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Geology of the Central Front of the Fra Cristobal Mountains, Sierra County, New Mexico

Richard C. Jacobs

GEOLOGY OF THE FRA CRISTOBAL MOUNTAINS • JACOBS

GEOLOGY

OF THE

CENTRAL FRONT OF THE FRA CRISTOBAL MOUNTAINS

SIERRA COUNTY, NEW MEXICO

By

Richard C. Jacobs

A Thesis

In partial fulfillment of the

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DEAN

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ABSTRACT

This report includes about seven square miles of the central front of the Fra Cristobal Mountains.

The area contains rocks of Precambrian, Cambrian, Pennsylvanian, and Quaternary age. Fragmentary exposures of the Permian sedimentary rocks are also present. The sedimentary sequence extending from Cambrian to Ordovician consists of quartzitic sandstone, limestone, and dolomite. Pennsylvanian beds comprise the greater part of the sedimentary sequence and consist principally of limestone. Precambrian rocks are predominantly granite gneiss. Unconformities are found at the bases of the Cambrian and Pennsylvanian systems. Quaternary deposits include basalt flows, pediment gravel, alluvium, and landslide material.

At least three periods of orogenic activity appear to have affected the area. These took place in the Precambrian, late Cretaceous, and Tertiary.

Structurally the area is dominated by features formed during Laramide and Tertiary orogeny. The Laramide structures consist of overturned folds trending generally northwest and overthrusts preserved as klippes. Tertiary features include numerous high-angle normal faults, largely with displacements in a dip-slip direction, and possibly some mild folding on pre-existing structures.

During Quaternary time it has been dominantly one of extrusion of basaltic lavas, erosion of Cenozoic structures, and filling of the Rio Grande trough.

Mineral deposits in the area include some low-grade iron deposits and a vein of flourspar.

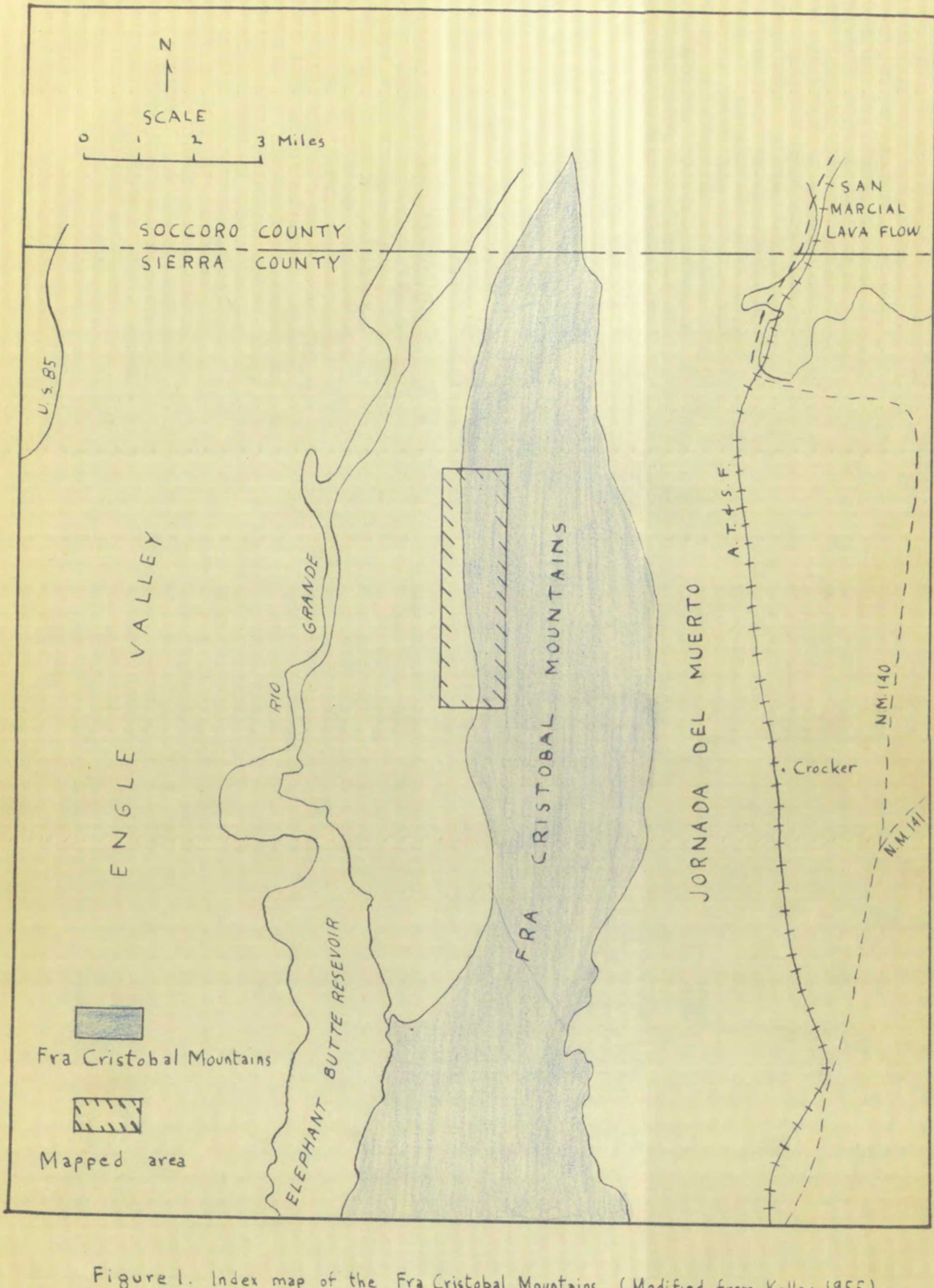

Figure 1. Index map of the Fra Cristobal Mountains. (Modified from Kelley, 1955)

INTRODUCTION

Geography

The Fra Cristobal Mountains are a part of the discontinuous chain of northward-trending linear mountains lying in the Mexican Highland section of the Basin and Range Province (Fenneman, 1930). The mountains are located in approximately the north-central part of Sierra County on the east side of the Rio Grande near the town of Truth or Consequences. On the west the range is bounded by the Rio Grande Valley, locally termed Engle Valley, and to the east by the Jornada del Muerto Valley.

The mapped area lies along the central front on the western side of the range. It covers about ~~seven~~ (4 ½) square miles bounded approximately by longitude 107° 07' and 107° 03' west and latitude 34° 18' and 34° 31' north.

The principal land form is the steep western face of resistant rocks which forms the escarpment and the crest of the range. At the foot of the escarpment, longitudinal valleys are locally developed which are flanked by long, narrow ridges. In the northern part of the mapped area, the topography is principally developed on Precambrian rock which is deeply dissected forming precipitous canyons and peaks. The piedmont slope occupying the westernmost part of the area forms a surface that slopes gently westward

to the Rio Grande. The elevations range from about 4800 feet along the piedmont slopes to well over 6000 feet at the crest of the range.

All the streams in the mapped area drain generally west into the Rio Grande. Most of the major streams descending the western escarpment flow transversely across the northwest trend of the topography; however, the small tributaries are aligned along the strike of the folded strata, producing a rude trellis pattern. On the piedmont slopes a dendritic drainage pattern prevails.

The climate is arid with an annual precipitation of less than 10 inches in the greater part of the area. The lowest mean monthly temperature is 41° F. occurring in the month of January. July is the warmest month with a mean temperature of 79.9° F. (Kelley and Silver, 1952, p. 18).

