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Geology of the Northern Part of the Fra Cristobal Range, Sierra and Socorro Counties, New Mexico

John T. McCleary

FRA CRISTOBAL RANGE, SIERRA AND SOCORRO COUNTIES - McCLEARY

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GEOLOGY OF THE NORTHERN PART OF THE FRA CRISTOBAL RANGE, SIERRA AND SOCORRO COUNTIES, NEW MEXICO

By

John T. McCleary

A Thesis

Submitted in Partial Fulfillment of the

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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

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ABSTRACT

The northern part of the Fra Cristobal Range contains rocks of Precambrian, Cambrian, Pennsylvanian, Permian, Cretaceous, Tertiary and Quaternary age. One of the northernmost exposures in New Mexico of the Cambrian Bliss formation occurs in the central part of the range. Here the Bliss formation wedges out due to widespread pre-Pennsylvanian erosion which removed all the other lower Paleozoic rocks.

The Pennsylvanian Magdalena group, which is predominantly limestone, rests unconformably on Precambrian rock and the Bliss formation. It forms the greatest part of the sedimentary sequence and is divided into three formations; the Red House, Nakaye, and Bar B formations which represent marine transgression, maximum transgression, and marine regression respectively. Permian time is represented by the dominantly clastic Abo and Yeso formations. Triassic, Jurassic, and early Cretaceous rocks are not present in the mapped area. At the north end of the Fra Cristobal Range, the Jose Creek beds of the Upper Cretaceous McRae formation form a coarse fanglomerate of gneissic boulders on the Precambrian granite gneiss. Northward the fanglomerate grades into the ordinary Jose Creek beds of sandstone and mudstone. These relationships indicate profound deformation and deep erosion in pre-McRae time. This area probably provides the best evidence found so far of a pre-McRae age for the beginning of strong Laramide orogeny in south-central New Mexico.

ABSTRACT

The northern part of the Fra Cristobal Range exposes rocks of Precambrian, Cambrian, Pennsylvanian, Permian, Cretaceous, Tertiary and Quaternary age. [illegible] northeastern exposures in New Mexico of the Cambrian Bliss formation occurs in the central part of the range. North the Bliss formation wedges out due to widespread pre-Pennsylvanian erosion which removed all the older Paleozoic rocks.

The Pennsylvanian Magdalena group, which is predominantly limestone, rests unconformably on Precambrian rock and the Bliss formation. It forms the greatest part of the sedimentary sequence and is divided into three formations: the Red House, Nakaye, and Bar B formations which represent marine transgression, maximum transgression, and marine regression respectively. Permian time is represented by predominantly clastic Abo and Yeso formations. Triassic, Jurassic, and early Cretaceous rocks are not present in the mapped area. At the north end of the [illegible] the Jose Creek beds of the Upper Cretaceous [illegible] form a coarse fanglomerate of [illegible] cambrian granite gneiss. Northward the [illegible] into the ordinary Jose Creek [illegible]. These relationships indicate profound [illegible] and deep erosion in pre-Jose time. This area presently provides the best evidence found so far [illegible] for the beginning of strong [illegible] in south-central New Mexico.

At least three periods of orogeny have affected the area. These took place in Precambrian, late Cretaceous and middle and late Tertiary time. Little is known of the Precambrian deformation. The structural features which are considered to be of Laramide age form a northward-trending belt of intense deformation along the west side of the range. This belt consists of overturned folds and associated thrust faults which have been highly modified by subsequent normal faulting and erosion. The Tertiary structures include open folds and high-angle normal faults trending predominantly northwesterly. Later movement on the Hot Springs and Fra Cristobal faults elevated the range to its present prominence.

No mining is being done within the mapped area at the present time; however, mineral deposits include a manganese deposit adjacent to the Hot Springs fault and an old mine at the head of Spring Canyon which probably produced copper. Galena is present in some of the quartz veins.

At least three periods of orogeny have affected the area. These took place in Precambrian, late Mesozoic, and middle and late Tertiary times. Little is known of the Precambrian deformation. The structural features which are considered to be of Laramide age form a northwest-trending belt of intense deformation along the west side of the range. This belt consists of overturned folds and associated thrust faults which have been highly modified by subsequent normal faulting and erosion. The Tertiary structures include open folds and high-angle normal faults trending predominantly northwesterly. Later movement on the Hot Springs and San Cristobal faults elevated the range to its present prominence.

No mining is being done within the mapped area at the present time; however, mineral deposits include a manganese deposit adjacent to the Hot Springs fault and an old mine at the head of Springs Canyon which probably contained copper. Galena is present in some of the quartz veins.

INTRODUCTION

Geography

The Fra Cristobal Range in Sierra and Socorro Counties, New Mexico forms a part of the discontinuous chain of north-trending mountains on the east side of the Rio Grande. The mapped area covers about 27 square miles, bounded approximately of longitude 107° 03' to 107° 08' west and latitude 33° 21' to 33° 30' north.

The principal land form is a relatively long and narrow mountain range. Fra Cristobal Peak is the most prominent elevation; however, it is slightly lower than a ridge to the south which has an elevation of 6900 feet and forms the highest point in the range. The base of the range on the east side has an elevation of about 4700 feet, and the Rio Grande Valley to the west is about 4400 feet above sea level.

The general area is reached by following State Road 140 north from Engle along which at Deep Well ranch, Lava Crossing, or Lava ranch approaches to the foot of the range may be made on poor roads or open ground on the alluvial fans. Access is difficult and travel by jeep or similar vehicle is recommended due to the general lack of roads.

The road from Engle leads to the north tip of the range. From there a poor road extends for three miles down the western side to the vicinity of the Blackie manganese

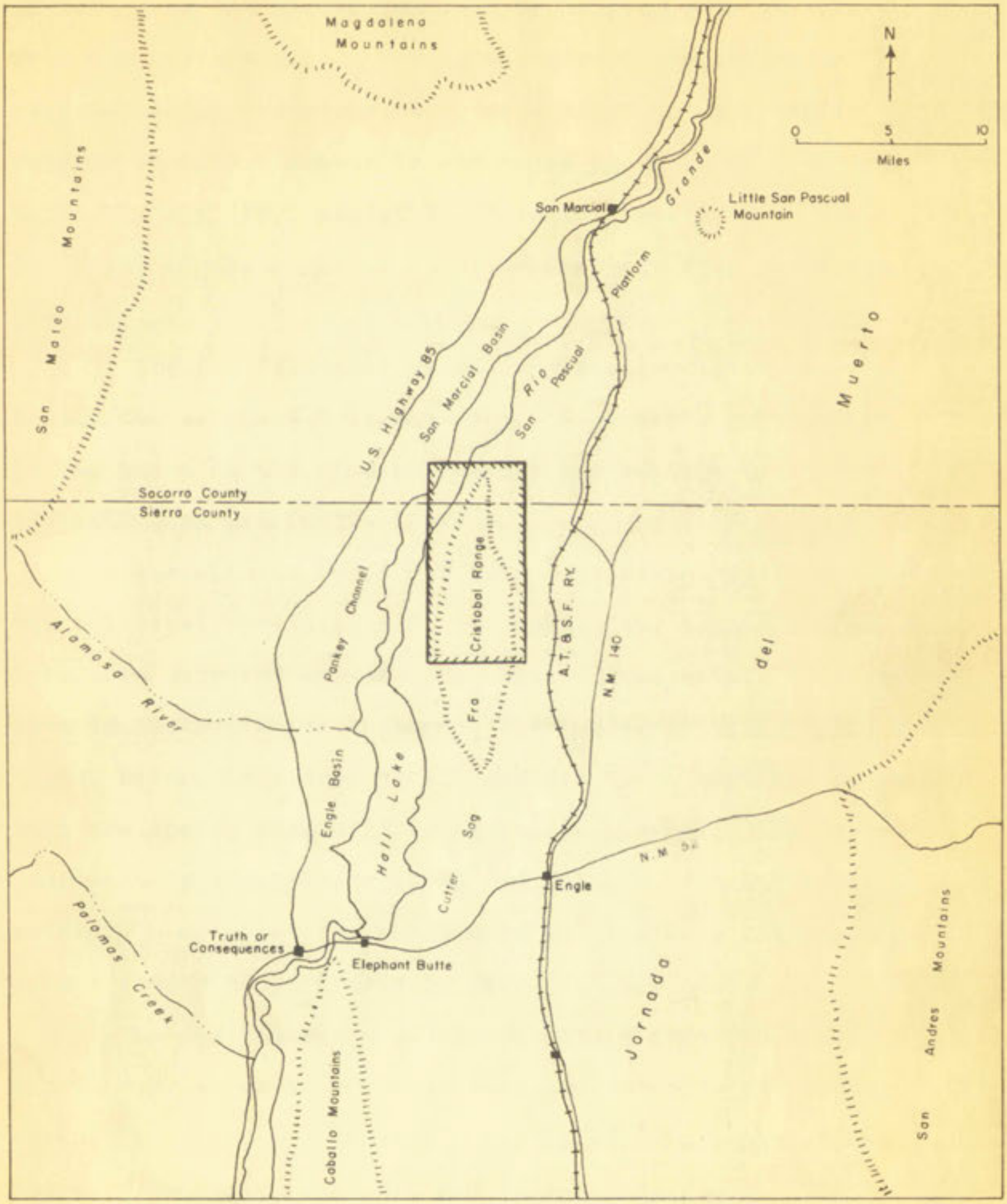

Figure I. Index map of the Fra Cristobal Range showing location of mapped area.

deposit. The rugged western slope of the range is reached on foot from the Blackie mine or by walking over the crest from the eastern side. During periods of high water in Elephant Butte Reservoir, this area might be most easily reached by boat. Access to the range can also be made from U. S. Highway 380, east of San Antonio, New Mexico. The north end of the range is about equidistant from there and from Engle.

The Fra Cristobal Range is entirely within the boundaries of the 850 section Pedro Armendaris grant which is now known as the Diamond A Ranch and belongs to the Victoria Land and Cattle Company.

The climate is of the arid continental type in which the principal precipitation, accompanied by thunderstorms, occurs in July and August. The mean annual rainfall is less than 10 inches in the lowlands, but increases slightly in the higher areas. The best conditions for field work are in the fall and spring when mild temperatures prevail. The lowest mean monthly temperature is 41° in January. At the other extreme, a monthly mean maximum of 90° has been recorded in June. Summer temperatures of over 100° are common.

On the pediments and low mountain areas the most common vegetation is creosote bush and mesquite and lesser amounts of cacti and grasses. On the highest parts of the range, piñon pine, juniper, and grasses are found. The swampy areas of the Rio Grande Valley support cottonwood deposit. The rugged western slope of the range is reached on foot from the Placitas area or by walking over the ridges from the eastern side. During periods of high water in Elephant Butte Reservoir, the range might be most easily reached by boat. Access to the range can also be made from U. S. Highway 380, east of San Antonio, New Mexico, on the north end of the range or by ranch roads westward from [illegible] from Engle.

The Fra Cristobal range is entirely within the boundaries of the old Pedro Armendaris grant which is now known as the Armendaris Ranch and belongs to the Victorio Land and Cattle Company.

The climate is of the arid continental type in which the principal precipitation, accompanied by thunderstorms, occurs in July and August. The mean annual rainfall is less than 10 inches in the lowlands, but increases slightly in the higher areas. The most comfortable field months are the fall and spring when mild temperatures prevail. The lowest mean monthly temperature is 41° in January. At the other extreme, a monthly mean maximum of 91° has been recorded in June. Summer temperatures of over 100° are common.

On the pediments and low mountain areas the most common vegetation is creosote bush and mesquite, and lesser amounts of cacti and grasses. On the highest parts of the range, piñon pine, juniper, and grasses are found. The swampy areas of the Rio Grande Valley support cottonwood trees and salt cedar. Growth in the Jornada del Muerto Valley is largely gramma grass and yucca.

Previous Work

The first entry in the Spanish Archives of New Mexico bears the date March 26, 1665, on which Pedro de Abalos filed the first mining claim in New Mexico. This mine was located in the northern part of the "Fray Cristobal Mountains" (Northrop, 1944, p. 18). The exact location of this claim is not known.

The next recorded event of geological significance took place nearly two centuries later when G. G. Shumard (1859, p. 352-355) visited the area. He recognized Carboniferous limestone beds at the north end of the range which dip 20° east. He deduced that the structure of the Jornada del Muerto is synclinal by observing the dips of the strata on each side.

C. R. Keyes (1903, p. 207-210) pointed out that the slope of the Jornada may be only 2° or 3°, whereas the underlying rock units dip 30° and in places are vertical. The geologic history as seen by Keyes included the tilting of orogenic blocks in late Tertiary time, accompanied by crushing and local folding. According to him, this period was followed by peneplanation, volcanic eruption, and a final period of erosion. In the next year, Keyes (1905, p. 168) showed the Jornada del Muerto in a generalized section as a syncline bounded on the west by block mountains formed by trees and [illegible]. [illegible] In the summer the [illegible] valley is largely grama grass and yucca.

