MEMOIR 11

Geology of Part of the Southern Sangre de Cristo Mountains, New Mexico

Stratigraphy, Structure, and Petrology of the
Tesuque—Velarde—Tres Ritos—Cowles
Thirty-Minute Quadrangle

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Pecos Baldy Lake and trace of north-south Jicarilla fault

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DEDICATION

To the memory of our coworker and comrade

JOHN PRESTON MILLER

January 5, 1923—July 29, 1961

Contents

Illustrations

FRONTISPIECE

Panorama of Pecos Baldy Lake and trace of north-south Jicarilla fault

Abstract

Precambrian metasedimentary and metaigneous rocks, Paleozoic sedimentary rocks, and Cenozoic sedimentary deposits and igneous rocks are exposed in the Tesuque—Velarde—Tres Ritos—Cowles thirty-minute quadrangle. The mapped area includes the main central and western parts of the southern Sangre de Cristo Mountains in north-central New Mexico and a part of the Rio Grande depression to the west.

Precambrian rocks, mostly exposed in the highest ridges as well as the deepest canyons of the mountains, consist of the older, metasedimentary Ortega Formation and the younger, chiefly metaigneous Vadito Formation, both intruded by the Embudo Granite. The Ortega Formation includes a lower 10,000-foot-thick quartzite, overlain by staurolite schist and muscovite-quartz-biotite phyllite, with a distinctive black carbonaceous phyllite at the top. The Vadito Formation, unconformable on the Ortega, contains minor conglomerate near its base, metarhyolite felsites, and minor muscovite-quartz-biotite phyllite as well as higher, thick-bedded, hornblende-andesine amphibolites. Pegmatites, quartz veins, and widespread hydrothermal mineralization are related to the intrusion of the Embudo Granite into the Ortega and Vadito rocks, and postdate the dynamothermal metamorphism of these two formations. Weak metallic mineralization, mainly of copper, occurs widely and is related to the hydro-thermal metamorphism. The only major mine is the once-productive Pecos Mine near Tererro which yielded zinc, lead, and copper.

The Precambrian rocks are isoclinally folded along general east-west-striking axes, with the axial planes dipping steeply southward and overturned to the north. Major divergences from this regional trend are the result of drag along the Picuris—Pecos fault and in part also may have been caused by injection of granite magma. Seven major folds were mapped in the Precambrian rocks. There has been a 23-mile, right-lateral, strike-slip separation of Precambrian units along the 53-mile-long north-south-trending Picuris—Pecos fault. This strike-slip faulting probably is Precambrian in age, but later episodes of vertical movement took place along the fault zone.

Paleozoic strata crop out in the eastern half of the mapped area, unconformable upon the Precambrian rocks, and include the Del Padre Sandstone of undetermined age (o to 75o feet thick); The Espiritu Santo Formation of undetermined age (o to 55 feet thick); the Mississippian Tererro Formation (o to 86 feet thick); the Pennsylvanian La Pasada, Flechado, and Alamitos formations (total thickness 2200 to 6500 feet); and the Sangre de Cristo Formation of Pennsylvanian and/or Permian age.

The Del Padre and Espiritu Santo formations were deposited sometime during the interval from Cambrian to early Mississippian time. The Del Padre Sandstone is thickest east of the Picuris—Pecos fault near the Truchas Peaks area and thins away from that area primarily by lateral interfingering with the limestones of the Espiritu Santo Formation. The Tererro Formation of Meramecian age unconformably overlies the older units in most areas and is divided into three members, in ascending order: the Macho Member of limestone-boulder conglomerate, the Manuelitas Member of light-gray limestone and limestone pseudobreccia, and the Cowles Member of silty, cross-bedded limestone.

The Pennsylvanian strata rest unconformably on all older rocks and show marked lateral changes in thickness and lithology from a thin shelf facies in the south (Pecos shelf) to a thick elastic trough facies in the north (Taos trough). In the south, the La Pasada Formation (i 000 feet thick) consists of alternating limestone, shale, and thin sandstones, ranging from Morrowan to middle Desmoinesian in age, and is overlain conformably by the Alamitos Formation (1200 feet thick) which is characterized by arkosic sandstone, gray to red shale, and limestone. It ranges from late Desmoinesian to Virgilian in age and is overlain by arkosic sandstone and red shales of the Sangre de Cristo Formation, of Virgilian and/or Permian age in the Pecos area.

North of Jicarilla Peak, the La Pasada Formation grades laterally into the Flechado Formation (2500 feet thick) which consists of sandstone and shale alternating with thin limestones. In the north, the Flechado is overlain by the Alamitos Formation (4000 feet thick), there made up of arkosic sandstone, conglomerate, and shale with limestone and siltstone in the upper part. The Alamitos Formation in the north is of upper Desmoinesian age and is overlain, apparently conformably, by the Sangre de Cristo Formation which is believed to be upper Pennsylvanian in age in that area and appears to grade southward into the upper part of the Alamitos Formation of the Pecos region.

Pennsylvanian terrigenous sediments were derived primarily from the west and northwest, from the southern part of the Uncompahgre highland, and reflect two major periods of uplift of the west side of the Picuris—Pecos fault. The first period began in Morrowan time and provided a predominantly metasedimentary rock source; the second period began in late Desmoinesian time and, in addition, exposed feldspar-rich metaigneous rocks to erosion.

Cenozoic deposits rest unconformably on various Paleozoic and Precambrian units in the western and northern parts of the mapped area. The Cenozoic units, in ascending order, are the Picuris Tuff, the Tesuque and Ancha formations of the Santa Fe Group, the Servilleta Formation (possibly equivalent to the Ancha Formation), glacial deposits, stream terraces, and floodplain alluvium.

Present major structural features are related to Laramide deformation but were controlled in their development by Precambrian structures. Vertical dip-slip movement occurred along the Picuris—Pecos fault (believed to be part of a regional geofracture) during Laramide time with no rotation of the fault plane from the vertical attitude established during Precambrian time. Precambrian rocks on the west, upthrown side were brought in contact with Pennsylvanian rocks on the east. East of the Picuris—Pecos fault are a major south-plunging syncline and an eastward-adjacent anticline of Laramide age. These folds form the southern terminus of the Sangre de Cristo Mountains about ten miles south of the mapped area where their plunge carries the resistant Precambrian crystalline rocks beneath the surface.

Introduction

SCOPE OF INVESTIGATION

The area described in this report is a thirty-minute quadrangle (pl. 1) which includes most of the southernmost part of the Sangre de Cristo Mountains in New Mexico and a portion of the Rio Grande depression that borders the mountains on the west. This joint report is devoted to the general geology of the map area. Additional reports on specialized aspects of the geology are planned for future publication.

The field work was done primarily during the summers from 1954 through 1959. Montgomery made a detailed investigation of the Precambrian rocks during parts of each summer during this period as a southward extension of his earlier study of the Precambrian rocks in the nearby Picuris Range (Montgomery, 1953). Sutherland spent the summers from 1956 through 1959 in geologic mapping and in a detailed study of the stratigraphic, sedimentary, and paleontological problems of the Paleozoic rocks. Miller spent the summers from 1955 to 1957 and a part 0f the 1958 field season doing geologic mapping and making a detailed investigation of the Cenozoic deposits and the geomorphology. Miller did reconnaissance mapping and geomorphic studies in the area around the Truchas Peaks during the summers of 1948 and 1949, and it was this early work which provided much of the inspiration and direction for the entire project. Miller's work was almost complete at the time of his tragic death in August 1961.

Areal geology was plotted in the field on air photographs (prepared by the U. S. Department of Agriculture Soil Conservation Service and the U. S. Geological Survey) or on topographic maps (U. S. Geological Survey, scale 1:24,000; contour intervals 20 and 40 feet) which are available for the western half of the quadrangle. These topographic maps have been used by the New Mexico Bureau of Mines and Mineral Resources as a source for compiling topography for a base map covering the western half of the quadrangle and having a contour interval of z00 feet. For the eastern half of the map area the New Mexico Bureau of Mines and Mineral Resources has compiled topography with a similar contour interval of 200 feet based upon the U. S. Geological Survey 1:250,000 map series.

Several other studies related to the geology of the map area, which are important by-products of this Sangre de Cristo project, have been published recently or are in preparation. Miller and Wendorf (1958) described the recent alluvial history of a portion of the Rio Grande depression. Miller (1958) contributed a study of the hydraulic and sediment-bearing properties of the high mountain streams. Montgomery and Sutherland (1960) prepared a popular guidebook to the geology of the upper Pecos Valley. The relationship between the chemical composition of certain rocks of the Sangre de Cristo Mountains and the lithology of drainage basins of the area has been considered in a paper by Miller (in press). A paper describing the extensive Pennsylvanian brachiopod faunas, by Sutherland and Francis H. Harlow, is in preparation. The Pennsylvanian rug0se coral faunas are being described for publication by Sutherland.

PREVIOUS GEOLOGIC WORK

The quadrangle here described has not been mapped in detail previously. The coverage of this area on Darton's (1928) *Geologic Map of New Mexico,* published by the U. S. Geological Survey, was based on reconnaissance. Cabot (1938) and Denny (1940) mapped in reconnaissance part of the western border of the Sangre de Cristo Range and part of the adjacent Rio Grande depression. A large part of Montgomery's map of the Picuris Range is included (on a reduced scale) in the geologic map accompanying this report. Read and Andrews (1944) did reconnaissance mapping near the town of Pecos south of the map area.

Several studies have dealt with special and localized aspects of geology in the region. Brill (1952) and Sidwell and Warn (1953) have done stratigraphic work near the southern edge of the map area. Baltz and Read (1960) have proposed new stratigraphic terms for the Mississippian and pre-Mississippian Paleozoic rocks. Ellis (1935) and Ray (1940) have given brief accounts of the glacial deposits in some of the high mountain valleys. Lindgren and Graton (1906), Lindgren, Graton, and Gordon (9 0), and Krieger (1932) discussed the economic geology in the vicinity of the Pecos Mine at Tererro. In addition, various other geologic investigations in northern New Mexico are related to this study and will be cited wherever pertinent.

ACKNOWLEDGMENTS

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The following served as field assistants: Laura Miller, Emery Cleaves, Alfred Hoyt, Robert Rodden, Lee McAlester, Dean Gerver, Philip Platt, Raymond Grant, Cooper Land, and Charles Rambo. Field work was greatly facilitated through the interest and assistance of many local residents, and through the expert help of these packers: Carpio and Beronil Archuleta of Truchas, Malaquias Romero of Cordova, and Geronimo Gonzales of Cowles. To the late Katherine Chaves Kavanagh, of Los Pinos Ranch at Cowles, go our special and very great thanks for long-continuing aid and encouragement without which this project never could have been carried through.

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Physical Setting

LOCATION AND ACCESSIBILITY

Location of the map area in relation to regional drainage and cultural features is shown in Figure 1. The Southern Rocky Mountains terminate about ten miles south of the map area. Portions of Santa Fe, San Miguel, Taos, Mora, and Rio Arriba counties are included. The following 7 1/2-minute U. S. Geological Survey topographic sheets cover the western half of the map area: Tesuque, Cundiyo, Chimayo, Velarde, Trampas, Truchas, Sierra Mosca, and Aspen Basin. The only available maps for the eastern half of the quadrangle are U. S. Department of Agriculture Soil Conservation Service planimetric sheets and the U. S. Geological Survey I :250,000 topographic maps.

The area is sparsely settled, with most of the population concentrated in small villages and nearly all the remainder on irrigated farms along stream courses. Except for Truchas and Tres Ritos, the larger villages are in the lower country west of the mountains.

A generally sparse network of secondary roads and wagon trails makes the areas of lower elevation within the map area fairly accessible; only a few of these are shown on the geologic map. At a few places roads penetrate short distances into the high country, but for the most part travel in the mountains is by horse or on foot along trails maintained by the U. S. Forest Service. Roughly, the eastern half of the quadrangle lies within the boundaries of the Santa Fe and Carson National Forests, and a major part of this segment is designated as the Pecos Wilderness Area.

PHYSICAL FEATURES

The thirty-minute quadrangle discussed in this report includes two physiographic divisions of sharply contrasting character, the north-northeasterly trending Sangre de Cristo Mountains (pls. 2-6) and the adjacent Rio Grande depression lying west of the mountains. Viewed at a distance from the west, the mountains appear to form a nearly straight west-facing escarpment rising abruptly above an extensive plain which slopes gently toward the Rio Grande. Actually, the mountain front is very irregular in plan, but it is sharply defined topographically on the west by low foothills which give way eastward to higher peaks and ridges. Closer inspection of the piedmont plain shows that it is not a single, smooth surface as it appears from afar; rather, the entire surface is laced by a close network of stream channels and in many places has typical "badlands" topography. Relief in the Rio Grande depression does not exceed a few hundred feet and is considerably less at most places.

The mountains range in altitudes from 7000 to 8000 feet at their western margin to a maximum of 13,102 feet at the top of South Truchas Peak. This peak is second highest in New Mexico, being exceeded only by Wheeler Peak, northeast of Taos, which rises to 13,150 feet. Nearly all the main peaks are 12,000 feet or higher. North from Jicarilla Peak, the crest of the range is poorly defined and consists of a broad, nearly flat, ridge greatly dissected by glaciated valleys. Southward from Jicarilla Peak, the range splits into tw0 parts and forms the drainage divide of the Pecos River. The eastern ridge, locally called the Rincon, Elk Mountain, or Las Vegas Range, and in part termed the East Divide in this report, is essentially smooth with no sharp-crested peaks. The western ridge, called the Truchas or Santa Fe Range, consists of rugged peaks connected by serrate ridges. Differences in the extent and duration of glaciation are in part responsible for these topographic contrasts, but the principal control is the nature of the bedrock. The Truchas Range is composed of very resistant plutonic and metamorphic rocks of Precambrian age, whereas most of the crest of the Rincon Range is composed of less resistant, bedded Paleozoic sediments. Local relief is greatest in the most severely glaciated areas, but amounts to two thousand feet or more in some of the nonglaciated canyons, notably the tributaries of the upper Pecos River.

The western slope of the Sangre de Cristo Range drains to the Rio Grande by way of Embudo Creek, Truchas River, Rio Santa Cruz, and Pojoaque River. Most of the southeastern part of the map area is occupied by the headwaters part of the Pecos River drainage basin. Throughout nearly its entire length in the quadrangle, the Pecos River flows in a narrow gorge cut i000 or more feet through Paleozoic sediments and into resistant Precambrian rocks. The most precipitous parts of all canyons in the area are associated with highly resistant quartzite or granite bedrock.

In the mountains, valleys are deep, narrow canyons, but westward beyond the mountain front in the unconsolidated deposits of the Rio Grande depression, valley depths decrease abruptly and widths increase markedly. Perennial stream flow is maintained in the mountains, but most streams become ephemeral within a mile or two from the mountain front because of percolation into the unconsolidated deposits. Characteristics of mountain streams in this area have been described in detail by Miller and properties of arroyos in the Rio Grande depression near Santa Fe have been discussed by Leopold and Miller (1956).

CLIMATE

Climate in the area studied is characterized by marked variation with altitude. Data obtained from the U. S. Weather Bureau station at Santa Fe are typical of the lowland part of the quadrangle, but there is very little precise climatic information for the high mountains.

Annual precipitation averages 10 to 12 inches in the vicinity of the Rio Grande and increases with ascending elevation to an estimated 3o to 35 inches on the highest peaks. Ordinarily, the summer rainy season begins about July 1 and continues into early September. Although precipitation generally occurs as brief, intense, afternoon thunderstorms, there are occasional extended rainy periods. Field work in the high country during the summers of 1955 and 1957 was much hampered by an exceptional number of rain and sleet storms. Winter snowfall ranges from about 15 inches near the Rio Grande to more than 60 inches in the mountains.

Summer temperatures may reach 80 degrees in the mountains and 90 to 100 degrees in the low country. Winter mean temperature is slightly below freezing in the lowlands, and

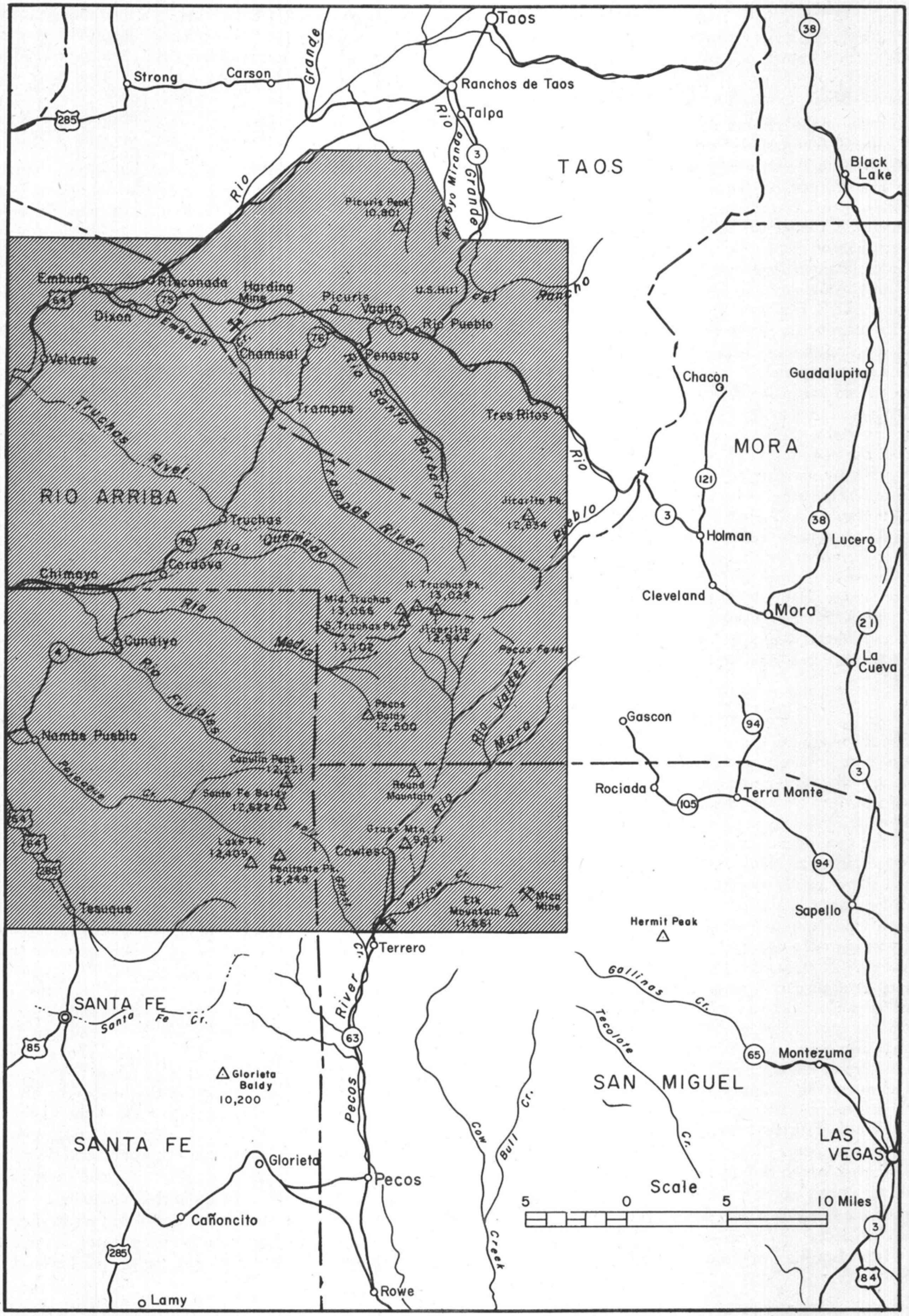

Figure 1

Index map

considerably lower in the mountains. Low humidity and much sunshine prevail the year around.

Zonation of climate according to altitude shows clearly in the distribution of natural vegetation. The porous, unconsolidated sediments which underlie the semiarid Rio Grande depression support only a sparse cover of sage, grasses, and cacti. In ascending vertical order of their occurrence, zones of piñon pine, yellow pine, aspen, spruce, and fir dominate the luxuriant forest which covers the mountains up to timberline, which is at II,000 t0 11,500 feet. Above timberline, there are a few clumps of dwarf trees and several kinds of arctic-type sedges and grasses. Geological field work was adversely affected by the dense timber cover. Not only are the rocks covered by soil and forest litter, but movement is greatly restricted in some areas by impenetrable tangles of "deadfalls."

Precambrian Rocks

by Arthur Montgomery

INTRODUCTION

Precambrian rocks are widely distributed throughout much of the mountainous part of the mapped quadrangle. Figure 2 shows their undifferentiated areal distribution. They are present both high up among the loftiest peaks of the Truchas Range and far down along the deepest canyons of the upper Pecos River and its tributaries. Because of their metamorphosed and generally resistant crystalline nature, erosion has characteristically sculptured these rocks, wherever exposed, into a rugged topography of jagged peaks and ridges and precipitous canyons.

All these Precambrian rocks, with the exception of certain of the youngest igneous intrusives, have been strongly folded and profoundly metamorphosed, by deep-seated regional metamorphism of dynamothermal character followed by widespread hydrothermal metamorphism associated with intrusion of granitic magma.

In general, these Precambrian rocks are similar in lithology, structure, and stratigraphic relationships to those throughout the Picuris Range, which borders on the north the north-central portion of the mapped quadrangle (pl. r). An earlier detailed petrologic study of the lithologic units there of Precambrian age (Montgomery) established a basis for their stratigraphic sequence and makes possible their close correlation with the Precambrian rocks mapped farther south. Evidence is strong, as will be brought out under *Structure*, that Precambrian bedded units, around the Truchas Peaks and in spotty outcrops east and south of there, represent once-continuous eastward extensions along the strike of lithologically similar, east-west striking units in the Picuris Range. The former, newly mapped, east-west striking units are, however, more than 20 miles south of their earlier mapped counterparts in the Picuris Range. Strike-slip movement along a great north-south-trending fault has caused this displacement of an earlier east-west continuity in the two groups of units. The close correlation between the two groups of units in lithology, stratigraphy, and structure makes unnecessary in this report detailed petrographic description of the newly mapped units south of the Picuris Range. As far as possible, the entire region of Precambrian rocks, including the area of the Picuris Range, will be treated as a unit and termed the mapped region in the following descriptions of lithology, structure, metamorphism, and geologic history. The area of chief interest in the ensuing discussion of Precambrian rocks, however, is that portion of the mapped quadrangle centering around, also some distance north, east, and south of, the Truchas Peaks. This latter generalized area will be termed hereafter the Truchas area to distinguish it from the areas of Precambrian rocks in and not far south of the Picuris Range, as well as those in and along the summit ridges and the west front of the Santa Fe Range.

LITHOLOGY

GENERAL SUMMARY

The Precambrian rocks consist partly of older, dominantly metasedimentary units, partly of younger, dominantly metaigneous units. Certain bodies of younger granitic rocks and of very minor diabase are unmetamorphosed.

In the Picuris Range Precambrian units (excluding granite) were found to consist chiefly of an older well-bedded, metasedimentary series, the Ortega Formation, and a younger series, the Vadito Formation, in part made up of well-bedded, metaigneous rocks. Although some of these latter units were presumed to represent metamorphosed sills, a considerable portion were judged to have originated as lava flows or as tuffaceous beds. It was for this reason that the major portion of the metaigneous rocks found interlayered with the metasedimentary units of the Vadito Formation were mapped with that formation and regarded as a stratigraphic part of it.

In compiling a stratigraphic column (fig. 3) to cover Precambrian rocks of the mapped region, all newly mapped metaigneous units (excluding granite) associated with metasediments of the Vadito Formation have been included as before within that formation. This has been done despite the fact that some of these units show evidence that they crosscut the metasediments south of the Truchas Peaks. Other newly mapped metaigneous units, similar to, interbedded with, and commonly grading into the metaintrusives, are believed to represent volcanic flows and tuffaceous deposits. They are intimately interlayered with the metasediments of the Vadito Formation. It has proved impossible to separate these metavolcanic and metaintrusive units from the associated metasediments of the Vadito Formation. The close association of the metasedimentary Vadito beds and these metavolcanics and metaintrusives, reasonably suggests a broad-scale affiliation of all these rocks in time as well as in space.

Granitic, granodioritic, and quartz-dioritic rocks, as well as genetically related granitic pegmatites, have intruded and also modified by means of accompanying hydrothermal solutions both metasedimentary and metaigneous rocks of the Ortega and Vadito formations. All the granite, although variable lithologically and in degree of metamorphism, is presumed to be related to the same parent magma and one protracted, magmatic episode (Montgomery).

Diabase dikes of very minor and localized occurrence are unmetamorphosed and are of unknown age. They are classed as latest Precambrian because of their megascopic resemblance to basic Precambrian metaigneous rocks of the Vadito Formation, but it is conceivable that they are younger than Precambrian, possibly Tertiary, in age.

ORTEGA FORMATION

The Ortega Formation, named by Just (1937), was redefined by Montgomery to cover correlatable rocks in the Picuris Range. As redefined, it includes a basal quartzite member, an overlying Rinconada Schist Member, and an uppermost Pilar Phyllite Member.

Lower Quartzite Member

The lower quartzite member comprises all the quartzite, including minor thin beds of gneiss and schist, which underlies the distinctive staurolite-bearing schists and gneisses found near the base of the Rinconada Schist Member.

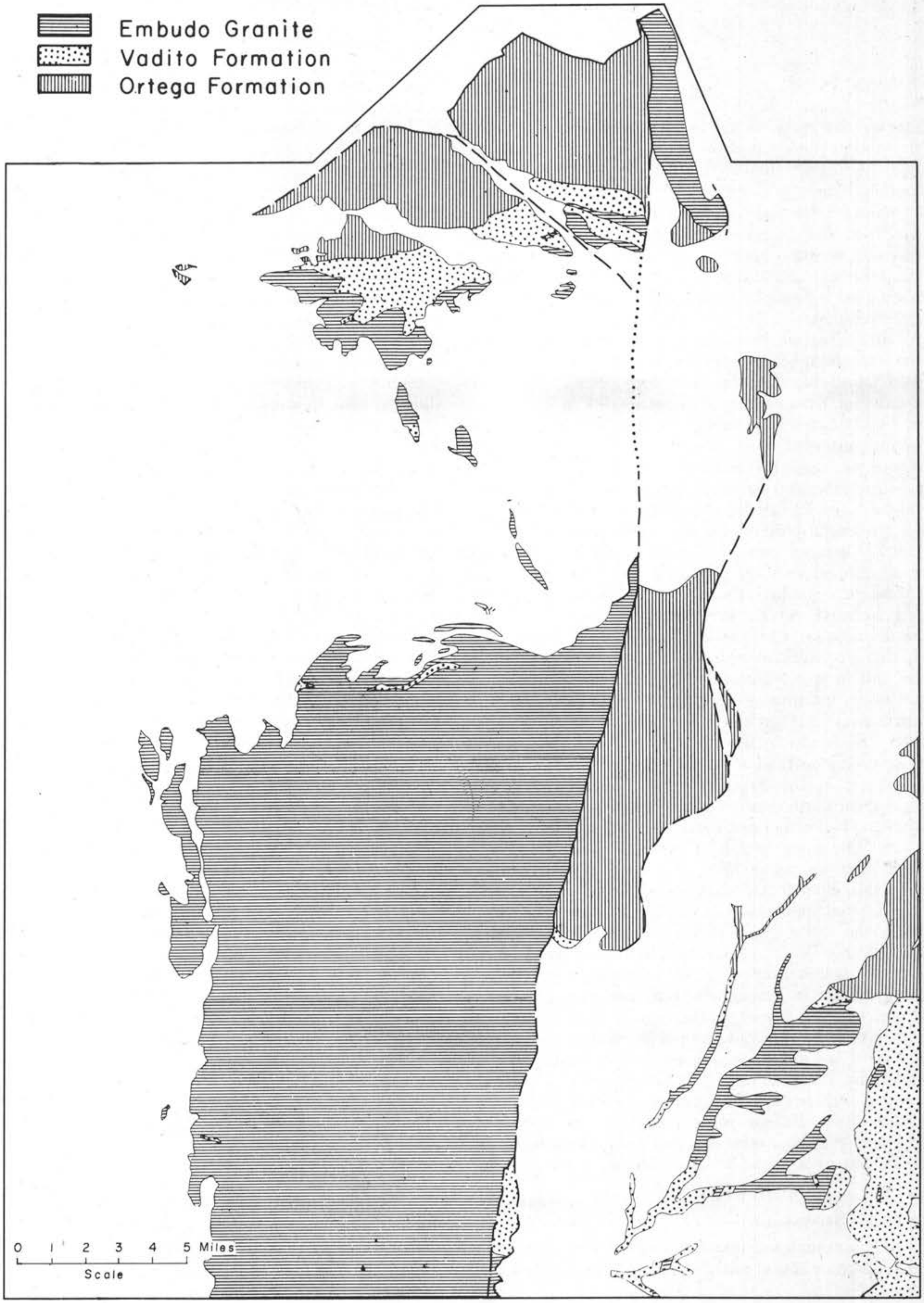

Figure 2

DISTRIBUTION OF PRECAMBRIAN ROCKS

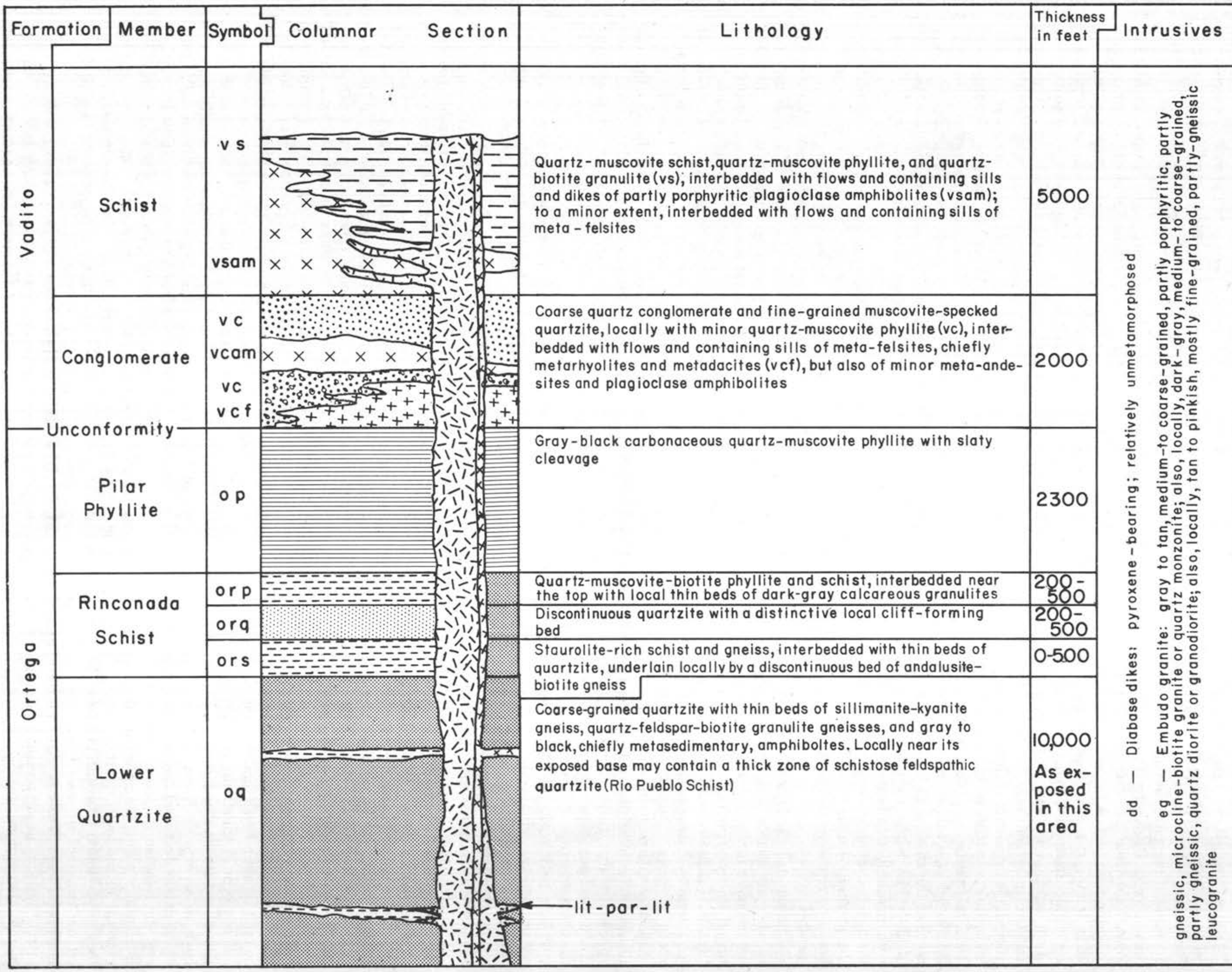

Figure 3

COLUMNAR SECTION OF PRECAMBRIAN ROCKS, SOUTHERN SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

In the Picuris Range, this quartzite occupies two extensive mile-wide, east-west belts bordered north and south by the Rinconada Schist Member. In the Truchas area, this lower quartzite is the predominant rock upholding the lofty summits of Pecos Baldy, the Truchas Peaks, and Jicarilla. From Pecos Baldy, the quartzite extends northward for ten miles to form a continuous highland belt from two to three miles wide. It appears also in large, scattered outcrops eastward for eight miles from these major peaks, as far as to the east edge of the quadrangle. About a mile south of Rio Pueblo Creek and two miles southeast of the village of Rio Pueblo, this quartzite is in contact with a schistose, richly micaceous and feldspathic, quartzite rock, apparently in part of mixed origin. This migmatitic quartzite, mapped separately as the Rio Pueblo Schist, continues northward to a point a short distance north of the creek. It also appears in two outcrops northwest of U. S. Hill where its northernmost exposure is in contact with northerly trending exposures of leucogranite. Neither the quartzite-migmatite contact south of Rio Pueblo Creek nor the northerly contact of this migmatite with granite is believed to represent the exposed base of the lower quartzite member.

The quartzite is typically massive, translucent, and gray to white. In places, it is as glassy and snow-white as vein quartz; more rarely, it is mottled or streaked with iron oxide, tinged smoky gray-black, or very rarely, pale bluish green. Locally, it is slabby and exhibits crude, widely spaced, parallel fractures. The quartzite is remarkably pure, generally about 98 percent quartz. Grain size is medium to coarse, with large quartz grains averaging 1 mm in diameter. The rock tends to have such a homogeneous, translucent, fused appearance that grain shapes are invisible megascopically. They stand out atypically only when outlined by thin, dark, discontinuous rims of iron oxide. Commonest accessory minerals are muscovite, sillimanite, kyanite, hematite and ilmenite, epidote, clinozoisite, pink to red thulite and piedmontite, blue-green tourmaline, zircon, and allanite. Commonly, the quartzite is specked with minute grayish blades of kyanite or with whitish to pinkish, radial-fibrous aggregates of sillimanite. Some quartzite has a fine, sparse, dark banding. Tiny muscovite flakes in thin mattings are abundant in some of these bands. At places, this dark banding is arranged in small-scale, incompletely developed, but unmistakably cross-bedded structures. Thinsections show that minute rounded grains of zircon typically are sparsely associated with these bands, as are knobby grains of leucoxene, allanite, and tourmaline. Thinsections of gray-black quartzite expose thickly disseminated minute prisms of greenish tourmaline or tiny black plates of hematite. Pale-green quartzite appears to be colored by abundant submicroscopic flecks of chrysocolla.

Thin beds of sillimanite and kyanite gneiss are characteristic of certain localized zones in the quartzite. These beds have an average thickness of several feet, measuring rarely up to tens of feet, and can be traced along the strike of the regional foliation for more than a mile before pinching out. Such zones occur most prominently near the northernmost exposure of the lower quartzite in the Picuris Range where they cross Hondo Canyon. They are also prominent in and on the flanks of the two branching summit ridges a mile north of North Truchas Peak in the Truchas area. Sillimanite and kyanite are present in these gneiss beds, with sillimanite always dominant over kyanite, and they may rarely amount to 10 or 20 or more percent of the rock. Muscovite in coarse flakes is associated intimately with both sillimanite and kyanite in such occurrences and is in part pseudomorphous after kyanite.

In the vicinity of the summits of the South and Middle Truchas Peaks (pl. 7C) are three lithologically distinctive zones of granulitic, feldspar-rich gneisses, amphibolites, and schists. These zones, up to half a mile wide and extending for several miles southwesterly along the regional strike, run roughly perpendicular to the north-south trend of the main summit ridge. These granulitic gneisses occur within the lower quartzite member of the Ortega Formation and are mapped separately (pl.). Wherever granite pegmatites are in close association, these feldspathic zones contain thin beds that are rich in sillimanite, kyanite, and ilmenite. Other beds of quartz-bearing amphibolites of likely metasedimentary origin are rich in calcic plagioclase, commonly bytownite or anorthite.

Muscovite-rich feldspathic quartzite, in part schistose, characterizes all the Precambrian quartzite exposures near Rio Pueblo Creek two miles southeast of the village of Rio Pueblo and to the south for about a mile. Similar rock makes up all of a small hill half a mile northwest of U.S. Hill and the northerly part of an adjacent larger hill to the north. This rock may represent granitized arkosic quartzite, but in large part it appears to consist of granitic material intruded into and probably intermixed with quartzite. This rock is so distinct from normal Ortega quartzite that it has been mapped as a separate migmatitic unit within the lower quartzite member of the Ortega Formation and is called the Rio Pueblo Schist. A similar migmatitic quartzite in the Petaca region 30 miles northwestward was termed the Petaca Schist by Just and mapped as a separate unit by him, by Jahns (1946), and by Barker (1958).

The more quartzose Rio Pueblo Schist, as exposed near the small bridge over Rio Pueblo Creek two miles southeast of the village of Rio Pueblo, resembles a weakly schistose, feldspathic quartzite. It is medium grained, of gray-brown, flesh-to-tan, or gray-green color, and has a crudely gneissic appearance. The weakly schistose rock exhibits on freshly broken surfaces a matting of haphazardly oriented, silvery muscovite flakes, up to 2 mm in size, and possesses a streaky foliation. The rock is highly variable in character, ranging from a gneissic quartz-muscovite-feldspar granulite to a rock resembling a weakly micaceous quartzite. In thinsections of gray-brown and gray-green schistose rock, the feldspar occurs in strung-out, relic patches of sericitized and sausseritized plagioclase, probably of original oligoclase composition. In lighter, flesh-to-tan rock, unaltered grains of microcline are common. In more quartzose, massive, gray-green rock, muscovite is scarce and microcline is absent. Streaky areas of pale-green chlorite are abundant. In certain areas, especially south of Rio Pueblo Creek, dikes of granite pegmatite are found partly crosscutting the schistosity or gneissic foliation of the Rio Pueblo Schist. Micaceous quartzite, resembling the Rio Pueblo Schist and possibly of migmatitic origin, is present in extensive outcrops southwest of Pilar (Montgomery). Some of this rock is pinkish because of the presence of abundant grains of thulite and piedmontite.

The thickness of the lower quartzite member of the Ortega Formation, as exposed in the ten-mile-long belt extending north from Pecos Baldy and measured north-south across the dominantly east-west regional strike of bedding and foliation, must be of the order of 10,000 feet. This allows for considerable repetition of beds by broad-scale folding.

Rinconada Schist Member

This member was defined for the Picuris Range (Montgomery) and includes there four distinctive units: andalusite-biotite hornfels (better termed a gneiss), staurolite-rich schist and gneiss (pl. 7A) intercalated locally with thin quartzite beds, quartzite, and muscovite-quartz-biotite-garnet phyllite (pl. 7B).

Although all these units are found in certain sections of the Truchas area, it is proposed to simplify the lithologic description of these to three units instead of four. In the Truchas area, the andalusite-biotite gneiss appears in such spotty and discontinuous outcrops that it is impossible to map this bed as a separate unit or to be sure of a characteristic mineral composition for it because of differential metamorphism along the strike. It is proposed, therefore, to redefine the Rinconada Schist Member for the mapped region to include, first, a lower series of beds of staurolite-rich schist and gneiss intercalated locally with thin quartzite beds: second, a thick bed of discontinuous quartzite lying above these; and, third, an uppermost series of beds of muscovite-biotite phyllite. The latter unit is characterized especially by its fine-grained texture, its carbonaceous nature near the top, and its gradation upward into the overlying, black, slaty, carbonaceous Pilar Phyllite Member.

One exceptional exposure northwest of Pecos Baldy in the Truchas area contains all the units of the Rinconada Schist Member, precisely as found in the northern Picuris Range.

Staurolite-Rich Schist and Gneiss. Staurolite-rich schist appears in scattered outcrops east of Pecos Baldy in the canyons of the upper Pecos River and Rio Valdez. A thick and extensive zone of staurolite-rich schist and gneiss is present still farther east near the head of Rio Mora. In some parts of the Truchas area quartzite is thinly interbedded with staurolite schist, also with quartz-muscovite phyllite.

The typical staurolite-rich schist bed is marked by large, perfectly formed, twinned crystals of dark-brown staurolite set in a silvery fine-grained matrix of quartz-muscovite-biotite schist. The staurolite crystals average I cm in greatest dimension, but may attain **4** cm. Where this schist is more quartzose, the rock is hard and resistant, and loose staurolite crystals do not weather out. This is typical of the Rio Mora zone. Where the rock is less quartzose and softer, as in some parts of the northern Picuris Range, perfect loose crystals weather out of the rock and lie on the ground in great profusion.

Quartzite. A wide zone of discontinuous quartzite, as much as half a mile wide, is locally present between staurolite schist and muscovite phyllite, as for example along the upper Rio Mora. This unit can be mapped with assurance only when it intervenes as a wide zone between staurolite schist and muscovite-quartz-biotite phyllite.

This quartzite is glassy white and translucent, but in major part it is massive, fine-grained, and gray-white in appearance. Some of it is finely micaceous and may be coarsely slabby through separation along parallel muscovite-rich layers.

Muscovite-Quartz-Biotite Phyllite. The muscovite-rid phyllite and schist is widely exposed in an east-west zone ex tending from the east slope of the Pecos Baldy to the upper Rio Mora and beyond to the east boundary of the quadrangle

The typical rock is a light-gray, fine-grained, muscovite-rich phyllite that is studded with tiny, dark lenticular crystals of biotite. It has a characteristic silvery sheen. Muscovite tends to be dominant over quartz, but the phyllite is noticeably more quartzose near its base. In the northern Picuris Range, reddish-brown almandite garnet crystals, 1 to 2 mm in di ameter, are abundant in thin layers of phyllite and of interbedded, somewhat coarser-grained schist. In the Truchas area, garnet phyllite is less common but occurs prominently in the wide phyllite zone exposed along the upper Rio Mora.

As exposed in the mapped region, the Rinconada Schist Member varies in thickness from several hundred feet to 1500 feet. This allows for repetition by close folding.

Pilar Phyllite Member. This gray-black, carbonaceous phyllite (Just's Hondo Slate) was described by Montgomery as the most distinctive and widespread horizon marker of the Picuris Range. Although in the Truchas area it is limited to two general areas, west of Pecos Baldy and along the upper Rio Mora, it remains a key lithologic unit in regional stratigraphic correlation. Since it was judged to be the youngest member of the Ortega Formation because of its presence in synclines, its presence in two parts of the Truchas area helps to clarify the regional structure and stratigraphy.

This rock is gray-black, dense, and slaty and has a gray sheen on cleavage surfaces due to densely matted muscovite flakes of microscopic size. Quartz is dominant over muscovite; hardly a trace of other minerals is present except for several percent of carbonaceous impurities and coarse streaky masses of brownish limonite. Very diagnostic of this rock in thinsections are wispy, lenticular, relic porphyroblasts, 0.1 to 0.5 mm in length, of unknown original composition but now altered to brownish-black iron oxides. Quartz veinlets are common in many outcrops of this phyllite, some coarser-grained ones following joint planes. Other small, ribbon-like veinlets cut across micaceous foliation and may be crenulated by small-scale folding.

Evidence found in several outcrops in the Picuris Range suggests that an unconformity exists between the youngest member of the Ortega Formation (Pilar Phyllite) and the overlying basal quartzite and conglomerate of the Vadito Formation. The last units appear to rest on both the Pilar Phyllite and the underlying muscovite phyllite of the Rinconada Schist Member.

As exposed in the Picuris Range, the minimum thickness of the Pilar Phyllite is 2300 feet, allowing for repetition by close folding. In the Truchas area, its exposed maximum thickness does not exceed 1000 feet.

VADITO FORMATION

The metasedimentary rocks assigned to the Vadito Formation in the southern Picuris Range have discontinuous, and in part stratigraphically uncertain, occurrences in the Truchas area. However, rocks similar to those observed **in** this formation in the Picuris Range occur at the expected stratigraphic position for them in the Truchas area. The stratigraphic correlation of these rocks is ambiguous in **the**

Truchas area because they are closely interlayered with, and, also have been invaded by igneous rocks of both basic and acid composition. Still more uncertain has been the mapping and inclusion within the Vadito Formation of isolated outcrops of metasedimentary rocks of lithologic character somewhat similar to normal Vadito metasediments. These outcrops are associated with the western and northern edges of the broad, north-south trending zone of granite that occupies the Santa Fe Range. In these outcrops, granite appears to have engulfed and largely obliterated all but small relic patches of the metasediments.