The aridity is emphasized by the character of the vegetation, which is sparse and of the desert type. Desert growths such as creosote bush, sage, prickly pear, and greasewood are common on the lower slopes. Except for a few junipers and pinons on the crest of the range there are no trees in the area.

Access to the western escarpment of the Fra Cristobal Mountains is gained by means of a good dirt road that leads from U. S. Highway 85 approximately 19 miles north of the

town of Truth or Consequences. From this point, the road proceeds eastward for about seven miles to the U. S. Geological Survey cable car which spans the Rio Grande at a locality known as the "Narrows". The crossing of the river is achieved by means of this cable car and the remaining three miles to the front of the range is covered by foot.

Previous Work

Probably because of the inaccessibility of the area, rather than lack of interest, little detailed geologic mapping has been done. However, from cursory observations, frequent references have been made in the literature to the structure and stratigraphy of the Fra Cristobal Mountains.

The "Fray Cristobals Mountains" were first mentioned in the <u>Spanish Archives of New Mexico</u> in 1685 (Twitchell, 1914, p. 1). The subject of this entry was a mining claim filed by Pedro de Abalos before the "governor and captain-general" of the territory. In 1859, G. G. Shumard (p. 345) recorded the first important description of the geology in the area. His efforts were directed toward describing the general features of the Jornada del Muerto and the adjoining mountains. Herrick (1899, p. 287) briefly mentioned the Fra Cristobal Mountains regarding its effect on diverting

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the course of the Rio Grande to the west. In a series of papers from 1903 to 1905 Keyes frequently cited the Fra Cristobals in his discussion of the geology of the region. In one article (1905, p. 165), he noted that the Caballo-San Cristobal Mountains are essentially a part of a single uplift. Lindgren and Graton (1906, p. 75-76), in describing the physiographic provinces of New Mexico, noted the lithology of the Precambrian rocks comprising the cores of the mountains in the immediate area. Lee (1907, p. 6) was probably the next to describe the geology of the region. In this paper, he noted that the Caballo-Fra Cristobal Range consists of granite and overlying sediments dipping eastward beneath the Jornada del Muerto. In 1909 Lee and Girty (p. 25) measured a stratigraphic section in the area at Saddle Peak. Their observations also led them to conclude that the northern part of the Fra Cristobal Mountains consists of limestone units belonging to the Magdalena group. Accompanying this report by Lee and Girty was a cross section showing the structural conditions at the north end of the range. Ten years after his last publication on the area, Keyes (1915, p. 261) proposed the name "Cristobal limestone" for the main body of late Ordovician limestone section found in the Fra Cristobal, Franklin, and Mimbres Ranges.

Darton (1928, p. 325) postulated that the Fra Cristobal Range is a detached northerly continuation of the Sierra

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Caballo and consisted mostly of the same type of rocks.

The most comprehensive report on the region is by Harley (1934, p. 194-196). It is a summary compiled from previous reports and personal observation. In reviewing the general geology, Harley described the Fra Cristobal Mountains and Sierra Caballo as the remains of two elongated domes, in which the western limbs of these domes were faulted down. Bryan's treatise (1938) on the Rio Grande depression briefly discussed the Hot Springs fault named by Kelley and Silver (1952, p. 195) as continuing northward along the western edge of the Fra Cristobal Mountains.

In their studies of the Caballo Mountains, Kelley and Silver (1952) extended the investigation of pre-Mississippian stratigraphy northward to the Fra Cristobal area. Several stratigraphic sections were measured to determine the northward change in lithology and thickness of the lower Paleozoic formations.

The first detailed mapping and study of the range was done by Sam Thompson (1955). This report concerns the southern part of the range and contains a detailed analysis of the fold and fault systems.

Present Investigation

The present investigation is concerned primarily with the stratigraphy and structural features found along

the western central front of the range--an area which magnified and grew in complexity as the investigation progressed. The original project was to complete a series of studies on the Fra Cristobal Mountains initiated by Sam Thompson (1955) and H. P. Bushnell (1952). Because of the imposed time limitation and inaccessibility of the area, the project was reduced to a more detailed investigation of the above area.

The field mapping program began in the fall of 1955 and continued through the winter months of 1956. Data collected in the field were annotated on an aerial photograph enlarged from a scale of 1:31,680 to approximately 1:7,900. The data were then transferred to a base map made from a U. S. Conservation Service planimetric map which was enlarged to a scale of 1:7,900.

A Brunton compass and a tape were used in measuring the stratigraphic section.

Acknowledgments

The writer is deeply indebted to Dr. V. C. Kelley at whose suggestion this study was undertaken, for his patience, guidance, and supervision of this project. A special note of appreciation is extended to the Geological Society of New Mexico for its financial contribution to the project which helped immeasurably to alleviate

the financial burden. To J. N. Pitch of the U. S. Geological Survey the writer would like to express his sincerest thanks for permission to use the cable car, which made access to the area possible. The writer is also indebted to D. L. Gaskill and E. R. Swift for their companionship and assistance in the field.

STRATIGRAPHY

General Statement

The rocks within the mapped area consist of consolidated and unconsolidated sediment and a few lava flows. The consolidated rocks range in age from Precambrian to Permian; however, several geologic systems not represented are Silurian, Devonian, and Mississippian. The sedimentary sequence extending from Cambrian to Ordovician consists of quartzitic sandstone and limestone units. Pennsylvanian and Permian rocks comprise the greater part of the sedimentary sequence and consist principally of limestone, with some shale and sandstone. The strata representing Cambrian, Ordovician, and Pennsylvanian systems have a combined thickness of 1438 feet, of which 1240 feet are Pennsylvanian. The Precambrian rocks represented in the area are principally granite gneiss. Quaternary deposits include basalt flows, pediment gravel, alluvium, and landslide material.

In the following stratigraphic description and discussion, standard terminology is employed wherever possible. For beddedness the following terms are used:

Laminated	--	less than one inch thick
Thin-bedded	--	one inch to one foot thick
Medium-bedded	--	one to three feet thick
Thick-bedded	--	three to six feet thick
Massive	--	six feet or more thick

Precambrian Rocks

Uplift in the Fra Cristobal Mountains has exposed Precambrian rocks along the base and upper slopes of the western escarpment. These outcrops form a continuous belt extending from about latitude 34° 18' north to the northern end of the range. Several small bands of Precambrian rocks occur within the faulted terrain of the lower Paleozoic rocks, just east of the large Precambrian belt (Fig. 2). A large mass is also exposed in Amphitheatre Canyon. Throughout the mapped area the Precambrian is overlain unconformably by the Bliss formation, but in the northern part of the range the Bliss erosionally thins out and strata of Pennsylvanian age overlie the Precambrian.

The Precambrian rocks have no established formation name or eonic classification. However, to the south in the Caballo Mountains the metamorphic rocks have been considered tentatively to be Archeozoic, whereas the granites are thought to be late Archeozoic or early Pro-

terozoic (Kelley and Silver, 1952, p. 33). Since the Precambrian rocks in the Fra Cristobal Mountains are very similar, the age may be the same.

Within the mapped area the dominant rock is a pink coarse-grained granite gneiss which weathers to a reddish brown. The gneissic structure is not prominently developed. Large feldspar crystals are scattered throughout the rock and weathering causes these crystals to stand out in relief. The mineral assemblage which is visible megascopically includes orthoclase, quartz, and small amounts of magnetite. In many places the Precambrian rocks are intruded by small dikes which consist principally of quartz and mica.