Previous Work

The first entry in the Spanish Archives of New Mexico bears the date March [illegible], 1685, an entry relating to the first mining claim in New Mexico. This claim was located in the northern part of the "Fray Cristobal Mountains" (Northrop, 1944, p. 141). The exact location of this claim is not known.

The next recorded event of geological significance took place nearly two centuries later when G. G. Shumard (1859, p. 152-153) visited the area. He recognized Carboniferous limestone beds at the north end of the range which dip 20° east. He deduced that the structure of the Jornada del Muerto is synclinal by observing the dips of the strata on each side.

C. R. Keyes (1903, p. 207-210) pointed out that the slope of the Jornada is only 2° to 5°, whereas the underlying rock units dip 30° and in places are vertical. The geologic history, as seen by Keyes, involved the uplifting of orogenic blocks in late Paleozoic time, accompanied by crushing and local folding. Accordingly, this uplift was followed by peneplanation, volcanic activity, and a long period of erosion. In the next year, Keyes (1904, p. 66) showed the Jornada del Muerto in a generalized section as a syncline bounded on the east by [illegible] faults.

three faults. In this report, he also noted a thrust plane in the Caballo Mountains which is older than the block faults.

Lee (Lee and Girty, 1909, p. 25-26) indicated the structure in the north part of the range with a diagrammatic east-west cross section near Fra Cristobal Peak. A fault which is downthrown on the east side is shown at the granite-sediment contact. The fault is almost vertical, but appears to dip about 85° west and is therefore a thrust fault.

Gordon (Lindgren, Graton, and Gordon, 1910, p. 220) places the "Cristobal" Range in his first type of mountain structures which are tilted mountains whose primary feature is due to the displacement of a crustal block. He considered the Jornada to be formed by block faulting.

Perhaps the most complete report on the range is that made by Harley (1934, p. 194-196) which is a compilation of previous reports and of observations made by him from a distance. He noted that the Precambrian is composed mainly of granite, but that schist, hornblende diorite and pegmatite are also found. The sediments include 1000 feet of Magdalena group, 400 feet of Abo, 385 feet of Yeso, and 650 feet of San Andres formation. Harley was unable to produce any facts concerning the mines or ore deposits of the Fra Cristobal Range, but placer gold was suggested as a possible prospect.

In conjunction with their report on the Caballo Mountains, Kelley and Silver (1952) made observations three faults. In this report, we give [illegible] in the Gabilan Mountains which is older than the [illegible] faults.

[illegible] (Lee and [illegible], 1969, p. 25-26) [illegible] the structure in the [illegible] part of the [illegible] with [illegible] east-west [illegible] [illegible] fault. [illegible] which is downthrown on the [illegible] sediment contact. The fault [illegible] to dip about [illegible] west and [illegible].

[illegible] ([illegible], [illegible], 1960, p. [illegible]) places the "[illegible]" [illegible] structures which are [illegible] whose primary feature is due to the displacement [illegible], is considered the [illegible] to be [illegible] faulting.

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In [illegible] with [illegible] Mountains, [illegible] and [illegible] ([illegible]) [illegible] concerning the structure and lower Paleozoic stratigraphy of the Fra Cristobal Range.

Thompson (1955, fig. 2) mapped the southern part, and Jacobs (1956, fig. 2) the central front of the Fra Cristobal Range. The area mapped by Jacobs is included in the southwestern corner of the map accompanying this report (Fig. 3).

Present Investigation

This report is concerned primarily with the structure and stratigraphy of the northern part of the Fra Cristobal Range. This project completes a series of studies of the Caballo-Fra Cristobal region which was initiated by a report on the Caballo Mountains (Kelley and Silver, 1952) and continued with reports dealing with the McRae Canyon area (Bushnell, 1953), the southern part of the Fra Cristobal Range (Thompson, 1955), and the central front of the Fra Cristobal Range (Jacobs, 1956).

The field work was done in the summer and fall of 1959. Field data were plotted on air photographs at a scale of 1:31,680. The data were then transferred to a base map made from a U. S. Soil Conservation Service planimetric map. A Brunton compass and tape were used in measuring the stratigraphic section.

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of the Fra Cristobal Range.

Thompson (1955, Fig. 2) mapped the [illegible]
and Jacobs (1956, Fig. 4) the central [illegible] of the Fra
Cristobal Range. The area mapped by Jacobs is [illegible]
the southwestern corner of the area [illegible] this report
(Fig. 3).

Present Investigation

This report is concerned primarily with the [illegible]
and stratigraphy of the northern half of the Fra Cristobal
Range. This project completes a series of studies of the
Caballo-Fra Cristobal region which was initiated by a report
on the Caballo Mountains (Kelley and Silver, 1952) and
continued with reports dealing with the [illegible] area
(Bushnell, 1953), the [illegible] part of the Fra Cristobal
Range (Thompson, 1955), and the [illegible] part of the Fra
Cristobal Range (Jacobs, 1956).

The field work was done in the summer and fall of
1959. Field data were plotted on air photographs at a scale
of 1:11,000. The data were later transferred to a base map
made from [illegible]
A Brunton compass and tape were used in measuring the
stratigraphic sections.

Acknowledgments

The writer is indebted to Dr. V. C. Kelley, at whose suggestion this study was undertaken, for his advice and helpful criticism. A special note of appreciation is extended to the Roswell Geologic Society for its financial contribution to this project.

STRATIGRAPHY AND PETROLOGY

Precambrian Rocks

Uplift of the Fra Cristobal Range has exposed Precambrian rocks along the western side of the range for a distance of nine miles. These rocks consist of granite, granite gneiss, and schist. Harley (1934, p. 195) reported the presence of hornblende diorite in the float of some canyons; however, none was found during this investigation.

The exposure of Precambrian rocks widens northward, and in the vicinity of Red Mountain (Fig. 3, in pocket) they form the greater part of the mountain mass. One small outcrop which has been brought to the surface by the combined effects of faulting and folding is found on the eastern side of the range just north of the mouth of Spring Canyon. No Precambrian rocks are exposed in the Fra Cristobal Range south of the area shown on the geologic map.

The dominant rock type is a pink, coarse-grained granite gneiss which weathers reddish-brown. Inspection of the rock in the field indicates that the minerals present are

Acknowledgments

The writer is indebted to [illegible] for [illegible] suggestion this study was undertaken, for his [illegible] helpful criticism. A special [illegible] to the Roswell Geologic Society [illegible] to this project.

[illegible] STRATIGRAPHY [illegible]

Precambrian Rocks

Uplift of the [illegible] has [illegible] Precambrian rocks along the [illegible] side of the range for a distance of nine miles. These [illegible] of gneiss, granite gneiss, and schist. [illegible] (1952, p. [illegible]) reported the presence of [illegible] in the [illegible] of [illegible] canyons; however, [illegible] this [illegible].

The exposure of Precambrian rocks [illegible] and in the vicinity of [illegible] (Fig. 3, in pocket) [illegible] form the greater part of the mountain [illegible]. [illegible] small [illegible] which has been brought to the surface by the [illegible] of faulting and folding [illegible] the [illegible] of the range just north of the [illegible]. Precambrian rocks are [illegible] south of the area shown on the geologic map.

The dominant rock type is [illegible] granite gneiss which weathers reddish-brown. [illegible] the rock [illegible] orthoclase, quartz, and some biotite and magnetite. In the vicinity of Contact Canyon and Long Canyon, there are irregular masses of green schist which appear to occur at random in the granite. The granite-schist contacts show very little gradation. The foliation in the metamorphic rock was found to trend northerly. Granite stringers fill fractures in the schist and large masses of schist appear to be completely surrounded by granite, indicating a younger age for the granite.

The Precambrian terrane contains innumerable quartz veins ranging in size from small stringers to wide silicified zones. Many of the quartz veins grade to pegmatite along the outcrop. Near the thrust fault on the eastern side of Red Mountain, the gneiss has been broken and crushed, it is notably iron-stained, and contains many quartz pegmatite, barite and calcite stringers.

The Precambrian rocks have no established formational name or age classification. However, to the south in the Caballo Mountains, the metamorphic rocks have been considered tentatively to be Archeozoic, whereas the granite is thought to be late Archeozoic or early Proterozoic (Kelley and Silver, 1952, p. 33).

orthoclase, quartz, and some biotite and magnetite. In the [illegible] vicinity of [illegible] there are irregular masses of granite schist which are [illegible] randomly in the granite. The granite-schist contacts [illegible] little gradation. The foliation in the schist [illegible] was found to trend northerly. Discrete xenoliths [illegible] in the schist and large masses of schist appear to be completely surrounded by granite, indicating [illegible] for the granite.

The Precambrian granite contains innumerable quartz veins ranging in size from small stringers to [illegible] zones. Many of the quartz veins grade [illegible] the outcrop. Near the [illegible] on the eastern edge of Red Mountain, the granite has been sheared and crushed. It is notably [illegible], and contains many quartz veins with barite and calcite stringers.

The Precambrian rocks have no [illegible] name or age classification. However, [illegible] in the Castle Mountains, the metamorphic rocks have been considered tentatively to be Precambrian, whereas the granite is thought to be late Precambrian or early [illegible] [illegible] 1952, p. 33).

Cambrian Rocks

The Bliss formation represents the only unit of Cambrian time in the mapped area. The type locality is in the Franklin Mountains where this formation was first noted by Jenney (1874, p. 25-26). He reported a "gray quartzite" 250 feet thick lying on the Precambrian. The Bliss sandstone was named by Richardson (1904, p. 7). In 1910, the usage of the term Shandon quartzite was extended from the Caballo Mountains to similar beds throughout southern New Mexico (Lindgren, Graton, and Gordon, 1910, p. 225-226). Later, Paige (1916, p. 3) and Darton (1917, p. 32) adopted the name Bliss sandstone for southern New Mexico.

Bridge and King (King, 1940, p. 153-156) concluded that the Bliss sandstone in the Franklin Mountains is Ordovician rather than Cambrian age. Rothrock (1946, p. 19-20) and Kelley (1951, p. 2200-2205) presented reasons for returning it to late Cambrian age. Flower (1955, p. 65) found paleontological evidence in south-central New Mexico that the lower beds are of middle late Cambrian age whereas the upper part is equivalent to lower Ordovician. The name "Bliss formation" was proposed and adopted by Kelley and Silver (1952, p. 33-34) because of the diverse lithology within the unit. The term Bliss formation is also used in this report.

Regionally, the Bliss formation is the most extensively distributed of the lower Paleozoic rocks in the

Cambrian Rocks

The Bliss formation represents the only known rock of Cambrian age in the mapped area. The Bliss sandstone, in the Franklin Mountains near El Paso, Texas, was first noted by Jenney (1874, p. 25-26). He reported a gray sandstone 250 feet thick lying on the Precambrian. The Bliss sandstone was named by Richardson (1904, p. 27). In 1910, the usage of the term Shandon quartzite was extended from the Caballo Mountains to similar beds throughout south-central New Mexico (Lindgren, Graton, and Gordon, 1910, p. [illegible]). Both Paige (1916, p. 3) and Darton (1917, p. [illegible]) adopted the name Bliss sandstone for rocks in New Mexico.

[illegible] (Sample, 1940, p. 113-114) considered that the Bliss sandstone in the Franklin Mountains is Ordovician rather than Cambrian age. Kottlowski (1946, p. 19-20) and Kelley (1951, p. 2480-2483) presented evidence returning it to late Cambrian age. Flower (1953, p. 8) found paleontological evidence in south-central New Mexico that the lower beds are of middle late Cambrian age whereas the upper part is equivalent to lower Ordovician. The term "Bliss formation" was proposed and adopted by Kelley and Silver (1952, p. 31-34) because of the diverse lithology within the unit. The term Bliss Formation is used in this report.

Regionally, the Bliss Formation is the most extensively distributed of the Paleozoic rocks in the southern part of New Mexico. From a zero thickness in the Fra Cristobal and Oscuro Mountains, the Bliss thickens progressively southward to 300 feet in the south-central part of the state and to about 400 feet in the southwestern part.

The contact with the underlying Precambrian rocks is marked by a profound unconformity which represents near peneplanation prior to deposition of the Bliss formation. In the mapped area, it is overlain unconformably by the Red House formation of the Magdalena group. To the south, in the area mapped by Jacobs (1956, fig. 2), the Bliss formation grades upward into the limestone of the Sierrite formation of the El Paso group, the change being marked only by a slight change in the limestone units (Jacobs, 1956, p. 12).

The northernmost extent of the Bliss formation in the Fra Cristobal Range is at the head of Spring Canyon where it dips 40°-65° east and forms a prominent ridge due to the resistance to erosion of the well-cemented sandstone units. In general, the lower part of the section consists of a series of thick-bedded sandstone beds composed of coarse-grained, crossbedded sandstone that has been highly silicified. There is abundant oölitic hematite and lesser amounts of glauconite. The upper part of the formation consists of thin-bedded limestone with intervals of fine-grained sandstone and siltstone. Because of the high iron content, the Bliss contrasts conspicuously in color with the adjacent rocks.

southern part of the area. [illegible] beds [illegible] in the Pre Cristobal [illegible] thickens progressively southward to [illegible] feet in the southern part of the area and to about [illegible] feet in the southwestern part.

