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Effect of the Pedernal Axis on Permian and Triassic Sedimentation

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PEDERNAL AXIS OF PERMIAN AND TRIASSIC SEDIMENTATION · HOCK

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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

EFFECT OF THE PEDERNAL AXIS ON PERMIAN AND TRIASSIC SEDIMENTATION

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June 16, 1970

Date

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EFFECT OF THE PEDERNAL AXIS ON PERMIAN AND TRIASSIC SEDIMENTATION

BY
PHILIP F. HOCK, JR.
B.S., Morehead State University, 1968

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Geology
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
August, 1970

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ABSTRACT OF THESIS

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ABSTRACT

The Pedernal Hills of north-central New Mexico form a prominent ridge between Estancia basin on the west and the Pecos Valley of the Great Plains on the east. They are remnants of an ancient Paleozoic highland.

The Pedernal Hills are composed of Precambrian rocks and form the area of greatest relief. Four major rock types compose these hills: 1) granitic gneiss, 2) quartzite, 3) a heterogeneous unit, consisting of chlorite-muscovite-quartz phyllite, epidote-amphibolite, quartzite, amphibolite, quartz monzonitic gneiss, cataclasite, and epidiorite, and 4) granite. Within the thesis area quartzite is the predominant rock type and represents several thousand feet of sandstone. This Precambrian sequence of sedimentary and igneous rocks was deformed and underwent regional metamorphism.

During Pennsylvanian time the Pedernal Hills were undergoing active uplift and vast amounts of sediment was being shed into the surrounding basins. The Estancia basin on the west received a minimum of 5,000 feet of sediment. By the end of Pennsylvanian time, the Pedernal uplift in conjunction with other regional structural elements, had divided the Pennsylvanian seas into interconnected basins. Also by this time a topography of relatively high relief had developed on the Precambrian.

The Yeso Formation laps onto the Precambrian core. During early Yeso time, the uplift of the Pedernal Hills

ABSTRACT

The Federal Hills of north-central New Mexico form a prominent ridge between Estancia basin on the west and the Pecos Valley of the Great Plains on the east. They are remnants of an ancient Paleozoic highland.

The Federal Hills are composed of Precambrian rocks and form the area of greatest relief. Four major rock types compose these hills: 1) granitic gneiss, 2) quartzite, 3) a heterogeneous unit, consisting of chlorite-muscovite-quartz phyllite, epidote-amphibolite, quartzite, amphibolite, quartz monzonitic gneiss, calcsilicate, and ankerite, and 4) granite. Within the thesis area quartzite is the predominant rock type and represents several thousand feet of sandstone. This Precambrian sequence of sedimentary and igneous rocks was deformed and underwent regional metamorphism.

During Pennsylvanian time the Federal Hills were undergoing active uplift and vast amounts of sediment was being shed into the surrounding basins. The Estancia basin on the west received a minimum of 3,000 feet of sediment. By the end of Pennsylvanian time, the Federal uplift in conjunction with other regional structural elements, had divided the Pennsylvanian seas into interconnected basins. Also by this time a topography of relatively high relief had developed on the Precambrian.

The Yeso Formation laps onto the Precambrian core. During early Yeso time, the uplift of the Federal Hills

ceased; however, they continued to shed large amounts of detritus to the surrounding basins. The upper Yeso represents a drastic climatic change and a time when the seas became restricted. Low areas of the Precambrian hills were covered and only minor amounts of sediment were supplied.

The Glorieta, San Andres, and Bernal formations lapped successively onto the Precambrian axis, and each of these formations thinned as they crossed the axis. Only a few isolated islands of Precambrian remained after these formations were deposited. The continental Triassic Santa Rosa Sandstone contains fragments of Precambrian and Permian formations in conglomerate. Conglomerate is also found in the Yeso, and is restricted to these two formations. At the time of their deposition the surrounding terrane was being actively eroded. Probably by the end of Triassic time the Precambrian was completely covered. Jurassic and Cretaceous rocks are absent in the area, probably due to later erosion.

During Tertiary time, a period of uplift and faulting resulted in a zone of faults and dikes on the western side of the Pedernal Hills.

Tertiary and Quaternary erosion initiated the exhumation of the Precambrian topography and also formed a prominent pediment surface around the Pedernal Hills.

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CONTENTS

ILLUSTRATIONS

Plates

Figures

INTRODUCTION

Location and Accessibility

The Pedernal area is 50 miles east of Albuquerque in portions of Torrance, Santa Fe, and San Miguel Counties (Fig. 1). It includes townships 7-10 north between the edge of Estancia Valley on the west and the Torrance-Guadalupe County line on the east. The area is 864 square miles.

The main access roads are U. S. Highway 66 and U. S. Highway 285. These two highways intersect at Clines Corners New Mexico, which lies near the northern boundary of the area. N. M. Highway 3 crosses the area in the north-south direction and constitutes the main access road on the eastern side of the area. In addition county and ranch roads are common throughout the area.

Purpose

The area surrounding the Pedernal Hills has been of scientific and economic interest for a number of years. The effect of the Pedernal axis on sedimentation and stratigraphy of late Paleozoic rocks is of major importance. The principal purposes of this study were to determine whether the Precambrian terrane was an active source of sediment and what effect it had on thickness of strata during Permian and Triassic time. The area was also mapped in as much detail as the scale (1:125,000) permitted.

Thickness variations and lithologic changes in the lower Permian and Triassic strata were the criteria used

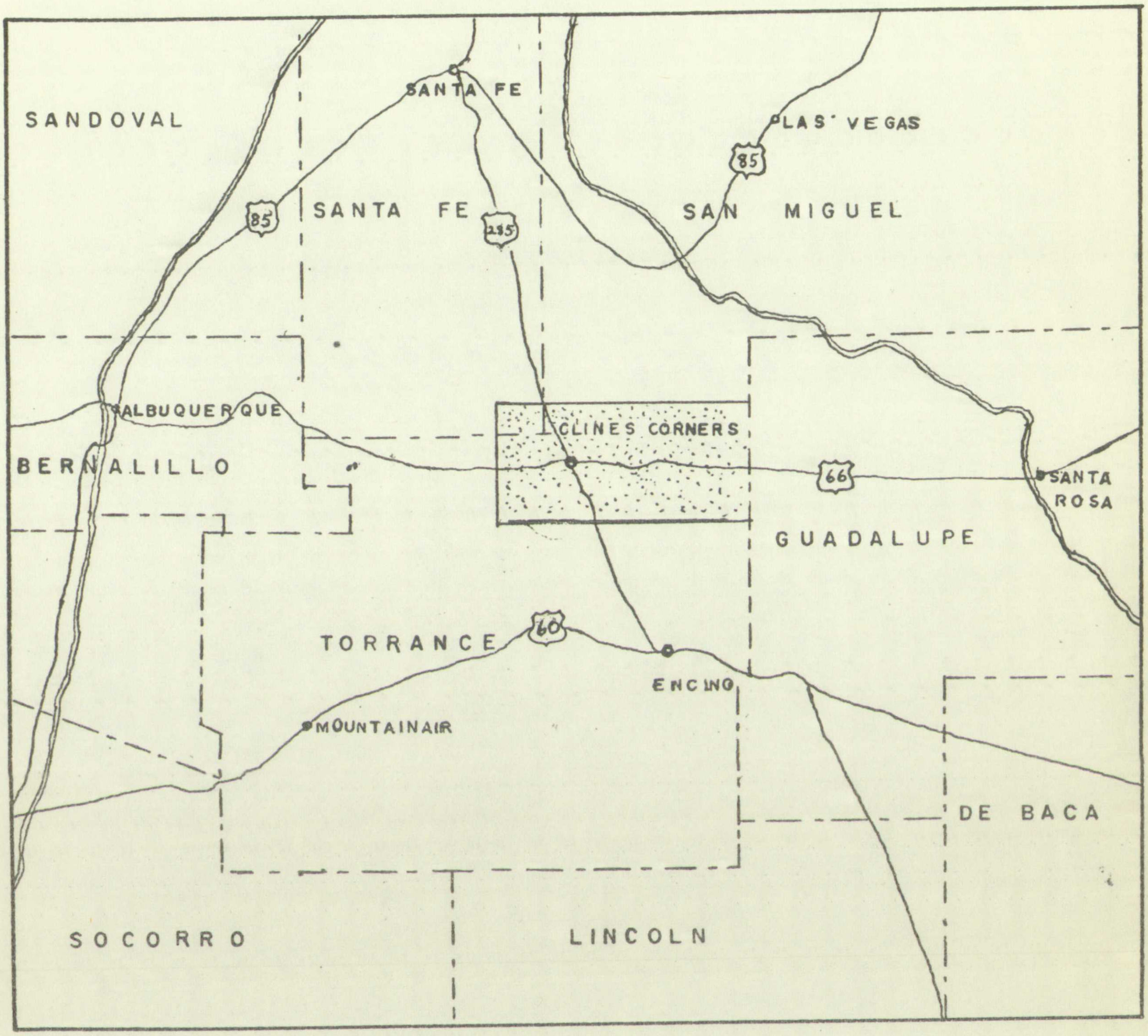

Figure 1. Index map showing location of area.

in trying to determine the influence of the Pedernal axis.