Cambrian and Ordovician Rocks

Bliss formation

The Bliss formation represents the only unit of Cambrian time in the mapped area. From paleontological evidence found in south-central New Mexico the lower beds are of middle Upper Cambrian age while the upper part is equivalent to Lower Ordovician (Flower, 1955, p. 65). Generally, this unit is known as the Bliss sandstone, noted by Jenney (1874, p. 25-26) and later named by Richardson (1904, p. 7) for a type locality at the southern end of Franklin Mountains. The name "Bliss formation" was proposed and adopted by Kelley and Silver (1952, p. 33-34)

in their report on the Caballo Mountains. Because of the diverse lithology of the unit, the above writers believed a better understanding would be achieved of the stratigraphic and paleontologic significance of the unit by the use of the term "formation". The writer will thus refer to the unit as the "Bliss formation" for the above reason.

Regionally, the Bliss formation is the most extensively distributed of the lower Paleozoic rocks in the southern part of New Mexico. From a zero thickness in the Fra Cristobal 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 (Kelley and Silver, 1952, p. 38).

Largely because of its high iron content which imparts a dark color, the Bliss formation contrasts rather conspicuously with the lighter Precambrian rocks and overlying buff-colored El Paso strata. Throughout most of the mapped area, the Bliss crops out as parallel ridges having a general northwest-southeast trend; elsewhere it rests as a "caprock" above slope-forming Precambrian rock. The contact with the underlying Precambrian rock is marked by a profound erosional unconformity, whereas the contact with the overlying El Paso group appears to be gradational, marked only by slight differences in the limestone units.

A 75-foot section of the Bliss was measured and found to consist in the lower part of the section of a series of thin-bedded sandstone. In the upper half of the section, limestone is present and alternates generally in sequence with sandstone and siltstone. The lower clastic units are made up chiefly of coarse-grained sandstone highly silicified, with an abundance of oölitic hematite and lesser amounts of glauconite. The principal rock in the upper part of the formation consists of thin-bedded limestone with intervals of fine-grained sandstone and siltstone. The upper unit of limestone merges into the base of the Sierrite limestone and is differentiated from the latter by its silt and glauconite content and by its apparent absence of chert.

A cursory examination of the formation failed to uncover any fossils. However, the following fossils were listed from the Bliss formation of the Caballo Mountains by Kelley and Silver (1952, p. 36):

Dendrograptus sp.
Lingulella acutangula?
Obolus sinoe
Orusia? *desmopleura*
Westonia stoneana

El Paso group

Overlying the Bliss formation with apparent conformity are strata of the early Ordovician El Paso group. Prior

to its assignment to a group status, the unit was known as the "El Paso limestone", named by Richardson (1904, p. 29) for a type locality at the southern end of the Franklin Mountains north of El Paso, Texas. In assigning group status to the "El Paso limestone", Kelley and Silver (1952, p. 42) divided the unit into two formations: the Sierrite limestone and the overlying Bat Cave formation. The two formations are easily recognizable in the mapped area, but because of cartographic limitations, they are mapped as a single unit.

Sierrite limestone

This lower formation of the El Paso group was named by Kelley and Silver (1952, p. 42) for exposures at Cable Canyon in the Caballo Mountains.

In the Fra Cristobal Mountains, the Sierrite limestone exposures are confined wholly within the mapped area (Fig. 2). The formation expresses itself topographically as steep banded cliffs above the less precipitous slopes of the underlying Bliss formation. The banded appearance of the limestone is a widespread feature that helps in delineating the unit from the confining formations, expecially in zones of overturning where the cliff-forming topography is not expressed.

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Sierrite limestone

This lower formation of the El Paso group was named by Kelley and Silver (1952, p. 43) for exposures at Scenic Canyon in the Caballo Mountains.

In the Fra. Cristobal Mountains, the Sierrite limestone exposures are confined wholly within the mapped area (Fig. [illegible]). The formation expresses itself topographically as gray, banded cliffs above the less precipitous slopes of the underlying Bliss formation. The banded appearance of the limestone is a widespread feature that helps in delineating the unit from the confining formations, especially in zones of overturning where the cliff-forming property is not expressed.

Except for the numerous chert laminations, the formation is mostly made up of thin-bedded limestone with local shale partings. The laminations consist of alternating layers of thin bands of chert and thicker bands of limestone, giving the unit the characteristic banded appearance. On fresh surfaces the limestone is medium to dark gray, but on weathered surfaces it is buff. In the lower part of the section, the limestone is commonly medium-grained and interlocking crystalline in texture, whereas the upper limestone units have a granular texture and are argillaceous.

Bat Cave formation

The upper member of the El Paso group is represented by the Bat Cave formation. The name is derived from a landscape feature located a few hundred yards northwest of the type locality in Cable Canyon (Kelley and Silver, 1952, p. 45). The formation appears to overlie the Sierrite limestone with no apparent unconformity.

Like the Sierrite limestone outcrops, the Bat Cave formation exposures are limited to areas within the project boundaries. It crops out along the ridges and lower slopes at the base of the western escarpment.

The bulk of the formation consists of a series of conglomeratic sandstone beds ranging in color from brick-

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red to light gray. The basal part of the formation is made up of medium-bedded, highly silicified limestone, which on fresh exposure is pinkish white and outwardly closely resembles the upper part of the Sierrite limestone. Two diagnostic features of the formation found in the Caballo Mountains---collapse-breccia and bioherms are conspicuously absent.

A cursory examination of the formation uncovered only fragmentary cephalopods. However, Kelley and Silver (1952, p. 50) reported in the Caballo Mountains the presence of stromatolitic bioherms, gastropods, trilobites, cephalopods, and bryozans.

Pennsylvanian Rocks

The thickest and most conspicuous sedimentary unit is the Pennsylvanian Magdalena group. The name "Magdalena group" was proposed by C. H. Gordon in 1907 for a type locality found in the Magdalena Mountains of New Mexico. In central New Mexico, the group includes the Sandia formation and the overlying Madera limestone. The Magdalena group in the Caballo Mountains has been divided by Kelley and Silver (1952, p. 96) in ascending order into the Red House, Nakaye, and Bar B formations.

The Magdalena group crops out along the entire northern part of the range, forming nearly the entire escarpment

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and crest. It rests with a marked erosional unconformity on rocks ranging in age from Precambrian to Ordovician.

In a section which measures 1240 feet in thickness, the Magdalena group was found to consist principally of limestone differing only in bedding thickness, color, and fossil content. The lower part of the group, which is slope-forming, consists largely of thin- to medium-bedded limestone with cherty units. Colors range on fresh exposure from light gray to dark gray. The middle and upper beds form ledges, which alternate with slopes and are composed of medium- to massive-bedded limestone and dark shale. Many of the massive units contain nodules and bands of chert and are intricately veined with calcite. The middle and upper units, on fresh exposure, exhibit colors ranging from medium gray to dark gray while the weathered surfaces are brown to gray.

Most of the limestone units measured were abundantly fossiliferous, but a few basal units appear to be barren. The greatest number of forms noted were fusulinids, corals, crinoids, and brachiopods. A large unidentified nautiloid was discovered in one of the upper limestone units (Pl. 1).