The contact with the underlying [illegible] is marked by a prominent unconformity which represents post-peneplanation prior to deposition of [illegible]. In the mapped area, [illegible] overlaps [illegible] the [illegible] formation of the [illegible] group. To the north, in the area mapped by [illegible] (1956, fig. [illegible]), the [illegible] grades upward into the limestone of the [illegible] formation of the [illegible] group, the change taking place [illegible] slight change in the [illegible] and is [illegible].

The northernmost extent of the [illegible] the Pre Cristobal [illegible] is at the base of [illegible] where it dips 40°-65° east and forms a prominent [illegible] due to the resistance to erosion of the well-cemented [illegible]. In general, the lower part of the [illegible] consists of a series of thick-bedded [illegible] grained, crossbedded sandstone which has been largely silicified. There is [illegible] glauconite. The upper part of the formation consists of thin-bedded limestone with interbeds of [illegible] and siltstone, [illegible] the [illegible] contrasts conspicuously in color with the adjacent rocks.

In the vicinity of Amphitheater Canyon, the Bliss formation is 75 feet thick (Jacobs, 1956, p. 13) and about a mile to the north it is 92 feet thick (Kelley and Silver, 1952, fig. 3). At the Old mine the thickness is about 45 feet.

Pennsylvanian Rocks

General Statement

The thickest, most conspicuous, and most widespread sedimentary unit in the northern part of the Fra Cristobal Range is the Magdalena group of Pennsylvanian age. The term Magdalena group was first proposed by Gordon (1907, p. 806) for exposures in the Magdalena mining district in Socorro County. He subdivided the group into a lower clastic unit called the Sandia formation and an upper part called the Madera formation. Needham (1940) suggested that the Pennsylvanian strata of New Mexico range through most of Pennsylvanian time, except that neither earliest nor latest Pennsylvanian time is represented. Thompson (1942, p. 27) rejected all previous nomenclature and applied a total of 25 new group, formation, and member names. These subdivisions are faunal zones, with poorly defined boundaries based on fusulinids which makes field mapping of them nearly impossible.

The U. S. Geologic Survey has generally used the division proposed by Gordon. Read and Wood (1947, p. 223) have divided the group into three principal parts:

In the vicinity of Amphitheater Canyon, the Bliss formation is 75 feet thick (Jacobs, 1956, p. 22) and about 3 miles to the north it is 92 feet thick (Kelley and Silver, 1952, fig. 3). At the Old mine the thickness is about 75 feet.

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General Statement

The thickest, most conspicuous, and most widespread sedimentary unit in the northern part of the Fra Cristobal Range is the Magdalena group of Pennsylvanian age. The term Magdalena group was first proposed by Gordon (1907, p. 806) for exposures in the Magdalena mining district in Socorro County. He subdivided the group into a lower clastic unit called the Sandia formation and an upper carbonate unit, the Madera formation. Needham (1940) suggested that the Pennsylvanian strata of New Mexico range through most of Pennsylvanian time, except that neither earliest nor latest Pennsylvanian time is represented. Thompson (1942, p. 27) rejected all previous nomenclature and applied a host of new group, formation, and member names. These subdivisions are faunal zones, with poorly defined boundaries based on fusulinids which makes field mapping of them nearly impossible.

The U. S. Geological Survey has generally used the division proposed by Gordon. Read and Wood (1947, p. 243) have divided the group into three principal units:

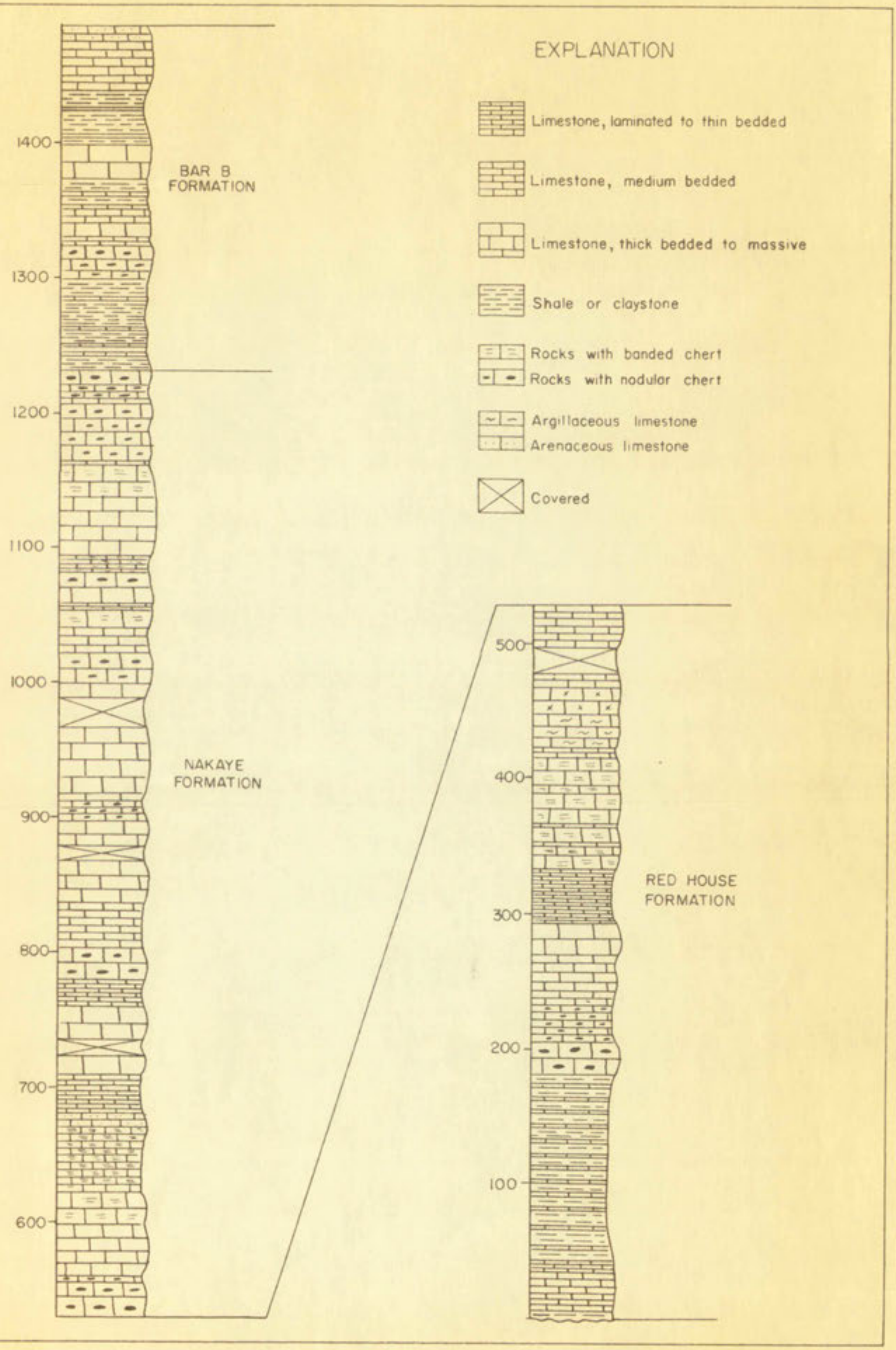

Figure 2. Composite geologic column of the Magdalena group

1. A suite of transgressive sediments.

2. Evenly and widely distributed marine sediments deposited during maximum transgression.

3. Unevenly distributed and restricted alternating marine and continental sediments that represent regression.

This three-fold transgressive to regressive sequence is present in the Fra Cristobal and Caballo Mountains where they form readily mappable units. In this report, the terminology used by Kelley and Silver (1952, p. 91) in the Caballo Mountains is extended to the Fra Cristobal Range. The three formations comprising the Magdalena group are in ascending order the Red House, Nakaye, and Bar B formations. The Red House formation is correlated with the Derryan and lower Desmoinesian, the Nakaye formation is correlated with the upper Desmoinesian and lower Missourian, and the Bar B formation is correlated with the upper Missourian, Virgilian and possibly the lower Wolfcampian (Kelley and Silver, 1952, fig. 11).

In general, the Magdalena group is easily distinguished in the field and on air photographs from other rocks by the numerous ledges that are developed on limestone lentils separated by shale lentils. In dip-slope exposures, a highly scalloped outcrop pattern is formed.

The Magdalena group in the mapped area rests unconformably on the Cambrian Bliss formation and on Precambrian rock. No rocks of Ordovician, Silurian, Devonian,

1. A [illegible] of transgressive sediments.

2. Grossly and strictly [illegible] sediments [illegible] [illegible].

3. [illegible] [illegible] [illegible] alternating [illegible] [illegible] [illegible] represents [illegible].

This three-fold break [illegible] [illegible] [illegible] is present in the [illegible] and Caballo [illegible] where they form readily mappable units. In this report, the terminology used by Kelley and Silver (1952, p. [illegible]) for the Caballo Mountains is extended to the [illegible] area. The three formations comprising the Magdalena group are in ascending order the Red House, Nakaye, and Bar B formations. The Red House Formation is correlated with [illegible] and lower Desmoinesian, the Nakaye formation is correlated with the upper Desmoinesian and lower Missourian, and the Bar B formation is correlated with the upper Missourian, Virgilian, and possibly the lower Wolfcampian (Kelley and Silver, 1952, fig. 11).

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The Magdalena group in the [illegible] area rests unconformably on the [illegible] [illegible] and on Precambrian rocks in [illegible] [illegible].

and Mississippian age are present; however, rocks of these periods were probably deposited in the mapped area and later removed by erosion. Each successively younger formation wedges out farther to the south in the Cutter sag and Caballo Mountain areas. The wedging of the lower Paleozoic rocks was thought by some to be the result of approach to a shoreline; however, Kelley and Silver (1952, p. 134) have shown that this wedge is largely the result of truncation by erosion rather than the result of nondeposition. This conclusion was reached on the basis of field observations that indicate only slight thinning and lithologic change at the places where these formations wedge out. In the mapped area, the Bliss formation does not change significantly in lithology where it wedges out in Spring Canyon. It is concluded that the lower Paleozoic seas may have spread across most of New Mexico (Kelley and Silver, 1952, p. 80).

Red House Formation

The Red House formation, which was named from Red House Mountain in the Caballo Mountains, is 530 feet thick north of the mouth of Spring Canyon where the section was measured. This formation varies considerably in thickness due to depositional onlap over the irregular pre-Pennsylvanian erosion surface. In the Caballo Mountains, it is 362 feet thick (Kelley and Silver, 1952, p. 92).

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Red House Formation

The Red House Formation, which was named after Red House Mountain in the Caballo Mountains, is 330 feet thick north of the mouth of [illegible] Canyon where the section was measured. This formation [illegible] due to its [illegible] the irregular [illegible] erosion surface. In the Caballo Mountains it is 362 feet thick (Kelley and Silver, 1952, p. [illegible]).

The Red House formation rests unconformably on beds of the El Paso group south of Amphitheater Canyon, on the Bliss formation between Amphitheater and Spring Canyons, and directly on Precambrian rock north of Spring Canyon. Wherever it crops out, the Red House formation forms a slope with thin limestone ledges which contrast strongly with the thick, prominent ledges of the overlying Nakaye formation. It is more easily eroded than the adjacent formations. Long and Contact Canyons are cut in the Red House outcrop which parallels the trend of the range.

The dominant lithology in the lower part is dark-gray shale alternating with fine-grained dark-gray thin- to medium-bedded limestone. Detrital quartz, fossil fragments, and limestone fragments are found in the lower 250 feet. Many beds are fossiliferous. The upper part is predominantly medium- to massive-bedded limestone that contains much chert in nodules and irregular bands and patches. Where the Red House overlies the Bliss, the basal unit locally consists of several feet of reworked Bliss sediment that contains productid brachiopods. Where it overlies the Precambrian granite in Long and Contact Canyons, the basal unit is a greenish arkosic sandstone several feet thick.

Nakaye Formation

The Nakaye formation is the thickest and most prominent part of the Magdalena group. It forms the vertical and

overturned ridges of the crest of the range and steep "box" canyons along the east side. The Nakaye formation which rests conformably on the Red House formation has a thickness of 700 feet in the Fra Cristobal Range and comprises almost one-half of the Magdalena group.

There is a cyclic nature to the bedding. Although it is not developed throughout the section, in general the following sequence of beds is found:

1. Massive limestone.

2. Thin- to medium-bedded clayey nodular limestone.

3. Shale.

There are about 14 such repetitions in the Nakaye formation, with an average thickness of 50 feet. The massive limestone beds comprise 20-40 feet of each sequence. Throughout the section, the shale and nodular limestone beds are more easily eroded and retreat 10-20 feet on the underlying massive limestone forming the numerous ledges and cliffs which characterize this formation.

The limestone is medium- to dark-gray to gray-brown and very fine to fine grained. Most of the beds weather to a light- to medium-brown or light- to medium-gray. Many stringers of calcite are found which are one-eighth to one-half inch wide. Most of the massive limestone beds contain much brown-weathering chert in lenses, nodules, and irregular patches. The chert is usually medium- to dark-gray on fresh surfaces.

