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Geology of the Southern Ladron Mountains, Socorro County, New Mexico

E.A. Noble

Noble — Geology of the Southern Ladron Mountains

GEOLOGY OF THE SOUTHERN LADRON MOUNTAINS SOCORRO COUNTY, NEW MEXICO

By

E. A. Noble

A Thesis

In partial fulfillment of the

Requirements for the Degree of

Master of Science in Geology

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ABSTRACT

The Ladron Mountains are a fault-block range consisting in large part of Pre-Cambrian rocks. They are flanked on the west by Paleozoic sediments and elsewhere by Tertiary and Quaternary deposits. The Pre-Cambrian rocks of the southern Ladron Mountains area consist of a thick sequence of quartzite and schist which has been granitized by a subjacent intrusion to such a degree that only remnants of unaltered quartzite and schist remain, the remainder of the rocks being largely paragneiss and para-granite. The nature of the intrusion is not known, but it is suggested that it may have been at least partly formed by palingenesis or anatexis during plutonic infolding of the metasediments.

The westward-dipping strata which form a prominent north-south hogback along the west side of the area are Mississippian and Pennsylvanian in age. The Mississippian rocks overlying the Pre-Cambrian rocks maintain a nearly uniform thickness of about 80 feet along most of the length of the area. Fossils found near the middle of the section apparently represent a Kinderhook fauna which more nearly corresponds to the fauna of the Escabrosa formation of Arizona than to any other fauna reported from New Mexico.

The Ladron Mountains, a [illegible] fault-block range, consist in large part of Pre-Cambrian rocks flanked on the west by Paleozoic sediments and [illegible] by Tertiary and Quaternary deposits. The Pre-Cambrian rocks of the southern Ladron Mountain area consist of a thick sequence of quartzite and schist which has been granitized by adjacent intrusion to such a degree that only remnants of unaltered quartzite and schist remain, the remainder of the rocks being largely migmatites and granite. The nature of the intrusion is not known, but it is suggested that it may have been at least partly formed by palingenesis or anatexis during which a fraction of the [illegible].

The westward-dipping [illegible] strata which form a prominent north-south hogback along the west [illegible] area are Mississippian and Pennsylvanian in age. The Mississippian rocks overlying the Pre-Cambrian rocks maintain a fairly uniform thickness of about [illegible] feet along [illegible] of the area. Fossils found near the middle of the section apparently represent a Mississippian fauna which more closely corresponds to the fauna of the Escabrosa limestone of Arizona than to any other [illegible] in New Mexico.

The Mississippian section in the Ladron Mountains is tentatively named the Caloso formation, for it cannot be correlated with any known New Mexico formation. Two brachiopods, *Dielasma chouteauensis* and *Spirifer* "*centronatus*", common in the Caloso formation, are not known to occur elsewhere in the State.

Deformation in the Ladron Mountains first occurred in Pre-Cambrian time. Following dynamic metamorphism and granitization of the Pre-Cambrian rocks, a strong northwesterly shear zone was probably produced by north-south forces. During Tertiary time early compressive forces from the southwest appear to have given rise to drag folds, overturned folds, thrust faults, and possibly strike-slip faults. Later in Tertiary, possibly Quaternary, time high-angle normal faulting resulted in the present uplift.

INTRODUCTION

Purpose and Scope

The purpose of this investigation was to map the general geology of the southern part of the Ladron Mountains. As far as is known, it has not heretofore been mapped except in a very general was by Darton (1928) on a scale of 1:500,000.

Of particular interest was the reported pinch-out of beds of Mississippian age. Surface outcrops of this age have not been identified farther north in the State. The information as to the Mississippian age of these strata lay in identification of several fossils collected by W. T. Lee (Gordon 1907a) in the south end of the Ladron Mountains. This report attempts to clarify the situation by mapping the Mississippian formation, by measuring its units in several places, and by dating it more exactly, with the aid of fossils. The problem of correlation is also considered, with inconclusive, but provocative, results.

The purpose of this work has been also to map the Pre-Cambrian rocks and study their relations and regional correlations. This aspect is of particular interest, for Pre-Cambrian exposures are rare on the west side of the Rio Grande in central New Mexico.

No topographic base map of the area exists. The base map used in preparing the geologic map (Plate 1) was modified from the 15-minute planimetric quadrangle No 248

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furnished by the Regional Office of the Cartographic Division of the U. S. Soil Conservation Service. The scale of this base map is about 1:31680. The geologic mapping was done in the field on vertical aerial photographs purchased from the Soil Conservation Service, and the geology was transferred to the planimetric base with the aid of a Vertical Sketchmaster.

Inasmuch as no thin-section or chemical studies were made, all rocks are described in the general terms used in ordinary hand-lens identification. Section measurement was done by hand-leveling with a Brunton compass.

Acknowledgments

The writer is greatly indebted to Dr. Vincent C. Kelley, who first suggested the Ladron Mountainsarea as a problem, and under whose guidance the work was undertaken. His suggestions and valuable criticisms in the preparation of the report have been greatly appreciated.

Special thanks are due Dr. Stuart A. Northrop for his painstaking identification of fossils and for his advice concerning the problems of the Mississippian rocks.

Dr. J. Paul Fitzsimmons generously gave his time to discussions of metamorphic problems and to criticisms of this report.

Location and Extent

The Ladron Mountains, or Sierra de los Ladrones, are named from the Spanish ladron, meaning thief. Many legends of the area concern buried Spanish treasure and outlaw hide-outs in these rugged mountains.

The mountains are located about 50 miles west of the geographical center of the State of New Mexico, in the north-

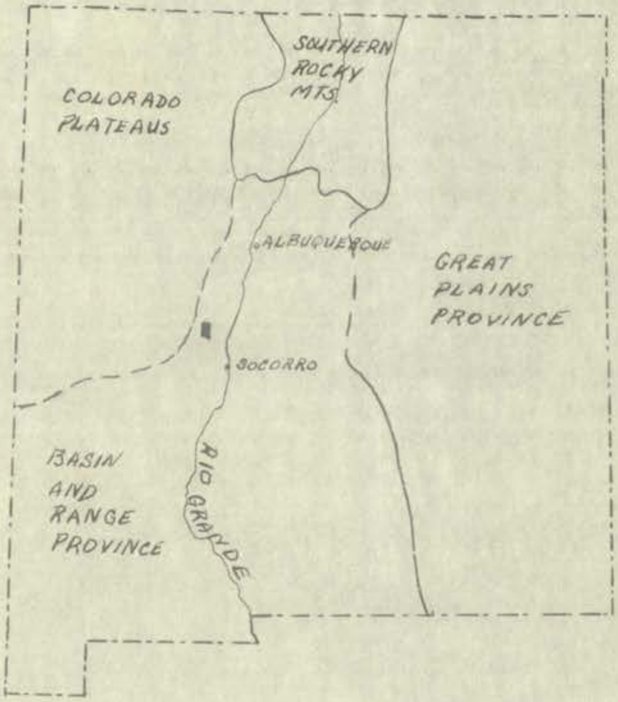

Figure 1. INDEX MAP OF NEW MEXICO
(after Fenneman, 1930)
Southern Ladron Mountains area shaded.

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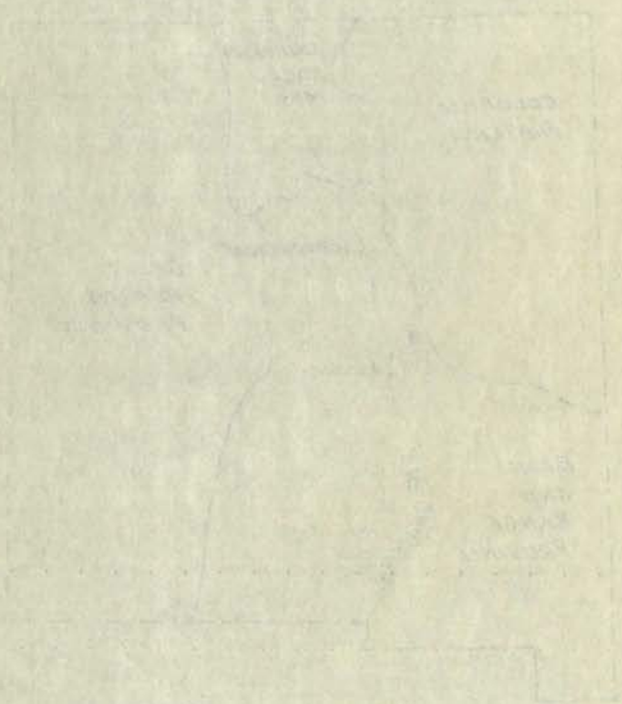

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ern part of Socorro County, about 15 miles west of the Rio Grande. They are included in an area about 10 miles long by 5 miles wide, the long axis running approximately north-south. The mountains lie within the area bounded by [illegible] and 34° 30' north latitude, and 107° 00' and 107° 10' west longitude. U. S. Highway 85 runs north and south about 12 miles east of the center of the area mapped in this report.

The area studied is roughly rectangular in shape, extending from the north boundary of La Joya Grant, about seven-eighths of a mile south of the highest peak, the so-called "South Peak" (elevation 9,177 feet) southward for about 6½ miles to the Rio Salado (elevation approximately 5,100 feet in the area studied) and extending for about 2½ miles east and west. The somewhat irregular western boundary of La Joya Grant runs roughly north and south near the center of this area and has its northwestern corner on the high sharp ridge of which South Peak is a part. Most of the remainder of the area lies along the western side of T. 2 N., R. 2 W., the range line forming the western border of the area.

Physiography, Geography, and Accessibility

The Ladron Mountains rise abruptly from surroundings of relatively low relief and exist more or less as a discrete range independent of nearby ranges. Their ruggedness and height are accentuated by their isolation and relatively limited horizontal extent. The abruptness of the rise of the mountains is most noticeable on the north and east sides where the adjoining pediments and alluvial fans are about 3,000 feet lower than the highest ridges which are less than two miles to the west and south.

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The rise in altitude is more gradual on the south and west sides. A thick section of uptilted Paleozoic limestone, predominantly Pennsylvanian in age, laps the western side of the range. This tilted limestone is eroded away to the east, forming a prominent hogback which decreases in elevation from approximately 7,500 feet just west of the highest part of the range to less than 5,500 feet at the Rio Salado, finally disappearing beneath Tertiary and Quaternary deposits a short distance to the south of this river.

The Ladron Mountains are drained by a more or less radial pattern of intermittent streams which eventually reach one of two important streams. The northernmost part drains into the Rio Puerco, a large intermittent stream which enters the Rio Grande about 14 miles to the east of the mountains. The area with which this report is concerned drains to the south and enters the Rio Salado, a large intermittent stream which flows eastward about 7 miles south of Ladron Peak. The Rio Puerco and Rio Salado, two of the most important tributaries of the Rio Grande in New Mexico, have very extensive watersheds but are dry, at least in their lowermost reaches, during much of the year. However, at times, particularly in summer, they carry large quantities of sediment and are subject to flash floods.

The Rio Salado, in the vicinity of the area studied, was never seen completely dry from June through February.

The rise in altitude is more gradual on the south and west sides. A thick section of eastward dipping Paleozoic limestone, predominantly Pennsylvanian in age, caps the eastern side of the range. This tilted limestone is eroded back to the west forming a prominent hogback which decreases in elevation from approximately 7,400 feet just west of the highest point of the range to less than 5,500 feet at the Rio Salado, finally disappearing beneath Tertiary and Quaternary deposits a short distance to the south of this river.

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The Rio Salado, in the vicinity of the area studied, was never seen completely dry from [illegible] through February.

However, during the driest periods it would often disappear into its sandy bed a mile or two downstream from the southeastern corner of the area mapped, and only after heavy showers would it remain a surface stream as far downstream as U. S. Highway 85, about 9 miles from the southeastern corner of the area. During the frequent showers of the summer, the river rises and falls almost daily. As autumn progresses, showers are less frequent, and parts of the river bed become dry sand and silt, which are ripple-marked by the wind. Good examples of sand dune formation can be seen where U. S. Highway 85 crosses the Rio Salado.

The chief hindrances to field work in this area are unfavorable weather and the small number of arroyos which are passable in a vehicle. Since there are no roads in the area proper, entrance must be gained via the Rio Salado. A poor road, not traversable after heavy showers, branches off Highway 85 about 8 miles south of Bernardo, the point of juncture of U. S. Highway 85 and U. S. Highway 60. This road runs roughly parallel to the Rio Salado for 9½ miles where it enters the bed of the Salado about a mile below the Box Canyon in which sheer walls rise on both sides of the narrowed channel. This canyon is shown on the map (Plate 1) as the tortuous bending of the Salado in the extreme southeastern corner of the map.

The youthful topography of the area, typified by steep-

sided canyons and arroyos with their falls, makes vehicular travel almost impossible except in certain of the larger washes. Even in the larger washes there are many obstacles and often a single bottleneck prevents the use of a considerable length of traversable dry stream bed above it.

The area is best reached by driving westward up the bed of the Salado from the point at which the above-mentioned road enters it, and turning up the tributary arroyos to the north. Most of these tributaries are of little help in penetrating the area by car, but there are two, Mule Spring Canyon and La Cueva Arroyo, which are of use.

Mule Spring Canyon would be the most useful were it not for the fact that even the lower part can be disastrous for anything but a 4-wheel-drive vehicle. With the use of a Jeep, this arroyo and a tributary, Old Man Arroyo, were traversed on several occasions for a distance of about 5½ miles, or to the north end of Cerro Colorado (see Plate 1) and to within half a mile of the limestone hogback. However, subsequent floods removed the boulders placed in front of certain ledges across the arroyo on earlier trips, and these were never replaced. The arroyo was easily traversable in its lower reaches only after the occurrence of a flood which, in its late stages, dumped enough fine material to make the floor of the wash reasonably smooth. Since smaller and more frequent "runs" of water had only the competence to remove the finer sided canyons and arroyos with steep walls, makes vehicular travel almost impossible except in the larger washes. Even in the larger washes there are many drop-offs, and often a single bottleneck prevents the use of a considerable length of traversable dry streambed above it.