Previous Work

Johnson (1902) briefly described the Precambrian rock types found in the Pedernal Hills. Meizner (1911) mentioned the Hills briefly in discussions of the geology and water resources of Estancia Valley. Darton (1928a) outlined the geology of the area in his discussion of the "redbeds" of New Mexico. Part of the area was included in a map by Read and Wood (1944). Thompson (1942) and Read and Wood (1947) discussed the effect of the Pedernal landmass on Pennsylvanian sedimentation. Rich (1921) discussed the possibility of a buried mountain range that might link with the Pedernal Hills.

More recent investigation of the Pedernal Hills has been carried out by two graduate students from the University of New Mexico. Fallis (1957) mapped the Pedernal Hills and the surrounding Permain formations, as well as dealing with some relationships within the Precambrian rocks. Gonzales (1968) mapped and made a petrographic study of the Precambrian. Kottlowski and Foster (1960) hypothesized the presence of ancient shoreline features surrounding the Pedernal Hills. Woodward (1968) described the major rock types found in the Pedernal Hills.

Present Work

Field work

Field mapping was conducted from July to September, 1969. Mapping was done on aerial photographs and transferred to the

base map by use of the Saltzman projector. Sections were hand levelled.

In descriptions of sections the nomenclature proposed by McKee and Wier (1953) was used for the bedding. The grade scale used in describing grain size was proposed by Wentworth (1922).

Map compilation

The base map was constructed from U. S. Geological Survey A. M. S. sheets enlarged to a scale of 1:125,000.

In constructing the structure contours two horizons were used: the contact between the Glorieta Sandstone and San Andres Limestone in the northern part and the Glorieta-Yeso contact in the southern part. Elevation points were transferred by inspection to the base.

Acknowledgements

I wish to thank Dr. V. C. Kelley for suggesting this problem and for his enthusiastic support during the preparation of this thesis. I would also like to extend my thanks to Dr. Lee A. Woodward and Mr. Charles B. Read for their constructive criticism of this paper.

PHYSIOGRAPHY

Provinces

The mapped area lies within the Basin and Range and the Great Plains geomorphic provinces. The boundary between the two is placed near the Pedernal Hills and continues northward through Glorieta Mesa. This boundary is a structural one separating the rolling topography of the Plains from the fault-block mountains farther west.

The area surrounding Clines Corners and the Pedernal Hills is both a structural and topographic high. Weathering and erosion of Permian and Triassic strata are responsible for the rolling topography found throughout the area. If placement of the boundary was based upon topography it could be moved to the eastern edge of the Sandia Mountains because the topography within Estancia Valley is similar to that found in the Great Plains. Based upon structure the geomorphic boundary is placed properly.

Topography

In general, the topography is a gently rolling grassland, and is formed on a moderately dipping Permian and Triassic strata. Standing above the countryside is Pedernal Peak which rises to an elevation of 7,580 feet and is the most prominent feature to be seen in the mapped area. The Pedernal Hills are a series of low hills which have been eroded from Precambrian quartzite.

North of the Pedernal Hills is a sandstone cliff which rises about 250 feet above the valley floor and marks the

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North of the Pedernal Hills is a sandstone cliff which rises about 250 feet above the valley floor and marks the western boundary of the Glorieta Mesa. This mesa is a flat-topped monoclinal feature that rises from Estancia basin (Fallis, 1957).

Along U. S. Highway 66, ten miles east of Clines Corners there is an east-facing escarpment. It can be traced northward into a cliff face which is considered the eastern edge of Glorieta Mesa. These two features appear continuous; however, to avoid carrying the nomenclature too far south, the escarpment in the mapped area is hereafter referred to simply as a mesa. It forms the most prominent feature in this portion of the area.

Three miles south of U. S. Highway 66 on N. M. Highway 3 an area of karst topography has developed on the San Andres limestone owing largely to solution within the limestone. Karst can also be seen in areas where the Glorieta is underlain by gypsum of the Yeso Formation and differs significantly from that seen on the San Andres. In the latter case the karst is seen as broad and shallow depressions, and on the San Andres the karst is similar to that found in the eastern United States. This difference is caused by solution of limestone in one case and by solution of gypsum in the other (Read, oral communication).

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STRATIGRAPHY

Precambrian

In mapping the area for this thesis, no attempt was made to differentiate the various Precambrian rocks. The reasons for this are: 1) emphasis is on the younger formations, and 2) the Precambrian of the Pedernal Hills has been studied and described in detail by other writers (Gonzales, 1968; Woodward, 1967, 1968).

The Pedernal Hills are composed of metasediments and igneous rocks. Fallis (1957) believed that about 10,000 feet of Precambrian beds are exposed in the area. Woodward (1968) described four major igneous and metamorphic rock units, which are based on petrographic studies. The rock units described from oldest to youngest are: 1) granite gneiss, 2) quartzite, 3) a heterogeneous unit, consisting of chlorite-muscovite-quartz phyllite, epidote-amphibolite, quartzite, amphibolite, quartz monzonitic gneiss, cataclasite, and epi-diorite, 4) granite.

The granitic gneiss and quartzite are the main units found in the mapped area. The granitic gneiss crops out in stream valleys along the western margin of the Pedernal Hills. The gneiss is reddish-brown and shows a well developed foliation which has an east-west strike. Gonzales (1968, p. 10) listed the essential minerals as quartz, potassium feldspar, plagioclase, and biotite.

The quartzite may represent several thousand feet of metamorphosed sandstone; however, the quartz grains have been

completely recrystallized to the extent that their original clastic texture is obscured. The rock gives a fused appearance and individual grains cannot be seen. Gonzales (1968) states that quartz and white mica compose 99 percent of the rock, accessory minerals present are magnetite, hematite, tourmaline, apatite, and zircon.

The quartzite is translucent, light gray to white, and generally thin-bedded; compositional layering can also be seen. The beds dip 40 degrees to the southeast. Two sets of joints in the quartzite give the outcrops a blocky appearance.

Two other rock types occur within the quartzite: 1) black to dark gray quartz-specularite schist intercalated with the quartzite, and 2) red-brown quartz-mica schist. The quartz-mica schist may represent clay-rich layers intercalated with a relatively pure sandstone (Gonzales, 1968).

Permian

General Statement

The Bursum and Abo Formations, which are considered to be the lowermost Permian units, do not crop out in the mapped area. Permian formations which are preserved are: 1) Yeso, red siltstone, shale, and gypsum, 2) Glorieta, clean, massive, white sandstone, 3) San Andres, gray, massive limestone, and 4) Bernal, massive red siltstone.

The Geological Survey has considered the Glorieta, San Andres limestone, and Bernal to be members of the San Andres Formation. However, many others have used the above units as formations and this practice is followed here. They are distinct units and readily mappable.

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Yeso Formation

General Statement

The Yeso, which is considered to be in the lower Leonard series, was named by (Lee and Girty, 1909) and considered to be the middle formation of the Manzano Group. The formation was named for Mesa del Yeso near Socorro. Lee defined the type section only in general terms. Needham and Bates (1943) redescribed the type section and included a detailed measured section.

They divided the Yeso into four members. The lower two members were described as the lower clastic zone and the middle evaporite zone, whereas the third member, which is dominantly gypsum, was named the Canas. The upper member was named the Joyita and is composed of pink and orange, thin-bedded sandstone. The lower clastic member was later named the Meseta Blanca Member by Wood and Northrop (1946). Wilpolt and others (1946) named the middle evaporite zone the Torres Member.

The Yeso is unconformable on the Precambrian. The contact with the overlying Glorieta is conformable in the thesis area and is represented by a distinct lithologic break.

Distribution and Thickness

The Yeso formation covers about 180 square miles in the area and crops out on all sides of the Pedernal Hills. On the western side it extends to the northern border of the map in a band about six miles wide. Due to the weakness of the formation it is generally found flooring the valleys. East of the Pedernal Hills and between U. S. Highway 285 and N. M.

[illegible] a cross section.

Regional Setting

The Yeso, which is equivalent to [illegible] of the lower Leonard series, was named by Lee and Girty (1909) and they gave it as the middle formation of the Manzano Group. [illegible] was named [illegible] that [illegible]. Needham and Bates (1943) redescribed the type section and included a detailed measured section.

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Highway 3 it floors a broad valley which extends to the southern border of the map. However, the Yeso can also be seen at the base of escarpments where it is held up by the more resistant Glorieta.

The Yeso contains limestone beds which are resistant to weathering; the nature of these beds is responsible for the large mesas which extend outward from the base of the main cliff face. It is also responsible for low hills and small mesas in the valleys.