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Bar B Formation

The Bar B formation is the upper part of the Magdalena group. It is entirely conformable with the underlying Nakaye formation. The name was taken from Bar B Draw near Blue Mountain in the Caballo Mountains (Kelley and Silver, 1952, p. 93).

At the south edge of the mapped area, the thickness is 258 feet. The only complete thicknesses are found where it is overlain by the Abo formation and thereby protected from erosion. Elsewhere, it is only several tens of feet thick and forms rounded ridges and crests where it is held up by the underlying Nakaye formation. The Bar B formation consists dominantly of gray claystone and shale with limestone beds from 4 inches to 2 feet in thickness. Some of the limestone is nodular and irregular. Several massive limestone beds are present near the middle of the formation. Some beds are highly fossiliferous and fusulinids are especially abundant.

The Bar B differs from the Nakaye formation in the change from dominantly limestone to dominantly shale. This change in lithology results in contrasting beddedness which serves to distinguish the two formations. In the Caballo Mountains, the Red House and Bar B have about the same ratio of shale and limestone (Kelley and Silver, 1952, p. 94); however, in the Fra Cristobal Range, the Red House contains a greater amount of limestone.

Bar B Formation

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For mapping purposes, the top of the Bar B formation was chosen at the uppermost marine limestone in the section which indicates the final marine withdrawal. However, this bed may be Permian in age (Deford and Lloyd, 1942, p. 534).

Permian Rocks

The rocks of Permian age in the mapped area are the Abo and Yeso formations. A small outcrop of what has been mapped and tentatively classified as the San Andres formation by Jacobs (1956, p. 19) is shown on the geologic map (Fig. 3).

The Abo and Yeso formations were first designated under the term Manzano series by Herrick (1900, p. 4). The first adequate definition of these formations was made by Lee and Girty (1909, p. 12) when they divided the Manzano group into these formations, but erroneously assigned them a Pennsylvanian age. Kelley and Silver (1952, fig. 12) show the Abo formation to be mostly Wolfcampian in age while the uppermost Abo, the Yeso, and the San Andres are of Leonardian age.

Abo Formation

Nowhere in the mapped area is a complete section of the Abo formation present. The outcrops in the southern part are small outliers in the process of being completely removed by erosion. East of Red Mountain, the Abo beds are somewhat protected from erosion by overthrust Precambrian rock. The Abo rests conformably on the Bar B beds, indicating that this

area was not affected significantly by the Marathon disturbance in contrast to the folded pre-Abo beds of the Sacramento and Hueco Mountains to the southeast.

The Abo formation is a typical floodplain deposit and is readily distinguished from the underlying and overlying formations by its red to reddish-brown hues. The dominant rock type is claystone, but siltstone and sandstone are also abundant. Lenses, nodules, and thin beds of gray-brown limestone are found in the red-brown claystone and shale. Greenish-brown limestone conglomerate is also present. The Abo formation is generally thin- to medium-bedded, but the bedding is irregular and crossbedding is common in the sandstone units. Immediately south of the mapped area the thickness is 450 feet (Thompson, 1955, p. 19).

Yeso Formation

The Yeso formation crops out in two small areas at the southern edge of the map. It consists mainly of sandstone and gypsum with lesser amounts of siltstone, limestone, and claystone. The thickness has been estimated to be 595 feet by Thompson (1955, p. 23) in the southern end of the range.

No Triassic or Jurassic rocks crop out in the Fra Cristobal Range. However, in the Sun Oil Company No. 1 Victoria Land and Cattle Company well, located 10 miles east of the range, red shale 170 feet thick was reported between the San Andres and Dakota formations (Kelley and Silver, 1952, area was not affected significantly by the [illegible] disturbance in contrast to the folded [illegible] beds of the [illegible] and Hueco mountains to the northeast.

The [illegible] formation is a [illegible] lime [illegible] is readily distinguished [illegible] underlying and overlying formations by its red to reddish-brown [illegible]. The [illegible] rock type is [illegible], [illegible] and [illegible] are also abundant. Lenses, nodules, and [illegible] of [illegible] limestone are found in [illegible] [illegible] [illegible]. Greenish-brown limestone conglomerate is [illegible] [illegible] the formation is generally [illegible] [illegible] bedding is irregular and crossbedding is common in the sandstone units. Immediately north of the mapped area the thickness is 450 feet (Thompson, 1955, p. [illegible]).

Jose Formation

The Jose formation [illegible] in [illegible] [illegible] along the southern edge of the [illegible]. It consists mainly of [illegible] and gypsum with lesser amounts of siltstone, limestone, and claystone. The thickness has been estimated to be [illegible] feet by Thompson (1955, p. 27) in the southern end of the [illegible].

No [illegible] or [illegible] rocks crop out in the [illegible] Cristobal Range. However, in the [illegible] [illegible] No. [illegible] Victoria Land and Cattle Company well, located [illegible] of the range, [illegible] 170 feet thick was [illegible] between the San Andres and [illegible] formations (Kelley and Silver, 1952).

p. 104). This interval probably consists of rocks of the Dockum group of Triassic age.

Cretaceous Rocks

The Dakota, Mancos, and Mesaverde formations do not crop out in the mapped area. However, they are present to the east in the Jornada del Muerto depression where Mesaverde beds are found locally at the surface.

McRae Formation

The Cretaceous rocks consist of the Jose Creek member of the McRae formation of late Cretaceous age which crops out at the northern end of the range. These rocks form a small mesa that rises about 100 feet above the surrounding Quaternary alluvium. The area of exposure is about one-half square mile.

The McRae formation was named by Kelley and Silver (1952, p. 115) from old Fort McRae three miles north of Elephant Butte. As early as 1905, Lee (p. 240) noted the "red strata" in the vicinity of Elephant Butte. Other geologists have mentioned the presence of this relatively thick sequence of beds. Bushnell (1953, p. 23) divided the formation into the basal Jose Creek member and the overlying Hall Lake member. The Hall Lake member consists of a thick sequence of purplish shale and purplish and buff sandstone beds. At the type locality southwest of Kettle Mountain, the lower part of the Jose Creek member consists largely of green shale and siltstone beds that are interbedded with

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The Jose Creek member has been assigned a late Cretaceous age on the basis of the presence of Geinitzia cf. formosa and the fact that Triceratops, a late Cretaceous dinosaur, has been found in the lower beds of the overlying Hall Lake member.

The McRae beds at the northern end of the Fra Cristobal Range resemble the Jose Creek beds in lithology and are therefore correlated with them. However, it is possible that they might intertongue somewhere within the Hall Lake member. The north end of the Jose Creek outcrop consists of flat-lying dark-brown sandstone, conglomeratic sandstone, bedded chert, and probably mudstone. As these beds are traced southward toward the ridges of Precambrian rock, they become interbedded with increasing amounts of volcanic conglomeratic material. Some of the conglomerate is bouldery andesitic coarse-grained, and to have [illegible] of greater [illegible] sandstone beds (Bushnell, 1953, p. 15). The upper part of the member is distinguished by coarse-grained and fine sandstone beds that weather dark-brown and by [illegible] bedded chert (Bushnell, 1953, p. 25). In the vicinity of the Elephant Butte Reservoir area, the sediments of the Jose Creek member are largely conglomeratic. Within two miles to the northwest, the sediments consist almost entirely of sandstone and shale. This suggests that the sandstone and shale have an interfingering relationship with the conglomerate (Bushnell, 1953, p. 25).

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The [illegible] beds of the [illegible] Range resemble the Jose Creek member in their [illegible] and are therefore correlated with them. However, it is possible that they might interfinger somewhere within the Hall Lake member. The north end of the [illegible] Creek [illegible] lying [illegible], [illegible] chert, and probably sandstone. [illegible] southward toward the [illegible], [illegible] interbedded with increasing amounts of [illegible] conglomeratic material. Some of the conglomerate is probably [illegible] fragments that have been highly weathered. Purplish tuff is also present. Closer to the Precambrian gneiss outcrops, angular to subrounded cobbles and boulders of gneiss become conspicuous in both the beds containing the volcanic material and in the interlayered beds of sandstone. Adjacent to the unconformable contact with the Precambrian rock, the gneiss fragments increase in size and quantity forming a coarse fanglomerate. In places, the fanglomerate has been highly silicified to chalcedonic masses, apparently by hot mineralized waters.

Two small outcrops of the Jose Creek member are found to the east of the large outcrop. These consist of white, coarse-grained poorly-cemented sandstone which is crossbedded and contains many well-rounded pebbles of various composition. Petrified wood is present, including palm wood. Some of the well-preserved petrified wood is of gem quality.

Cenozoic Rocks

For mapping purposes, all the Cenozoic sediment between the Hot Springs fault and the Rio Grande Valley has been designated as the Santa Fe formation. However, some younger sediments, which are difficult to distinguish from the Santa Fe formation, occur in various places.

The name Santa Fe marl was first used by Hayden in 1869 (Wilmarth, 1938, p. 1923) to describe a sequence of beds that are found in the Rio Grande Valley near Santa Fe. Cope fragments that have been highly weathered. Purplish tuff is also present. Closer to the Precambrian gneiss outcrops, angular to subrounded cobbles and boulders of gneiss become conspicuous in both the beds containing the volcanic material and in the interlayered beds of sandstone. Adjacent to the unconformable contact with the Precambrian rock, the gneiss fragments increase in size and quantity, forming a coarse fanglomerate. In places, the fanglomerate has been highly silicified to chalcedonic masses, apparently by hot mineralized waters.

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(1881, p. 308) was the first to point out that the sediment in the Engle Valley and corresponding sediment in other parts of southern New Mexico are correlative with that described by Hayden. Although the basin-filling sediment of this area was referred to as the Palomas gravel by Gordon and Graton (1907, p. 92), later workers have referred to it as the Santa Fe formation.

According to Wood, et al. (1941, p. 31), the Santa Fe formation is predominantly late Miocene and early Pliocene in age and middle and upper Pliocene elements are probably also present. It is typical of alluvial fan and playa deposits, consisting of poorly sorted marl, clay, silt, sand, and gravel whose color is white, buff, and brown. The bedding is lenticular and channel-form. Bentonitic clay, lava flows, and tuff beds that are found elsewhere in the Santa Fe were not observed in the mapped area.

Quaternary deposits include alluvial fans, valley fill, wave-cut terraces, sand dunes, and lava flows. Alluvial fans are found on both sides of the range, but are better developed on the eastern side at the mouths of major canyons. Quaternary valley fill is found in the bottom of the Rio Grande Valley where it may be as much as 200-300 feet thick (Bryan, 1938, p. 218). Wave-built terrace deposits are found at the edges of the Rio Grande Valley. These deposits were formed at the base of the bluffs of the Santa Fe formation during periods

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A lava flow of probable Quaternary age is found at the north edge of the mapped area. It overlies the Santa Fe formation. This flow was extruded on a lower erosion surface than the San Marcial flow several miles to the north which indicates that it is younger. The source appears to be a cone about eight miles to the east of the Fra Cristobal Range.

STRUCTURE

Regional Setting

The Fra Cristobal Range is a horst block on the east side of the Rio Grande depression. The range is separated from surrounding structural features by bounding faults that intersect at the northern and southern ends. The Rio Grande depression has been interpreted as an echelon series of north-trending grabens flanked by areas of relative uplift (Kelley, 1952). The Rio Grande depression is bounded on the west by the essentially undeformed Colorado Plateau and on the east by the gently-tilted Great Plains. This region is part of the Sonora-Chihuahua system of the Basin and Range province. In it the mountain units trend roughly north and the structures within the ranges are due to folding, thrusting, and normal faulting (Eardley, 1951, p. 474).

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To the east of the Fra Cristobal Range is the Jornada del Muerto depression (Fig. 1, following p. 3) which extends north-south for about 100 miles. It is, in general, a broad syncline which is faulted down adjacent to the Fra Cristobal Range. It has not suffered as strong downfaulting in Tertiary or Quaternary time as the Engle basin to the west of the Fra Cristobal Range.

A constriction in the Rio Grande depression to the west of the mapped area forms the Pankey channel which connects the San Marcial basin to the north with the Engle basin to the south (Fig. 1, following p. 3). These basins have received several thousand feet of sediment in Tertiary time (Kelley, 1952, p. 92).

The Fra Cristobal Range is separated from the Caballo Mountains by the Cutter sag (Fig. 1, following p. 3) which has experienced deformation that is complex although not as pronounced as that of the adjoining uplifts. It is a basin which received a possible maximum thickness of 7000 feet of Cretaceous sediment (Bushnell, 1953, p. 56) from the adjacent uplifts. North of the Fra Cristobal Range is the broad San Pascual platform (Fig. 1, following p. 3).

Faults

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Faults

For convenience of discussion and reference to the geologic map (Pl. 1) the normal faults have been designated N1, N2, N3, . . etc., and the thrust faults T1, T2, . . ., etc.

Most of the faults in the mapped area are high-angle. The normal faults generally dip 60°-70^{0} and the thrusts dip 30^{0}-60^{0}.