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The other passable arroyo, La Cueva Arroyo, is very much better for driving than is Mule Spring Canyon, as its gravel floor is nearly free from boulders. This arroyo is largely outside the mapped area, but it is possible to turn westward from it into the northern part of Mule Spring Canyon which leads to the Cement Tank Spring shown on Plate 1. A point half a mile beyond this spring is the farthest that a vehicle can penetrate the area. A ledge across Mule Spring Canyon makes necessary this entrance via La Cueva Arroyo.

According to Lasky (1932, p. 87) the Ladron Mountains are, "accessible only during certain parts of the year, when the Rio Salado and its numerous tributary arroyos are dry or nearly so, and always with difficulty." However, field work done from June, 1949, to February, 1950, showed that the range usually was inaccessible via the Salado for only a few days at a time, when rainfall was particularly heavy. Daily fluctuation due to showers anywhere in its extensive watershed often make it inadvisable to enter the Salado at any given time, especially during the summer season. Many trips to the area were halted at the banks of the river due to high water resulting from rainfall in the western part of its watershed. A route reaching all the way to Mule Spring Canyon without entering the Salado was finally developed, but material, the result was a boulder-strewn floor over which driving was impracticable.

The other possible route, La Cueva Arroyo, is not much better for driving than is Mule Spring Canyon, as its gravel floor is nearly everywhere bouldery. This arroyo is largely outside the mapped area, but it is possible to walk westward from it into the northern part of Mule Spring Canyon which leads to the Centre Tank Spring shown on Plate 1. A point half a mile beyond this spring is the farthest that a vehicle can penetrate the area. A ledge across Mule Spring Canyon makes necessary this entrance via La Cueva Arroyo.

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The river bed is at its best for driving when moist, but with a minimum of water actually flowing. Moisture is apparently supplied from the high water table of the stream bed by capillary action. During protracted rainless periods, the water table drops and the resulting dry sand makes travel difficult. On the coldest mornings of winter it was found that the frozen moisture in the sand provided a hard surface which was excellent for driving. However, ice in the main channel added a hazard at these times, for the stream must be crossed at numerous places. In summary, it can be said that conditions which are too dry, wet, or cold are all unfavorable, but normal for this region.

The biota of the Ladron Mountains region may be classified according to Merriam's Life Zones Concept (Bailey, 1913) as varying between Upper and Lower Sonoran through to the Transition Zone. The Lower Sonoran, represented in the Rio Salado area, is characterized by mesquite, creosote bush (greasewood), Spanish bayonet, prickly pear cactus, pincushion cactus, and also the road runner. Characteristic of the Upper Sonoran Zone, which includes the greater part of the area studied, are piñon, juniper, blue grama grass, century plants, and also ground squirrels, piñon jays, larks, and woodpeckers. Scrub oak, yellow pine, and chickadees are characteristic of the Transition Zone, found in the higher elevations.

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GENERAL GEOLOGY

Pre-Cambrian Rocks

General Statement

Pre-Cambrian rocks form the greater part of the terrain mapped in this report, other rocks being found only along the western and southern sides of the area. A thick sequence of steeply-dipping quartzite and schist is present in the form of a partly granitized roof-pendant in a subjacent mass which is most nearly represented by a rock of granitic texture underlying the metasediments. Large masses of gneiss illustrate an advanced stage of granitization. In addition to the above definite rock units is an "undifferentiated complex" composed of rocks in general representing varying degrees of granitization of metasediments.

The Pre-Cambrian rock units described in this report were chosen for their convenience of megascopic or field description and practicability of mapping on the scale of 2 inches equals 1 mile.

Blue Canyon Quartzite

The southern part of the Ladron massif, to a great extent, is made up of quartzite with its variations and modifications. Most of the rocks of the high ridge (hereafter referred to as South Ridge) south of Ladron Peak consist of quartzite, altered to a greater or lesser degree by intrusion from below. This quartzite is herein called the

[illegible]

Pre-Cambrian Rocks

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Blue Canyon quartzite, from its occurrence in the steepest part of Blue Canyon. Great thicknesses of more or less pure quartzite, with intercalated sericitic quartz schist, form the bulk of the highlands, or continuation of South Ridge, about 2 miles south of Ladron Peak (see Plate 3). The beds have a general north to northeast strike, with a dip usually between 30° and 65° east.

Detailed measured sections of the Pre-Cambrian metasediments were not made because the outcrops are incomplete. However, there is probably a minimum thickness of 5,000 feet of metasediments (schist and quartzite) present.

The quartzite is remarkable throughout much of its thickness for the purity and massiveness of some of its beds, especially those high in the section. In these beds it is generally fine-grained and light colored. Pale shades of green, lavender, and red are common, with occasional black bands probably due to fine particles of hematite. Sorting must have been generally excellent. Occasional narrow conglomeratic beds are present and stretched quartz pebbles were found in local conglomeratic zones. Interbedded with the purer quartzite beds are light-gray beds of quartz and sericite schist.

In the northern part of the quartzite exposure, feldspar, which appears to have been introduced from the subjacent granite, becomes more abundant. Indications are that the quartzite extended at least as far north as Ladron Peak and that

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In the northern part of the [illegible], [illegible], which appears to have been [illegible] quartzite, becomes more abundant. [illegible] quartzite extended at least as far north as [illegible] it has been permeated and altered in character by emanations from the stock-like granitic mass which forms the deeper core of the mountains.

The quartzite appears to have originated from sandstones containing relatively small amounts of argillaceous material. Occasional silty beds and impurities probably account for the intercalated schist.

The abundant fractures and, in places, the well-developed joints, provide for abundant and extremely resistant talus material. Consequently, travel is difficult and exposures poor. Outcrops are good only in vertical cliffs.

The sericitic schist and massive, fine-grained quartzite in the southern exposures probably indicate a relatively low-grade, regional type of metamorphism. Farther north the increasing granulitic texture and the presence of stretched quartz pebbles, plus the obliteration of quartzite bedding and greater permeation of the granitic materials, all indicate a more intense metamorphism.

Correlation of these rocks with those in nearby Pre-Cambrian terranes is difficult due to the small, isolated occurrence and lack of really distinctive features in the quartzite. Stark and Dapples (1946, pp. 1128, 1133) in their work on the Los Piños Mountains on the opposite or eastern side of the Rio Grande depression, describe a westward-dipping sequence of quartzite which may or may not be an equiva-of the Blue Canyon quartzite.

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Torres Schist

Although the only extensive occurrence of schist is located above the quartzite in the northwestern part of the area, there are scattered and, in most cases, remnant-type outcrops of schistose rocks in gneiss and granite. These outcrops are found chiefly to the west and southwest of the main mass of the Torres schist, notably along the western base of Cerro Colorado and as discontinuous outcrops underlying the basal sediments of the Mississippian northward from the latitude of Cerro Colorado. It is believed that a pre-Pennsylvanian fault, further described under "Structure" was responsible for the discontinuity of the present schist occurrences.

The greatest thickness of schist lies to the east of the quartzite in the northeastern part of the mapped area. This formation is termed the Torres schist, named for the Juan Torres prospect (see Plate 1). The Torres schist appears to lie conformably upon the Blue Canyon quartzite. Like the quartzite, the schist has a north to northeast strike and a steep easterly dip, in general becoming rather more steep eastward from the quartzite. The schistosity is parallel or nearly parallel to the original bedding. The exposed thickness of the Torres schist is comparable to that of the quartzite.

All the schistose rocks, having relatively poor resis-

tance to weathering, are generally slope-formers. Good exposures are almost solely found where streams cut through and expose the rocks along the sides of the stream beds.

Lithologically, they are mostly mica, chlorite, and hornblende schists, which range from silvery-gray through green to black. Quartz is probably a major constituent, and epidote is often visible. Locally, phyllite, amphibolite, and nondescript greenstone are present. Where granitization and injection have been active, migmatites and various types of quartz-feldspar schist and gneiss have resulted (see Plates 4A, 7A) with complete gradations to rocks of an obviously granitic texture.

Most of the schist and related rocks are indicative of a low- to medium-grade metamorphism. Very likely they owe their present state chiefly to the same regional stresses which formed the quartzite.

Many of these schist bodies, as well as the main mass of the Torres schist, are evidently correlative with the more granitized schists found in the "Undifferentiated complex", but are treated separately because of their comparative lack of alteration by granitization.

The difficulties of correlation of the schist are similar to those of the Blue Canyon quartzite. Like the quartzite, the schist may be equivalent to somewhat similar rocks across the Rio Grande to the northeast and east described by Reiche (1949) and by Stark and Dapples.

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Gneisses

Rocks of gneissic texture occur chiefly in and around Cerro Colorado (see Plate 4B). Except for schistose rocks at the western base of this hill, a mixed zone around the northeastern base, and a few isolated schist remnants, the entire hill is composed of rocks best described as gneiss. Outcrops in general are fairly well exposed except where covered by talus material in the higher parts of the hill and residual debris and terrace gravels around the base.

The gneiss of Cerro Colorado displays several shades of red, whence came the Spanish name for the hill. The considerable variation in compostion, texture, and grain size will be noted in the descriptions that follow. In general, the base of the hill at the south and east has a coarse texture while the upper portions are finer-grained and have, structurally, an almost sedimentary aspect perhaps inherited from the rocks present before granitization took place.

There is only one place in the gneiss where a continuous contact can be drawn to distinguish different types. This is the boundary between the coarse, porphyroblastic, Bug Spring gneiss around the south and east base of the hill and the finer-grained, Cerro Colorado gneiss of the higher portions. Even within these two types there are many gradations, most of them so gradual that no sharp contacts could be drawn.

The textural differences of the rock make comparison of

the actual amounts of dark minerals difficult. However, the chief mineralogical difference between the two gneisses appears to be in the quantities of dark minerals, which seem to be predominantly a dark-green biotite. The biotite appears also to be altered in part to chlorite. The fine-grained gneiss in many places is leucocratic, whereas the coarser varieties are generally richer in mafic material.

The Cerro Colorado gneiss in many places has a foliation which is very similar in attitude to that of the schist and quartzite to the north. The Bug Spring gneiss and some coarser phases of the Cerro Colorado gneiss have a strong foliation only in certain zones, and in all outcrops the foliation is much less indicative of the structure of the original rocks than is believed to be the case with the finer-grained gneisses.

Bug Spring gneiss

The Bug Spring gneiss, named for a spring near the eastern margin of the gneiss (see Plate 1), is predominantly red, reflecting the color of the feldspar. There are extensive zones, however, in which the feldspar is grayish in color; here the overall appearance is a greenish-gray, the greenish hue being furnished by the dark-green biotite or chlorite which is partly masked where the feldspar crystals are red or pink.

Due to coarseness of texture, outcrops of the Bug Spring gneiss are characteristic of those of a deeply-weathered, the actual amounts of dark components of [illegible], the chief mineralogical difference between the two gneisses appears to be in the composition of dark minerals, which seems to be predominantly a dark-green biotite. [illegible] appears also to be altered in part to chlorite. [illegible] gneiss in many places is [illegible], whereas the coarser varieties are generally richer in mafic material.

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Due to coarseness of texture, outcrops of the Bug Spring gneiss are characteristic of those of a [illegible]-weathered [illegible] coarse-grained, granite terrane (see Plate 5A). On slopes where water has little scouring effect, residual debris (gruss) is plentiful, but the canyon walls provide relatively fresh exposures. Some joint planes in the coarse gneiss are smooth, but once weathering starts to roughen the surface, the entire surface weathers rapidly.

This coarse-grained gneiss is generally porphyroblastic in texture, the porphyroblasts ranging in size and face development from place to place. The average porphyroblast ranges from one-half to three-quarters of an inch in length. These metacrysts are often irregular in size and shape, especially where the rock is strongly foliated. The porphyroblasts probably are microcline or microperthite (Kesler, 1936, p. 41). Megascopically, the groundmass consists chiefly of feldspar, quartz, and dark-green to black biotite. The plagioclase content is difficult to estimate. The quartz is subordinate in amount to the feldspar in most cases, but the proportions are variable. In many places, especially where foliation is strongest, the biotite is curved around the feldspar augen. This is particularly true of border zones, where feldspar and quartz apparently have been introduced into the biotite schist. This situation suggests that the dark minerals of the porphyroblastic gneiss are in many places simply remnants of partially granitized schist. The mica which curves around the feldspar and quartz grains owes its curved form to the expansion of large crystals of the latter minerals during their growth.

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The Bug Spring gneiss is concluded to be a paragneiss; its origin is discussed further under "Granitization".

Cerro Colorado gneiss

The second, or fine-grained, type of gneiss found in this locality is also predominantly red in color. It forms the bulk of Cerro Colorado. When viewed from a distance, the pronounced banding in some outcrops gives the appearance of sedimentary beds (see Plate 4B). In the hand specimen, this gneiss appears to be fine- to medium-grained. The minerals are essentially the same as in the Bug Spring gneiss, but there is probably, on the average, a little less biotite and a little more quartz. The proportion of felsic materials appears to diminish with increasing grain size.

The Cerro Colorado gneiss is considered to be a paragneiss. A further discussion of its origin may be found under "Granitization".

Capirote Granite

The granite of this area, named for Capirote Hill, is found chiefly in two nearly adjacent areas, one to the north-northwest, and one to the northeast, of Cerro Colorado. Both areas are separated from Cerro Colorado by a belt of mixed rocks; otherwise, they are bounded chiefly by schist. A third occurrence is a small outcrop in the extreme northwest corner of the area.

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The granite underlies the metamorphic rocks in nearly all cases. Near-granites appear in other places, particularly in the undifferentiated zone, but rocks mapped as granites are only those which, regardless of origin, have a fairly even, granitic texture, with a minimum of foliation.

The usual granite is a red, medium-grained rock. In places it grades into a light-gray color, due to lack of color in the feldspar. Distinctive structures are lacking, except for occasional inclusions and the rare presence of weak foliation. The inclusions are often composed of a relatively unaltered schist, and their schistosity and alignment does not differ radically from the surrounding metamorphic rocks. The gneissosity in the granite is apparently due to almost completely granitized schists which need only a change in texture to resemble granite. The occasional weak foliation somewhat resembles flow structure, but it is thought to be a feature retained from the metamorphic rock.

The megascopic mineral assemblage consists principally of potash feldspar and quartz, with varietal or accessory amounts of green biotite or chlorite. It is thus similar in composition to the Cerro Colorado gneiss.