Permian Rocks

Abo formation

This formation is confined to one small exposure on Engle Crest. Only the lower unit is present and overlies the Magdalena group with apparent conformity. The formation is easily distinguishable by its red-brown color from the light-colored limestone of the Magdalena group.

The base of the formation consists chiefly of reddish brown siltstone, clay, and a few thin-bedded argillaceous sandstone beds. No section was measured, but immediately to the south of the mapped area the formation attains a thickness of 450 feet (Thompson, 1955, p. 19).

The Abo formation is considered to be continental floodplain deposit with no marine fossils (Kelley and Silver, 1952, p. 101). Although no fossils were observed in this small exposure, Thompson (1955, p. 20) reported the discovery of reptile tracks in an exposure just three miles southeast of this locality.

San Andres formation

Along the western side of the Hot Springs fault in the Rio Grande trough, a limestone crops out which is probably part of the San Andres formation. Lithologically it resembles none of the limestone of the Magdalena group

Ute formation

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and appears to be unfossiliferous. The tentative correlation is thus based on lithologic similarity to units of the San Andres formation in the southern part of the Fra Cristobal Mountains.

This formation is composed of a dense, medium- to coarse-grained limestone which is locally argillaceous. On fresh exposure the rock is light gray and locally stained by hematite and limonite and contains numerous veins of calcite. The weathered surfaces are medium gray. In most places, the bedding is obscured by local deformation and the few distinguishable beds are medium- to thick-bedded.

Quaternary Rocks

Sediment of Quaternary age, consisting of pediment gravel and alluvial-fan material has been designated for mapping purposes as Quaternary alluvium.

The alluvial-fan material constitutes the bulk of the Quaternary deposits and occurs principally along the base of the range as large coalescing fans built upon pediment gravel. The pediment gravel is largely concealed in the mapped area by alluvial-fan debris and only small exposures are present along the deeper arroyos.

Very little landslide material is found in the area, considering the steepness of the escarpment; however, locally small talus piles of limestone are present at

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the base of the escarpment. Most of the landslide material occurs in the Precambrian rocks in the northern part of the area. Terrace gravel is found along some of the streams and is composed of material derived from the adjoining uplands.

Igneous Rocks

The Quaternary igneous rocks are all basaltic, consisting of several flows and a dike. The basalt flows are located in the southwest part of the mapped area and are presumably of Pleistocene age (Kelley and Silver, 1952, p. 129). The easternmost flow rests on overturned Cambrian, Ordovician, and Pennsylvanian beds and contains a great deal of crudely stratified tuff and breccia. Dissection of this flow has revealed what appears to be a small volcanic vent. This is thought to be the source for the flows found on the upthrown side of the Hot Springs fault.

The only other igneous rock of Quaternary or possibly Tertiary age is a small basaltic dike which parallels fault A-5 (Fig. 2). It is nearly vertical and about two feet wide and appears to occupy the brecciated zone of the above fault.

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STRUCTURE

Regional Setting

The dominant structure of the Rio Grande depression of central New Mexico is expressed as a series of north-trending grabens arranged in echelon and flanked by areas of relative uplift. Most of the uplifts are bounded by late Tertiary faults, which parallel the general trend of the grabens. Movements of these faults appear to have occurred chiefly in a horizontal direction with only incidental vertical displacement (Kelley, 1952, p. 66). Kelley (op. cit.) also stated that the grabens were formed by compressional stresses acting as a couple on a deep-seated shear zone. This interpretation also accounts for the echelon arrangement of the grabens.

The main part of the Fra Cristobal Range is a fault block or horst of eastward-dipping beds lying on Precambrian rocks which are exposed on the western side. On the west, the range is bounded by the Engle valley trough, and on the east, by the Jornada del Muerto trough. Each of the troughs is separated from the Fra Cristobal uplift by north-trending faults, which intersect to the north near the San Pascual platform. At its southern end, the uplift is separated from the Caballo Mountains by a lowland area known structurally as the Cutter sag. Along the western

STRUCTURE

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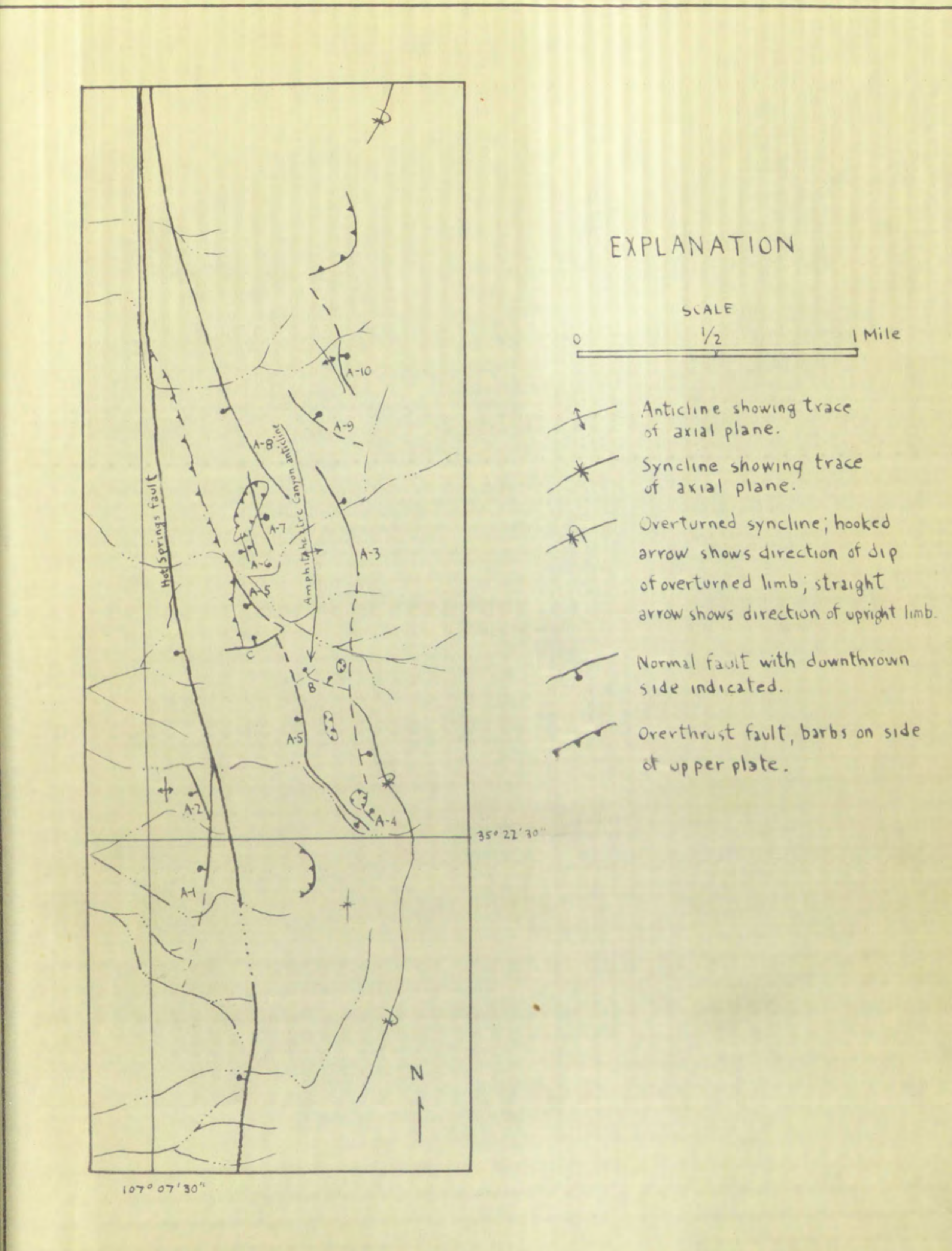

Figure 4. Tectonic map of the central front of the Fra Cristobal Mountains.

escarpment where the Precambrian rocks are exposed, a zone of intense deformation is reflected in the lower Paleozoic and Pennsylvanian strata.