Normal Faults

The Hot Springs fault was originally named by Kelley and Silver (1952, p. 159). It has been mapped from the north end of the Caballo Mountains, across the Cutter sag, and northward along the front of the Fra Cristobal Range to the northern end where it intersects the Fra Cristobal fault zone. Along this 30-mile course, the Hot Springs fault is consistently downthrown on the west side and has a dip of 65°-75° westward. The strike changes from N. 25° E. in the Caballo Mountains and Cutter sag to N. 10° W. in the southern part of the Fra Cristobal Range, and then swings back to N. 10°-30° E. in the northern part of the range. North of Elephant Butte the throw is at a minimum where the Santa Fe formation abuts the Hall Lake member of the McRae formation. From this locality the stratigraphic throw progressively increases northward to the Fra Cristobal Range where Precambrian rocks lie on the upthrown side. The Santa Fe formation is found on the downthrown side throughout the entire length. However, in several places, rocks older than the Santa Fe formation are also found on the downthrown side. About 1.5 miles south of the Blackie mine, there is a small block of Magdalena limestone that dips 45° west adjacent to

Most of the faults in the mapped area are high-angle. The normal faults generally dip 60°-70° and the [illegible] dip 30°-50°.

Normal Faults

The Hot Springs fault was originally named by Kelley and Silver (1952, p. 159). It has been mapped from the northern end of the Caballo Mountains, across the Cutter sag, and northward along the front of the Fra Cristobal Range to its northern end where it intersects the Fra Cristobal fault zone. Along this 30-mile course, the Hot Springs fault is consistently downthrown on the west side and has a dip of 65°-75° westward. The strike changes from N. 20° [illegible] in the Caballo Mountains and Cutter sag to N. 10° W. in the southern part of the Fra Cristobal Range, and then swings back to N. 10°-30° E. in the northern part of the range. North of Elephant Butte the throw is at a minimum where the Santa Fe formation abuts the Hall Lake member of the McRae Formation. From this locality the stratigraphic throw progressively increases northward to the Fra Cristobal Range where Precambrian rocks lie on the upthrown side. The Santa Fe formation is found on the downthrown side throughout the entire length. However, in several places, [illegible] the Santa Fe Formation are also found on the upthrown side. About 1.5 miles south of the Nogal [illegible] there is a small block of Magdalena limestone that [illegible] the fault. Four miles to the south, Jacobs (1956, fig. 2) mapped a similarly inclined block of San Andres limestone. The presence of the San Andres formation adjacent to Precambrian rocks indicates a stratigraphic throw of at least 3500 feet. Silicification is abundant in most places along the fault which causes it to form a prominent ridge above the more easily eroded Santa Fe formation and Precambrian rock. The silica is jasper that has been brecciated and recemented with quartz.

The Fra Cristobal fault zone was named by Thompson (1955, p. 41). This zone extends for 14 miles along the eastern side of the range. It changes strike from N. 20° E. at the southern end of the range to N. 10° W. and then back to N.-S. at the northern end where it intersects the Hot Springs fault. The zone consists of two or three faults that dip 50°-70° east. Fault N2 is the most continuous fault of the zone. It begins south of the mapped area as an anticline, changes into a fault and gradually increases in stratigraphic throw to 500 feet where it drops the Yeso formation against the Bar B formation (Thompson, 1955, p. 49). The throw decreases to 100-200 feet north of cross fault N1 where Nakaye beds are found on both sides. Fault N2 parallels synclines S1 and S2 and faults down their east limbs (Fig. 3, Section F-F'). At its northern end, fault N2 dies out and changes to syncline S3. Fault N3, which is also a part of the Fra Cristobal zone, has a stratigraphic throw of 50 feet the fault. Four miles to the south, Kondo (1954, fig. 2) mapped a similarly brecciated block of [illegible] Limestone. The presence of the Sandia Formation against the Precambrian rocks indicates a stratigraphic throw of at least 3500 feet. Silicification is [illegible] along the fault which causes it to form a prominent ridge above the more easily eroded Sandia Formation and Precambrian rocks. The silica is younger than [illegible] brecciated and recemented with quartz.

The Pre Cristobal fault zone was named by Kottlowski (1955, p. 45). This zone extends for [illegible] along the eastern side of the range. It changes strike from N. 20° W. at the southern end of the range to N. 10° W. and then back to N.-S. at the northern end where it intersects the Salt Springs fault. The zone consists of two or three faults that dip 50°-70° west. Fault 32 is the east-most fault of the zone. It begins south of the range [illegible] anticline, changes into a fault and gradually increases in stratigraphic throw to 300 feet where it brings the Yeso Formation against the Madera Formation (Thompson, 1942, p. 49). The throw decreases to 100-200 feet north of [illegible] where [illegible] beds are found on both sides. Faults [illegible] synclines 41 and 40 and [illegible] down the east limb (Fig. 3, Section F-F'). At its northern end, [illegible] changes to syncline 41. Faults 42, [illegible] the Pre Cristobal zone, [illegible] and trends northward for one-half of a mile. It is continuous with and passes into syncline S2 to the south. The eastern fault of the zone is covered by alluvium adjacent to the range in the mapped area, but it is exposed at the southern end of the range. There the Mesaverde formation appears at the surface, suggesting a throw of 1000-2000 feet (Thompson, 1955, p. 50). The throw is estimated to be less in the mapped area. A well drilled adjacent to the southeastern corner of the mapped area penetrated a thick limestone section covered by about 100 feet of alluvium. The limestone is thought to be the Magdalena group; if so, a throw of 600-800 feet is indicated for this fault. North of fault N3, the Fra Cristobal zone is buried by alluvium.

The Maddux fault is a major feature in the uplift of the mountain block and forms the most prominent scarp in the area. It can be traced along a trend of N. 40° W. for 3.5 miles from the eastern edge of the range to the head of Spring Canyon. The stratigraphic throw, which is about 600 feet at the southeastern end, decreases northwestward. The fault only slightly displaces the beds of the overturned syncline. The Maddux fault duplicates the thickness of the Nakaye formation and divides this part of the range into two distinct southeasterly sloping benches. The northern half of the fault zone is highly silicified and in many places it forms a conspicuous ridge 5-50 feet wide. Thin stringers of galena are found in parts of the silicified zone. The and trends northward for one-half of a mile. It is continuous with and passes into syncline S2 to the south. The eastern fault of the zone is covered by alluvium adjacent to the range in the mapped area, but it is exposed at the southern end of the range. There the Mesaverde formation appears at the surface, suggesting a throw of 1000–2000 feet (Thompson, 1955, p. 50). The throw is estimated to be less in the mapped area. A well drilled adjacent to the southeastern corner of the mapped area penetrated a thick limestone section covered by about 100 feet of alluvium. The limestone is thought to be the Magdalena group; if so, a throw of 600–800 feet is indicated for this fault. North of fault N3, the Fra Cristobal zone is buried by alluvium.

The Maddux fault is a major feature in the uplift of the mountain block and forms the most prominent scarp in the area. It can be traced along a trend of N. 40° W. for 1.5 miles from the eastern edge of the range to the head of Spring Canyon. The stratigraphic throw, which is about 600 feet at the southeastern end, decreases northwestward. The fault only slightly displaces the beds of the overturned syncline. The Maddux fault duplicates the thickness of the Nakaye formation and divides this part of the range into two distinct southeasterly sloping benches. The northern half of the fault zone is highly silicified and in many places it forms a conspicuous ridge 5–50 feet wide. Thin stringers of galena are found in parts of the silicified zone. The several small blocks of limestone between the Maddux fault and the minor branch faults have been tilted diversely.

Fault N1 is continuous with the fault that Thompson (1955, fig. 2) designated Z1. It strikes northeasterly and is downthrown about 150 feet on the southeastern side. Bar B beds are dropped opposite the Nakaye formation. Thompson (1955, p. 48) reported a left separation of 1.5 miles.

Fault N4, just south of the Maddux fault, strikes N. 50° W. and dips 65° northeasterly. The stratigraphic throw is 80 feet at the southeastern end and decreases northwestward. A short fault south of N4 has the same orientation, but the displacement is only 40 feet.

Fault N5 has a stratigraphic throw of about 200 feet at the northern end where Abo beds on the western side are dropped below the beds of the Bar B formation on the east. Southward the throw increases to about 400 feet where the Bar B is opposite the lower part of the Nakaye formation. This fault, which continues to the south, has been designated as fault X3 by Thompson (1955, fig. 2). The beds on the western side dip steeply to the east whereas the beds on the eastern side are inclined only 3°-6° southeast. A minor fault branches westerly from fault N5 and slightly displaces the Abo-Bar B contact.

Fault N6 strikes N. 15° W. across the head of Amphitheater Canyon. The Bar B formation on the western side is dropped below the Nakaye on the east. The throw is about 150 several small blocks of limestone between the major faults and the minor branch faults [illegible].

Fault 34 is [illegible] (1953, figure 2, [illegible]). [illegible] is down [illegible] about 150 [illegible] beds are dropped opposite the [illegible]. Gilluly (1956, p. 48) reported a [illegible].

Fault 34, just south of the [illegible], strikes N. 50° W. and dips 83° northeastward. The stratigraphic throw is 50 feet at the southeastern end and increases northwestward. A short fault south of 34 has the same orientation, and its displacement is only [illegible] feet.

Fault 35 has a stratigraphic throw of about 200 feet at the northern end where Abo beds on the western side are dropped below the base of the Bar B formation on the east. Southward the throw increases to about 400 feet where the Bar B is opposite the lower part of the [illegible]. This fault, which continues to the north, was first designated as fault 13 by Gilluly (1956, fig. 2). The beds on the western side dip steeply to the east whereas the beds on the eastern side are inclined only 5-10° eastward. [illegible] fault branches nearly [illegible] the Abo-Bar B contacts.

Fault 36 strikes N. 15° W. across the head of [illegible] Canyon. The Bar B formation on the western side is dropped below the [illegible] on the east. The throw is about [illegible] feet at the head of the canyon and decreases in both directions. Fault N7 may be continuous with N6; however, the granite-sediment contact is not displaced.

Faults N7, N8, N9, and other faults in this area are confined wholly to the Precambrian rock, making estimates of the displacement difficult. However, most are probably less than 200 feet.

Fault N9 extends northward from Fra Cristobal Peak to Contact Canyon where it is cut off by cross fault N14. The strike is northerly at the southern end and swings to N. 20° E. as the fault is traced northward. The dip is 58°-77° west. The fault plane has been silicified along the southern end, but is occupied by a pegmatite dike south of Contact Canyon.

Fault N10 is transverse to most of the structures of the mapped area. It strikes N. 80° W. The northern side is downthrown 60-70 feet, causing displacement of the Nakaye-Bar B contact.

Faults N11 and N12 mark a local steepening to 19°-22° of the dip of the beds of the Nakaye formation. Both faults trend N. 40° W. and dip 60° northeastward (Fig. 3, Section B-B').

Fault N13 trends N. 20° W. and dips 60° northeastward. The Nakaye and Bar B beds are displaced about 50 feet.

Three small normal faults that strike easterly and are downthrown on their northern sides cut the Abo outcrop east of Red Mountain. The northernmost of these faults drops feet at the head of the canyon and decreases in both directions. Fault N7 may be continuous with N5; however, the granite-sediment contact is not displaced.

Faults N7, N8, N9, and other faults in this area are confined wholly to the Precambrian rocks, making estimates of the displacement difficult. However, most are probably less than 200 feet.

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Fault N13 trends N. 20° W. and dips 50° northeastward. The Nakaye and Bar B beds are displaced about 30 feet.

Three small normal faults that strike easterly and are downthrown on their northern sides cut the Abo outcrop east of Red Mountain. The northernmost of these faults drops the Abo formation below the alluvium.

The movement on fault N14 was mainly strike-slip, although it is also downthrown on the northern side.

Thrust Faults

Thrust fault T1 is exposed for a distance of 1.5 miles along the eastern side of Red Mountain. The dip of the fault was measured at several places and found to be 50°-63° to the west. The strike is N. 30° E. The fault cuts the westward-dipping overturned limb of a syncline. The Precambrian rock which is crushed and broken is thrust over Magdalena and Abo beds which are overturned against the fault. At its northern end, the overthrust block is less eroded and covers the entire thickness of 1488 feet of the Magdalena group and the basal part of the Abo formation. This indicates a dip-separation of at least 1500 feet. The outcrop of the thrust is displaced slightly by three normal faults.

Thrust fault T2, which crops out on the western side of Contact and Long Canyons, is probably a continuation of fault T1 that has been offset by cross fault N14. These canyons, where eroded in the Red House formation, and the Precambrian rock, have cut down through the plane of the thrust.

At the saddle between Long Canyon and Contact Canyon where there has been less erosion, a klippe is preserved. The klippe consists of Precambrian gneiss and black schist the Ahe formation below the [illegible].

The [illegible] [illegible] [illegible], although it is in [illegible] [illegible] [illegible] surface trace.

Thrust Faults

Thrust fault VII is mapped for a distance of [illegible] miles along the eastern side of [illegible]. The dip of the fault was measured at several places and found to [illegible] to the west. The strike is N. [illegible] W. The fault near the west-dipping overturned limb of a syncline; the fault [illegible] rock which is crushed and broken and [illegible] over [illegible] beds which are overturned against [illegible]. [illegible] the overthrust [illegible] [illegible] [illegible] thickness of 1520 feet of the [illegible] group and the [illegible] part of the Ahe formation. This [illegible] of at least 1500 feet. The outcrop of the [illegible] slightly by these narrow faults.