This rock is chiefly a granitization product of schistose metamorphics as indicated by the evidence mentioned above and by the fact that the metasediments dip into it.

Undifferentiated Complex

The area mapped as undifferentiated metamorphic complex

is found in one continuous, irregular belt extending from the Paleozoic rocks on the west to the eastern border of the area, and north of Cerro Colorado. They consist chiefly of schist, gneiss, and granite, in most places too mixed, too variable, or too limited in extent to map separately. More dikes and sills are found in this area than elsewhere. As a whole, the area represents a transition zone from relatively unaltered metasediments to rocks which have been rather completely granitized.

There are several large areas in this zone which appear from a distance to consist largely of one rock type, but closer inspection shows considerable variation. For example, a sizeable red-hued hill to the southwest of Cement Tank Spring (see Plate 1) appears at a distance to be composed entirely of red granite. Investigation proves, however, that the rock has considerable gneissic foliation and contains extensive areas of a granitized schistose rock having the color of granite.

Dikes and Sills

The majority of all dikes and sills of the area are Pre-Cambrian in age, and occur principally in the undifferentiated complex. Compositions vary from basic to acidic; textures vary from aphanitic to pegmatitic. Relations vary from cross-cutting to conformity with planes of schistosity; often a single intrusive body is a dike in one place and a sill in is found in one continuous, irregular belt [illegible] in the Paleozoic rocks on the west in the western part of the area, and north of [illegible]. [illegible] of [illegible], gneiss, and granites, [illegible] mostly [illegible] or too limited in extent to map separately. [illegible] dikes and sills are found in this area than elsewhere [illegible], the area represents a transition zone from [illegible] of [illegible] metasediments to rocks which have been more completely granitized.

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The dikes which are most abundant are probably those of quartz-feldspar composition, and of varying grain size. Inasmuch as these intrude all Pre-Cambrian rocks, they are considered a relatively late event, but they could have been intruded during many stages of the granitization process. It was not determined whether they actively promoted granitization, since many of the "dikes" are not intrusive in character but are in themselves products of replacement mechanisms associated with granitization.

The quartz-feldspar dikes vary in texture from aplitic to pegmatitic, but are chiefly pegmatitic. Most of them have no observable accessory minerals, being composed entirely of quartz and pink potash feldspar. Some exhibit small books of muscovite. These quartz-feldspar dikes vary in size from a fraction of an inch to several feet in width, but the greater number do not exceed 2 feet. They often appear to have random

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a fraction of an inch [illegible]
number do not exceed [illegible]

attitudes, but many have a consistent north to northwest trend.

Dikes of dark-green to black color and mostly of lamprophyric composition are found chiefly in the undifferentiated zone (see Plate 6A). Locally they are sill-like in character as they follow planes of foliation or schistosity. They cut all Pre-Cambrian rock units, as do the pegmatites. They may be younger than the latter, for some pegmatites were observed to be offset, while the basic dikes gave no evidence of offset. Inasmuch as the two types were not compared in like situations, this difference alone is not proof of dissimilar age, but the presence of basic dikes in Pennsylvanian limestone (see Plate 6B) was noted. Diabase dikes were found in both Pre-Cambrian and Pennsylvanian rocks, but not in comparable areas. Basalt dikes found in the undifferentiated complex looked relatively fresh, and they may all be younger than the pegmatite, possibly Tertiary in age. However, at least some of them may be related in age to a pre-Pennsylvanian episode of movement along the Ladron fault.

The basic dikes apparently have no particular trend. They are less widespread than the pegmatites and, despite a comparable range in widths, are noticeably rarer in widths of less than a foot.

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Pre-Cambrian Metamorphism

General Statement

The subject of metamorphism is of prime importance to this problem, because metamorphic rocks are exposed over a large part of the mapped area. It is thought that the southern Ladron Mountains metamorphic problem is worthy of more thorough investigation, but that field observations, in themselves, are deserving of a report.

Dynamic Metamorphism

Evidence of early dynamic metamorphism is difficult to find by field methods because of the limited and pendant-type character of the ungranitized metasediments. The quartzite is of little help as a gauge of the intensity of metamorphism, but the intercalated sericitic schist and the darker colored mica and hornblende schists suggest their origin by a regional-type metamorphism. This type of origin is also suggested by the occurrence of rocks of similar type and age in other parts of the Middle Rio Grande Valley. Local occurrences of contortion (see Plate 6A) and more highly metamorphosed rocks are found, mostly in the undifferentiated complex, but because many of these are likely due to stresses brought about during the intrusion and granitization of the metasediments, they are considered under "Granitization". At least some of this contortion, however, may be due to faulting.

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In some Rio Grande [illegible], several phases of [illegible] morphism were suggested (Stark and Dapples, p. 1140; Reiche, p. 1197). This is probably also the case in the Ladron region, where the folding of the sediments took place before the granitization episode. It is possible that there was movement along the Ladron fault in Pre-Cambrian time. This last possibility will be considered under "Structure".

Granitization

The term "granitization" is here used in describing a type of metamorphism well represented in the Pre-Cambrian rocks of the southern Ladron Mountains area. One of the chief objections of Grout (1941), in his critical review and discussion of metasomatism, was the vagueness, or entire lack, of definition of the terms used in papers written by otherwise reputable geologists. Concerning the term "granitization" he has written, (p. 1539), "One can almost say it has no meaning, for no two papers seem to agree."

Grout (p. 1540) defined granitization to include "a group of processes by which a solid rock (without enough liquidity at any time to make it mobile or rheomorphic) is made more like granite than it was before, in minerals, or in texture and structure, or in both". It is evident, from what has already been said in this paper, that this process has been active in the area under discussion. All areas mapped as gneiss, granite, and undifferentiated rocks have undergone granitization, as defined above, to a greater or lesser degree. The total mapped area of these granitized rocks morphism were suggested (Hatch and [illegible], [illegible], p. 1197). This is probably also the case in the [illegible] region, where the [illegible] of [illegible] rocks took place before the granitization of [illegible]. It is possible that there was movement along the [illegible] fault in pre-Cambrian time. This last possibility will be considered under "Structure".

Granitization

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Grout (p. [illegible]) defines granitization [illegible] of processes by which [illegible] at any time to make it [illegible] more like granite than it was before, in minerals, or texture and structure, [illegible]. It [illegible] already been [illegible] active in the [illegible]. [illegible] gneiss, granite, and [illegible] granitization, as defined above, [illegible] degree. The total [illegible] reaches and constitutes a large part of the Pre-Cambrian rocks in the area studied. The only sizeable remnant of ungranitized Pre-Cambrian rocks is the large pendant-type exposure of Blue Canyon quartzite and Torres schist in the high region in the north central part of the mapped area.

Applying the definition that granitization is the process or processes making a rock "more like granite than it was before", and with the fairly certain knowledge that the "before" rocks were metasediments, it appears obvious that the Capirote granite represents a nearly completed process. The Capirote granite has undergone the most extreme changes in minerals, texture, and structure. The Cerro Colorado gneiss retains an outline of the original structure, but has been changed in minerals and texture. The undifferentiated rocks show extreme variation from unaltered metasediments to injection and to the nearly complete changes found in the granite. It should be emphasized that the rocks called granite and gneiss are para-granite and paragneiss, respectively.

Although no real proof of the absence of outcrops of a true intrusive granite has been given, evidence has been suggested. From what is known generally of the Ladron Mountains farther north, a large stock-like body of an intrusive granite is probably present. For this reason, the name "Ladron granite" is reserved for the granite stock which is believed to form the central core of the mountains. The rock herein referred to as the Capirote granite might later reaches and constitutes a large part of the [illegible] rocks in the area studied. The only distinctive remnant of ungranitized Pre-Cambrian rocks is the large [illegible] exposure of Blue Canyon quartzite and [illegible] in the ridge region in the northwestern part of the mapped area.

Applying the definition that granitization is the process or processes making a rock "more like granite than it was before", and with the fairly definite knowledge that the "before" rocks were sedimentary, it becomes obvious that the Capirote granite represents a nearly completed process. The Capirote granite has undergone the most extreme changes in minerals, texture, and structure. The [illegible] gneiss retains a portion of its original structure, but has been changed in minerals and texture. The [illegible] rocks show extreme variation from the altered [illegible] to injection and to the nearly complete changes found in the granite. It should be emphasized that the [illegible] and gneiss are [illegible].

Although no real proof of the absence of any [illegible] true intrusive granite has been given, evidence has been suggested. From what is known generally of the [illegible] Mountains farther north, a large stock-like body of intrusive granite is probably present. For this reason, the name "Ladron granite" is reserved for the granitic rock which is believed to form the central core of the mountains. The rock herein referred to as the Capirote granite [illegible] be considered a part of the Ladron granite, but it is at present believed to be only the border-phase granitization product of the Ladron intrusive.

The supposition that granitization was the dominant metamorphic process in this locale is supported by abundant evidence. Striking examples of the gradations between black hornblende schist and pink granitic rock are common. Pink feldspar crystals in the dark schist represent the first stage. This is followed by a general lightening of color as more light minerals appear throughout the rock. In an advanced stage, hornblende disappears and the schistose structure is almost obliterated.

Another convincing proof of granitization can be seen near the base of the northeastern part of Cerro Colorado where schist can be followed southwestward along its strike until it merges by insensible gradation into the fine- and medium-grained granitic gneiss of Cerro Colorado. As mentioned previously (p. 20), the Cerro Colorado gneiss in part retains a sedimentary aspect when viewed from a distance.

An interesting example of the selective action of granitization processes is the frequent and almost complete granitization of thick sections of rock on one side of a plane of schistosity, while a dark schist on the other side of the plane is apparently almost unaffected. This selective action may be responsible for the frequent preservation of remnants of green schist in rocks of granitic and gneissic texture (see Plate 7A).

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Another convincing proof of granitization may be seen near the base of the [illegible] part of [illegible] where schist on [illegible] along the strike until it merges by [illegible] into the fine- and medium-grained granitic gneiss of [illegible] (mentioned previously [illegible]), the latter [illegible] retains a sedimentary [illegible].

An interesting example of the [illegible] action of granitization processes is [illegible] granitization of [illegible] on one side of a plane of schistosity, while [illegible] on the other side of the plane is apparently [illegible]. [illegible] may be responsible for [illegible] preservation of [illegible] of green schist in [illegible] (see Plate 7A).

Many dikes, pods, stringers, and lenses of feldspar and/or quartz in a schist or greenstone are obviously of replacement[1] origin. That they owe their origin to the introduction of felsic material is indicated by the increase in number and size toward a contact with a more highly feldspathic rock; also, some of the host rocks are no doubt too lacking in the necessary elements to be a source. However, most of the so-called mica schists are probably much less mafic in composition than they appear at the surface.

It is difficult to present much of a case against granitization. The best field for argument lies not in the question of the proof of granitization, but in the relative importance, in some area, of injection versus replacement, and in the question of the location and part played by a true intrusive body.

The replacement processes common to granitization are difficult to illustrate in some of the rocks of the undifferentiated complex, and the general appearance in some outcrops is that of injection rather than replacement. However, a more complete picture shows an undoubted transition, by means of granitization, from dark schistose rocks to rocks of light granitic aspect. The end result in this area, then, is the complete dominance of replacement over injection.

Just what part is played by injection is not clear. It

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[1] Goodspeed, 1940, p. 194, concept of replacement dike.

is to be expected that a certain amount of injection of the more volatile constituents would take place in the late stages of emplacement of an intrusive body. This idea is supported by the presence of pegmatitic and aplitic dikes whose cross-cutting character shows that their intrusion represents late activity in the area. Other pegmatite, aplite, and granite dikes are less clear in their relations; some of these appear to be earlier, and all of them could have been associated with the granitization process.

The time of granitization has already been suggested (pp. 25-26); it is believed, although there is a lack of conclusive evidence, that it occurred as a result of the deep infolding of the upper portions of the crust to a depth at which palingenesis[2] took place. This postulated palingenesis resulted in the formation and/or enlargement of a true magma in the deeper zones, grading upward through a granitized zone to schists and quartzite. The magma probably possessed the means of granitization, which are very likely the same means which provide injection pegmatites and aplites, but differing in scale and in processes and methods of escape. Movement engendered during the folding processes could have been a factor in making possible the extensive granitization of rocks above the magma body, but the actual processes by which the magma extended its influence upward were probably

[2] Tyrrell, 1926, p. 336, " a ... general term indicating widespread re-fusion of rocks with or without intimate interpenetration by granite".

is to be expected that a partial removal of fractions of the more volatile constituents would take place in the late stages of emplacement of the granitic body. This idea is supported by the presence of pegmatites of aplitic and cross-cutting character which shows that their formation represented a late activity in the area. Other pegmatites, aplites, and granitic dikes are less clear in their relations; none of these appears to be earlier, and all of them could have been associated with the granitization process.

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---

[2] Tyrrell, 1926, p. [illegible], "a ... general term indicating widespread re-fusion of rocks with or without [illegible] infiltration by granite".

largely the replacement mechanisms associated with granitization. Whether dikes and sill acted as carriers of volatiles or other agents contributing to granitization could not be ascertained, but they were probably not vital to the process; at least, large masses of granitized rock show no sign of dike or sill feeders.

It would be unwise to state, however, that early dikes and sills are of no importance in this type of metamorphism, even though they appear to play a minor role. Some "beds" of fine-grained or aplitic rock may have been sills of magmatic or hydrothermal origin rather than replaced metasediments. In any event, a final decision as to the injection-replacement problem should await thin-section study. The end result is the important thing in this particular investigation, and there appears to be little doubt that mass granitization or replacement is responsible for the greatest part of the exposed metamorphic rocks in the area, other than the remnants of the original schist and quartzite.

It is the disappearance of thick sequences of metasediments on a large scale that is of a more fundamental and regional interest than the relatively small-scale replacement or granitization heretofore described, although both phenomena are part of the same process. It is the large-scale disappearance of the metasediments and the indisputable presence of intrusive dikes that suggests the presence of a large subjacent intrusion. This intrusion must owe largely the replacement masses are associated with granitization. Whether dikes and sill served as carriers of volatiles or other agents contributing to granitization can not be ascertained, but they were probably not vital to the process; at least, large masses of granitized rock show no sign of dike or sill feeders.