Folds

The main structural feature of the mapped area may be best described as an overturned syncline passing northward into a relatively simple upwarp. It thus becomes apparent that the area was subjected to deforming forces of considerable intensity. Field evidence indicates with a considerable degree of certainty that the entire Magdalena group is involved, as well as the Abo formation. From the above field relations, it appears that the folds developed after the deposition of the Abo. A more rigorous age assignment necessitates the process of dating by analogy with similar folds found in the Caballo Mountains that were probably developed during Laramide time.

Perhaps some of the most striking features in the area are the zones of overturned strata. The principal zone of overturning is a part of the unfaulted limb of an anticline, and the other is the west limb of a syncline (Fig. 3, B-B'). The latter is exposed along the eastern edge of the Precambrian massif about 1/2 mile east of the Hot Springs fault (Fig. 2). This zone of overturning extends from the entrance of Amphitheatre Canyon southward

for about three miles where it passes into a non-overturned fold that terminates at the Hot Springs fault. Generally, the overturned limb dips 27°-86° west. Owing to the warping within the limb, small flexures are developed and express themselves as small recumbent synclines and anticlines (Pl. 2).

Another zone of overturning is prominently exposed in the south-central part of the mapped area. From all appearances, this zone represents the unfaulted east limb of an overturned anticline and west limb of an overturned syncline (Fig. 3, B-B'). This exposure is about 1/2 mile long and strikes about N. 13°W. The exposed limb consists of Cambrian, Ordovician, and Pennsylvanian strata that generally dip 79°-86° west. Erosion and subsequent faulting of this flexure has exposed a patch of Precambrian rocks.

One of the principal structural features is the large overturned syncline found in the south-central part of the mapped area (Fig. 2). The trace of the axial plane trends generally northward along the base of the Magdalena escarpment. At its northern end the axial trace appears to swing to the northwest as the structural element of this fold passes into an anticline. The lower limb of the overturned syncline dips 25°-55° east while the overturned syncline limb dips 13°-85° west.

In the extreme northeastern part of the mapped area, the Bliss formation and the overlying Magdalena group begin to overturn to the west along a strike approximating N. 11° E. This overturning develops northward into an excellently exposed overturned syncline along the crest of the range.

The largest non-overturned fold in the area is the Amphitheatre Canyon anticline. This flexure is an open, asymmetrical, south-plunging anticline whose axial plane is nearly vertical. The trend of this structure is generally southward, but along the northern end the axis curves slightly to the northwest. The length of this fold is slightly more than one mile with a maximum width of probably not more than 1/4 mile. Dips in the vicinity of the axis range from 14° to 17° on the eastern limb and from 15° to 19° on the western limb. The fold is preserved in Cambrian and Ordovician strata, but most of the strata have been removed and the ensuing erosion has cut deeply into the underlying Precambrian rocks along a deep canyon. At its western and eastern edges the structure is in part bounded by faults (Fig. 2). Numerous high-angle faults are also present along the western flank, but the most conspicuous feature is the klippe of Precambrian rocks that overlie Cambrian-Ordovician strata (Fig. 3, A-A').

In the [illegible] the Sitka [illegible] begin to [illegible] ing E. 12°E. [illegible] an essentially [illegible] of the range.

The [illegible] Amphitheatre [illegible] asymmetric [illegible] is nearly vertical [illegible] gently northward [illegible] slightly to [illegible] slightly southward [illegible] ably not more [illegible] axis range from [illegible] 15° to 20° on the [illegible] in Canterbury [illegible] have been recognized [illegible] into the southwest [illegible] At its western [illegible] bounded by [illegible] are also [illegible] conspicuous [illegible] then overall [illegible]

To the northeast and on the north side of Amphitheatre Canyon, the eastern limb of the above anticline is bounded by a high-angle fault, which separates it from a small chevron-like flexure striking about N. 39° W. (Fig. 2). The eastern flank of this small anticline is displaced downward by a fault that trends almost along the apex. Erosion and subsequent faulting have exposed a small patch of Precambrian rock along the axis. One of the most unusual features of this asymmetrical fold is the presence of Magdalena and Bliss on the eastern flank, and Sierrite and Bliss on the western limb. This, of course, is attributable to the pinching out of the Ordovician rocks in the immediate vicinity of the structure.

Immediately west of the Hot Springs fault lies a small, asymmetrical anticline developed in the San Andres limestone (Fig. 2). This flexure trends northward and has an approximate length of less than 1/8 of a mile.

In the easternmost basalt flow a small synclinal structure was mapped. It is developed in the stratified volcanic eruptives and oriented north-south. The fold is less than 1/8 mile long and bounded on the west by what appears to be a volcanic vent (Pl. 5).

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structure [illegible]
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adjacent [illegible]

Faults

The fault pattern is relatively simple with most of the trends northward or northwestward. With the exception of some of the thrusts, all of the faults are high angle and most of the displacement occurs predominantly in a dip-slip direction. Stratigraphic throws, with the exception of the Hot Springs fault, are estimated to be less than 300 feet.

In the following description, an attempt is made to group faults into related sets such as A-1, A-2,..; B, and C (Fig. 4).

Hot Springs and related faults

The Hot Springs fault was named by Kelley and Silver (1952, p. 159) and forms one of the longest uninterrupted late Tertiary faults in the region. It extends generally northward from about latitude 33° 05' in the Caballo Mountains to latitude 33° 30' in the Fra Cristobal Mountains.

In the mapped area, this fault trends almost due north and forms the physiographic boundary between the Fra Cristobal Mountains on the east, and the Engle Valley trough to the west (Fig. 2). Along its outcrop length in the mapped area the Quaternary sediment on the west side is downthrown against Precambrian rock on the east side. Locally, outcrops of San Andres limestone also occupy the west side.

The fault plane dips 60°-67° west and is excellently marked by a thick zone of silicified breccia which forms a low wall-like scarp.

West of the Hot Springs fault in the outcrop of San Andres limestone, two faults of diverging trends were recognized (Fig. 4). The larger of these two faults, designated as A-1, strikes N. 11° E. and is about 1/2 mile long, but may extend farther south beneath the cover of Quaternary sediment. The apparent downthrown side is on the west; however, owing to the lack of horizon markers, the downthrown side is inferred from topographic expression and alignment of the displaced blocks. In its northeasterly trace, this fault intersects with fault A-2 and branches into the Hot Springs fault. Fault A-2 in the same area trends northwestward from its intersection with fault A-1 and is about 1/4 mile long, but may proceed, like fault A-1, beneath the Quaternary mantle for some undetermined distance. Relative movement and approximate trend of faults A-1 and A-2 suggests a close genetic relationship with the Hot Springs fault.