In the Picuris Range, the metasedimentary rocks of the Vadito Formation are characterized especially by the presence of quartz conglomerate and micaceous quartzite near the base of the formation. The phyllites and schists of this formation are typified by their lack of garnet, staurolite, kyanite, and sillimanite. The metasedimentary rocks in the upper parts of the formation are characterized by an interbedding of fine-grained, feldspathic, granulite beds and layers of lustrous, pearly gray, muscovite phyllite and by the absence of quartzite and quartz conglomerate.

In the Truchas area the metasedimentary rocks of the Vadito Formation are not easily differentiated. Quartzite is rare. Quartz conglomerate was observed only in two localities. Areas of muscovite phyllite and sandy muscovite-quartz phyllite were observed, but these exposures are not continuous along the strike and appear to lens out into, or to have been surrounded and engulfed by, metaigneous rocks of various types, especially plagioclase amphibolites. Garnet is very rare, and staurolite, kyanite, and sillimanite are absent from these phyllites. The lack of these minerals is diagnostic for they are also lacking in the Vadito phyllites of the southern Picuris Range.

In the Picuris Range, the Vadito Formation was partly defined in terms of the abundance of distinctive metaigneous amphibolitic and felsitic rocks. The abundance of these rocks increases still more in the mapped quadrangle, especially southward and southeastward from Pecos Baldy to the borders of the quadrangle. Although certain of these rocks are judged to be partly metaintrusive, their inclusion in the Vadito Formation has been continued. Otherwise, widespread correlation of rocks of the Vadito Formation would be impossible. Although in the Truchas area, amphibolites are usually higher in the formation and felsites lower, these strati-graphic positions are not so well defined as they are for similar rocks in the Picuris Range. The stratigraphic correlation of these amphibolites and felsites is extremely difficult in the Truchas area because of their close association with and large-scale invasion by granitic rock.

Conglomerate Member

Quartz conglomerate. Coarse quartz conglomerate was observed in one major exposure and in a number of very minor ones in the Truchas area. The major exposure is on the west bank of the upper Rio Mora about two miles north of the confluence of the Mora and Valdez rivers. This occurrence shows a bed at least several hundred feet thick but very limited in strike-length exposure. Similar quartz conglomerate, interbedded with fine-grained micaceous quartzite, attains a maximum thickness of moo feet in the southern Picuris Range (Montgomery).

The rock by the Rio Mora has a grayish matrix of finely foliated micaceous quartzite or quartzose phyllite. The pebbles and cobbles are almost wholly of light or dark quartzite, with ellipsoidal shapes eight and ten inches in greatest dimensions. They are commonly much flattened and their shapes lie roughly in parallel orientation with the micaceous foliation of the surrounding rock matrix.

Quartzite is not present in the Vadito Formation in the Truchas area. It is possible that the beds of micaceous quartzite that characterize the conglomerate member of this formation in the southern Picuris Range are equivalent in stratigraphic position to the quartzose phyllites and schists present in the southerly part of the Truchas area.

Stern and Stieff (oral communication), using the Larsen Method, have determined that detrital zircon from conglomerate of the Vadito Formation, near the Harding Mine in the Picuris Range, is 1500 (± 175) million years old.

Felsites. Those metaigneous rocks of the mapped region classed as felsites (and felsitic) are minutely grained, light-colored rocks commonly made up chiefly of alkalic feldspar, quartz, and muscovite or biotite. Such rocks are in places megascopically indistinguishable from quartzite.

Felsitic rocks are closely associated with all Precambrian conglomerate in the Truchas area. This is also true of the felsites near the base of the Vadito Formation in the Picuris Range. Felsitic rocks are widespread and diversified south and southeast of Cowles to the borders of the quadrangle. In this area, flows, tuffaceous beds, and likely meta-intrusive bodies undoubtedly occur higher in the Vadito Formation. It seems best to include all these felsitic rocks in the conglomerate member of the Vadito Formation.

Felsites are closely associated and interbedded with thin beds of conglomerate in several places along the west banks of the upper Pecos and Mora rivers; these felsites are of metarhyolite composition. In the vicinity of Tererro and to the southeast, felsitic rocks in great abundance and of bewildering variety occur in association with amphibolites and Embudo Granite.

Many of the felsitic rocks in the Truchas area show partial gradation into and likely replacement by granite. It seems that rocks of felsitic composition, not appreciably different from a normal granitic composition, have tended to become preferentially changed to, or replaced by, granite. It is impossible to draw any dividing line between such partly granitized felsitic rocks and fine-grained granite in some of these occurrences.

Felsites are largely of metarhyolitic composition and are both nonporphyritic and porphyritic. The former are very difficult to distinguish from fine-grained micaceous quartzite, from fine-grained feldspathic granulite, and from fine-grained cataclastic granite. The dominant rocks are dense, massive, and gray-white to flesh-pink. Some are weakly schistose, due to an abundance of very minute parallel-oriented muscovite flakes; others are gneissic with thin dark streaks or bands due to parallelism of tiny biotite plates. Other felsites are slabby because of easy separation along surfaces parallel to mica-rich layers; still others show a small-scale, light-colored, parallel streaking suggestive of flow-banding as found in some lavas. Certain felsites, common to the eastern slopes of the East Divide north of Elk Mountain as well as of the Doctor Creek area three miles west of the Pecos Mine, are white and dense, and have a porcelain-like appearance.

Grayish felsites are apt to contain minute parallel plates of biotite rather than muscovite, and parallel, crudely prismatic crystals of hornblende with strong blue-green pleochroism. These rocks are probably metamorphosed quartz-latite or dacite. Some of them are thinly interlayered with lighter-colored felsitic rocks, resulting in a finely banded, whitish to pinkish and grayish to gray-black rock.

Thinsections show that many felsites contain streaky lenticular patches of quartz and microcline grains intergrown in a mosaic texture. The coarser grain size of these patches and their mineral composition are suggestive of encroaching veinlets of granitic material.

Schist Member

Quartz-muscovite schist and phyllite, muscovite-quartz-biotite phyllite, and quartz-biotite granulite. In the Picuris Range the Vadito Formation becomes increasingly rich in muscovite and/or feldspar in its upper parts. In the Truchas area, quartz conglomerate and micaceous quartzite are uncommon in the Vadito Formation. Whereas quartz-muscovite phyllite and muscovite-quartz-biotite phyllite are the dominant metasedimentary rock types. The latter are closely associated with metaigneous felsites and amphibolites. Quartzbiotite granulite, which is common in the southerly Picuris Range, is very uncommon in the Truchas area.

Phyllites of the schist member of the Vadito Formation can be recognized in the Picuris Range by their pearly gray smoothness and densely, minutely grained, micaceous character. Their lack of garnet and staurolite porphyroblasts is another diagnostic feature. They are characterized also by stubby porphyroblasts of biotite partly altered to chlorite. In the Truchas area, phyllites of the schist member of the Vadito Formation are similar in general character to those of the Picuris Range, but biotite porphyroblasts are minute or absent. Where muscovite much exceeds quartz in some of these rocks, the phyllite is a dense, pearly gray, felted mass of muscovite flakes so minute as to be individually invisible megascopically. In numerous outcrops, such rock has a pale greenish gray color, due chiefly to chloritization of its tiny biotite porphyroblasts. In some occurrences, as for those phyllites west of Pecos Baldy and those south of Beatty's Cabin along the upper Pecos River, it is impossible to be sure of proper stratigraphic correlation for these rocks.

Amphibolites. Those rocks of the mapped region classed as amphibolite are greenish black to black, consist chiefly of hornblende and plagioclase (andesine usually) in about equal parts, and commonly possess a crudely foliated or banded structure due to parallel orientation of blade-like prisms of hornblende.

In the Picuris Range, some amphibolites are associated with the conglomerate member of the Vadito Formation, but even more are present in the schist member of that formation. Southward from the Picuris Range and west of the north-south trending Picuris—Pecos fault, amphibolites are present in scattered outcrops. The amphibolites in these exposures are generally mixed intimately with and partly engulfed by Embudo Granite. South of the Picuris Range and east of the fault, amphibolites are not exposed for a distance of 20 miles. Their northernmost outcrops in the southerly Truchas area are located a mile north of Cowles and several miles north of Elk Mountain. Southward and eastward from these two locations, to the borders of the quadrangle, amphibolite exposures are increasingly large, despite encroachment by closely associated granite. An almost continuous two-mile-wide belt of amphibolites extends north-south for seven miles along the east slopes of the East Divide north and east of Elk Mountain.

In the Truchas area, amphibolites are judged to be dominantly of metaintrusive character, mostly in the form of thick sills, but they are present also in the form of flows. In both instances, these amphibolites appear to be mostly interbedded with metasedimentary rocks of the Vadito Formation. However, they are, in part, crosscutting and also seem to have engulfed and partially blotted out the older metasediments. In the vicinity of Santa Fe and north and south along the west and north borders of the Santa Fe Range, amphibolite exposures are small and disconnected and surrounded by granite. It is impossible here to determine whether or not granite has largely obliterated an earlier, much more extensive zone of amphibolites and associated rocks.

Amphibolites of the mapped region are variable in character; the most common types are fine- to medium-grained, dark greenish black to gray-black, hornblende-rich rocks. The two dominant and distinctive types of amphibolite are a partly porphyritic, coarse- to medium-grained type and a dense, very fine-grained type. The coarser-grained, partly porphyritic, types are judged to be largely metaintrusive sills of original diabase. The very fine-grained ones are presumed to have been original flows or tuffaceous beds of basaltic character.

In the Truchas area, the most prevalent amphibolite exposed in extensive outcrops is a massive, homogeneous, fine-to medium-grained rock of gray-black color. In this rock, tiny, black hornblende prisms average o. 5 to 1 mm in length and are of blade-like shape. When this rock is examined microscopically, a majority of these hornblende prisms may be lined up in crude parallelism, although megascopic examination may suggest their haphazard orientation. Their roughly parallel arrangement is also shown by the glistening light reflections from fracture surfaces. The rock ordinarily has a blocky jointing and weathers to a light gray or brownish color on exposed surfaces. Such amphibolites are well exposed in extensive outcrops south and southeast of Cowles. Here considerable hydrothermal alteration is evident. Biotite flakes and epidote and sphene, or sphene-ilmenite, granules are common. Some chlorite is present. The patchy grains of plagioclase, intergrown with largely haphazardly oriented, knobby hornblende prisms, are in part opaque with sausseritized material; also they are, in part, clear of inclusions, showing clean-cut twin lamellae indicative of andesine-oligoclase composition. Certain denser, very fine-grained amphibolites, especially widespread along and east of the East Divide north of Elk Mountain, contain round or elliptically shaped cavities, and solid, augen-like areas filled with greenish epidote or buff plagioclase. These structures are abundant enough in such rocks to suggest original amygdaloidal structures.

Despite likely repetition by folding, a very large minimum aggregate thickness of amphibolites, perhaps 5000 feet or more, is exposed in the wider parts of the north-south belt of these rocks northeast of Elk Mountain in the Truchas area.

PLUTONIC ROCKS

Embudo Granite

The Embudo Granite borders the Picuris Range on the south and east. Southward from the Picuris Range and west of the Picuris—Pecos fault, exposures of Embudo Granite become increasingly widespread. Here this granite makes up the main mass of the Santa Fe Range, extending southward from Cordova for 3o miles in a continuous eight-mile-wide belt as far as Glorieta Baldy and the south end of the Sangre de Cristo Mountains. East of the Picuris—Pecos fault and southward from the Picuris Range, Embudo Granite does not appear for 15 miles. Its northernmost outcrops here are about six miles southeast of the Truchas Peaks, along the upper Pecos River and along both the Valdez and Mora rivers. Southward from these latter two locations there stretches a four-mile-wide zone of Embudo Granite. Extensive outcrops exposed in the deep middle canyons of Rio Mora and Bear Creek suggest that this granite zone may continue for nine miles to the south border of the quadrangle beneath obscuring Paleozoic sediments. Widespread occurrences of amphibolites lie both east and west of parts of this granite zone.

In the Picuris Range, the Embudo Granite was described (Montgomery) as being a somewhat variable rock type, but with the different types evidently related to a single magma source. Lithologic differences between the three most common granite types, biotite granite, gneissic granite, and flesh-pink leucogranite, were explained as due in large part to the degree of assimilation (pl. 7D) of foreign rock material or else to deformational and metamorphic effects.

In the Truchas area and in the Santa Fe Range, much the same lithologic types of Embudo Granite are present. A first type, better termed microcline-biotite granite, is commonly medium- to coarse-grained and grayish in color, but also may be tan to flesh-pink. It is dominantly of quartz-monzonite or granodiorite composition, with about ten percent biotite and/or hornblende. Nearly equal parts of quartz, microcline, and albite-oligoclase are present. A second type, which is gradational into granodiorite, is a dark gray, in part distinctly gneissic, quartz diorite containing no microcline. Quartz is very minor; biotite and hornblende average about 20 percent each, while plagioclase (oligoclase-andesine) ranges from 4o to 5o percent. Apatite, magnetite-ilmenite, and sphene are very abundant accessory minerals; allanite and zircon are scarce accessories, as they are in all types of Embudo Granite. Perhaps in part this second "granite" type owes its dark-gray color and quartz-diorite composition to partial assimilation of amphibolitic rocks. A third type, termed leucogranite, may be either very coarse-grained or very fine-grained. It is usually pinkish to flesh-pink, or else tan, and is almost lacking in dark minerals which average less than one percent and never exceed three percent. Aside from this lack of dark minerals and the extreme variability in quartz content, the minerals contained are the same as those in the microcline-biotite granite. The rock has an unusually high silica and soda-potash content. It possibly owes its light color and abnormally low content of dark minerals to hydrothermal metamorphism. Such a transformation would entail a soaking into and large-scale replacement of an earlier light-colored felsitic rock of feldspar-rich metarhyolite composition by silica-bearing hydrothermal solutions related to intrusion of the Embudo Granite.

A variation of the first and third types of Embudo Granite is a light-colored,- streaky, foliated granite, very spotty and localized in outcrop extent and comprising either a microcline-biotite granite or a pinkish leucogranite. In thinsections of such granite, small plates and patchy aggregates of muscovite are abundant, evidently derived in large part from alteration of feldspar. This gneissic rock type seems largely a product of local deformational effects, such as shearing, which developed later than regional metamorphism.

It is possible that two or more episodes of granitic intrusion have affected this region. Rare patchy areas of gray, gneissic, granodiorite or quartz diorite, surrounded by structureless pinkish leucogranite, suggest such a possibility, as do also very complex intrusive relationships between felsitic and amphibolitic rocks on the one hand, and evidence in some outcrops of several generations of granite pegmatites on the other. But such evidence is extremely fragmentary at best and it is impossible to differentiate such rocks in mapping. It is simpler to relate genetically all the granitic rocks to a single magma source, realizing that the intrusion of these rocks encompassed a protracted magmatic episode in time. The intrusion of earliest differentiates of the granitic magma could well have been of quartz-dioritic composition and may have been syntectonic in part. The latest formation of Embudo leucogranite may represent the final, post-tectonic differentiates of the same magma in the form of pegmatitic magma and silica-bearing hydrothermal solutions of a powerfully pervasive character.

The distribution of Embudo Granite is structurally and stratigraphically controlled, to a partial extent at least; this will be treated under *Structure.*

The Embudo Granite is intrusive into and younger than the Ortega and Vadito formations. The pegmatite of the Harding Mine in the Picuris Range, genetically related to this granite through mineralogy and field relationships (Montgomery), was first dated by Ahrens (1949) at 800 million years, using the strontium-rubidium method. Its age has been determined more recently by Aldrich, Weatherill, and Davis (1957) to be 1300 million years. Recent determinations were based on the strontium-rubidium and potassium-argon methods.

Dikes and Veins

Pegmatites. In the Picuris Range, granite pegmatites, all presumably related genetically to the Embudo Granite, are only abundant in certain localized areas. The distribution of these areas of abundance was plotted on a map, showing in large part a control by proximity to the Embudo granite. The distribution of pegmatites in the mapped quadrangle is too spotty, with two possible exceptions, to make possible any mapping here of areas of greatest pegmatite abundance.

Pegmatites differ in size from tiny veinlets to dikes tens of feet thick and hundreds of feet long. They are of very coarse-grained granitic texture and are of the usual simple mineral composition of flesh-pink, partly perthitic microcline, white to grayish quartz, and silvery-gray muscovite. Topaz in coarse gray-white crystals is rare, as are small platy crystals of ilmenite and columbite. Small greenish masses of fluorite very rarely are present, as are also small, stubby prismatic crystals of white beryl.

Quartz veins. Quartz veins, from tiny veinlets to dikes several feet thick, are prevalent in various rocks, especially in areas not far distant from intrusive Embudo Granite, Some of the veins contain thin, streaky bands of minute, matted needles of black tourmaline. Rarely, quartz veins show slight evidences of metallic mineralization, chiefly as thin coatings of secondary blue-green copper minerals on fracture surfaces.

Diabase dikes. Scattered diabase dikes in the Picuris Range are believed to be younger than the regional metamorphism and younger than all other Precambrian rocks of the Picuris Range (Montgomery). They are characterized by the presence of pyroxene (augite), which does not occur in the regionally metamorphosed amphibolites. In general megascopic appearance, however, they resemble the amphibolites. Because of their spotty occurrences in the Picuris Range, trending parallel to the Pilar—Vadito tear fault, their intrusion was presumed to be related in time to the tear faulting, perhaps very late in Precambrian time.

Only one isolated occurrence of diabase, similar petrographically to that of the Picuris Range, was observed in the southerly Truchas area. This is on the south side of Doctor reek, a mile west of Holy Ghost Canyon and three miles west of the Pecos Mine. In the field, this rock cannot be differentiated from surrounding greenish black amphibolites.

STRUCTURE

In the Picuris Range, bedded Precambrian rocks generally strike east-west and dip steeply southward (Montgomery). This apparent homoclinal structure is due to a system of tightly compressed isoclinal folds, the axial planes of which strike east-west and dip steeply south. Four major folds, two anticlines and two synclines, with wave lengths of one to two miles, are exposed. These folds are doubly plunging, with plunges averaging 20 to 3o degrees. Smaller drag folds lie on the limbs of the major folds.

In the Precambrian rocks south of the Picuris Range and east of the north-south trending Picuris—Pecos fault, similar major folds with east-west axes are present, but they are not all so tightly compressed as those in the Picuris Range. Seven such major folds are in the Truchas area and the locations of their axes are shown in Figure 4. Four of the five folds lying south of South Truchas Peak have been correlated with the four major folds mapped in the Picuris Range. They represent eastward extensions of those earlier mapped folds.

In the region south of the Picuris Range and west of the Picuris—Pecos fault, the regional structure of the Precambrian metasediments is largely obliterated by large-scale intrusion of granite.

In the Picuris Range an unconformity or a major fault, probably the former, was believed to form the contact between the Ortega and Vadito Formations. The same contact is exposed in the Truchas area. Exposure of this unconformity is discontinuous because of Paleozoic cover, but it can be traced eastward from the area of its intersection with the Picuris—Pecos fault, two miles west of Pecos Baldy, as far as the east border of the quadrangle, I r miles distant. As in the Picuris Range, this contact may be traced, and verified as a likely inconformity, by the presence of conglomerate beds lying above the contact at or near the base of the Vadito Formation. Metaigneous felsites at or near the contact also are characteristic of this unconformity.

Faults affecting the Precambrian rocks are believed to be of at least three generations: strike-slip faults of likely Precambrian age, normal or thrust faults of likely Laramide age, and post-Laramide normal faults, including the border faults of the western Santa Fe Range. Only the faults of Precambrian age will be discussed here. The great north-south-trending Picuris—Pecos tear fault is the most significant structural feature of the mapped region. It has been traced for about 5o miles. The strike-slip movement along this fault has displaced beds a horizontal distance of 23 miles.

Most of the exposed contact of Embudo Granite with other Precambrian rocks, except along the Picuris—Pecos fault, is intrusive. This granite has intruded all other Precambrian rocks except the unmetamorphosed diabase dikes. Some of the granite is gneissic, or foliated, parallel to regional foliation. The main intrusion of this granite is presumed to have been a very late phase of the main Precambrian orogeny, but some very late-stage intrusive and hydrothermal effects associated with the intrusion are clearly younger than the metamorphism. Localized aplitic and pegmatitic dikes apparently preceded that final magmatic episode by a very short interval.

Here, as in the Picuris Range, long-continued Precambrian orogeny, probably 1300 million years ago, profoundly deformed and metamorphosed the older rocks of this region through stresses exerted in a north-south direction. The final episode of this orogeny may well have included strike-slip faulting of great magnitude, followed by a relaxation from the north-south stresses, and terminating with small-scale, localized intrusion of diabase dikes.

FOLDS

Axes of the seven major folds mapped in the Truchas area trend east-west. In most instances, beds in the limbs of these folds strike east-west and dip steeply southward. Beds in the limbs of the southernmost fold, the Pecos Valley anticline, do not conform to this rule, as these beds strike nearly north-south and dip either steeply eastward or westward. In most exposures of the other six folds, axes appear to plunge steeply westward, as much as 45 degrees and more. In general, however, these folds are presumed to be doubly plunging along the strike; it is impossible to explain otherwise the east-west trends extending for many miles in relatively thin beds on the limbs of the folds.

The seven major folds, proceeding southward from the area of the campground on Rio Santa Barbara and lying east of the Picuris—Pecos fault, are named the Santa Barbara anticline, Truchas Peaks syncline, Pecos Baldy anticline, Brazos Cabin syncline, Middle Mora anticline, Rociada Trail syncline, and Pecos Valley anticline.

The Santa Barbara and Pecos Baldy anticlines are broad folds occupied chiefly by a great thickness of the lower quartzite member of the Ortega Formation. The Truchas Peaks and Brazos Cabin synclines are less broad folds occupied chiefly by schists and gneisses of the lower quartzite and Rinconada Schist members of the Ortega Formation. The Middle Mora anticline is a poorly exposed, narrow fold occupied by the lower quartzite of the Ortega Formation. The Rociada Trail syncline is a poorly exposed, rather broad fold, in which are mainly metaigneous felsites and minor conglomerate of the Vadito Formation. Granite increasingly occupies this syncline westward from the East Divide. The Pecos Valley anticline is a huge, uniquely broad fold, poorly exposed under Paleozoic cover, occupying the southernmost third of the entire Truchas area. This fold is expressed chiefly in a great thickness of amphibolites and felsitic rocks of the Vadito Formation and by widespread areas of intrusive granite.

Figure 5 lists the evidence supporting correlation among four major folds in the Picuris Range and the Truchas area (fig. 4). This correlation depends mainly on similar rocks and rock sequences and on certain major rock contacts, but other features, such as zones of similar copper mineralization, are also diagnostic clues.

The Pecos Valley anticline in the southernmost Truchas area can be correlated similarly with the broad anticline that is only partly exposed in the southwesternmost Picuris Range. North-northeasterly bedding strikes are similar in the north limbs of both folds. The prevailing north-south strikes of beds in the Pecos Valley anticline, roughly perpendicular to the regional east-west strike of Precambrian beds elsewhere, need clarification. Granite occupies much of the central part of this fold east of Tererro; it is possible that forceful intrusion of granite has wedged apart this fold so drastically as to flatten out the north and south limbs along a north-south direction and to steepen the plunge of its earlier westward-plunging axis into a nearly vertical position. Steep westward dips of foliation and bedding in this fold therefore may represent overturning. Similar powerful wedging apart of rocks of the Vadito Formation by granite was described for the southwesterly part of the Picuris Range (Montgomery).

FAULTS

Detailed mapping of Precambrian rocks northwest, west, and southwest of the Truchas Peaks has revealed a great north-south-trending tear fault. For a distance of II miles, southward from a point two and one half miles west of the campground on Rio Santa Barbara at the north to the head of Horsethief Canyon two miles west of Pecos Baldy summit at the south, the trace of this fault trends N. o° E. It separates granite on the west from Precambrian metamorphic rocks on the east. For four miles north of the head of Horse-thief Canyon, the metamorphic rocks east of the fault all veer sharply from a generally southwesterly trend to a northwesterly one. This marked change of strike is interpreted as the effect of drag.

The Picuris—Pecos fault has been traced far north and south from the area described. Its total traced length is approximately 5o miles. For eight miles north of the point two and one half miles west of the campground on Rio Santa Barbara, the trace of the fault is covered by unconsolidated Cenozoic deposits. North of this eight-mile stretch of alluvial cover, the fault continues as the Alamo Canyon fault, which was traced for seven miles northward from the vicinity of Vadito to the White Caves at the north border of the Picuris Range. Along this fault Pennsylvanian rocks and Precambrian granite on the east are separated from Precambrian metamorphic rocks on the west. Where east-west-striking beds approach the fault on the west, they swing around sharply southward to south-southeasterly strikes. This change in strike was interpreted as due to powerful drag (Montgomery). Mistakenly, however, as a further interpretation, the Alamo Canyon fault was believed to terminate near Vadito against the Pilar—Vadito fault (pl. 1).

The Picuris—Pecos fault continues for ten miles southward from the head of Horsethief Canyon to the south border of the quadrangle three and one half miles west of Tererro. Along much of this ten-mile stretch, Pennsylvanian beds east of the fault lie against Precambrian granite to the west. For four miles near the southerly termination of this stretch, however, a half-mile-wide zone of Precambrian rocks, chiefly phyllite and amphibolite, separates the granite from the Pennsylvanian beds. South of the mapped quadrangle the fault continues for another ten miles as far as the termination of the Precambrian rocks west of Pecos. Granite is against Paleozoic beds for much of this distance, but there are also narrow north-south zones of other Precambrian rocks interspersed between granite and Paleozoic beds.

The fact that Pennsylvanian beds have been separated from granite along part of this fault, with the former generally striking parallel to the fault and dipping steeply eastward away from it, indicates that movement with a pronounced vertical component has occurred in post-Pennsylvanian time. The vertical slip is at least 1500 feet. Vertical movement, long after the original strike-slip movement, perhaps at the close of the Laramide revolution or more recently, was inferred for both the Pilar—Vadito and Alamo Canyon faults (Montgomery). Evidence can be found for the distinction between these two periods of faulting near the Truchas Peaks, where later vertical movement has occurred along the subsidiary Jicarilla fault. This fault swings around to the east side of the peaks against Pennsylvanian beds to the east, and to the west appears to have uplifted both quartzite and granite, together with the old tear fault that separates them.

The original strike-slip movement caused a north-south, horizontal, 23-mile displacement of beds. This movement probably took place in Precambrian time. Extreme plasticity was required for rocks to be dragged so strongly without producing conspicuous fracturing and granulation. Such movement and associated plastic deformation could have resulted from deep-seated Precambrian folding and attendant regional metamorphism.

Localized zones of shearing, brecciation, and silicification are found in association with the Picuris—Pecos fault. It is not known whether these effects were caused during earlier strike-slip movement or later vertical movement. At the northern end of the fault, near White Caves at the north edge of the Picuris Range, Precambrian quartzite west of the quartzite-granite contact here marking the fault has been ground up to a loose, fine-granular gouge for hundreds of feet parallel to and also west of the fault. Various Precambrian rocks dragged southward on the west side of the fault, around Picuris Peak and north and south of there, merge into an extensive north-south silicified zone indistinguishable from brecciated quartzite near the fault. Precambrian rocks dragged northward on the east side of the fault, west of Pecos Baldy, grade into a localized zone of very coarse breccia in which subangular fragments of various Precambrian rocks, up to several inches across, are set in a matrix of tan silicified gouge. At a few localities, large ribs of brecciated and silicified Precambrian rocks, chiefly quartzite and granite, hundreds of feet long along a north-south direction parallel to the fault and up to a hundred feet wide stand up as prominent landmarks many tens of feet above the surrounding terrain. Especially good examples of such ribs are to be seen near the Brazos Cabin along the Rio Medio and near the head of Doctor Creek at

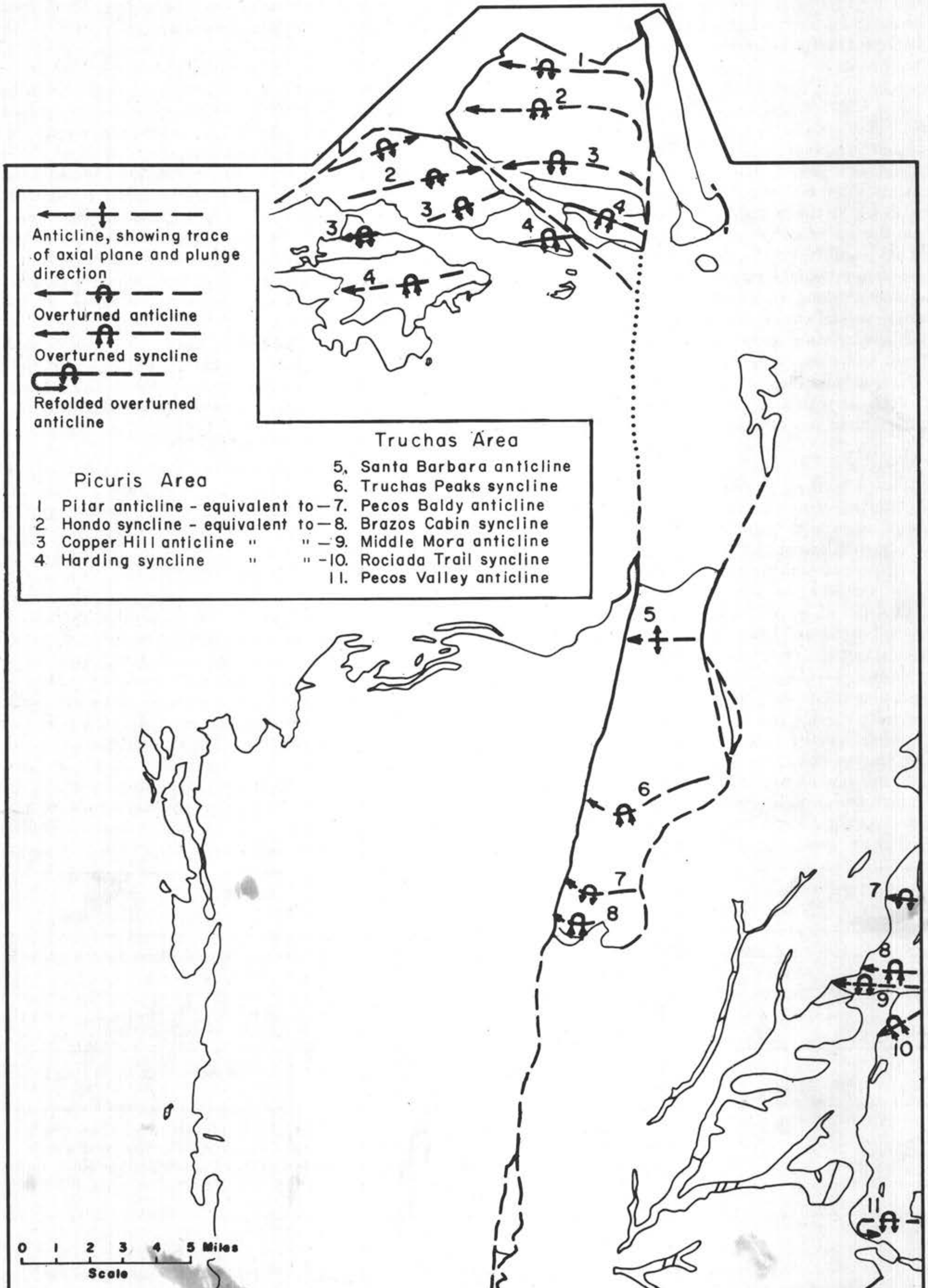

Figure 4

Axes of Precambrian folds

the south boundary of the quadrangle. These ribs lie from hundreds up to thousands of feet distant from the mapped trace of the fault. Such widely spaced zones of shearing suggest that the Picuris—Pecos fault is, in part at least, a very wide fault zone.

OTHER STRUCTURES

Joints

In the Precambrian rocks of the Picuris Range, there are three main joint sets, the attitudes of which average north-south, vertical; N. 6o° W., dip steeply NE.; and N. 3o° E., dip steeply SE. In the mapped region south of there, predominant joint sets average N. 5° W., vertical; N. 45° W., dip steeply SW.; and N. 50° E., dip steeply SE.

These joint sets could have been formed by north-south or east-west compression. In the widespread granite of the Santa Fe Range, several major canyons and numerous tributary arroyos show trends of about N. 6o° E, or N. 6o° W. These directions, best seen in the canyon trends of Rio Capulin, West Panchuela Creek, Big Tesuque Creek, Rio Nambe, and Rio Frijoles, are within I o or I 5 degrees of the strikes of two of the three main joint sets observed in Precambrian rocks.

Foliation

Foliation is well developed in metasedimentary Precambrian rocks other than quartzite. This is commonly a schistosity caused by parallel orientation of muscovite flakes, large or small. Such micaceous foliation parallels bedding.

Felsites and amphibolites may exhibit a crude foliation, caused by parallel orientation of minute muscovite flakes in the felsites and of blade-like hornblende prisms in the amphibolites. Certain amphibolites and felsites, especially those around and east of Terrero, are minutely grained, dense, and do not show any visible foliation.

The Embudo Granite shows in part a weakly developed gneissic foliation due to parallel streaking of biotite flakes. Such gneissic granite occurs typically where the rock approaches the composition of a granodiorite or quartz diorite. Fine-grained, pinkish-to-tan leucogranite commonly is massive and structureless, suggesting that it originated after the regional metamorphism. Granite pegmatites are not foliated.

Whether the regional, generally east-west, foliation is an axial-plane or a bedding foliation, or a combination of both caused by more than one episode of folding, is unknown. It is believed to be a bedding foliation.

Lineation and Stretched Pebbles

Lineation was not commonly observed in the Precambrian rocks, but may be well developed locally in certain rocks under special circumstances. Where observable on foliation surfaces, there are three principal types of lineation. One consists of a general lining-up of elongate minerals, such as lenticular biotite flakes, sillimanite needles, or hornblende prisms. A second, found in some phyllites especially, is a small-scale crinkling or corrugation caused by the intersection of a slip-cleavage with planes of foliation. A third is caused by a crude alignment of the long axes of stretched pebbles and cobbles in the coarse quartz conglomerate beds of the Vadito Formation.

The common trend of these three types of lineation is directly, or nearly, down the dip of the associated foliation planes (pl. 8A). There is no apparent parallelism between the lineation and the axial plunges of associated major folds.

INTRUSION OF PLUTONIC ROCKS

In the Picuris Range bodies of Embudo Granite lie along the southwestern, southern, and easternmost borders of the range. Southward from there for eight miles and west of the Picuris—Pecos tear fault, Precambrian rocks are largely covered by unconsolidated Cenozoic deposits. Where isolated rock outcrops appear in this area, however, these are nearly all of granite.

An unbroken north-south zone of granite, eight miles wide, extends 20 miles southward from the towns of Truchas and Cordova. This zone upholds the high westerly Santa Fe Range. Together with associated Precambrian rocks, it terminates near Glorieta, ten miles south of the south border of the quadrangle. This extensive zone of Embudo Granite is in intrusive contact with older Precambrian rocks in the southern Picuris Range but is in fault contact with Paleozoic beds along much of its eastern edge farther south. Evidence based on the attitude of Pennsylvanian beds which dip steeply eastward away from this fault contact, as well as on their stratigraphic position more than moo feet above the

Offset Folds		
Picuris Range	*Truchas Area*	*Evidence*
Pilar anticline	Pecos Baldy anticline	Both are occupied by lower Ortega quartzite and contain zones of sillimanite-rich gneiss in the north limbs.
Hondo syncline	Brazos Cabin syncline	Both are occupied by same Ortega schists (Rinconada Schist and Pilar Phyllite members). Distinctive andalusite-biotite gneiss occurs at same horizon in outer, north limbs of both.
Copper Hill anticline	Middle Mora anticline	Both are occupied by lower Ortega quartzite marked by widespread blue-green staining from inclusions of secondary copper minerals.
Harding syncline	Rociada Trail syncline	Both cores are partly occupied by Vadito phyllite. Both folds widen westward where they are occupied by Embudo Granite. Both north limbs are marked by felsite and minor conglomerate. South limbs are chiefly amphibolite with zones of abundant granite pegmatities. Tantalum-lithium-rich Harding (Picuris) and Pidlite (by Rociada trail 1 mile east of map) pegmatites are at same horizon on north edge of amphibolite.

Figure 5

TABULATED EVIDENCE FOR EQUIVALENCE OF OFFSET PRECAMBRIAN FOLDS older Paleozoic beds normally resting upon the Precambrian basement in this area, points to a great uplift of the granite belt along this fault. Scattered patches and narrow isolated belts of schists and gneisses within the granite, near the westerly borders of the zone, indicate the effects of their intrusion, engulfment, and partial assimilation by granite. How extensive may be the obliteration of older rocks along this zone by granite is unknown; but uplift of this western block along the Picuris—Pecos fault may well have brought to the level of the present surface rocks belonging to a deeper stratigraphic position in the crust than Precambrian rocks now exposed at the surface east of the fault.

All granite east of the Picuris—Pecos fault is in apparent intrusive contact with associated rocks. The presence of abundant pegmatites and quartz veins, and the effects of widespread hydrothermal mineralization in rocks near the granite and the rare presence of partly assimilated xenoliths of surrounding rocks in the granite near its contact with those rocks, show that the Embudo Granite has intruded rocks of the Vadito Formation on a very wide scale in the Truchas area. The clearest evidence of assimilation is where dark amphibolites have been engulfed, partly assimilated, and strewn through the intrusive granite in such a way as to create a dark-colored, biotite-rich granite. This process at a few places has created a gray-black, coarse-grained rock of quartz diorite composition, in appearance identical to the typical quartz diorite found at many localities.

There is a noteworthy map relationship in the Truchas area between felsitic rocks of the Vadito Formation and certain zones of Embudo Granite. In the southeasterly corner of this area, along the east slopes of the East Divide, isolated patches of granite appear only in belts of felsitic rocks. West of the East Divide, granite increasingly occupies and largely blots out similar belts of felsites. These belts of felsite and granite follow the regional strike of the bedded Precambrian rocks. Slight chemical changes would be needed to transform such felsitic rocks, chiefly fine-grained metarhyolites, into fine-grained granite. Much fine-grained, tan leucogranite may represent an original metarhyolite transformed by hydrothermal alteration and metamorphic replacement into a fine-grained, granite-like rock.

The question arises: How much does the presence of widespread felsitic rocks control the occurrence of granite in this region? Map relationships suggest that such control is extensive. Felsitic rocks are not present in the Ortega Formation and granite does not appear associated with this formation.

The occurrence of the migmatitic quartzite (Rio Pueblo Schist) of the Ortega Formation, as in the outcrops near U.S. Hill and two miles southeast of the village of Rio Pueblo, suggests that here granitic material has been intruded into sheared quartzite in lit-par-lit fashion. This could be regarded as a partial granitization effect. Quartzite beds here may have been horizontal originally, then could have been domed up by a push of granite magma from below. With fracturing taking place parallel to the bedding planes, thin layers of granitic material might then have been injected to make a micaceous, schistose or gneissic, feldspathic quartzite.

METAMORPHISM

The Precambrian rocks of the Picuris Range were subjected to a regional metamorphism ranging from middle grade to high grade. They were also affected by a later widespread hydrothermal metamorphism related to granite intrusion (Montgomery). Since the Embudo Granite shows in part the effects of dynamic metamorphism, it is believed that regional compressive forces continued after the granitic intrusion. It is concluded therefore, that these two main episodes of metamorphism were not far apart in time and were related parts of a single orogenic process occurring in Precambrian time.

The regional metamorphism was a result of dynamothermal processes. The hydrothermal metamorphism developed under reduced stress conditions soon after the regional metamorphism. The hydrothermal solutions, active during this metamorphism, were given off by bodies of crystallizing granitic magma.

In the Precambrian rocks south of the Picuris Range, the effects of these same two kinds and periods of metamorphism are clearly seen. Evidence for the differential recognition of the grades of regional metamorphism is quite obscure and the mapping of distinct grade zones, as was done in the Picuris Range, has proved impossible. In the Picuris Range, three such zones of metamorphism were mapped, a sillimanite zone (highest grade), a kyanite zone (upper middle-grade), and a staurolite zone (middle grade). In the Truchas area sillimanite and kyanite seem largely associated with extreme conditions of hydrothermal metamorphism. All regionally metamorphosed rocks of the quadrangle are classed as middle grade (staurolite).

REGIONAL METAMORPHISM

In the Picuris Range, it was concluded that the principal period of regional metamorphism was closely associated with the main folding and in part related to depth. The higher grade metamorphic minerals, sillimanite and kyanite, were only observed in those rocks of the Ortega Formation of deepest stratigraphic position. In the Truchas area, sillimanite and kyanite are so scattered in rocks of the Ortega Formation, and so closely associated with quartz veins and pegmatites in localized areas intensely affected by hydrothermal mineralization, that the locations of these minerals cannot be related to regional metamorphic zoning of the Ortega Formation.

The amphibolites of the Vadito Formation in the Truchas area, as in the Picuris Range, are rich in an aluminous hornblende of bluish green pleochroism that is characteristic of middle-grade metamorphism. The occurrence of abundant staurolite at many places in the schists and gneisses of the Rinconada Schist places them in the middle-grade zone of regional metamorphism. It is assumed that metasedimentary, amphibolitic, and felsitic rocks of the Truchas area belong in the zone of middle-grade regional metamorphism.

West of the Picuris—Pecos fault and south of the Picuris Range, hydrothermal mineralization associated with widespread granitic intrusion is so strong in all Precambrian rocks that evidence of regional metamorphic zoning is lacking.

HYDROTHERMAL METAMORPHISM

The same widespread effects of hydrothermal metamorphism observed in the Picuris Range (Montgomery) are present in all Precambrian rocks of the quadrangle, except the unmetamorphosed diabase. Much of this hydrothermal metamorphism is presumed to be related in origin to one prolonged episode of hydrothermal mineralization. Very striking features are the widespread quartz veins and pegmatites and the extensive tourmalinization of rocks adjacent to them. Less obvious are the effects of infiltration and partial replacement of felsites by pinkish microcline and the resilicification of much of the Ortega quartzite to a rock resembling translucent, milky vein quartz. Extensive outcrops of this altered quartzite are stained blue-green by secondary copper minerals, or they may be dark-colored because of inclusions of iron-oxide minerals. Additional features diagnostic of hydrothermal mineralization are certain coarse-grained sillimanite-rich, also kyanite- and andalusite-bearing, gneisses.

The principal metasomatic changes in the rocks were additions of boron, yielding abundant tourmaline, and of potash, resulting in widespread formation of pink microcline. Various metals, chiefly copper and iron, are present in small, local concentrations of ore minerals, usually associated with abundant, coarsely prismatic, black tourmaline. At the Pecos Mine near the mouth of Willow Creek, two huge ore bodies of zinc, lead, and copper sulfides were formed along zones of fractured, brecciated rock and are associated with very abundant tourmaline. Such metallic mineralization is evidently related to the same long-continued period of hydrothermal metamorphism.

RETROGRADE METAMORPHISM

The effects of retrograde metamorphism seem slight in these Precambrian rocks. The effects observed, in thinsection study, include the alteration of sillimanite and kyanite to muscovite in the lower quartzite of the Ortega Formation. They include also the alteration of original, mineralogically indeterminate porphyroblasts in the Pilar Phyllite of the Ortega Formation to streaky, black patches of iron oxide. Further effects are the alteration of biotite crystals to chlorite in various phyllites, schists, gneisses, and grayish felsites of the Vadito Formation. They include also the sausseritization of plagioclase and the alteration of hornblende in the Vadito amphibolites to biotite, chlorite, epidote, and ilmenite-sphene aggregates. The more gneissic occurrences of Embudo Granite show breakdown of alkalic feldspar to sericite and alteration of biotite to streaky patches of chlorite and iron oxide.

PRECAMBRIAN GEOLOGIC HISTORY

The earliest episode on which there is geologic evidence in the area covered by this report was the deposition of many thousands of feet of pure quartz sands. As much as Io,000 feet of these sands piled up on a subsiding shelf of a shallow sea. With deepening of the sea, hundreds of feet of sandy mud, followed by at least several thousand feet of such mud containing carbonaceous impurities, were laid on top of the sands. These sediments became consolidated; were uplifted and eroded; then were depressed at or slightly below sea level once again. On the eroded surface of these oldest consolidated sediments of the Ortega Formation, hundreds of feet of additional sediments were deposited. Argillaceous quartz sand, coarse gravel, and sandy mud were laid down in connection with a fluctuating sea level and a land surface of considerable relief; these sediments later became part of the Vadito Formation. Lava flows and tuffaceous deposits were interlayered with the Vadito sediments. The earliest of these volcanic rocks were chiefly rhyolitic, but later ones were predominantly andesitic and basaltic. Some of the basalts were amygdaloidal. Then, with increasing igneous activity, sills and dikes of both acid and basic composition were intruded into the earlier, deeply buried sedimentary and volcanic rocks of the Vadito Formation. These intrusives were in part interlayered with, but in part also engulfed and obliterated by, the intruded sediments and eruptive igneous rocks. The intrusions followed the deposition and consolidation of sediments and eruptive rocks of the Vadito Formation, yet were related compositionally to the earlier volcanics, and hence probably represent the last phase of a long-continuing series of genetically related igneous episodes. These inferred relationships between the sediments and associated igneous rocks has led to the inclusion of all of them within the Vadito Formation.