The Yeso averages 200 feet thick several miles from the Precambrian. However, near the Precambrian, the Yeso wedges to a thin edge.

Lithology

Near the Pedernal Hills there are two distinct units found within the Yeso, a lower tan to buff sandstone and an upper red siltstone unit.

The lower unit lies unconformably on the Precambrian and consists of tan to yellowish-brown, thin-bedded sandstone and shale. Intercalated with these are thick-bedded limestone and conglomerate beds. The sandstone contains 10 to 15 percent feldspar and is arkosic. They are composed of fine- to coarse-grained, angular quartz. Small-scale crossbeds can be seen in several localities. The shale ranges from very thin- to thin-bedded, is commonly variegated, and composed of silt-sized, angular quartz. Intercalated limestone is thick-bedded ranging from 2 to 3 feet in most exposures. It is dense, nonporous, light-gray, and generally oolitic.

[illegible]

[illegible]

[illegible]

[illegible]

The [illegible]

[illegible]

[illegible]

[illegible] zone. [illegible]

[illegible] in the [illegible]

The [illegible]

[illegible]

to a thin edge.

Lithology

Near the [illegible]

found within the [illegible]

upper red siltstone [illegible]

The lowest unit [illegible]

consists of [illegible]

and shale. Internally [illegible]

and conglomerate [illegible]

cent feldspar and [illegible]

coarse-grained, [illegible]

be seen in several [illegible]

thin- to thick-bedded [illegible]

silt-sized, [illegible]

Thick-bedded [illegible]

[illegible]

Fragments of the conglomerate are mostly angular quartzite ranging from one to two inches in diameter in a sand matrix. The quartzite fragments exhibit some rounding so they are properly termed conglomerates rather than breccia.

Pale-red to reddish-brown thick-bedded siltstone and sandstone interbedded with gypsum and limestone constitute the unit which overlies the buff sandstone. The siltstone is reddish-brown and ranges from thick- to very thick-bedded, in some cases exceeding 35 feet. They are composed of silt and clay sized, angular to subangular quartz grains; mica is generally less than one percent. Fifty percent of the upper unit is made up of siltstone.

The sandstone is pale-red to buff, thick-bedded and composed of very fine grained, angular quartz. Gypsum is white to light gray, thick- to very thick-bedded. On weathered surfaces it is pitted and appears finely granular, while on fresh surfaces it has a crystalline appearance. Thin laminations of organic material, with minor amounts of calcite, occur throughout the gypsum and rarely are the laminations found undisturbed or continuous. The limestone beds are about two feet thick and are composed of thinner beds separated by thin shale partings. The limestone is light gray, porous, and generally crystalline. Large quantities of mudstone are commonly present in the limestone and in fact, in places approaches limey mudstone.

The lower buff sandstone unit might be correlated with the Meseta Blanca Member even though the buff sandstone is coarse grained. The proximity of the Pedernal Hills to the fragments of the conglomerate are mostly angular quartzite ranging from one to two inches in diameter in a sand matrix. The quartzite fragments exhibit some rounding so they are properly termed conglomerates rather than breccia.

Pale-red to reddish-brown thick-bedded siltstone and sandstone interbedded with gypsum and limestone constitute the unit which overlies the buff sandstone. The siltstone is reddish-brown and ranges from thick- to very thick-bedded in some cases exceeding 30 feet. They are composed of silt and clay sized, angular to subangular quartz grains; mica is generally less than one percent. Fifty percent of the upper unit is made up of siltstone.

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Glorieta Sandstone

General Statement

The following statements are quoted from Needham and Bates (1943, p. 1662).

> The name Glorieta was first used by Keyes (1915) who applied it to the main body of the Dakota sandstone (Cretaceous) around the south end of the Rocky Mountains. Although Keyes gave no type locality, presumably the sandstone was named from the Glorieta Mesa in Santa Fe and San Miguel Counties, New Mexico, or the town of Glorieta at the north end of the mesa. Cretaceous formations do not crop out at either of these places. Common usage has determined the Glorieta to be a prominent sandstone well developed and exposed on Glorieta Mesa that separates the Yeso and San Andres formations.
>
> The Glorieta was first designated Permian by Hager and Robitaille (1919)....

Needham and Bates (1943) designated the type section of the Glorieta Sandstone from a section measured one mile west of the village of Rowe, San Miguel County, New Mexico. This formation is thought to belong to the Leonard series.

Some controversy has surrounded the origin of the Glorieta sandstone. King (1942) believed that the Glorieta was derived from islands in the Permian seas. The Glorieta is probably correlative with the Coconino of Arizona and contains sand grains which are frosted and pitted. Noble (1922) described the cross-bedding in the Coconino and he classified the deposit as a dune deposit. Heaton (1933) agreed with Noble in that he felt the sands were deposited by wind action. He also ascribes a northwestern source for the sand. Bachman (1953) buff sandstone could explain the coarseness of the sand within this unit.

Glorieta Sandstone

General Statement

The following statements are quoted from Needham and Bates (1943, p. 1662).

> The name Glorieta was first used by Keyes (1915) who applied it to the main body of the Dakota sandstone (Cretaceous) around the south end of the Rocky Mountains. Although Keyes gave no type locality, presumably the sandstone was named from the Glorieta Mesa in Santa Fe and San Miguel Counties, New Mexico, or the town of Glorieta at the north end of the mesa. Cretaceous formations do not crop out at either of these places. Common usage has determined the Glorieta to be a prominent sandstone well developed and exposed on Glorieta Mesa that separates the Yeso and San Andres formations.
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The Glorieta-Yeso contact is conformable in the thesis area.

Distribution and Thickness

The Glorieta Sandstone is widespread covering about 200 square miles within the mapped area. It is about 175 feet thick along an escarpment in T. 9 N. To the west of this escarpment, the Glorieta is seen as a narrow band of sandstone which extends to the northern boundary of the map (Pl. 1). East of this escarpment the Glorieta crosses U. S. Highway 285 as a band one mile wide. After the sandstone crosses the highway, the outcrop pattern widens to about three miles. East of the mesa the sandstone forms a band that ranges up to ten miles wide and extends to the northern and southern boundaries of the map.

Section 2 measured along the eastern edge of the mesa contains about 125 feet of sandstone. The formation thickens to 205 feet in Pintada Canyon. Pintada is 15 miles east of the Pedernal axis whereas the mesa section is nearly on the axis and this relationship is suggestive of either onlapping of the sandstone or to the subsequent rise and removal of Glorieta prior to deposition of the San Andres. The thinning is due to depositional onlap rather than erosion, as there is no evidence of erosion between the Glorieta and San Andres; in fact, the two formations interfinger indicating continual indicates that the Glorieta was a beach sand deposited as the San Andres sea transgressed. In the Tinnie area the Glorieta appears to be a mixture of beach and dune deposits.

The Glorieta-Yeso contact is conformable in the Tinnie area.

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Lithology

The Glorieta is a clean white sandstone which is resistant to weathering and a cliff-former. The formation erodes into large blocks that usually have an iron oxide coating on their outer surfaces.

In the basal 30 feet of the formation, it is thin-bedded and large-scale crossbeds can be seen. The sandstone consists of fine-grained, well rounded quartz. The grains are frosted and pitted, suggesting a possible aeolian environment. Higher in the section the bedding ranges from thick to very thick and becomes regular; in addition crossbedding decreases in frequency, and the angularity and size of the sand grains increase. It is generally loosely cemented with calcite or silica and consequently is friable. In some localities, the sandstone contains zones of iron concretions.

San Andres Limestone

General Statement

The San Andres Limestone, which is thought to occupy the upper part of the Leonard series, was named by Lee (Lee and Girty, 1909) from the San Andres Mountains. Needham and Bates (1943) redescribed the San Andres and located their type section in Rhodes Canyon, which seemed to fit the deposition. The interfingered sandstone does represent periods when sealevel was lower. They are considered to be part of the San Andres Formation and show thickening away from the axis. They range from 1 to 3 feet in section 2 and increase to thicknesses of 10 feet both east and west of the axis.

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The contact with the Glorieta is transitional but in mapping the base of the San Andres was chosen at the first appearance of limestone above the Glorieta. Interbedded Glorieta-type sandstone beds in the basal beds are considered to be part of the San Andres. These beds are similar to the Glorieta, in that they are thick and consist of medium-grained angular quartz. They thicken to the east and to the west of the axis. Not only are individual sandstone beds found within the San Andres, but near the Pedernal axis the entire formation contains a high percentage of sand generally ranging from 10 to 20 percent. This percentage decreases to the east until in Pintada Canyon sand represents only about one percent of the rock; west of the axis the sand decreases to about 5 percent.

Distribution and Thickness

The San Andres Limestone crops out in several thin bands within the area. It weathers rapidly and is generally found in the valley floors and at the base of escarpments.

