............	50
9.	SHALE: dark gray, brown, and black, fairly soft, carbonaceous, contains some coal..........	11
8.	SANDSTONE: light gray and buff, fine grained, friable, silty; some thin gray shale beds.....................................	235
7.	SHALE: dark gray to brown, soft, flaky.........	15
6.	SANDSTONE: white and light gray, fine to medium grained, well sorted, friable, massive bedded; a few resistant beds...........	55
5.	SHALE: dark gray and brown, carbonaceous, flaky, silty and sandy.........................	25
4.	SANDSTONE: light gray to yellowish-tan fine to medium grained, subrounded, iron stained, massive bedded, ridge former...........	25
3.	SANDSTONE AND SHALE: sequence of alternating sandstone and shale beds. SANDSTONE: light gray to buff, fine to medium grained, subrounded, massive bedded; SHALE: dark gray, carbonaceous, contains a few thin coal seams..	64

No.	Description	Thickness (feet)
	Point Lookout Sandstone	
2.	SANDSTONE: light gray and buff, fine grained, subangular to subrounded massive bedded, argillaceous, micaceous, friable; small amount of shale alternating with sandstone in lower part........................	90
1.	SANDSTONE AND SHALE: alternating sequence, sandstone dominating. SANDSTONE: light gray, fine to medium grained, subrounded, speckled appearance, slightly micaceous, calcareous; SHALE: dark gray and drab, flaky, calcareous..............................	40
	TOTAL:	650

Dakota sandstone, Section No. 2
$NE\frac{1}{4}$ Sec. 35, T. 23 N., R. 1 W.

No.	Description	Thickness (feet)
	(Mancos shale above)	
	Top of Dakota sandstone	
8.	SANDSTONE: light gray and light orange, fine grained, well sorted, friable, massive bedded, slightly argillaceous, iron stained, cliff forming, good porosity....................	17
7.	PARTLY COVERED: sandstone: light gray, fine grained, soft, slope forming; with some gray shale near base......................	40
6.	SHALE: gray, blocky, sandy and silty, slope forming................................	27
5.	SANDSTONE: light orange, medium to coarse grained, subrounded, iron stained, friable, good porosity................................	3
4.	SHALE: dark gray, silty, blocky...............	$2\frac{1}{2}$
3.	SANDSTONE: light brown, brown, and white, fine to medium grained, subangular to subrounded, 6- to 12- inch beds, argillaceous...	$11\frac{1}{2}$
2.	SANDSTONE: white, fine grained, soft, slope forming, partly covered..................	67

No.	Description	Thickness (feet)
1.	SANDSTONE AND CONGLOMERATE: alternating sequence of sandstone and conglomerate; SANDSTONE: white and light orange, fine to medium grained, subrounded to subangular, argillaceous, crossbedded; CONGLOMERATE: white, granule to cobble size particles, quartz, quartzite, clay nodules, ridge forming........................	31
	TOTAL:	199

Morrison formation, Section No. 3
NE¼ Sec. 24, T. 23 N., R. 1 W.

	(Dakota sandstone above)	
	Top of Morrison formation	
	Conglomerate member	
15.	SANDSTONE: light gray and light orange, medium grained, subrounded, calcareous, argillaceous, massive bedded, conglomeratic, widely scattered pebbles, cliff forming..........	23
14.	SHALE: green, soft, fissile, slope forming, partly covered................................	37
13.	SANDSTONE AND CONGLOMERATE: alternating sequence; SANDSTONE: light brown to buff, medium grained, subrounded to rounded, calcareous, slightly argillaceous, massive bedded; CONGLOMERATE: buff to light brown, pebbles are from granule size to 2 inches in diameter, quartz, quartzite, chert, limestone, claystone nodules, beds are from 3 inches to 2 feet thick, cliff forming.........	62
	Green claystone member	
12.	COVERED: slope forming, probably shale.........	40
11.	SHALE: green, soft, fissile, slope forming, partly covered........................	105
10.	SANDSTONE: light brown to buff, fine to medium grained, poorly sorted, argillaceous, 6- to 18- inch beds, crossbedded, ledge former..	17
9.	SHALE: green, soft, interbedded with 2 to 6 inch siltstone and fine-grained sandstone lenses, red-brown concretions, slope forming................................	86

No.	Description	Thickness (feet)
	Buff sandstone member	
8.	SANDSTONE: light olive-tan, fine grained, subangular to subrounded, fair sorting, argillaceous, massive bedded, friable, soft, slope forming, weathers to rounded forms..............................	18
7.	SANDSTONE: light greenish-gray, fine to medium grained, subrounded to wellrounded, calcareous, slightly argillaceous, bedding 2 feet thick, sorting fair, glauconitic, weathers to dark brown.........................	4
6.	SILTSTONE: pale green, sandy, calcareous, thin bedded, lenses with short lateral extent....................................	32
5.	CLAYSTONE: cocoa-brown, silty and sandy, soft, slope forming...........................	4
4.	SHALE: green, flaky, silty, numerous concretions, red-brown clinker rock............	38
3.	SILTSTONE: white to light gray, sandy, calcareous, contains concretions...............	29
2.	SANDSTONE: white and light gray, very fine grained, silty, fair sorting, slightly argillaceous, alternates with a few 6- to 12-inch beds of cocoa-brown claystone, ledge forming, weathers to a bad-land type topography...................................	150
1.	COVERED: from unit no. 2 to top of Todilto gypsum....................................	145
	TOTAL:	790

LITERATURE CITED

Armstrong, A. K., 1955, Preliminary observations on the Mississippian system of northern New Mexico: New Mexico Bur. Mines and Min. Res. Circ. 39.