Crustal unrest, as evidenced by the accelerating igneous activity, finally culminated in a major orogeny. Rocks of the Ortega and Vadito formations were now at great depth in the crust where high temperatures existed, and they were subjected to forces of lateral compression. The rocks became compressed and plastically deformed into folds with east-west axes. So began a long-continuing period of intense and widespread regional metamorphism. All rocks were recrystallized. Sandstone became quartzite; shale became phyllite and schist; rhyolitic flows, sills, and dikes became light-colored felsites; andesitic and basaltic flows, sills, and dikes became dark-colored amphibolites. In some of these rocks the newly recrystallized minerals of platy and blade-like habit imparted to the rocks a marked east-west foliation.

When compressional forces diminished, granitic magma was intruded in such a way as to push aside, engulf, and partly obliterate the intruded rocks. As the granite crystallized, some of its residual magma rich in volatiles and rare elements was forced upward into the overlying rocks as dike-like bodies of pegmatite. With final crystallization of the granitic magma, it gave off water-rich and silica-rich solutions which penetrated surrounding fractured and permeable rocks. This was the period of intensive hydrothermal metamorphism. Quartz veins were formed abundantly in the fractured rocks. Boron-bearing gases caused the widespread formation of tourmaline. All these episodes related to granitic intrusion continued over an extended period. The earliest intrusions of granitic magma preceded the termination of the compressional forces associated with regional metamorphism. These intrusions, chiefly of dark-gray granodiorite and quartz-diorite composition, show a fairly well-developed gneissic foliation. Later granite intrusions, gray or tan in color, are richer in potash and soda. Such granite tends to be structureless and must have formed after regional metamorphism. The latest formation of granite, yielding a tan to flesh-pink, fine-grained leacogranite, appears to have been largely the result of replacement of metarhyolitic rocks by hydrothermal solutions given off during final crystallization of granitic magma. During the hydrothermal metamorphism, ore-bearing minerals of copper, gold, silver, lead, and zinc were deposited in certain of the quartz veins. There were recurring short episodes of compressional stress. The fracturing produced by these stresses may have been a decisive factor in the localization of the ore-bearing solutions that formed the rich deposits of the Pecos Mine near Tererro.

Still later, presumably during Precambrian time, extensive tear faulting took place. Strike-slip movement, resulting in a north-south, 23-mile horizontal displacement, extended for 5o miles from the north border of the Picuris Range near the White Caves to Glorieta Baldy, ten miles south of the Pecos

Mine and of the south edge of the quadrangle. Rocks west of the fault were moved northward, while rocks east of the fault were moved southward. Drag was exerted on steeply inclined beds of schists and gneisses striking roughly perpendicular to the fault. These beds were dragged southward from easterly strikes on the west side of the fault in the Picuris Range, and northward from southwesterly strikes on the east side of the fault in the area of the Truchas Peaks. A smaller subsidiary tear fault trends N. 5o° W. across the Picuris Range for six miles, with rocks east of it displaced northward relative to those on the west. Later vertical movement developed along both of these extensive tear faults.

A final event in Precambrian time may have been the small-scale, localized intrusion of diabase dikes.

Paleozoic Rocks

by Patrick K. Sutherland

INTRODUCTION

Paleozoic rocks in the southernmost Sangre de Cristo Mountains include the following units in ascending order: an unfossiliferous quartzitic sandstone and conglomerate of undetermined age, here named the Del Padre Sandstone, up to 75o feet thick; a recrystallized limestone and dolomite sequence of undetermined age, named the Espiritu Santo Formation (Baltz and Read, 196o), up to 55 feet thick; a Mississippian limestone named the Tererro Formation (Baltz and Read, 196o), as much as 86 feet thick; a thick sequence of Pennsylvanian sandstone, conglomerate,, shale, and limestone named in this paper the La Pasada, Flechado, and Alamitos Formations, total thickness 2200 to 6500 feet; and unfossiliferous sandstone, conglomerate, and red shale of Pennsylvanian and/or Permian age included in the Sangre de Cristo Formation (fig. 6): Additional Permian formations are exposed in the foothills south and east of the Sangre de Cristo Mountains but are not included in this discussion.

This description is a summary of the Paleozoic rocks in the southernmost Sangre de Cristo Mountains based on 26 partial or complete stratigraphic sections of pre-Pennsylvanian rocks and 22 partial stratigraphic sections of Pennsylvanian strata (fig. 7). About 600 thinsections of Pennsylvanian rocks and about 500 thinsections of pre-Pennsylvanian rocks have been studied. Only type stratigraphic sections for new forma

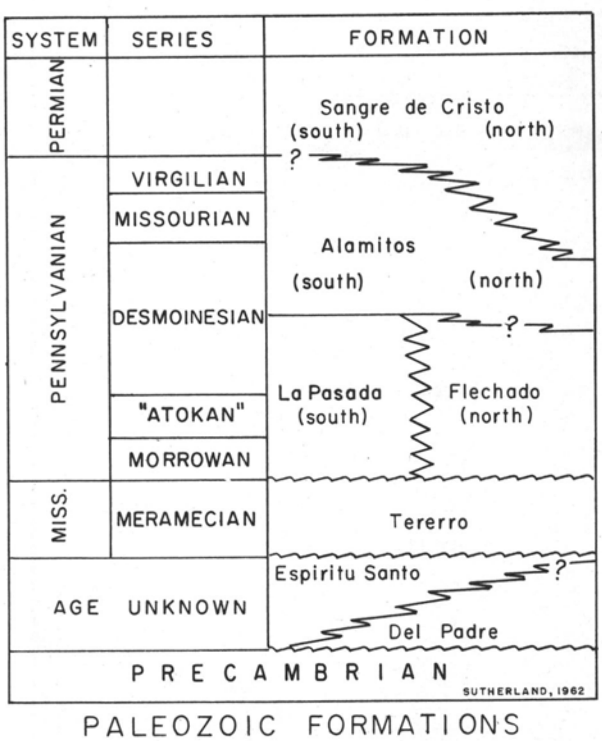

Figure 6

TABLE OF PALEOZOIC FORMATIONS

tions are included. Later papers are planned which will describe some of the more detailed aspects of the geology presented in this summary paper. The classifications proposed by Folk for the description of terrigenous sedimentary rocks (1954) and for carbonate rocks (1959) have been used.

PRE-MISSISSIPPIAN? AND MISSISSIPPIAN ROCKS

Pre-Pennsylvanian sedimentary rocks in north-central New Mexico typically consist of thin limestone units underlain locally by unfossiliferous sandstone. The limestones are sparsely fossiliferous, and uncertainty about their ages has resulted.

Baltz and Read (196o) summarized the nomenclature for rocks of pre-Pennsylvanian age in the southern Sangre de Cristo Mountains and proposed new formation names for two of the three pre-Pennsylvanian formations recognized in this paper.

DEL PADRE SANDSTONE

Designation

The name *Del Padre* is here proposed for an unfossiliferous orthoquartzitic sandstone of undetermined age in the southern Sangre de Cristo Mountains area. Where observed, it rests unconformably (pl. 9A) on Precambrian igneous or metamorphic rocks. This sandstone was included by Baltz and Read (196o) as the lower of four lithologic members of the Espiritu Santo Formation. However, those authors did not describe the sandstone and conglomerates in the outcrop areas of its maximum development. The Del Padre is conformably overlain by the Espiritu Santo Formation, and its upper part is believed to interfinger laterally with that formation *(see* discussion of Espiritu Santo Formation).

The bluff on the north side of the Rito del Padre at its junction with the Pecos River (sec. 4) is here designated the type locality for the Del Padre Sandstone. Beatty 's Cabin, a well-known historical landmark, is on the river flat opposite the Del Padre bluff (pl. r oB). At this locality, the basal contact with the Precambrian is well exposed but the upper contact with Mississippian limestone is covered. The shale and siltstone in the lower part of the formation at the type locality is not a consistent feature. The base of the section is at the Precambrian contact a short distance above the river level and continues up the steep bluff formed by the Del Padre Sandstone. The top of Unit 6 forms the cliff crest. Unit 7 forms a gentle grassy slope above the cliff. Unit 8 is about 30o yards north along the bluff top on the west side of the Pecos River.

SECTION 4. TYPE LOCALITY OF THE DEL PADRE SANDSTONE. BLUFF AT JUNCTION OF RITO DEL PADRE AND PECOS RIVER

UNIT No.	DESCRIPTION	THICKNESS (feet)
Terrero Formation, Cowles Member		
8.	Limestone, large blocks, irregularly slumped, nearly in place; thickness not determined	
7.	Covered, may conceal Espiritu Santo Formation	20
Del Padre Sandstone		
6.	Sandstone, pale yellowish-brown to very pale-orange,	

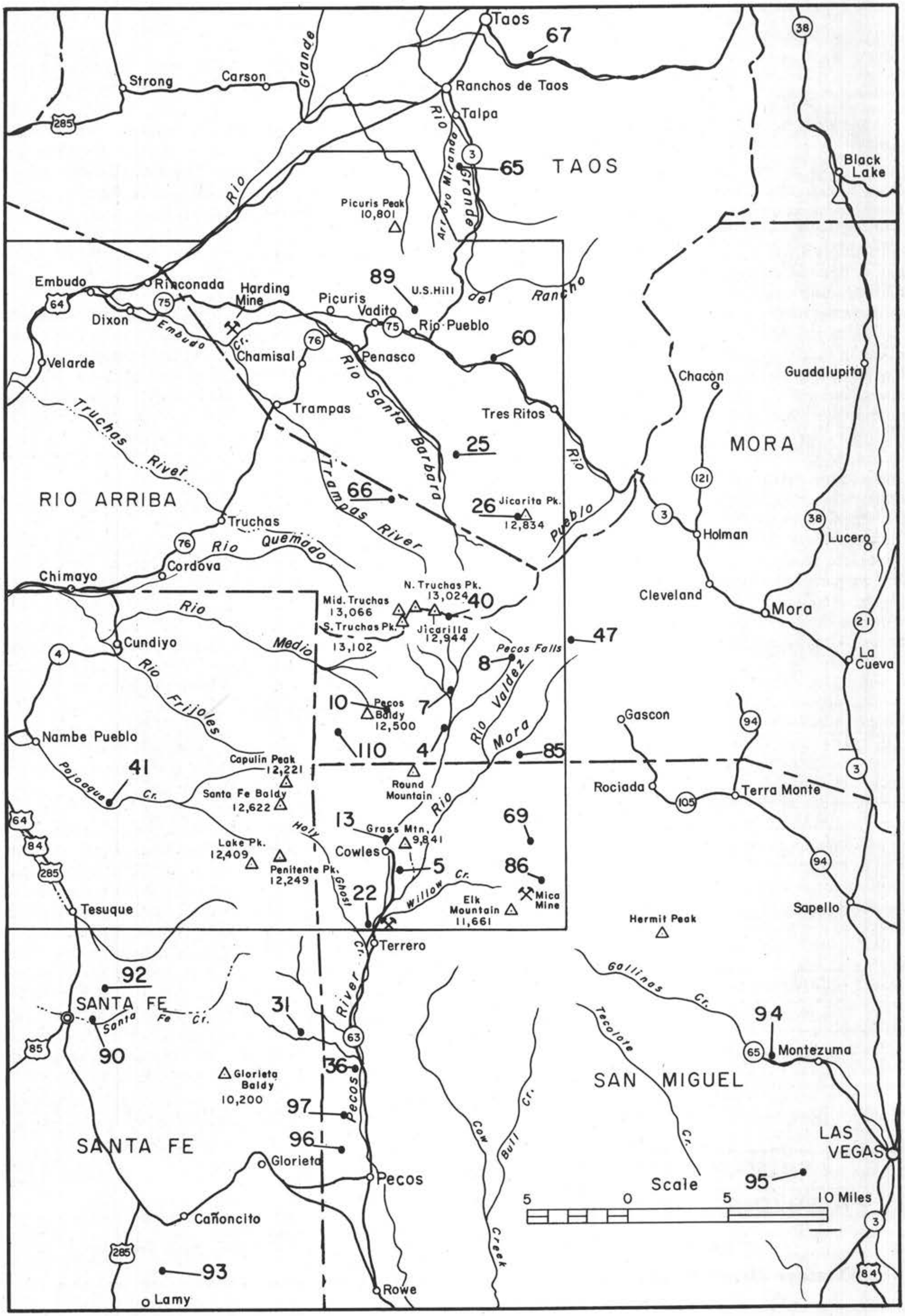

Figure 7

MAP OF PALEOZOIC LOCALITIES CITED

Unit No.	Description	Thickness (feet)
	medium- to coarse-grained with some granule and pebble layers; noncalcareous; calcareous near top; thick-bedded	73
	Thinsections:	
	a. 63 feet above base: *bimodal, coarse- and very fine-grained sandstone; immature, quartz-overgrowth- and authigenic clay-cemented orthoquartzite*	
	b. 27 feet above base: *coarse-grained sandstone; mature quartz-overgrowth and authigenic clay-cemented orthoquartzite*	
	c. 13 feet above base: *coarse-grained sandstone; mature, quartz-overgrowth-cemented orthoquartzite*	
5.	Siltstone, pale-brown, sandy, micaceous, irregularly bedded	2
4.	Sandstone, pale yellowish-brown, coarse-grained; conglomeratic in part; poorly sorted; basal contact irregular (thinsection 2 feet above base: *very coarse-grained sandstone; submature, muscovite-bearing, quartz-overgrowth-cemented orthoquartzite)*	4
3.	Sandstone and shale: sandstone, grayish-red and moderate yellowish-brown, fine-grained, micaceous, poorly sorted; alternating with micaceous silty shale (thinsection 2 feet above base: *fine-grained sandstone; immature, muscovite-bearing, hematite-cemented orthoquartzite)*	7
2.	Covered, talus of shale, grayish-red, silty, micaceous	6
1.	Conglomerate, very poorly sorted; subangular to subrounded pebbles and cobbles of quartzite to 5 inches in diameter; local and irregular in occurrence; basal contact irregular	0-1
	Total thickness Del Padre Sandstone	93
Precambrian		
0.	Phyllite	

Lithologic Character and Thickness

The Del Padre Sandstone consists of orthoquartzitic sandstone and conglomerate which are lithologically consistent throughout the area studied. The sandstone layers are medium- to coarse-grained, immature to mature, with locally developed conglomerate layers throughout the formation but more common in the lower part. Cementation is by quartz overgrowth except in the upper part of the formation where it is partly calcareous. Authigenic clay is commonly present as a minor cementing agent. The quartz grains show slightly undulose to semicomposite extinction. The granules, pebbles, and boulders are composed of quartzite similar in character to the quartzite of the Ortega Formation and sparse fragments of schistose quartzite. Feldspar is not present in the sandstone except locally in the basal layers in some areas where the formation rests directly on Precambrian granite.

In most localities the bedding is even, in layers one to two feet thick, with rare beds three to four feet thick (pl. 9B). Irregular bedding associated with coarse conglomerate occurs locally in the lower part of the formation with quartzite boulders more than one foot in diameter (pl. 8C). Such conglomerates infrequently reach tens of feet in thickness.

Regionally the thickness of the Del Padre Sandstone is highly variable, being thickest in the immediate vicinity of the Precambrian Ortega quartzite outcrops (Truchas Peaks to upper Mora area) and thinning away from them. Figure 8 shows points of known thickness of the Del Padre Sandstone in relation to the distribution of Precambrian rock types. This sandstone is derived from the local Ortega quartzite and related metamorphic rocks and filled the depressions on the sharply undulating, eroded pre-Del Padre surface. At those localities where the formation rests on granite or amphibolite, the eroded surface on the Precambrian is much less hilly than in the areas where the Del Padre Sandstone rests on quartzite. In the Pecos Valley between Macho and Indian Creeks, the pre-Del Padre surface on granite exposed in the sides of the valley seems to be almost flat. Careful analysis of the topography of the surface on Precambrian rocks in the Pecos Valley will not be possible until accurate topographic maps are available. A regolith several feet in thickness is preserved on the granite and amphibolite surface at many localities (pl. 8D).

At Pecos Falls (sec. 8), Pennsylvanian strata rest directly on the Precambrian quartzite at a place where this rock formed a high positive element on the pre-Paleozoic surface; the quartzite here may never have been covered by pre-Pennsylvanian Paleozoic deposits. At Beatty's Cabin (sec. 4), three miles southwest, the lower part of the Del Padre Sandstone was deposited in a small valley on the pre-Del Padre surface locally developed in a 600-foot-wide band of phyllite in the Ortega Formation. The Del Padre here is 93 feet thick. A mile

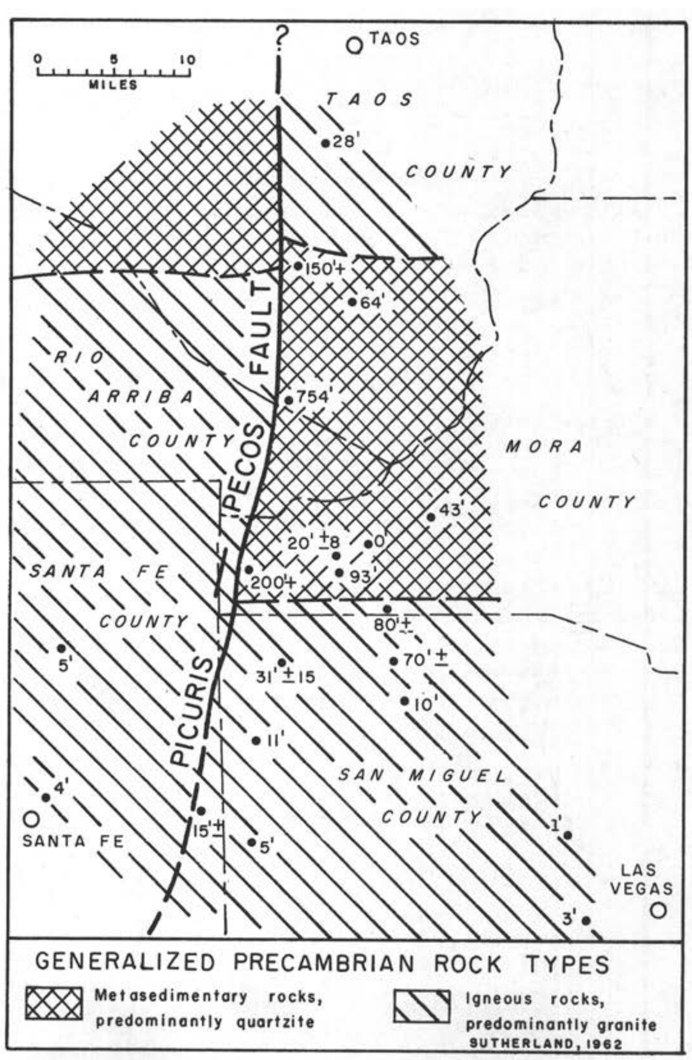

Figure 8

Points of known thickness of the Del Padre Sandstone in relation to the distribution of Precambrian rock types north at section 7, where the sandstone rests on what was probably a pre-depositional quartzite high, the thickness is about 20 feet. In the Pecos River gorge, about one and a half miles south of Beatty's Cabin, the basal contact of the Del Padre Sandstone with the underlying Precambrian quartzite is well exposed at several places along the bluff (pl. 9A). Here the river cuts through buried hills of Precambrian quartzite which have a local relief of at least 150 feet. Conglomerates composed of boulders of Ortega quartzite fill the lower parts of depressions in the old erosional surface and thin laterally on the flanks of the buried hills. Near Cowles (secs. **13 and** 5), seven to eight miles south of Beatty's Cabin, the Del Padre Sandstone ranges from 3o to 5o feet in thickness. Southward from this area there is a decrease in the thickness of the sandstone that corresponds with an increase in the thickness of the Espiritu Santo Formation in an apparent intertonguing relationship (fig. 9). At Tererro (sec. 22), five miles south of Cowles,. the Del Padre Sandstone is only 11 feet thick, and still further south in the lower Pecos Valley at Dalton Bluff (sec. 36), the sandstone is five feet thick.

The geographic limit of the Del Padre Sandstone is well defined in the southeast, south, and southwest parts of the Sangre de Cristo Mountains area. The sandstone is thin or absent at Gallinas Canyon (sec. 94) and west of Agua Zarca (sec. 95) southeast of the mountains, and at Nambe Falls (sec. 41) and Bishop's Lodge (sec. 92) southwest of the mountains (fig. 8). The sandstone extends eastward from the mountains into the subsurface at least as far as the Continental No. Duran well, about 4o miles east of section 6o, where its thickness is undetermined.

The sandstone thins northward, but its extent in that direction is unknown. It is 64 feet thick at Rio Pueblo (sec. 6o) and thins to 28 feet northward near Talpa (sec. 65), the most northerly exposure observed, where it rests on granite. At Rio Pueblo, the sandstone rests on schistose Ortega quartzite (Rio Pueblo Schist) in beds parallel to the bedding of the Precambrian quartzite *(see* discussion of dip variations in schistose quartzite in chapter on Precambrian rocks). Baltz and Read (1956, p. 78) mistakenly included the quartzitic sandstone of the Del Padre at this locality (pl. 9B) with the underlying Precambrian quartzite, and thus, in their later paper (196o) they record an incorrect measurement of less than five feet of Paleozoic sandstone here. Neither megascopically nor in thin-section does this quartzitic sandstone resemble the underlying, highly metamorphosed Ortega quartzite, here schistose and feldspathic (Rio Pueblo Schist).

Abnormal thicknesses of quartzitic sandstone assigned to the Del Padre occur at three widely separated localities. All are near the Picuris—Pecos fault and their anomalous features may be related to it in origin. The sandstone at all three localities is underlain by Precambrian quartzite:

(1) At Rio Chiquito (sec. 66), the sandstone is 754 feet thick and its lithology is similar to that at other localities already discussed, except for numerous conglomerate layers. The quartz grains and quartzite fragments in the lower beds have been derived from an intensely sheared source. Bedding is commonly even. At this locality the sandstone is directly overlain by Pennsylvanian strata.

(a) Southwest of Pecos Baldy (sec. o), the minimum thickness exceeds zoo feet; the upper contact is not exposed, and the sandstone is atypical, consisting of subangular to subrounded boulders and cobbles of quartzite poorly bedded in a quartzose-sand matrix. Exposures are poor. The few samples thinsectioned show no sheared quartz grains.

(3) North of Rio Pueblo in Osha Canyon (sec. 89), thickness is in excess of 15o feet. The sandstone is poorly exposed except for the lower 3o feet which is poorly bedded and conglomeratic with subangular to subrounded boulders of quartzite, a few of which exceed two feet in diameter.

Age and Correlation

No fossils have been recovered from the Del Padre Sandstone, and its age is unknown. It could be any age from late Precambrian (postmetamorphic) to early Mississippian, but it is presumed to have been deposited sometime during the Paleozoic part of this interval. Unidentifiable fossil fragments, probably bryozoans, were seen in a thinsection from the irregularly calcareous upper part of the formation, 133 feet below the top at section 66.

The sandstone is conformably overlain by the Espiritu Santo Formation with which it probably interfingers laterally.

ESPIRITU SANTO FORMATION

Designation

The Espiritu Santo Formation was named by Baltz and Read (196o). They subdivided the formation into four informal lithologic members. The basal sandstone member is described above as the Del Padre Sandstone and the Espiritu Santo Formation is restricted to that part of the original formation composed primarily of limestone and dolomite. The entire formation is well exposed at the type locality (sec. 22 of this report), a small quarry at Tererro in the Pecos Valley near the mouth of Holy Ghost Creek.

Lithologic Character and Thickness

Basically the formation is a limestone which has been almost completely recrystallized or dolomitized. Where dolomite beds are interlaminated with limestones, dolomitization may have been penecontemporaneous. Those rare limestones which preserve relict structures include micrite, pelsparite, and what may be algal biosparite.

The size of recrystallized calcite crystals varies markedly from bed to bed but typically increases upward within a bed. Some beds show curved cleavage surfaces several inches across and are typically brownish gray. Near the top of the formation, sugary-textured, granular, recrystallized limestones occur locally.

Some layers are arenaceous and most sequences show sparse, thin sandstone lenses or layers. Rarely, as at Rio Pueblo (sec. 6o), intercalated sandstone beds are more than two feet thick. The sandstone is an orthoquartzite identical in character to the underlying Del Padre Sandstone.

Bedding is even but undulating to wavy in layers 3 to 12 inches thick. Many of the dolomitized layers in the upper part of the formation weather to a distinctive pale yellow/ brown. Banded, light- to dark-gray chert nodules occur locally in the middle and upper part of the formation.

The Espiritu Santo Formation changes laterally in thickness. The maximum recorded is 5o feet at Nambe Falls (sec. 41) west of the mountains, with thick sections also present at Bishop's Lodge (sec. 92; 47 feet) and at Dalton Bluff (sec. 36; 42 feet). At all these localities, the underlying Del Padre Sandstone is thin. The formation gradually thins (fig. 9) northward in the Pecos Valley. This thinning coincides with a corresponding increase in the thickness of the underlying Del Padre Sandstone. Partial thinning may have resulted from differential truncation of the upper surface of the forma-

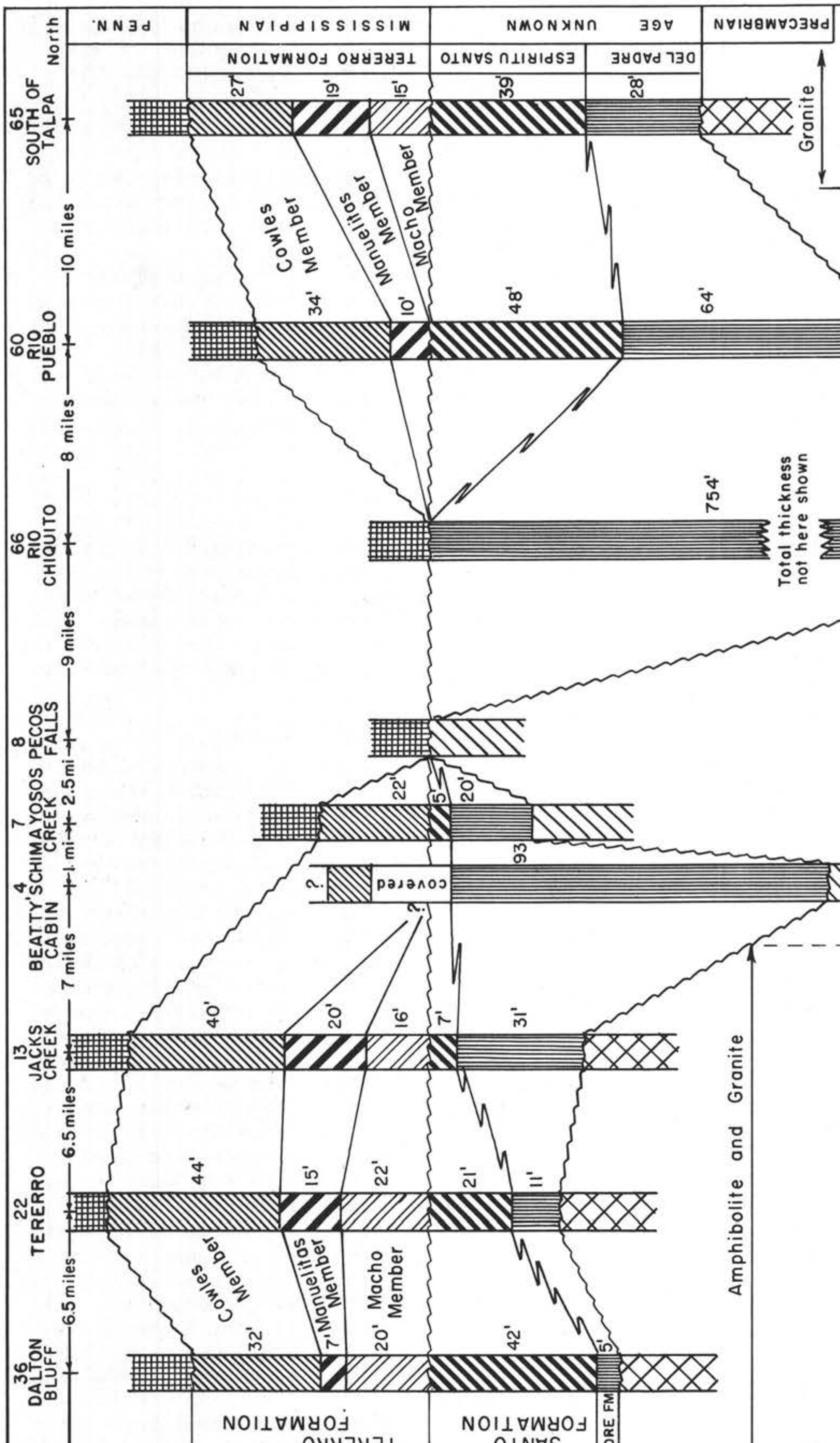

Figure 9

South-north correlation of pre-Pennsylvanian formations tion along the unconformity at the base of the Tererro Formation. Irregular, low-angle truncation can be seen at many places, including sections 22 and 13 (pl. I oC). The eroded surface of the Espiritu Santo Formation is continuous though undulating. There was no development of a karst topography on this surface but there is local evidence of minor solution action.

The formation is seven feet thick at Jacks Creek (sec. 13) and about the same in the high mountain country at section 4. It is thick and typically developed in the northern part of the map area at Rio Pueblo (sec. 6o; 39 feet) and near Talpa (sec. 65; 39 feet).

Vertical fractures can be detected at most localities which do not extend upward into the overlying Mississippian strata (pl. IoC). This relation suggests mild deformation of the unit prior to the deposition of the Tererro Formation. If deformation did occur, it may thus be a reason for the extensive recrystallization of the Espiritu Santo Formation.

Age and Correlation

No fossils have been found in the Espiritu Santo Formation. Its age is unknown and, as with the Del Padre Sandstone of which it is partly a lateral equivalent, it could be any age from late Precambrian (postmetamorphic) to early Mississippian.

Armstrong (1958) reported occasional specimens of an unidentified species of *Plectogyra* in the lower I o to 20 feet of the pre-Pennsylvanian limestone sequence of the southeastern part of the Sangre de Cristo Mountains. The age of this foraminiferal species has not been established. Armstrong indicated that this species occurs in the lowermost limestone layer west of Agua Zarca (sec. 95 of this report). There, limestone samples from the lower beds are completely recrystallized and no fossils were seen in thinsections.

Based on gross lithology, Baltz and Read (196o) correlated the Espiritu Santo Formation with the Ouray and Elbert formations in the San Juan Mountains of south-central Colorado and the Del Padre Sandstone with the upper part of Ignacio Quartzite in the same area. They considered all these formations to be Late Devonian in age. Even a tentative age designation of "Devonian (?)," based on lithologic correlation of an almost totally recrystallized and dolomitized limestone with rocks 15o to 200 miles away, is inadvisable. The correlation of the Del Padre Sandstone with the Ignacio Quartzite is even more tenuous in that the Del Padre Sandstone is clearly local in origin and should bear no relation to the Ignacio Quartzite in Colorado.

TERERRO FORMATION

Designation

The Tererro Formation was named by Baltz and Read (196o) for a sparsely fossiliferous limestone sequence of Mississippian age which is as much as 86 feet thick. The formation rests unconformably on the Espiritu Santo Formation and is in turn truncated by Pennsylvanian strata. The type locality is in the bluff at Tererro on the west side of the Pecos River about loo yards upstream from the mouth of Holy Ghost Creek.

The Tererro Formation is well exposed at many places in the southern Sangre de Cristo Mountains area. Along the steep bluffs of the Pecos River Valley, it is exposed almost continuously for seven miles from Tererro northward to a point a mile north of Cowles. The lithology is consistent throughout this area.

The formation was divided into three members by Baltz and Read (196o), which are, in ascending order, (I) the Macho Member, a poorly bedded limestone conglomerate; (2) the Manuelitas Member, which consists of irregularly bedded and locally collapsed limestone layers; and (3) the Cowles Member, a silty, cross-bedded limestone.

Macho Member

The Macho Member consists of a limestone boulder conglomerate which in most of the area forms the most distinctive and easily recognized unit in the Mississippian sequence. The bed is composed of rounded to subrounded, poorly sorted, limestone clasts which range from pebble size to boulders more than two feet in diameter (pl. 1 oA). Size analyses of the clasts at five scattered localities in the Pecos Valley shows that the median diameter (approximately seven inches) and the sorting change but little along the valley over a distance of at least 12 miles. The boulders show no observable preferred orientation.

The Macho Member rests unconformably on the Espiritu Santo Formation with a distinctive undulating basal contact. The member has poorly developed irregular bedding but locally shows bedded limestone lenses in the lower part, as at Jacks Creek (sec. 13; pl. 10C).

Up to five percent of the boulders are of chert, and a few boulders of quartzite are present. At Hamilton Mesa road (sec. 5), one such quartzite boulder, rounded and partly silicified, is more than four feet in length (pl. 10D). The percentage of matrix commonly increases upward, the upper part of the unit consisting of limestone with scattered boulders and cobbles. The matrix is of sandy limestone with fine- to medium-grained, well-rounded quartz grains. Several different types of limestone boulders occur, the most common being pelsparite, biopelsparite, oomicrite, and dismicrite. The majority of these are lithologically similar to the overlying bedded limestones of the Manuelitas Member.

Totally recrystallized boulders are rare except locally, as in the lower few feet of the member at Tererro. None of the boulders observed at any locality, even those that are recrystallized, is similar to the coarsely crystalline limestone characteristic of the upper part of the underlying Espiritu Santo Formation. No dolomite boulders were found. Both boulders and matrix show minor secondary recrystallization which may explain the fact that the member exfoliates and weathers as a unit at many localities (pl. r IA). Minor secondary dolomitization affecting the matrix and margins of the boulders occurs both at the base and at the top of the member.

The upper few feet of the Macho Member and the lower part of the overlying Manuelitas Member show at all localities marked irregular secondary silicification, recrystallization, and solution brecciation which usually obliterated the contact between the two members. Sink holes and possible channels in the upper part of the Macho Member are filled with limestone boulders and blocks associated with the overlying Manuelitas Member.

The Macho Member is consistent in general character over an area of at least 800 square miles in the southern Sangre de Cristo Mountains region. It apparently was deposited in an area which partly surrounded but never covered the quartzite positive area (fig. 9). Hence, it is missing at Rito

Chimayosos (sec. 7) and also at Rio Pueblo (sec. 6o). The Macho is well developed at many localities in the Pecos Valley, on the west side of the mountains at Nambe Falls (sec. 41) where it reaches its greatest observed thickness of 28 feet, and north of the map area at Talpa (sec. 65; 15 feet). This conglomerate tends to be thin and poorly developed and locally absent in the foothills area east of the mountains. It is three feet thick at Gallinas Canyon (sec. 94) and 1 I feet thick west of Agua Zarca (sec. 95).

Sutherland and Land (1959) pointed out that all evidence suggests a depositional origin for the Macho limestone boulder conglomerate. However, Baltz and Read (196o, p. 1761) claimed that the unit originated as a solution breccia of the underlying Espiritu Santo Formation. They stated: "Much of the Macho Member was formed by collapse of cavernous parts of the Espiritu Santo Formation during the period of subaerial weathering preceding Early Mississippian deposition. These collapsed rocks may have been mainly loose, uncemented piles of breccia. . . ." The evidence against this contention and in favor of a depositional origin is summarized as follows:

(I) Samples of boulders representing all different rock types observable on the outcrop were taken near the base and near the top of the Macho Member at sections 36, 22, 13, 41, and 65. Random samples of boulders were taken at all other localities. No boulders have been seen which show definite similarity to the distinctive lithologies of the underlying Espiritu Santo Formation, the brownish-weathering dolomite and coarsely recrystallized limestone characteristic of the underlying formation being absent. In contrast, most of the boulders, including those at the base of the member, are composed of only slightly recrystallized limestone similar in character to types found in the overlying Manuelitas Member. This suggests a close relation in the depositional history of these two members.

(2) The boulders are not angular breccia fragments but are subrounded to well-rounded boulders and cobbles of all sizes (pl. I o-A).

(3) Rounded boulders of chert and quartzite are included.

(4) The contact of the member with the underlying Espiritu Santo Formation is invariably sharp and continuous, though undulating (pls. 1 o-C, I-A). Irregular, low-angle truncation occurs, but there is no evidence of extensive karsting or pseudobrecciation at the top of the underlying unit, and only minor local evidence of solution action was found.

(5) Bedded limestone lenses occur locally at the base of the formation, intercalated with the boulders (pl. Io-C).

Manuelitas Member

The Manuelitas Member, which overlies the Macho Member, consists of 8 to 20 feet of medium- to light-gray limestone which occurs in irregular beds one to four feet thick. The limestones are mainly of oolites or fossil fragments with scattered pellets in a sparry calcite matrix. Some layers are silty and others contain scattered, rounded, medium- to coarse-grained quartz grains. These layers pass locally into irregular masses of coarse limestone pseudobreccia and into collapse-structures and possible channels filled with large limestone fragments of similar lithology. A few such features are as large as 15 to 20 feet in diameter and cut vertically through as much as 20 feet of strata. Most are smaller in size. Some penetrate the upper five to ten feet of the underlying Macho Member. There are local, large, irregular masses of secondary chert up to three feet across. These are most frequent at the base of the member along the boundary with the Macho conglomerate and usually obliterate the boundary between the two. Secondary recrystallization and dolomitization are locally present. Extensive dolomitization of the member has been observed at sections 41 and 65.

The Manuelitas Member is believed to have resulted from recurring development of a karst topography alternating with shallow marine deposition. Karsting occurred at more than one horizon with resulting irregularity in the bedding.

The distribution of the Manuelitas Member is similar to that of the Macho Member, but it is more extensive and rests directly on the Espiritu Santo Formation at Rio Pueblo (sec. 6o).

Cowles Member

The Manuelitas Member is overlain unconformably by the Cowles Member, the highest Mississippian unit in the area. The Cowles Member is in turn overlain unconformably by Early Pennsylvanian sandstones, shales, and thin limestones. This member, as much as 62 feet thick, is the most widely distributed Mississippian unit but locally has been partly or fully removed by erosion during late Mississippion or Early Pennsylvanian time. Typically, the rock consists of fossil fragments, oolites, or pellets in a sparry calcite matrix. It varies from slightly to highly silty, or arenaceous; insoluble residues show well-sorted silt or fine sand as high as 5o percent. A striking feature of some beds is the excellent sorting of pellets and quartz sand.

Thick units with higher elastic percentages are typically cross-bedded and thick-bedded and weather yellowish gray to dusky yellow. These units alternate with beds one to four feet thick which are low in silt, weather light gray, and seem similar on the outcrop to individual beds of the underlying Manuelitas Member. Scattered chert nodules are typical of these beds. Near the top of the Cowles Member, the elastic percentages increase locally and the cross-bedded units are calcareous, fine-grained sandstones which weather greenish gray.

The Cowles Member does not show the karst features characteristic of the underlying Manuelitas Member, but it locally fills small depressions in the irregular upper surface of that member. The Cowles Member is lithologically distinctive and laterally consistent in character. Variations in thickness are believed to be the result of erosion during late Mississippian or Early Pennsylvanian time.

Age and Correlation

The Tererro Formation includes many beds containing fossil fragments but even diligent effort resulted in the collection of only a few identifiable megafossils, listed as follows:

(I) Macho Member, from a boulder seven feet below the top of the member at Jacks Creek (sec. 13) and not associated with a collapsed structure:
  (a) A small species of *Dialasma* or *Beecheria*
(2) Manuelitas Member
  (a) *Dibunophyllum* sp. (one incomplete specimen from section 13)

(b) A small species of *Dialasma* or *Beecheria* from section 13 which seems to be the same as that in the Macho Member, listed above

(c) Brachythyris? cf. *altonensis* Weller (upper part of of formation at Agua Zarca (sec. 95)

(3) Cowles Member (near Talpa, sec. 65, at top)

(a) *Lithostrotion* aff. L. *whitneyi* Meek (a large phaceloid form, partly silicified)

All these forms suggest a Mississippian age but do not form an adequate basis for more precise determination.

Specimens of *Endothyra* have been collected from all three members. These include the following:

(1) Common, well-preserved endothyrids in three different boulders from the Macho member, collected at points not related to collapsed structures, at Jacks Creek (sec. 13). One boulder was collected at the base of the member where it rested directly on the unconformity with the underlying Espiritu Santo Formation. The other two were collected at points four feet and nine feet above the base. The member is 16 feet thick at this locality.

(2) Well-preserved endothyrids from the lower beds of the Manuelitas Member at Jacks Creek (sec. 13) and from the upper part of this member at Agua Zarca (sec. 95).

(3) Poorly preserved endothyrids from the highest beds in the Cowles Member at Agua Zarca.

These endothyrid assemblages have been studied by Donald A. Zimmerman, Sun Oil Company Research Laboratory, who recently completed a study of endothyrids in Mississippian rocks of the Mississippi Valley area. He states that the endothyrids from all three members are definitely of Meramecian age. Forms from both the Macho and Manuelitas members are similar to species in the Salem Limestone of the mid-continent area.

Baltz and Read (196o, p. 1765) gave faunal lists for three megafossil collections from the Manuelitas Member in Gallinas Canyon. The fossils, which were identified by J. T. Dutro, Jr., were said to "indicate a probable Early Mississippian age." However, none of the species listed, which are primarily brachiopods, is identified with certainty and since the "fossils generally are poorly preserved" (Baltz and Read, 196o, p. 1766), the well-preserved endothyrid faunas discussed above are believed to provide a more reliable indication of probable age. The entire Tererro Formation is therefore best considered to be Meramecian in age, as previously proposed by Armstrong (1958, p. 971), who studied endothyrid faunas from various Mississippian localities in northern New Mexico.

PENNSYLVANIAN ROCKS

Two basically different concepts have been used in regional descriptions of Pennsylvanian rocks in New Mexico. One, used primarily for preliminary geologic maps of the U.S. Geological Survey's Oil and Gas Investigations series covering parts of north-central New Mexico, recognizes three, thick, generalized lithologic divisions: ( ) a lower predominantly clastic-rock unit called the Sandia Formation, (2) a middle predominantly carbonate-rock unit called the "lower gray limestone member" of the Madera Limestone, and (3) an upper clastic-rock and limestone unit called the "upper arkosic limestone member" of the Madera Limestone (Read and Andrews, 1944). This system has been used in areal mapping on a small scale but has not been applied in conjunction with detailed faunal and petrographic studies.

A second method has been to make major subdivisions of the Pennsylvanian based on fusulinid zones. This was used by Needham (1937, p. 14) because, as he stated, "the plane of division between the two (the Sandia and Madera Formations) is so inconsistent and the lithologic character of the Pennsylvanian rocks varies to such an extent from place to place that divisions corresponding with the Sandia and Madera Formations cannot be recognized in many parts of the state." Thompson (1942) further refined fusulinid zonation of the Pennsylvanian rocks and as a result delineated the series' names (oldest to youngest) as Derryan, Desmoinesian, Missourian, and Virgilian. Similar procedures were followed by Stark and Dapples (1946) in a study of the Los Pinos Mountains and by Kottlowski et al. (1956) in a memoir on the geology of the San Andres Mountains. In the latter two studies, no formation names were used; fusulinid occurrences were listed and utilized, and the rocks were described in detail.

Many geologists have pointed out the difficulty in subdividing Pennsylvanian strata in New Mexico on the basis of gross lithology. The rocks are cyclic, and thus there is repetition of similar types throughout hundreds of feet of strata. In many areas, there are marked lateral facies changes and a general absence of key beds which can be traced laterally or recognized in isolated exposures. Few of the formations which have been proposed in New Mexico for Pennsylvanian rocks are mappable units in the sense suggested by the Code of Stratigraphic Nomenclature (1961). Another complicating factor is the isolation of exposed Pennsylvanian rocks in New Mexico by surrounding Permian, Mesozoic, and Cenozoic deposits. Lateral tracing from this region to others therefore is not possible. Use of names for thick generalized units over wide areas provides a simple regional stratigraphic nomenclature but obscures important local and regional stratigraphic relationships and renders impossible meaningful conclusions about geological history. The problem is further confused by the fact that the Sandia and Madera formations cannot be evaluated adequately in the absence of any published detailed study of the Pennsylvanian rocks in the Sandia Mountains where the names Sandia and Madera were first used more than 5o years ago.

The stratigraphic nomenclature proposed in this paper for the Pennsylvanian rocks exposed in the southern Sangre de Cristo Mountains is based both on detailed mapping and detailed petrographic study. The formations proposed are rock-stratigraphic units recognizable in the field. Extensive collections of fossils were made wherever possible. The two main faunal elements, fusulinids and brachiopods, have been studied and a resulting zonation based on both these groups is presented in the Table of Faunal Zones of Figure 1 o. Only the described brachiopod species are listed. The correlations shown are also based on more than 25 new brachiopod species. These biostratigraphic zones are not dependent upon, nor should they be confused with, the rock-stratigraphic formations.

An attempt was made to use the Sandia and Madera Formations and the two members as applied to the Pennsylvanian sequence at the southern edge of the Sangre de Cristo Mountains near the town of Pecos by Read et al. (1944), Brill (1952), and Sidwell and Warn (1953). The papers by Brill and by Sidwell and Warn, which were published almost simultaneously, each included detailed stratigraphic sections for the important river-bluff exposure at Dalton Campground six miles north of Pecos, here called Dalton Bluff. Their sections show a striking difference in the designation of the boundary between the Sandia and Madera formations. Brill (p. 852) gave the thickness of the Sandia Formation as 318 feet, whereas Sidwell and Warn (p. 1007) measured a thickness of 482 feet for this unit. Seemingly different horizons were selected as the boundary between the two formations.

The author's study of many exposures in the lower Pennsylvanian sequence in the upper Pecos Valley area, including the Dalton Bluff exposure, yielded no criteria for consistently delineating the Sandia Formation in this area. Consequently, the name is not used in this paper.