Fault A-3, which strikes almost due north along its entire trace, is located at the base of the Magdalena escarpment (Fig. 4). Only at the northern end is the stratigraphic throw measurable with any degree of certainty. In this locality, the throw is about 75 feet, with the

downthrown Ordovician beds abutting against the Bliss formation on the east. Southward, Magdalena beds on the east side of the fault are apparently downthrown against Ordovician rocks on the west side. Still farther south the fault trace appears to pass into the upturned units of the Magdalena limestone and almost defies detection except for the alignment represented by the topographic saddles. At its southern terminus, fault A-3 intersects a small transverse fracture A-4 which has upthrown, with fault A-5, a block of Precambrian rock between Magdalena beds. This relationship is not clearly understood. However, this block of Precambrian rock may somehow be attributed to a topographic high rather than an uplifted block. These two faults are not sharply defined by fault planes, but are inferred from the above stratigraphic relationship. Thus, the above suggestion is only a possibility.

Fault A-5, which is about 1 1/4 miles long, trends along its lower outcrop length in a northwesterly direction, and then assumes a more northerly direction and intersects fault C where it is offset laterally. The downthrown side is to the west with Pennsylvanian strata abutting against Precambrian. To the north Ordovician rocks occupy the downthrown side and abut the Precambrian rocks on the east (Fig. 2). Dips range from 35° to 50° west with progressive steepening from south to north. Accompanying the fault

trace is a zone of brecciation in which angular fragments of widely different sizes have been recemented by silica and iron oxide (Pl. 3).

On the western limb of the Amphitheatre Canyon anticline two small northwest-trending longitudinal faults were recognized. Both of these faults, designated as A-6, are short step-faults with the apparent downthrown side on the west.

The next fault, A-7, is another northwestward-trending fault with the downthrown side on the east. The dip of the fault plane is 68° east. Paralleling fault A-7 is fault A-8 which is about two miles long and to the northwest intersects the Hot Springs fault. As with fault A-7 the stratigraphic throw is small, but the downthrown side is on the west with the fault plane dipping 85° west. Thus, a small graben is formed between the two faults.

Two small northwestward-trending high-angle faults occur northeast of fault A-8. Fault A-9, which strikes about N. 48°W., has downthrown the Sierrite limestone on the northeast against the Bliss formation. Fault A-10, which is about 1/2 mile long, strikes generally N. 15°W. The downthrown side is on the northeast with an estimated stratigraphic throw of 50 feet.

Thrust faults

Although overthrusting may have been extensive in the area, only remnants of the thrust sheet are preserved as klippes. The largest of these klippes is found on the western limb of the Amphitheatre Canyon anticline with Precambrian rocks overlying beds of Cambrian-Ordovician age in a nearly flat contact (Fig. 3, A-A'). The dip of the fault plane averages 17° west, whereas the underlying beds have, in general, an inclination of 15° west.

In the east-central part of the mapped area near fault A-3 (Fig. 4), a small klippe was recognized. The bedrock relationship here suggests that the fault, according to Billings' classification (1942, p. 175), is a stretch thrust of shallow dip.

The other klippes occur in the south-central part of the area. Like the klippes to the north, the overriding block is composed of rock older than that beneath the thrust, but the contact of the thrust plates is sharply at variance with the attitude of the underlying strata.

In the vicinity of Amphitheatre Canyon a thrust fault is mapped which is related to the overturning of the Bliss formation. Two other thrust plates were mapped in the area. Both are of small magnitude, with tongues of Precambrian rock overriding younger sedimentary rocks of Cambrian and Ordovician age.

Thrust Faults

Although [illegible] Early [illegible] the area, [illegible] as slippage. [illegible] through the western [illegible] Precambrian [illegible] age in [illegible] (Fig. [illegible]). [illegible] the fault plane [illegible] been [illegible]

In the [illegible] fault A-3 (Plate 1) [illegible] bedrock [illegible] ing to [illegible] thrust of [illegible]

The [illegible] the area. [illegible] block is [illegible] but the [illegible] with the [illegible]

In the [illegible] is mapped [illegible] formation. [illegible] area. [illegible] Cambrian and [illegible]

Other structures

Several short, transverse high-angle faults, designated as B and C, occur in about the central part of the mapped area. Fault C which laterally offsets fault A-5, is downthrown to the north, and drag features also indicate horizontal shifting of the downthrown block to the east. Fault B, which consists of two short intersecting faults, is principally inferred from the contrasting dips of adjoining strata along breccia zones.

Structural Development

The structural features of the rocks in the mapped area are the result of three periods of orogeny. These periods of orogenic activity occurred during Precambrian, late Cretaceous, and early or middle Tertiary times.

Although there is some possibility of deciphering the Precambrian deformation more clearly through a regional study, little can be said about it from the local confines of this project. However, field evidence in the mapped area suggests that this period of deformation was complete long before the deposition of the Cambrian beds.

During the Paleozoic era, the area locally appears to have been tectonically stable except for some regional warping to the south (Kelley and Silver, 1952, p. 132).

Other structures

Several [illegible] as B and C, [illegible] area. [illegible] thrown to the [illegible] ceded [illegible] B, which [illegible] principally [illegible] ing strata [illegible]

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No direct information is available as to the deformational events that occurred during Mesozoic time, since stratigraphic units of that era are absent. However, from observations made by Kelley and Silver (1952, p. 135), the region appears to have been stable with only accelerated crustal subsidence occurring during late Cretaceous. Thus, it appears that little or no orogenic activity affected the area from Precambrian time until Laramide time.

Orogenic deformation, occurring during Laramide epoch, appears to have left its impress. However, it must be pointed out that the structures are dated on the basis of similarity with structures found in the Caballo Mountains where a more rigorous dating is possible. It thus seems reasonable to assume that some of the structures in the mapped area are of Laramide inception. Two phases of deformation occurring in the Cenozoic era are recognized, Laramide and middle or late Tertiary.

The obvious north-northwesterly trends and opposed asymmetry of the folds suggest that the orogenic forces, initiated during Laramide time, were the result of a northeast and southwest compression or a combination of compression and coupling. As the northeast force increased, crustal shortening in that direction commenced, which resulted in overfolding and thrusting. Because the intensity of force differed along the horizontal as well as vertical

direction, the area was subjected to differential stresses, which produced a complex system of folds.

The most intense zone of deformation, or where maximum crustal shortening appears to have occurred, is in the vicinity of the Amphitheatre Canyon anticline. Here the area responded to compressional forces by overfolding along the western flank of the anticline with subsequent rupturing and overthrusting. Southward the intensity of compression becomes less pronounced where crustal shortening occurs principally by folding.

Only two small faults, other than the thrusts, appear to have developed during this stage of deformation. These two faults, designated as B, are assumed to be tear faults developed between zones of contrasting deformation.

Following the Laramide orogeny the next deformational event in the area occurred during middle or late Tertiary. This period of orogenic activity was characterized by high-angle faulting and mild local folding. All the faults belonging to set A appear to have developed at this time. Or at least they suggest a later date of tectonism than the overfolds and thrusts.

The dominant north-northwest trend of faults A-1 to A-10 indicates that some control existed during deformation. If broad regional warping preceded faulting, differential vertical movement acting under compression must have been

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Only two small faults, other than the thrusts, appear to have developed during this stage of deformation. These two faults, designated as S, are assumed to be tear faults developed between zones of contrasting deformation.