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

Baltz, E. H., Jr., 1953, Stratigraphic relationships of Cretaceous and early Tertiary rocks of a part of northwestern San Juan Basin: Univ. New Mexico unpub. master's thesis, 101 p.

Beaumont, E. C., and Read, C. B., 1950, Geologic history of the San Juan Basin area, New Mexico and Colorado: New Mexico Geol. Soc. Guidebook, p. 48-52.

______, Dane, C. H., and Sears, J. D., 1956, Revised nomenclature of the Mesaverde group in the San Juan Basin, New Mexico: Amer. Assoc. Petroleum Geologists Bull., v. 40, p. 2149-2162.

Dane, C. H., 1946, Stratigraphic relations of the Eocene, Paleocene, and latest Cretaceous formations of eastern side of San Juan Basin, New Mexico: U. S. Geological Survey Oil and Gas Invest. Prelim. Chart 24.

______, 1948, Geologic map of part of eastern San Juan Basin, Rio Arriba County, New Mexico: U. S. Geological Survey Oil and Gas Invest. Prelim. Map 78.

______, and Bachman, G. O., 1957, Preliminary geologic map of the northwestern part of New Mexico: U. S. Geological Survey Map 1-224.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geological Survey Bull. 794, 356 p.

Duschatko, R. W., 1953, Fracture studies in the Lucero uplift, New Mexico: U. S. Atomic Energy Commission Report, 49 p.

Eardley, A. J., 1951, Structural geology of North America: New York, Harper & Brothers, 624 p.

Fenneman, N. M., 1931, Physiography of the western United States: New York and London, McGraw-Hill, 534 p.

Fitter, F. L., 1958, Geology of the French Mesa Area, Rio Arriba County, New Mexico: Univ. of New Mexico unpub. master's thesis.

Fitzsimmons, J. P., Armstrong, A. K., and Gordon, M. Jr., 1956, Arroyo Penasco formation, Mississippian north-central New Mexico: Amer. Assoc. Petroleum Geologists Bull., v. 40, p. 1935-1944.

LITERATURE CITED

Armstrong, A. K., 1955, Preliminary observations on the Mississippian system of northern New Mexico: New Mexico Bur. Mines and Mineral Res. Circ. 39.

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

Baltz, E. H., Jr., 1953, Stratigraphic relationships of Cretaceous and early Tertiary rocks of a part of northwestern San Juan Basin: Univ. New Mexico unpub. master's thesis, 101 p.

Beaumont, E. C., and Read, C. B., 1950, Geologic history of the San Juan Basin area, New Mexico and Colorado: New Mexico Geol. Soc. Guidebook, p. 48-52.

______, Dane, C. H., and Sears, J. D., 1956, Revised nomenclature of the Mesaverde group in the San Juan Basin, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 2149-2162.

Dane, C. H., 1946, Stratigraphic relations of Eocene, Paleocene, and latest Cretaceous formations of eastern side of San Juan Basin, New Mexico: U. S. Geological Survey Oil and Gas Inv. Prelim. Chart 24.

______, 1948, Geologic map of part of eastern San Juan Basin, Rio Arriba County, New Mexico: U. S. Geological Survey Oil and Gas Inv. Prelim. Map 78.

______, and Bachman, G. O., 1957, Preliminary geologic map of the northwestern part of New Mexico: U. S. Geol. Survey Misc. Geol. Inv. Map I-224.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico with an outline of the geology of the State: U. S. Geological Survey Bull. 794, 356 p.

Duschatko, R. W., 1953, Fracture studies in the Lucero uplift, New Mexico: U. S. Atomic Energy Comm. Tech. Report [illegible].

Eardley, A. J., 1951, Structural geology of North America: New York, Harper & Brothers, 624 p.

Fenneman, N. M., 1931, Physiography of western United States: New York and London, McGraw-Hill, 534 p.

Fitter, F. L., 1958, Geology of [illegible] area, Rio Arriba County, New Mexico: Univ. of New Mexico unpub. master's thesis.

Fitzsimmons, J. P., Armstrong, A. K., and Gordon, M., Jr., 1956, Arroyo Penasco formation, Mississippian, north-central New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 1935-1944.

Gardner, J. H., 1910, The Puerco and Torrejon formations of the Nacimiento group: Jour. of Geol., v. 18, p. 702-741.