It would be unwise to state, however, that the dikes and sills are of no importance in this type of mass replacement, even though they appear to play neither role of a parent magma. Veins of fine-grained or aplitic rock may have been media of magmatic or hydrothermal origin rather than simply metasomatic elements. In any event, a final decision as to the major replacement problem must await thin-section study. The end result is the important thing in this particular investigation, and there appears to be little doubt that mass granitization or replacement is responsible for the greatest part of the exposed metamorphic rocks in the area; they are the remnants of the roots of an ancient mountain system.

It is the disappearance of whole masses of sediments on a large scale that is of a more fundamental and regional interest than the relatively small-scale replacement or granitization effects described, although both phenomena are part of the same process. It is the large-scale disappearance of the sedimentary rocks and the noticeable presence of intrusive rocks that suggests the presence of a large subjacent intrusion. Such intrusion must have much of its mass to the metasediments.

It might still be argued that there is no true intrusive rock, but the great extent of granitization, plus the dikes, are more easily explained with the presence of a largely fluid mass to supply the granitizing agents and the dike materials. Also, some of the larger flexures and smaller contortions in the undifferentiated zone may be due to forceful intrusion or movements of a viscous granitic rock. Evidence of this is indicated in several outcrops.

This is not to say that the intrusion could not have formed entirely from material within the original metamorphosed sediments; it is not possible, on the other hand, to say whether there was activity on the part of a magma of other origin. The surface exposures show only that there was granitization and that there was dike and sill injection; they also show rocks of granitic texture. However, it is believed that the rocks mapped as granite, although in places evidencing an intrusive character, very likely were never an integral part of a molten magma of low viscosity. The granite is too similar in composition to some of the gneiss of granitization origin to have been mixed with a fluid medium which would have probably caused a further change in composition. This reasoning is based partly on observation of a light-colored granite of a considerably lower mafic content found farther north in the mountains. It is believed that the higher mafic content, and possibly the much of its mass to the released [illegible].

It might still be argued that there is no [illegible] intrusive rock, but the great extent of [illegible], [illegible] and dikes, are more easily explained with the [illegible] [illegible]ly fluid mass to supply the granitizing [illegible] [illegible] materials. Also, some of the larger [illegible] contortions in the [illegible] zone may [illegible] ful intrusion or movements of a viscous granitic mass. Evidence of this is indicated in several outcrops.

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If the intrusive was entirely of para-origin (from the metasediments) the further granitization of dark metasediments implies that there must have been a segregation within the intrusive in order continually to supply felsic material to the metasediments. If intrusive material of extraneous origin was present, it or its residual extracts probably were acidic in nature, because the granitization process was chiefly an exchange of mafic material of the metasediments for felsic material from below. The cooling and consequent segregation of material in an intrusive could be a source for a long-continued supply of residual felsic material.

From the above suggestions, it can be seen that field observation can determine the presence of granitization but cannot solve the problem of the source and processes of granitization.

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From the above suggestions, it can be seen that field observation can determine the [illegible] of granitization but cannot solve the problem of the source and mechanics of granitization.

Some of the major conclusions concerning granitization can be listed briefly:

1. The Torres schist and the Blue Canyon quartzite dip steeply eastward, losing their identity in the granitic rock below.

2. A transition zone between the above metasediments and the granitic rocks exhibits abundant proof of the occurrence of granitization.

3. The Capirote granite is probably a granitization product which has not gone through an essentially fluid stage, and is thus not a true intrusive rock; however, it may have had some mobility given by partial fluidity.

4. The presence of a subjacent intrusive body is indicated by the widespread granitization and numerous dikes and sills; the intrusive body is believed to be exposed in the central core of the Ladron Mountains.

5. The intrusive body owes much of its volume to the granitization and cross-assimilation of the metasediments, but the question of the presence of molten material of other origin is a complete unknown.

The work of Reiche indicates three or more stress episodes in the Pre-Cambrian history of the northern Manzano Mountains area. In the southern Ladron Mountains area, folding of unknown date and intensity probably produced the schist and quartzite long before the period of granitization. The schist might have been a product of higher grade meta-

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3. The [illegible] in [illegible] granite [illegible] which has not [illegible] through [illegible] stage, and is thus not a true intrusive rock; however, [illegible] some mobility given by partial [illegible].

4. The presence of a [illegible] intrusive body is [illegible] by the widespread granite [illegible] the intrusive body is believed to be [illegible] the central core of the Ladron Mountains.

5. The intrusive body [illegible] the [illegible] granitization and [illegible] assimilation of [illegible] question of the presence of [illegible] is a complete unknown.

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morphism, later undergoing retrograde metamorphism. Many possibilities present themselves; the most straightforward one has been postulated, whereby the granitization was associated with a palingenesis brought about by a deep infolding of the metasediments.

On the basis of work done in analogous areas by Reiche, and by Stark and Dapples, it is believed that all this metamorphism took place before the end of the Pre-Cambrian. Reiche places the oldest rocks exposed in the Manzano Mountains in the Proterozoic. Basing the age determination of the Ladron quartzite and schist partly on the reasonable assumption that they are similar in age to those mentioned by Reiche, and partly on the vulnerable reason that no other Pre-Cambrian metamorphic rocks were found, it is here assumed that the deposition and metamorphism (including granitization) of the oldest Ladron sediments took place entirely within the Proterozoic. However, it is possible that the Ladron Pre-Cambrian rocks as well as those in the Los Piños and Manzano Mountains are Archeozoic in age.

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Paleozoic Rocks

General Statement

With the exception of a few small outcrops of Permian age, all Paleozoic rocks in the mapped area are Carboniferous in age. The greater part of these rocks belongs to the Magdalena group of Pennsylvanian age, but a significant thickness of Mississippian rocks is also present.

The Mississippian and Pennsylvanian systems are best represented in the west-dipping hogback along the western margin of the mapped area, and lie unconformably on a Pre-Cambrian surface, except in the extreme northwestern corner of the area, where the sediments are separated from the Pre-Cambrian rocks by a fault contact. The only other sizeable exposure is located south of Cerro Colorado. Smaller outcrops are found as fragments along the Cerro Colorado fault.

A complete section of Paleozoic rocks is not present within the confines of the area mapped, since the uppermost strata of the hogback are eroded back, down-dip, to the west. Both the thick Pennsylvanian and thinner Mississippian sections consist principally of limestone at the top, with predominantly clastic rocks at the base. The Mississippian contains the northernmost fossils of that age reported in New Mexico.

It is not the purpose of this paper to consider at length the origin and environments of deposition of the Paleozoic

sediments. This is not to say, however, that the problem is unimportant; study over a larger area has already led to valuable information as to source areas and regional diastrophic history (Read and Wood, 1947)

Mississippian System

Caloso formation

The Mississippian strata lie unconformably on rocks of Pre-Cambrian age. Except for relatively small outcrops in the faulted area south of Cerro Colorado, the Mississippian section is found principally only along the base of the limestone hogback in the western side of the area (see Plates 3, 8B), along the western side of T. 2 N., R. 2 W. Its name is here derived from Caloso Arroyo, which is located in the same area. It is more resistant than most of the overlying Sandia formation, and thus provides noticeable outcrops, whereas the Sandia is largely a slope-former.

Its overall thickness remains relatively constant throughout about 4 miles of exposure, with a maximum thickness of 86 feet near the southern end. The individual units, however, change in thickness. In general, the lower half increases in thickness northward from the southernmost exposure, whereas the upper half decreases. A pinch-out of the Mississippian was not found, for it disappears under float in the Rincon area (see Plate 1) and is apparently faulted out by the Ladron fault.

The Caloso formation in this area can be tentatively

divided into three members (see Plate 7B). The lower member is chiefly made up of an arkose and locally conglomeratic basal sandstone or shale, limy sandstone and shale, and shaly limestone beds (see Plate 7B). The middle member is comprised of massive or thick-bedded, resistant, and generally unfossiliferous limestone with a brown-weathering cherty gray limestone bed at the top, containing Dielasma fossils in places. The Dielasma bed is not known, as such, in the southern 1½ miles of the Mississippian exposure, but its horizon is recognizable. The upper member, which thins northward, is generally a medium-gray, medium-bedded limestone containing many nodules and lenses of white and gray chert, especially in its southern part, and in certain zones is made up largely of white criquina (Tester, 1941, p.6), a rock consisting largely of crinoid fragments. A few fragments of spirifers were also found in this member. There is a disconformity or unconformity at the top of the Dielasma bed, between the middle and upper members, but its significance is not known.

The so-called Dielasma bed produces the only fossils of value. The fauna of this bed contains the following, as identified by Dr. Stuart A. Northrop:

Dielasma chouteauensis (common)
Dielasma sp., shorter and wider than D. chouteauensis (rare)
Spirifer sp., aff. S. "centronatus" (common)
Straparolus (Euomphalus) luxus (fairly common)
Corals, possibly Triplophyllites (fairly common)

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Dielasma sp., shorter and wider than *D. chouteauensis* (rare)
Spirifer sp., aff. *S. "centronatus"* (common)
Stenoporoids (*Rhombopora*) *lepis* (fairly common)
Corals, possibly *Triplophyllites* (fairly common)

Some further remarks by Dr. Northrop are here quoted.

> The fauna listed above for the brown-weathering cherty gray limestone member is peculiar in several respects, notably in its small number of species as contrasted with the individual abundance, in the comparatively robust appearance of all the forms, and in the absence of Productids (which are so common in the Mississippian of southern New Mexico).
>
> Neither Dielasma chouteauensis nor Spirifer "centronatus" are reported from the Caballero or Lake Valley formations of southern New Mexico. On the other hand, Spirifer "centronatus" and Straparolus (Euomphalus) luxus are characteristic of the Lower Mississippian Escabrosa limestone of southeastern Arizona and of equivalent formations to the west, in Nevada, to the north, in Utah and Colorado, and still farther north and west. The Sierra Ladrones Spirifer is somewhat more robust than the one described and illustrated by White (1877, p. 86-87, pl. 5, figs. 8a-c)from Mountain Spring, old Mormon road, Nevada. Stoyanow (1948, p. 320) has noted that the Mississippi Valley Spirifer centronatus Winchell (founded on types from Ohio) is not conspecific with the characteristic Southwestern form generally called Spirifer "centronatus". Stoyanow also commented on the absence of this species in the Lake Valley of New Mexico.
>
> Straparolus (Euomphalus) luxus was founded on material from "below Ophir City, Utah" (White, 1877, p. 94-95, pl. 5, figs. 13 a-b).

The Caloso formation has some lithologic similarities to the Lake Valley formation as described by Laudon and Bowsher (1949, p. 10-15), and an even closer correspondence to the Kelly limestone of Corkscrew Canyon, Lemitar Mountains, described by the same authors. However, the Kelly is generally believed to by younger than the Lake Valley, and the Lake Valley has a seemingly younger fauna than that of the Caloso, which has a Kinderhook aspect. The Kelly of Corkscrew Canyon suggests the possibility that the Kelly may be equivalent to the Caloso, and both of them older than the Lake Valley because of the Kinderhook affinities of the

Some further [illegible] by [illegible] are [illegible].

The [illegible] [illegible] [illegible] [illegible] quartz [illegible] [illegible] [illegible] [illegible], [illegible] [illegible] [illegible] [illegible] [illegible] with [illegible] [illegible] [illegible] [illegible] [illegible] notes [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible].

[illegible] [illegible] [illegible] [illegible] "[illegible]" [illegible] [illegible] [illegible] Valley [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] are [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] equivalent [illegible] [illegible], [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] and [illegible]. The [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] White (1877, p. [illegible], pl. [illegible]) [illegible] Spring, [illegible] [illegible] [illegible], [illegible] [illegible] has noted that the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] with the character [illegible] [illegible] [illegible] called [illegible] "[illegible]". [illegible] [illegible] on the [illegible] [illegible] [illegible] [illegible] [illegible] Lake Valley, New Mexico.

[illegible] ([illegible]) [illegible] [illegible] material from [illegible] [illegible], [illegible], p. 94-96, pl. 3, figs. [illegible].

The Calomo formation has [illegible] [illegible] [illegible] to the Lake Valley formation as [illegible] by [illegible] and Bowsher (1949, p. [illegible]) [illegible] [illegible] [illegible] [illegible] to the Kelly limestone of [illegible] [illegible] [illegible] described by the same [illegible]. [illegible], the Kelly [illegible] [illegible] believed [illegible] [illegible] [illegible] [illegible] Lake Valley [illegible] [illegible] [illegible] [illegible] Calomo, [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] Canyon suggests [illegible] [illegible] [illegible] [illegible] equivalent [illegible] [illegible], [illegible] [illegible] [illegible] [illegible] Lake Valley [illegible] [illegible] [illegible] [illegible] [illegible].

Caloso fossils.

Laudon and Bowsher (p. 16) show the Kelly seaway approaching the Ladron region from southwestern New Mexico and Arizona, and not extending far enough to the east to include the Lake Valley and Caballero of south-central New Mexico. This adds support to the statement by Dr. Northrop that the Ladron fauna resembles the fauna of the Escabrosa more than that of the Lake Valley or Caballero, and emphasizes the need of reviewing the evidence which led to the present dating of the Kelly.

In summary, the lithology of the Caloso has some resemblance to the Lake Valley and a greater resemblance to the Kelly of Corkscrew Canyon in the Lemitar Mountains, a few miles to the south. However, the Caloso fauna is noticeably dissimilar to the Lake Valley fauna and the Kelly fauna, having more in common with that of the Escabrosa of Arizona. The Caloso fauna is unique in the southwest, or at least in New Mexico, and may well contribute to the solution of some of the Mississippian problems of this region.