The only consistent lithologic break observed by the writer in the southernmost Sangre de Cristo Mountains coincides at Dalton Bluff with that designated by Brill (1952, p. 849) as the boundary between the lower gray limestone and upper arkosic limestone members of the Madera. The beds above this horizon are marked either by a significant increase in the percentage of feldspar, as at Dalton Bluff (sec. 36), or, farther north, by the first appearance of feldspar, as at Pecos Baldy Ridge (sec. 10) and Jicarilla Ridge (sec. 4o) (fig. o). This lithologic change was recognized throughout the area studied in the southernmost Sangre de Cristo Mountains. On this basis, the Pennsylvanian rocks in the southern part of the area are here divided into two new formations: (1) the La Pasada Formation, 973 feet thick at Dalton Bluff and equal there to the Sandia Formation plus the lower gray limestone member of the Madera Limestone, as used in this area by Brill; and (2) the Alamitos Formation, about 1275 feet thick in the Alamitos and Pecos Valley areas, equal to the upper arkosic limestone member of the Madera Limestone of Brill. The stratigraphic relations of these formations to the "Madera Limestone" of the Sandia Mountains is unknown. The term *Madera* is not used in the southern Sangre de Cristo Mountains area.

The term *Magdalena Group* is not used here because, as pointed out by Thompson, it is essentially synonymous with the systemic term *Pennsylvanian.*

The Pennsylvanian was not subdivided into Formations on Plater because of the extensive covered areas in the high, heavily timbered country.

Figures 1 o and I I show the correlation of Pennsylvanian rocks northward from the Pecos area to the Rio Pueblo area, a distance of 40 miles. North of Jicarilla Ridge (sec. 4o) there is an abrupt facies change to a dominantly elastic sequence with a marked increase in thickness. In the Rio Pueblo area two lithologic units are recognizable: a lower, nonarkosic, mainly elastic unit here named the Flechado Formation, which is about 2500 feet thick at Rio Pueblo; and an upper arkosic unit with included limestones correlative with the Alamitos Formation. The Alamitos Formation is about 4000 feet thick in the Rio Pueblo region, giving a total thickness of about 6500 feet for rocks in the area definitely identifiable as of Pennsylvanian age. The highest limestones in the Rio Pueblo area are late Desmoinesian in age. In contrast, the highest limestones in the Pecos Valley, where the total Pennsylvanian sequence is 225o feet thick (fig. I I), are Virgilian in age.

In this study, the series names *Morrowan, "Atokan," Desmoinesian, Missourian,* and *Virgilian* are used. The boundary of the Morrowan—"Atokan" is drawn at the upper limit of beds containing numerous brachiopod species similar to those occurring in the Morrowan formations of northwest Arkansas and northeast Oklahoma. The "Atokan"—Desmoinesian boundary is based on fusulinid correlations with the lowermost Desmoinesian in New Mexico and in the mid-continent region as interpreted by Thompson. The *"Atokan" Series* is written in quotation marks since its true nature as a timestratigraphic unit cannot be adequately determined in its type area in Oklahoma where it is poorly fossiliferous. Brachiopods listed in this report as being of "Atokan" age are so designated because they are considered to be post-Morrowan and pre-Desmoinesian in age. The series boundaries as used here do not necessarily represent precise time correlations with the equivalent boundaries as used in the mid-continent area.

The term Derryan *Series* is not used because its relation tc the Morrowan and "Atokan" Series has not been determined. The term *Derryan Series* was proposed by Thompson (1942 p. 26) "for all rocks in the central to the extreme south-central areas of New Mexico between the base of the Pennsylvanian System and the basal part of the Pennsylvanian Des Moines Series." Thompson stated that at its type locality in Sierra County, southern New Mexico, the entire Derryan Series is post-Morrowan in age and is the age equivalent of the Atoka Formation of Oklahoma. At its type section, the Derryan Series rests unconformably on Devonian rocks. However, in north-central New Mexico, rocks occur which carry abundant and particularly distinctive brachiopod faunas of Morrowan age. The distribution and southern limit of rocks of Morrowan age in north-central and central New Mexico have not been determined. In the northern Sandia Mountains, near Placitas, at an exposure about 5o miles southwest of Dalton Bluff, Peltier (1958, p. 18) reported the occurrence of Desmoinesian fusulinids less than 15o feet above the base of the Pennsylvanian sequence. He did not establish the age of the lower part of the section which could presumably include rocks of both Morrowan and Derryan age. The stratigraphic relations of rocks of Morrowan age to the Derryan Series needs to be investigated in central and north-central New Mexico.

LA PASADA FORMATION

Designation

Dalton Bluff (sec. 36), on the west side of the Pecos Valley overlooking Dalton Campground, is here designated the type locality of the La Pasada Formation (pl. C). For a road log along the Pecos Valley, see Montgomery and Sutherland (196o, p. 14). The name is taken from the small Spanish settlement of Upper La Pasada near the foot of Dalton Bluff just south of Dalton Campground. The entire formation is present at Dalton Bluff. The base rests unconformably on Mississipian rocks and the top of the formation is about 125 feet below the crest of the bluff.

Lithologic Character and Thickness

Figure 12 illustrates the lithologic character of the La Pasada Formation at Dalton Bluff. It is primarily a cyclic carbonate-rock unit which includes a variety of rock types. At

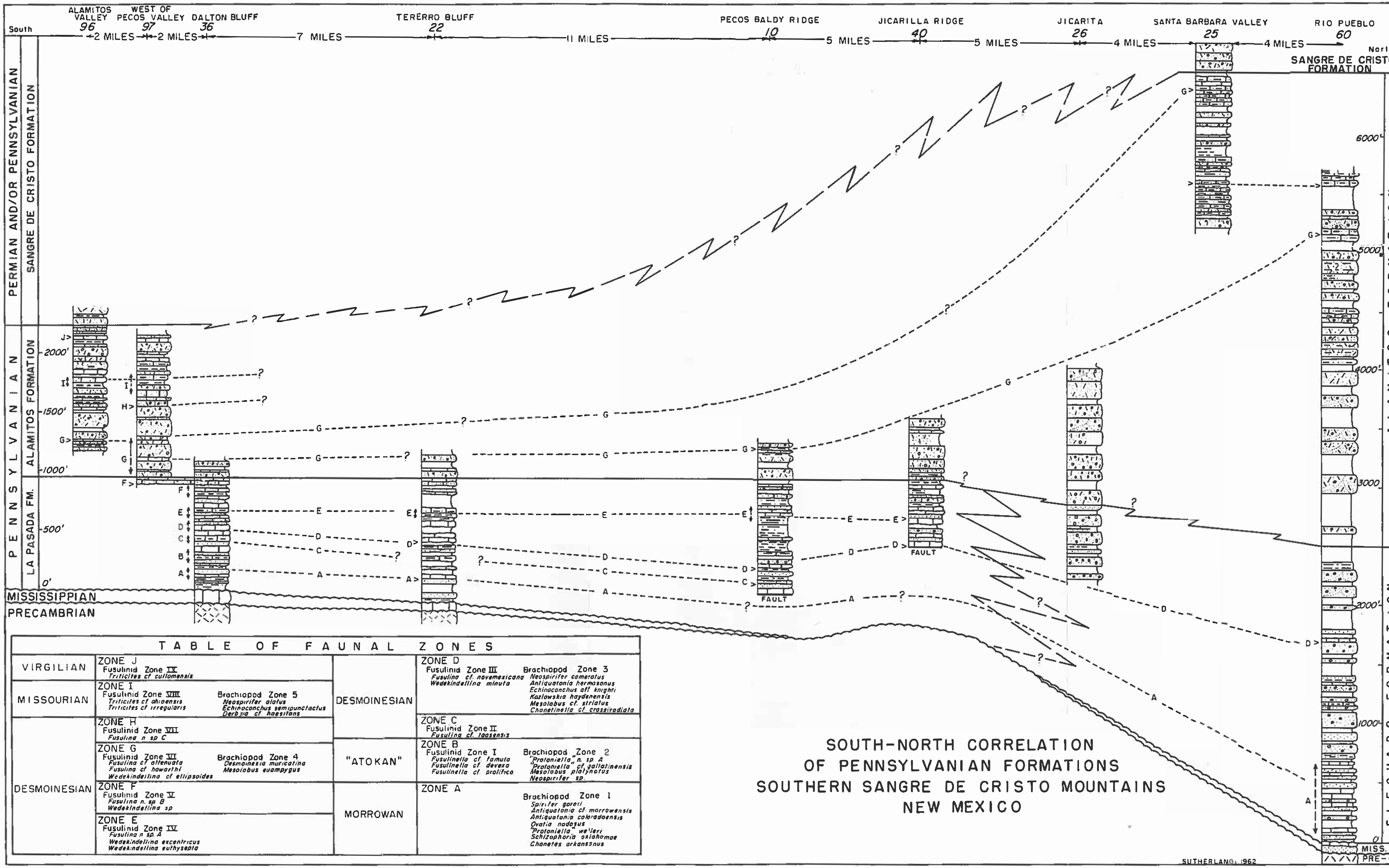

TABLE OF FAUNAL ZONES

VIRGILIAN	ZONE J Fusulinid Zone IX *Triticites cf cullomensis*	DESMOINESIAN	ZONE D Fusulinid Zone III *Fusulina cf. novemexicana* *Wedekindellina minuta* Brachiopod Zone 3 *Neospirifer cameratus* *Antiquatonia hermosanus* *Echinoconchus aff. knighti* *Kozlowskia haydenensis* *Mesolobus cf. striatus* *Chonetinella cf crassiradiata*
MISSOURIAN	ZONE I Fusulinid Zone VIII *Triticites cf. ohioensis* *Triticites cf irregularis* Brachiopod Zone 5 *Neospirifer alatus* *Echinoconchus semipunctactus* *Derbyia cf haesitans*	DESMOINESIAN	ZONE C Fusulinid Zone II *Fusulina cf. taosensis*
DESMOINESIAN	ZONE H Fusulinid Zone VII *Fusulina n sp C*	"ATOKAN"	ZONE B Fusulinid Zone I *Fusulinella cf. famula* *Fusulinella cf. devexa* *Fusulinella cf. prolifica* Brachiopod Zone 2 *"Profoniella" n. sp. A* *"Profoniella" cf. gallatinensis* *Mesolobus platynotus* *Neospirifer sp.*
DESMOINESIAN	ZONE G Fusulinid Zone VI *Fusulina cf attenuata* *Fusulina cf haworthi* *Wedekindellina cf ellipsoides* Brachiopod Zone 4 *Desmoinesia muricatina* *Mesolobus euampygus*	MORROWAN	ZONE A Brachiopod Zone 1 *Spirifer goreii* *Antiquatonia cf. morrowensis* *Antiquatonia coloradoensis* *Ovatia nodosus* *"Profoniella" welleri* *Schizophoria oklahomae* *Chonetes arkansanus*
DESMOINESIAN	ZONE F Fusulinid Zone V *Fusulina n. sp B* *Wedekindellina sp*	MORROWAN	
DESMOINESIAN	ZONE E Fusulinid Zone IV *Fusulina n sp. A* *Wedekindellina excentricus* *Wedekindellina euthysepta*	MORROWAN	

Figure 10

South-north correlation of Pennsylvanian formations

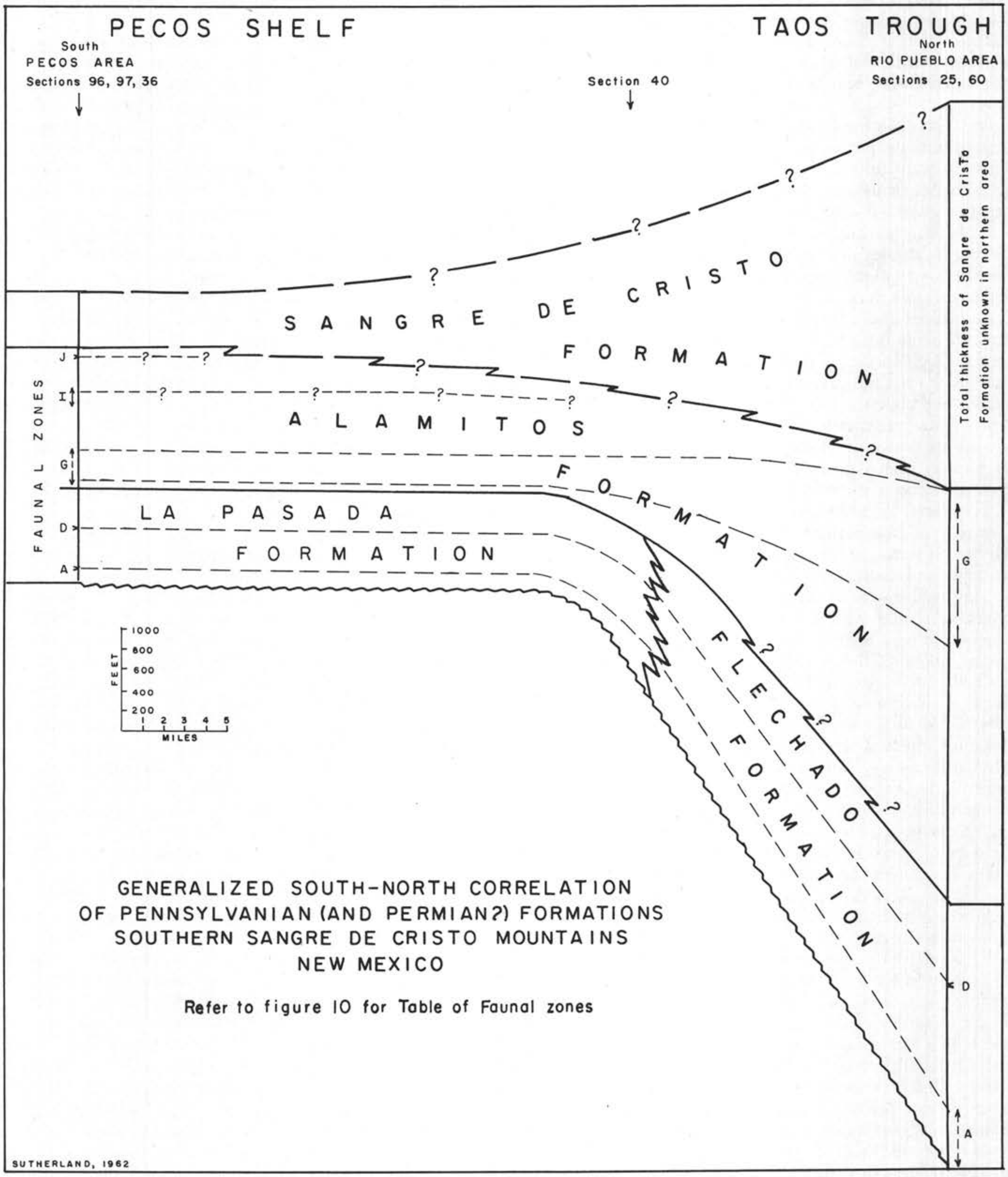

Figure 11

Generalized south-north correlation of Pennsylvanian (and Permian?) formations

Dalton Bluff, elastic rocks decrease in number upward and no lithologic basis for subdivision was found. The lowest 5o feet of the section is characterized by dark-green mudstones and siltstones which rest upon the surface eroded on Mississippian limestones. The percentage of green clay decreases upward.

At Dalton Bluff, sandstone and conglomerate make up 23 percent of the exposed beds in the lower 203 feet of section. This interval (units 25 to 69), contains rocks of Morrowan age. The sandstones are typically thin-bedded, poorly sorted, negatively skewed, quartz-overgrowth-cemented orthoquartzites. Varying percentages of quartzite fragments are recognizable in thinsection. In the "Atokan" interval (187 feet thick, units 70 to 96) the sandstone-conglomerate percentage decreases to an average of 18. The sandstones are similar to those below but are better sorted and many have carbonate cement. Some beds also contain a few percent of feldspar. In the Desmoinesian part of the formation (583 feet thick, units 97 to 179), the sandstone-conglomerate percentage drops to nine and occurs in thin, widely separated units. The sandstones and conglomerates show an erratic occurrence of from one to 20 percent feldspar, which is mainly unweathered microcline„ and a predominance of sparry calcite cement. Otherwise they are similar to the lower sandstones.

The lowest limestone occurs 56 feet above the base of the formation at Dalton Bluff. About 27 percent of the exposed Morrowan rocks are limestones. Almost all these are cleanly washed nonmicritic, and composed of fossil fragments with a varying terrigenous admixture of subangular to subrounded quartz sand and with a sparry calcite cement. These lime sones occur most often as isolated beds one to three feet thick and weather brownish gray. Some are gradational with coarse-grained, calcite-cemented sandstones and a few are gradational with thin, nodular limestone beds alternating with shale. Most of the fossil fragments are broken and abraded, the most common types being crinoids, bryozoans, brachiopods, and rare algae and microfossils. Above in the "Atokan" interval, the over-all limestone content is 39 percent. Some of the granular, thick-bedded, sandy, brownish-gray-weathering limestones occur, but most have a decreased percentage of terrigenous material which is finer-grained than in the Morrowan limestones. There is a gradual increase upward in the percentage of nodular, mainly nonterrigenous, light-gray-weathering limestones similar to those in the overlying Desmoinesian sequence.

In the Desmoinesian rocks, the limestone units comprise 67 percent of the total outcrop. The limestones are typically biosparudites, as in the underlying intervals, but many have almost no terrigenous mateial and are composed of fossil fragments in a sparry calcite matrix. A few biomicrites are present. Crinoidal material is scattered throughout the unit but averages less than in the Morrowan and "Atokan" units. The most common fossils are algae, fusulinids, brachiopods, pelecypods, and gastropods. These limestones are typically light to dark gray and weather light buff-gray. They occur in beds up to four feet thick and in thin nodular layers. The nodular limestone beds commonly grade upward into more massive ledges. Both types alternate with thin, gray, calcareous shale beds, and in some instances the nodular layers pass laterally into gray shales with limestone nodules. At Dalton Bluff, some of the interbedded limestone-shale sequences are more than 100 feet thick and form high cliffs. These intervals have a distinctive, wavy, banded appearance on the weathered cliff surface.

At Dalton Bluff, shale and siltstone beds, as well as sandstones and conglomerates, decrease in abundance upward in the La Pasada Formation as the limestone percentage increases. Shale and siltstone comprise 5o percent of exposed rock in the Morrowan interval but drop to 43 percent in the "Atokan" interval and to 24 percent in the Desmoinesian part of the formation. As stated earlier, the shales in the lower 5o feet of the formation are dark green and noncalcareous. The higher shales and siltstones are gray to dark gray. The shales associated with sandstones are commonly micaceous and noncalcareous, and those associated with limestones are calcareous and commonly fossiliferous.

The lower half of the La Pasada Formation at Dalton Bluff, which includes the Morrowan, "Atokan," and lower Desmoinesian intervals, is primarily a shallow marine near-shore sequence with less common nonmarine intervals. Local thin coal beds occur. The upper half of the formation at this locality was deposited primarily under neritic, off-shore, marine conditions alternating with infrequent near-shore and nonmarine intervals. Throughout the formation, the terrigenous rocks have been derived primarily from a quartzite with minor amounts from granite in the upper half of the section.

Striking lateral facies changes occur in the lower part of the La Pasada Formation which demonstrate the impossibility of separating the locally more clastic basal sequence as a separate formation or member (i.e., Sandia Formation). Westward from Dalton Bluff, the carbonate percentage in rocks of Morrowan age greatly increases and the sandstone-conglomerate percentage sharply decreases. At Nambe Falls (sec. 41; fig. 7), Bishop's Lodge (sec. 92), and the Santa Fe River (sec. 9o), the limestone content of the outcrop is 39, 51, and 73 percent, respectively. At Nambe Falls, the lowest of many limestones occurs one foot above the base of the Pennsylvanian. In contrast, north and northeast from Dalton Bluff the Morrowan rocks are much more elastic. At Tererro (sec. 22), the sequence is poorly exposed, but the sandstone-conglomerate percentage in the Morrowan interval is at least twice that at Dalton Bluff and is coarser grained and in general positively skewed. At the Eastern Santa Barbara Divide (sec. 47), sandstone-conglomerate comprises more than 5o percent of the rocks exposed. The Morrowan beds in both these sections are predominantly nonmarine.

Massive and nodular, light-buff, gray-weathering limestones and gray shales, which form the dominant rock types in the upper part of the La Pasada Formation and which are of Desmoinesian age, were deposited over much of the southernmost Sangre de Cristo Mountains area. Brill (1952, p. 826) reported that the sequence at Gallinas River northwest of Las Vegas, 20 miles east of Dalton Bluff, is similar to that at Dalton. The Desmoinesian part of the La Pasada Formation is rarely exposed on the west side of the mountains, but at Nambe Falls (sec. 41) an incomplete section of at least 400 feet of typical Desmoinesian limestones and shales is present. This sequence is similar to that at Dalton Bluff and contains at least Fusulinid Zones II and III.

The Desmoinesian part of the La Pasada Formation is lithologically recognizable as far north as Jicarilla Ridge (sec. 4o; fig. 1 o). Northward, the percentage of shale increases, and the limestones are less massive. Feldspar is absent in this formation at both Pecos Baldy Ridge (sec. 10) and Jicarilla Ridge

The La Pasada Formation at Dalton Bluff is 973 feet thick, It increases to 1002 feet at Tererro, seven miles to the north, and probably has an even greater thickness at Pecos Baldy Ridge, 11 miles north of Tererro. Other measured sections of the formation in the region are fragmentary.

Age and Correlation

A zonal summary of the brachiopod and fusulinid faunas is given in Figure 10, and their ranges for the La Pasada Formation at Dalton Bluff are shown in Figure 12. In this area, the formation ranges in age from Morrowan through middle Desmoinesian.

FLECHADO FORMATION

Designation

The type section for the Flechado Formation is here designated as the lower 2500 feet of the Rio Pueblo section (sec. 6o); this is the only complete section of this formation exposed in the area *(see* figs. 7, i o, and 13). The section is on the north side of the Rio Pueblo valley starting at the base of the Pennsylvanian near the point where Tio Maes Creek enters the valley three miles east of the junction of N.M. Highway 3 with N.M. Highway 75. The top of the Flechado Formation is a few hundreds yards up the hill eastward from the mouth of Gallegos Creek. This creek enters the Rio Pueblo valley from the north about one and four-tenths miles east of the lower part of the section. The formation name is taken from the next large creek east of Gallegos Creek which also enters the valley from the north.

Lithologic Character and Thickness

The Flechado Formation, which is the approximate northern equivalent of the La Pasada Formation, is composed mainly of sandstone (with a low feldspar content) and shale. The north-south relationship of the two formations is illustrated in Figures 10 and 1 x . There is an abrupt facies change in the five miles between the predominantly carbonate-rock sequence at Jicarilla Ridge (La Pasada Formation) to the predominantly clastic sequence at Jicarita Peak (sec. 26) and Rio Pueblo, as well as a marked increase in thickness. It is also noteworthy (fig. I o) that the northern extent of the La Pasada Formation coincides with the location of the Precambrian metasedimentary area east of the Picuris—Pecos fault which existed in Mississippian time as a positive area and possibly continued as a minor positive area at the northern margin of the Pecos shelf in Early Pennsylvanian time. This contention is suggested by the apparent thinning of the interval between Faunal Zones D and E at Jicarilla Ridge.

Figure 13 shows in detail the lithology of the Flechado Formation at Rio Pueblo (sec. 6o). This is designated as the type section in spite of its many covered intervals because it is the only complete section found in the area. Much better exposed partial sections near Talpa (sec. 65) and Taos Canyon (sec. 67) help fill in lithologic details. The contact of the Flechado and Alamitos formations is concealed at Rio Pueblo in a covered interval more than 200 feet thick. The contact is placed here because all sandstone layers sampled below this interval have less than three percent feldspar, whereas those above have 3o or more percent feldspar. This change from orthoquartzite to arkose is obvious in the field. The contact is exposed in the large cirque on the west side of Jicarita Peak (sec. 26).

The basal contact of the Flechado Formation with Mississippian limestone is covered at Rio Pueblo but is well exposed near Talpa (sec. 65). At the latter locality, the contact is unconformable, the highest Mississippian strata being locally truncated. The basal Pennsylvanian beds consist of olive-brown siltstones with scattered chert nodules. At least the lower 633 feet at Rio Pueblo are probably Morrowan in age (fig. 13) and a section more than 500 feet thick at Talpa contains Morrowan fossils. At Talpa, sandstones and conglomerates make up 27 percent of the exposed rock in this interval, whereas limestones comprise ten percent and shales and siltstones 63 percent. At Rio Pueblo, the percentages are probably comparable but on the average the sandstones seem to be coarser-grained. In the Morrowan interval, the sandstones are moderately sorted, typically negatively skewed, sparry calcite- and quartz-overgrowth-cemented orthoquartzites. The grains are typically subrounded and there is a high percentage of quartzite fragments. The rare, isolated limestone beds in the Morrowan part of the section are composed predominantly of broken fossil fragments in a sparry matrix. They are moderately to highly terrigenous, the quartz particles being typically coarse-grained and angular. Crinoid, bryozoan, and algal fragments are the most common fossil elements. Micrites are rare. The limestones are essentially like those in the lower part of the Morrowan at Dalton Bluff (sec. 36) and Nambe Falls (sec. 41) to the south. They occur as massive, brownish-to dark-gray-weathering granular layers.

The post-Morrowan part of the Flechado Formation is poorly fossiliferous in all localities studied but it includes both "Atokan" and Desmoinesian strata. At Rio Pueblo (sec. 6o), this part of the formation is about 1800 feet thick and poorly exposed (fig. 13). Diagnostic fossils of the middle Desmoinesian Brachiopod Zone 3 (unit 124) occur about 800 feet below the top of the formation. Section 67 at Taos Canyon duplicates the lower g00 feet of the post-Morrowan part of the formation and contains "Atokan" fusulinids and brachiopods in the lower part. The Taos Canyon section is exceptionally well exposed. There, sandstones and conglomerates make up 37 percent of the exposed rock, limestones 5 percent, and shales and siltstones 58 percent. This represents a moderate upward increase in the sandstone-conglomerate percentage over that of the Morrowan interval as observed at the Talpa section (sec. 65) and a decrease in the percentage of limestones. In the post-Morrowan sequence of Taos Canyon the sandstones are moderately to poorly sorted, positively skewed, and the grains subangular to subrounded. All cementation is by quartz overgrowth. One to three percent feldspar, both microcline and plagioclase, is present in some beds. The rare limestone layers in this interval are essentially biosparudites.

Precambrian metasedimentary rocks, mainly quartzite and quartzose schists which contain minor percentages of feldspar, were the source for the Flechado terrigenous rocks. The Morrowan interval is interpreted as a predominantly near-shore marine sequence. Its sandy biosparudites and gray calcareous shales contain broken crinoid, bryozoan, and algal fragments. Many of the sandstones in this sequence contain broken fossil fragments, have calcareous cement, are negatively skewed, moderately sorted, and have subrounded grains. The post-

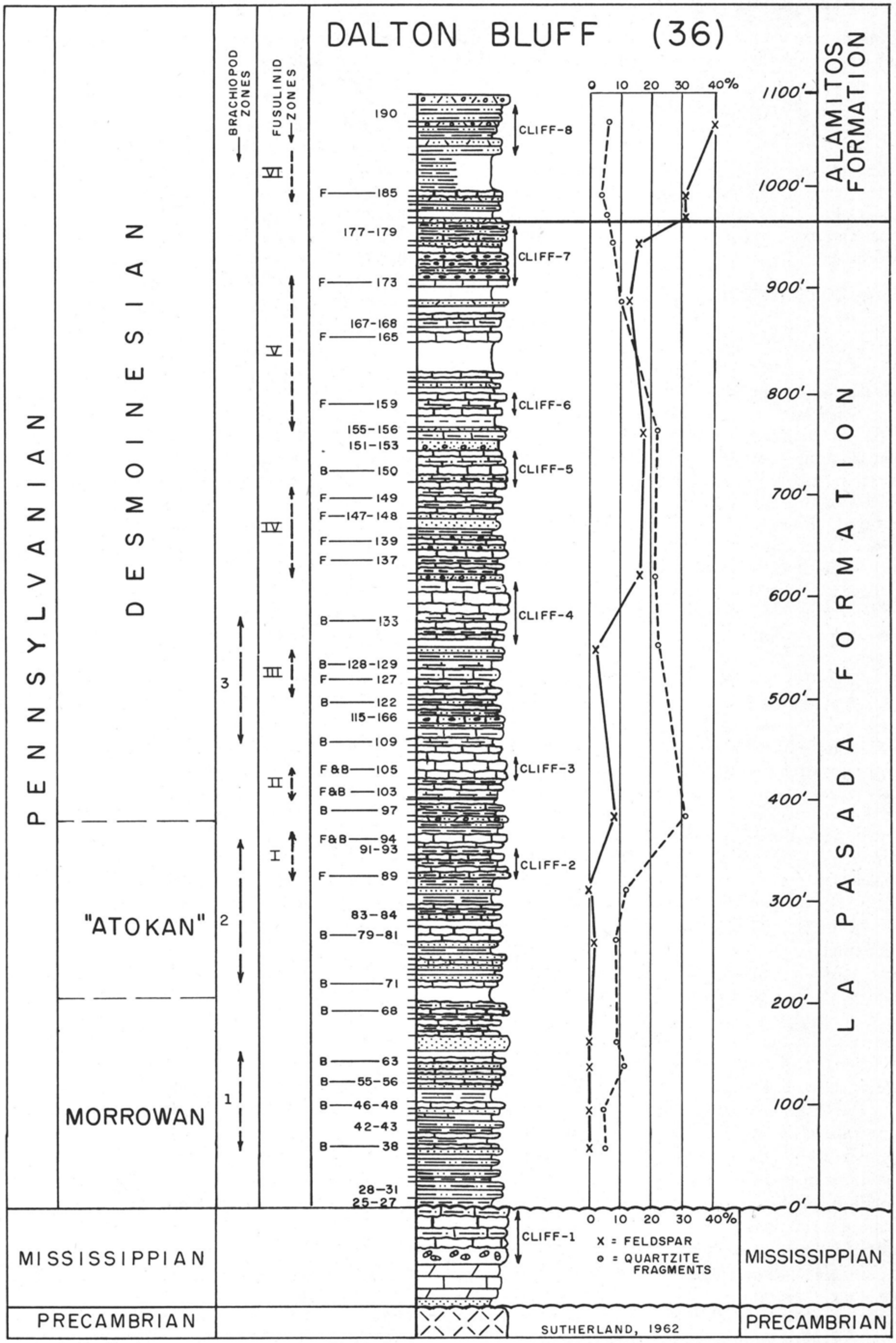

Figure 12

Type section for the La Pasada Formation, Section 36, Dalton Bluff

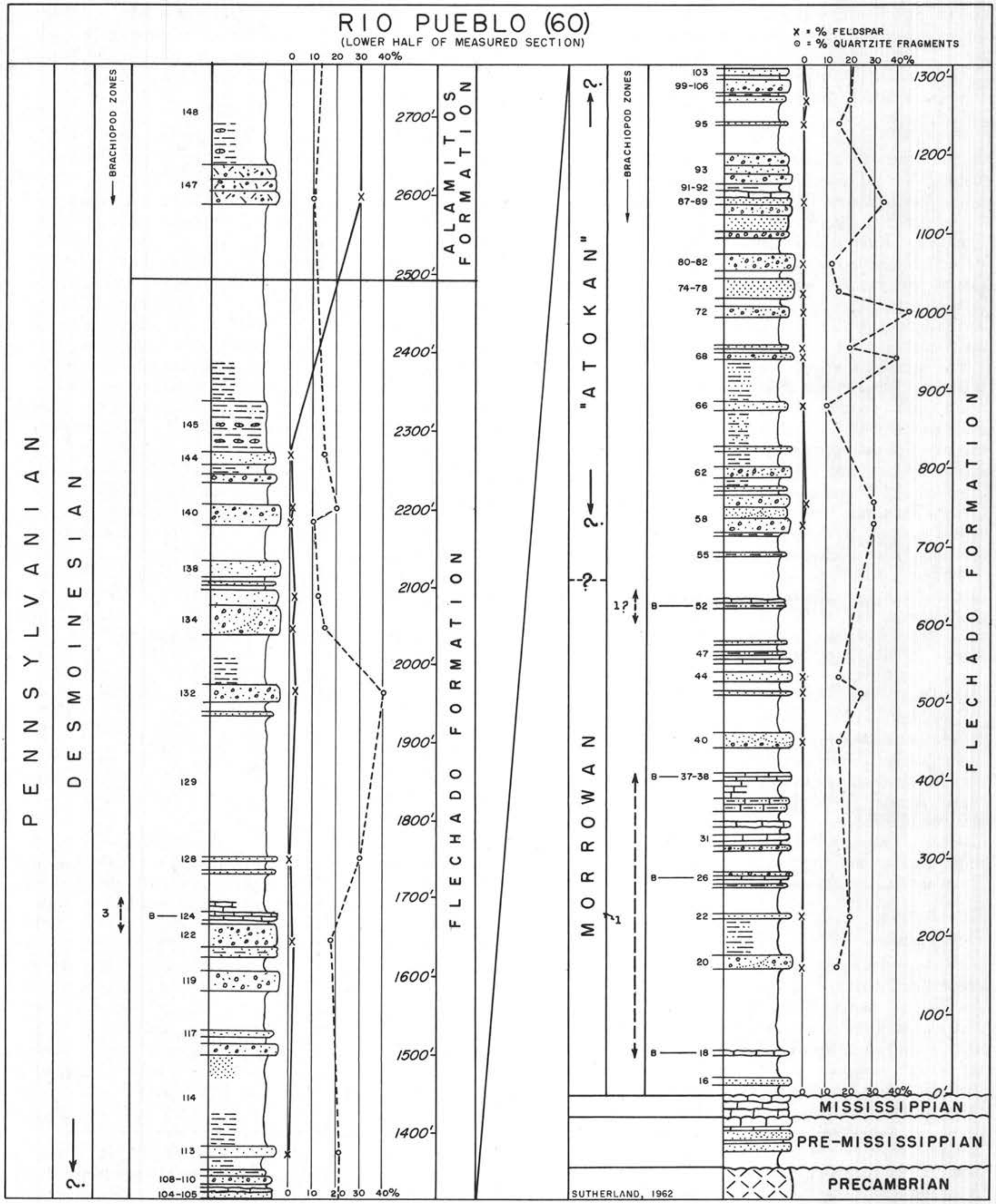

Figure 13

TYPE SECTION FOR THE FLECHADO FORMATION, SECTION 60 (LOWER HALF), RIO PUEBLO VALLEY

Morrowan sequence is interpreted as predominantly continental and fluvial with minor near-shore marine invasions. In this sequence, the sandstones are poorly sorted and positively skewed, and the grains are subangular to subrounded. Almost all cementation is quartz overgrowth and not calcareous. The silty shales and siltstones are gray to olive and micaceous. Limestones are rare.

A sequence similar to the section at Rio Pueblo occurs in the subsurface about 40 miles east of this locality in the Continental No. I Duran oil test near Ocate in Mora County, where the thickness of the Flechado Formation is 2310 feet (top at depth of 5260 feet). The sequence in the well differs from that of Rio Pueblo in having a higher percentage of gray shales, a lower percentage of coarse-grained sandstones, only sparse conglomerates, a virtual absence of limestones except for a few thin layers in the lower 250 feet of the formation, and the presence of several thin coal layers in the middle of the formation.

The samples from this well are exceptionally good. The boundary between the Alamitos and Flechado formations could not be precisely determined by binocular microscopic examination but was accurately established by crushing fragments of the various sandstones and estimating the feldspar percentage under oil immersion with a petrographic microscope. All sandstone samples from the 5260-to-5270-foot interval downward have an estimated feldspar content of ten or less percent. All those from the 5230-to-5240-foot interval and above have a feldspar percentage of 30 or more.

The source of the Flechado elastic sediments is believed to have been from the west or northwest where it was the southernmost part of the Uncompahgre highland. There is no evidence to support a source of any significance from the east.

Age and Correlation

The Flechado Formation is sparsely fossiliferous but sufficiently so to show a range in age from Morrowan to middle Desmoinesian. Morrowan brachiopods occur at several horizons in the lower 500 to 600 feet at both sections 60 and 65. Fossils in the "Atokan" and lower Desmoinesian intervals are rare. In the lower part of the Taos Canyon section, "Atokan" fusulinids and brachiopods are common and in the upper part of the formation at Rio Pueblo (unit 124) middle Desmoinesian Brachiopod Zone 3 is well represented.

ALAMITOS FORMATION

Designation

Alamitos Formation is the name here proposed for the arkose and limestone sequence which overlies the La Pasada and Flechado Formations. It, in turn, is overlain by red shales and arkoses of the Sangre de Cristo Formation and is approximately equivalent in the Pecos area to what has been called the arkosic limestone member of the Madera Limestone by Brill. No single section exposes the entire formation, and for this reason two measured sections are designated as type sections. The total thickness for the formation in the Pecos area is approximately 1275 feet. The primary type section is in Alamitos Canyon (sec. 96; fig. 14) and exposes the upper 1000 feet, including the contact with the overlying Sangre de Cristo Formation. Section 97, on the ridge between the Pecos Valley and Alamitos Canyon, is designated the secondary type section; it includes the lower 1200 feet of the formation. The Alamitos Formation is poorly exposed at section 97 but this locality is important because it provides the contact with the underlying La Pasada Formation and the lower 250 feet of the formation which is not exposed in Alamitos Canyon.

Lithologic Character and Thickness

Figure 14 summarizes the lithologic and faunal relations of the sections at Alamitos Canyon (sec. 96) and on the ridge between the Pecos Valley and Alamitos Canyon (sec. 97). The lower 250 feet of section 97 combined with the whole of section 96 gives an overall lithologic aspect as follows: sandstone and conglomerate, *50* percent; limestone, 21 percent; and shale and siltstone, 29 percent of the exposed rocks. In sections 96 and 97, coarse-grained elastic rocks are dominant in the lower two thirds of the formation up to about unit 96-40 (sandstone-conglomerate, 65 percent; limestone, 0 percent) and carbonate rocks are more important in the upper one third (sandstone-conglomerate, 26 percent; limestone, 40 percent). This general division into a lower elastic and an upper carbonate interval is not sharp nor is it consistent laterally. All lithologies show marked lateral and vertical variations (pl. 9C).

The contact with the underlying La Pasada Formation, well exposed in the upper part of the Dalton Bluff section, is placed at a marked lithologic change from a sequence composed primarily of limestone in the upper half of the La Pasada Formation to a sequence with major percentages of arkosic sandstone and conglomerate in the lower part of the overlying Alamitos Formation. Percentage composition of beds exposed in each formation near the contact in the upper part of section 36 and the lower part of section 97 is as shown below:

	La Pasada Formation	*Alamitos Formation*
Limestone	67%	21%
Sandstone and conglomerate	9%	50%
Shale and siltstone	24%	29%

Even more striking is the correspondingly abrupt increase in the percentage of feldspar from erratic occurrences of from one to 20 percent in the upper sandstone layers of the La Pasada Formation to 30 or more percent in all the sandstones and conglomerates examined in the Alamitos Formation. The feldspars are mainly unweathered microcline with erratic, minor percentages of plagioclase. Most of the sandstones are poorly sorted, quartz-overgrowth-cemented and contain minor percentages of unoriented, partly unweathered micas, principally biotite. Fragments of granite are common. Minor percentages of metasedimentary rock fragments are also present throughout the formation. Some of the sandstones, particularly in the upper part, are moderately sorted and these almost invariably have some sparry calcite cement; some are gradational with limestones.

The limestones are virtually all sandy biosparudites with almost a complete absence of micrite. Terrigenous material varies from a trace to 40 percent and is generally coarse-grained, angular, and moderately sorted. Almost all the limestones contain feldspar. Fossil fragments typically are abraded. Crinoid and bryozoan fragments are the most abundant fossils

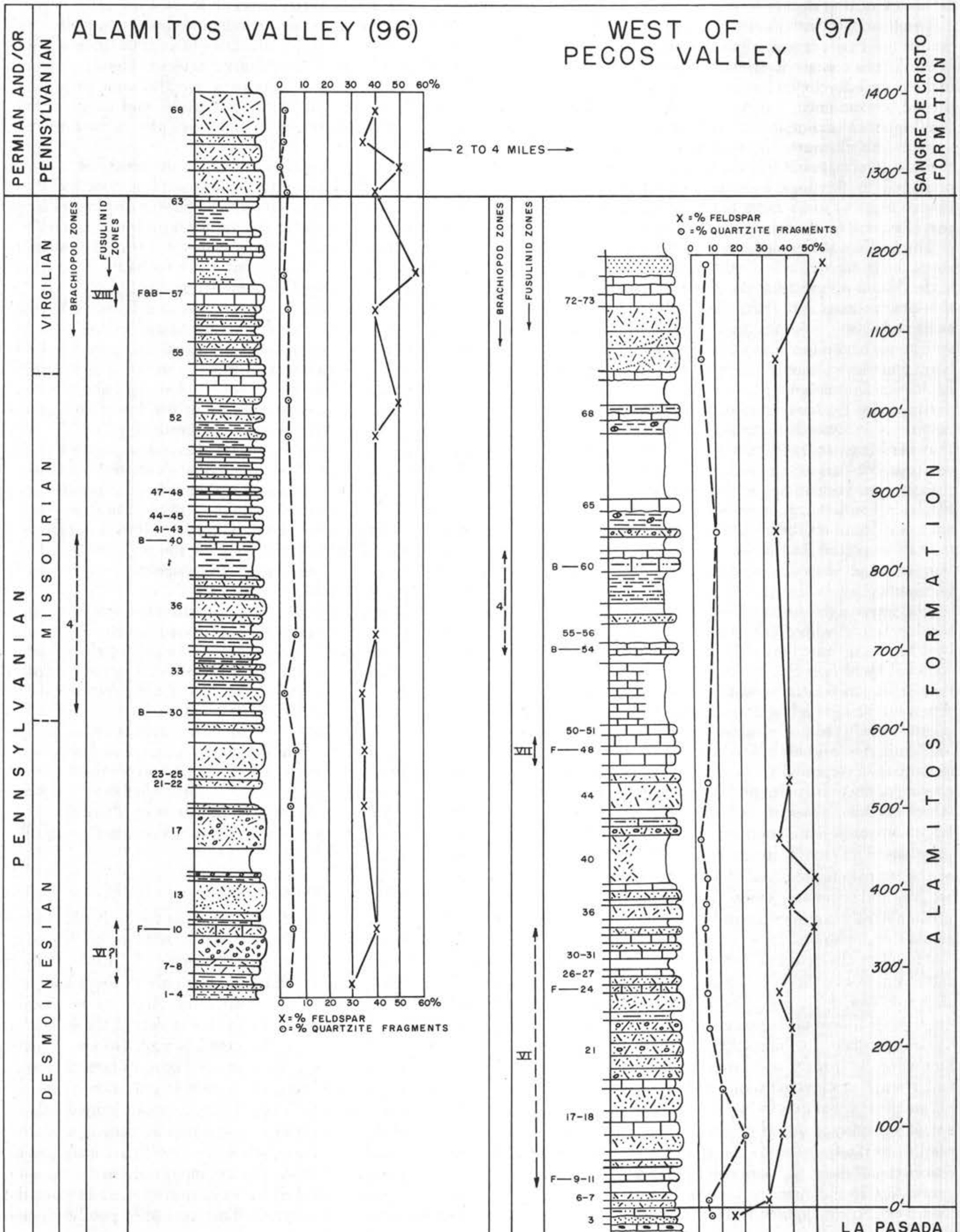

Figure 14

Type sections of the Alamitos Formation, Sections 96 and 97 with varying minor percentages of brachiopods, pelecypods, foraminifera, and algae.

The boundary with the overlying Sangre de Cristo Formation in the Pecos region is gradational. In Alamitos Canyon (sec. 96) the contact is arbitrarily placed at the top of the highest, well-developed limestone. In the Pecos area, sections 96 and 97 combined, the Alamitos Formation ranges in age from upper Desmoinesian to Virgilian.

Figure 1 0 illustrates the marked facies changes which occur in this formation. Only the lower part of the formation is preserved in the high mountain country, but in the Rio Pueblo area, 35 to 40 miles north, section 25 and the upper part of section 60 are believed to contain the entire formation.

The La Pasada Formation retains its dominance of carbonate rocks as far north as Jicarilla Ridge, but the lower part of the Alamitos Formation becomes increasingly clastic within the same distance. At Pecos Baldy Ridge (sec. 0) and Jicarilla Ridge (sec. 40), the coarse-grained, poorly sorted arkosic sandstones of the formation contrast sharply with the underlying nonarkosic, mainly limestone and shale sequence of the La Pasada Formation.

In the Rio Pueblo area (sec. 25 and 60), the Alamitos Formation is estimated to total approximately 4000 feet in thickness (fig. I 0) and retains the over-all character of a coarse-grained arkose. In section 60, both the lower part of the Alamitos Formation and the upper part of the underlying Flechado Formation are coarse-grained clastic units. The separation is based on the abrupt increase in feldspar from less than three percent in the sandstones of the Flechado Formation to more than 30 percent in those of the Alamitos Formation.