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The dominant north-northwest trend of faults A-1 to A-10 indicates that some control existed during deformation. If broad regional warping preceded faulting, differential vertical movement acting under compression must have been

the principal force in controlling the trends. However, predetermined zones of weakness incurred during the Laramide orogeny is another possible control. In any event, the forces constituting the compression appear to have been directed in a northeast-southwest direction.

It is rather difficult to discern the amount of folding that developed at this time. However, the element of symmetry in the open fold of the Amphitheatre Canyon anticline suggests that this structure is more closely related to Tertiary orogeny than to Laramide.

Later deformation in the area is marked by fissure eruptions of lava.

GEOLOGIC HISTORY

Following the Precambrian orogeny, a long period of erosion reduced the surface of the Precambrian massif to a peneplane. This surface was then depressed beneath Cambrian seas in a broad regional downwarp to the south, and deposits of arenaceous clastic material accumulated. Further subsidence or possibly small eustatic changes of sea level initiated the deposition of limestone which continued without notable pause into Ordovician time. Under increasing conditions of instability attributed to a greater rate of subsidence or an increase of orogenic activity in the source area, the coarse sediment of the Bat Cave

formation was deposited.

Much of the history of the time from Ordovician to Pennsylvanian is lost to view. If deposition occurred during this time interval, the evidence was removed by subsequent erosion which also thinned out the Cambrian and Ordovician formations.

Following this period of erosion the area was submerged by Pennsylvanian seas. Crustal subsidence must have been great, since over 1200 feet of sediments accumulated. It appears that stable shelf conditions existed during the early phases of sedimentation, since the limestone beds are of the normal marine type. Later phases of sedimentation indicate increasing instability of the shelf with limestone of the dense nodular variety predominating.

The next episode in the geologic history was the emergence of the area above the marine environment into one that was characteristically continental as indicated by the Abo formation. A return to a marine environment followed as limestone of the San Andres formation was deposited.

Owing to another void in the stratigraphic record, little can be said of the stratigraphic units following the deposition of the San Andres formation. If deposition occurred in the area, erosion removed all evidence.

During the closing stages of the Mesozoic era the area was subjected to orogenic activity which produced

Formation was deposited.

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overturned folds and thrusts. After a short period of tectonic quiescence, the area again was marked in early or middle Tertiary by crustal unrest. This period produced the emergence of the Fra Cristobal block and was presumably accompanied by the deposition of the Santa Fe beds in the Rio Grande depression.

In early Quaternary time, lava was erupted and poured over some of the older pediment surfaces which began to form after the uplift of the Fra Cristobal block.

Present-day activity appears to be confined to erosion of the Cenozoic structures and filling of the Rio Grande trough.

MINERAL DEPOSITS

No economic mineral deposits are being worked in the mapped area, nor has any mining gone on in the past. However, a small mine is found about two miles north of the mapped area. Thompson (1955, p. 13) stated that a geologic survey was made of the region, but nothing of commercial value was discovered.

Small, low-grade iron deposits occur throughout the mapped area. The deposits are beds of oölitic hematite which occur in the basal units of the Bliss formation. The hematitic beds are about 2-8 feet thick.

overturned fold in the [illegible]
tectonic quiescence, [illegible]
or middle Tertiary [illegible]
duced the [illegible]
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A small fissure vein of fluorspar was found immediately adjoining the Hot Springs fault in the vicinity of the San Andres outcrop. The exposed vein is about 4 feet wide and about 25 feet long.

DESCRIPTIVE STRATIGRAPHIC SECTIONS

Amphitheatre Canyon Section I

No.	Description	Thickness (Feet) Unit	Cumulative
	(Abo formation above)		
	Top of Magdalena group:		
68.	LIMESTONE: massive; very fine grained; light to medium gray, weathers brown; calcite veins; chert nodules.	12	1240
67.	LIMESTONE: massive; medium gray; calcite veins.	15	1228
66.	LIMESTONE: medium- to thick-bedded; stringers	131	1213
65.	LIMESTONE: medium- to thick-bedded; fine grained; medium gray	10	1082
64.	LIMESTONE: thin-bedded; gray; very fine grained; blocky.	15	1072
63.	LIMESTONE: massive; medium gray; fine grained; nodular chert.	30	1057
62.	LIMESTONE: medium- to thick-bedded; very fine grained; medium gray; fossiliferous.	23	1027
61.	COVERED	12.5	1004
60.	LIMESTONE: medium-bedded; gray-black; cherty.	4.5	991.5
59.	COVERED	6	987
58.	LIMESTONE: massive; dark gray; very fine grained; chert bands	20	981
57.	LIMESTONE: medium-bedded; light gray; fine grained.	29	961
56.	COVERED	12	932
55.	LIMESTONE: like 16.	1	920
54.	COVERED	6	919
53.	LIMESTONE: medium-bedded; gray black; very fine grained	1.5	913
52.	SHALE: gray.	5.5	911.5
51.	LIMESTONE: thick-bedded; light gray; very fine grained; calcite veins; very cherty in middle.	17	906
50.	COVERED	6	889
49.	LIMESTONE: like 10	20	883
48.	LIMESTONE: medium-bedded; fine grained; gray-black; lower part shaly; chert banding	6	863
47.	LIMESTONE: medium-bedded; fine grained; medium gray; fossiliferous.	19	857
46.	COVERED	1	838

No.	Description	Thickness (Feet) Unit	Cumulative
45.	LIMESTONE: like 17	15	837
44.	COVERED	5.5	822
43.	LIMESTONE: thick-bedded; medium grained; sandy; fossiliferous	3	816.5
42.	LIMESTONE: thin-bedded; black; very fine grained; locally shaly; nodular surface; even-bedded.	25.5	813.5
41.	SHALE: black.	.5	788
40.	COVERED	23	787.5
39.	LIMESTONE: thick- to thin-bedded; gray-black; fine grained; local shale partings at bottom.	4	764.5
38.	SHALE: laminated; black	2	760.5
37.	LIMESTONE: medium-bedded; light gray; fine grained; chert bands and lenses.	2.5	758.5
36.	LIMESTONE: medium-bedded gray; very fine grained.	23	756
35.	COVERED	5.5	733
34.	LIMESTONE: massive; grey; cherty. . .	30	727.5
33.	COVERED	65	647.5
32.	LIMESTONE: massive; very fine grained; fossiliferous with numerous brachiopods and corals	25	632.5
31.	COVERED	5.5	607.5
30.	LIMESTONE: thin- to medium-bedded; medium grained; gray; chert bands and calcite stringers; numerous corals	10	602
29.	COVERED	1	592
28.	LIMESTONE: medium-bedded; coarse grained; light gray	5.5	591
27.	LIMESTONE: thick-bedded; fine grained; light gray; numerous chert bands up to 6 inches thick	10	585.5
26.	LIMESTONE: thin-bedded; blackish gray fine grained.	25	575.5
25.	SHALE: very dark gray; limy	.5	550.5
24.	COVERED	19	550
23.	LIMESTONE: thin- to medium-bedded; light gray, weathers brown; sandy; calcite stringers	6	531
22.	COVERED	2	525
21.	LIMESTONE: medium-bedded; medium grained; light gray; abundant crinoids	5	523
20.	COVERED	17	518
19.	LIMESTONE: medium-bedded; medium grained; light gray; fossiliferous	11	501
18.	LIMESTONE: medium-bedded; light gray; fine grained; banded streaks of calcite	42	490