Thrust fault IX, which [illegible] out on the eastern [illegible] of Contact and Long canyons, is probably a continuation of fault VI that has been offset by cross faulting. These canyons, where exposed in the [illegible] the Precambrian rock, have not been [illegible] [illegible] thrust.

[illegible] [illegible] [illegible] where there has been [illegible], a [illegible] is preserved. The klippe consists of [illegible] [illegible] [illegible] [illegible] which overlies beds of the Red House and Nakaye formations. It dips west at about 20°.

Folds

The most prominent structural feature of the Fra Cristobal Range is the overturned syncline which forms long segments of the crest of the range. The overturn, which has deformed the Bliss, Magdalena, and Abo beds, is continuous from the southern edge of the mapped area to the eastern side of Red Mountain where it plunges beneath the Quaternary alluvium. The strike of the axial plane changes several times along the 5.5-mile length of the overturn. South of the klippe, the trend is N. 10° E., between the klippe and fault N14 the trend is N. 10° W., and east of Red Mountain the trend is N. 30° E. The axial plane dips 15°-20° west.

Contact Canyon and Long Canyon are cut in the Red House formation and the Precambrian rock. The western side of these canyons is a ridge of gneiss and granite, and the eastern side is formed by overturned Nakaye and Red House beds. The major canyons on the eastern side of the range have cut down through the overturned beds to a level below the axial plane. These conditions cause the trace of the axial plane to form separate loops around the segments of the ridge composed of overturned strata. In one location south of Fra Cristobal Peak, the axial plane also intersects the west side of the canyon.

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It dips west at about 20°.

Folds

The most prominent structural feature in the San Cristobal range is the [illegible] syncline which forms long segments of the crest of the range. The syncline, which has deformed the Bliss, Magdalena, and Red House, is continuous from the southern edge of the map area to the western end of Red Mountain where it plunges under the [illegible] alluvium. The strike of the axial plane changes several times along the 5.5-mile length of the syncline. South of the Kilbey, the trend is N. 15° W., between the Kilbey and fault 214 the trend is N. 15° W., and east of the [illegible] the trend is N. 75° W. The axial plane dips 75°–85° west.

[illegible] Canyon and Long Canyon are cut in the Red House formation and the Precambrian rocks. The western side of these canyons is a ridge of gneiss and granite, and the eastern side is formed by overturned [illegible] and Red House beds. The major canyons on the western side of the range have cut down through the overturned beds to a level below the axial plane. These canyons cause the trace of the axial plane to form separate loops around the segments of the range composed of overturned strata. [illegible] south of San Cristobal [illegible], the axial plane [illegible] the west side of the canyon.

A striking feature is the abruptness of the overturning of the beds. At a distance of 200-300 feet east of the syncline axis, the strata dip 3°-10° southeastward. Nearer the syncline, the dips steepen to 10°-20° and then at the axial plane the beds are sharply bent to vertical or overturned.

From the southern end to fault N14, the overturned syncline has a very slight plunge to the north. Northeast of N14, the strike changes to N. 30° E. and the plunge steepens to about 5°.

The upright folds in the mapped area are designated A1, A2, . . etc., for anticlines; and S1, S2, . . etc., for synclines. The axial plane of these folds is nearly vertical. They do not show the intensity of deformation that is indicated by the overturned syncline.

Anticline A1 marks an over-all change in direction of dip of the strata of the eastern side of the range. The beds on the southern side are inclined southeasterly 3°-10°. The beds of the shorter and steeper northern limb dip 8°-20°.

Anticline A2, which parallels the overturned syncline for about one-half mile, trends N. 5° E. The western limb dips into the overturned syncline at angles of 10°-30°. Dips of 30° were measured on the northern end of this anticline where it plunges rapidly to the north.

Three synclines labeled S1, S2, and S3 are found along the eastern edge of the range in the southeastern part of the

A striking feature [illegible] is the [illegible] of the [illegible] turning of the beds. [illegible] dip [illegible] of the syncline axis, [illegible] 0°-[illegible] [illegible]. Nearer the syncline, the dips [illegible] to [illegible] and [illegible] at the axial plane the beds are [illegible] and [illegible] overturned.

From the [illegible] due to Fault [illegible], the overturned syncline has a very slight plunge to the [illegible]. [illegible] of NI4, the strike [illegible] to N. 30° [illegible], and the plunge steepens to about 5°.

The upright folds in the [illegible] area are [illegible] A1, A2, [illegible] etc., for anticlines, and [illegible] for synclines. The axial [illegible] of these folds [illegible]. They do not show the intensity of deformation that is indicated by the overturned syncline.

Anticline A1 [illegible] change in direction of dip of the strata [illegible] the eastern side of the [illegible]. The beds on the southern side [illegible] [illegible]. The beds of the shorter and steeper northern limb [illegible].

Anticline A2, which parallels the overturned syncline for about one-half mile, trends N. 5° [illegible]. The western limb dips into the overturned syncline at angles of [illegible]-20°. [illegible] of 30° were measured on the northern end [illegible] where it changes rapidly to [illegible].

Three synclines labeled [illegible] and [illegible] [illegible] the eastern edge of the range in [illegible] of the mapped area. The Magdalena beds, in general, dip southeasterly, but they have been bent upward along the eastern face of the range, forming these synclines.

Syncline S1 parallels fault N2 for one mile. The dip of the western limb is 1°-2° easterly. The eastern limb dips 10°-20° west. Syncline S2 parallels fault N2 for about 3 miles, with a trend of N. 15°-25° W. The trace of the axial plane is about 500 feet west of the fault. The dip of the eastern limb ranges from 3° to 30° west. The average is 13° west. At its northern end, this fold dies out and changes into normal fault N3.

Syncline S3 has a general trend of N. 20° W. The eastern limb has been sharply folded and dips 45° west. This fold brings Precambrian rocks to the surface in one small area. This is the only exposure of Precambrian rock on the eastern side of the range that is overlain by sediments. The east limb of the fold is composed principally of beds of the Red House formation.

Synthesis

The structural features of the rocks in the mapped area are the result of three periods of orogeny occurring during Precambrian, late Cretaceous, and middle and late Tertiary time.

Although there is some possibility of deciphering the Precambrian deformation more clearly through a regional study, mapped area. The Magdalena beds, in general, dip southeasterly, but they have been bent upward along the eastern face of the range, forming these synclines.

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Syncline S3 has a general trend of N. 20° W. The eastern limb has been sharply folded and dips 45° west. This fold brings Precambrian rocks to the surface in one small area. This is the only exposure of Precambrian rock on the eastern side of the range that is overlain by sediments. The east limb of the fold is composed principally of beds of the Red House Formation.

Synthesis

The structural features of the rocks in the mapped area are the result of three periods of deformation occurring during Precambrian, late Cretaceous, and middle and late Tertiary time.

Although there is some possibility of deciphering the Precambrian deformation more clearly through a regional study, little can be said about it from the field work of this project. However, the contact of the Precambrian rock with the overlying strata indicates that this period of deformation was complete long before the deposition of the Cambrian beds, which were deposited on a profound erosion surface of low relief. It appears that little or no orogenic activity affected the area from Precambrian to Cretaceous time. The Paleozoic and Mesozoic tectonics of the region were entirely epeirogenic. The principal of structure developed during this time consisted of broad regional warps (Kelley and Silver, 1952, p. 131).

Laramide Features

The structural features of the mapped area which are considered to be of Laramide age are localized in a belt that extends from the southwestern corner of the area to the east side of Red Mountain. The intensely folded and faulted features of this belt contrast strongly with the gently-folded and faulted blocks which form the rest of the Fra Cristobal Range.

At the type locality in the Cutter sag, the Upper Cretaceous McRae formation is not close enough to its source areas to make definite conclusions as to the origin of the sediments. However, the basal Jose Creek member of the McRae formation crops out at the northern end of the Fra Cristobal Range. This locality probably provides the best, little can be said about [illegible] of this project. However, the contact of the Franciscan [illegible] with the overlying strata indicates that this period of deformation was completed long before the deposition of the Cenomanian(?) beds, which were deposited on a surface of moderately [illegible] of low relief. It appears that little or no orogenic activity affected the area from Pennsylvanian to Cretaceous time. The Paleozoic and Mesozoic sections of the [illegible] were [illegible] epeirogenic. The principal of structure developed during this time consisted of broad regional warping (Kelley and Silver, 1952, p. 131).

Laramide Features

The structural features of the mapped area which are considered to be of Laramide age are located in a belt that extends from the southwestern corner of the area to the east side of Red Mountain. The [illegible] folded and faulted features of this belt contrast strongly with the gently-folded and faulted blocks which form the rest of the Fra Cristobal Range.

At the type locality in the Carthage area, the Upper Cretaceous McRae formation is not thick enough at the [illegible] areas to make definite conclusions as to the origin of the sediments. However, the basal Jack Rabbit member of the McRae formation crops out at the southern end of the Fra Cristobal Range. This locality [illegible] the [illegible], more or less direct evidence found so far of a pre-McRae date for the beginning of the strong Laramide orogeny in south-central New Mexico.

Jose Creek beds form a fanglomerate upon the slopes of the Precambrian granite gneiss. Northward from this contact, the Jose Creek beds are dominantly sandstone and mudstone. Large angular to subrounded cobbles and boulders of gneiss comprise the fanglomerate and intertongue northward into the sandstone and mudstone. Less than one mile to the south, the gneiss is thrust over Pennsylvanian and Permian sediments by fault T1 which has a dip separation of at least 1500 feet.

These relationships indicate profound deformation and deep erosion in pre-McRae time. Approximately 7000 feet of Paleozoic and Mesozoic strata must have been stripped from the upthrust plate prior to the deposition of the Jose Creek beds on the gneiss.

Beginning in late Cretaceous time, the Fra Cristobal area was subjected to compressional forces. In the northern part of the range, the belt of thrusting and overturning trends north-south to N. 20° E. This indicates that the effective compressive forces were oriented approximately east-west. The over-all structural aspect of the northern part of the Fra Cristobal Range suggests the former presence of a northward-trending overturned anticline and syncline that have been highly modified by faulting and erosion. Most of the large outcrop of Precambrian granite in the mapped

area probably represents the core of the overturned anticline. The westward-dipping upright limb of this anticline has been almost completely removed by erosion. The beds which form the overturned western limb of the syncline along the crest of the range, from a point about one mile south of the Old mine to the east side of Red Mountain (Fig. 3, sections B-B', C-C', D-D' and E-E'), are remnants of the limb between the synclinal and anticlinal axial planes.

The only place in the range where the strata of the westward-dipping limb of this anticline has been preserved is in the area extending from 0.5 mile north of Amphitheater Canyon southward to the point where the Hot Springs fault cuts the anticlinal nose in the southwestern corner of the mapped area. This anticline was named the Amphitheater Canyon anticline by Jacobs (1956, p. 24), and is designated as A3 on the geologic map (Fig. 3). There is evidence for the former presence of the Amphitheater Canyon anticline in the area north of Fra Cristobal Peak. In three places in the Precambrian terrane there are planar surfaces which dip westerly about 15°-25°. These surfaces are present on the top of a small butte immediately west of fault N8, on the north side of Fra Cristobal Peak, and on the first ridge north of Fra Cristobal Peak (Plate 3, p. 59). These surfaces are thought to be the folded and faulted remnants of the pre-Pennsylvanian erosion surface. A cursory examination

failed to disclose the presence of any sedimentary rock on these surfaces. The lack of sedimentary rock may be related to the fact that this area is north of the wedge out of the Bliss formation. The quartzitic lower beds of the Bliss formation are very resistant to erosion and have undoubtedly aided in the preservation of the Cambrian and Ordovician rock in the vicinity of Amphitheater Canyon. However, north of the line where the Bliss formation wedges out, the Red House formation rests directly on the Precambrian rock. The Red House formation is easily eroded and has probably been completely stripped from the pre-Pennsylvanian erosion surface north of Fra Cristobal Peak.

The tear fault (N15) one mile south of the Old mine separates areas that were affected differently by the Laramide compressive forces. It appears that the area north of the tear fault was subjected to a stronger compressive force than was the area immediately to the south. On the north side of this fault the beds are overturned and dip about 85° to the west and therefore the postulated northward extension of the Amphitheater Canyon anticline was overturned. On the south side of the tear fault the limbs of the Amphitheater Canyon anticline are upright and dip about 25° to the east and 20° to the west. It appears that the difference in intensity of the forces caused shearing to occur in a direction oblique to the direction of the compression.

failed to disclose the presence of any [illegible] on these surfaces. The lack of [illegible] may be related to the fact that this area is north of the wedge [illegible] of the Bliss formation. The [illegible] of the Bliss formation are very resistant to [illegible] and [illegible] aided in the preservation of the [illegible] rock in the vicinity of [illegible]. However, north of the line where the Bliss [illegible] out, the Red House formation rests directly on the Precambrian rock. The Red House formation is readily eroded and has probably been completely stripped from the pre-[illegible] erosion surface north of the Cristobal Peak.