Section 2 along the eastern edge of the mesa is the only place where the formation was well enough exposed to get a measured section. Here it is 70 feet thick, and from this section the San Andres continues around the southern end of the mesa as a thin band of limestone and near the fault in T. 9 N., R. 11 E. about 110 feet is partially exposed. West description of the canyon mentioned by Lee when he named the formation. The redescribed section consisted of 35' feet of limestone.

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Lithology

The San Andres Formation contains limestone, sandstone, and gypsum. The limestone is gray, finely crystalline, and where observed thick-bedded. It is nonporous, weathers into a fretted surface, and within the area is sparingly fossiliferous. Several brachiopod shells were found in one outcrop east of N. M. Highway 3. Sand in the limestone is subangular to subrounded, fine-grained quartz. The sandstone of the San Andres is white to tan and thick-bedded. It consists of medium-grained, angular quartz cemented weakly with calcite. The gypsum is white and massive and similar to that found in the Yeso. It is finely granular with organic laminae also present.

Bernal Formation

General Statement

The Bernal of northern New Mexico is Guadalupian in age and is part of the Artesia Group of the lower Pecos Valley (Tait, et al., 1962). The existence of the Bernal beds was first recognized by Read (1944). However, it was not until 1953 (Bachman) that formal U. S. Geological Survey acceptance of the fault the San Andres continues to the west border of the map as a band of limestone which widens to two miles wide. The San Andres crops out in Rinconada Canyon and again appears to thicken. From Pintada Canyon the San Andres continues to the northern border of the map and the outcrop pattern is somewhat sinuous and rapidly changes in width.

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The contact between the Bernal and San Andres appears to be conformable in the mapped area. However, this contact is disconformable in other areas of northern New Mexico and the San Andres appears to have been subjected to long periods of erosion and solution of the limestone (Read, oral communication).

Distribution and Thickness

The Bernal Formation is co-extensive with the underlying San Andres and the overlying Santa Rosa (Plate 1). The Bernal is not found in outcrop in most of the area. However, where outcrops were lacking the presence of this formation could be ascertained by soil color and topographic form. This unit is slightly indurated, weathers rapidly, and does not contain limestone or gypsum beds as does the Yeso. For this reason, the Bernal does not form a prominent scarp, but rather a gentle slope below the more resistant Santa Rosa.

North of U. S. Highway 66 there are two well exposed sections of the Bernal. The first section is five miles west of Clines Corners. Here the Bernal is 46 feet thick. Fallis (1957) stated that he measured 156 feet of Bernal in this area, but the measurement made by Fallis constitutes was given to the name. Baldwin described a type section for the Bernal Formation one mile east of Orata, New Mexico, in a 120-foot section, although the name came from a locality near Bernal and Chapelle villages in San Miguel County. He states that the Bernal is a brownish-red siltstone and fine-grained sandstone and that the formation averages 100 feet in thickness.

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There is also a narrow band of Bernal to the east of N. M. Highway 3. The formation is seen best in Pintada Canyon. There 76 feet of Bernal was measured.

Lithology

The Bernal Formation is composed of pale-red to reddish-brown siltstone and shale and is very consistent throughout the area in both color and lithology. Several buff to tan sandstone beds are found in Pintada Canyon which is the only area where much variation is seen. These beds are composed of fine-grained, subrounded to rounded quartz and have a calcite cement. They cannot be traced more than 50 feet before returning to a pale-red, so they probably represent zones of leaching by ground water, explained by increased porosity within these zones.

Siltstone ranges from thick-bedded to very thick-bedded and is composed of subangular to subrounded quartz grains. The shale is generally thin-bedded, averaging between 5 to 7 inches thick, and occasionally ranging up to 4 feet in thickness. It is fissile and lightly indurated and consists of silt and clay-sized quartz. Calcium carbonate is the main cement in both the siltstone and shale.

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Triassic

General Statement

The Santa Rosa Sandstone is the lower formation of the Dockum Group. The Dockum beds were described by Cummins in 1890 as conglomerate, sandstone and red clay, 150 feet thick near Dockum, Texas (Wilmarth, 1938). In eastern New Mexico the Dockum Group consists of two formations: 1) the Santa Rosa Sandstone and 2) the Chinle Formation which is principally a maroon to purplish-red shale with some interbedded sandstone. No Chinle is present in the mapped area.

Santa Rosa Sandstone

General Statement

The Santa Rosa is Upper Triassic in age. The name Santa Rosa was first used by Darton (1922) for some sandstone exposures near the town of Santa Rosa, New Mexico. No exact type locality was given.

Kelley and Wood (1946) state that the maroon, reddish-purple and brown colors are prominently developed and often serve as formation identification. The Santa Rosa contains between 20 and 30 percent heavy minerals, e.g. magnetite, garnet, epidote, and rock fragments; their presence can be used to delimit the Santa Rosa (Read, oral communication). In doing the mapping for this thesis both the color and the presence of an increased percentage of heavy minerals was used for picking the contact between the Bernal and Santa Rosa.

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The contact with the Bernal is disconformable and represents late Permian and early and middle Triassic. Within the thesis area the contact appears to be one of nondeposition; however, at some localities in New Mexico, the Santa Rosa rests directly on the Glorieta Sandstone or on beds as late as Ochoa. Therefore the contact represents a period of extended erosion.

Distribution and Thickness

The Santa Rosa sandstone covers about 150 square miles in two main areas: 1) Glorieta Mesa and 2) east of N. M. Highway 3.

In section 1 (Pl. 2), at the southern end of the mesa, the Santa Rosa forms a steep escarpment. A thickness of 75 feet was measured here. Section two along the eastern side of the mesa contains 220 feet of sandstone. The Santa Rosa also crops out along the eastern border of the area. The area north of U. S. Highway 66 and east of N. M. Highway 3 contains few outcrops but is characterized by a purplish, sandy soil which indicates the presence of the Santa Rosa. Pintada Canyon again contains the best exposures. Section three measured in the canyon contains 170 feet of Santa Rosa. Each of the three sections can be divided into two parts: the maroon lower sandstone and an upper buff sandstone.

Lithology

The Santa Rosa can be divided into two distinct units, although due to the map scale they could not be mapped separately. The upper unit is composed of buff sandstone and conglomerate.

The maroon member consists of thick- to very thick-bedded sandstone. These are composed of fine-grained, angular to subangular quartz, and are highly cemented with calcium carbonate.

There are several thin-bedded conglomerate beds within the maroon member. These differ from those found higher in the section in that the clasts are siltstone fragments. The matrix is fine-grained sand cemented with calcium carbonate. The clasts compose 50-70 percent of the rock and appear to be fragments from both the Bernal and Santa Rosa formations.

The maroon member forms a gentler slope than the overlying buff sandstone. This is due to the presence of abundant shale interbeds, ranging from 5 inches to over 15 feet, within the maroon member.

The overlying buff sandstone member consists of thick-bedded, yellow to buff sandstone. The sand is medium to coarse grained, subangular quartz. This sandstone closely resembles the Glorieta; however, the buff sandstone is coarse-grained and contains a higher percentage of heavy minerals. Both the Glorieta and the buff sandstone member of the Santa Rosa contain siliceous cement.

Conglomerate found in the upper member is of two types: 1) orthoquartzite conglomerate and 2) limestone conglomerate.

The orthoquartzite conglomerate was defined by Pettijohn (1957) as a conglomerate that has a simple composition and the pebbles are resistant to wear, such as quartzite, quartz, and chert. The conglomerates found in the buff sandstone member exhibit the above characteristics. The matrix consists of the same type of sand as that found in nonconglomerate beds.

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The clasts are quartzite and chert pebbles. The pebbles are well rounded and average about one-half inch in diameter.

Limestone conglomerate also occurs within the buff sandstone member. There are instances where limestone conglomerate has been found several hundred miles from any source of limestone. In these cases, the clasts tend to be concentrically banded, probably due to accretion (Read, oral communication). Within the thesis area, the limestone clasts are subangular to subrounded, dense limestone showing evidence of abrasion and without any hint of banding. For these reasons, I believe that the limestone conglomerate, at least in the thesis area, is indicative of a nearby source for the limestone.

Cenozoic

Sedimentary Rocks

The entire area is covered by soil and small areas of caliche which were not mapped. Only two areas were mapped as Quaternary and these were: 1) the pediment surface which surrounds the Pedernal Hills and 2) Pleistocene, Lake Estancia.

The pediment which surrounds the Pedernal Hills is best developed along the northern and eastern sides. It bevels the underlying Yeso and consists of a caliche gravel cap. The gravel is composed of angular quartzite fragments which range up to three inches in diameter. The frequency of these fragments decreases at greater distances from the Pedernal Hills, until at the front edge of the pediment there is little but caliche, which is dense, gray calcium carbonate. Darton (1922) correlated this pediment surface with the Ogallala

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Formation of the Great Plains.