No.	Description	Thickness (Feet) Unit	Cumulative
17.	LIMESTONE: thin-bedded; medium grained; medium gray.	10	448
16.	LIMESTONE: medium-bedded; fine grained; medium gray; chert bands; calcite stringers	21	438
15.	LIMESTONE: thin-bedded; black; very fine grained; cherty; chalky appearance.	15	417
14.	SHALE: dark gray.	1	402
13.	COVERED	2	401
12.	LIMESTONE: medium-bedded; blue-gray; granular; fossiliferous	63	399
11.	LIMESTONE: medium- to thick-bedded; blue-gray; fossiliferous.	110	336
10.	LIMESTONE: thin-bedded; granular; medium gray; sandy, cherty.	14	226
9.	LIMESTONE: thick-bedded; blue-gray; granular; numerous fusulinids	12	212
8.	SHALE AND LIMESTONE: laminated; blackish gray; fossiliferous	5.5	200
7.	LIMESTONE: thin- to medium-bedded; light gray; calcite veins; cherty . . .	67.5	194.5
6.	LIMESTONE: laminated; dark gray; shaly.	.5	127
5.	LIMESTONE: medium-bedded; granular; light gray; calcite veins; cherty, fusulinids and brachiopods.	72.5	126.5
4.	COVERED	26	54
3.	CHERT: laminated; brown	2	28
2.	LIMESTONE: medium-bedded; blue-gray; granular.	16	26
1.	LIMESTONE: medium-bedded; blue-gray; granular; sandy	10	
	Total Magdalena group	1240	

Amphitheatre Canyon Section 11

No.	Description	Unit	Cumulative
	Top of Bat Cave formation:		
40.	DOLOMITE: thick-bedded; light to medium gray; crystalline; weathers brown . . .	14	276.5
39.	SANDSTONE: thick-bedded; green; medium to fine grained; micaceous.	21	262.5
38.	CONGLOMERATE: dense; granulitic; light gray.	3	241.5
37.	CONGLOMERATE: brick-red; granulitic to pebbly; arkosic	7	238.5

No.	Description	Thickness (Feet) Unit	Cumulative
36.	COVERED	12.5	231.5
35.	CONGLOMERATE: dense; red; pebbly; highly silicified.	3	219
34.	LIMESTONE: medium-bedded; pinkish white; micro-crystalline; siliceous.	17.5	216
	Total Bat Cave	78	
	Top of Sierrite limestone:		
33.	LIMESTONE: medium- to thick-bedded; buff; granular; lenticular chert; silty	38.5	148.5
32.	LIMESTONE: red-brown; thin shale partings; granular.	17.5	160
31.	LIMESTONE: like 33.	3	142.5
30.	LIMESTONE: thin-bedded, laminated; buff; medium grained; chert; hematite stains, becomes less ferruginous in middle part . .	64.5	139.5
	Total Sierrite	123.5	
	Top of Bliss formation:		
29.	LIMESTONE AND SILTSTONE: thin-bedded; alternating green siltstone and red-green crystalline limestone; glauconite	5	75
28.	COVERED	2	70
27.	SILTSTONE: thin-bedded; laminated; green; upper part fine-grained sandstone. .	3	68
26.	SANDSTONE: thin-bedded; glauconitic; intercalated limestone; ferruginous	5	65
25.	LIMESTONE: thin-bedded, laminated; green; glauconitic; sandy	2	60
24.	SANDSTONE: like 26.	5	58
23.	SILTSTONE: like 27.	6	53
22.	COVERED	2	47
21.	LIMESTONE: like 25.	1	45
20.	LIMESTONE: thin-bedded; laminated; concretionary; ferruginous; medium-grained crystals; brown-black; glauconitic.	6	44
19.	SANDSTONE: fine to coarse grained; brown-black; oölitic, highly ferruginous.	2	38
18.	SANDSTONE: medium gray; rounded hematite grains; cross-bedded, foreset dip northeasterly; locally conglomeratic	6	36
17.	LIMESTONE: like 20.	1	30
16.	SANDSTONE: like 19.	.5	29
15.	SANDSTONE: thin-bedded; fine to coarse grained; light pink; very dense; feldspathic	1	28.5
14.	SANDSTONE: thin-bedded; medium grained; granulitic and pebbly; buff; well cemented.	4	27.5

No.	Description	Thickness (Feet) Unit	Cumulative
13.	SANDSTONE: like 15	3.5	23.5
12.	SANDSTONE: like 14 plus clay galls	2	20
11.	SANDSTONE: thin- to medium-bedded; medium grained to granulitic; green, weathers red; irregular parting paralled to bedding	.5	18
10.	COVERED	2	17.5
9.	SANDSTONE: like 15.	1	15.5
8.	SANDSTONE: thin-bedded; medium grained; granulitic and pebbly; buff; well cemented.	1	14.5
7.	SANDSTONE: like 15.	3	13.5
6.	SANDSTONE: like 11.	3	10.5
5.	SANDSTONE: like 15.	.5	7.5
4.	MUDSTONE: thin-bedded; yellow-green; arenaceous.	1	7
3.	COVERED	2	6
2.	SANDSTONE: like 15.	1	4
1.	SANDSTONE: like 15.	3	
	Total Bliss.	75	

Top of Precambrian
GRANITE GNEISS: medium grained; pink; foliation N. 5°E.

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Plate 1. Large unidentified nautiloid found in the Magdalena group.

Plate 2. View south along the Magdalena escarpment.

Plate 1.

Plate 2.

Plate 3. Well-cemented breccia occurring along one of the Tertiary faults.

Plate 4. View northwest of klippe of Precambrian rocks overlying Cambrian and Ordovician beds.

Plate 5.

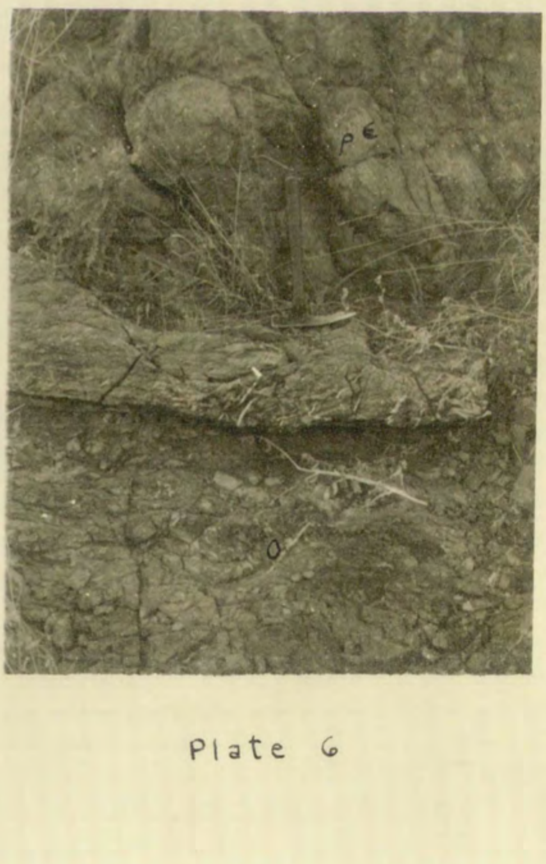

Plate 6

Plate 5. View east toward the central front of the Fra Cristobal Mountains.

Plate 6. Klippe of Precambrian rocks overlying Sierrite limestone at the western limb of Ampitheatre Canyon anticline.

Plate 3.

Plate 4.

Figures 2 and 3
in pocket