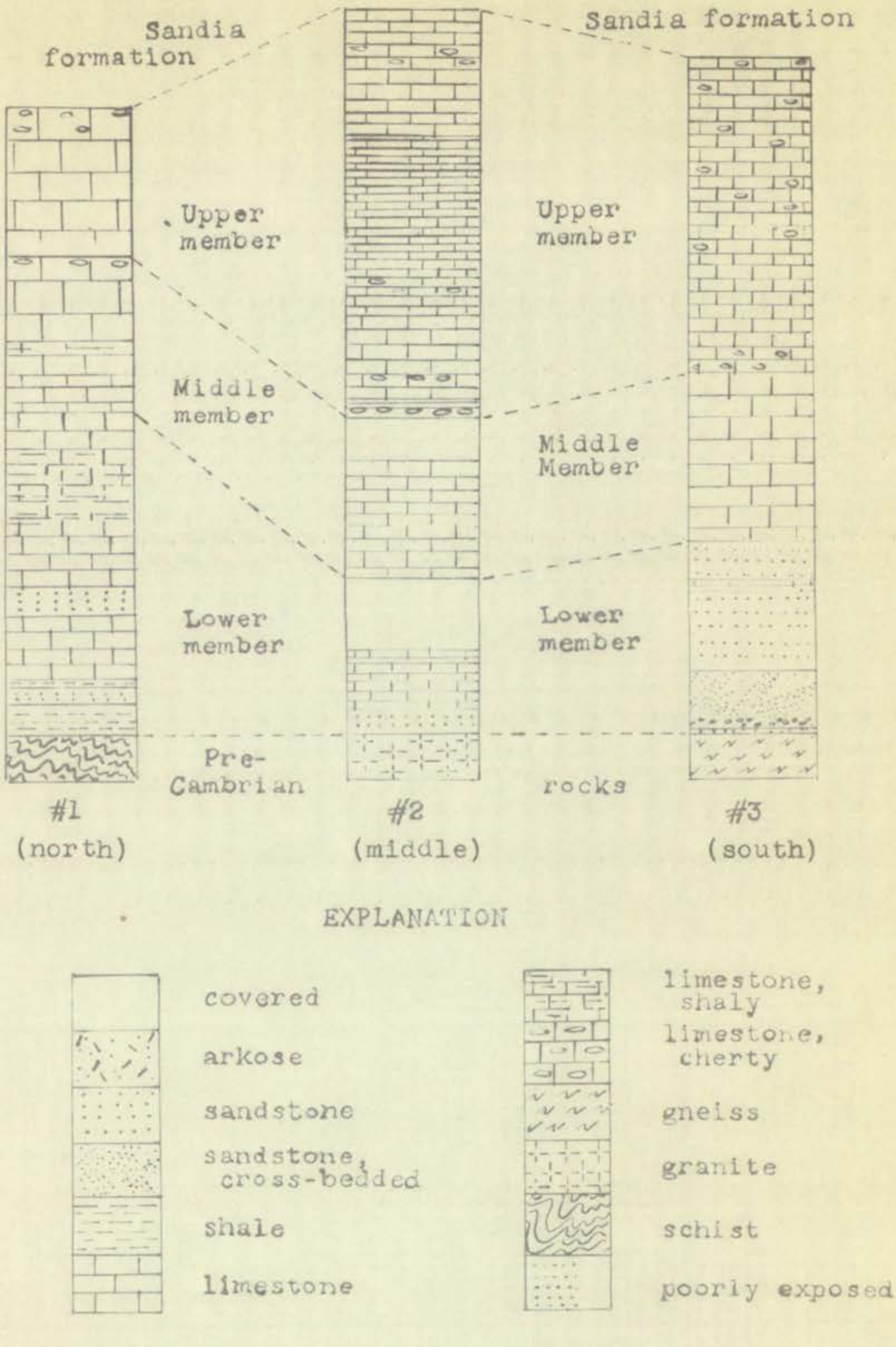
Caloso formation.

Laudon and Bowsher (p. 10) note that Kelly faunas approaching the Ladron area from the southeast are [illegible] and Arizona, and not extending far enough to the east to include the Lake Valley and Caballero of south-central New Mexico. This adds support to the statement by Mr. [illegible] that the Ladron fauna resembles the fauna of the Escabrosa more than that of the Lake Valley or Caballero, and emphasizes the need of reviewing the evidence which led to the previous dating of the Kelly.

In summary, the lithology of the Caloso bears some resemblance to the Lake Valley and [illegible] to the Kelly of [illegible] Canyon in the Lemitar Mountains, [illegible] miles to the south. However, the Caloso fauna appears dissimilar to the Lake Valley fauna and the Kelly fauna, having more in common with that of the Escabrosa of Arizona. The Caloso fauna is unique in the southern [illegible] New Mexico, and may well contribute to the solution of some of the Mississippian problems of this region.

FIGURE 2

GRAPHIC SECTIONS OF CALOSO FORMATION *



Vertical scale: 1 inch = 20 feet

* See pages 42, 43, and 44 for locations of sections.

TABLE 1

MEASURED SECTION (#1) OF CALOSO FORMATION*

Description	Feet
1. Limestone: gray, massive in part . . . . Basal 1 foot covered, mostly medium-granular, local crinoid zones (small fragments) at 14 feet from base. At 15½ feet from base, 6 inches of dark-brown-weathered, gray cherty limestone. At 16 feet from base, a 1 foot fragmental limestone bed. At 17 feet from base, a 1 foot cherty bed.	18
2. Limestone: gray, massive, fine-crystalline, some fine calcite veins . . . . Basal 2 feet, weathered brown, then weathered gray, becomes medium-granular at 3½ feet, becomes medium-bedded at 6 feet. Top 1½ feet, cherty, nearly black, 2 to 4 inch chert beds separated by limestone. Top 3 inches, mixed brown and white, medium-granular limestone.	10
3. Limestone: light gray, weathers brown, fine-crystalline, very slightly quartzose . . . . Top 1½ feet, shaly limestone, weathers olive drab, crystalline.	8.5
4. Limestone: . . . . Basal 1 foot, light gray, medium-granular, medium- to thick-bedded. At 1 foot, 7½ feet weathered brown, interbedded with 4 inch shale beds, crystalline. At 8½ feet, 3 feet the same as basal 1 foot bed. Top 3½ feet, pink to olive drab, weathers reddish brown, fine- to medium-crystalline, slightly quartzose, resistant.	15
5. Limestone: gray, medium-bedded, crystalline, partly conglomeratic, slightly quartzose, weathers to cobbles .	6
6. Sandstone: white, brown stain, medium-bedded, medium-grained, fair sorting, calcareous, more calcareous at top, slightly coarser at base	3.5
7. Limestone: gray, nodular, pebble to boulder size nodules, shale curved around nodules, poorly resistant . . .	7.5
8. Shale: gray, slightly micaceous, 2 or 3 laminae of coarse sandstone	1
9. Sandstone: light green stain, thin-bedded, fine to granulitic, sub-angular to sub-round, calcareous, resistant, slightly ferruginous, after basal 1 foot, grades into finer, highly siliceous sandstone	2
10. Shale: light green and dark purple, clayey, a few sandy laminae, unconformable on Pre-Cambrian	3.5
Schist: Pre-Cambrian.	
	75

* Located one half mile northwest of Juan Torres prospect.

TABLE 2

MEASURED SECTION (#2) OF CALOSO FORMATION*

	Description	Feet
1.	Limestone: gray, thin-bedded, medium-granular or medium-crystalline, poor crinoid traces at base, a few inches above, concentrically-banded white chert	36
	At 4 feet from base, scattered white chert lenses and nodules, several feet long but less than 1 foot thick, crinoid fragments more or less throughout.	
	Top 15 feet, medium-bedded and more massive in character.	
	Top 2 feet, reddish-brown, medium-crystalline, apparently unfossiliferous except for patches of crinoid fragments.	
	At 30-32 feet, gray, medium-crystalline, in white cherty zone, apparently an intraformational breccia.	
2.	Limestone:	10
	At 1 foot from base, light brown, some irregular black hematite stain, medium-crystalline, irregular weathering, occasional very small crinoid fragments weathered out on the surface in large numbers in some places.	
	At 4 feet from base, considerable white chert in rough-weathered limestone, weathers gray and brown.	
	At 5 feet, mostly covered, mostly gray and brown weathered limestone, rather similar to below, many small fragments of crinoids in gray limestone at approximately 9 feet.	
3.	Limestone: light brown to light gray, weathers brownish-green, very fine- crystalline, welded to top of cherty layer, some of it covering weathered-out fossils of cherty layer, apparently a disconformity or unconformity	1
4.	Chert:	1
5.	Covered:	5
6.	Limestone: light brown, scattered outcrops of limestone, bedding probably medium to thick, medium-crystalline, irregular resistance	14
	At 5 feet, limestone partly gray, at 9½ feet, brown again. At 11 feet, 3 feet of light mat gray, very fine-crystalline limestone.	
7.	Covered:	9
8.	Limestone: light gray, outcrops in places only, thin-bedded, medium-crystalline, surface looks slightly sandy, but "sand" is fine to medium calcite grains weathered out on dull mat surface.	7
9.	Sandstone: white, coarse-grained, fine pebble size in places, sub-round to sub-angular, including angular quartzite pebbles, well sorted in places, apparently calcareous cement, resistance only fair	3
	Granite: Pre-Cambrian	
		86

* Located 1 mile west of Mule Spring.

TABLE 3

MEASURED SECTION (#3) OF CALOSO FORMATION*

Description		Feet
1.	Limestone: gray, medium- to thick-bedded, slightly resistant . . . . Basal 3 feet contain irregular chert nodules, occasional chert nodules above 15 feet, crinoid fragments above 5 feet, becoming more numerous up the section.	37.5
2.	Limestone: dark gray, massive, fine-crystalline, resistant, nearly unfossiliferous	20
3.	Sandstone: massive, medium-grained, calcareous, pitted surface	5
4.	Limestone: dark gray, fine-crystalline, resistant . .	1
5.	Sandstone: pale green, weathers light purple, medium-bedded, fine-grained	9.5
6.	Sandstone: white, limonite stain on weathered surface, grades from granulitic conglomerate in basal 2 feet to coarse-grained sandstone, cross-bedded, predominantly quartz	7
7.	Arkose: probably residual, quartz fragments up to 1½ inches, sub-angular to sub-round, changes in thickness from 6 inches to 2 feet in 25 feet along strike . . .	0.5
	Gneiss: Pre-Cambrian.	
		80.5

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* Located 2 miles north of the Rio Salado.

Pennsylvanian System

The Pennsylvanian rocks are here designated as the Magdalena group, consisting of the Sandia formation and the Madera limestone. The Magdalena group is a name denoting the entire rock assemblage of the Pennsylvanian system in New Mexico. It was first applied by Gordon (1907b), and named for the development in the Magdalena Mountains of New Mexico.

The terms Sandia and Madera have persisted in spite of vacillatory usage by Keyes and a proposal by Thompson (1942, p. 22) that the term Madera be dropped and the term Sandia restricted to the Sandia Mountains section. Further subdivision and several other classifications of Pennsylvanian rocks have been made in some areas of the State, but none is widely used at the present time.

Sandia formation.

The term Sandia is derived from the mountains of the same name, where Herrick (1900, p. 115) used the term to include the lower Pennsylvanian clastic sediments and a few limestone beds. The name is now the most commonly used term, in the northern and central parts of the State, to include the lower, predominantly clastic, part of the Magdalena group. Its thickness varies considerably from one locality to another.

In the area studied, the Sandia formation is considered to include everything between the top of the Caloso formation

Pennsylvanian System

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The terms Sandia and Madera have [illegible] vacillatory usage by [illegible] Thompson (1942, p. 22) that the term Madera be dropped and the term Sandia restricted to the Sandia mountains [illegible]. Further subdivision and several other classifications of Pennsylvanian rocks have been made in some areas of the State, but none is widely used at the present time.

Sandia Formation.

The term Sandia is derived from the mountains of the same name, where Herrick [illegible] first used the term to include the lower Pennsylvanian clastics [illegible] limestone beds. [illegible] the term has been commonly used both in the northern and central parts of the State, to include the lower, predominantly clastic, part of the Magdalena group. Its thickness and lithology vary considerably from one locality to another.

In the area studied, the Sandia [illegible] to include everything between the base of the [illegible] unconformity and the base of the first massive limestone of the upper part of the Pennsylvanian. It is fairly well exposed along the steep eastern side of the hogback (see Plates 3, 8B) which lies along the entire western edge of the area. As a whole, the Sandia is a slope-former, and only a few of the sandstones and conglomerates show any degree of resistance.

The Sandia in this locality is relatively thick as compared to thicknesses to the north. It was measured in two places about 2 miles apart, and the thickness differs no more than would be expected in a deposit of this type. It is 642 feet thick in the southernmost measured section, about 2 miles north of the Rio Salado, but decreases northward to 402 feet in the northernmost measured section.

The Sandia formation alternates in thin to massive beds of fine to coarse clastic material with occasional thin fossiliferous limestone beds. Silty shale, sandstone, and granule conglomerate dominate the formation. Sorting and angularity of the fragments in the sandstones and conglomeratic rocks are highly variable. Cementing material is usually calcareous or siliceous, but ferruginous cementing material is also present. Iron stains of several colors are widespread.

Fossils are generally scarce and often lacking, except in a few highly fossiliferous strata. Notable among the fossiliferous rocks is a green, calcareous, micaceous shale which breaks off in slabs, the surfaces of which may be rich in partially weathered-out fossils, particularly brachiopods and the base of the first massive limestone of the upper part of the Pennsylvanian. It is fairly well exposed along the steep eastern side of the hogback (see Plates 3, 4B) which lies along the entire western edge of the area. As a whole, the Sandia is a slope-former, and only a few of the sandstones and conglomerates show any degree of resistance.

The Sandia in this locality is relatively thick as compared to thicknesses to the north. It was measured in two places about 2 miles apart, and the thickness differs no more than would be expected in a deposit of this type. It is 542 feet thick in the southernmost measured section, about 2 miles north of the Rio Salado, but decreases northward to 402 feet in the northernmost measured section.

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Fossils are generally scarce and often lacking, except in a few highly fossiliferous strata. Notable among the fossiliferous rocks is a green, calcareous, micaceous shale which breaks off in slabs, the surfaces of which may be rich in partially weathered-out fossils, particularly brachiopods and bryozoa. Some sandstones contain fossil plants.

Much speculation has been made concerning the origin and environment of deposition of the Sandia, but much has yet to be learned. Cursory observations of the locally highly quartzose formation suggest that it represents a slow or halting transgression of an epeiric sea over an old surface. Northward overlap is indicated in many places in the relationship shown in a number of sandstone-conglomerate beds. Mud cracks are suggested in some of the shales, and cross-bedding is obvious in several sandstones.