Rejuvenation of the streams in Pleistocene and Holocene time is resulting in the destruction of the pediment.

Also in the Pleistocene the southwestern part of the mapped area was covered by a fresh water lake, strand lines can still be seen. The lake bed is predominantly unconsolidated sand, which is fine-grained, subangular to subrounded quartz. The sand of Lake Estancia was deposited over the exposed Permian formations.

Igneous Rocks

Two sets of dikes are found within the thesis area and they trend slightly west of north and are emplaced in the Yeso Formation. One set is in E½, T. 8 N., R. 11 E., and is emplaced along zones of weakness created by faulting. Their lengths range from 5 to 150 feet whereas the thickness ranges from 1 to 8 feet. The second set occurs in the E½, T. 8 N., R. 12 E. and does not appear to be related to any faults. They are about 50 feet long and 5 feet wide.

The dikes in E½, T. 8 N., R. 11 E. do not exhibit flow directions. They are composed of about 90 percent plagioclase feldspar, minor amounts of magnetite and quartz are also present. An aphanitic and finely crystalline texture is present; contact metamorphism cannot be seen at the contact with the Yeso. Based upon the aphanitic texture, the lack of contact metamorphism and the fact that they do not exhibit any textural changes from the outer contact to their centers the dikes were probably emplaced at relatively low temperatures.

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Comparing these dikes with the basic dikes described by Bates and others (1947, p. 39), they are probably diabase.

The dikes which occur in the E½, T. 8 N., R. 12 E. are similar to the above in that they do not exhibit a flow direction, but the similarity ends here. They are composed of randomly oriented hornblende crystals, which range from 1 to 3 millimeters in length and constitute 30 percent of the rock. These crystals are found within a white to gray groundmass, which is feldspar, and is about 60 percent of the rock. Quartz, mica, and accessory minerals account for the remaining 10 percent. The dikes are phaneritic and coarsely crystalline in texture. The contact between the dike and the Yeso is not seen because it is covered by soil; therefore, the presence or lack of contact metamorphism could not be ascertained. These dikes appear to be similar to the hornblende diorites described by Bates and others (1947).

Comparing these dikes with the basic dikes described by Bates and others (1947, p. 30), they are probably diabase.

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DISCUSSION

It is believed that section 2 represents the crest of the late Paleozoic Pedernal axis because within this section, the formations are thin and they thicken appreciably in sections 1 and 3 (Pl. 2). At the present time, section 2 is structurally high and although this is due to later structural activity, the thickness variation seen across the area indicates that this present configuration probably existed at the time that the Permian formations were deposited.

The Yeso Formation wedges out against the Precambrian and conglomerate beds containing quartzite fragments are seen throughout the lower member of the formation. Arkosic sandstone and oolitic limestone indicate that the Precambrian was not only a source of sediment but that shallow, agitated conditions were prevalent during the deposition of the lower Yeso.

That the Pedernal axis remained as a stable, positive area during the deposition of the Glorieta, San Andres, and Bernal can be seen by the fact that each of these formations thin as they onlap the axis. The high percentage of sand within the San Andres indicates that locally sand was being derived from the Precambrian and was being deposited near its source, due to rapid deposition of limestone. Sandstone within the lower San Andres thickens east and west of the axis.

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The Santa Rosa is just the opposite of what is seen in the Permian formations, in that, it does not show any evidence of thinning. However, the presence of abundant conglomerate beds indicates that material was being actively eroded from Precambrian and also from nearby Permian formations. The absence of thinning can be explained by the fact that during deposition of the Santa Rosa, all but a few islands of Precambrian near the present Pedernal Peak, were buried and the area was probably near base level. Therefore, the effect of the Precambrian on Triassic and younger strata was reduced by the thick Permian section already present.

The thinning within the Permian formations coincides with the axis of an anticline outlined by structure contours (Pl. 1). Although the folding cannot be dated accurately, the relationship between the Santa Rosa and the underlying Bernal indicates that it is post-Santa Rosa and based upon the regional structure, is probably Laramide in age. If the thinning was the result of tectonic processes, it should also be seen in the Santa Rosa. However, the Santa Rosa remains fairly constant in thickness across the area. The thinning is therefore not considered to be related to the Laramide arch. Post-Bernal erosion might account for some of the thickness variations seen in the Bernal. However, erosion cannot be used to explain the thinning of the Glorieta and San Andres as they crossed the late Paleozoic axis because their contact is transitional and represents continued sedimentation. Therefore, it can be assumed that erosion did not play a major role in the thicknesses of the Permian formations. The late Paleozoic Pedernal axis affected the Permian formations as a pre-existing ridge supplying debris to the onlapping formations, conglomerate beds indicates that material was being actively eroded from Precambrian and also from nearby Permian formations. The absence of thinning can be explained by the fact that during deposition of the Santa Rosa, all but a few islands of Precambrian near the present Pedernal Peak were buried and the area was probably near base level. Therefore, the effect of the Precambrian on Triassic and younger strata was reduced by the thick Permian section already present.

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GEOLOGIC STRUCTURE

Paleotectonics

The Pedernal Hills represent the exhumed topography of a Pennsylvanian and Permian topographic high and can be considered to be part of the "Ancestral Rockies."

The Pedernal Hills are bounded on the west by Estancia basin which, during the Pennsylvanian, received a thickness of 4,000 to 5,000 feet of sediment. This thick sequence of strata would indicate that the basin was actively subsiding during sedimentation due to faulting along the western side of the Pedernal Hills. Renewed activity along this fault during the Tertiary is probably responsible for the present elevation of the Pedernal Hills.

The Rowe-Mora basin to the northeast of the Pedernal Hills lies between the ancestral Uncompagre uplift and the Sierra Grande arch. Read and Wood (1947, Fig. 2) indicate that the basin divides around the Pedernal Hills, and also hypothesized a possible connection between the Estancia basin and the western limb of the Rowe-Mora basin north of the Pedernal Hills. Kottlowski (1961, p. 101) has stated that the Pennsylvanian section is missing in this area and if a connection did exist it was a shallow strait.

Well data indicate that another basin existed on the eastern side of the Pedernal Hills. Thick sequences of Pennsylvanian and Permian strata have been logged in wells drilled east of the Pedernal Hills. This basin might be the eastern limb of the Rowe-Mora basin or it could also be part of the

Tucumcari basin and is probably the latter. Baltz (1965) has a saddle which separates the Rowe-Mora basin from the ancestral Tucumcari basin, between the Pedernal Hills and the Sierra Grande arch. This saddle may represent the Pedernal axis. Structure contours (Pl. 1) not only delimit an anticline, but also coincide with the Pedernal axis and have a northeasterly trend in the northern part of the mapped area. If these structure contours are extended beyond the map, they pass through the northwestern edge of Guadalupe County and if superimposed on Baltz' figure 3, indicate a possible connection between the Pedernal axis and the Sierra Grande arch (Fig. 2).

Local Features

Folds

Minor open, symmetrical folds with their axial planes striking north-south and their limbs having a maximum dip of 10 degrees are found within the lower unit of the Yeso Formation. The maximum dip is found in the beds nearest the axial plane and decreases away from the axial plane until the beds become horizontal. The beds which have the largest amount of dip also thin at their crests, whereas the horizontal beds do not exhibit this thinning. This geometry could be caused by folding contemporaneous with deposition. However, compaction would also give the same result. The fact that the lower unit of the Yeso was deposited on an uneven Precambrian surface would seem to support the latter explanation in that compaction over the high areas of the