The tear fault (115) one mile [illegible] separates areas that were affected differently by the [illegible] compressive forces. It appears that the area north of the tear fault was subjected to a stronger compressive force than was the area immediately to the south. On the north side of this fault the beds are overturned and dip about 80° to the west and therefore the postulated northward extension of the Amphitheater Canyon anticline was overturned. On the south side of the tear fault the limbs of the Amphitheater Canyon anticline are upright and dip about 45° to the east and 30° to the west. It appears that the [illegible] the forces [illegible] the direction of [illegible].

In the area south of Amphitheater Canyon, the most intense overturning and associated thrust faulting occurred in conjunction with the folding of syncline S4 which is parallel to and on the west side of the Amphitheater Canyon anticline (Fig. 3, sections F-F' and G-G'). However, the dip of the limbs of the Amphitheater Canyon anticline increases southward from Amphitheater Canyon and the east limb is folded to vertical about 0.5 mile north of the south edge of the mapped area. The north end of syncline S4 is cut off by a southwestward-dipping normal fault, but it may have originally extended farther north. However, it does not seem to be expressed in the pre-Pennsylvanian erosion surface north of Fra Cristobal Peak.

It appears that in the area south of Amphitheater Canyon, and possibly farther north, two anticlines and a syncline formed as a result of Laramide compressive forces. In most places, the east limbs of the anticlines were overturned and in several places thrusting occurred. Unequal stress distribution and inhomogeniety of the rocks probably caused the folds to become overturned in some places and remain upright elsewhere.

The beds of the overturned syncline along the crest of the range have been folded very sharply. At a distance of 200-300 feet east of the syncline axis, the strata have a dip of 3°-10° to the east. Nearer the syncline the dip steepens to 10°-20° and then the beds are abruptly overturned.

In the area south of Amphitheater Canyon, the most intense overturning and associated thrust faulting occurred in conjunction with the folding of syncline 54 which is parallel to and on the west side of the Amphitheater Canyon anticline (Fig. 3, sections F-F' and G-G'). However, the dip of the limbs of the Amphitheater Canyon anticline increases southward from Amphitheater Canyon and the east limb is folded to vertical about 0.5 mile north of the south edge of the mapped area. The north end of syncline 54 is cut off by a southwestward-dipping normal fault, but it may have originally extended farther north. However, it does not seem to be expressed in the pre-Pennsylvanian erosion surface north of Fra Cristobal Peak.

It appears that in the area south of Amphitheater Canyon, and possibly farther north, two anticlines and a syncline formed as a result of Laramide compressive forces. In most places, the east limbs of the anticlines were overturned and in several places thrusting occurred. Unequal stress distribution and inhomogeneity of the rocks probably caused the folds to become overturned in some places and remain upright elsewhere.

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The abruptness of the bending in the hinge area, the occurrence of overturned beds, and the presence of thrust faults, suggest that this fold is of the chevron type. In the process of chevron folding, the steeply-dipping limb is sheared obliquely to the principal stress and parallel to the fold axis, the other limb is simply tilted with slip occurring along the bedding planes. The gently-dipping limb maintains its original thickness; however, there is thickening of the steeply-dipping limb.

Slip along the bedding planes probably occurs when the bedding is well defined as is that of the Magdalena group which consists almost entirely of alternating shale and limestone beds. The beds of the overturned limb have presumably undergone shearing which consisted of minute displacements along closely spaced shear planes which dip westward and have approximately the same inclination as the thrust faults. Thrust faulting probably occurred when the oblique shearing stress of the overturned limb was concentrated in the plane of the thrust, causing rupture to occur.

Middle and Late Tertiary Features

This period of orogenic activity was characterized by high-angle faulting and mild local folding.

When possible, the dating of structures is done largely by the study of their associations with sedimentary rocks

The structures of the complex in the [illegible] [illegible], the occurrence of overturned beds, and the presence of [illegible] faults, suggest that these [illegible] of the [illegible] [illegible]. In the process of [illegible] [illegible], the [illegible] [illegible] [illegible] sheared obliquely to the [illegible] [illegible] and [illegible] to the fold axis, the upper limb is simply [illegible] [illegible] occurring along the bedding planes. The [illegible] limb maintains its original [illegible] [illegible], [illegible] of the steeply-dipping limb.

[illegible] along the bedding [illegible] [illegible] [illegible] [illegible] the bedding [illegible] [illegible] [illegible] the [illegible] group which [illegible] almost [illegible] [illegible] [illegible] [illegible] limestone [illegible]. The [illegible] of the overturned [illegible] [illegible] presumably underwent shearing which [illegible] [illegible] [illegible] displacements [illegible] [illegible] moved about [illegible] [illegible] westward and have [illegible] [illegible] [illegible] the thrust faults. Thrust faulting [illegible] [illegible] oblique shearing [illegible] of the overturned limb [illegible] concentrated in the plane of the [illegible] [illegible] [illegible] occur.

Middle and late Tertiary [illegible]

This [illegible] of [illegible] [illegible] [illegible] [illegible] by high-angle faults and [illegible] [illegible].

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] by the [illegible] of [illegible] [illegible] [illegible] [illegible] [illegible].

which are involved in the deformation and those that are derived from the deformation. Due to the lack of such sedimentary relationships in the mapped area, another method must be used for dating faults N2 through N13 and folds A1, S1, S2 and S3. They are dated by analogy to similar faults and folds in the Caballo Mountains, Cutter sag, and the south part of the Fra Cristobal Range.

This group of structural features in places modifies the overturns and thrust faults and therefore is definitely younger than Laramide. In the Caballo Mountains, these faults and folds involve the deformation of the Palm Park and Thurman formations of possible Oligocene and Miocene age (Kelley and Silver, 1952, p. 146). Most of the same structures do not appear to have involved the Santa Fe formation. For these reasons, the predominantly northwest-trending high-angle normal faults and open folds are considered to be of middle Tertiary inception. However, due to the fact that the age of the Palm Park and Thurman formations is not perfectly known, an exact age assignment cannot be made. Orogenic activity has possibly been more or less continuous in this region throughout Cenozoic time.

Inasmuch as the Santa Fe formation is considered to be largely derived from uplifts bordering the Rio Grande depression, and since it is considered to be Miocene and Pliocene in age, the inception of the Hot Springs and Fra Cristobal faults that bound the uplift is assumed to have which are involved in the deformation and those that are derived from the deformation. Due to the lack of such sedimentary relationships in the mapped area, another method must be used for dating faults N2 through N13 and folds A1, S1, S2 and S3. They are dated by analogy to similar faults and folds in the Caballo Mountains, Cutter sag, and the south part of the Fra Cristobal Range.

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Inasmuch as the Santa Fe formation is considered to be largely derived from uplifts bordering the Rio Grande depression, and since it is considered to be Miocene and Pliocene in age, the inception of the Hot Springs and Fra Cristobal faults that bound the uplift is assumed to have occurred in Miocene time.

The structure of the Jornada del Muerto depression is considered to be, in general, a broad syncline that has been modified by folding and faulting which occurred in middle Tertiary time. Uplift of the Fra Cristobal horst block and relative lowering of the Jornada and Rio Grande depressions was undoubtedly related to movement along the Fra Cristobal and Hot Springs faults. However, it may be assumed that gentle folding preceded the uplift. This folding in the Jornada depression is reflected in the mountains by folds S1, S2, and S3, along the eastern margin of the range. Continued uplift caused rupture and the creation of faults N2 and N3. These faults are an exposed part of the Fra Cristobal fault zone which parallels the fold axes.

Movement on the Fra Cristobal and Hot Springs faults was probably rejuvenated in late Pliocene time. This is indicated by the fact that these faults cut off the middle and late Tertiary faults which are covered by the Santa Fe formation west of the Hot Springs fault. The Hot Springs fault appears to involve Santa Fe beds on the downthrown side, which also indicates movement in post-Santa Fe time.

Northeast-trending faults, with large components of horizontal displacement, have been reported in the southern part of the Fra Cristobal Range (Thompson, 1955, p. 55). Of the faults in the mapped area, only fault N1 exhibits this occurred in Miocene time.

The structure of the [illegible] Mountains is considered to [illegible] that has been modified by folding and faulting which occurred in middle Tertiary time. Uplift of the [illegible] block and relative lowering of the [illegible] depressions was undoubtedly related to movement along the Pre-Cristobal and Hot Springs faults. However, it may be assumed that gentle folding preceded the faulting. Folding in the [illegible] syncline is [illegible] by folds S1, S2, and S3, along the eastern margin of the range. Continued uplift caused rupture and the [illegible] of faults N2 and N3. These faults are an [illegible] part of the Pre-Cristobal fault zone which [illegible].

Movement on the Pre-Cristobal and Hot Springs faults was probably rejuvenated in late Pliocene time. This is indicated by the [illegible] faults [illegible] the middle and late Tertiary [illegible] which are [illegible] by the [illegible] formation west of the Hot Springs fault. The Hot Springs fault appears to [illegible] on the [illegible] side, which also indicates movement in post-[illegible] time.

Northeast-trending [illegible] with large [illegible] of horizontal displacement have been [illegible] in the northern part of the Pre-Cristobal Range ([illegible], 1937, p. 25). Of the faults in the mapped area, [illegible] characteristic. It probably separates blocks that acted as units during the late Tertiary deformation. The effects of strike movement on N1 account for the difference in throw of the Fra Cristobal fault zone north and south of where it is cut by fault N1.

The dominant trend of Tertiary normal faults N4, N6, N7, N8, N10, N11, N13 and the Maddux fault, is northwesterly, indicating that a control existed during deformation. It appears that differential vertical movement caused by a couple was the principal control on the trends of these faults. The couple was probably oriented eastward to the north and westward to the south of the mapped area. With this orientation of a couple, the axis of minimum stress might trend northeast and be approximately perpendicular to the trend of this group of normal faults.

Tertiary faults N2, N3, N5, and N9 and folds S1, S2, and S3 are thought to have developed under essentially the same stress conditions as those of the preceding paragraph; however, they deviate from the northwesterly trend. The trends of these features are probably controlled partially by predetermined zones of weakness incurred during the Laramide orogeny. The trend of synclines S1, S2, and S3, which is northerly to northwesterly, appears to be related to Laramide zones of weakness which trend approximately northly. The trend of faults N2 and N3, which are an exposed part of the Fra Cristobal fault zone, is parallel to and

controlled by the location of synclines S1, S2 and S3. The trend of N5, N9, and the Hot Springs fault is parallel to the belt of Laramide deformation.

A small graben is present between two northward-trending normal faults north of anticline A1. The block between the faults has been depressed about 50 feet and forms a flat floor which has not been disected by erosion, suggesting recent faulting. Further evidence for recent faulting is the fact that the beds of the Nakaye formation east of the graben have been subjected to landsliding and slumping. This is a marked contrast to the usual outcrops of the Nakaye formation which elsewhere in the range form steep cliffs which may be traced continuously for long distances.

GEOLOGIC HISTORY

In Precambrian time, the area was affected by orogenic activity. The creation of the metamorphic rocks was followed by the intrusion of the granite. Following the Precambrian orogeny, a long period of erosion reduced the surface to a peneplain. In late Cambrian time, this surface was depressed beneath the sea in a broad regional downwarp to the south. The sea covered most of southern New Mexico and extended a considerable distance north of the mapped area. As the sea advanced, arenaceous clastic material was spread over the floor, forming the Bliss formation. The limestone of the El Paso group was deposited without notable pause into Ordovician time.

controlled by the location of synclines S1, S6 and S11, the trend of S5, S9, and the Hot Springs fault is part of the belt of Laramide deformation.

A small graben is present between two parallel east-trending normal faults north of [illegible]. The block between the faults has been depressed about 50 feet and forms a flat floor which has not been dissected by erosion, suggesting recent faulting. Further evidence for recent faulting is the fact that the beds of the [illegible] formation east of the graben have been subjected to landsliding and slumping. This is in marked contrast to the usual outcrops of the Magdalena group which elsewhere in the range form steep cliffs which may be traced continuously for long distances.

GEOLOGIC HISTORY

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The history of the time between Ordovician and Pennsylvanian is lost to view. If deposition occurred in the mapped area during this time interval, the evidence was removed by pre-Pennsylvanian erosion which caused thinning of the Cambrian and Ordovician formations. Following this period of erosion, the Pennsylvanian sea transgressed over the subsiding erosion surface and a broad seaway was formed that extended from a vicinity east of the Sacramento Mountains westward into Arizona and northward in the form of several arms separated by island chains (Kelley and Silver, 1952, p. 97).

The Red House formation was deposited during transgression of the sea. The Nakaye formation was probably deposited during a time of maximum stability. Marine regression is represented by the Bar B formation. Following the retreat of the sea, the Abo formation was formed on a wide floodplain. The transition to a continental environment appears to be one of conformity as was the gradual change back to marine conditions in later Permian time, as indicated by the Yeso and San Andres formations. If deposition recurred during Triassic, Jurassic, and early Cretaceous time, the evidence was removed by subsequent erosion. The region remained tectonically stable during most of Mesozoic time.