Counterparts of the Sandia formation would be expected to occur throughout a large part of the State, and such occurrences have been widely observed. In the northwest part of the Ladron Mountains, Kelley and Wood (1946) found the Sandia formation to be about 400 feet thick, in places underlain by granite and in places underlain by a few feet of limestone. The age of this limestone was undetermined, due to the lack of fossil evidence, but a pre-Pennsylvanian age was suggested as a possibility. Limestone separates the Sandia clastic sediments from the Pre-Cambrian in other localities to the north, where the age is also problematical. In some of these places, in particular the sections just northwest of the Ladron Mountains, this lowermost limestone might be correlative with the lower part of the Mississippian rocks of the southern Ladron Mountains area, since fossils are scarce or lacking in the lower part of the section.

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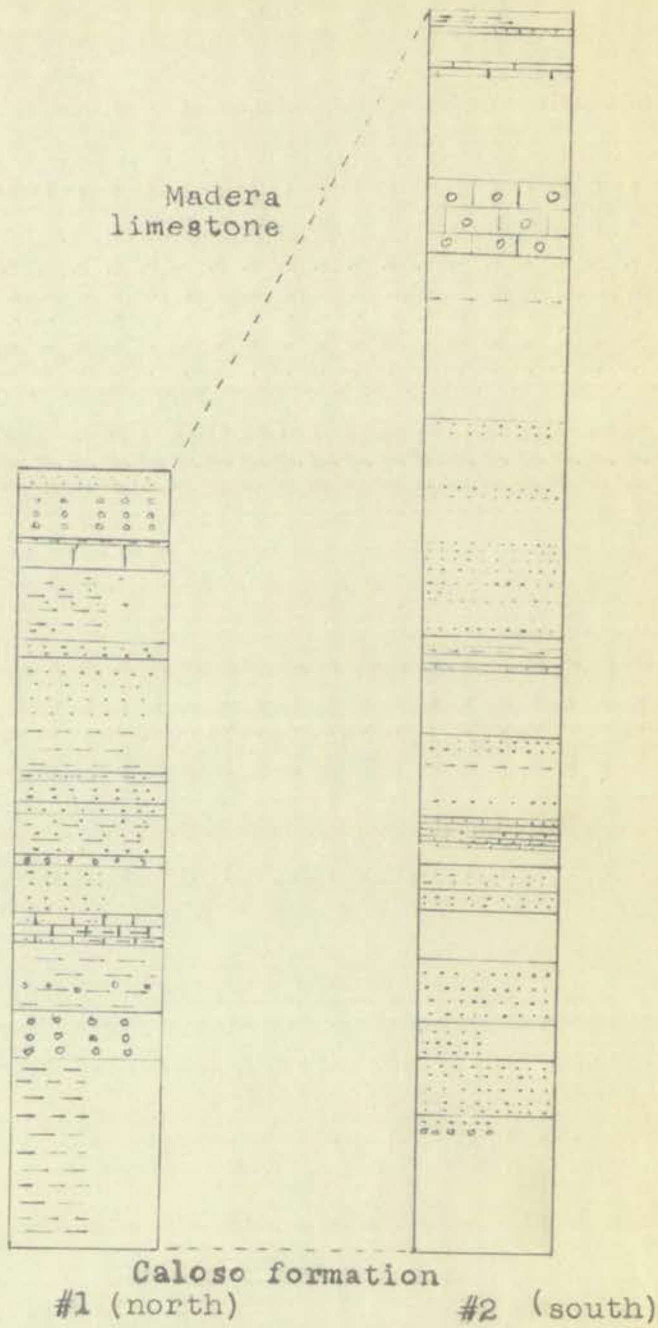
FIGURE 3

GRAPHIC SECTIONS OF SANDIA FORMATION *



1 inch = 100 feet
Symbols same as for Caloso Formation, p. 41.

* See pages 49 and 51 for locations of sections.

TABLE 4

MEASURED SECTION (#1) OF SANDIA FORMATION*

Description	Feet
1. Covered: indications of thin-bedded sandstone, fine to very fine, calcareous, micaceous, probably limier near top	8.5
2. Granulitic conglomerate: white, some iron stains, thick to massive-bedding, poor sorting, becomes finer at 12 feet, coarser at 20 feet.	29.5
3. Shale: calcareous, weak	2
4. Limestone: greenish gray, weathers dark olive drab with rusty spots, medium-massive beds (one 3½ foot bed near center), crystalline, hackly surface, 1 foot basal granule conglomerate, highly calcareous, limestone is fossiliferous, with brachiopods, crinoids, etc., medium-coarse crystalline, fossils are generally fine fragments throughout the rock, but near the top of the outcrop is almost a fossil slab at the top of one bed.	10
5. Covered: indications of shale, sandy in places . .	37
6. Sandstone: white, medium-thick-bedding, fine- to medium-grained, sub-angular to sub-round, fair sorting, becoming shalier and thinner-bedded with green stain, slightly calcareous and slightly micaceous. . . .	6
7. Covered: strong indication of greenish shale, then brown and red-stained white fine sandstone . . .	54
8. Sandstone: slightly green, greener and shalier at top, thick to medium-bedded, very fine, slightly shaly, shalier at top, siliceous, resistant "cross-bedding".	2.5
9. Sandstone: greenish with heavy brown and black iron staines, becomes massive at 9 feet, silty, slightly micaceous.	12
10. Sandstone and granulitic conglomerate:white with brown stain, thick- to thin-bedded, very fine- to medium-grained, cross-bedded, poorly sorted, resistant	6.5
11. Sandstone: with interbedded silty sand and shale, becoming shalier at 10 feet, dark green stains, heavy hematite stains on some surfaces, thin- to medium-bedded, sandstone is highly quartzitic, fine- to medium-grained, slightly micaceous.	21
12. Quartzite conglomerate: a medium sandstone with very irregular beds and pockets containing angular quartz pebbles ½ inch in diameter, iron stains irregular, often deep stains around cracks and pockets . . .	14

* Located one half mile northwest of Juan Torres prospect.

TABLE 4

MEASURED SECTION (#1) OF SANDIA FORMATION (cont.)

Description	Feet
13. <u>Covered</u>: indications of fine sandstone	27.5
14. <u>Limestone</u>: heavy black hematite stain and brown <u>limonite</u> stain, interbedded with highly siliceous sandstone and shale, thin- to medium-bedded . . .	4.5
15. <u>Shale</u>: light gray with iron stain in fractures, 3 foot conglomeratic bed at 12 feet, becomes more fissile at 30 feet.	46
16. <u>Granule conglomerate</u>: poorly sorted, bottom 1 foot <u>contains not many</u> quartz and limestone pebbles up to 2 inches, weathers, white with slight iron stain, iron stains give banded structure characteristic of rhythmic precipitation, thick-bedded to massive, sub-angular, calcareous	22
17. <u>Covered</u>: indications of calcareous shale	99
	402

TABLE 5

MEASURED SECTION (#2) OF SANDIA FORMATION *

Description	Feet
1. Covered: shale indicated in lower half	16
2. Conglomerate: slight iron stain, cross-bedded, medium sand to pebble sizes, angular to sub-angular, siliceous, grades into sandstone in top few inches	3
3. Covered:	9.5
4. Limestone: dark gray, weathers dark greenish-brown, thick-bedded, shaly partings at 1½ feet and 3 feet, slightly fossiliferous, shaly partings are more fossiliferous	4
5. Covered:	51
6. Intraformational breccia type: with limestone nodules of 1 to 6 inches in a fissile calcareous shale, slightly fossiliferous, toward the top the limestone is in the form of lenses interbedded in shale, lenses of both limestone and shale are thicker at top (up to 3 feet thick), portions of top partly covered . . .	39
7. Covered: . . . . At 62 feet from base, 2 feet of fissile, non-resistant shale.	84
8. Partially covered with many outcrops: . . . . Basal 1½ feet sandstone, iron stained, slightly cross-bedded, sub-angular to sub-round, poorly sorted, calcareous, very slightly fossiliferous. At 1½ feet from base, 1 foot covered. At 2½ feet, 1 foot sandstone, iron stain particularly in fractures is slightly greener, sub-angular, calcareous, some feldspar, nearly ½ brachiopods lying parallel to bedding. At 3½ feet, 13 feet covered. At 16½ feet, 15 feet sandstone, probably slightly cross-bedded, very poorly sorted, coarser going up, some calcareous cement, highly quartzose, bottom 3 feet more resistant, non-fossiliferous until top 7 feet which are slightly fossiliferous. At 31½ feet, 4 feet covered. At 35½ feet, 3 feet sandstone, calcareous, few coarse quartz grains, non-resistant, highly fossiliferous, with fossils greater than sand, all fossil fragments small. At 38½ feet, 10 feet sandstone, slight brown stain, medium-bedded, medium- to coarse-grained, well sorted. At 48½ feet, 25 feet covered.	112.5

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* Located 2 miles north of the Rio Salado.

TABLE 5

MEASURED SECTION (#2) OF SANDIA FORMATION (cont.)

	Description	Feet
	At 73½ feet, 5 feet sandstone, thick-bedded, becoming thin-bedded higher in the section, fine- to coarse-grained, sub-angular to sub-round, calcareous, slightly fossiliferous. At 78½ feet, 29 feet covered. At 107½ feet, 5 feet sandstone, light gray-green, fine to very fine, quartz grains, slightly micaceous, partly covered.	
9.	Covered:	7
10.	Shale: pistachio green, thin-bedded, sandy, calcareous, slightly micaceous	5
11.	Covered:	5
12.	Limestone: highly fossiliferous, crinoid stems, brachiopods	1
13.	Covered:	35
14.	Covered largely with occasional outcrops: . . . At 12 feet from the base, a 3 foot resistant layer of highly siliceous sandstone, light green, very fine-grained. At 27 feet, a 5 foot resistant layer of silty shale, iron stain, shiny hematite stain on top part, slightly calcareous. At 32 feet, 2 feet covered. At 34 feet, 1 foot of sandstone, gray-green, slight iron stain, fine to coarse, contains weathered feldspar grains, highly siliceous. At 35 feet, 6 feet covered. At 41 feet, 2 feet of sandstone, dark-green, very fine, fine particles of red iron material, highly siliceous.	43
15.	Sandstone: greenish black, very fine-grained, silty, fine interstitial limonite, slightly resistant. . .	2
16.	Covered:	3
17.	Sandstone: granulitic and slightly conglomeratic with fine to medium ground mass, highly siliceous . . .	4
18.	Sandstone: conglomeratic with granulitic ground mass, fine interstitial limonite, sub-angular, highly siliceous	4
19.	Sandstone: light gray, iron stains penetrate ½ inch along fractures, very fine, silty, resistant . . .	1
20.	Covered:	9

TABLE 5

MEASURED SECTION (#2) OF SANDIA FORMATION (cont.)

	Description	Feet
21.	Sandstone: light gray on fresh surface, iron stained on weathered surface, highly siliceous	14
22.	Sandstone: light green, very fine, silty, resistant .	10
23.	Covered:	25
24.	Sandstone: similar to #23, but less resistant, 1 foot of granulitic quartz conglomerate 3 feet from top. .	33.5
25.	Covered: probably similar to #24, but more shaly and less iron stain	17.5
26.	Sandstone: light gray on fresh surface, iron stains penetrate $\frac{1}{2}$ inch along fractures, very fine, silty, resistant.	33.5
27.	Covered: top 2 to 3 feet have indications of the same as #26 . . . . 5 feet from the top are indications of a white granulitic conglomerate.	71
		642.5

Madera limestone

The term Madera was first applied by Keyes (1903) to certain Upper Pennsylvanian limestones in the Sandia Mountains region, but his later usage of the term was inconsistent. Madera is now widely used in New Mexico, especially in the northern and central parts of the State, as an inclusive term to take in all Pennsylvanian rocks above the Sandia. It consists chiefly of limestone.

In the southern Ladron Mountains area, it is present chiefly as the upper part of the hogback (see Plate 2B), the lower portions of which contain the Sandia formation and the Mississippian section. The Madera is a relatively resistant formation which exists as a "rim" in many exposures throughout the Rio Grande region.

Much of the upper Madera is eroded far back down the western slope of the hogback; thus, a complete section is not found in the mapped area. However, Kelley and Wood measured about 1,900 feet of Madera near the northwest corner of the Ladron Mountains. They divided the Madera into three members, the lower or Gray Mesa member, the Atrasado member, and the upper or transitional Red Tanks member.

In the southern Ladron Mountains area the Madera is largely composed of limestones, many of them massive beds of 20 feet and much greater in thickness. Cherty limestones are predominant throughout some parts of the section, especially the lower parts. Fossils are typical of the Madera of other regions.

Strata of the Madera are predominantly marine, resulting from deposition in the sea which transgressed the region in Sandia time. Some of the uppermost strata may represent a transition to terrestrial deposition of Abo (Permian) time.

Counterparts of the Madera are found under the same name throughout large areas of the State. It represents the first thick limestone formation to be deposited, or at least to be preserved, north of latitude 34° 20' in New Mexico.

Permian System

Abo(?) formation

Small outcrops of dark-red, ferruginous sandstone and siltstone are found, chiefly in the region of Bug Spring, along the Cerro Colorado fault. These highly fractured rocks in many places are much pulverized. Their similarity to the Abo sandstone[3] elsewhere and their association with limestones of Mississippian and Pennsylvanian age along the fault suggest that they are Abo in age.

The Abo formation is found a few miles to the west (Kelley and Wood), where it lies as a continental deposit over the Madera limestone. Kelley and Wood consider the Red Tanks member of the Madera a transition from marine Pennsylvanian deposition to continental Abo deposition of probable Permian age.

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[3] Named by Lee, 1909.

Yeso formation

A single massive outcrop of gypsum occurs along the Cerro Colorado fault zone in the southern tip of the range. This gypsum is almost certainly a part of the Yeso[4] formation, for no other formation associated with the late Paleozoic rocks of this general area contains evaporites in any quantity.

Some or all of the narrow outcrops in the Cerro Colorado fault zone which are designated Abo(?) may actually belong to the Yeso formation, particularly the limy and lightly red-stained outcrops of highly fractured sediments.

The Yeso formation overlies the Abo formation a few miles to the west of the Cerro Colorado fault. The Yeso of the Cerro Colorado fault zone may be equivalent to part of the Los Vallos, or upper, member of the Yeso formation as described by Kelley and Wood (Op. cit.).