The lower 2500 feet of the Alamitos Formation includes few limestones, whereas the upper 1500 feet are characterized by alternating limestones, siltstones, shales, and sandstones (typified by section 25). In the lower 2500 feet of the formation in section 60, the sandstones and conglomerates, in addition to being highly arkosic, are mostly coarse-grained, poorly sorted, positively skewed, with an abundance of silt and some clay, and are silica-cemented (both microcrystalline and quartz-overgrowth). Almost all the feldspar is fresh, coarse-grained, angular, and mainly microcline, much of which is white. These rocks form high cliffs and many show large scale cross-lamination (pl. 9D) and scattered wood impressions. The same features are true for the lower 1300 feet of the formation preserved in section 26. All exposed shales are gray and commonly sandy. This sequence is interpreted as predominantly c0ntinental and fluvial in 0rigin with minor shallow sea invasions.

The most characteristic feature of the upper 1500 feet of the Alamitos Formation is the presence of several units, more than 250 feet thick, composed of thin, wavy layers of dark-gray, silty limestone, calcareous siltstone, and gray, silty, calcareous shale. In thinsection, the limestones are typically laminated biosparites with an abundance of coarse silt and fine-grained sand which is moderately well sorted. These layers are poorly fossiliferous but many commonly have spines or spicules of undetermined origin. Crinoid and bryozoan fragments are rarely present. The sparry calcite cement is fine-textured and dirty, the dark color presumably due to organic impurities. In the upper part of the formation, there are limest0nes which are lighter in color, have coarser-grained terrigeous material, and contain fragments of pelecypods, brachiopods, fusulinids, bryozoans, and algae.

Some of the sandstones, closely interbedded with the dark limestone-siltstone units, are fine- to medium-grained, well sorted, and have some carbonate cement. However, in the upper part of the formation there are also some intervals of coarse-grained, poorly sorted sandstones and conglomerates similar to those described for the lower part of the formation in section 60.

The top of the Alamitos Formation in section 25 is placed at the top of the highest, well-developed limestone sequence. The change to the overlying clastic Sangre de Cristo Formation seems to be sharp but the contact is covered. Faunal Zone G (Fusulinid Zone VI) occurs near the top of the Alamitos Formation (fig. 0); consequently, the formation in this area is no later than upper Desmoinesian in age.

The 4000 feet comprising the Alamitos Formation in the Rio Pueblo area is believed to be equivalent only to the lower 500 feet of the formation in sections 96 and 97, 40 miles to the south. The limestones in the southern area are of latest Desmoinesian, Missourian, and Virgilian ages and are interpreted as being time equivalents to the lower part of the Sangre de Cristo Formation to the north (figs. 10, I 1). The presence of red shales in the middle and upper part of the Alamitos Formation in section 96 supports this contention. Some of these red shales are intimately interbedded with marine limestones and are interpreted as equivalents of the red shales and arkoses of the Sangre de Cristo Formation in the Rio Pueblo area. In both regions, the red color is believed to reflect the environment of the terrigenous source area to the west or northwest.

The Uncompahgre highland to the west was the source of the Alamitos terrigenous rocks. East from the Rio Pueblo area, the formation shows a decrease in grain size and thickness. In the Continental No. I Duran well, 40 miles east of locality 60, the Alamitos Formation is 2360 feet thick (top at a depth of 2900 feet). The formation in the well differs from that exposed near Rio Pueblo in having only a few conglomerates, a lower percentage of coarse-grained sandstone, and in increased percentage of shale (predominantly dark gray or greenish gray). There is no evidence to support a terrigenous source of any significance from the east during the time of deposition of the Alamitos Formation in the Rio Pueblo area.

SANGRE DE CRISTO FORMATION

Hill (1899) used the name *Sangre de Cristo Formation* for the entire sequence of Pennsylvanian strata in the Sangre de Cristo Mountains of southern Colorado. In northern New Mexico, this name has been applied only to the arkose and redbed sequence which overlies the Alamitos Formation. The author has studied only the lower part of the formation in a few localities and no attempt was made fully to describe its characteristics. Near the town of Pecos, its boundary with the underlying Alamitos Formation is gradational and the lower beds consist of coarse-grained, poorly sorted arkoses interbedded with red shales and siltstones. Individual arkose beds are similar to arkose beds in the upper part of the underlying Alamitos Formation. At the top of section 25, 35 miles north of Pecos, 700 feet of rocks are referred here to the Sangre de Cristo Formation. They consist of poorly exposed arkoses which are coarse grained, poorly sorted, and positively skewed.

The exact age of the Sangre de Cristo Formation is uncertain. Near the town of Pecos, this formation seems to interfinger with Virgilian limestones. To the north, it overlies upper Desmoinesian limestones but the contact is covered. If the two lithologies interfinger, the lower contact markedly transgresses time laterally. This possibility was pointed out by Brill (1952, p. 832), but he thought it more likely that the basal contact is unconformable and that the arkose and red-bed sequence could be Wolfcampian in age. Locally in the southernmost Sangre de Cristo Mountains region, the Sangre de Cristo is known to rest unconformably on older rocks. This is the case near Lamy (sec. 93), ten miles southwest of the town of Pecos, where the arkose and red-bed sequence rests unconformably on typical limestones of the La Pasada Formation which carry Brachiopod Fauna III. Also seven miles southwest of Las Vegas, the Sangre de Cristo Formation rests directly on various earlier rock units, including the Precambrian (Northrop et al., 1946). Conclusive proof is lacking, but the author believes that a regional intertonguing facies relationship is more likely in which the formation is locally unconformable on older rocks (fig. I 0.

PALEOZOIC GEOLOGIC HISTORY PRE-

PENNSYLVANIAN HISTORY

The distribution and lithologic character of the oldest preserved Paleozoic strata in the southern Sangre de Cristo Mountains are closely controlled by the nature of the eroded Precambrian surface. The area of Precambrian metasedimentary rocks (chiefly quartzite) east of the Picuris—Pecos fault (fig. 8) was the major source for the pre-Pennsylvanian terrigenous deposits. The positive area, cut on Precambrian rocks, had a highly irregular surface developed upon it and a regional relief of at least several hundred feet. These Precambrian rocks are exposed today in the Truchas Peaks and intermittently eastward in the Pecos River drainage basin and on the East Divide. In contrast, the area of dominantly metaigneous Precambrian rocks in the southern and western parts of the mapped quadrangle on both sides of the Picuris-Pecos fault had little relief and formed a lowland stretching southward and westward away from hills composed mainly of Precambrian quartzite. This low-lying surface on metaigneous rocks was intensely weathered with several feet of soil developed in some places (pl. 8D).

The nature of the pre-Paleozoic depositional surface farther north and west of the Picuris—Pecos fault area of the present-day westerly and central parts of the Picuris Range is unknown. If there were any pre-Pennsylvanian deposits, they were removed by erosion during post-Mississippian time.

The sparsely fossiliferous Del Padre and Espiritu Santo formations, the oldest preserved Paleozoic units, presumably were deposited sometime during the interval from Cambrian to early Mississippian time. The Del Padre sands were laid down by a sea transgressing onto an upland underlain by the Precambrian quartzite lying east of the Picuris—Pecos fault. The sediments that were indurated to form the orthoquartzitic sandstones and conglomerates of the Del Padre Sandstone mainly filled the lower areas of the upland between the quartzite hills (fig. 8). As a result, the lateral thickness of the sandstone varies greatly in the upland area underlain chiefly by quartzite, and thins progressively away from this upland. The Del Padre Sandstone is abnormally thick, locally in excess of 700 feet, at Rio Chiquito (sec. 66), Osha Canyon (sec. 89) and the divide west of the Pecos Baldy (sec. 110; see fig. 8). These unusual thicknesses are believed to represent accumulations along a fault scarp as a result of vertical movement of unknown magnitude on the Picuris—Pecos fault. Such a contention is supported by the quartz grains and quartzite fragments in the lower beds of the Del Padre Sandstone near the head of Rio Chiquito (sec. 66) derived from source rocks consisting of intensely sheared Precambrian quartzite.

Thinning of the Del Padre Sandstone away from the quartzite source area occurs chiefly by means of a facies change, a lateral interfingering with the limestones of the Espiritu Santo Formation. These limestones were deposited in a shallow sea which spread across a surface of low relief eroded primarily upon Precambrian metaigneous rocks and which partly surrounded the upland area of quartzite. Presumably no granite was exposed to erosion during deposition of these two formations.

Deposition and lithification of the Del Padre and Espiritu Santo formations was followed by broad arching of the region and by mild deformation which resulted in vertical j0inting of both formations and in extensive recrystallization and dolomitization of the Espiritu Santo Formation. Small solution features developed here and there on the eroded surface of the Espiritu Santo Formation but no extensive karst topography was formed.

In Middle Mississippian, Meramecian time, the area now occupied by the southernmost Sangre de Cristo Mountains was covered intermittently by a shallow sea, in which a series of closely related limestone units were deposited as part of a single cycle; all these units are included in the Tererro Formation. The upland area underlain by quartzite east of the Picuris—Pecos fault continued through Meramecian time as a probable source for the fine-grained terrigenous sediments and was rarely, if ever, covered by the sea.

The oldest preserved Meramecian strata are the limestone boulder conglomerates of the Macho Member, derived primarily from a still older Meramecian limestone. Rare boulders of quartzite in the Macho indicate erosion of Precambrian quartzite at this time. Only a few boulders were derived from the underlying Espiritu Santo Formation. The rounded to subrounded, poorly sorted limestone clasts range from pebble size to boulders more than two feet in diameter. Size analyses of the boulders at several localities in the Pecos Valley between Dalton Bluff (sec. 36) and Jacks Creek (sec. 13) reveal little lateral change in median diameter and in sorting. Irregular bedding occurs locally and the percentage of sandy limestone matrix increases upward in the unit. The Macho boulder conglomerates were deposited over an extensive area covering most of the southern, western, and extreme northern parts of the map area in a pattern that apparently encircled, but never covered, the quartzite upland. The conglomerate is consistent in lithologic character over much of its areal extent. The mechanics of deposition are not clear. Deposition and partial or complete lithification of the Meramecian limestone sequence from which the boulders were primarily derived would appear to have been followed by elevation of the area above sea level. With the sea advance which followed, the unit was subjected, possibly as a limestone cliff, to high-energy wave action which fragmented the layers, partly rounded the fragments, and deposited them more or less in *situ as* the sea advanced.

The limestones in the boulders of the Macho Member are closely similar to those of the overlying Manuelitas Member The gradational boundary between these two members anc their faunas also suggests a close relationship. Partial contem poraneous deposition of these two units is believed to have been likely. The limestones of the Manuelitas Member were deposited as a series of thin, shallow marine deposits with deposition interrupted repeatedly by variations in sea level that exposed the area to erosion and allowed recurring development of karst topography. Fine-grained quartz sand which occurs as a minor element in both the Macho and Manuelitas members is believed to have been derived from a nearby, but low-lying, upland of quartzite.

The repeated emergence and submergence characteristic of Manuelitas deposition changed later in Meramecian time with the sustained deposition of the Cowles Member. This member consists predominantly of silty limestone with a higher percentage of fine-grained quartz sand and silt than is present in the older members of the Tererro Formation. The percentage of silt increases upward, so that the member is locally a calcareous siltstone in the upper part. The Cowles Member was deposited 0ver a greater part of the upland quartzite area than was the case for the older members of the Tererro, but it probably never covered the entire area. In the Truchas area, the Cowles Member locally rests on the Espiritu Santo Formation (sec. 7).

Partial recrystallization and dolomitization unequally affected the members of the Tererro Formation after deposition. The Macho Member was least affected, with recrystallization and dolomitization restricted primarily to the margins of boulders and to the matrix in the basal and upper parts of the member. Patches of silicification commonly obscure the boundary between the Macho and Manuelitos members. The Manuelitas and Cowles members show marked local variation in the degree (from slight to extensive) of recrystallization and dolomitization.

The evidence presented suggests that the pre-Pennsylvanian strata of the southernmost Sangre de Cristo Mountains represent two distinct deposits: ( ) the Del Padre and Espiritu Santo formations, of undetermined age, which possibly was followed by a major period of erosion, and (2) the Tererro Formation of Mississippian, Meramecian age, formed during periods of shallow-water carbonate-rock deposition that alternated with periods of emergence and erosion. The area now occupied by the southernmost Sangre de Cristo Mountains was apparently above sea level and exposed to erosion during Late Mississippian time. At Pecos Falls (sec. 8) in the Truchas area, Pennsylvanian strata rest directly on Precambrian quartzite in a locality which may never have been covered by pre-Pennsylvanian sediments.

PENNSYLVANIAN HISTORY

The strike-slip movement which is presumed to have occurred on the Picuris—Pecos fault during Precambrian time has been discussed by Montgomery in the chapter on Precambrian structure. As suggested above, probable pre-Mississippian vertical movement took place on this fault just before or during deposition of the Del Padre Sandstone. In the chapter on Laramide Orogeny, it is demonstrated that large-scale vertical movement took place on this fault in post-Paleozoic time. Further vertical movements are postulated on this fault as occurring both in the Early Pennsylvanian (Morrowan) and Middle Pennsylvanian (late Desmoinesian), uplifts that served to control major events in the Pennsylvanian depositional history in northern New Mexico.

Figure 15 shows a north-south line marking the trace of the Picuris—Pecos fault and also an inferred north-south line drawn on the eastern edge of the Uncomphagre highland in southern Colorado (Mallory, 1960). The two lines meet if projected across the intervening area, 50 miles wide, which is underlain by Cenozoic volcanic rocks and alluvial deposits extending across the Rio Grande structural depression. The author postulates that the two lines represent parts of one long north-south fault trace along which differential vertical uplift on the west side provided a source of elastic sediments, the Uncompahgre highland. Figure 15 also shows the present-day general distribution of Precambrian rock types. The distinct southern metasedimentary-granite intrusive contact west of the Picuris—Pecos fault has been established in the southern Picuris Range by Montgomery. In this area the metasedimentary rocks strike east-west. A less distinct general northern

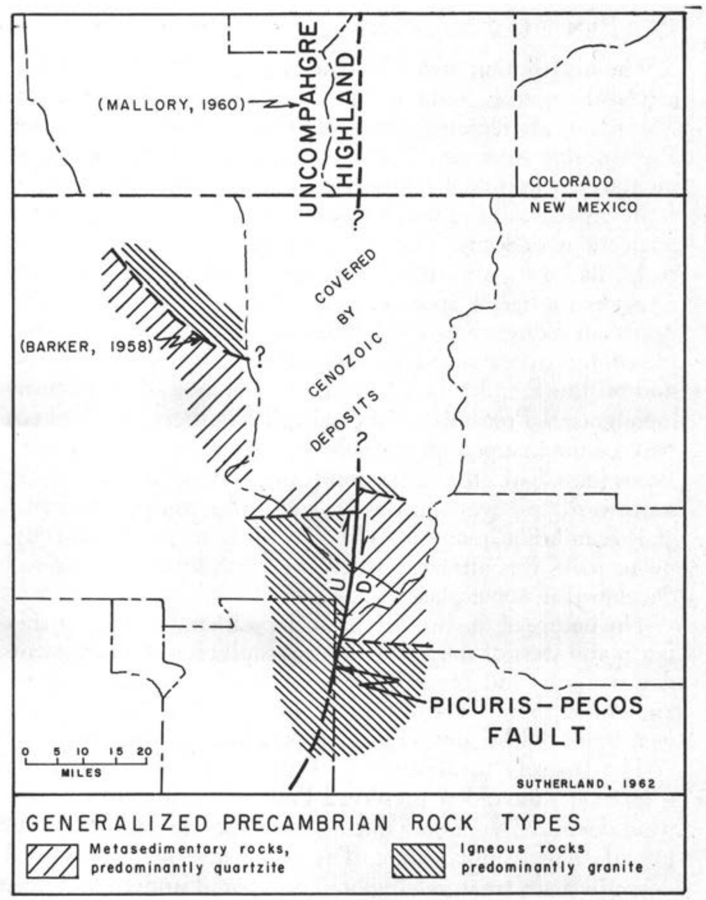

Figure 15

Generalized pre-Paleozoic subcrop map of the southern Sangre de Cristo mountain area in relation to the Picuris–Pecos fault and the postulated location of the Uncompahgre Highland in southern Colorado limit of this band of metasedimentary rocks west of the fault seems to occur along a highly irregular northwest-southeast trending line in eastern Rio Arriba County (Barker 1958; Foster and Stipp, 1961). Here, the metasedimentary rocks strike generally northwest-southeast. Locally, Precambrian pegmatites have intruded this metasedimentary sequence, as in the Petaca, La Madera, and Ojo Caliente area, but the total volume of these granitic rocks is small compared to that of the host metasedimentary rocks. Farther to the east, the northern limit of this band of metasedimentary rocks is unknown, being buried beneath the Cenozoic deposits of the Rio Grande depression, but it is presumed to be in north-central Taos County.

The depositional history of Pennsylvanian strata in the mapped area is divisible into two distinct phases. The first extended from Morrowan to middle Desmoinesian time and is represented by the nearly simultaneous deposition of the La Pasada and Flechado formations. The second phase, extending from late Desmoinesian time to Late Pennsylvanian or Early Permian time, resulted in the widespread deposition of the Alamitos Formation and the lower beds of the Sangre de Cristo Formation.

The nature of these Pennsylvanian sediments indicates a major source of terrigenous materials to the west. During the first phase, from Morrowan to mid-Desmoinesian time, this source was predominantly of metasedimentary rocks. In the second phase, the late Desmoinesian to Virgilian interval, the major source from the west was of granitic rocks. During both intervals, the Uncompahgre highland was the source area; its location is somewhat hypothetical in southern Colorado and in Rio Arriba County where its remnants are covered by Cenozoic rocks, but in the southern Sangre de Cristo Mountains area, the eroded base 0f the Uncompahgre highland is exposed, and the Precambrian rocks west of the Picuris—Pecos fault are the types that provided the terrigenous sediments in the Pennsylvanian beds. The distribution of shelf and trough sediments during early Pennsylvanian time indicates that the metasedimentary source-rocks west of the Picuris—Pecos fault extended several miles farther south than the present southern limit of these rocks in the southern Picuris Range (fig. 16). Such a contention would be possible if the upper intrusive contact of the granite were variable and undulating, and sloped downward and northward at a low angle beneath the metasedimentary rocks to the north.

Phase I—Morrowan to Middle Desmoinesian

The early Pennsylvanian was marked by an upward movement of the Uncompahgre highland along the northerly extension of the Picuris—Pecos fault. The Precambrian metasedimentary area (chiefly of quartzite) extending from about the northern edge of Santa Fe County (fig. 16) for an unknown distance northward, was elevated and provided the predominant source for the sediments deposited to the east, southeast, and south. This uplifted metasedimentary fault block constituted the southern end of the Uncompahgre highland during the first part of the Pennsylvanian (fig. 8).

Figure 17 shows the main tectonic elements of the region in Early Pennsylvanian time. The Taos trough was developed on the downthrown, eastern side of the Picuris—Pecos fault as a southern extension of the Central Colorado trough (Mallory). The Taos trough merged southward with the Pecos shelf in western Mora County. The fault-block movements involved in producing these structures were complex with a probable rotational movement on the Picuris—Pecos fault and possible secondary faulting at right angles to this fault along the strike of the Precambrian metasedimentary rocks. Such secondary faulting may coincide with the boundary between the Pecos shelf and the Taos trough accounting for the rectangular pattern of the tectonic features (fig. 17).

The La Pasada Formation averages about I 000 feet in thickness and was deposited as a dominantly marine, carbonate-rock sequence across the broad Pecos shelf (figs. 17, 18). This shelf extended east of Las Vegas, and westward at least as far as Santa Fe and possibly even to the eastern margin of the Peñasco axis as outlined by Kottlowski (1961). To the south in northern Torrance County, it was presumably bordered by the Pedernal highland and was interrupted locally by minor positive areas. The La Pasada Formation extends northward to the north margin of the Pecos shelf (fig. I 7) where it grades laterally by a pronounced facies change into the Flechado Formation (figs. I0, 11, and 8). The north margin of the Pecos shelf coincides with the southern edge of the Precambrian quartzite area east of the Picuris—Pecos fault (fig. 15), which existed as a positive area in Mississippian time and probably remained higher than adjacent areas in Early Pennsylvanian time. At Pecos Falls (loc. 8), an undetermined horizon in the La Pasada Formation rests directly on the Precambrian quartzite. The apparent thinning of the interval between Faunal Zones D and E near Jicarilla Ridge (fig. 0), though not adequately substantiated,

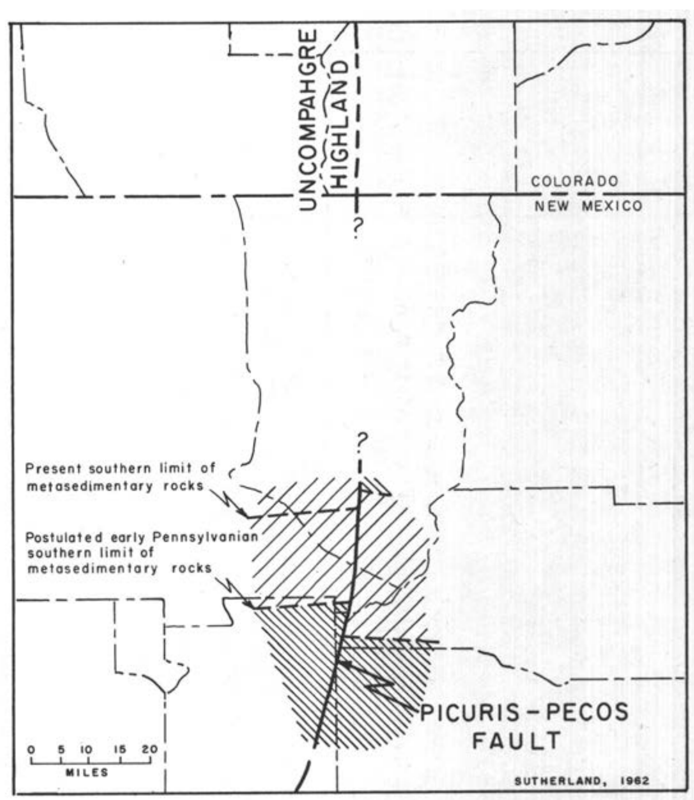

Figure 16

POSTULATED EARLY PENNSYLVANIAN SOUTHERN LIMIT OF METASEDIMENTARY ROCKS WEST OF THE PICURIS–PECOS FAULT suggests that this east-west-trending quartzite area continued as a min0r positive feature into Desm0inesian time.

The Flechado Formation consists mainly of coarse-grained, poorly sorted orthoquartzite alternating irregularly with thicker units of gray shale, mudstone, and siltstone. Limestones are scarce. The formation is about 2500 feet thick and its elastic sediments coarsen westward or northwestward. The formation was deposited in a sinking, north-south elongated, fault trough in which the rate of sedimentation equaled or more than kept pace with the rate of sinking. Only rarely did the sea invade the trough from the south where the marine shelf deposits of the La Pasada Formation were accumulating. The Morrowan sequence, the lower part of the Flechado Formation, probably is a series of alluvial deposits alternating with minor near-shore marine units. These pass upward into the "Atokan" and Desmoinesian beds which are anastomosing alluvial fans that thin eastward and show irregular cross-lamination and poor sorting. Scarce interbeds are of shallow-water, near-shore marine strata.

Metasediments, predominantly quartzites, were the primary source rocks of the La Pasada and Flechado formations. During "Atokan" and early Desmoinesian times, micaceous and some feldspathic quartzite and quartz-mica schist cropped out in the eroded source area. During this interval, a secondary, local granite source occurred to the south and supplied feldspar that makes up as much as 20 percent of elastic beds in the upper part of the La Pasada Formation at Dalton Bluff (fig. 12). This source of feldspars could have been a local granite high on the Pecos shelf or presumably the Pedernal highland to the south in northern Torrance County.

The metasedimentary area west of the Picuris—Pecos fault is believed to pass northward into an area composed predominantly of granite in north-central Taos County as it does in east-central Rio Arriba County (fig. 15). Thus, one would expect the nonarkosic Flechado sandstones to change northward in the trough, in northern Taos County, into arkosic elastics of equivalent age. In southern Colorado, 25 miles north of Taos County at an exposure west of Chucara in eastern Costilla County, Ames (1957) described a thick, predominantly elastic Pennsylvanian sequence which is arkosic throughout. In his section, the lowest-occurring identifiable fossils are early Desmoinesian fusulinids found 1342 feet above the base of the section.

The Uncompahgre highland is not believed to have extended south of the northern edge of Santa Fe County during Morrowan to middle Desmoinesian time. Read and Wood's (1947, p. 225) statement that the highland extended south "at least as far as central Torrance County" apparently is based on their misinterpretation of the faulted sequence in Apache Canyon near Lamy (sec. 93 of this paper). This they believed to be a section in which all parts of the Pennsylvanian are thin as a result of having been deposited near a highland. At this locality, the Morrowan—"Atokan" part of the La Pasada Formation is poorly exposed, but it is equal in thickness to the same interval at Dalton Bluff. The "Atokan" strata are faulted against limestones of the early Desmoinesian part

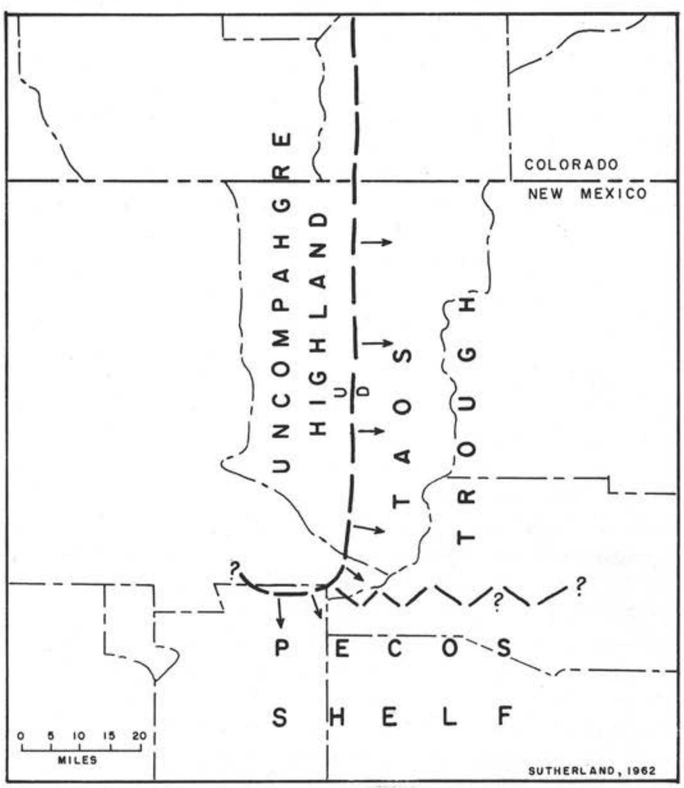

Figure 17

Principal tectonic elements in Early Pennsylvanian time

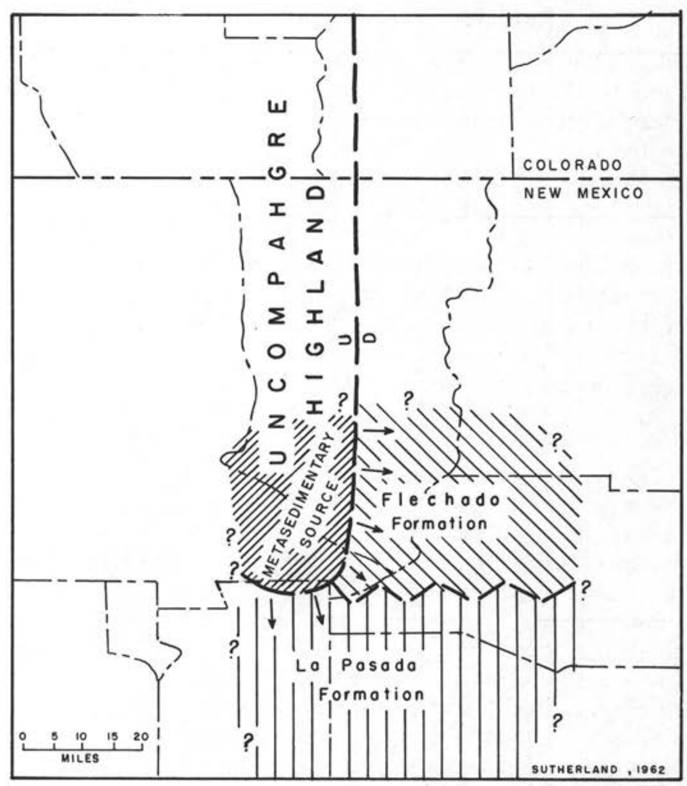

Figure 18

Depositional pattern, Morrowan to Middle Desmoinesian time

of the La Pasada Formation which carries Brachiopod Zone 3. Thus, this part of the section is "condensed" by faulting, not by deposition. Furthermore, these early Desmoinesian limestones are overlain unconformably by the Sangre de Cristo red beds (*see* discussion under Phase II). Evidence against the presence of a major north-south elongated highland in the Santa Fe area during the early part of the Pennsylvanian includes the following: (I) The Morrowan rocks with the largest percentage of limestone in the region occur near Santa Fe and at Nambe Falls on the west side of the Sangre de Cristo Mountains (secs. 41, 90, and 92) and carry extensive brachiopod faunas similar to those found in the lower part of the section at Dalton Bluff in the Pecos Valley; (z) the highly fossiliferous middle Desmoinesian limestones of the upper La Pasada Formation crop out at Nambe Falls (sec. 41) north of Santa Fe in the area of Read and Wood's postulated highland.

Phase II—Late Desmoinesian to Virgilian

Late Desmoinesian time (fig. 19) marked the second major Pennsylvanian movement on the Picuris—Pecos fault. The Uncompahgre highland was uplifted and remained high throughout the remainder of the Pennsylvanian Period. This uplift apparently was more intensive and more extensive than that of the Early Pennsylvanian movement. In late Desmoinesian time, it exposed extensive granite outcrops of the Uncompahgre highland north and south of the metasedimentary exposures which had been almost the sole clastic sources for the La Pasada and Flechado formations. A partial factor in the change to a granite provenance was the decreas

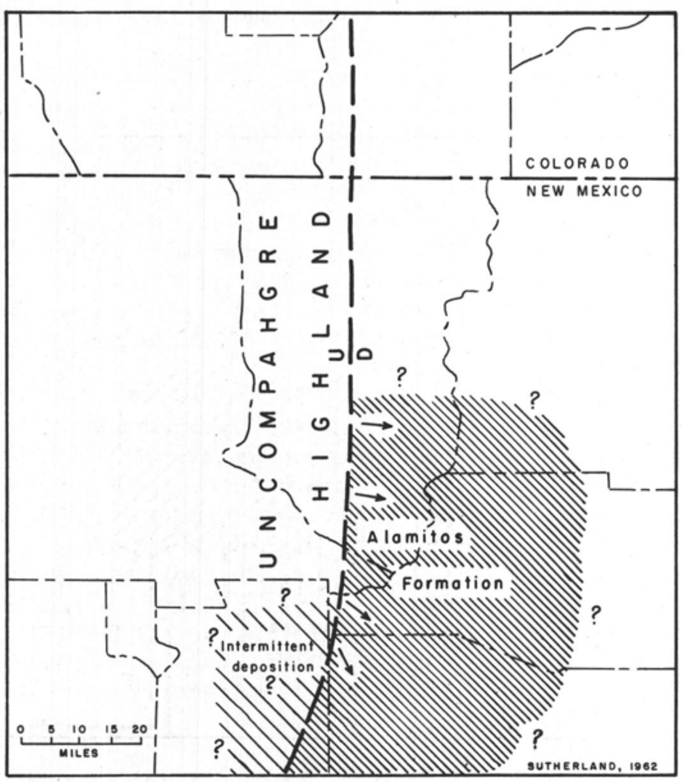

Figure 19

DEPOSITIONAL PATTERN, LATE DESMOINESIAN TIME

ing width of the east-west-trending belt of metasedimentary rock due to erosion. The Taos trough and Pecos shelf continued as tectonic features in Phase II but the southern end of the Uncompahgre highland may have extended farther south with exposure of granite in northeast Santa Fe County. The area around the city of Santa Fe was probably uplifted sufficiently to partly disrupt deposition but this region never was a major source area. The pre-Pennsylvanian and Early Pennsylvanian formations preserved near Santa Fe were not removed by erosion during later Pennsylvanian time.

The abrupt, widespread appearance of arkose at the base of the Alamitos Formation (beginning of Phase II) denotes the marked change in the depositional history of the southern Sangre de Cristo Mountains area. The Alamitos Formation in the Pecos area (figs. 10, 14) is about 1275 feet thick and ranges in age from late Desmoinesian to Virgilian. Coarse-grained arkoses are characteristic of the entire formation but in the lower two thirds they are interbedded with shale and siltstone and with thin limestones. The upper one third of the formation is of arkosic, sandy limestones and red shales interbedded with arkoses. The coarse-grained arkoses in the lower part of the formation contrast sharply with the dominantly carbonate beds of the conformably underlying La Pasada Formation.

In the Rio Pueblo area, the Alamitos Formation is about 4000 feet thick and is of late Desmoinesian age (fig. 0). There, the lower 2500 feet of the formation is predominantly coarse-grained, poorly sorted, cross-bedded arkose with scattered wood impressions alternating irregularly with poorly exposed, extensive intervals of gray shale and siltstone. Limestones are scarce. The upper 1500 feet are of alternating limestones, siltstones, shales, and sandstones.

Thus, Phase II was marked by a sharp increase in sedimentation in the Taos trough leading to accumulation of 4000 feet of sediments during late Desmoinesian time. The lower 2500 feet of strata were vast alluvial fans and deltaic deposits spreading eastward from the elevated Uncompahgre highland with periodic shallow marine invasions. The upper 1500 feet of the Alamitos Formation (fig. 10; sec. 25) represents the final major marine invasion of the southern part of the Taos trough during the Pennsylvanian. In the Pecos area, only about 500 feet of sediments accumulated on the Pecos shelf during late Desmoinesian time, and those rocks, in contrast, are shallow marine strata alternating with coarse-grained alluvial deposits which periodically spread south and southeast over the shelf.

During the Missourian and Virgilian Epochs, the Uncompahgre highland continued to provide large volumes of coarse-grained elastic rocks and muds which more than filled the Taos trough and formed extensive, irregular anastomosing alluvial fans which spread eastward from the margin of the highland. This clastic sequence is the Sangre de Cristo Formation. At this time, there was also an important climatic change in the Uncompahgre source area. Red sediments are sparse in older Pennsylvanian rocks of the area. However, many of the shales, mudstones, and sandstones in the Sangre de Cristo Formation of the Rio Pueblo area are red and are believed to reflect the environment of the source area.

On the Pecos shelf to the south, deposition of the Alamitos Formation continued through Missourian and Virgilian times (contemporaneously with deposition of the Sangre de Cristo Formation in the Taos trough), with no appreciable change in depositional pattern from that of the late Desmoinesian sequence (fig. 20). Sandy, arkosic, shallow-water marine limestones alternate and interfinger by rapid lateral facies changes with red alluvial mudstones and coarse-grained arkoses derived from the northwest.

Late in Virgilian time, the shallow sea in which the highest limestones of the Alamitos Formation were deposited gradually withdrew southward, replaced by prograding alluvial deposits of the Sangre de Cristo Formation derived from the northwest. Presumably, deposition of the Sangre de Cristo Formation continued into Permian time across both the Pecos shelf and Taos trough areas.

During late Pennsylvanian or Permian time, the Pecos shelf area was disrupted by local faulting or folding which elevated some regions so that the Alamitos and La Pasada formations were locally removed by erosion, and the Sangre de Cristo Formation was deposited locally on older formations.

Sierra Grande Arch

There is no evidence to suggest that the western part of the Sierra Grande arch supplied terrigenous sediments to the mapped area during the interval from Morrowan through Desmoinesian times. Thickness and average grain size decrease eastward in the La Pasada and Flechado formations. The western margin of the arch, as it appears today in the subsurface of eastern Mora and west-central San Miguel counties, probably did not develop until late Pennsylvanian or Permian time. Thus, the eastern disappearance of the La Pasada and Flechado formations on the present-day west flank of the Sierra Grande arch may have resulted from postdepositional truncation and not by onlap. A careful subsurface study in the Las Vegas area might prove or disprove this contention.

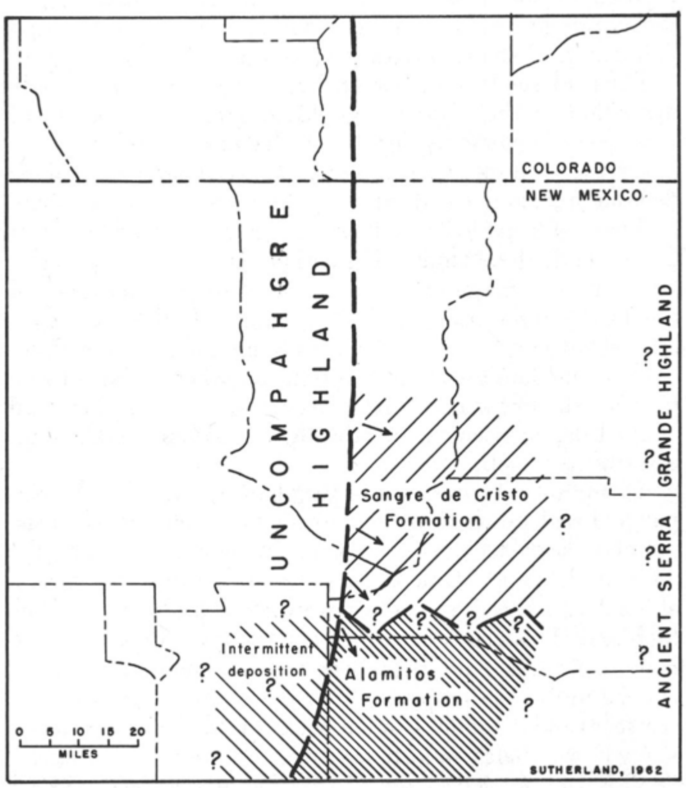

Figure 20

DEPOSITIONAL PATTERN, MISSOURIAN AND VIRGILIAN TIME

(Compare with Figure 11)

PALEOZOIC LOCALITIES CITED

4. Beatty's Cabin. Bluff on east side of Rito del Padre at its junction with the Pecos River, opposite Beatty's Cabin; approximately seven miles northeast of Cowles, Mora County (Montgomery and Sutherland, 1960, p. 28). Type locality of Del Padre Sandstone.

5. Hamilton Mesa road. Abandoned quarry on east side of Hamilton Mesa road 0.2 mile from junction with State Highway 63, 1.4 miles south of Cowles, San Miguel County. Good exposure of Tererro Formation.

7. Mouth of Rito de los Chimayosos. Bluff on northwest side Rito del Padre, just above its junction with Rito de los Chimayosos, about one mile north of Pecos River and Beatty's Cabin, Mora County (Montgomery and Sutherland, p. 47). Cowles Member of Tererro Formation is unconformable on Espiritu Santo Formation.

8. Pecos Falls. Located on the Pecos River approximately ten miles north of Cowles, Mora County (Montgomery and Sutherland, p. 33). Small exposure of unconformable contact of La Pasada Formation and Precambrian quartzite at top of falls.

0. Northeast ridge of Pecos Baldy. Ridge running northeast from northeast face of Pecos Baldy, located due north of Pecos Baldy Lake, Mora County; about seven miles north of Cowles (Montgomery and Sutherland, p. 43), La Pasada Formation is faulted against Precambrian quartzite.

13. Jacks Creek. Bluff on northwest side of Pecos River 30 yards above mouth of Jacks Creek, about one mile north of Cowles, San Miguel County (Montgomery and Sutherland, p. 37). Excellent exposure of Tererro, Espiritu Santo, and upper part of Del Padre formations.

22. Tererro (pre-Pennsylvanian). Bluff on west side of Pecos River opposite Tererro post office, 80 to 100 yards north of mouth of Holy Ghost Creek, San Miguel County (Montgomery and Sutherland, p. 20). Good exposure of Tererro and Espiritu Santo formations; poor exposure of Del Padre Sandstone.

22. Tererro (Pennsylvanian). Bluff on west side of Pecos River, opposite point on State Highway 63, 1.3 miles north by road from the Tererro post office and about one mile north along river from section 22 (pre-Pennsylvanian), San Miguel County. Poor exposure of La Pasada and lowest part of Alamitos formations.

25. Santa Barbara Valley. Bluff exposure on east side of Rio Santa Barbara. Base of section is at bridge 6.5 miles south of junction with State Highway 75 at Peñasco, Taos County. Highest part of section is poorly exposed on wooded hill about two miles southeast of base of section. Upper part of Alamitos and lower part of Sangre dc Cristo formations.

26. Jicarita Peak. Section extends from lowest rock exposure on south side of large cirque on west side of peak to top of peak, Taos County. Exposes upper part of Flechadc and lower part of Alamitos formations.

31. Dalton Canyon. North side of Dalton Canyon 4.2 miles by jeep road west of junction with State Highway 63 in Pecos Valley, Santa Fe County. Poor exposure of pre-Pennsylvanian formations.

36. Dalton Bluff. West side of Pecos River 6.6 miles by road north of junction of State Highway 63 and Alternate U. S. Highway 84-85 at the town of Pecos, San Miguel County (Montgomery and Sutherland, p. 16). Type locality of La Pasada Formation; good exposure of pre-Pennsylvanian formations.

40. East ridge of Jicarilla Peak. Ridge running east from east face of Jicarilla Peak and forming the boundary of Mora and Rio Arriba counties and the drainage divide between the Santa Barbara and Pecos rivers. La Pasada Formation is faulted against Precambrian quartzite.

41. Nambe Falls. Exposures along Pojoaque Creek for one-quarter mile below falls; located about three miles southeast of Nambe Pueblo, Santa Fe County. Exceptional exposures of pre-Pennsylvanian rocks and the Morrowan part of La Pasada Formation.

47. Eastern Santa Barbara Divide. Exposure in wall of east-facing cirque, near crest of East Divide, about one mile east of head of Rio Valdez, Mora County. Basal La Pasada Formation is unconformable on Del Padre Sandstone.

60. Rio Pueblo (pre-Pennsylvanian). Del Padre Sandstone measured near river level on north bank of Rio Pueblo, three miles east on State Highway 3 from junction with State Highway 75, Taos County. Espiritu Santo and Tererro formations measured 0.2 mile westward, high on cliff, about 200 yards north of Rio Pueblo. Good exposures of Del Padre and Espiritu Santo formations.

60. Rio Pueblo (Pennsylvanian). Partly exposed on bluffs on north side of the Rio Pueblo, Taos County. Base of Pennsylvanian is in bottom of Tio Maes Canyon at point three miles east on State Highway 3 from junction with State Highway 75, Taos County. Top of section is at top of high forested ridge about 0.2 mile north of point on State Highway 3, 3.8 miles east of base of Pennsylvanian section. Type locality of Flechado Formation.

65. Near Talpa. High timbered north-south ridge between Arroyo Miranda and Rio Grande del Rancho, Taos County. Section is reached by going south of Talpa to a point on State Highway 3, 3.65 miles south of junction with U. S. Highway 64; then west across Rio Grande del Rancho and up small canyon to crest of high ridge. Section was measured from site where beds of Del Padre Sandstone stand vertical at crest of ridge, thence due eastward down small canyon. Good exposures of all the pre-Pennsylvanian formations and of the Morrowan part of the Flechado Formation.

66. Near head of Rio Chiquito. High bluff on northeast side of Rio Chiquito where creek runs due westward one-quarter mile south of boundary between Taos and Rio Arriba counties. Located approximately five miles south of village of Llano and three miles southwest of campground on Rio Santa Barbara. Exposes thickest section found of Del Padre Sandstone; site is located east of and adjacent to Picuris-Pecos fault.

67. Taos Canyon. Bluff on north side of Taos Canyon, Taos County. Base of section at highway level 2.8 miles southeast of junction in Taos of U.S. Highway 64 with State Highway 3. Top of section is at highest exposure on bluff. Excellent exposure of the "Atokan" (and early Desmoinesian?) part of the Flechado Formation.

69. East (Elk Mountain) Divide. Exposure at east edge of crest of East Divide approximately 2.5 miles south of boundary between San Miguel and Mora counties and 3.5 miles north of point where Mica Mine road crosses crest of Divide. Good exposure of pre-Pennsylvanian formations; westward dip of beds ranges from low dip to more than 80 degrees.

85. Ridge north of Rito del Oso. West-facing hill on east-west ridge, Mora County, between Rito del Oso and Rio Mora and about one mile east of their junction. Poor exposure pre-Pennsylvanian formations.

86. Ridge north of Hollinger Canyon. Exposure on crest of east-west ridge between Hollinger and Beaver canyons, San Miguel Canyon, approximately 1.5 miles east of East (Elk Mountain) Divide. Pre-Pennsylvanian formations exposed.

89. North of Osha Canyon. Hillside exposures on northwest side Osha Canyon about one mile above its junction with Telephone Canyon, Taos County. Site is about three-fourths mile east of Picuris-Pecos fault. Poor exposure of Del Padre Sandstone.

90. Santa Fe River. Exposure in bed of tributary creek which enters the Santa Fe River from north at short bend in road to Twomile Reservoir where it crosses tributary, 1.2 miles east of road junction with Gonzales Road, Santa Fe County. Morrowan part of La Pasada Formation is exposed.

92. Southeast of Bishop's Lodge. Exposures for one-half mile along Little Tesuque Creek southeastward from Bishop's Lodge, Santa Fe County. Pre-Pennsylvanian and lower part of La Pasada formations well exposed.