Gilkey, A. K., 1953, Fracture studies in the Zuni uplift, New Mexico: U. S. Atomic Energy Commission Report (unpublished).

Granger, W., 1914, On the names of lower Eocene faunal horizons of Wyoming and New Mexico: Amer. Mus. Nat. Hist. Bull., v. 33, p. 201-207.

Kelley, V. C., 1950, Regional structure of the San Juan Basin: New Mexico Geol. Soc. Guidebook, p. 101-108.

______, 1955, Regional tectonics of the Colorado Plateau and relationships to the origin and distribution of uranium: Univ. New Mexico publication in geology, No. 5, 120 p.

______, 1957, Tectonics of the San Juan Basin and surrounding areas: Four Corners Geol. Soc. Guidebook, p. 44-52.

Kirkland, D. W., 1958, The environment of deposition of the Jurassic Todilto basin, northwestern New Mexico: Univ. New Mexico unpub. master's thesis.

Koogle, R. L., 1955, Tertiary geology of the La Jara Creek Area: Unpublished field problem, Univ. of New Mexico, 7 p.

Lookingbill, J. L., 1953, Stratigraphy and structure of the Gallina uplift, Rio Arriba County, New Mexico: Univ. New Mexico unpub. master's thesis, 118 p.

McKee, E. D., 1951, Triassic deposits of the Arizona-New Mexico border area: New Mexico Geol. Soc. Guidebook, p. 85-92.

Momper, J. A., 1957, Pre-Morrison stratigraphy of the southern and western San Juan Basin: Four Corners Geol. Soc. Guidebook, p. 85-94.

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

______, 1950, General geology of northern New Mexico: Soc. of Vert. Paleontology Guidebook, p. 26-48.

Parker, J. W., 1957, Nacimiento Mountains - history and relations to the San Juan Basin: Four Corners Geol. Soc. Guidebook, p. 73-76.

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

Gardner, J. H., 1910, The physical and stratigraphic [illegible] of the Nacimiento group: [illegible] Geology, v. [illegible], p. [illegible].

Gilkey, A. K., 19[illegible], [illegible] in the [illegible] U. S. Atomic Energy Commission Report (unpublished).

Granger, W., 1914, On the names of Lower Eocene faunal horizons of Wyoming and New Mexico: Amer. Mus. Nat. Hist. Bull., v. 33, p. [illegible].

Kelley, V. C., 1950, Regional structure of the San Juan Basin: New Mexico Geol. Soc. Guidebook, p. 101-108.

_____, 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: Univ. New Mexico Publications in geology, No. 5, [illegible] p.

_____, 1957, Tectonics of the San Juan Basin and surrounding areas: Four Corners Geol. Soc. Guidebook, p. [illegible].

Kirkland, D. [illegible], 1958, The [illegible] of the [illegible] Todilto [illegible], northwestern New Mexico: Univ. [illegible] master's thesis.

Koogle, R. L., 1973, [illegible] of the [illegible] report: unpublished field [illegible] Univ. of New Mexico, [illegible] p.

Lookingbill, J. L., 1953, Stratigraphy and structure of the Gallina uplift, Rio Arriba County, New Mexico: Univ. New Mexico unpublished master's thesis, 116 p.

McKee, E. D., 1951, Triassic deposits of the Arizona-New Mexico border area: New Mexico Geol. Soc. Guidebook, p. [illegible].

Mouper, J. A., 1957, Pre-Morrison stratigraphy of the southeastern San Juan Basin: Four Corners Geol. Soc. Guidebook, p. [illegible].

Northrop, S. A., [illegible] and [illegible], Jr., [illegible] Geologic map of [illegible] Mountains, San Pedro [illegible] and adjacent areas, [illegible] and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Oil and Gas Invest. Prelim. Map [illegible].

_____, 19[illegible], Geological [illegible] of [illegible] New Mexico: [illegible] Paleontology: Guidebook, [illegible].

Parker, J. W., 1957, [illegible] upper [illegible] and [illegible] to the San Juan Basin: Four Corners Geol. Soc. Guidebook, p. [illegible].

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

Reeside, J. B., et al., 1957, Correlation of the Triassic formations of North America exclusive of Canada: Geol. Soc. America Bull., v. 68, p. 1451-1513.

Renick, B. C., 1931, Geology and ground-water resources of western Sandoval County, New Mexico: U. S. Geol. Survey Water-Supply Paper 620, 117 p.

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

Silver, Caswell, 1948, Jurassic overlap in western New Mexico: Amer. Assoc. Petroleum Geologists Bull., v. 32, p. 68-81.

Simpson, G. G., 1948, The Eocene of the San Juan Basin, New Mexico: Amer. Jour. Science, v. 246, p. 257-282 and p. 363-385.

Swift, E. R., 1956, Study of the Morrison formation and related strata, north-central New Mexico: Univ. New Mexico unpub. master's thesis, 77 p.

Figure 5 in pocket