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[4] Named by Lee, 1909.

Cenozoic Rocks

General Statement

Cenozoic rocks are not of great concern to this report. They are present only along the south and southeast borders of the area.

The Tertiary Popotosa and Santa Fe(?) formations are discussed only briefly because of the incomplete sections present. Quarternary deposits consist of valley alluvium and terrace gravels, and may include the formation herein described as Santa Fe(?).

Popotosa Formation

The Popotosa formation was first described by Denny (1940, pp. 77-84), who gives no origin for the name, although an Arroyo Popotosa, east of the area in this report, is indicated on his map. The formation occupies several tens of square miles in the area east of the Ladron Mountains, and south of the Rio Salado in the San Acacia Hills and Lemitar Mountains. Thick exposures are present in the Box Canyon of the Rio Salado (Plate 9A), but only a part of its total thickness is exposed in the area covered by this report. Although it weathers easily into covered slopes, vertical ledges of the formation are prominent along some of the arroyos, particularly along the lower part of Mule Spring Canyon. Denny (p. 80) estimated that it has a probable minimum thickness of 3,000 feet and a possible maximum of 5,000 feet.

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General Statement

Cenozoic rocks are not of great concern in this report. They are present only along the southern and [illegible] edges of the area.

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Popotosa Formation

The Popotosa formation was first described by Denny (1940, pp. 77-84), who gives no origin for the name, although an Arroyo Popotosa, east of the area in this report, is indicated on his map. The formation occupies several tens of square miles in the area east of the Ladron Mountains, south of the Rio Salado [illegible] Mountains. Thick exposures are present in the [illegible] of the Rio Salado (Plate 2A), but only a part of the total thickness is exposed in the area covered by this report. Although it weathers easily into gentle slopes, resistant ledges of the formation are prominent along some of the arroyos, particularly along the lower part of [illegible] Canyon. Denny (p. 80) estimated that in his area [illegible] minimum thickness of 3,000 feet and a [illegible] of 5,000 feet.

The Popotosa of the mapped area is best described as a purple to brown, well-cemented fanglomerate composed very largely of a variety of volcanic rocks, varying in size from sand to boulders. Occasional fragments of pre-Tertiary rock are present.

The deposit appears to be a fan deposit derived chiefly from volcanic accumulations of breccias, flows and tuffs. The great predominance of volcanic debris and its considerable volume indicates prior or contemporaneous volcanic activity on a fairly large scale. The distribution and the fragment size of the Popotosa, plus its content of Pre-Cambrian rocks resembling those of the Ladron region, strongly suggests a very local origin.

Denny (p. 81) in his studies of Tertiary geology of the San Acacia "tentatively" considered the formation to be of late Miocene age.

Santa Fe(?) Formation

The name Santa Fe was first applied by Hayden (1869) to certain upper Tertiary deposits of the Rio Grande region of New Mexico. The Santa Fe(?) is found principally in the southwestern part of the mapped area, where it lies unconformably on Paleozoic and Popotosa rocks. It is found in small patches in the Cerro Colorado fault zone. It is resistant enough to stand up in cliffs in the sides of the arroyos. A complete section of the formation could not be measured in the Ladron area. Denny (p. 93) states that the formation probably has a minimum thickness of 2,000 feet in the Rio

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Salado area.

The lithology of the Santa Fe(?) in this location can be summed up by calling it a poorly-sorted alluvial fan deposit consisting almost entirely of limestone fragments in a matrix of what was apparently a limy mud. Only a few fragments of volcanic and Pre-Cambrian rock are included. Sizes of limestone fragments range up to boulders well over 6 feet in diameter in places, but pebble and cobble sizes predominate. Sub-angular to sub-round particles make up most of the deposit. The particles are very firmly cemented in a fine, calcareous matrix which usually weathers to a light limonitic tan.

Although a river deposit in many places, the Santa Fe(?) here is obviously a locally-derived fan deposit, whose particle size increases greatly as it approaches the base of the limestone hogback. A close dating of the Santa Fe(?) in this area is not possible, but Denny's (p. 93) work on the Tertiary geology in the region indicated to him that it is Middle to Upper Pliocene in age. According to him, it is correlative with basin deposits throughout much of the Rio Grande depression.

The term Santa Fe, in this report, is followed by a query because of the possibility that the gravels actually are of Quaternary age. They are locally derived and, except for the occurrences along the Cerro Colorado fault, have been largely undisturbed. Solution of the problem

of the age of the deposit will require a more exact dating of the structure than was possible on the basis of observations made in the mapped area.

Denny, in his study of the Tertiary geology of the San Acacia area, has designated the deposit as Santa Fe. Because his studies embraced an extensive area, a digression from his nomenclature in this report is not felt justifiable.

Calcareous tufa deposits, evidently spring deposits, are found at the top of the gravels in at least two places in the southwestern portion of the mapped area. One of these spring deposits is of special interest in that it apparently was deposited over a mud in which many bee-like insects had their capsules. The age of the insects was not determined, but is believed worthy of investigation.

Quaternary Deposits

Deposits of this age were not considered in detail. They consist chiefly of terrace or pediment gravels of uncertain history and limited alluvial deposits along the north bank of the Rio Salado. The alluvium was mapped, but residual mantle and pediment gravels were omitted. The formation mapped as Santa Fe(?) may be Quaternary in age, as mentioned above.

The pediment gravels are too dissected to be easily correlated with pediment gravels covering the several erosion surfaces so noticeable nearby. These gravels are also in places indistinguishable from what may be Sants Fe(?)

of the age of the deposit will require a more exact dating of the structure than was possible on the basis of observations made in the mapped area.

Denny, in his study of the Tertiary geology of the San Acacia area, has designated the deposit as Santa Fe. Because his studies embraced an extensive area, a digression from his nomenclature in this report is not felt justifiable.

Calcareous tufa deposits, evidently spring deposits, are found at the top of the gravels in at least two places in the southwestern portion of the mapped area. One of these spring deposits is of special interest in that it apparently was deposited over a mud in which many bee-like insects had their capsules. The age of the insects was not determined, but is believed worthy of investigation.

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gravels which have become uncemented due to weathering. The alluvium along the river is unconsolidated and variable in texture and composition.

The river has cut through alluvial material which was deposited at a higher stage over a broader area (see Plate 9B). The recency of this downcutting is apparent in several ways, one of the most obvious indications being the lack of adjustment of the tributaries to the main stream in the southwest corner of the area.

gravels which have become unconsolidated by weathering. The alluvium along the river is unconsolidated and variable in texture and composition.

The river has cut through alluvial material which was deposited at a higher stage (early Wisconsin? (see Plate 2B). The recency of this downcutting is shown in several ways, one of the most obvious indications being the lack of adjustment of the tributaries to the main stream in the southwest corner of the area.

STRUCTURE

Regional Setting

The Ladron Mountains are located in the Mexican Highland section of the Basin and Range Province, very near Fenneman's boundary separating this province from the Colorado Plateaus Province. The range is on the west edge of the Rio Grande trough, immediately southeast of the greater part of the Lucero Uplift.

Folds

Folds in the southern Ladron Mountains fall into three categories, those in the Pre-Cambrian only, those in the Paleozoic strata, and those caused by compression and drag along faults.

The Pre-Cambrian folds are closed, or possibly isoclinal, as suggested by the steeply-dipping metasediments. These metasediments in general have a north-northeast strike, and dip eastward at angles ranging from 30° to 75°.

The most obvious fold in the Paleozoic strata is shown by the westward-dipping hogback. This hogback is the east limb of a synclinal bend. The strike of the Paleozoic beds is roughly north-south.

A noticeable fold can be seen in the metamorphic rocks adjacent to the Ladron fault (see Plate 1). This fold was apparently caused by forces acting generally north and south,

resulting in a relatively northwestward movement of the southwest side of the fault. Many small-scale drag folds are found along faults in the Paleozoic strata. Most of these folds are located along the curving, and roughly east-west, fault which passes through the limestone hogback slightly over a mile north of the Rio Salado. Here they indicate a relatively eastward movement of the rocks south of the fault. A small fold in Pennsylvanian limestone in the Rincon area (see Plate 1) has apparently also resulted from compressional forces from the southwest.

Faults

The faults of this area are products of compressional and tensional forces, probably occurring in three or more separate episodes. Both types of movement are represented in the same faults or fault zones. The two greatest faults, the Cerro Colorado fault and the Ladron fault, trend generally northeastward and northwestward, respectively.

Along the Ladron fault in the north-central part of the area, there is evidence of a strike-slip movement of considerable magnitude in the Pre-Cambrian terrane, the south side of the fault moving northwestward relative to the north side. The granite and schist outcrops on opposite sides of the fault show considerable separation, but the exact nature of the movement cannot be determined. Farther northwest along the Ladron fault, in the northwest corner of the mapped

resulting in a relatively northwest [illegible] of the south-
west side of the fault. [illegible]-slip [illegible]
found along faults in the Paleozoic strata. [illegible]
folds are located along the [illegible], [illegible] northwest-
fault which [illegible]
over a mile [illegible] are [illegible]
relatively [illegible] movement [illegible] of the fault.
A small fold in [illegible] in the [illegible]
(see Plate 1) [illegible]
forces from the southeast.

The faults of this area are products of compressional and tensional forces, probably occurring in [illegible] separate episodes. Both types of [illegible] in the same faults or fault zones. [illegible] the Cerro Colorado fault [illegible] northeastward [illegible].

Along the [illegible] fault in the [illegible] part of the area, there is evidence of [illegible] of considerable magnitude [illegible], the [illegible] side of the fault moving [illegible] relative to the [illegible] side. The [illegible] the fault show considerably [illegible] of the movement cannot be determined. [illegible] along the [illegible] fault, [illegible] area, Pennsylvanian limestone has been faulted against Pre-Cambrian rocks by a movement which apparently was essentially vertical.

The other large fault in this area, the Cerro Colorado fault, is actually a fault zone, with a general northeasterly trend in the mapped area. Only a relatively small part of the fault is found within the mapped area, and exposures are limited because of the presence of much unconsolidated material. Like the Ladron fault, the Cerro Colorado fault or associated faults show evidence of different types of movement. The fault extending from the main fault zone westward through the hogback apparently has experienced some strike-slip movement. The east side of the Cerro Colorado fault zone has a great vertical displacement, as indicated by the downfaulting of the Tertiary Popotosa formation against Pre-Cambrian rocks.

A noticeable scarp is present in places in the Cerro Colorado fault zone where the coarse-grained Pre-Cambrian gneiss abuts younger formations. Brecciation can be observed in many places in the gneiss. The fault zone is essentially the zone separating the Pre-Cambrian rocks from the Tertiary rocks to the east, but outcrops of various rocks of intermediate age occur throughout the fault zone in the mapped area. These intervening outcrops appear to be slices in the fault zone.

Origin of Structures

The steep attitude of the eastward-dipping metasediments is believed to have been the result of deep folding. The attitude of these metasediments was probably even steeper, and possibly nearly vertical, before the rotation accompanying the high-angle Tertiary faulting.

The Ladron fault may be the earliest fault in this area. The fact that the horizontal separation in the metamorphic rocks is apparently not recorded in the overlying Mississippian and Pennsylvanian rocks indicates a pre-Mississippian age for the fault. The lack of evidence of early Paleozoic disturbances in this region further suggests a Pre-Cambrian age. The relationship of the fault to the granitization episode is not clear, but the absence of a granitized border zone where the schist and granite meet, and the suggestion of a fault contact between the quartzite and granite in Structure Section A-A', Plate 1, indicate that granitization took place before the faulting. This would suggest a post-granitization, Pre-Cambrian age for the movement.

The small fold just southwest of the Ladron fault, in the Rincon area, indicates a probable compression from the southwest. This fold is apparently broken off by later, normal, dip-slip movement in the opposite direction along the Ladron fault during the late uplifts of the mountains.

The south side of the fault which passes through the

Origin of Structures

The steep attitude of the Precambrian metasediments is believed to have been developed very early. The attitude of these metasediments was probably steep [illegible], and possibly nearly vertical, before the intrusion accompanying the high-angle [illegible].

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The small fold [illegible] of the [illegible] in the Rincon area, indicates a probable compression from the southwest. This fold is apparently [illegible] normal, dip-slip movement on the [illegible] the Ladron fault during the late [illegible].

The south side of the fault [illegible]

hogback was probably moved eastward by the compressive forces mentioned above. This fault is considered a part of the Cerro Colorado fault zone, because it is possible that the zone may have undergone movement or become weakened by the same compressional force from the west.

The normal(?) faults responsible for the downfaulting of the Popotosa and Santa Fe(?) formations are believed to have followed this compressional episode. Slivers of Santa Fe(?) gravels in the eastern part of the Cerro Colorado fault zone closely resemble gravels which lie nearly undisturbed on the faults resulting from the compressional episode.

The faults shown in the southern part of the map (Plate 1) are all inferred, as no surface exposures were observed. It is felt necessary to map a fault between the small outcrop of Popotosa and the Madera limestone because the Popotosa, younger in age, is found at a considerable lower altitude in the outcrop. The north-south cross-faults are inserted to account for the different elevations at which equivalent Madera limestone outcrops are found.

The vertical separation or throw of the Cerro Colorado fault was not determined in this area, for the thickness of the downfaulted Popotosa formation is not here known, and the fault may not be a simple gravity fault. However, a projection of the dips of the Paleozoic rocks permits an estimation of the vertical separation to which the fault-zone occurrences of Paleozoic rocks have been subjected. This

measurement apparently increases northeastward along the fault, from a minimum of about 3,000 feet near the Rio Salado to a maximum of over 4,000 feet where Mule Spring Canyon crosses the Cerro Colorado fault zone. To these figures should be added at least the thickness of the Popotosa formation at these locations. The maximum vertical separation of the Cerro Colorado fault zone would then far exceed 5,000 feet.

The exact ages of any of the faults are not directly determinable on the basis of evidence found in the mapped area. Denny (p. 98) places the time of greatest movement along the Cerro Colorado fault in post-Popotosa-pre-Santa Fe time. This report would be more exact, if the age of the gravels mapped as Santa Fe(?) could be determined satisfactorily. For reasons stated previously in this report (p.59) the gravels mapped as Santa Fe(?) are very possibly Quaternary in age. If this is true, movement along the Cerro Colorado fault has taken place in Quaternary time. The presence of a scarp (p. 64) also supports the argument in favor of recency of faulting, although differential erosion may be responsible for the maintenance of this scarp.