93. Near Lamy. Low bluff facing Santa Fe Railway on west side of valley of Galisteo Creek, Santa Fe County, about 2.5 miles northeast of Lamy and 3.5 miles southwest of Cañoncito. Faulted and poorly exposed Pennsylvanian sequence; Sangre de Cristo Formation unconformable on La Pasada Formation.

94. Gallinas Canyon. East-facing bluff at small tributary on north side of Gallinas Canyon 4.4 miles west by road from steel bridge over Gallinas River at Montezuma, San Miguel County. Good exposure of pre-Pennsylvanian formations.

95. West of village of Agua Zarca. Exposures in creek bank 50 feet south of State Highway 103, at a point 1.9 miles west by road from Agua Zarca church and 5.1 miles west of junction of this highway with U.S. Highway 85, San Miguel County. Good exposures of pre-Pennsylvanian formations.

96. Alamitos Canyon. Exposures along east side of Alamitos Canyon, San Miguel County. Section is reached by road from point on Alternate U.S. 84-85, 1.1 miles west of the town of Pecos and main highway junction. Base of section is at lowest exposure in creek bed 4.2 miles north by road from Alternate U.S. 84-85 and two miles north of abandoned concrete mill abutments of the Pecos Mine. Upper part of section is east of tailings dam on creek about one-half mile east of point on unpaved road

a mile north of Alternate U.S. 84-85. Primary type locality for Alamitos Formation; basal 250 feet are not exposed.

97. Ridge between Pecos Valley and Alamitos Canyon. Section starts at base of cherty limestone two-thirds up steep slope on west side of dry valley west of triangular-shaped hill on west side of Pecos River 4.3 miles north by road from junction of State Highway 63 and Alternate U.S. 84-85 at town of Pecos, San Miguel County. The cherty limestone interval is equal to units 36-174 to 36-178 which form the seventh cliff at Dalton Bluff, located about 2.5 miles to the north. Section continued westward for two miles along crest of ridge to as far as highest point on main ridge between Pecos Valley and Alamit0s Canyon. Secondary type locality of Alamitos Formation; upper I 00 feet are not exposed here.

0. Main Divide west of Pecos Baldy. Site is a small northeast-southwest-trending ridge rising above Main Divide, about one mile west of western summit of Pecos Baldy, Mora County, and about one-quarter mile east of Picuris—Pecos fault. This is the westernmost exposure in Mora County of Del Padre Sandstone; incomplete and poorly exposed section.

Laramide Orogeny

by Patrick K. Sutherland

INTRODUCTION

The map area described in this report covers a part of the southern Sangre de Cristo Mountains area. This southernmost range of the Rocky Mountains terminates about 10 miles south of the map area where the resistant Precambrian rocks upholding it plunge beneath less resistant southward-dipping Paleozoic strata. The structural patterns observable in the map area are complicated and are the end result of at least four major periods of structural deformation. These are summarized as follows:

(1) Precambrian; includes the following events which are discussed in detail in the chapter on Precambrian rocks:
   (a) intensive folding along east-west axes of metasedimentary rocks which are extensively exposed in the Picuris Range and in the Truchas Peaks area.
   (b) twenty-three miles of right-lateral strike separation on the north-south-trending Picuris—Pecos fault which bisects the map area and has been traced north to south 38 miles in the map area.

(2) Pennsylvanian; uplift on the west side of the Picuris-Pecos fault during at least two distinct phases as indicated by the types of Pennsylvanian sediments deposited to the east of this fault. This is discussed in detail in the chapter on Paleozoic rocks.

(3) Late Mesozoic-early Cenozoic; Laramide deformation, discussed below.

(4) Middle and late Cenozoic; deformation resulting in uplift of the mountains and development of the Rio Grande depression that borders them on the west, discussed in chapter on Cenozoic Rocks.

LARAMIDE DEFORMATION

The term Laramide is used in a somewhat general manner to cover the long period of time from late Cretaceous into the early Tertiary. The time of this "Laramide" orogeny cannot be closely dated in the mapped area. Cretaceous rocks are involved in the north-south folding on the east side of the Sangre de Cristo Mountains (Northrop et al., 1946) but within the mapped area, the youngest strata affected are in the lower part of the Sangre de Cristo Formation. West of the mountains, at Nambe Falls (sec. 41) and on the east edge of the city of Santa Fe, steeply tilted and faulted Pennsylvanian beds are overlain by gently dipping strata of the Santa Fe Group. Deformation of the Pennsylvanian rocks is pre-Santa Fe, and therefore appears to be pre-Miocene in age.

The western half of the map area is underlain by Cenozoic deposits. These are mostly in depositional contact with Precambrian rocks and thus obscure any evidences of Laramide deformation. The Laramide structural features discussed below may be observed in the eastern half of the map area.

PICURIS—PECOS FAULT

The most impressive structural feature in the map area is the Picuris—Pecos fault. Vertical, dip-slip movement occurred along this fault during Laramide orogeny with no rotation of the fault plane from the vertical attitude established during the Precambrian strike-slip faulting. The west side of the fault was upthrown during Laramide time, bringing Precambrian rocks in contact with Pennsylvanian strata in both the southern and northern parts of the map area. West of Cowles, in the south-central part of the map area, Precambrian granite on the west is in fault contact with the Alamitos Formation to the east which indicates that the throw of the fault is at least 1500 feet.

For about five miles north of the south boundary of the map area, the fault trace lies within a belt of Precambrian rocks. A secondary, eastward-dipping normal fault, less than a mile east of the major fault, separates this Precambrian fault-slice from Pennsylvanian rocks to the east.

The fault has been traced continuously in the map area for about 38 miles. It can be traced intermittently for an additional i5 miles south from its southernmost trace in the map area to Cañoncito, near Glorieta. This extends the confirmed trace of the fault to about 53 miles. In the ten-mile interval south of the map area, the fault swings in a broad arc to a south-southwest alinement. In this region, the fault does not invariably coincide with the contact between Precambrian and Paleozoic rocks but lies partly within the area of Precambrian rocks. Locally, the band of Precambrian rocks east of the fault is in normal contact with Paleozoic strata.

The Picuris—Pecos fault can be termed a *geofracture*, a term used by Osterwald (1961) for a major, ancient fracture zone along which recurrent movement has taken place during later tectonic periods. It is likely that the Picuris—Pecos fault is part of a more extensive geofracture extending farther south and north of its 53-mile known length. The following points favor this supposition:

( ) South of the Sangre de Cristo Mountains area, in alinement with the Picuris—Pecos fault, Read and Andrews (1944) mapped a fault which cuts Mesozoic rocks and extends for about 20 miles south-southwest from the Cañoncito—Lamy area before it is covered by extensive Cenozoic deposits.

(2) In the northern part of the map area, as far as the northern boundary of the Picuris Range, the Picuris-Pecos fault has a north-south alinement. If projected northward, the trace of the fault would be alined with the east margin of the remarkably straight north-south lineation of the Rio Grande Valley between Taos and the Colorado line. The development of this segment of the Rio Grande depression in Cenozoic time may well have occurred along an ancient fault zone related to the Picuris—Pecos geofracture which is in alinement with it to the south. This hypothesis is supported by the supposition that this same alinement coincided with the eastern, faulted border of the Uncompahgre highland during Pennsylvanian time, as discussed under *Paleozoic rocks.*

The plane of the Picuris—Pecos fault apparently has remained essentially vertical in the map area throughout its geologic history. There is no evidence in the mapped area to suggest that it has ever been a thrust fault nor is there any observable field evidence to support the contention by Baltz and Read (1956, p. 50) that "the Picuris Range is primarily a massif of Precambrian [rocks] that has been thrust eastward across Paleozoic sediments in the vicinity of U.S. **Hill."**

JICARILLA FAULT

A major subsidiary fault, here called the Jicarilla, lies two to four miles east of and mainly parallel to the Picuris—Pecos fault in the central part of the map area. It appears to have originated during the Laramide orogeny. This fault separates the Precambrian quartzite upholding the Truchas Range from Pennsylvanian sedimentary rocks to the east. Its curving trace has been mapped for about 12 miles north-south along the east flank of the Truchas Range. The fault could not be mapped in areas of poorly exposed Pennsylvanian rocks both to the south, southwest of Pecos Baldy, and to the north, in the valley of Rio Santa Barbara. It may extend still farther north-northeastward and terminate in the north-south elongated anticlinal fold which exposes Precambrian rocks in the valley of Rio Pueblo, as discussed below.

The Jicarilla fault, where its nature can be detected, is a reverse fault with the fault plane dipping steeply to the west. An excellent exposure of the fault plane may be seen on a high, partly wooded ridge about one-half mile east of the west fork of the Rio Santa Barbara and two and one-half miles north of Jicarilla Peak. Here the fault plane dips westward 65 to 70 degrees beneath quartzite.

Near the Jicarilla fault, Pennsylvanian sedimentary rocks are turned up steeply *(see* Frontispiece). The beds are locally overturned, as at the exposure of the fault plane just described, or are folded, as at Jicarilla Peak (pl. 2C). The deformed Pennsylvanian rocks east of the fault revert to a nearly horizonal attitude within about one-quarter mile east of the fault *(see pl.* **12A).**

No accurate measurement is possible of the vertical displacement on the Jicarilla fault. At Jicarilla Peak and at Pecos Baldy, the middle part of the Pennsylvanian La Pasada Formation is in fault contact with the Precambrian Ortega quartzite. This would suggest a minimum throw of 300 to 500 feet, depending on the variable thickness of the Del Padre Sandstone in the area.

The Jicarilla fault is believed to represent a high-angle branch of the vertical Picuris—Pecos geofracture two to four miles to the -west. The location of the fault is related to the east-west-trending band of Precambrian Ortega quartzite. During Laramide movement, the west side was upthrown on both faults. The block of Precambrian quartzite acted as a rising bulwark crumpling adjacent, less resistant, Pennsylvanian rocks lying east of the Jicarilla fault.

PECOS VALLEY AREA

The southeast part of the map area, around the valley of the upper Pecos River and east of the Picuris—Pecos fault, is characterized primarily by a major south-plunging syncline and a similar eastward-adjacent anticline. These two broad folds with north-south-trending axes originated during Laramide deformation. The syncline, here named the Holy Ghost syncline, trends north-south with its axis less than one mile east of the Picuris—Pecos fault zone, which it parallels, and about two to three miles west of the Pecos River south of Cowles in the mapped area. It crosses near the head of Holy Ghost Canyon about four miles northwest of Tererro. This syncline can be traced northward for about ten miles from the south edge of the map and appears to have its northern terminus in the sharp synclinal structure immediately west of Pecos Baldy.

The anticline to the east, here named the Elk Mountain anticline, is sharply asymmetrical to slightly overturned eastward. It trends north-northeastward and its axis coincides for four miles north of the south edge of the map with the crest of the Elk Mountain (East) Divide. Beds in the west limb of this anticline dip gently westward, averaging five to ten degrees, and occupy most of the Pecos drainage area. A southward plunge of about two to three degrees for beds in this west limb can be noted at many exposures along the Pecos River valley. Bedding in much of the east limb of the Elk Mountain anticline is steeply inclined eastward to vertical to slightly overturned. In the map area, minor displacements occur locally along the overturned synclinal axial plane adjacent to the east. Most of the sedimentary strata occupying the east flank of the Elk Mountain anticline have been removed by erosion, exposing Precambrian rocks in the deep canyons and on most of the sharp east-west ridges separating Burro, Hollinger, and Beaver canyons.

Baltz and Bachman (1956, p. 107) mentioned the occurrence at the east foot of Elk Mountain, in the southeast corner of the map area, of "a major westward-dipping low-angle thrust fault." No such major fault was observed by the writer. A detailed study has not been made of the foothills area east and southeast of the map area by the writer.

Minor normal faults are common throughout the area of Pennsylvanian outcrop in both the southern and northern parts of the map area. These faults generally strike north-south, parallel to the major faults of the region, but poor exposures make lateral tracing of most of them impossible. One of the larger of these faults, with a throw of about 60 feet and here named the Cowles fault, is along the Pecos River valley at Cowles. The fault plane appears to be vertical and beds are downthrown to the west. This fault can be traced for about one and one-half miles and may be a primary factor in the north-south location of the Pecos River in the Cowles area. The fault may extend for several miles farther south along the Pecos Valley, but its trace is lost in the Precambrian rocks exposed in the bottom of the Pecos Canyon. Such faults are presumed to have developed during Laramide deformation.

RIO PUEBLO AREA

Considerable variation in structure occurs in the northeast part of the map area but very poor exposures make meaningful interpretations difficult or impossible.

An important structural feature in the Rio Pueblo canyon area is the symmetrical anticlinal fold with a north-south trending axis, which can be observed in cross-section along the canyon of the Rio Pueblo, one and one-half to three miles east of the village of Rio Pueblo. This fold, which apparently originated during Laramide deformation, has dips on its east and west flanks of from 20 to 40 degrees and exposes Precambrian quartzite in its core for a north-south distance of about four miles. The fold appears to lie at the northern terminus of the Jicarilla fault and north-south faulting is possible al0ng the anticline.

A poorly exposed, high-angle reverse fault which strikes north-south crosses the Rio Pueblo canyon about one and one-half miles west of Tres Ritos, near the entrance to the Tres Ritos ski area. The poorly exposed upper part of the Alamitos Formation on the upthrown west side is faulted against a higher part of this formation to the east. The throw on this fault is probably no greater than l00 to 300 feet. The poorly exposed beds west of the fault are folded and overturned near the fault plane. The limestone layers exposed z00 to 200 yards east of the fault on the north side of the valley are deformed by small-scale drag folds.

CONCLUSIONS

Two major conclusions can be drawn:

( ) The development of the major structural features in the map area related to Laramide deformation were controlled by structural features already present in the Precambrian basement rocks.

(2) During Laramide deformation, movement on the major faults had much larger vertical than horizontal components.

These conclusions support the regional observations made by Osterwald (1961, p. 219) in his review of regional tectonic problems in the Cordilleran foreland, which includes the southern Rocky Mountains area.

Cenozoic Deposits

by John P. Miller

INTRODUCTION

Rocks of Cenozoic age are confined entirely to the Rio Grande depression. Also widely distributed in the Rio Grande depression and extending into the foothills are unconsolidated fan gravels and alluvium of terraces adjacent to the streams. In the high mountains, the only Cenozoic deposits known are those attributable to the Pleistocene glacial and frost action, plus minor amounts of recent alluvium. In general structure of the Cenozoic rocks and unconsolidated deposits is quite simple. Large sedimentary volumes rather than tectonic complexity accounts for the distinctive features of the Cenozoic deposits.

For many years the Tertiary and Quaternary deposits of the Rio Grande depression were referred to as the "Santa Fe Formation," a name given by Hayden (1869), who considered the beds to be of lacustrine origin. Davis (1900) and Johnson (1903) recognized the fluviatile character of these deposits. Within the last two or three decades, usage of the term *Santa Fe Formation* has changed somewhat. In the area northwest of Albuquerque, Bryan and McCann (1938) divided the Santa Fe Formation into three units: the lower gray, middle red, and upper buff members. Subsequently, various local formation names have been applied to units considered equivalent to these members. The Abiquiu Formation (Smith, 1938) and Picuris Tuff (Cabot) are supposed equivalents of the lower member, and Puye Gravel (Smith) and Tuerto Gravel (Stearns, 1953) of the upper member. Baldwin (1956) proposed that the term *Santa Fe* be raised to group status and that the middle member in Bryan's terminology be called the *Tesuque. Formation.* He also proposed the name *Ancha Formation* for the upper member. Butler (1946) and Montg0mery (1953) described the Servilleta Formation as consisting of alluvial deposits and basalt flows unconformably overlying the Santa Fe Formation. Possibly the Servilleta Formation is equivalent to the Ancha Formation. If not equivalent, the Servilleta is younger than the Tesuque but older than the Ancha. The Servilleta is not described below under lithology but is treated as a separate unit of Quaternary age on the geologic map (pl.).

Correlations of the various proposed formations are not yet known, and as the present study d0es not provide a basis f0r definitely establishing such correlations, the designations used here are Picuris Tuff, Tesuque Formation of the Santa Fe Croup, Servilleta Formation, and Ancha Formation as the upper gravel unit of the Santa Fe Group (fig. 21).

LITHOLOGY

TERTIARY

Picuris Tuff

Cabot assigned the name Picuris Tuff to beds of tuff and conglomerate which occur in the Picuris re-entrant near Vadito. This unit reaches a maximum thickness of more than 1200 feet (Montgomery) and consists of water-laid tuff interbedded with thick, coarse conglomerates, clays, and thin basalt flows. The conglomerate near the base of the sequence was derived from Precambrian and Pennsylvanian rocks whereas the upper part includes pebbles and boulders of volcanic origin.

Small patches of similar tuff and conglomerate are exposed near the mountain front southward from Chimayo. Exposed thicknesses in this area do not exceed 200 to 300 feet. The name *Picuris* is used for these deposits, but there is no way to demonstrate their equivalence to the type Picuris. Baldwin proposed a new name, *Bishop's Lodge Member* of the Tesuque Formation, for similar deposits a short distance to the south.

The Picuris Tuff underlies the Santa Fe Formation and its exact age is unknown, although several writers (Montgomery; Baldwin) have indicated a Miocene age.

Tesuque Formation

The Tesuque Formation of the Santa Fe Group, as defined here, consists of poorly consolidated, water-laid silt, sand, and gravel, mostly tan in color (pl. 13A). Abrupt changes in texture, both vertically and horizontally, are the rule. Bedding is locally distinct, but few beds can be traced more than a mile or two. Some of the sandstone beds are fairly well sorted and locally cross-bedded. Their coherence is due to cementation by calcium carbonate. At most places, even in unconsolidated materials, the sediments are highly calcareous.

The Tesuque Formation was derived from Paleozoic and Precambrian rocks of the mountains. The presence of a considerable quantity of quartzite pebbles, for example near Tesuque, indicates drainage southward from Rio Santa Cruz or Rio de Truchas, which requires a radical difference from the present drainage pattern. Locally, especially in the Po-

FORMATION	LITHOLOGY AND THICKNESS
Alluvium	Sand and silt deposits of modern floodplains and postglacial streams; up to 100 feet thick.
Ancha and Servilleta formations	Ancha Formation is of sand and gravel of several different ages but distinguished from recent alluvium by position and consolidation; Servilleta Formation is of gravels and micaceous sand, in part covered by surface or near-surface basalt flows; 300 to 500 feet thick.
Tesuque Formation	Sand, silt, gravel, volcanic ash, clay, and intraformational breccia, mostly buff-colored and slightly consolidated; locally contains thin basalt flows; 500 to 3500(?) feet thick.
Picuris Tuff	Coarse basal conglomerate; brick-red, yellow, green, and white clay; volcanic breccia; water-laid volcanic tuff with interbedded coarse and fine gravels and thin basalt flows, compact marl beds and thin shales; 200 to 1200 feet thick.

Figure 21

TABLE OF CENOZOIC DEPOSITS

joaque area, white to gray tuff layers a few feet thick are interbedded with the alluvial deposits.

The total thickness of the Tesuque Formation cannot be estimated accurately from structural considerations. Denny suggested 3000 to 4000 feet maximum. Baldwin estimates that as much as 7000 feet may be possible but indicates that repetition by faulting may halve this amount. So far as is known, the deepest drill hole in the area (near Nambe) is about 500 feet deep and penetrates only the Santa Fe Formation.

The present study contributes no new information on the age of the Tesuque Formation. Essentially no fossils were found. Frick (1937), Simpson (1933), and others assign a vertebrate fauna found near Pojoaque and Espanola to a Miocene—Pliocene age.

QUATERNARY

Ancha Formation (Upper Member of Santa Fe Group)

Extensive remnants of a once-continuous sheet of unconsolidated gravel cover much of the area between the western part of the Sangre de Cristo range and the Rio Grande. Locally, these gravel deposits are more than 30o feet thick, and remnants of the original depositional surface now stand 100 to 300 feet above the present streams. Thicknesses of the gravels are greatest near the mountains, decreasing gradually westward. The sediments, which are crudely bedded and poorly sorted, range in size from silt to boulders, the latter made up mostly of quartzite, as much as four feet in diameter. Exceptionally good exposures occur at the village of Truchas (pl. 13B), at the south end of Santa Cruz Reservoir along the Santa Cruz Reservoir road, and at various other places. Gravels that make up the well-defined terraces along Rio Santa Barbara upstream from Penasco are also part of the same gravel sequence.

Cabot considered the extensive gravel deposits in this area to be of pediment origin. However, at most places they are much thicker than he supposed, and despite considerable dissection, there are still sufficient remnants to permit reconstruction of the original fan form. In all instances, the largest fans are located opposite the largest streams.

Age relations of the fan gravels are uncertain. They overlie the Tesuque Formation of presumed Miocene—Pliocene age. Thus far, no fossils have been found in the gravels. However, there are several lines of argument which lead to the conclusion that they are Pleistocene and at least partially related to glaciation.

At most places, the fan gravels consist of 75 to 85 percent of metamorphic rocks (mainly quartzite) derived from the uppermost headwater reaches of the streams. This is two to three times the amount of quartzite carried by modern streams (Miller), suggesting that the source of the gravel was concentrated in the highest part of the mountain range where glacial action would logically provide a process for gravel production. It is believed that glaciation and accompanying outwash from meltwater streams is the most logical way to account for this source of coarse fan gravels. There is another related kind of evidence that seems to support the contention that the fan gravels are Pleistocene in age and ultimately glacial in origin. The volumes of the fan gravels are several times the volumes of glacial debris found in the glaciated valleys themselves or in the form of outwash terraces downstream from the limit of glaciation. Glacial action in mountainous terrane usually produces debris in quantity and lack of such debris would be unexpected.

The fact that 100 to 300 feet of dissection has occurred since deposition of the fans indicates a considerable antiquity. The degree of weathering of the deposits reinforces this conclusion. In most exposures, oxidation of iron extends to a depth of ten or more feet, and many of the granite boulders are thoroughly rotten. Above the oxidized zone, there is a layer of caliche generally two to three feet thick and locally six or more feet in thickness. These two contrasting kinds of weathering apparently reflect the influence of a former, more humid climate, followed by aridity and caliche formation. At most places, the top of the caliche layer lies approximately two feet below the surface. It is not readily apparent whether caliche is forming under present climatic conditions.

Volcanic ash is interbedded with the fan gravels at a few localities. The best such exposure is a road cut one-quarter mile north of Truchas village, where approximately ten feet of bedded volcanic ash occurs near the top of the fan deposits. The only likely source for this ash is the Valle Grande caldera 3o miles due west. According to Swineford (1949), Valle Grande eruptions were the sole source of the Pearlette Ash (Kansan) which occurs in the Great Plains from South Dakota to Texas. It is likely that the ash layer in the fan gravels is the Pearlette; the possibilities of proving such a relation are remote indeed.

Glacial Deposits

More than 6o cirques are recognized in this part of the Sangre de Cristo range, and all lie at elevations between 10,70o and I1,700 feet. Well-defined moraines and masses of glacial till lacking morainal form occur in the upper parts of most valleys. However, morainal form is poorly preserved in most instances and, because nearly all the moraines are below timberline, detailed mapping is almost impossible.

Moraines in this portion of the Sangre de Cristo Mountains are not well enough exposed to establish a sequence that might be correlated with the glacial sequence of other areas. On the basis of good exposures in the upper part of Rio Nambe and fair exposures in a few other valleys, there appears to be evidence for not more than two substages of glaciation plus a protalus rampart composed of coarse blocks located well in front of the modern talus on the cliffs of the cirques. None of the moraines shows appreciable evidence of weathering. It seems probable that they are of Wisconsin age, but possibilities for a firm correlation do not exist.

Remnants of terraces, probably of outwash origin, were noted along most valleys where the timber cover is thin or absent. In the valley of Rio Santa Barbara, there is a fairly prominent terrace that stands 22 to 34 feet above the present stream, but it cannot be definitely associated with a particular moraine. Downstream from a gorge roughly a mile above the Santa Barbara campground, this terrace decreases in height by about ten feet. At several places in the same valley, there is another terrace 6o to 7o feet above the present stream. In the valley of Rio Nambe, where moraines are quite well developed, terraces are fragmentary or absent. However, such evidence as is available, when combined with the degree of weathering on moraines and the number of moraines themselves, indicates not more than two valid glacial substages.

Practically all areas above 10,000 feet have been greatly affected by frost action. The type of features and deposits present in a particular place are closely related to bedrock lithology, as well as elevation, topographic characteristics, and drainage conditions.

Frost action has had a vastly greater effect on sandstone than on other rocks present in this area. At most places near and above timberline, it is difficult to find a sandstone out crop in place. On steep slopes, such as those on the edges of valleys and around the margins of cirques, great blocks 3o to 5o feet in maximum diameter have been pried loose and have slipped downhill en masse. On more gentle slopes, sandstone outcrops are covered with coarse rubble, commonly five to ten feet in diameter, and locally several tens of feet in thickness. The effects of frost action granite and quartzite are considerably less than on sandstone.

many places, but especially at sandstone outcrops, enormous block fields are prominent features. They are sometimes almost continuous on the slopes, even, though the slopes are now covered by vegetation. They were especially well developed in the Rio Santa Barbara drainage (pl. 13D) where they meet the valley slopes and locally extend onto the floor of the valley.

Patterned ground of various kinds occurs on the flat divides, especially between the various forks of Rio Santa Barbara, and on the divide between Rio Valdez and Rio La Casa. Stone nets ranging in diameter from eight to 25 feet are exceedingly common.

There is no satisfactory way to estimate accurately the age of frost features in high mountain areas. It seems reasonable to suppose that duration and intensity of frost processes differ from place to place, and that the features are not all of the same age. The main block fields of this area occupy the walls of cirques and must, therefore, postdate the last glaciation. Also, in some valleys, block fields definitely overlie glacial deposits which can be traced to recognizable moraines. On the other hand, if the protalus ramparts are correctly correlated with the Little Ice Age (1600- 1800 A.D.), as several writers have suggested, then the block fields are clearly older than a century or two. However, age relations of patterned ground cannot be bracketed in this fashion. Patterned ground features occur on sites where conditions favoring frost action existed during various stages of the Pleistocene. Hence, their age relations may span this entire period of time. The southern part of the Sangre de Cristo Mountains at present has the highest incidence of freezing and thawing of any area in all of North America; thus, it may well be that frost processes are continuing to be reasonably active in this area, even at the present time.

Recent Alluvium

In the Rio Grande depression, west of the Sangre de Cristo range, most valleys show two well-developed alluvial terraces (Miller and Wendorf). Commonly, the higher of these two terraces occupies a belt several hundred yards wide on both sides of the stream channel. The lower terrace occupies a narrow strip adjacent to the channel. The alluvium underlying these terraces is dominantly silt and fine-grained sand, with the low terrace alluvium somewhat coarser than that of the high terrace. These recent alluvial deposits are restricted almost entirely to the Rio Grande depression and do not extend any appreciable distance into the mountains.

Radiocarbon and pottery dates of Tesuque Valley alluvium indicate that the alluvium of the high terrace was deposited approximately 2230 years ago and that deposition had ceased by 125o A.D. The low terrace is made up of deposits laid down since 125o A.D. and before 1880. Since 188o, erosion has been occurring in most valleys. The alluvial sequence of the Tesuque Valley is typical of a large area of north-central New Mexico. Furthermore, the chronology of alluvial events in this area is similar to the known chronology elsewhere in the Southwest (Miller and Wendorf).

STRUCTURE

Strata of the Santa Fe Formation are inclined westward toward the axis of the Rio Grande depression. Dips range up to 3o degrees near the mountains and decrease gradually westward to ten degrees or less.

Although the contact between the pre-Tertiary rocks and the Santa Fe Formation was previously supposed to be the result of normal faulting, this mapping suggests that it is more commonly an unconformity with local minor faulting. In general, the amount of displacement along the faults cannot be determined, but there is no reason in most instances for supposing it to be more than a few hundred feet, and probably it is less. The field relations suggest a major border fault between the pre-Tertiary and younger rocks, and this fault, if present, separates the Rio Grande depression from the western border of the Sangre de Cristo range. However, such a fault apparently predates the Santa Fe Formation, which in general appears to display the original attitude of deposition, except locally where it is displaced by minor faulting.

Locally, the Ancha gravels show dips of seven to eight degrees. Probably in most instances, this reflects the original dip of the depositional surface, but in- some instances there may be some slight additional inclination due to tectonic factors.

GEOMORPHOLOGY

PEDIMENTS

There is striking evidence for successive pedimentation of the Santa Fe Formation during late Pliocene and Pleistocene time. These features have been discussed by Cabot, who attributes them to erosion by streams from the mountains. The various pediment surfaces were formed during periods of stability of the Rio Grande, which is the master stream of the area.

Bryan (1938) summarized information on pediments at many localities in the Rio Grande drainage. For the area considered here, Cabot briefly described several sloping gravel-covered surfaces along the western mountain front and in the Rio Grande depression. He interpreted these features as remnants of once-extensive pediments graded to the Rio Grande. He believed that two pediments were represented. The higher was supposed to be cut on crystalline rocks near the base of the mountains (the two localities cited are near the town of Truchas and east of Santa Cruz Reservoir). Projection of this surface reaches the Rio Grande I 10o feet above the present stream. Black Mesa near Espanola and the mesa between Velarde and Dixon, both lava-capped, are considered to be remnants of this pediment. The lower surface, which is supposed to be extensive north of Rio Tesuque, projects 500 feet above the Rio Grande.

Recent publication of excellent topographic maps of the western slope of the Sangre de Cristo gives the authors an advantage which Cabot did not have, a point which should be considered in connection with subsequent remarks.

Cabot did not explain his reasons for calling the sloping gravel-covered surfaces remnants of pediments. For several reasons, we believe that these features are remnants of alluvial fans rather than pediments. In the first place, there are a few localities where a rock-cut surface can be seen. Second, the gravel layers commonly are more than 1 oo feet thick, which is much greater than the amount usually considered characteristic of a pediment. Third, the remnants of these surfaces are most extensive opposite mouths of large streams (Rio de Truchas, Rio Santa Barbara) where they show typical fan form.

The fan along Rio Santa Barbara in the Pefiasco—Rodarte—Llano area (pl. 3C) is composed of poorly sorted gravel and boulders (up to three feet in diameter) in a matrix of sand, having a total thickness of more than 200 feet. Evidently, the deposit was laid down in a previously formed wide valley cut in the Santa Fe Formation. At any rate, these deposits form a strikingly smooth terrace standing zoo feet above the present stream. Remnants of this surface are scarce in the bedrock valley, but they can be traced upstream where they merge with glacial deposits laid down during the earliest recorded phase of glaciation. Terraces are even more difficult to trace up the Truchas River, but it is believed that relations are similar to those in Rio Santa Barbara. The surface portions of the alluvial deposits at Truchas, along Rio Santa Barbara, near Santa Cruz Reservoir, and at various other places, are iron-stained to a depth of several feet, which is another reason for believing them to be of the same age.

Since deposition of the Pleistocene alluvial fans, there has been downcutting of 30o feet or more, the exact amount depending on stream size and the presence or absence of downstream control by resistant bedrock.

POST-LARAMIDE GEOLOGIC HISTORY

The geologic events of post-Laramide time can be divided into three episodes summarized as follows:

1. Widespread volcanic activity commenced in middle Tertiary time. Volcanic deposits of the Picuris Tuff, hundreds of feet thick, are found in extensive outcrops throughout the northeastern part of the Picuris Range (Montgomery). Deposits of this unit are also found in small, isolated outcrops along the western foothills of the Santa Fe Range, correlative with the Bishop's Lodge Member of the Tesuque Formation. Normal faulting took place during this long-continued vulcanism, as distinctive types of rocks are first observable in the Picuris Tuff in coarse boulder beds high above the basal gravel and volcanic deposits. The rocks of these distinctive clasts, such as the Precambrian Pilar Phyllite which is characteristic of outcrops in the Picuris Range, were not exposed to erosion during the early stages of this middle Tertiary vulcanism; thus they must have been uplifted and eroded later.

2. The Rio Grande depression was developed in Miocene time (Kelley, 1956) as a result of normal faulting along the west margin of the Sangre de Cristo Mountains. The mountains were uplifted along such bounding faults with no appreciable folding. Concomitant erosion resulted in the deposition of the thick Tesuque Formation to the west in the Rio Grande depression. Renewed movement may have occurred at this time along the Picuris—Pecos fault and Jicarilla fault, with uplift on the west side, and followed the trends of faulting which had originated earlier during the Laramide orogeny. Late in Tertiary time vulcanism largely ceased. Long-contiued erosion of the mountains ensued, leading to the deposition during Miocene and Pliocene times of the thousands of feet of alluvial beds in the Tesuque Formation. These strata piled up in the down-faulted areas of the Rio Grande depression along the western base of the Sangre de Cristo Mountains.

3. Further periods of faulting and epeirogenic movements followed the deposition of the Tesuque Formation and probably are continuing to the present day. These major vertical movements were responsible for the main features of the present-day topography of the southernmost Sangre de Cristo Mountains in New Mexico. They also caused the steep tilting of the Santa Fe beds around the northwest border of the Picuris Range (Montgomery) and lesser tilting on the west slope of the Santa Fe Range. Extensive erosion subsequently planed off these tilted beds to create the widespread, flat-lying surfaces upon which the gravels, sands, and basalt flows of the Servilleta and Ancha formations were deposited in Pleistocene time. Intensive mountain glaciation occurred during this period, shaping the rugged crests of the highest mountains and intensifying the effects of erosive forces. Thus considerable thicknesses of gravel and very large boulders were deposited in the beds of the Ancha Formation that cover the lower slopes of the foothills west and north of the Santa Fe and Truchas ranges.

Economic Geology

by Arthur Montgomery

MINERAL DEPOSITS OF PRECAMBRIAN AGE

INTRODUCTION

In the Picuris Range, the economic minerals of Precambrian age are chiefly white beryl, muscovite, minerals of tantalum and lithium in pegmatites, and minerals of copper, gold, lead-silver, and bismuth in quartz veins (Montgomery). The ore-bearing quartz veins, as well as the pegmatites, are related genetically to the Embudo Granite. Tourmaline is common to nearly all these occurrences. Metallic minerals of copper and bismuth are found in some pegmatites, as in the Harding pegmatite, and such minerals also typify many ore-bearing quartz veins. Tourmaline, characteristic of ore-bearing quartz veins and pegmatites, is always present in Precambrian rocks near intrusive Embudo Granite.

Mineral deposits of possible economic value in the Precambrian rocks of the quadrangle are similar in mineralogy to all those mentioned above, except that bismuth minerals have not been observed. The ore deposits of the Pecos Mine are unique in this area for their immense concentrations of zinc, lead, copper, silver, and gold.

ORE DEPOSITS IN PEGMATITES

South of the Picuris Range, some of the larger pegmatites contain abundant muscovite mica and small quantities of white beryl and columbite-tantalite. Only one pegmatite is believed to be of possible economic importance, that of the mica mine in the Kept Man group of claims two miles northeast of Elk Mountain. Mica was produced from this pegmatite during World War II and some coarsely platy muscovite remains. This deposit has been mapped and described by Jahns, who also discussed several other mica-bearing pegmatites near and west of Elk Mountain.

Muscovite-rich pegmatites are common south and east of Cordova, where patches of muscovite schists and amphibolites are surrounded by Embudo Granite. During recent years, there has been considerable mining in this area and even some small-scale milling. Very little mica, scrap or otherwise, appears to have been produced and marketed; much of the activity has been of an uneconomic and promotional nature.

ORE DEPOSITS IN QUARTZ VEINS AND RELATED OCCURRENCES

Pale-greenish stains of secondary copper minerals in translucent, snow-white, hydrothermally metamorphosed quartzite of the lower quartzite member of the Ortega Formation are present in the northern Picuris Range and in the easterly Truchas area. Some quartz veins in rocks of the Vadito Formation farther south in the Truchas area show traces of mineralization, usually observed as coatings of green and blue copper carbonates on fracture surfaces. Rarely, these coatings are found on fracture surfaces of brecciated and silicified amphibolites and of other rocks of the Vadito Formation. Black tourmaline is typically associated with these occurrences. A number of such occurrences of slight copper mineralization were observed in amphibolites and felsites near and north of Doctor Creek three miles west of the Pecos Mine. Copper minerals and zinc and lead sulfides in highly brecciated Precambrian rocks have been mined on a small scale at the Johnny Jones Mine, five miles southwest of the Pecos Mine and two miles south of the south border of the quadrangle. The mineralogy of this deposit is similar to that of the Pecos Mine.

ORE DEPOSITS OF THE PECOS MINE

The dumps of the abandoned Pecos Mine are near the mouth of Willow Creek two miles north of Tererro. This mine, one of the large deposits of the Southwest, was worked extensively by the American Metal Company (now American Metal Climax, Inc.) from about 1927 to 1939 for zinc, lead, and copper sulfides. Appreciable amounts of gold and silver were also recovered. A million and a half tons of ore running up to 16 percent zinc, four percent lead, one percent copper, three ounces of silver to the ton, and 0.1 ounce of gold to the ton were mined, then milled near the town of Pecos. Much ore, but of lower grade, was said to be still left in the deposit when the operation terminated.

The geology of the ore deposits has been discussed by Krieger and earlier by Stott (1931). Chief ore minerals were sphalerite (mostly black and iron-rich), galena, and chalcopyrite. The mineralization is pre-Mississippian. This conclusion is based on the fact that oxidized ore underlies unmineralized beds of Mississippian limestone. Two extensive, flattened-lenticular, pancake-shaped ore bodies were discovered, tilted up almost vertically and trending N. 45° E. along a great shear zone in the brecciated Precambrian rocks. The country rock is chiefly amphibolite. Most of the ore minerals appear to have replaced finely micaceous, chlorite-rich rocks which Krieger believed to be hybrid rocks formed by the partial assimilation and replacement of amphibolite (called diabase by Krieger and others) by intrusive granite.

The cause of the shearing and the location of the great breccia zone (said to be up to 500 feet wide), along which the ore deposits were formed, are most difficult problems to solve. The trend of this breccia zone, N. 45° E., is not parallel to the strike of regional foliation in this area, which runs about N. 0° E. It is parallel, however, to a principal steeply-dipping joint direction very prominent in the Precambrian rocks of this area, including the dike-like body of pink granite crossing Willow Creek two miles east of the mine.

The mineralogy of the ores of the Pecos Mine is similar to that of the many uneconomic deposits found in the mapped region. Copper minerals, traces of gold and silver, and abundant tourmaline are characteristic of many of these deposits which are presumably related genetically to late-stage differentiation of Precambrian granitic magma. The mineralogy of all these occurrences is typical of high-temperature ore mineralization related to granite. The high concentration of zinc and lead sulfides found at the Pecos Mine is unique for this general area, but small amounts of these minerals do occur in other places, such as near the head of Hondo Canyon in the northern Picuris Range (Montgomery).

MINERAL DEPOSITS OF POST-PRECAMBRIAN AGE

Economic mineral deposits of post-Precambrian age were not observed in the Picuris Range. In the Truchas area, small, scattered deposits of metallic sulfides, chiefly pyrite, have been noted in rocks of Pennsylvanian or Mississippian age. Such deposits commonly are adjacent to faults separating Precambrian and Paleozoic rocks. Just north of Jicarilla Peak and near the head of the west fork of Rio Santa Barbara, Pennsylvanian beds are turned up steeply against the fault here separating Precambrian quartzite from Paleozoic sediments. Traces of galena and copper carbonates, as well as considerable pyrite, were noted at several localities here, chiefly in shaly and limy Pennsylvanian beds.

Stories of important gold strikes made in the general area of the Truchas Peaks are still current. Rich gold discoveries have been reported near the northeast base of Pecos Baldy, along the canyons of Rito Chimayosos and Rito del Padre, and near the head of the west fork of the Rio Santa Barbara. In the latter area, signs of an ancient timbered shaft, caved in completely, are observable close to the creek and not far from ruins of an old cabin. Many persons over the years have sought in vain to rediscover the sites of these and other reported gold strikes of the region. It is possible that all the stories are legends without foundation in fact; but if any such deposits do exist, it is likely that they will be found in close proximity to major faults separating Precambrian and Paleozoic rocks.

The mineral deposits in Paleozoic rocks and associated with faults, presumed related to Laramide orogeny, undoubtedly are of early Tertiary age.

Description of Selected Pennsylvanian Measured Sections

by Patrick K. *Sutherland*

Descriptions of the four Pennsylvanian stratigraphic sections designated as type localities of new formations are presented below. Section 36 is designated as the type section for the La Pasada Formation and it is presented in graphic form as Figure **12.** Sections 96 and 97 are designated as typical sections for the Alamitos Formation and are presented in graphic form as Figure 14. The lower part of section 60 is designated the type section for the Flechado Formation and it is presented in graphic form as Figure 13.

All sections were measured and are numbered upward in sequence. All notes concerning lateral shifts in section measurement are in accordance with this procedure.

The primary part of each rock unit description is made up of the field classification. It includes the following characteristics, where pertinent: (1) rock name; **(2)** color on fresh fracture followed by weathered color (using the rock-color chart prepared by the National Research Council); (3) grain size or crystallinity; (4) sorting and roundness; (5) compositional adjective; that is, cements and detrital minerals such as calcareous, siliceous, arkosic; (6) bedding, special characteristics, and topographic expression. The description of bedding follows that proposed by Ingram (1954), which is here adopted as follows:

Very thick-bedded .... over three feet
Thick-bedded .... from one to three feet
Medium-bedded ....from four to twelve inches
Thin-bedded ....from one to four inches
Very thin-bedded .... from one-third inch to one inch
Laminated ....less than one-third inch

The field description is followed in some instances by a thinsection description given in parentheses and italicized. The classifications proposed by Folk for the description of terrigenous sedimentary rocks (1954) and for carbonate rocks (1959) have been used. The thinsection description is preceded by the location within the unit from whence the hand-specimen was collected, indicated by the number of feet above the base of the unit. The twofold petrographic description for terrigenous rocks includes grain size and mineral composition, and it is followed by an estimate of the feldspar percentage.

The most important fossil genera and species are listed at the end of the units where they occur.

SECTION 36. DALTON BLUFF, TYPE SECTION FOR THE LA PASADA FORMATION

Bluff on west side of the Pecos River, 6.6 miles by road north of the junction of State Highway 63 and Alternate U.S. Highway 84-85 at town of Pecos. This is one of the most important Paleozoic exposures in the southern Sangre de Cristo Mountains. The lowest part of the La Pasada Formation (units 25 to 35) was measured in a small draw beginning at the top of the cliff formed by the Mississippian Tererro Formation, due west of a point on the road 0.5 mile south of the bridge over the Pecos River at the Dalton Campground and 0.1 mile south of a small cluster of houses which make up the village of Upper La Pasada. Units 36 to 63 were measured in a draw west of point on the road 0.4 mile south of the bridge. The remainder of the section, from unit 64 upward, was measured in the largest draw on the cliff face, located west of a point on the road 0.15 mile south of the bridge. The cliff at the top of the La Pasada Formation, formed by the cherts and limestones of units 174 to 178, was traced southward along the west side of the Pecos Valley for **21/2** miles, and the same interval forms the basal part of section 97. (Section described by Patrick K. Sutherland and Dean Gerber, August 1957.)

The Dalton Bluff section also has been described by Brill (1952, p. 849) and by Sidwell and Warn (1953, p. 1005). Brill indicated which units in his measured section form prominent cliffs. In the section here described, the cliffs indicated by Brill, beginning at the bottom of the bluff, are as follows: cliff 1, Mississippian limestone; cliff **2,** units 89-92; cliff 3, unit 105; cliff 4, units 133-135; cliff 5, unit 150; cliff 6, unit **159;** cliff 7, units **173-178;** and cliff 8, units 187-190.