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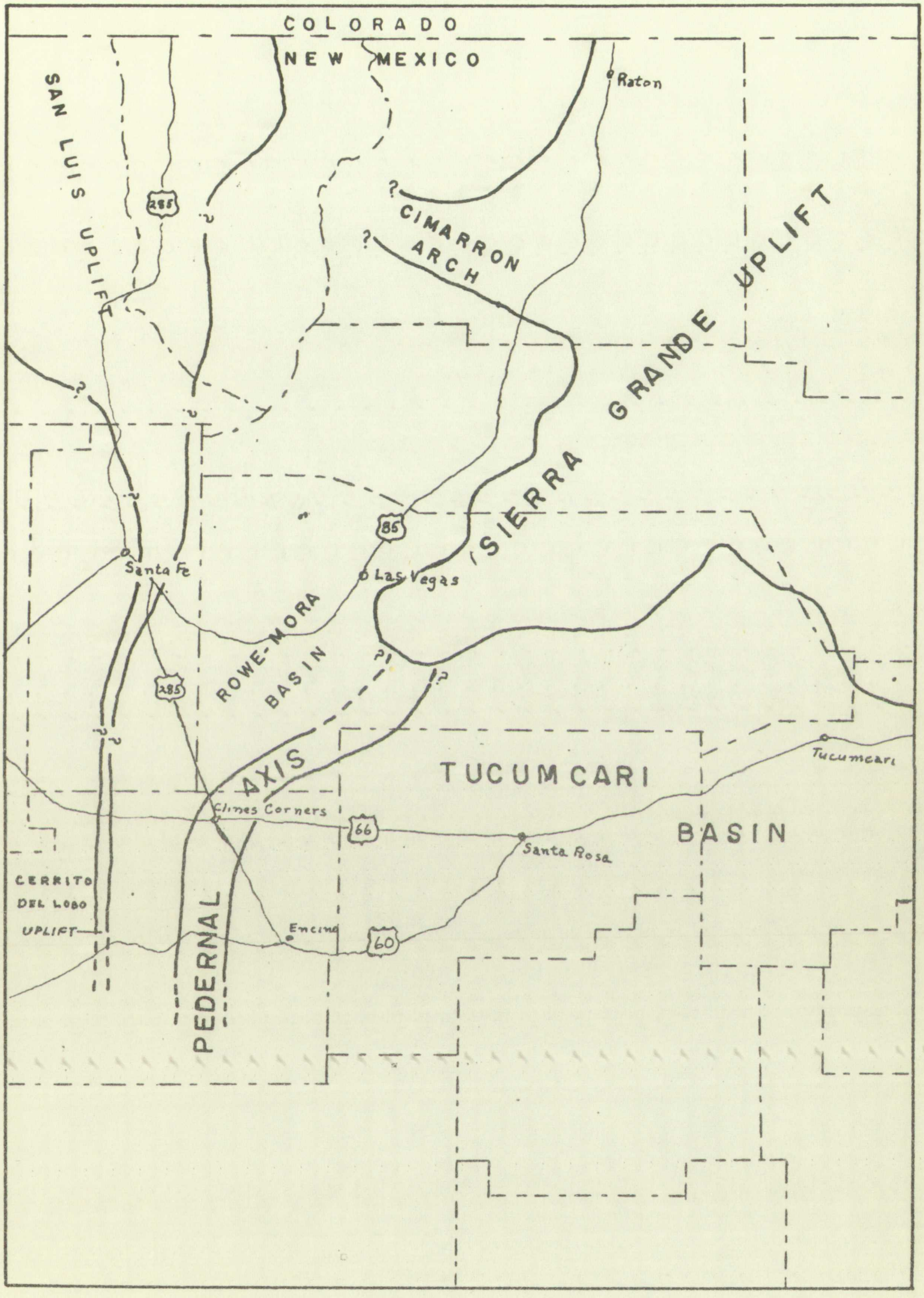

Figure 2. Possible connection between the Pedernal axis and Sierra Grande arch. (Modified from Baltz, 1965).

Precambrian would cause the beds to thin at their crests whereas the limbs remained relatively unaffected.

Small asymmetrical folds with the axial plane striking north-south and dipping to the east are also seen in the upper unit of the Yeso and are restricted to thin, interbedded shale and sandstone beds. The wave length of these folds ranges from 1 to 3 feet in length. The folded beds are found between strata which have not been folded and based upon this and their relatively small size, they are considered to be the result of flowage due to the influence of gravity.

The principal structure is a broad anticline which plunges to the northeast, although closure cannot be seen within the thesis area. The limbs of the fold have a maximum dip of 6 degrees, although in most areas the strata are nearly horizontal. The Precambrian may have exerted some control on the folding because the axis of the fold coincides with the buried Pedernal ridge as positioned by thickness variations within the Permian strata. An east-west compressional couple probably caused the quartzite to fracture and the resultant upward movement along these faults created the folding in the overlying strata.

Faults

All the evidence of faults is west of the Pedernal Hills. In T. 7 N., R. 12 E. a major fault separates Precambrian quartzite from the Yeso Formation and it is possible that this fault represents the structural boundary between the Precambrian of the Pedernal Hills uplift from Estancia basin to the west.

Precambrian [illegible]

whereas the [illegible]

[illegible]

north-south [illegible]

upper part of [illegible]

shale and [illegible]

ranges from 1 [illegible]

between strata [illegible]

this and their [illegible]

be the result of [illegible]

The principal [illegible]

plunges to the [illegible]

within the [illegible]

dip of 6 degrees [illegible]

horizontal. [illegible]

the folding [illegible]

buried Pedernal [illegible]

within the [illegible]

probably caused [illegible]

upward movement [illegible]

overlying strata [illegible]

Faults

All the [illegible]

In T. 7 N., R. [illegible]

quartzite from [illegible]

fault represe[illegible]

of the [illegible]

Activity along this fault probably resulted in the initial uplift of the Pedernal Hills. The fault trace strikes to the north and the fault plane appears to have a near vertical dip. It appears to be normal and downthrown to the west, although the amount of stratigraphic separation could not be determined.

There is a salient of Precambrian quartzite west of the above mentioned fault. Due to outcrop pattern of the Yeso and the fact that Yeso beds dip into the Precambrian in places, the possibility of an overthrust was considered. However, it was found that Yeso beds dipped into the Precambrian at only two isolated outcrops and at all other outcrops the beds dipped away from the Precambrian with an average dip of 3 degrees. It is possible that these blocks of Precambrian represent isolated blocks that slid onto the Yeso. However, it is believed that normal onlap accompanied by later slumping is a better explanation. The outcrop pattern of the Yeso can be explained by original deposition and later erosion. It was deposited within existing valleys and across the Precambrian. Generally, the Yeso has been stripped from the quartzite, although in places it can be seen near the crests and in saddles within these hills. These remnants are resistant to erosion because they exhibit a greater degree of induration than that seen elsewhere in the Yeso.

Several normal faults downthrown to the west are located within the salient and exhibit only a small stratigraphic separation. They range from about 100 feet to three-quarters of a mile in length and trend to the north.

Directly west of the Precambrian salient, there is a fault which is slightly arcuate and trends to the northeast for about 5 miles. It is a normal fault, downthrown to the west with the dip of the fault plane ranging from 60 degrees west to 90 degrees. A block of Glorieta sandstone is found at the fault plane and is considered to be a part of the eastern block which has been drug along the fault to its present position. If it were a part of the western block, it would have to be overturned and this is not indicated. The tops of the beds are to the west, as shown by cross-bedding and some graded beds. Movement has also occurred within the block, both along bedding planes and perpendicular to them, and where movement has occurred, the quartz grains have been crushed. The fault has placed the upper unit of the Yeso and lower part of the Glorieta adjacent to the lower unit of the Yeso so the minimum stratigraphic separation is about 100 feet.

In the northern part of T. 9 N. and the southern part of T. 8 N., R. 11 E. an arcuate fault trends to the north for about 6 miles. It dies out to the north in the monoclinal flexure of the Glorieta Mesa, and to the south it is truncated by the fault described above. It is a normal fault downthrown to the west as indicated by slickensides. The fault plane dips about 70 degrees and some brecciation is seen along the fault.

The outcrop patterns along the northern half of the fault seem to indicate a reversal of the direction of movement on the fault from normal to reverse. This apparent reversal is

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The outcrop patterns along the northern half of the fault seem to indicate a reversal of the direction of movement on the fault from normal to reverse. This apparent reversal is probably due to drag at the northern end of the fault, causing the eastern block to rotate. Once initiated, this rotation may have proceeded at a greater rate than the movement of the western block or may have continued after the western block had come to rest, thus giving the appearance of a reverse fault in this area. Some drag also occurred at the southern end resulting in a slight anticlinal warp in the eastern block. San Andres has been faulted into contact with the Yeso with a minimum stratigraphic separation of about 175 feet.

Based upon regional relationships an east-west compressional couple is probably responsible for the structure seen in the area, with the major force directed from the west. These forces caused renewed activity on Pennsylvanian faults in the Precambrian quartzite. The upward movement of the Precambrian caused the overlying strata to begin to fold; along the western side, the break between Estancia basin and the Precambrian was greater than on the eastern side where the Precambrian seems to shelve into the Tucumcari basin. Because of this, the folding was more intense on the western side where faulting finally occurred. This episode of folding and faulting is probably Laramide in age.

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GEOLOGIC HISTORY

Events of Precambrian

Little is known about the events of the Precambrian in New Mexico. Precambrian rocks are represented by a sequence of regionally metamorphosed sedimentary, volcanic, and by intrusive and nonmetamorphosed igneous rocks.

The quartzite probably represents a thick sequence of sand deposited in the Precambrian. However, Woodward (1967) stated that it may be the result of precipitation of silica and that the quartzite and interbedded specularite-rich layers represent annual increments. Later metamorphism has obscured the true nature of the quartzite. After deposition, the sand and mud were intruded by dikes and sills and this sequence was folded and regionally metamorphosed. The degree of metamorphism ranges from lower almandine-amphibolite facies in the quartzite to upper greenschist facies in the heterogeneous unit. The emplacement of the granite in the southern part of the Pedernal Hills was post-kinematic and occurred both by assimilation and forceable intrusion, as evidenced by xenoliths and cataclasite, respectively (Gonzales, 1968). After emplacement of the granite, the area underwent regional upwarp and erosion.