In summary, there is evidence that there may have been compressive force applied in Pre-Cambrian time from the south. The next recorded earth movements apparently were measurement apparently increases northeastward along the fault, from a minimum of about 3,000 feet near the Rio Salado to a maximum of over 4,000 feet where Mule Spring Canyon crosses the Cerro Colorado fault zone. To these figures should be added at least the thickness of the Popotosa formation at these locations. The maximum vertical separation of the Cerro Colorado fault zone would then far exceed 5,000 feet.

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In summary, there is evidence that there may have been compressive force applied in Pre-Cambrian time from the south. The next recorded earth movements apparently were brought about by compressive force from the southwest, probably in Tertiary time. Normal faulting followed the relaxation of the compression, probably in late Tertiary and/or Quaternary time.

GEOLOGIC HISTORY

The first event recorded in this area was the accumulation of thick sequences of sandstone and shale during Pre-Cambrian time. These were subsequently folded, faulted, metamorphosed, and finally invaded by granitic material which effected considerable granitization.

Extensive erosion reduced the Pre-Cambrian terrane to a near-peneplain by Mississippian time, but resistant rocks such as the Blue Canyon quartzite may have stood higher than their surroundings. Slight subsidence, or a rise in sea level, in early Mississippian time was evidently the first opportunity of seas from the southwest to invade this region. However, Mississippian sediments were either not deposited in later Mississippian time or were removed by subsequent erosion.

After a possible minor orogeny related to disturbances in the Colorado and Ouachita regions, an undetermined amount of erosion preceded the deposition of sediments of early Pennsylvanian age. The thick Sandia, or basal Pennsylvanian, formation probably represents the transgression of a shallow epeiric sea over a weathered Pre-Cambrian and Mississippian surface. Later Pennsylvanian sediments were largely limestones deposited in a widespread shallow sea. A marine regression is indicated by the Abo(?) redbeds, but the overlying Yeso, with its occasional evaporites, suggests repeated evaporation of the sea water in an arid climate.

Mesozoic deposition is not recorded in this area, but sediments of this age were undoubtedly present and subsequently removed by erosion.

Probably in early Tertiary time, compressive forces from the southwest resulted in folding and thrusting. Relaxation of compressive forces was apparently responsible for large-scale normal faulting, a process which is believed to have continued into Quaternary time.

The conglomeratic Popotosa formation of Tertiary age represents a basin deposit derived by erosion of volcanic material from sources in or near the present Ladron Mountains area. Present-day processes are chiefly erosion and dissection.

ECONOMIC GEOLOGY

There are very few prospects or mineral deposits in the southern part of the Ladron Mountains. Most of the mineral deposits are little more than shows. Of these, fluorite and copper have been prospected and a little lead and manganese were observed. The only prospect of any size is the Torres prospect near Cement Tank Spring (see Plate 1). According to Lasky (p. 89), "Fluorite is prominent, and a small amount of fluorspar is the only shipment made from the prospect. The copper mineralization ... seems to have been ignored."

A few small garnet crystals were uncovered in a prospect in the Pennsylvanian rocks about half a mile north of the Rio Salado, near the top of the hogback. They probably were the result of contact metamorphism resulting from the intrusion of a shaly limestone by a diabase dike.

Hot spring deposits in the vicinity of the Cerro Colorado fault in several places apparently were the reason for a few small prospects dug in these places.

Water supplies are scarce. There are no perennial streams in the area, and ground water must be replenished by local precipitation. At one place, Cement Tank Spring, there is a small cattle tank. The supply for this is probably the intersection of a fracture system in the Pre-Cambrian rocks by the Ladron fault. Three or four other springs are present, most of them also located along faults.

In summary, this area appears to contain no mineralization of commercial grade, and very little available ground water.

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PLATE 2

Panorama of the Ladron Mountains, looking west from a point 9 miles west of U. S. Highway 85. a) Popotosa formation, b) Cerro Colorado, c) hogback, d) South Ridge, e) South Peak.

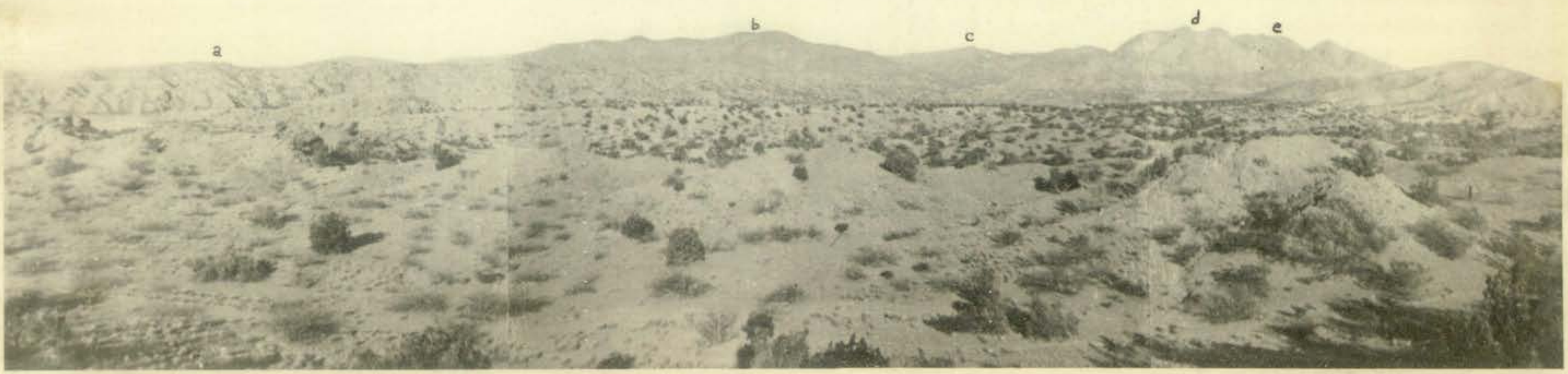
a
b
c
d
e

PLATE 3

Ladron massif from the south. Photograph taken from a point half a mile northwest of the base of Cerro Colorado. a) Capirote granite, b) Caloso formation, c) Sandia formation, d) Madera limestone, e) Blue Canyon quartzite.

PLATE 3

Ladron massif from the south. Photograph taken from a point half a mile northwest of the base of Cerro Colorado. a) Capirote granite, b) Kelly limestone, c) Sandia formation, d) Madera limestone, e) Blue Canyon [illegible].


e
a
b
c
d

PLATE 4

A. Granitized quartz-mica schist. Hammer lies on schist remnant. Flat-surfaced rock near the top of the shadow at the left shows an early stage in granitization. The location is the southwest base of Cerro Colorado.

B. View of Cerro Colorado from the northwest.

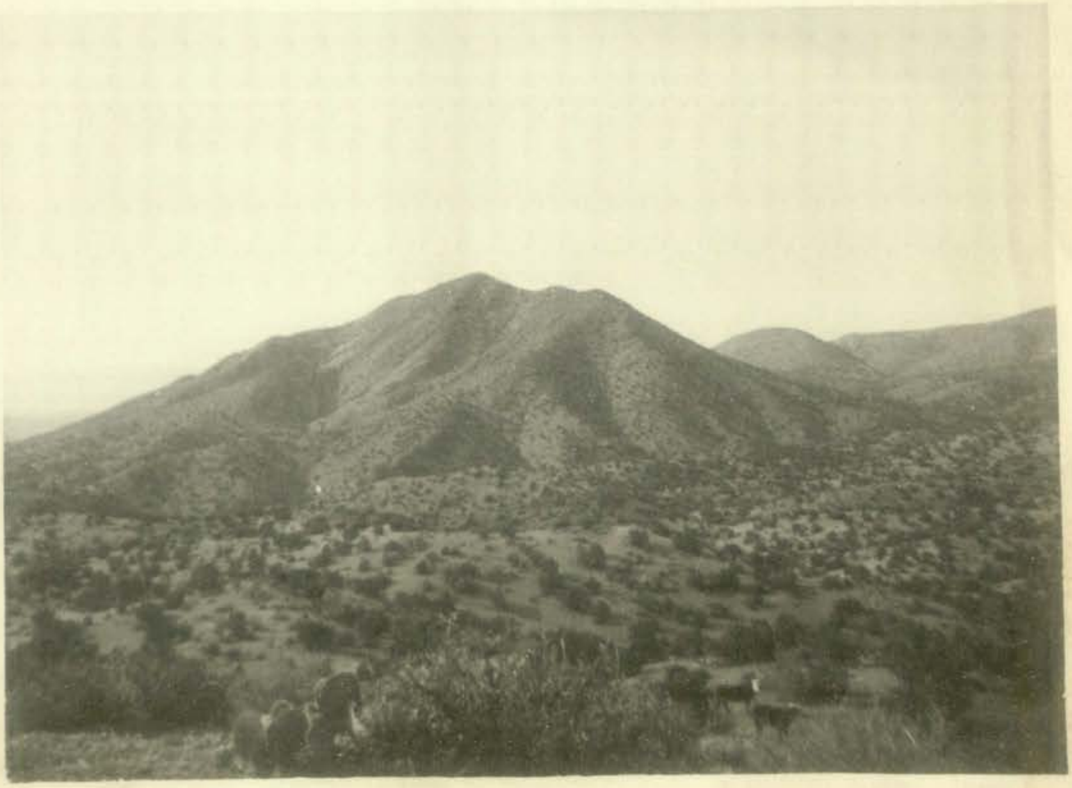

PLATE 5

A. Weathered boulders of Bug Spring gneiss. The location is the southwest base of Cerro Colorado, looking north to the Ladron massif (South Ridge). The massive resistant limestone in the ledge in the left center is the middle member of the Caloso formation.

B. Dike-like schist remnants, slightly granitized, in fine-grained granitic gneiss. The location is Mule Spring Canyon.

A. Weathered boulders of [illegible] well exposed in the southwest base of [illegible], [illegible] the Ladron massif [illegible] range. [illegible] resistant limestone in the ledge [illegible] the middle member of the [illegible] formation.

B. Dike-like [illegible] remnants, [illegible], in a de- graded [illegible] rocks [illegible] Spring Canyon.

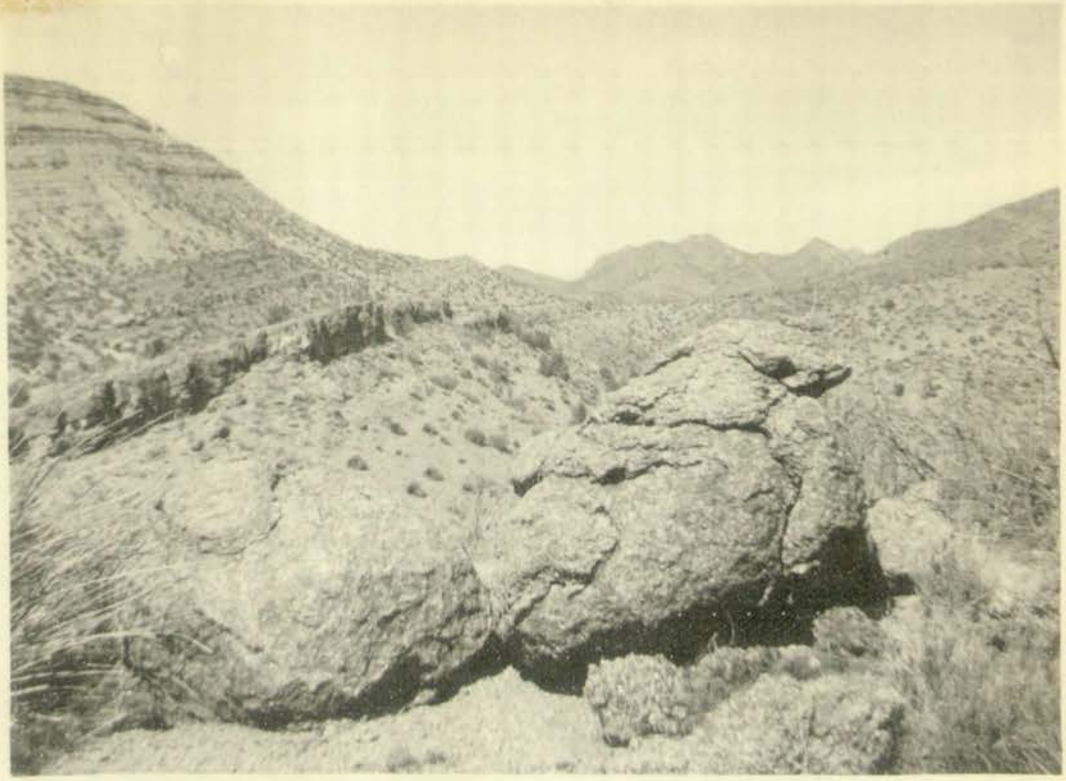

PLATE 6

A. Basalt dike, at right, intruding contorted and partly granitized schist. The location is Mule Spring Canyon.

B. Andesitic or basaltic dike, intrusive in the Sandia formation. The location is one fourth of a mile east of the canyon through the hogback, in the next arroyo south of Caloso arroyo.

PLATE 8

A. Basal Mississippian sandstone, showing ripple marks. The Pre-Cambrian schist lies 2 feet below, in the shadow at the right center. The location is near the head of Caloso arroyo. The west slope of Cerro Colorado may be seen at the top right.

B. Hogback west of Cerro Colorado. Figure in lower left gives scale. a) Caloso formation, b) Sandia formation, c) Madera formation.

A. Basal Mississippian sandstone, showing ripple marks. The Pre-Cambrian granite lies 2 feet below, in the shadow at the right center. The location is near the head of Caloso arroyo. The west slope of Cerro [illegible] may be seen at the top right.

B. Looking west at [illegible]. Figure in lower left gives scale. a) Caloso formation, b) Sandia formation, c) Madera formation.


c
b
a

PLATE 9

A. Popotosa formation in the Box Canyon of the Rio Salado.

B. Canyon of the Rio Salado through the Paleozoic hogback. Vertical cliff of Quaternary alluvium in the right center. The white precipitates are salts, hence the name Rio Salado.