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	Top of section is highest exposure at crest of Dalton Bluff, west of a point on the road 0.2 mile south of the bridge at Dalton Campground	
	Alamitos Formation	
191	Conglomerate and sandstone: conglomerate, grayish orange, weathers light yellowish gray; granular to pebbly; quartz, feldspar, and minor amphibolite fragments; poorly sorted; angular to subrounded, scattered pebbles to 50 mm, arkosic; interbedded irregularly with sandstone, coarse-grained, conglomeratic, poorly sorted (3 feet above base: *sandy granule conglomerate; silica-cemented, submature arkose;* feldspar 30%)	9
190	Siltstone, light olive-gray, sandy, calcareous; interbedded with sandstone, fine-grained, thin-bedded (10 feet above base: *clayey siltstone;* calcareous cement)	20
189	Conglomerate, medium gray, weathers light yellowish gray, coarse-grained to granular, arkosic; scattered quartz pebbles to 30 mm; calcareous (*sandy, granule conglomerate; calcite-cemented, submature, glauconite-bearing arkose;* feldspar 40%)	2
188	Shale and siltstone: shale, medium light gray, weathers light gray, silty, calcareous, platy; interbedded in upper part with siltstone, thin-bedded, sandy, calcareous	11½
187	Siltstone and sandstone: siltstone, medium gray, weathers medium dark gray, sandy, platy; interbedded in upper part with sandstone, silty, calcareous, thin-bedded (3 feet above base: *clayey siltstone;* calcareous cement)	15

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
186	Covered; talus of siltstone and shale, weathers light yellowish gray	41
185	Limestone, medium light gray, weathers light yellowish gray; thin, nodular bedding *(algal biosparudite); Fusulina* sp.	3
184	Sandstone, dusky yellow-green, weathers same, fine-grained, arkosic, well-sorted, locally conglomeratic *(granular sandstone; clay-bonded arkose;* feldspar 30%)	2
183	Covered	7
182	Sandstone, greenish gray, weathers light gray; very fine-grained *(very fine-grained sandstone; clay-bonded, immature, feldspathic graywacke)*	2
181	Covered	11
180	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted; quartz and feldspar pebbles to 5 mm *(coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 30%)	2
	Partial thickness of Alamitos Formation	125½
	La Pasada Formation	
179	Siltstone and limestone: siltstone, weathers light yellowish gray, micaceous, very calcareous	1
178	Limestone, medium light gray, weathers light gray, medium-grained, thick-bedded (base: *slightly sandy biosparudite); Fusulina* sp.	3
177	Sandstone and limestone: sandstone, light gray, weathers same, fine-grained, calcareous, slightly micaceous; scattered nodules of sandy limestone (8 feet above base: *fine-grained sandstone; calcite-cemented, immature calclithite-bearing subarkose)*	19
176	Sandstone, light gray, weathers same, medium- to coarse-grained, poorly sorted, partly conglomeratic *(coarse sandstone; calcite-cemented, submature subarkose;* feldspar 15%)	2
175	Limestone, light gray, weathers same, very silty, partly silicified (3 feet above base: *silty, partly silicified intrasparite)*	6
174	Chert, limestone, and siltstone: chert, very light gray, weathers same, calcareous, partly silty; nodular layers up to 1 foot thick; interbedded with limestone, light gray, finely crystalline, partly silty, partly silicified; and siltstone, light gray, calcareous, partly silicified (2 feet above base: *slightly silty biomicrosparudite;* 9 feet above base: *intrasparite,* with small, brownish spicules; 17 feet above base: rock totally replaced by microcrystalline silica, with common spicules; 28 feet above base: *silty, partly silicified intrasparite)*	30½
173	Limestone, medium light gray, weathers light gray, crinoidal, sandy, thick-bedded *(slightly sandy, fusulinid-bearing biomicrosparudite); Fusulina* n.sp. B, *Wedekindellina* sp.	3
172	Covered	16½
171	Sandstone, greenish gray, weathers same, coarse-grained, poorly sorted, partly conglomeratic *(very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature subarkose;* feldspar 12%)	1½
170	Covered	7
169	Limestone and shale: limestone, medium gray, finely crystalline, silty; nodular layers up to 1 foot thick; interbedded with shale, silty, calcareous; layers up to 5 inches thick (2 feet above base: *silty biosparite)*	4½
168	Shale, black, weathers dark yellowish gray, calcareous, platy	1½
167	Limestone and shale: limestone, medium dark gray, weathers dark yellowish gray; even-bedded layers up to 8 inches thick; interbedded with shale, black, calcareous, platy; layers up to 6 inches thick	6½
166	Covered	5
165	Limestone, medium gray, weathers light gray, sandy, fragmental (6 feet above base: *slightly sandy biosparudite);* 6 feet above base: *Fusulina,* n.sp. B, *Wedekindellina* sp.	10½
164	Covered	32
163	Limestone and siltstone: limestone, light bluish gray, weathers medium gray; nodular layers up to 4 inches thick; interbedded with siltstone, calcareous, thin-bedded (2 feet above base: *biomicrudite)*	4
162	Covered	4
161	Limestone, light gray, weathers same, sandy, fragmental, thick-bedded (3 feet above base: *very sandy biosparudite)*	4½
160	Covered	5
159	Limestone and shale: limestone, medium dark gray, weathers dark yellowish gray; thin, nodular layers at base grading upward into thick-bedded layers at top; interbedded with shale, calcareous, platy, partly silty; containing cannonball limestone concretions up to 6 inches in diameter in lower part (10 feet above base: *algal biosparudite);* 21 feet above base: *Fusulina* n.sp. B	25
158	Shale, dark gray, weathers light gray, very calcareous, friable	6
157	Covered, probably shale	3
156	Sandstone, greenish gray, coarse-grained to granular; subrounded, poorly sorted, quartz pebbles to 30 mm *(conglomeratic, coarse sandstone; poikilitic-calcite-cemented, submature subarkose;* feldspar 20%)	2
155	Covered	3
154	Limestone and siltstone: limestone, light gray, weathers light yellowish brown, silty, thin-bedded; interbedded with siltstone, weathers light yellowish brown, calcareous, platy	5½
153	Sandstone, weathers olive-brown, coarse-grained, moderately well-sorted	2
152	Covered	3
151	Sandstone, dusky yellow, weathers olive-brown, very coarse-grained; angular quartz and feldspar fragments, scattered pebbles up to 10 mm; scattered wood fragments (3 feet above base: *conglomeratic, coarse sandstone; poikilitic-calcite-cemented, submature subarkose;* feldspar 20%)	8
150	Limestone and siltstone: limestone, medium dark gray, weathers medium gray, fragmental, partly oolitic; nodular layers 3 inches to 1 foot thick; interbedded with thinner layers of siltstone, medium gray, calcareous; unit forms cliff (10 feet above base: *algal biosparudite);* lower 12 feet: *Antiquatonia hermosanus, Echinoconchus* aff. *knighti, Buxtonia* n.sp. B, *Calliprotonia* sp.	31
149	Limestone and shale: limestone, medium dark gray, weathers light yellowish gray; nodular layers 2 inches to 2 feet thick; interbedded with shale, calcareous, platy; layers 2 to 8 inches thick (8 feet above base: *slightly sandy, partly recrystallized biosparite);* 6 feet and 23 feet above base: *Fusulina* n.sp. A	35
148	Limestone, dark gray, weathers light gray, sandy, poorly sorted; common *Fusulina* n.sp. A	2
147	Covered	2
146	Sandstone, light yellowish brown, weathers same, coarse-grained, poorly sorted, partly conglomeratic	1½
145	Covered	1½
144	Sandstone, dark greenish gray, weathers same, fine-grained, poorly sorted, partly conglomeratic (2 feet above base: *fine sandstone; silica-cemented, immature, feldspathic subgraywacke;* feldspar 10%)	7½
143	Shale, olive-brown, micaceous, poorly exposed	3
142	Limestone, light gray, weathers light yellowish gray, coarsely fragmental	1
141	Shale, mostly covered	2
140	Sandstone, weathers light yellowish gray, coarse-grained, conglomeratic, poorly sorted	4

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
139	Limestone, weathers moderate reddish brown, silty, thin nodular bedding; at top: *Wedekindellina* sp.	2½
	Section shifted on unit 139 about 100 yards south to second largest gully	
138	Conglomerate and sandstone: pale olive, weathers light yellowish brown; conglomerate, very coarse-grained to granular, poorly sorted; scattered pebbles to 30 mm, feldspathic; irregularly bedded with sandstone, coarse-grained, poorly sorted, conglomeratic	6½
137	Limestone and shale: limestone, medium dark gray, weathers light yellowish gray, silty, crinoidal; nodular layers 2 inches to 1 foot thick; interbedded with shale, calcareous, platy; layers 1 to 2 inches thick; 20 feet above base: *Fusulina* n.sp A, *Wedekindellina excentricus*	23
136	Conglomerate, yellowish gray, weathers light yellowish gray, coarse-grained to granular; poorly sorted, pebbles to 10 mm, feldspathic (3 feet above base: *granular, very coarse sandstone; poikilitic-calcite-cemented, submature subarkose;* feldspar 20%)	5
135	Limestone and shale: limestone, medium light gray, weathers light gray; nodular layers 3 inches to 1 foot; interbedded primarily in lower part with shale in thin layers (6 feet above base: *algal biomicrudite)*	10
134	Limestone, light olive gray, weathers light gray; layers 1 to 4 feet thick (4 feet above base: *algal biomicrudite)*	13
133	Limestone and shale: limestone, light olive gray; nodular layers 2 to 4 inches thick in lower part grading upward into layers up to 1 foot thick at top; interbedded with thin layers of shale, gray, calcareous (6 feet above base: *slightly silty, partly recrystallized biosparite;* 35 feet above base: *silty biosparudite); Antiquatonia hermosanus, Echinoconchus* aff. *knighti, Desmoinesia nanus?, Buxtonia* n.sp. B, *Spirifer* n.sp. A, *Spirifer* n.sp. B, *Neospirifer cameratus, Mesolobus* cf. *striatus, Derbyia* n.sp. A, *Hustedia mormoni, Phricodothyris perplexa, Beecheria millepunctata, Chonetinella* cf. *crassiradiata, Cleiothyridina pecosi*	37½
132	Covered	7
131	Sandstone, light greenish gray, weathers light gray, very coarse-grained; subrounded, poorly sorted; scattered pebbles to 5 mm *(coarse sandstone; carbonate-cemented, submature, calclithite-bearing orthoquartzite;* feldspar less than 1%)	2
130	Siltstone, yellowish gray, weathers light yellowish gray, calcareous, thin-bedded; containing scattered, small limestone nodules	5½
129	Limestone and shale: limestone, dark greenish gray, weathers medium gray; thin nodular layers up to 4 inches thick; interbedded in upper half with thin layers of shale, gray, calcareous *(gastropod biosparudite)*	7
128	Shale and limestone: shale, weathers light olive-gray, calcareous; nodular limestone layers in lower part; highly fossiliferous: *Desmoninesia nanus?, "Spirifer"* n.sp. A, *Mesolobus* cf. *striatus, Cleiothyridina pecosi*	2
	Section shifted southward 25 yards to next gulley	
127	Limestone and siltstone: limestone, light olive-gray, weathers light gray; thin nodular layers; alternating with siltstone, light gray, weathers same, nodular, thin layers; thick-bedded in top two feet (8 feet above base: *biosparudite);* 8 feet above base *Fusulina* cf. *novemexicana, Wedekindellina* sp.	10
126	Limestone and shale: limestone, medium dark gray, weathers same; thin nodular layers up to 4 inches thick; interbedded primarily in lower part with dark gray shale layers of similar thickness	7
125	Limestone, medium dark gray, weathers same; nodular bedding; scattered platy algae *(algal biosparudite)*	1½
124	Limestone and shale: limestone, medium dark gray, weathers same; thin nodular layers up to 4 inches thick; interbedded with dark gray shale layers of similar thickness (2 feet above base: *algal biosparite)*	4½
123	Limestone, medium gray, weathers light yellowish gray, silty, thick-bedded	2½
122	Limestone and shale: limestone, dark gray, weathers medium gray; irregular, thin nodular layers; alternating with thin layers of shale, dark gray, calcareous, platy; *Kozlowskia* cf. n.sp. A, *Spirifer* cf. n.sp. A, *Neospirifer* cf. *cameratus, Mesolobus* cf. *striatus*	7
121	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic	3
120	Shale, weathers olive-brown, micaceous, platy	1
119	Covered, probably shale	1
118	Limestone, dark gray, weathers medium gray, medium-bedded	1
117	Covered	2
116	Siltstone, weathers moderate red-brown, partly sandy, thin-bedded	1
115	Siltstone and limestone: siltstone, yellowish gray, calcareous, partly cherty; conchoidal fracture; contains scattered, small limestone nodules, dark gray, interbedded with uncommon thin silty chert layers (3 feet above base: *fine sandstone; calcite-cemented, mature, spicular orthoquartzite)*	13½
114	Siltstone and limestone: siltstone, dark gray, weathers same, very calcareous; thin nodular layers, banded; interbedded with limestone, silty; thin nodular layers	5
113	Limestone, light gray, weathers same; very sandy, becoming conglomeratic in upper 6 inches with scattered chert pebbles up to 20 mm (base: *sandy biosparite)*	3
112	Siltstone, light olive-gray, weathers same, slightly calcareous, micaceous	2
111	Limestone and shale: limestone, weathers light yellowish gray; nodular layers up to 4 inches thick interbedded with thin layers of shale, gray, calcareous	1½
110	Limestone, light olive-gray, weathers light gray, algal, thick-bedded (2 feet above base: *recrystallized intraclast-bearing algal biosparudite)*	3
109	Shale and limestone: shale, dark gray; interbedded with thin nodular layers of limestone, dark gray, fossiliferous; *Kozlowskia* n.sp. A, *Cleiothyridina pecosi, Neospirifer cameratus*	8½
108	Limestone, medium dark gray, weathers medium gray, fragmental, thick-bedded (2 feet above base: *biosparudite)*	4
107	Covered	2
106	Limestone, medium light gray, weathers light yellowish gray; occurring in layers up to 1 foot thick alternating with thin layers (3 feet above base: *biosparite;* 7 feet above base: *biomicrite)*	8
105	Limestone, light gray, weathers light yellowish gray, unbedded, massive; weathers with a distinctive pitted surface (5 feet above base: *intrasparudite);* at top: *Fusulina* cf. *taosensis;* lower 5 feet: *Hystriculina* cf. *wabashensis*	18
104	Covered, probably shale	5
103	Limestone and shale: limestone, light olive-gray, weathers light yellowish gray, partly algal; occurring in nodular layers 1 inch to 1 foot thick; interbedded with thin layers of shale, calcareous; highly fossiliferous (9 feet above base: *recrystallized, intraclast-*	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	bearing algal biosparudite); 5 feet above base: *Fusulina* cf. *taosensis;* lower 7 feet: *Hystriculina* cf. *wabashensis, Antiquatonia hermosanus, Kozlowskia* n.sp. A, *Desmoinesia nanus, Cleiothyridina pecosi, Chonetinella* cf. *crassiradiata*	14
102	Shale, weathers light yellowish gray, micaceous	4/10
101	Coal	3/10
100	Clay, black	1/10
99	Siltstone, dark gray, hard	2/10
98	Covered	4
97	Limestone and shale: limestone, medium gray, weathers medium light gray; slightly to highly silty; occurring in thick-bedded layers 1 to 2 feet thick; interbedded with shale, gray to black, calcareous; sparsely fossiliferous (5 feet above base: *silty biosparudite);* upper 6 feet: *Antiquatonia hermosanus*	13
96	Conglomerate and sandstone: conglomerate, weathers yellowish gray; poorly sorted, subrounded granules; basal two feet sandstone, fine-grained, becoming coarse-grained and conglomeratic upward (1 foot above base: *bimodal, coarse and very fine sandstone; calcite- and silica-cemented, biotite-bearing subarkose;* feldspar 10%)	5
95	Siltstone and shale: siltstone, weathers light yellowish gray, occurring in platy and nodular beds; interbedded with shale, silty, micaceous	13
94	Limestone, medium light gray, weathers light gray, crinoidal, platy to thick-bedded (6 feet above base: *crinoidal biosparudite);* at top: *Fusulinella* cf. *famula;* lower 5 feet: *"Protoniella"* cf. *welleri*	9
93	Shale and limestone: mostly covered talus of dark gray shale and thin-bedded, nodular limestone	3
92	Limestone, medium dark gray, weathers light gray; nodular layers, algal *(recrystallized intraclast-bearing algal biosparudite)*	2
91	Limestone and shale: limestone, dark gray, weathers light yellowish gray; thin nodular layers; interbedded with shale, calcareous	3½
90	Limestone and shale: medium gray, weathers dark yellowish gray; thick-bedded layers in upper half of unit which are gradational with thin nodular layers in lower half which are interbedded with thin irregular layers of shale, dark gray, calcareous (15 feet above base: *biomicrudite)*	23
89	Limestone, light to medium gray, weathers same, partly silty, fragmental (3 feet above base: *biosparite);* at top: *Fusulinella* cf. *devexa*	4
88	Siltstone and shale: siltstone, greenish gray, weathers same, micaceous; platy layers up to 6 inches thick; interbedded with shale, silty, micaceous	10½
87	Sandstone, light brownish gray, weathers same, fine-grained, calcareous, well-sorted, cross-bedded (3 feet above base: *fine sandstone; calcite-cemented, mature orthoquartzite;* rare trace feldspar)	3
86	Shale, weathers brownish gray, very calcareous; interbedded in upper 3 feet with thin layers of siltstone	12
85	Limestone, medium gray, weathers medium light gray, thick-bedded, hard	3
84	Shale, black, weathers same, slightly calcareous	3½
83	Limestone and shale: limestone, dark gray, weathers light gray; silty, nodular layers; interbedded in lower half with thin layers of silty shale	5
82	Covered	11
81	Shale, dark gray, friable	2
80	Limestone, brownish gray, weathers same, silty, thick-bedded, banded; interbedded in middle part with thin shale layers	3
79	Limestone and shale: limestone, medium dark gray, weathers same; nodular layers 1 to 6 inches thick; interbedded with shale, dark gray to black, calcareous; in layers up to 6 inches (3 feet above base: *biosparudite);* lower two feet: *"Protoniella"* n.sp. A, *Kozlowskia* n.sp. A	7½
78	Sandstone, pale yellowish brown, weathers same, medium-grained, moderately sorted; scattered granules, calcareous (at top: *medium sandstone; calcite-cemented, mature, orthoquartzite;* rare trace feldspar)	2
77	Shale, weathers medium gray; some layers nodular and silty	10
76	Sandstone, dark yellowish brown, weathers light yellowish brown, fine-grained, subrounded, well-sorted, micaceous; wood fragments	7
75	Sandstone, olive-gray, weathers same, medium-grained, subrounded, well-sorted, highly calcareous	1
74	Sandstone, dusky yellow-gray, weathers same, silty, highly micaceous, poorly sorted, partly granular	4
73	Covered	12
72	Sandstone, dark greenish gray, weathers same, fine-grained with scattered granules, calcareous	2
71	Limestone and shale: limestone, light olive, weathers dark olive-gray; occurring in hard nodular layers 6 inches to 2 feet thick; interbedded irregularly with shale, calcareous; in layers up to 6 inches thick; lower half: *"Protoniella"* cf. *gallatinensis, "Spirifer"* n.sp. C	6
70	Covered	20
69	Limestone and shale: limestone, dark gray, weathers dark yellowish gray, silty; nodular layers up to 8 inches thick; interbedded with thin layers of silty shale	6
68	Limestone, olive-gray, weathers light gray, thick-bedded, fossiliferous (4 feet above base: *biosparudite); "Protoniella"* cf. *welleri, Neospirifer* sp.	5½
67	Shale, weathers light gray, calcareous, friable; thickness irregular; strike N. 55° W., dip 5° SW	1
66	Limestone and shale: limestone, medium dark gray, weathers same; hard nodular layers 2 to 8 inches; interbedded with shale, thin-bedded, platy, very calcareous; upper surface undulating (14 feet above base: *slightly silty biosparudite)*	19½
65	Sandstone, weathers light yellowish gray, medium-grained; becomes calcareous and conglomeratic in upper 4 feet with scattered pebbles up to 8 mm	19
64	Covered	13
	Units 36 to 63 were measured in the draw west of a point on the road 0.4 mile south of the bridge over the Pecos River. The section was shifted from that draw northward on top of the Mississippian limestone bluff to the large draw opposite a point on the road 0.15 mile south of the bridge. In this draw, the section is mostly covered from the top of the Mississippian limestone to the base of unit 65. The difference in the thickness of this covered interval and that of the interval from units 25 to 63, measured farther south, provides the thickness of unit 64	
63	Limestone and shale: limestone, medium gray, weathers light yellowish gray, coarse-grained, partly crinoidal; irregular hard beds up to one and one-half feet thick; interbedded with shale, weathers light yellowish gray, friable, calcareous; *"Sinuatella"* n.sp. A, *"Spirifer"* n.sp. C	5½
62	Covered	2
61	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted *(granular, very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature orthoquartzite;* no feldspar)	2
60	Covered	4
59	Limestone, light brownish gray, weathers same, highly crinoidal *(very slightly sandy, crinoidal biosparudite)*	1
58	Sandstone, dark green, weathers light yellowish	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	green, fine- to medium-grained, poorly sorted	1½
57	Covered	1
56	Limestone and shale: limestone, medium gray, weathers same, crinoidal; interbedded with thin layers of calcareous shale in middle of unit (base: *sandy, crinoidal biosparudite); "Sinuatella"* n.sp. A, *"Protoniella" welleri*	2½
55	Covered	3
54	Sandstone, weathers olive-brown, coarse-grained, poorly sorted	1
53	Covered	2
52	Sandstone, dark olive-gray, weathers medium gray, medium-grained, poorly sorted; thin nodular limestone layer at top (base: *medium sandstone; clay- and quartz-overgrowth-cemented, immature orthoquartzite;* no feldspar)	1
51	Shale, weathers light yellowish gray, calcareous, friable	2
50	Covered	7
49	Shale, weathers light yellowish gray; slumped	4
48	Limestone and shale: limestone, light olive-gray, weathers same; sandy with scattered subrounded quartz grains to 2 mm; occurring in nodular layers to 4 inches thick; interbedded with thin layers of shale, weathers light yellowish gray, calcareous, friable *(sandy biosparudite); "Buxtonia"* n.sp. A, *Schizophoria oklahomae, "Spirifer"* n.sp. D	1
47	Shale, weathers light yellowish gray, poorly exposed	1
46	Sandstone, light olive-gray, weathers same, calcareous to highly calcareous, partly conglomeratic, partly crinoidal and fossiliferous; thickness variable (base: *medium sandstone; calcite-cemented, submature, fossiliferous orthoquartzite;* no feldspar)	2½
45	Sandstone and siltstone: sandstone, light olive-gray, weathers same, fine- to medium-grained; grading upward into siltstone, micaceous, partly sandy, thin-bedded; upper surface of unit irregular (base: *medium sandstone; clay- and quartz-overgrowth-cemented, immature orthoquartzite;* no feldspar)	5
44	Covered; shale and thin-bedded fossiliferous limestone talus	12½
43	Siltstone, dark gray, weathers dark yellowish gray, thick-bedded	2½
42	Shale and siltstone: shale, weathers moderate red-brown, friable; interbedded in upper part with thin layers siltstone, olive-brown	7½
41	Limestone, brownish gray, weathers same, sandy, fragmental, poorly sorted; crinoidal at top *(sandy biosparudite)*	2
40	Covered, probably shale	5
39	Shale, weathers light yellowish gray to maroon, partly silty	4
38	Limestone and shale: limestone, light gray, weathers light yellowish gray; occurring in nodular layers; interbedded with thin layers of shale, calcareous *(algal biosparudite); "Protoniella"* cf. *welleri, Schizophoria texana, Reticulariina? campestris*	2½
37	Sandstone and shale; sandstone, greenish black, medium- to coarse-grained, poorly sorted; hard, irregular layers up to 1 foot thick; interbedded with shale, light yellowish gray, partly micaceous, friable (2 feet above base: *coarse sandstone; clay-bonded, immature orthoquartzite;* no feldspar)	2½
36	Covered	7
	Section shifted from the draw west of a point on the road 0.5 mile south of the bridge northward to the next draw, located opposite a point on the road 0.4 mile south of the bridge, where the Pennsylvanian sequence is mostly covered below unit 37. The difference in thickness of this covered interval and the thickness of units 25 to 35, measured 0.1 mile farther south, provided the thickness of unit 36	
35	Siltstone, weathers moderate red-brown, micaceous, partly shaly	3
34	Covered	8
33	Sandstone, medium gray, weathers same, fine- to medium-grained, hard; upper surface of unit irregular (1 foot above base: *fine sandstone; clay-bonded, immature orthoquartzite;* no feldspar)	1½
32	Shale, weathers light yellowish gray; interbedded with thin layers of siltstone in lower two feet; partly slumped and covered	8½
31	Sandstone, olive-gray, weathers olive-brown, fine- to coarse-grained, poorly sorted, silty, calcareous; strike N. 65° W., dip 19° SW	½
30	Siltstone, light olive-gray, weathers same; unit pinches out northward within lateral distance of 15 feet, apparently due to truncation by overlying unit (2 feet above base: *sandy mudstone; clay-bonded, immature, muscovite-bearing orthoquartzite;* no feldspar)	3
29	Sandstone, grayish yellow, very fine-grained, well sorted; basal contact irregular *(very fine sandstone; quartz-overgrowth-cemented, mature orthoquartzite)*	1½
28	Siltstone, olive-gray, weathers same; weathers in plates and blocks (4 feet above base: *silty mudstone; clay-bonded, immature, muscovite-bearing orthoquartzite;* no feldspar)	11
27	Mudstone, olive-brown, weathers same, partly silty; contains scattered, partly silicified limestone nodules up to 8 inches in diameter	5
26	Siltstone, dusky yellow-green, coarse-grained, slightly calcareous; scattered, small, irregular brownish red chert nodules; unit irregular in thickness *(very fine sandstone; clay-bonded, immature orthoquartzite;* no feldspar)	1½
25	Shale, greenish gray, silty; unit highly variable in thickness due to irregularity of unconformable contact with Mississippian limestone	1
	Total thickness of La Pasada Formation	973
	Unconformity	
	Tererro Formation (Mississippian)	

SECTION 96. ALAMITOS FORMATION (TYPICAL SECTION A), ALAMITOS VALLEY

No complete, well-exposed section of the Alamitos Formation has been found in the Pecos area. The section here describes the upper 1000 feet. Correlation between sections 96 and 97 (*see* fig. 14) suggests a total thickness for the formation of about 1275 feet. To reach the section, turn northwestward on an unpaved and unmarked road from Alternate U.S. 85, 1.1 miles west of the highway junction at Pecos. The base of the section starts at the lowest exposure in the bed of Alamitos Creek 4.2 miles by road northwest of U.S. 85 and 2 miles northwest of the gigantic concrete abutments at an abandoned mill (best reference point). The section was measured through southward-dipping beds along the east side of the valley by means of frequent lateral offsets. Most of the units are well exposed and some can be traced laterally for considerable distances along the valley side. The top of the Alamitos Formation, arbitrarily placed at the top of the highest well-developed limestone, is located on a wooded hillside on the east side of the silted-up lake east of a point on the unpaved road about 1 mile northwest of U.S. 85. The approximate equivalent to the highest beds of the formation in the measured section can also be observed in the northward-facing bluff on the Pecos River west of the bridge on State Highway 63, at the north edge of the town of Pecos. Section described by P. K. Sutherland, Charles Rambo, and C0oper Land, June 1959.

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	Top of section stops arbitrarily in the lower part of the Sangre de Cristo Formation in wooded hills northeast of Alamitos Creek about 0.2 mile east of the tailings dam forming a silted-up lake. Section overlain by poorly exposed maroon-weathering shales and irregularly bedded sandstones.	
	Sangre de Cristo Formation	
68	Sandstone, pinkish gray to greenish gray, weathers same, medium- to coarse-grained, well-sorted, arkosic, very calcareous, thick-bedded, poorly exposed (20 feet above base: *coarse sandstone; calcite-cemented, mature arkose;* feldspar 35%)	55
67	Sandstone, pinkish gray, weathers light gray, medium-grained, well-sorted, arkosic, cross-bedded; interbedded with scattered, irregular, light yellowish brown, sandy limestone lenses up to 6 feet in length and 2 feet thick (4 feet above base: *medium sandstone; calcite-cemented, mature, biotite-bearing arkose;* feldspar 35%)	10
66	Sandstone, yellowish gray, weathers light yellowish gray, fine-grained, well-sorted, calcareous, thin-bedded; shaly partings	24
65	Sandstone and limestone: sandstone, light brownish gray, very coarse-grained, poorly sorted, arkosic, very calcareous; grading upward into limestone, medium light gray, sandy (8 feet above base: *sandy, partly fossiliferous intrasparudite)*	9
64	Sandstone, yellowish gray, medium- to very coarse-grained; well-sorted in lower part, becoming poorly sorted upward; arkosic; calcareous at top (5 feet above base: *sandy granule conglomerate; quartz-overgrowth and calcite-cemented, submature arkose;* feldspar 40%)	34
	Section measurement shifted eastward down dip on unit 63 approximately a quarter of a mile	
	Partial thickness Sangre de Cristo Formation	132
	Alamitos Formation	
63	Limestone, light gray, weathers same, medium-grained; unit thickens southward (10 feet above base: *slightly sandy biosparudite)*	13
62	Shale, moderate red, poorly exposed	29
61	Limestone, pinkish gray, weathers light gray, medium-grained, sandy, feldspathic (4 feet above base: *sandy, partly recrystallized biosparudite)*	8
60	Shale, medium light gray, weathers light gray, silty, calcareous, friable; mostly covered	10
59	Limestone, medium light gray, weathers medium gray, fragmental, thin-bedded (6 feet above base: *bryozoan and crinoidal biosparudite)*	14
58	Shale, sandstone, and covered: shale, moderate red, mostly covered; irregular layers of sandstone, light gray to pale red, weathers same, conglomeratic, poorly sorted, highly arkosic; unit mostly slumped and covered (at top: *granule conglomerate; calcite-cemented, submature arkose;* feldspar 55%)	33
57	Limestone, light olive-gray, weathers same, fragmental, nodular, thin-bedded (20 feet above base: *partly silicified, siliceous, spicule-bearing biomicrudite); Wellerella immatura;* approximately the same horizon 125 feet below the top of the formation in the Pecos River bluff at the north edge of Pecos town contains similar brachiopods and *Triticites* cf. *cullomensis*	25
56	Sandstone and shale: sandstone, medium gray to pale red, granular, subrounded, arkosic, calcareous; unit poorly exposed (40 feet above base: *granular, very coarse sandstone; quartz-overgrowth- and calcite-cemented, mature, green biotite- and magnetite-bearing arkose;* feldspar 40%)	45
55	Sandstone and shale: sandstone, pinkish gray, weathers light gray, very coarse-grained, conglomeratic, subangular, very poorly sorted; scattered pebbles to 30 mm, arkosic, very calcareous, cross-bedded; interbedded in lower 10 feet of unit with poorly exposed gray shale	28
54	Limestone, pinkish gray, weathers light gray, very coarse-grained, sandy, feldspathic; lower half of unit poorly exposed containing thin layers of sandstone (10 feet above base: *granular, partly recrystallized, feldspathic biosparudite)*	14
	Small draw at this point in section conceals fault with throw of 20 to 30 feet	
53	Limestone, grayish red-purple, weathers medium gray; lower 15 feet of unit sandy (12 feet above base: *sandy biosparite)*	26
52	Shale and sandstone: shale, moderate red, very poorly exposed; interbedded with sandstone, light gray to pale red, very coarse-grained to granular, angular, arkosic, partly calcareous; layers up to 1 foot thick (30 feet above base: *sandy granule conglomerate; quartz-overgrowth- and calcite-cemented, submature arkose;* feldspar 40%; at top: *sandy granule conglomerate; calcite-cemented, mature arkose;* feldspar 50%)	66
51	Limestone and shale: limestone, medium gray, weathers light yellowish gray, medium-grained, partly fragmental, partly nodular; unit becomes coarse-grained and crinoidal in upper 10 feet (19 feet above base: *partly recrystallized biosparudite)*	34
50	Sandstone, dark yellowish orange, weathers same, very coarse-grained to granular, moderately sorted, arkosic (2 feet above base: *coarse sandstone; quartz-overgrowth-cemented mature arkose;* feldspar 30%)	7
49	Covered; talus of sandstone, coarse-grained	10
	Section measurement crosses fence at south boundary of National Forest on the line between sections 29 and 30, T. 16 N., R. 12 E.	
48	Limestone and shale: limestone, grayish red-purple; nodular layers 1 to 2 feet thick; interbedded with shale, grayish red-purple (6 feet above base: *silty biosparite)*	13
	Units 40 to 47 are well exposed on a partly timbered hill on the east side of the valley 0.5 mile south of the abutment (1.7 miles north of U.S. 85) and just south of the mouth of a northeast side valley. These units can be traced with difficulty southward down dip to where unit 47 reaches valley level on the shore of the silted-up lake. This point is at the north side of the next canyon southward entering from the northeast opposite a point on the gravel road 0.9 mile south of abutment (1.1 miles north of U.S. 85). Marked lateral facies changes can be observed within a distance of half a mile. Unit 47 rests directly on unit 43 at its most southerly exposure. Unit 42 passes locally into a thick-bedded channel sandstone and in turn rests directly on unit 40 southward	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
47	Limestone, very light gray, weathers grayish red-purple at northern exposure, changing to light gray, weathering southward *(slightly silty, pelecypod biosparudite)*	3
46	Covered; locally talus of sandstone, coarse-grained, feldspathic	5
45	Limestone, light gray, weathers same, thick-bedded *(biomicrosparite)*	4
44	Limestone and shale: limestone, light olive-gray, weathers light gray, nodular; interbedded with shale, black, silty (11 feet above base: *partly recrystallized, brachiopod biosparudite)*	22
43	Limestone, light olive-gray, weathers light gray, feldspathic *(granular, fossiliferous oomicrosparudite)*	2
42	Covered; probably shale: changes to very coarse-grained sandstone which appears to be a channel filling one quarter of a mile to the south	4
41	Limestone, light olive-gray, weathers same, very coarse-grained, sandy *(slightly sandy, crinoidal biosparudite)*	2
40	Shale and limestone: shale, grayish olive-green, weathers same, platy, soft; interbedded with limestone, medium gray, weathers light yellowish gray, nodular, hard, partly sandy (9 feet above base: *partly silicified, crinoidal biosparudite); Neospirifer alatus, Echinoconchus semipunctatus*	20

The northeast side valley at 0.4 mile south of the abutment (1.8 miles north of U.S. 85) is developed along a fault in which rocks on the south side of the valley are displaced downward about 100 feet. Units 37 to 40 can be clearly recognized on both sides of the valley, allowing a southward shift in stratigraphic measurement.

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
39	Shale, black, weathers gray, calcareous, friable; gradational with overlying unit	36
38	Limestone, light brownish gray, weathers same, very coarse-grained, sandy *(very coarse, sandy biosparudite);* abundant solitary rugose corals	2
37	Sandstone and shale: sandstone, moderate red, coarse-grained, arkosic; interbedded with poorly exposed red shale	23
36	Sandstone, moderate olive-brown, weathers same, very coarse-grained, poorly sorted, arkosic *(very coarse sandstone; quartz-overgrowth-cemented, clay-bonded, immature, biotite-bearing arkose;* feldspar 35%)	20
35	Shale and sandstone: shale, moderate red; interbedded with sandstone, dusky yellow-green, weathers light gray, medium-grained, moderately sorted, arkosic (34 feet above base: *pebbly, very coarse sandstone; quartz-overgrowth-cemented, mature, green biotite-bearing arkose;* feldspar 40%)	41
34	Limestone, medium light gray, weathers light gray, coarse-grained, feldspathic, sandy *(sandy oosparudite);* strike N. 17° E., dip 15° SE; stratigraphic measurement shifted southeast on unit 34	8
33	Shale and sandstone: shale, grayish red-purple to grayish green, weathers same; interbedded with sandstone, light yellowish gray, cross-bedded; in lenticular bodies 1 to 10 feet thick which appear to be highly irregular channel sands; this unit is very well exposed in cut of abandoned railway 0.3 mile south of abutment	44
32	Sandstone, grayish yellow-green, coarse- to very coarse-grained, poorly sorted, angular, arkosic, calcareous; occurring in thick-bedded, lensing layers 2 to 8 feet thick alternating with thin layers of reddish shale (11 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature, green biotite-bearing arkose;* feldspar 35%)	20
31	Covered; talus of shale, red; and sandstone, coarse-grained arkosic	10

Unit 30 traced south along west-facing bluff from about one quarter of a mile north of abutment. Minor faulting near north end of abutment disrupts section, but unit 30 can be recognized south of abutment in railway cut

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
30	Limestone, medium light gray, weathers light gray, thick-bedded; middle of unit covered, shaly (base: *sandy, algal, biosparudite;* top: *brachiopod biomicrudite); Neospirifer* cf. *alatus*	6
29	Covered; talus in upper 3 feet of sandstone, green, coarse-grained	10
28	Sandstone, light olive-gray, weathers light gray, medium- to very coarse-grained, poorly sorted, angular, conglomeratic, arkosic; variations in grain size divide bedding into thick and thin layers	9
27	Covered; talus of shale, weathers maroon, sandy	15
26	Sandstone, light brownish gray, weathers light brown, very coarse-grained to granular, conglomeratic, poorly sorted; pebbles of quartz, feldspar, igneous and metamorphic rock fragments (12 feet above base: *sandy granule conglomerate; poikilitic- calcite-cemented, submature arkose;* feldspar 30%)	34
25	Sandstone, olive-gray, weathers same, medium-grained, moderately sorted, arkosic, silty	5
24	Sandstone, dark yellowish brown, weathers olive-gray, poorly sorted, conglomeratic, arkosic *(pebbly, very coarse sandstone; quartz-overgrowth-cemented, immature, green biotite-bearing arkose;* feldspar 30%)	1
23	Sandstone, pale olive, weathers same, very fine-grained, well-sorted, micaceous, slightly calcareous, cross-bedded	5
22	Sandstone, pinkish gray, weathers light gray, very coarse-grained, angular, poorly sorted, arkosic, partly conglomeratic; thickness of unit variable, basal contact irregular *(granular, very coarse sandstone; calcite-cemented, submature arkose;* feldspar 30%)	1
21	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, conglomeratic, arkosic	10
20	Covered; scattered talus of siltstone and sandstone, coarse-grained, poorly sorted	22
19	Sandstone, moderate brown, weathers same, coarse-grained, poorly sorted, partly granular; unit cross-bedded *(very coarse sandstone; quartz-overgrowth-cemented, immature, green biotite-bearing arkose;* feldspar 35%)	6
18	Siltstone, olive-brown, weathers same, sandy, micaceous, thin-bedded, poorly exposed	6

Unit 17 described from exposure on hillside on east side of canyon directly opposite small sawmill and cluster of houses, 0.9 mile north of abutment, where it forms a massive, cross-bedded cliff. Top of unit was traced southward on hillside, down dip, to river level, at a point 0.5 mile north of abutment. In this distance, the unit changes character to alternating layers of sandstone and sandy shale. At new location, unit has strike N. 60° E., dip 8° SW and is overlain by a 44-foot covered interval. Units 18 to 21 described at northern exposure of unit 17.

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
17	Sandstone and conglomerate: sandstone, dark yellowish brown, weathers dusky yellow, very coarse-grained, poorly sorted, arkosic (6 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, immature, green biotite-bearing, arkose;* feldspar 40%); scattered cobbles of granite, schist, and quartzite up to 150 mm; large-scale cross-bedding	45
16	Covered	29
15	Conglomerate, greenish gray; poorly sorted boulders	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	and cobbles of subrounded granite and metamorphic rock fragments up to 150 mm; much matrix of grayish green, shaly sand	6
14	Sandstone and shale: sandstone, weathers light yellowish brown, very coarse-grained, poorly sorted, arkosic, conglomeratic, thin-bedded; with shale, green, sandy	5
13	Sandstone, grayish orange, weathers light yellowish brown, coarse-grained, moderately sorted, arkosic; large-scale cross-bedding; unit forms prominent cliff which exfoliates as a unit; unit becomes conglomeratic upward with large boulders occurring locally; thickness variable (6 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, mature, biotite-bearing arkose;* feldspar 40%)	40
	Starting with unit 7, near the point where the section begins, the measurement is continuously shifted southward along the east side of the valley on the top of each resistant unit. Units 9 to 12 can be observed to change markedly in character southward within half a mile. East of the most northern house in the valley, at 1.1 miles north of the abutment, unit 13, which forms the massive bluff on the east side of the valley, rests directly on unit 9. Units 10 to 12 have disappeared southward by both facies change and truncation	
12	Sandstone, light olive-gray, weathers same, coarse-grained, subangular, well-sorted, arkosic, calcareous; cross-bedded; unit becomes increasingly calcareous southward (5 feet above base: *very coarse sandstone; calcite-cemented, mature, fossiliferous arkose;* feldspar 40%)	10
11	Shale, weathers dusky yellow, micaceous, calcareous; grades into thin-bedded sandstone one quarter mile to south	5
10	Sandstone, light yellowish gray, coarse-grained, subangular, poorly sorted, arkosic, slightly calcareous, locally conglomeratic (4 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature, biotite-bearing arkose;* feldspar 40%); unit grades southward within half a mile into limestone, light gray, coarse-grained, sandy, feldspathic, crinoidal (7 feet above base: *sandy, feldspathic, crinoidal biosparudite);* upper part of unit is thick-bedded; lower 3 feet nodular; *Fusulina* sp.	13
	At a point 1.4 miles north of the abutment, a small graben about 200 feet across, with a throw of 40 feet, disrupts the section, displacing downward the thick-bedded sandstone of unit 13 against units 10 to 12 which form the side of the graben	
9	Conglomerate, light olive-brown, weathers same; subangular boulders of quartz, feldspar, granite, and schist average 30 to 40 mm ranging to 120 mm; poorly sorted, sandy; unit becomes less conglomeratic southward and within half a mile, the lower half of the unit is sandstone, weathering yellowish gray, conglomeratic, thick-bedded, and the upper half is non-conglomeratic green and red shale	30
8	Sandstone and siltstone: sandstone, light yellowish gray, weathers same, medium- to coarse-grained, poorly sorted, arkosic; highly cross-bedded; interbedded with siltstone; upper 3 feet of unit locally conglomeratic; upper surface irregular and locally truncated	16
7	Sandstone, light yellowish gray, weathers light gray, medium-grained, well-sorted, arkosic, very calcareous	3
6	Shale, weathers dusky yellow, silty, slightly calcareous	12
	Section measurement shifted to east side of road on top of unit 5 and strike changes to N. 35° W., dip 9° E; dip changes to southward within 0.2 mile south	
5	Sandstone, light olive-gray, weathers light gray, fine- to medium-grained, well-sorted, calcareous, thin-bedded; interbedded with thin layers of shale (4 feet above base: *medium sandstone; calcite- and quartz-overgrowth-cemented, submature, fossiliferous, biotite-bearing arkose;* feldspar 30%)	7
4	Shale, weathers yellowish gray, calcareous; scattered calcareous lenses	2
3	Sandstone and siltstone: sandstone, greenish gray, medium- to very coarse-grained, poorly sorted, arkosic; interbedded irregularly with 1-foot layers of siltstone, green, micaceous (3 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, immature, green biotite-bearing arkose;* feldspar 30%)	7
2	Shale, weathers grayish blue-green, sandy; conglomeratic at base	3
1	Conglomerate, weathers light olive-brown; subrounded boulders of quartz, feldspar, granite, and schist to 120 mm, very poorly sorted; irregular matrix of micaceous silty shale; beds strike N. 60° W., dip 6° NE; exposed in stream bed	2
	Remainder of section is below stream level	
	Partial thickness of Alamitos Formation	1006

SECTION 97. ALAMITOS FORMATION (TYPICAL SECTION B), WEST OF PECOS VALLEY

This section describes almost the whole of the Alamitos Formation (about 100 feet are missing at the top) and the upper part of the underlying La Pasada Formation. The base of section 97 is about two thirds of the way up the partly timbered slope on the west side of a north-trending dry valley due west of the triangular erosional block west of the Pecos River, 1.3 miles north of the State Fish Hatchery on Highway 63. At this point, the Pecos Valley becomes restricted southward. The section begins arbitrarily at the base of the distinctive white and light gray chert and silty limestone sequence which forms the main part of the seventh cliff in section 36 at Dalton Bluff two miles to the north (units 36 to 174) and occurs near the top of the La Pasada Formation. This unit was traced southward along the bluff from Dalton to the base of section 97.

From its base, section 97 was measured westward up the first bluff and then continued west-southwest for a distance of about one and one-half to two miles. Measurement was accomplished by means of a series of downdip offsets, mainly along the crest of a ridge which is crossed by a series of poorly exposed north-northwest-trending cuestas. The beds strike generally N. 30° W. and dip 8° to 10° SW. The sequence is poorly exposed on the whole and is difficult to trace in many places. Exact location of most offsets and most units in the sequence could not be recorded because of the difficulty of accurately estimating distances in the rough mountain country and the lack of a topographic map of the area. At only two places west of the base, the section can be located with certainty. The first is the abandoned concrete platform located on the ridge crest where the aerial tramway of the now-abandoned Pecos Mine (located in the Pecos Valley north of Tererro) reached a high point between the mine and the mill in the Alamitos Valley several miles to the southwest (mentioned in the introduction to section 96). Unit 65 forms the ridge crest at the concrete platform. This point is about one to one and a half miles west-southwest of the Pecos Valley. The second place is the highest topographic point on this part of the drainage divide between the Pecos River and Alamitos Creek. This nob is also the highest stratigraphic horizon on the ridge and is formed by a remnant of a Cenozoic terrace composed of unconsolidated, unsorted, subrounded pebbles and boulders of granite up to three feet in diameter and less common fragments of metamorphic rocks. The generally flat-surfaced, timber-covered, terrace deposit is at least 60 feet thick and covers an area about a quarter of a mile long and a few hundred yards across. It occurs at an elevation of over 9000 feet above sea level. This feature is located about one half to two thirds of a mile west of the abandoned concrete platform mentioned above.

Section 97 is important in spite of its poorly exposed nature, because it includes the lower part of the Alamitos Formation not exposed in section 96 and the contact with the underlying La Pasada Formation. Its higher beds can be correlated with those of section 96 *(see* fig. 14).

Before measuring section 97, a persistent attempt was made to trace the Pennsylvanian sequence south along the main Pecos Valley to the well-exposed highest Pennsylvanian beds at the river bluff on the north edge of the town of Pecos, but this was not possible. The white chert sequence mentioned above (unit 174, section 36, and unit 2, section 97) can be traced southward along the west side of the Pecos Valley for about one and a half miles from the base of section 97 to a point just south of the State Fish Hatchery where it forms the crest of the prominent bluff overlooking the hatchery on the west and southwest and extending as a spur eastward restricting the width of the Pecos Valley. At this point, the Pecos River is sharply deflected to the east, coinciding with an abrupt change in direction and amount of dip southward. The chert unit dips gently to the southwest, west of the hatchery, and changes to a steep south dip just south of the hatchery. Immediately south of this point, the sequence is broken by faulting and the exposures are poor, making further definite tracing of the sequence in this area impossible. Section 97 was described by P. K. Sutherland, Charles Rambo, and Cooper Land, June 1959.