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Paleozoic and Mesozoic History

During the early Paleozoic, central and northern New Mexico were part of the Transcontinental arch which was supplying sediment to southern New Mexico. Sand was being derived from this source and was deposited within the Cambrian seas. In early Ordovician, a transgressing sea was depositing lime mud across the Cambrian and at the end of El Paso time deposition ended. This surface was upwarped and beveled by erosion which not only removed the El Paso but also cut deeply into the Precambrian, particularly in the western and northern parts of New Mexico. Late Ordovician was characterized by deposition of dolomite and also represents a period when deposition was interrupted by uplift and erosion as evidenced by local unconformities in the section. At the end of Montoya time and continuing into early Silurian, the Ordovician surface was uplifted and eroded. This surface was buried in middle and late Silurian by lime mud which was later dolomitized. The Silurian underwent an extended period of erosion prior to deposition of the Devonian, whose sediment is not only preserved in southern New Mexico but is also found in the northern part of the state.

Devonian and Mississippian strata have been found in northern New Mexico along the flanks of the Sangre de Cristo Mountains and in the Raton basin (Baltz, 1965). The Devonian rocks were deposited as marine sand and dolomite. The Mississippian strata are similar but they also contain marine conglomerate and limestone breccia. McKee (1951) believed that these rocks were deposited along the margin of a landmass located in central New Mexico. This landmass connected with the Defiance positive area and continued into northeastern Arizona. The evidence given by McKee is that Devonian and Mississippian rocks are not found in central New Mexico, also derived from this source and was deposited within the Cambrian seas. In early Ordovician, a transgressing sea was depositing lime mud across the Cambrian and at the end of El Paso time deposition ended. This surface was upwarped and beveled by erosion which not only removed the El Paso but also cut deeply into the Precambrian, particularly in the western and northern parts of New Mexico. Late Ordovician was characterized by deposition of dolomite and also represents a period when deposition was interrupted by uplift and erosion as evidenced by local unconformities in the section. At the end of Montoya time and continuing into early Silurian, the Ordovician surface was uplifted and eroded. This surface was buried in middle and late Silurian by lime mud which was later dolomitized. The Silurian underwent an extended period of erosion prior to deposition of the Devonian, whose sediment is not only preserved in southern New Mexico but is also found in the northern part of the state.

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Early Pennsylvanian seas covered large portions of New Mexico. They were transgressive seas and deposited the Sandia Formation which is the basal unit of the Magdalena Group and mainly clastic. The detritus was derived from local sources. However, only minor quantities were being supplied. At this time the Pedernal Hills were supplying detritus to Estancia basin.

The Madera Limestone represents maximum marine transgression. At this time very little detritus was being supplied. Read and Wood (1947) indicate that the Lower Gray limestone member was deposited in Des Moinesian time.

The Pedernal Hills along with other elements of the "Ancestral Rockies" underwent renewed uplift during late Des Moinesian time. This crustal movement which had begun in early Pennsylvanian was accelerated in late Pennsylvanian. This created a greater differential between highlands and the basins of deposition. Stream gradients were increased and erosion was rapid. The rapid sedimentation that was occurring probably caused local regression because the amount of sediment exceeded subsidence. The continental Sangre de Cristo and Abo formations were deposited at this time. Read and Wood (1947) state that this continental sedimentation represented the final phase of geosynclinal filling for the cycle and indicates geanticlinal maturity and old age. These sediments are actually shelf-type sediments.

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By late Pennsylvanian and early Permian, central and northern New Mexico consisted of separate basins and highlands. The Pedernal Hills were probably islands within these seas and continued to shed detritus to the surrounding basins. Within these basins local rather than major unconformities were the rule. However, the top of the Magdalena Group generally represents the limit of marine sedimentation within the area. About this time a topography of high relief was formed on the Precambrian. In early Leonard time, most of northern and eastern New Mexico was covered by a saline epicontinental sea which deposited the Yeso.

The seas were probably very close to normal marine during the time in which the Meseta Blanca member of the Yeso was deposited. However, the proximity of the Pedernal Hills played a greater role in the sediment characteristics of the lower sands than the condition of the sea water. The Pedernal Hills were supplying large amounts of detritus at this time. This is seen in the fact that the sands contain a very high percentage of feldspar. There are numerous conglomerate beds found in the lower unit and the clasts are Precambrian quartzite. Limestone within the Meseta Blanca member is generally oolitic, indicating shallow, high-energy conditions.

During late Yeso time, the Pedernal Hills were no longer a major factor in sedimentation. The climate had become semi-arid to arid and very little erosion was taking place. During this time, climate and salinity played the major role in sediment character. The salinity increased and the individual basins were periodically cut off from the open sea. At these times the thick gypsum and anhydrite beds formed. At times and northern New Mexico consisted of separate basins and highlands. The Federal Hills were probably islands within these seas and contributed coarse detritus to the surrounding basins. Within these basins local rather than major unconformities were the rule. However, the top of the Magdalena Group generally represents the limit of marine sedimentation within the area. Note that a topography of high relief was formed on the Precambrian. In early Leonard time, most of northern and eastern New Mexico was covered by a saline epicontinental sea which deposited the Yeso.

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During middle Leonard time, the sea once again transgressed the area. The lower part of the Glorieta was deposited mainly by winds with the sand being supplied from a western source. At this time local highs accounted only for a small portion of the detritus. In late Glorieta time, erosion of local highs and wave action of the transgressing sea played a greater role than wind in the deposition of the Glorieta sand. Farther to the west wind action probably acted as the main depositional agent throughout Glorieta time.

In upper Leonard time, the Permian sea spread northward following closely the deposition of the Glorieta Sandstone, i.e. where the Glorieta thins the San Andres thickens. The San Andres lime mud was deposited above the Glorieta generally under open marine conditions. Near the end of Leonard time the seas became more restricted and anhydrite and gypsum were deposited.

In the Pedernal Hills area, the contact between the San Andres and Glorieta is transitional and represents a period when the environments were migrating across the area. This migration was probably due to eustatic fluctuation of the sea level across the Pedernal axis. The basal San Andres sediments are similar to the calcareous facies as described by Pettijohn (1957, p. 612), in that they were deposited in when basins were open to normal marine conditions, gray lime muds and reddish-tan sands were deposited. Since the basins were periodically open to normal marine waters, the sediments represent a cyclic deposit in that they alternate between evaporitic and normal marine sediments.

During middle Leonard time, the sea once again transgressed the area. The lower part of the Glorieta was deposited mainly by winds with the sand being supplied from a western source. At this time local highs accounted only for a small portion of the detritus. In late Glorieta time, erosion of local highs and wave action of the transgressing sea played a greater role than wind in the deposition of the Glorieta sand. Farther to the west wind action probably acted as the main depositional agent throughout Glorieta time.

In upper Leonard time, the Permian sea spread northward following closely the deposition of the Glorieta Sandstone, i.e. where the Glorieta thins the San Andres thickens. The San Andres lime mud was deposited above the Glorieta generally under open marine conditions. Near the end of Leonard time the seas became more restricted and anhydrite and gypsum were deposited.

In the Federal Hills area, the contact between the San Andres and Glorieta is transitional and represents a period when the environments were migrating across the area. This migration was probably due to eustatic fluctuation of the sea level across the Federal axis. The basal San Andres sediments are similar to the calcareous facies as described by Pettijohn (1957, p. 612), in that they were deposited in relatively shallow seas near a stable landmass. In early phases of deposition, the sea withdrew several times, the level was lowered and sand was deposited; during periods when sea level rose lime mud was deposited. During later phases the sea reached its maximum level, although it remained relatively shallow near the crest of the axis, and deposited lime mud. Sand being derived from the crest and nearby Precambrian islands was rapidly incorporated into the lime mud being deposited on the axis. This removed the sand from the effects of wave action thereby preventing the sand from being carried into the surrounding basins.

The San Andres sea began to withdraw in Guadalupian time and Bernal sand, silt, and mud were deposited as the seas regressed. By this time the Pedernal Hills were probably very near base level and only a few locally high areas were still shedding some debris. Locally, the San Andres was being eroded and a sink-hole topography was being developed. Sea level continued to fluctuate and the sink-hole topography was subsequently buried beneath the silt and mud of the Bernal. Sedimentation was continuous in the basins. Even though most of the Pedernal axis was covered by early Permian sediments, it still affected the geometry of the Bernal beds causing them to thin as they crossed the axis.

Upper Permian and lower and middle Triassic strata are absent, probably due to nondeposition. During Upper Triassic time the sea had withdrawn from the area and the Santa Rosa and Chinle floodplain sediments were deposited.