The area was subjected to horizontal east-west compressive forces in Laramide time. Laramide structural features are present in a belt along the western side of the range. The deforming forces probably resulted in the formation of an anticline on the western side and a syncline on the eastern side of the belt in the mapped area. Continued

The majority of the time between Ordovician and Pennsylvanian is lost to [illegible] in [illegible] the mapped area during this time [illegible] raised. [illegible] by pre-Pennsylvanian erosion which removed the [illegible] the Cambrian and Ordovician formations. [illegible] erosion, the Pennsylvanian [illegible] erosion surface [illegible] from a [illegible] of [illegible] Arizona and [illegible] in the form of [illegible] island chains (Kottlowski and [illegible] 1962, p. [illegible]).

The [illegible] Formation was deposited during [illegible] gression of the sea. The [illegible] Formation was probably deposited during a time of continued stability. [illegible] is represented by the [illegible] Formation [illegible] of the sea, the [illegible] Formation [illegible]. The transition to a continental environment [illegible] of conformity as [illegible] in later Permian time, as indicated by the [illegible] formations. [illegible] deposition occurred during Triassic, [illegible] and early Cretaceous time, [illegible] subsequent erosion. The region remained [illegible] during most of Cenozoic time.

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compression caused the east limb of the anticline to become overturned. Locally, the oblique shearing in the overturned limb was concentrated into westward-dipping thrust faults. Deep erosion accompanied the profound deformation by folding and thrusting. At the north end of the range, 7000 feet of Paleozoic and Mesozoic strata were stripped from the upthrust block prior to the deposition of the Jose Creek fanglomerate on the Precambrian rock.

In upper McRae time, the Laramide orogeny had generally ceased, the floodplain sediments of the Hall Lake member were deposited. This period of erosion in the source areas probably continued into early Tertiary time and reduced the mountains to areas of relatively low relief.

In middle Tertiary time, a period of open folding, followed by normal faulting, began in the Fra Cristobal area. During this period of orogeny, the deformation appears to have been the effect of a couple which was oriented eastward to the north and westward to the south of the mapped area. The Laramide folds which had been deeply eroded in early Tertiary time were almost completely destroyed by faulting and erosion. The uplift of the horst block along the Hot Springs and Fra Cristobal faults was accompanied by deposition of the Santa Fe formation in the Rio Grande depression. Later movement on the bounding faults distorted the Santa Fe formation and elevated the range to its present prominence. Deposition of the Santa Fe formation was followed by the planation of the Cuchillo Surface in the Engle Valley. The widespread planation may have begun in late Pliocene time. In Quaternary time, lava flows covered parts of the planed surface.

compression caused the east limb of the anticline to become overturned. Locally, the [illegible] of [illegible] the [illegible] limb was concentrated into westward-dipping thrust faults. Deep erosion accompanied the [illegible] deformation by folding and thrusting. At the north end of the range, rocks of Paleozoic and Mesozoic age were stripped from the [illegible] block prior to the deposition of [illegible] on the Precambrian rock.

In upper Eocene time, the Laramide orogeny had largely ceased, the [illegible] sediments of the [illegible] were deposited. This period of erosion in the [illegible] area probably continued into early Tertiary time and reduced the mountains to areas of relatively low relief.

In middle Tertiary time, a period of [illegible], followed by normal faulting, began in the [illegible] area. During this period of orogeny, the [illegible] appears to have been the effect of [illegible] which was [illegible] to the north and [illegible] to the [illegible] of the [illegible] area. The Laramide folds which had been [illegible] in early Tertiary time were almost completely destroyed by faulting and erosion. The uplift of the [illegible] along [illegible] and [illegible] faults were [illegible] Santa Fe formation [illegible] east on the bounding fault [illegible] and elevated the range to [illegible] present [illegible] of the Santa Fe formation [illegible] Quaternary [illegible] may have begun in late Pliocene time, [illegible] flows covered parts of the [illegible].

MINERAL DEPOSITS

No mining is being done in the Fra Cristobal Range at the present time. The largest known mineral deposit is the Blackie manganese claim which is located on the western side of the range about one-half mile south of the Sierra-Socorro County line. Development work was done in 1954 when a road was built into the area and the vein was uncovered. The principal vein is in a small normal fault which branches to the east off the Hot Springs fault. The vein strikes north-south and dips 70° west. The vein cuts a transverse pegmatite dike in the Precambrian rock. The mineralized zone along the vein is about 6 inches to one foot thick. North-south fractures in the Precambrian rock and in the Hot Springs fault show manganese staining. The margins of the pegmatite dike are also stained with manganese. The manganese minerals include psilomelane and wad which fill the interstices in the vein-filling material which consists of brecciated gneiss and quartz. The deposit appears too low grade and the vein too narrow to be worked successfully at present.

A few scattered pieces of malachite were found at the outcrop of fault T1 east of Red Mountain and the klippe at the head of Spring Canyon.

Fault N9 contains small amounts of flourite and some malachite just south of Contact Canyon.

The vein in the Maddux fault contains mostly barren quartz. However, there are small spots and stringers of galena. The quartz mineralization is frequently up to 50 feet wide, but the part that contains the galena is very narrow.

Various quartz veins in the Precambrian terrane show slight amounts of lead, copper, manganese, and flourite.

The Old mine which is located at the head of Spring Canyon is on a continuation of the Maddux fault. It is in the area of Precambrian rock adjacent to the Bliss formation. Malachite and azurite, which are the most abundant minerals in the tailings, indicate that this was principally a copper mine.

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DESCRIPTIVE STRATIGRAPHIC SECTION

Magdalena Group

	(Abo formation above) Top of Bar B formation:	Thickness (feet) Unit	Cumulative
68	Limestone: medium-bedded; gray, weathers buff; fine-grained; sandy	12	1488
67	Limestone: medium-bedded; dark-gray, weathers gray-brown; fine-grained fossiliferous	32	1476
66	Limestone: massive; gray-brown; very fine grained; stringers of yellow calcite	4	1444
65	Claystone: pink; contains irregular 2-3 inch stringers of greenish limestone	39.5	1440
64	Limestone: massive; gray, weathers light gray-brown; fine-grained	18	1400.5
63	Limestone: massive; gray, weathers light-gray; fine-grained with some coarse detrital grains	10	1382.5
62	Shale: dark-gray; contains thin fine-grained limestone stringers	15	1372.5
61	Limestone: medium-bedded; gray; weathers buff to gray; fine-grained	17	1357.5
60	Limestone: massive; dark-gray, weathers gray-brown; very fine grained; fossiliferous	9.5	1340.5
59	Limestone: thin-bedded; dark-gray; very fine grained	6	1331
58	Limestone: massive to thin-bedded; gray; weathers brown; very fine grained; much dark-brown chert in lower part; some thin parting of shale; fusulinids	27	1325

		Thickness (feet)	
		Unit	Cumulative
57	Shale: gray; contains nodular limestone stringers 4 inches to 1 foot thick, dark-gray	25	1298
56	Claystone: gray; contains nodular limestone stringers 2-3 feet thick	26	1273
55	Claystone: gray; contains limestone stringers 6 inches to 1 foot thick	16	1247
	Total Bar B:	258	
	Top of Nakaye formation:		
54	Limestone: massive; gray, weathers light-grey; very fine grained	8	1231
53	Limestone: medium-bedded; gray; very fine grained; mottled red-brown chert and some greenish chert nodules	16	1223
52	Limestone: massive; gray-brown; fine-grained; nodules of white chert	18	1207
51	Limestone: thick-bedded; dark-gray; very fine grained	8	1189
50	Limestone: massive; gray-brown, weathers gray; fine-grained; brown chert nodules	13	1181
49	Limestone: thin-bedded; dark-gray; fine-grained; mottled brown chert	5	1168
48	Limestone: massive; gray-brown; fine-grained; chert lenses 1-2 inches thick	21	1163
47	Limestone: thick-bedded; gray-brown, weathers light-brown; very fine grained	20	1142
46	Limestone: massive; dark-gray, weathers gray-brown; fine-grained	27	1122

		Thickness (feet)	
		Unit	Cumulative
45	Limestone: thin-bedded; gray; fine-grained; mottled red-brown chert	12	1095
44	Limestone: massive; dark-gray; very fine grained; buff chert on bedding planes	9	1083
43	Limestone: massive, dark-gray; weathers gray-brown; lower 2 feet is thin-bedded and fossiliferous	17.5	1074
42	Limestone: massive; dark-gray, weathers gray-brown; fine-grained; banded chert	17	1056.5
41	Limestone: medium-bedded; brown-gray, weathers buff, fine-grained; fossiliferous	18	1039
40	Limestone: massive; dark-gray, weathers gray-brown; fine-grained; mottled chert on surface	25	1021
39	Covered	27	996
38	Limestone: massive; dark-gray, weathers gray-brown; fine-grained	32	969
37	Limestone: massive; gray-brown, weathers gray; fine-grained	24	937
36	Limestone: medium-bedded; gray, fine-grained; much nodular buff-colored chert	15	913
35	Limestone: massive, dark-gray, weathers gray-brown; fine-grained	17	898
34	Covered	12	881
33	Limestone: massive; gray-brown, weathers brown; fine-grained; banded chert in lower half	29	869

		Thickness (feet)	
		Unit	Cumulative
32	Limestone: medium- to thick-bedded; dark-gray, very fine grained	43	840
31	Limestone: massive; gray-brown, weathers gray; fine-grained; Mottled chert in lower part	13	797
30	Limestone: thick-bedded; dark-gray, weathers light-gray; very fine grained	6	784
29	Limestone: thin-bedded; gray-brown, weathers light-brown; fine-grained; mottled chert	17	778
28	Limestone: massive; gray-brown; fine-grained	26	761
27	Covered	7.5	735
26	Limestone: massive; dark-gray; fine-grained	17	727.5
25	Limestone: thin-bedded; gray; fine-grained	29	710.5
24	Limestone: medium-bedded; dark-gray; fine-grained; chert stringers 2-3 inches thick; sandy in upper part	59	681.5
23	Limestone: massive; gray-brown; very fine grained; bands of buff chert	21.5	622.5
22	Limestone: massive; gray-brown; very fine grained	42	601
21	Limestone: medium-bedded; gray; nodular chert; clayey	4	559
20	Limestone: massive; gray-brown; weathers light-brown; fine-grained; contains many dark-brown chert nodules	25	555
	Total Nakaye:	700.5	

		Thickness (feet)	
		Unit	Cumulative
	Top of Red House formation:		
19	Limestone: medium-bedded; dark-gray; fine-grained; a few fossils	34	530
18	Covered	17	496
17	Limestone: medium-bedded to massive; dark-gray; fine-grained; mottled chert on surface; calcite veinlets in lower part	15	479
16	Limestone: massive; gray-brown; fine-grained; limonite stain in fractures	14	464
15	Limestone: massive; dark-gray; weathers gray; fine-grained; buff chert; clayey	25	450
14	Limestone: thin-bedded; gray; very fine grained; mottled buff chert on surface	9	425
13	Limestone: massive; dark-gray; fine-grained; banded chert; fossiliferous	7.5	416
12	Limestone: thin-bedded to massive; dark-gray; fine-grained; banded chert fossiliferous	72	408.5
11	Limestone: thin-bedded; lower 10 feet is massive; dark-gray; fine-grained; dark-brown bands of chert	51.5	336.5
10	Limestone: thick-bedded; medium-gray; medium-grained	16	285
9	Limestone: medium- to thick-bedded; gray-brown; weathers brown; fine-grained; fossiliferous	25.5	269

		Thickness (feet)	
		Unit	Cumulative
8	Limestone: medium- to thick-bedded; dark-gray; fine-grained nodular chert	38.5	243.5
7	Limestone: massive; dark-gray; weathers gray; brown chert nodules; fossiliferous	17.5	205
6	Shale and limestone: dark-gray; limestone, thin-bedded, dark-gray; fine-grained	54	187.5
5	Shale and limestone: dark-gray; limestone, thin-bedded; fine-grained; fossiliferous	55	133.5
4	Shale and limestone: dark-gray; limestone, thin-bedded; gray-brown; fossiliferous	33	78.5
3	Limestone: thin- to medium-bedded; dark-gray; fine-grained; contains detrital quartz and fossil fragments	11	45.5
2	Limestone: medium-bedded; gray to dark-gray; fine-grained; fossiliferous; top 1.5 feet has detrital quartz	28.5	34.5
1	Shale: brownish-green	6	6
	Total Red House:	530	

Top of Precambrian: (pink gneiss)

Plate 1. View south from the klippe at the head of Spring Canyon, showing the overturned syncline.

Plate 2. Fanglomerate of the Jose Creek member of the McRae formation at the north end of the Fra Cristobal Range.

Plate 3. View south from Contact Canyon toward Fra Cristobal Peak.

Plate 4. View north along Contact Canyon. Red House and Nakaye beds form the ridge at the right. The beds overturn at the far end of the ridge. The granite peak is Red Mountain. Rio Grande at left. Magdalena Mountains in distance.

One map in pocket