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Conglomerate is abundant in the first 100 feet of the Santa Rosa sands. The clasts within the conglomerate consist of fragments of Bernal, San Andres, and Precambrian quartzite. The fragments of Bernal and San Andres are angular to subangular and indicate short transportation. The quartzite and chert fragments are well-rounded but the nearest source for these fragments was the Pedernal Hills. They were derived from areas which had not been buried by Permian sedimentation. The Pedernal Hills were probably buried completely by the end of Triassic time.

Jurassic and Cretaceous sediments are not found within the thesis area. However, they are found in nearby areas and probably covered the Pedernal Hills at one time. These sediments have been removed by post-Cretaceous erosion.

Intense Laramide deformation is not seen in the Pedernal Hills; however, the folds and faults seen to the west of these hills were probably initiated at this time.

Cenozoic History

During middle and late Tertiary time, uplift and normal faulting occurred throughout New Mexico. Renewed activity on the faults along the western side of the Pedernal Hills probably took place at this time. The dikes were probably emplaced shortly after this renewed activity began, and this faulting and regional tilting probably raised the Pedernal Hills close to their present elevation.

The stream gradients increased and the overlying Permian and Triassic sediments were removed by erosion. In early

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Quaternary time this surface was reduced to relatively low relief. Quartzite being eroded from the Pedernal Hills was deposited on this surface by streams which rapidly lost their velocity on the beveled slope and caliche was formed due to evaporation of ground water.

During Pleistocene time a fresh water lake occupied Estancia Valley. Beach deposits can be seen in the south-western portion of the thesis area.

The Pedernal Hills reached their present elevation some time during the Pleistocene. The streams were rejuvenated and the pediment surface began to be destroyed. Precambrian topography is being exhumed.

CONCLUSIONS

The main conclusions of this thesis are as follows:

1) During Pennsylvanian time the Pedernal Hills were being actively uplifted and large amounts of detritus were being shed to Estancia basin and farther west and the Tucumcari basin on the east. Also the topography of the Precambrian exhibited a high relief.

2) While the Meseta Blanca Member of the Yeso was being deposited, the Pedernal Hills were still being uplifted and acting as a major source of sediment. At the end of Yeso time, uplift had ceased and only fine-grained sediment was being shed into the surrounding basins.

3) The Glorieta, San Andres, and Bernal Formations represent a transgressive-regressive cycle of sedimentation. At the time of their deposition, the Pedernal Hills were stable and variations within these formations are due to eustatic changes in sea level across the axis. Low areas of the Pedernal axis were buried at this time.

4) The Yeso wedges out against the Pedernal axis whereas the Glorieta, San Andres, and Bernal thin drastically as they onlap the axis. After the deposition of the Bernal several islands of Precambrian, near the present Pedernal Peak, remained above the surrounding terrane.

5) Upper Permian and early Triassic sediments were not deposited in the area. The Santa Rosa was derived in part

CONCLUSIONS

The main conclusions of this study are as follows:

1) During Pennsylvanian time the Pedernal Hills were being actively uplifted and large amounts of sediment were being shed to Estancia basin on the west and Tucumcari basin on the east. Also during this period, the Precambrian exhibited a high relief.

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3) The Glorieta, San Andres, and Bernal formations represent a transgressive-regressive cycle of sedimentation. At the time of their deposition, the Pedernal Hills were stable and variations within these formations are due to eustatic changes in sea level across the axis. Low areas of the Pedernal axis were buried at this time.

4) The Yeso wedges out against the Pedernal axis whereas the Glorieta, San Andres, and Bernal thin dramatically as they onlap the axis. After the deposition of the Bernal several islands of Precambrian, near the present Pedernal Peak, remained above the surrounding terrain.

5) Upper Permian and early Triassic sediments were not deposited in the area. The Santa Rosa was derived in part

from remnants of Precambrian rocks which extended above the Permian and from the surrounding Permian sediments. The Precambrian of the Pedernal Hills was covered entirely by late Triassic time.

6) In Tertiary and Quaternary time, erosion exhumed large parts of the Precambrian. A pediment surface was formed which is now preserved as erosional remnants around the Pedernal Hills.

STRATIGRAPHIC SECTIONS

Section 1 - Bernal Formation and Santa Rosa Sandstone measured near Highway 66 (N. E. ¼, T. 9 N., R. 11 E.).

Santa Rosa Sandstone:	Thickness (feet)
8. Sandstone, buff to tan, coarse-grained, angular quartz, thick-bedded, Contains a one-foot conglomerate bed, yellow to buff, well-rounded quartzite and chert pebbles up to one inch in diameter ..	11.0
7. Shale, purplish-red, silt-sized, angular to subangular quartz, thin-bedded	19.0
6. Sandstone, purplish-red to brown, fine-grained subangular quartz, high percentage of heavy minerals, thick-bedded	9.0
5. Shale, purplish-red, subangular, thin-bedded	6.0
4. Conglomerate, dark reddish-maroon, fine-grained subangular quartz, thin-bedded; clasts mainly siltstone fragments, range from coarse sand to pebble-sized particles	5.9
3. Shale, reddish-brown, angular, thin-bedded, forms slope	11.6
2. Sandstone, purplish-red, fine-grained, subangular to angular quartz sand, thin-bedded, small-scale crossbeds present	12.0
Total:	74.5

Bernal Formation	
1. Sandstone, pinkish-red, very fine-grained, angular to subangular quartz, thick-bedded, contains shale interbeds, forms slope at base of Santa Rosa	46.0
Total:	46.0

Section 2 - Glorieta Sandstone through Santa Rosa Sandstone measured (N. E. ¼, T. 10 N., R. 12 E.).

Santa Rosa Sandstone	Thickness (feet)
5. Sandstone, buff to tan, medium- to coarse-grained, angular to subangular, thick-bedded. Contains conglomerate lenses, tan to yellow, medium-grained	

Thickness (feet)

quartz, thin-bedded. Clasts are predominantly quartzite and chert averaging about one-half inch in diameter 169.0

4. Sandstone, purplish-red, fine-grained, angular quartz grains, thin- to thick-bedded, crossbeds are present, cement is calcium carbonate 50.5

Total: 219.5

Bernal Formation

3. Sandstone, pale red to red, very fine-grained, subangular, thick-bedded. Interbedded with siltstone 34.6

Total: 34.6

San Andres Limestone

2. Gypsum, pale white to gray, massive, contains thin organic laminae 10.0
Limestone, gray, finely crystalline, thick-bedded, unfossiliferous, high percentage of sand, lower 20 feet contain thin-bedded sandstone beds, the sand is medium-grained and subangular quartz 60.0

Total: 70.0

Glorieta Sandstone

1. Sandstone, yellowish-brown to white, fine- to medium-grained, thin- to thick-bedded, predominantly clean, subangular quartz sand. Base is covered 75.0

Total: 75.0

Section 3 - Santa Rosa Sandstone and Bernal Formation measured in Pintada Canyon (N. E. ¼, T. 7 N., R. 15 E.).

14. Sandstone, buff to tan, medium-grained, subrounded quartz sand, thin-bedded, crossbeds are present, calcium carbonate cement, abundant plant fragments 10.0

	Thickness (feet)
13. Conglomerate, yellowish-brown to tan, coarse-grained subangular quartz, thick-bedded, well indurated, the clasts are limestone fragments ranging in size from ½ inch to 2 inches. The fragments are angular and constitute 60% of the rock	4.0
12. Sandstone, buff to tan, coarse-grained sub-rounded quartz sand, thin-bedded, calcium carbonate cement, abundant plant fragments	14.0
11. Sandstone, yellowish-tan, medium-grained, angular quartz sand, small percentage of heavy minerals, few plant fossils	28.0
10. Shale, purplish-red, silt-sized, angular quartz grains, thin-bedded	25.0
9. Sandstone, maroon, medium-grained, subangular sand, some crossbedding, generally very thick-bedded, high percentage of heavy minerals	46.0
8. Sandstone, maroon, medium- to coarse-grained, angular quartz sand, thick-bedded, high percentage of heavy minerals, contains conglomerate lenses, matrix as described for main sandstone, clasts small fragments of siltstone and shale ..	26.0
7. Sandstone, purplish-red, fine- to medium-grained, subangular to angular, thin-bedded, quartz sand, well indurated	8.0
Total:	171.0

Bernal Formation

6. Siltstone, pinkish-red, silt and clay-sized particles, subangular, thick-bedded	8.0
5. Shale, pale red, subangular, thin-bedded	4.0
4. Siltstone, pinkish-red, thick-bedded, forms a slope	2.0
3. Sandstone, buff to tan, fine-grained, rounded quartz sand, massive	15.0
2. Siltstone, pale red to pinkish-brown, forms a slope, contains minor amounts of mica	12.0

Bernal Formation (cont.)

	Thickness (feet)
1. Sandstone, yellowish-tan, fine-grained, subrounded, thin-bedded, calcium carbonate cement, friable	15.0
Total:	76.0

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