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	Cenozoic terrace deposit	
78	Conglomerate, unconsolidated, unsorted boulders up to 3 feet in diameter composed predominantly of granite, uncommonly of metamorphic rock fragments; thickness approximate	60
77	Covered	15
	Total preserved	75
	Unconformity	
	Alamitos Formation	
76	Sandstone, moderate red, coarse-grained, poorly sorted, conglomeratic, arkosic; middle part of unit poorly exposed (at base: *sandy, granule conglomerate; quartz-overgrowth-cemented, submature arkose, feldspar* 45%; at top: same as at base except feldspar 55%)	25
75	Covered, siltstone and shale talus, moderate red	10
74	Limestone and siltstone: limestone, grayish red-purple, silty; occurring in nodular layers; interbedded with thin layers of siltstone, calcareous	12
73	Covered, limestone talus similar to unit 74	11
72	Limestone, brownish gray, weathers medium gray, sandy, feldspathic (2 feet above base: *sandy, feldspathic biosparudite)*	5
71	Sandstone, light brownish gray, weathers moderate red, coarse-grained, poorly sorted; conglomeratic with pebbles to 30 mm, arkosic; upper 30 feet mostly covered by sandstone talus; forms crest of an east-west ridge (10 feet above base: *sandy granite conglomerate; quartz-overgrowth-cemented, submature, impure arkose;* feldspar 35%)	82
	Section shifted westward to a point about one half mile west of the abandoned concrete platform on top of unit 70	
70	Limestone, medium gray, weathers same, sandy; partly nodular and thin-bedded, crinoidal	12
69	Covered; lower 5 feet has limestone and red shale talus	31
68	Limestone and siltstone: limestone, medium light gray, weathers light yellowish gray; nodular and thin-bedded in lower half, becoming thick-bedded and crinoidal in upper part; interbedded in lower half with thin-bedded siltstone, calcareous; forms crest of first northwest-trending cuesta west of the concrete platform	18
67	Shale, olive-brown, platy; containing scattered limestone nodules up to 3 inches in diameter	11
66	Covered talus of sandstone and nodular limestone	76
	Section shifted to a point 500 yards west of concrete platform on top of unit 65	
65	Limestone, light olive-gray, weathers same, nodular to thick-bedded; caps crest of ridge supporting concrete platform	16
64	Shale, light olive-gray, weathers same, platy; contains small limestone nodules	21
63	Conglomerate and sandstone: conglomerate, light olive-gray, weathers greenish gray, sandy, poorly sorted; with scattered granite cobbles; unit grades upward in top 3 feet into sandstone, coarse-grained, calcareous (base: *very coarse sandstone; calcite- and quartz-overgrowth-cemented, submature, chlorite-bearing arkose;* feldspar 35%)	10
62	Covered	18
61	Limestone, light olive-gray, weathers light gray, finely crystalline; gradational with underlying unit	5
60	Limestone and siltstone: limestone, light olive-gray, weathers light yellow, silty; occurring in nodular, thin layers; interbedded in lower half with thin layers of siltstone, calcareous, platy; lower 5 feet: *Echinoconchus semipunctatus, Neospirifer alatus*	20
59	Shale, medium gray, weathers light gray, calcareous, silty, platy	40
58	Covered	15
57	Sandstone, medium light gray, weathers olive-gray, medium-grained, arkosic	6
56	Covered	29
55	Sandstone, grayish olive to grayish red, coarse-grained, poorly sorted, granular, arkosic	1
54	Limestone, light olive-gray, weathers medium light gray, sandy; thick, nodular bedding; fossiliferous;	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	unit forms crest of cuesta (10 feet above base: *slightly sandy biosparudite); Echinoconchus semipunctatus, Neospirifer alatus*	14
53	Covered, scattered talus of limestone, medium gray, sandy	19
52	Covered, scattered talus of coarse-grained sandstone in lower part	70
51	Limestone, yellowish gray, weathers light gray; nodular bedding (2 feet above base: *very slightly silty biosparite)*	6
50	Limestone, pinkish gray, weathers light gray; poorly exposed on gentle westward dip slope of cuesta (2 feet above base: *sandy recrystallized biosparudite)*	8
49	Limestone, yellowish gray, weathers same, sandy, feldspathic, thick-bedded, slightly cross-bedded; middle of unit forms crest of cuesta (8 feet above base: *sandy algal biosparudite)*	14
48	Conglomerate and limestone: conglomerate pinkish gray, poorly sorted, arkosic, calcareous, partly covered; interbedded with thin layers of limestone, yellowish gray, crinoidal (4 feet above base: *sandy biosparudite);* 4 feet above base: *Fusulina* n.sp. C	5
47	Limestone, yellowish gray, weathers light gray, fragmental, sandy; unit slumped (5 feet above base: *sandy biosparudite)*	15
46	Covered, talus of coarse-grained sandstone and red shale	18
45	Sandstone, medium light gray, weathers light gray, coarse-grained, arkosic, very calcareous	2
44	Sandstone, dusky yellow, weathers light olive-gray coarse-grained, granular, arkosic; upper half of unit poorly exposed (12 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature arkose)*	44
43	Covered, scattered talus of coarse-grained sandstone	11
42	Limestone and siltstone: limestone, light olive-gray, weathers medium gray; nodular layers; interbedded with siltstone, weathers greenish gray; unit partly covered (4 feet above base: *sandy algal biosparudite)*	10
41	Conglomerate, weathers olive-gray; very poorly sorted with boulders up to 100 mm of quartz, phyllite, quartzite, and feldspar; sand and chloritic matrix	6
40	Sandstone and covered: sandstone, moderate olive-brown, coarse-grained, poorly sorted, arkosic; unit partly covered (9 feet above base: *granular, very coarse sandstone; slightly silica-cemented, submature, biotite-bearing arkose;* feldspar 35%)	70
39	Limestone, yellowish gray, weathers light gray, fragmental, highly sandy to conglomeratic, feldspathic; unit partly covered (3 feet above base: *very sandy biosparite)*	4
38	Sandstone, light olive-brown, weathers light yellowish gray, coarse-grained to granular, poorly sorted, arkosic; unit partly covered	12
37	Covered, talus of limestone in upper 2 feet *(sandy foraminiferal biosparite)*	7
36	Sandstone, light brown, weathers same, coarse-grained, partly granular, poorly sorted, arkosic; upper half of unit poorly exposed (base: *granular very coarse sandstone; slightly silica-cemented, submature, biotite-bearing, arkose;* feldspar 35%; 12 feet above base: *sandy granule conglomerate; slightly silica-cemented, submature, biotite-bearing arkose;* feldspar 40%)	22
35	Covered	13
34	Sandstone, grayish orange, weathers light gray, very coarse-grained to granular, poorly sorted, partly conglomeratic, arkosic, calcareous, thin-bedded (at top: *granule conglomerate; sparry calcite-cemented, mature, fossiliferous arkose;* feldspar 40%)	11
33	Limestone, yellowish gray, weathers light gray, fragmental, sandy, cross-bedded; gradational with overlying unit	6
32	Sandstone, yellowish gray, weathers light yellowish brown, coarse-grained, poorly sorted, arkosic; poorly exposed	5
31	Limestone, light gray, weathers same, coarsely fragmental	1
30	Covered, scattered limestone talus	10
29	Sandstone, moderate olive-brown, weathers olive-green, coarse-grained to granular, poorly sorted, arkosic *(granular coarse sandstone; quartz-overgrowth-cemented, immature arkose;* feldspar 40%)	2
28	Covered	10
27	Limestone, moderate pink, weathers light pink, fragmental, very sandy, feldspathic, fossiliferous	2
26	Limestone, light gray, weathers same, sandy, nodular bedding, poorly exposed	3
25	Sandstone, light gray, weathers same, coarse-grained, partly covered	9
24	Limestone and sandstone: limestone, light brownish gray, weathers light yellowish gray, very sandy, feldspathic; interbedded irregularly with sandstone, very calcareous, coarse-grained, arkosic; unit partly covered (10 feet above base: *coarse sandstone; sparry calcite-cemented, mature, fossiliferous arkose;* feldspar 40%); 6 feet above base: *Fusulina* cf. *haworthi*	15
23	Sandstone and conglomerate: sandstone, yellowish gray, weathers light gray, calcareous, coarse-grained to pebbly, poorly sorted, arkosic; interbedded irregularly in middle and upper part of unit with conglomerate, poorly sorted, arkosic (20 feet above base: *sandy granule conglomerate; sparry-calcite-cemented, submature, fossiliferous arkose;* feldspar 35%)	24
22	Siltstone, light olive-gray, weathers pale brown, calcareous; occurs in even beds 1 inch to 1 foot thick; undulating upper surface truncated by overlying unit	5
21	Conglomerate and sandstone: conglomerate, grayish yellow, weathers same, poorly sorted; pebbles and cobbles up to 120 mm of quartz, feldspar, and quartzite; interbedded with sandstone, poorly sorted, coarse-grained; beds up to 3 feet thick; unit coarsest in lower part; exposed in a series of partly covered benches (35 feet above base: *coarse sandstone; quartz-overgrowth-cemented, submature, green biotite-bearing arkose;* feldspar 40%)	92
20	Sandstone, medium light gray, weathers light yellowish brown, medium- to fine-grained, very calcareous, arkosic, thin, wavy, banded layering (base: *medium sandstone; calcite-cemented, mature, fossiliferous arkose;* feldspar 30%)	2
19	Sandstone, dusky to grayish yellow, weathers light gray, coarse-grained, partly conglomeratic, arkosic; partly covered (25 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, mature, impure arkose;* feldspar 40%)	28

Units 1 to 18 were measured on the irregular bluff facing eastward to the Pecos Valley above the base of the section. Unit 16 forms the crest of this north-trending ridge top, just south of the deep side valley which enters the Pecos Valley from the west about 300 yards north of the base of the section. The sequence is poorly exposed on the gentle westward dip slope which forms the ridge crest west of unit 18 for a distance of about half a mile. Thus, the section was shifted westward along the south side of the deep side valley mentioned above for about half a mile on unit 2. From there the section was measured up the steep valley side southward over a partly covered slope which repeats units 3 to 18 and which provides exposures of units 19 to 23. All units in the

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	section above unit 23 were measured westward on the series of ridge and cuesta crests as described in the introduction to this section.	
18	Limestone, medium gray, weathers pale grayish red, nodular, thin-bedded	6
17	Limestone, light brownish gray, weathers light yellowish brown, crinoidal; upper part sandy; uneven beds up to 1 foot thick (4 feet above base: *partly recrystallized biosparudite)*	9
16	Limestone, medium dark gray, weathers grayish orange, silty, thin-bedded; lower part of unit poorly exposed (13 feet above base: *very slightly silty brachiopod biomicrosparudite)*	15
15	Sandstone, grayish yellow, weathers same, very coarse-grained, conglomeratic, poorly sorted; upper part of unit poorly exposed (8 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature, biotite-bearing arkose;* feldspar 30%)	21
14	Covered; talus of sandstone, coarse-grained	11
13	Sandstone, pale olive, weathers same, fine-grained; well-sorted, becoming coarser-grained near top	10
12	Covered	9
11	Limestone, light olive-gray, weathers yellowish gray, silty; blocky fracture *(slightly sandy, algal biomicrosparudite)*	2
10	Siltstone, light olive-gray, weathers same, platy, thin-bedded	5½
9	Limestone, light gray, weathers yellowish gray, fragmental, sandy *(sandy biosparudite); Fusulina* sp.	1½
8	Covered, scattered talus of siltstone	20
7	Sandstone, yellowish gray, weathers same, medium-grained, moderately sorted, arkosic	2
6	Covered, scattered talus of siltstone and sandstone	13
5	Sandstone, grayish yellow, weathers light yellowish gray, medium- to coarse-grained, poorly sorted, partly conglomeratic, arkosic (2 feet above base: *medium sandstone; quartz-overgrowth and calcite-cemented, mature, muscovite-bearing arkose;* feldspar 30%)	4
	Partial thickness of Alamitos Formation	1198
	La Pasada Formation	
4	Limestone, siltstone, and shale: limestone, light olive-gray, weathers same, silty, partly silicified; interbedded in thin nodular layers with calcareous siltstone and thin layers of gray shale (5 feet above base: *silicified silty biosparite)*	10½
3	Sandstone, yellowish gray, weathers light yellowish gray, medium-grained, calcareous, feldspathic; partly covered (3 feet above base: *medium sandstone; calcite-cemented, mature, biotite-bearing subarkose;* feldspar 20%)	7½
2	Chert, limestone, and siltstone: chert, white to light gray, calcareous; occurring in nodular beds up to 1 foot thick; interbedded with limestone, light gray, finely crystalline; partly silty, partly silicified and with siltstone, light gray, calcareous, partly silicified; equal to unit 174 in section 36 (three feet above base: rock almost totally replaced by microcrystalline silica; abundance of rod-shaped features which could be spicules)	33
1	Limestone and shale: limestone, light olive-gray, weathers light orange-gray, partly silty; occurring in beds 6 inches to 1 foot thick; abundant fusulinids in top 1 foot; equal to unit 173 in Section 36 (top: *fusulinid-bearing biosparudite)*	3
	Partial thickness of La Pasada Formation	54

SECTION 60. PENNSYLVANIAN FORMATIONS IN RIO PUEBLO VALLEY

Section 60 was measured on the partly exposed bluffs on the north side of the Rio Pueblo Valley by a series of down-dip offsets, as indicated on the Location Map of Measured Section 60 (fig. 22). The Mississippian—Pennsylvanian contact is not exposed but is located in the bottom of Tio Maes Canyon just north of State Highway 3 at a point 3 miles east on this highway from its junction with State Highway 75. The top of the section is at the highest stratigraphic horizon on the crest of a high forested ridge about a quarter of a mile northeast of a point on State Highway 3 about 3.8 miles by road and about 3 miles in a straight line southeast of the base of the section. There is a gradual shift in strike southeastward from about N. 40° W. in the lower part of the section to N. 2o° E. in the upper part of the sequence.

Pennsylvanian rocks are poorly exposed in the northeast part of the map area, and no single section exposes the entire Pennsylvanian sequence. However, section 25 provides exposures of the upper part of the Pennsylvanian beds not included in section 60. The lower 2500 feet of section 6o is designated the type section of the Flechado Formation in spite of its many covered intervals, because it is the only complete section of the formation observed in the area. Better exposed partial sections of the formation are sections 65 and 67.

Minor faulting may occur at the base and in the lower part of the Pennsylvanian sequence in the bottom and just east of Tio Maes Valley where Pennsylvanian rocks in the 200 feet of the section above unit 20 show minor evidence of disturbance. No part of the sequence appears to be duplicated nor can any appreciable amount of the section have been eliminated by faulting. The Morrowan fauna and rock types in this lower part of the section are very similar to the lower part of section 65 where the Lower Pennsylvanian interval is in exposed contact with Mississippian rocks. Section 60 described by P. K. Sutherland and Dean Gerber, July 1957. For a graphic presentation of the lower part of section 60, *see* Figure 13.

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	Alamitos Formation	
256	Shale and limestone: shale, medium gray, calcareous, poorly exposed; interbedded with uncommon thin layers of limestone, medium gray, weathers light yellowish gray, crinoidal; sandy with scattered wood fragments (2 feet above base: *very sandy biosparudite)*	5
255	Limestone, dark gray, weathers dark yellowish gray, crinoidal, thin-bedded; interbedded with thin layers of silty shale (3 feet above base: *sandy biosparudite)*	8
254	Sandstone, light olive-gray, weathers light yellowish gray, fine-grained; carbonaceous with wood fragments, calcareous (3 feet above base: *very fine sandstone; calcite-cemented, submature, muscovite-bearing arkose)*	5
253	Covered; talus of shale, dark gray, calcareous, and limestone, silty, nodular	47
252	Limestone and siltstone: limestone, medium gray, weathers light yellowish gray, partly silty; thick-	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	bedded layers half a foot to 3 feet thick; interbedded in upper 20 feet with thin layers of calcareous siltstone and shale; partly covered near top (12 feet above base: *very slightly sandy biosparudite);* 15 to 20 feet above base: *Antiquatonia* cf. *portlockianus, Echinoconchus* sp. (fauna similar to that occurring in unit 24 of section 25)	29
251	Limestone, siltstone, and shale: limestone, medium gray, partly fragmental, silty, partly crinoidal; occurring in even layers one-half to 1 foot thick; interbedded with thinner layers of siltstone, medium to dark gray, calcareous, micaceous, and shale, dark gray, silty, calcareous, platy; shale layers more abundant in upper 10 feet; unit sparsely fossiliferous (base: *very sandy biosparudite;* 30% very fine sand; 23 feet above base: *very sandy biosparudite;* 35% very fine sand)	22
250	Covered; lower 30 feet talus of thick-bedded, poorly sorted sandstone and conglomerate; higher talus of thin-bedded, dark gray silty limestone and calcareous siltstone	210
249	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; quartz and feldspar pebbles to 20 mm, arkosic, calcareous; interbedded irregularly with sandstone, coarse-	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	grained, poorly sorted, arkosic, calcareous; unit highly cross-bedded	6
248	Covered	33
247	Conglomerate, weathers light yellowish gray, poorly sorted; quartz and feldspar pebbles to 20 mm, arkosic	7
246	Covered	19
245	Limestone, medium gray, weathers light gray, partly silty, nodular *(partly recrystallized, algal biosparudite)*	2
244	Covered; probably shale	10
243	Conglomerate, weathers light yellowish gray, poorly sorted; pebbles of quartz and feldspar up to 20 mm, arkosic, calcareous cement	4
242	Covered; lower six feet has talus of sandstone; weathers light yellowish gray; medium-grained, highly calcareous, thin-bedded *(medium sandstone; calcite-cemented, submature arkose;* 30% feldspar)	15
241	Conglomerate, weathers light yellowish gray, poorly sorted; pebbles to 15 mm; sandy, calcareous cement	7
240	Covered	10
239	Conglomerate and sandstone: unit weathers light yellowish gray, poorly sorted; pebbles of quartz and feldspar up to 20 mm; arkosic, calcareous cement; interbedded irregularly with sandstone, coarse-	

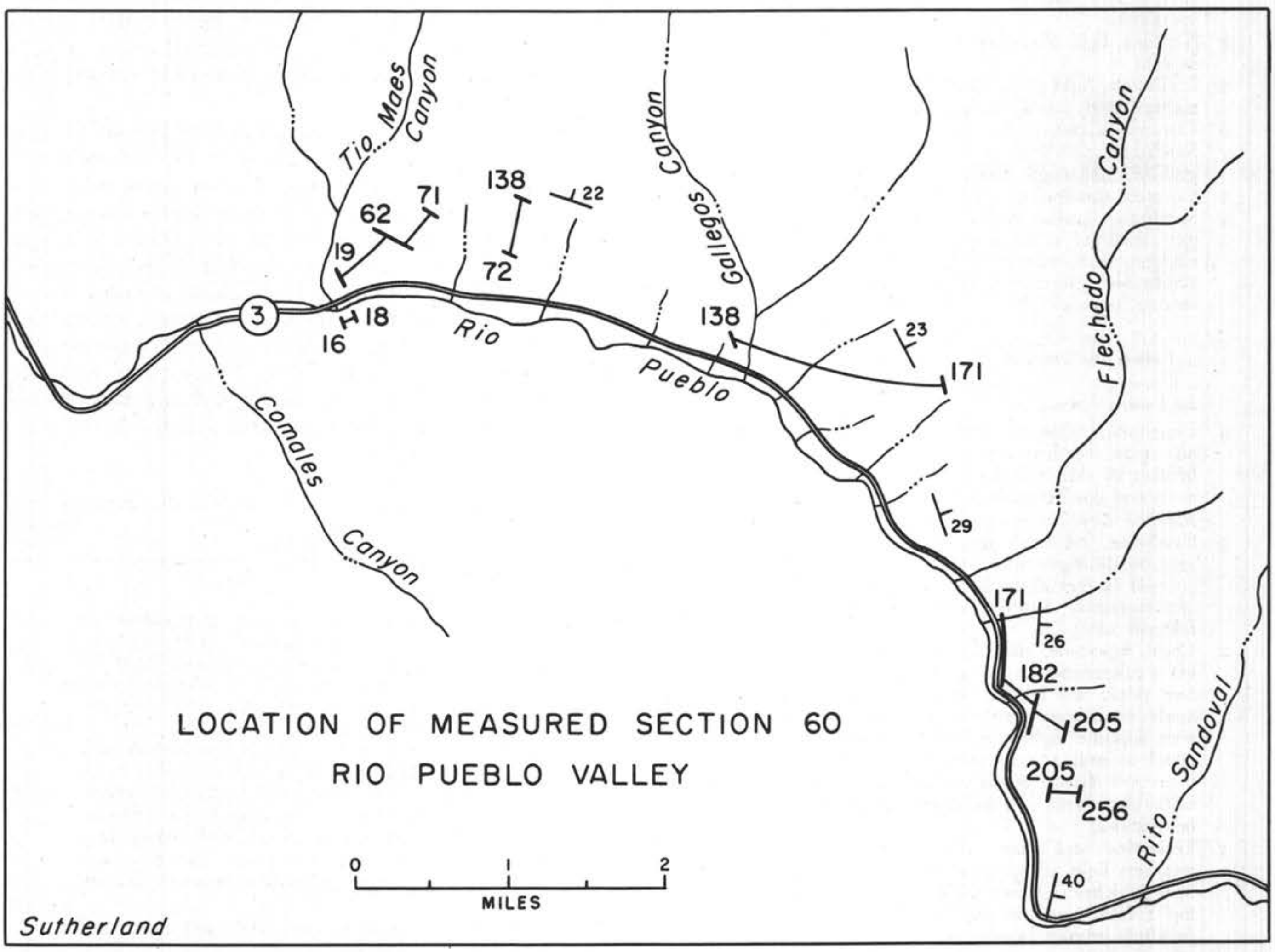

Figure 22
Location of measured section 60, Rio Pueblo Valley

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	grained, poorly sorted, conglomeratic, calcareous cement; unit highly cross-bedded, thick-bedded, forms cliff (8 feet above base: *sandy granule conglomerate; quartz-overgrowth-cemented, submature arkose;* feldspar 35%)	14
238	Covered	5
237	Limestone, medium gray, weathers light yellowish gray, sandy *(slightly sandy, algal biosparudite)*	1
236	Covered	7
235	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; pebbles of quartz and feldspar up to 20 mm; arkosic, calcareous cement; interbedded irregularly with sandstone, coarse-grained, poorly sorted, conglomeratic, arkosic; calcareous cement; unit highly cross-bedded, basal contact irregular (5 feet above base: *very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature arkose;* feldspar 35%)	12
234	Covered; probably shale and siltstone	6
233	Limestone, medium gray, weathers light gray, finely crystalline, thick-bedded	7
232	Limestone and shale: limestone, medium gray, weathers light yellowish gray, thin-bedded; nodular layers 2 to 4 inches thick; interbedded with thin layers of shale, dark gray, calcareous, partly silty (3 feet above base: *biomicrudite); Desmoinesia muricatina, Mesolobus euampygus*	5
231	Covered	12
230	Limestone, dark gray, weathers light yellowish gray, finely crystalline, nodular to irregularly bedded; at top: *Fusulina* cf. *attenuata, Wedekindellina* cf. *ellipsoides, Pseudostafella* sp.	3
229	Shale and siltstone: shale, dark gray, silty, calcareous, platy; interbedded with thin layers of siltstone	2
228	Siltstone and limestone: siltstone, medium gray, weathers light yellowish gray, calcareous, very thin-bedded; interbedded with scattered thin- to medium-bedded layers of limestone, silty, nodular (15 feet above base: *fine sandstone; calcite-cemented, mature, muscovite- and biotite-bearing arkose)*	23
227	Limestone, medium gray, weathers light yellowish gray, finely to coarsely crystalline, partly crinoidal, thick-bedded (3 feet above base: *very slightly sandy biosparudite)*	8
226	Siltstone, dark gray to black, weathers dark yellowish gray, very calcareous, thin-bedded	18
225	Covered; possibly siltstone or shale	27
224	Siltstone, dark gray to black, weathers dark yellowish gray, very calcareous, thin-bedded	5
223	Covered; talus of shale, silty; micaceous in lower 10 feet; forms wide bench	72
222	Sandstone, weathers light yellowish gray, medium- to coarse-grained, arkosic, calcareous, partly carbonaceous, thin-bedded (18 feet above base: *medium sandstone; calcite-cemented, submature, fossiliferous arkose;* feldspar 35%)	45
221	Covered, probably shale or siltstone	17
220	Conglomerate and sandstone: unit weathers light yellowish gray; poorly sorted with pebbles of quartz and white feldspar up to 10 mm; interbedded irregularly with sandstone, coarse-grained, poorly sorted, conglomeratic, arkosic (5 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature arkose,* feldspar 35%)	12
219	Covered	12
218	Conglomerate, weathers light yellowish gray; poorly sorted with pebbles to 30 mm; arkosic, cross-bedded	7
217	Sandstone, weathers light yellowish gray, medium- to coarse-grained, arkosic, thin-bedded; upper 15 feet poorly exposed (20 feet above base: *medium sandstone; quartz-overgrowth-cemented, submature, muscovite- and biotite-bearing arkose;* feldspar 40%)	36
216	Shale and sandstone: shale, dark gray, silty, micaceous, partly covered; interbedded with widely spaced sandstone layers up to 3 feet thick, poorly sorted, partly conglomeratic, cross-bedded	54
215	Sandstone, weathers light yellowish gray, medium-grained, arkosic	31
214	Covered; scattered shale and siltstone talus	55
213	Sandstone, weathers light yellowish gray, very coarse-grained, poorly sorted, partly conglomeratic, cross-bedded; strike N. 23° E., dip 23° SE	9
212	Covered	8
211	Conglomerate, weathers light yellowish gray, poorly sorted; pebbles to 10 mm; arkosic, highly cross-bedded	8
210	Covered by talus from above	8
209	Conglomerate, weathers light yellowish gray, poorly sorted, arkosic; pebbles up to 50 mm	10
208	Covered by talus from above	11
207	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; subrounded quartz and feldspar pebbles up to 50 mm; interbedded irregularly with sandstone, thin-bedded, cross-bedded (5 feet above base: *coarse sandstone; calcite- and quartz-overgrowth-cemented, mature, muscovite-bearing arkose;* feldspar 40%; 15 feet above base: *sandy granule conglomerate; quartz-overgrowth-cemented, submature, muscovite- and biotite-bearing arkose;* feldspar 40%)	21
206	Covered	35
	Section shifted about half a mile south along steep bluff by tracing unit 205 laterally, and then continued eastward up the ridge	
205	Conglomerate, weathers light yellowish gray, sandy, poorly sorted; subrounded to subangular quartz and white feldspar pebbles up to 80 mm; some layers carbonaceous; unit highly cross-bedded, forms high cliff (40 feet above base: *granular coarse sandstone; quartz-overgrowth-cemented, submature, muscovite-bearing arkose;* feldspar 40%)	62
204	Covered by talus from above	66
203	Limestone, siltstone, and shale: limestone, dark gray, weathers brown, finely crystalline, silty, thin-bedded; interbedded with siltstone, calcareous, thin-bedded, and shale, silty, calcareous; grades in top 5 feet into continuous limestone; unit forms cliff (10 feet above base: *very fine sandstone; calcite-cemented, mature arkose)*	34
202	Covered; probably shale and siltstone	11
201	Shale and sandstone: shale, dark gray, micaceous, partly covered; interbedded with sandstone, medium-grained, thin-bedded	8
200	Limestone, dark gray, weathers dark yellowish gray, finely crystalline, thin-bedded, poorly exposed (2 feet above base: *slightly sandy biomicrosparudite)*	3
199	Conglomerate, weathers light yellowish gray, poorly sorted; scattered pebbles of quartz and white feldspar up to 10 mm, irregularly thick-bedded (5 feet above base: *granular, coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%)	20
	Units 197 to 199 form a major west-facing cliff on bluff	
198	Sandstone, light olive-gray, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic (3 feet above base: *coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 35%)	6
197	Conglomerate, weathers light yellowish gray, sandy, poorly sorted; scattered pebbles of quartz and white feldspar up to 10 mm (3 feet above base: *very coarse*	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	sandstone; quartz-overgrowth-cemented, submature arkose; feldspar 35%)	15
196	Sandstone, medium light gray, weathers light yellowish gray, coarse-grained, poorly sorted; partly conglomeratic with scattered pebbles up to 10 mm; arkosic; upper 5 feet of unit thin-bedded (6 feet above base: *granular medium sandstone; quartz-overgrowth- and calcite-cemented, submature, muscovite- and biotite-bearing arkose;* feldspar 35%)	19
195	Covered by talus from above	40
194	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic, arkosic	3
193	Covered	16
192	Sandstone, weathers light yellowish gray, medium- to coarse-grained, poorly sorted, partly conglomeratic, highly cross-bedded; strike N. 20° E., dip 23° SE (8 feet above base: *medium sandstone; quartz-overgrowth-cemented, submature, muscovite- and biotite-bearing arkose;* feldspar 35%)	16
191	Covered, talus of shale, silty, micaceous	13
190	Sandstone, medium light gray, weathers light yellowish gray, medium-grained, arkosic, calcareous, highly cross-bedded (11 feet above base: *medium sandstone; calcite-cemented, mature, muscovite- and biotite-bearing arkose;* feldspar 30%)	20
189	Conglomerate, weathers light yellowish gray, very poorly sorted, sandy, irregularly bedded; scattered quartz pebbles up to 20 mm; scattered white feldspar pebbles to 10 mm (5 feet above base: *sandy granule conglomerate; quartz-overgrowth-cemented, submature arkose;* feldspar 40%)	18
188	Covered, probably shale and siltstone	9
187	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; grains average 3 to 5 mm but range up to 20 mm; arkosic; interbedded with sandstone, coarse-grained, poorly sorted, very calcareous (7 feet above base: *very coarse sandstone; calcite-cemented, submature arkose;* feldspar 45%)	15
186	Siltstone, weathers light olive-gray, sandy, micaceous, thin-bedded	3
185	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; scattered pebbles to 10 mm; arkosic; interbedded irregularly with sandstone, coarse-grained, poorly sorted, arkosic; unit highly cross-bedded (14 feet above base: *granular very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%)	19
184	Shale and sandstone: shale, dark gray, micaceous, friable; beds up to 9 feet thick, partly covered; interbedded with sandstone, weathers light yellowish gray, very coarse-grained, partly conglomeratic, cross-bedded layers up to 2 feet thick	34
183	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic; scattered pebbles to 10 mm; arkosic; thick, irregular, cross-bedded layers; includes uncommon thin layers of dark gray silty shale (9 feet above base: *medium sandstone; quartz-overgrowth-* and *calcite-cemented, mature arkose;* feldspar 30%)	30
182	Shale, sandstone, and conglomerate: shale, dark gray, partly micaceous; interbedded with sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, arkosic; conglomerate, poorly sorted, sandy; unit predominantly shale where measured, but a 30-foot interval in lower part of unit grades laterally southeastward along the roadcut into a sequence of predominant sandstone in a distance of 100 yards	110
	With unit 182, the section measurement leaves the highway roadcuts at a sharp bend and continues east-southeastward up steep bluff	
181	Covered, probably shale; measured at a small draw from the north at a sharp bend in the highway; interval approximate	9
180	Sandstone, weathers light yellowish gray, very coarse-grained, poorly sorted, partly conglomeratic, thin-bedded	2
179	Shale, dark gray, weathers same, micaceous, silty	5
178	Sandstone, medium light gray, weathers light yellowish gray, medium- to coarse-grained, poorly sorted, partly conglomeratic, arkosic, irregularly bedded; partly covered (8 feet above base: *medium sandstone; quartz-overgrowth-cemented, submature, muscovite- and biotite-bearing arkose;* feldspar 35%)	21
177	Covered; probably shale and siltstone	16
176	Conglomerate, weathers medium gray, poorly sorted; grains average 3 to 4 mm; scattered pebbles to 10 mm; sandy, calcareous cement, arkosic (3 feet above base: *very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature arkose;* feldspar 35%)	6
175	Shale and sandstone: shale, dark gray, weathers medium gray, micaceous, friable; interbedded with sandstone, weathers light yellowish gray, fine-grained	8
174	Conglomerate, sandstone, and shale: conglomerate, weathers light yellowish gray, poorly sorted; scattered pebbles up to 10 mm; arkosic, micaceous, sandy, calcareous cement; thick-bedded irregular layers up to 3 feet thick; interbedded with thin irregular sandstone layers and with dark gray micaceous shale (2 feet above base: *granular, very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature arkose;* feldspar 35%)	17
173	Shale, siltstone, and sandstone: shale, medium gray, micaceous, friable to platy, partly silty; interbedded with scattered layers up to 6 inches thick of siltstone and sandstone, dark gray, weathers light yellowish gray, fine-grained, moderately to poorly sorted, arkosic (7 feet above base: *fine sandstone; quartz-overgrowth-cemented, immature, muscovite- and biotite-bearing arkose;* feldspar 35%)	19
172	Covered; probably shale and siltstone	60
171	Sandstone and conglomerate: unit weathers light yellowish gray, poorly sorted, varies irregularly from coarse-grained, conglomeratic sandstone to conglomerate; great variation in grain size from one layer to another; in some, quartz and white feldspar pebbles range up to 10 mm, in others, scattered quartz pebbles over 40 mm occur; unit highly cross-bedded with considerable variation in thickness of individual layers laterally; unit well exposed in roadcut 0.9 mile mile southeast of Si Pa Pu Lodge where its thickness appears to be considerably greater than in buff exposures to the northwest; unit forms prominent high cliff; at roadcut exposure, lower 10 feet of unit contains thin intervals of thin-bedded sandstone and unit is gradational with underlying shale (5 feet above base: *medium sandstone, quartz-overgrowth-cemented, submature, muscovite-bearing arkose;* feldspar 30%; 15 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%; 35 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%); *see* Plate 9-D	125

Units 171 to 182 measured in roadcuts beginning with unit 171 at a point 0.9 mile southeast of Si Pa Pu Lodge and continuing southeastward by lateral offsets. At this point, unit 171 has a north strike and dips 25° E. Section measurement was offset on unit 171 from an exposure on a high bluff about one and one-half miles north-northwest of the roadcut where the unit has a strike of N. 14° W. and a dip of 23°

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	NE. There is a gradual change in strike in the intervening area	
170	Covered, probably partly shale; 5 feet of shale exposed at top at roadcut locality	98
169	Conglomerate, weathers light yellowish gray, poorly sorted; scattered pebbles up to 40 mm; arkosic, cross-bedded	7
168	Covered	40
167	Conglomerate, weathers light yellowish gray; poorly sorted with scattered pebbles to 20 mm; arkosic, highly cross-bedded, partly covered	43
166	Covered, interval approximate	170
165	Conglomerate, weathers light yellowish gray, poorly sorted; subrounded milky-white quartz pebbles up to 100 mm, dark gray chert and white feldspar pebbles up to 30 mm; cross-bedded	4
164	Covered	14
163	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, arkosic, conglomeratic	1
162	Covered	19
161	Conglomerate and sandstone: unit weathers very light gray, poorly sorted; irregular variation from conglomerate to sandstone; arkosic; irregularly cross-bedded	44
160	Covered	28
159	Conglomerate, weathers light yellowish gray, poorly sorted; grains average 2 to 4 mm, scattered pebbles up to 30 mm; highly arkosic; large-scale cross-bedding	23
158	Covered	19
157	Conglomerate and sandstone: unit weathers light yellowish brown; conglomerate, poorly sorted; grains average 2 to 6 mm, scattered rounded quartz pebbles to 40 mm; highly arkosic, sandy; interbedded irregularly with conglomeratic, arkosic, coarse-grained sandstone; unit has large-scale cross-bedding and forms a high cliff on ridge (10 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature arkose; feldspar* 40%; 32 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%; 50 feet above base: *granular very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%)	71
156	Covered; lower 30 feet probably thin-bedded siltstone or shale	176
155	Conglomerate, weathers light yellowish gray, poorly sorted; grains average 2 to 4 mm, scattered pebbles up to 10 mm; sandy, highly arkosic	4
154	Covered	14
153	Sandstone, light gray, weathers light yellowish gray, very coarse-grained, partly conglomeratic, poorly sorted, highly arkosic (4 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%)	12
152	Covered	22
151	Conglomerate and sandstone: unit weathers light yellowish brown; conglomerate, poorly sorted; grains average 4 to 6 mm, quartz pebbles up to 50 mm, white feldspar pebbles up to 30 mm; interbedded irregularly with sandstone, coarse-grained, poorly sorted, conglomeratic (7 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%; 25 feet above base: *very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%)	34
150	Covered	12
149	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; grains average 3 to 6 mm, rounded quartz pebbles up to 50 mm occur in scattered layers; highly arkosic; interbedded irregularly with thinner layers of sandstone, coarse-grained, conglomeratic; large-scale cross-bedding; unit forms prominent cliff (8 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%; 20 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature arkose;* feldspar 40%; 50 feet above base: *granular, very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature arkose;* feldspar 30%)	62
148	Covered; lower 50 feet has scattered talus of black shale and small limestone nodules, silty, fossiliferous; remainder of unit brush-covered	280
147	Sandstone and conglomerate: unit weathers light yellowish gray; sandstone, coarse-grained, poorly sorted, partly conglomeratic, arkosic; calcareous cement; interbedded irregularly with thinner layers of conglomerate with scattered quartz pebbles up to 40 mm; unit irregularly cross-bedded; forms cliff; strike N. 30° W., dip 26° NE (3 feet above base: *granular medium sandstone; quartz-overgrowth- and calcite-cemented, submature, muscovite-bearing arkose;* feldspar 30%)	55
	Partial thickness Alamitos Formation	3175
	Flechado Formation	
146	Covered; lower 50 feet probably shale; remainder of interval brush-covered with scattered sandstone and limestone talus	253
145	Shale, black, friable; containing numerous small, silty, fossiliferous limestone nodules and uncommon thin micaceous siltstone layers	66
144	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, conglomeratic, micaceous, carbonaceous, partly covered	16
143	Covered; talus of shale, black, micaceous, friable, and siltstone, micaceous	11
142	Conglomerate, weathers light yellowish gray, poorly sorted; grains average 2 to 4 mm; scattered pebbles of quartz up to 40 mm	12
141	Covered	27
140	Sandstone, light olive-gray, weathers light yellowish gray, coarse-grained, poorly sorted, conglomeratic; scattered pebbles of quartz up to 50 mm in top two feet; forms cliff at east side of Gallegos Valley about one quarter of a mile north of highway; strike N. 20° W., dip 26° NE (5 feet above base: *granular, coarse sandstone; quartz-overgrowth-cemented, submature, muscovite-bearing orthoquartzite;* no feldspar; 25 feet above base: *granular, medium sandstone; quartz-overgrowth-cemented, submature, muscovite- and feldspar-bearing orthoquartzite;* feldspar 1%)	27
139	Covered; bottom of Gallegos Creek, interval approximate	45
	Section shifted southeastward on unit 138 from highest exposure on high east-west-trending ridge due north of a point on the highway about one half mile east of the base of the section to a point near the road level at the east end of the ridge, due west of Gallegos Creek and about 500 yards north of highway	
138	Sandstone, weathers light yellowish gray, medium- to coarse-grained, poorly sorted, partly conglomeratic; scattered quartz pebbles up to 40 mm; irregularly bedded; forms low cliff at highest point on ridge; strike N. 70° W., dip 22° NE (10 feet above base: *medium sandstone; quartz-overgrowth-cemented, mature muscovite-bearing orthoquartzite;* no feldspar)	22
137	Covered	6
136	Sandstone, weathers light yellowish gray, coarse-	

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
	grained, poorly sorted, partly conglomeratic; scattered pebbles up to 10 mm	2
135	Covered	5
134	Sandstone and conglomerate: unit weathers light yellowish gray; sandstone, poorly sorted, fine-grained to pebbly; interbedded with conglomerate, poorly sorted; subrounded quartzite pebbles up to 120 mm and scattered dark gray chert pebbles; beds one-half to 1 foot thick are highly variable in thickness laterally; large-scale cross-bedding; forms high cliff (16 feet above base: *granular, medium sandstone; quartz-overgrowth-cemented, submature, muscovite- and feldspar-bearing orthoquartzite;* feldspar 1%; 35 feet above base: *coarse sandstone; quartz-overgrowth-cemented, muscovite- and feldspar-bearing orthoquartzite;* feldspar 2%)	59
133	Covered; shale talus in lower half	70
132	Sandstone and conglomerate; unit weathers light yellowish gray; sandstone, coarse-grained, poorly sorted, partly conglomeratic; interbedded irregularly with conglomerate; grains average 4 to 7 mm but some irregular layers with quartz and quartzite pebbles up to 80 mm; unit forms cliff (8 feet above base: *sandy, granule conglomerate; quartz-overgrowth-cemented, submature, feldspar-bearing orthoquartzite;* feldspar 3%; 15 feet above base: *granular, medium sandstone; quartz-overgrowth- and calcite-cemented, submature, muscovite- and feldspar-bearing orthoquartzite;* feldspar 3%)	21
131	Covered	13
130	Sandstone and conglomerate: unit weathers light yellowish gray, coarse-grained, poorly sorted; interbedded with thinner layers of conglomerate with pebbles up to 50 mm	5
129	Covered	181
128	Sandstone, medium light gray, weathers light yellowish gray, very coarse-grained, poorly sorted; conglomeratic with scattered pebbles up to 10 mm; cross-bedded	4
127	Covered	12
126	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted	2
125	Covered; lower 10 feet with talus of limestone, dark gray, finely crystalline, silty, nodular, algal	53
124	Limestone, medium dark gray, finely crystalline, partly fragmental; nodular layers 2 to 10 inches thick (5 feet above base: *partly recrystallized, algal biomicrudite); "Spirifer"* n.sp. A, *Kozlowskia* n.sp. A, *Beecheria* n.sp. A, *Cleiothyridina pecosi,* and *Phricodothyris perplexa*	10
123	Covered	6
122	Conglomerate and sandstone: weathers light yellowish gray; conglomerate, poorly sorted; grains average 3 to 6 mm, scattered pebbles up to 20 mm; thick-bedded; interbedded irregularly with thin layers of sandstone, coarse-grained, poorly sorted; unit forms cliff (9 feet above base: *granular, coarse sandstone; quartz-overgrowth- and calcite-cemented, submature, feldspar-bearing orthoquartzite;* feldspar 2%)	30
121	Sandstone and shale: sandstone, weathers light yellowish gray, very coarse-grained, poorly sorted; beds up to 1 foot thick; interbedded with poorly exposed sandy shale intervals of similar thickness	13
120	Covered	17
119	Conglomerate, weathers light yellowish gray, poorly sorted; grains average 4 to 6 mm; many scattered pebbles up to 40 mm	25
118	Covered	50
117	Sandstone, weathers light yellowish brown, very coarse-grained, poorly sorted, partly conglomeratic	9
116	Covered; probably shale or siltstone	8
115	Sandstone, weathers light yellowish brown, very coarse-grained, poorly sorted, partly conglomeratic; scattered quartz pebbles up to 10 mm; thick-bedded layers 1 to 4 feet thick interbedded with thin-bedded layers up to 1 foot thick	15
114	Covered; shale talus in lower 20 feet, sandstone talus in top 30 feet	120
113	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic; scattered pebbles up to 10 mm; irregular, thick-bedded layers 1 to 2 feet thick, interbedded with uncommon thin layers of sandy shale; strike N. 90° E., dip 24° N. (5 feet above base: *coarse sandstone; quartz-overgrowth-cemented, submature, feldspar-bearing orthoquartzite;* feldspar 2%)	14
112	Covered; scattered shale talus	16
111	Shale and sandstone: shale, weathers dark gray, micaceous, sandy; interbedded with thin layers sandstone, medium-grained; unit poorly exposed	8
110	Conglomerate and sandstone: unit weathers light yellowish gray; conglomerate, poorly sorted; grains average 2 to 6 mm, scattered quartz and quartzite pebbles up to 30 mm; interbedded irregularly with sandstone, coarse-grained, conglomeratic; unit cross-bedded	5
109	Covered	3
108	Sandstone, weathers light yellowish gray, very coarse-grained, poorly sorted, partly conglomeratic	3
107	Covered	7
106	Limestone, dark gray weathers moderate brown, finely crystalline, fossiliferous; nodular, hard beds 2 to 3 inches thick; interbedded with thin layers of shale	1½
105	Covered	1
104	Sandstone, weathers light yellowish brown, coarse-grained, poorly sorted, partly conglomeratic; scattered quartzite pebbles up to 30 mm	7
103	Covered, talus of gray, micaceous shale, and fine-grained, thin-bedded sandstone	3
102	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic; scattered quartz and quartzite pebbles up to 30 mm (4 feet above base: *coarse sandstone; quartz-overgrowth-cemented, immature, muscovite-bearing orthoquartzite;* no feldspar)	9
101	Covered; talus of gray, micaceous shale, and fine-grained, thin-bedded sandstone	3
100	Sandstone, weathers light yellowish brown, coarse-grained, poorly sorted, conglomeratic; scattered quartzite pebbles up to 30 mm; irregularly bedded, gradational with underlying unit	12
99	Conglomerate, weathers light yellowish gray, poorly sorted; grains average 4 to 6 mm; many scattered cream-colored quartzite pebbles up to 50 mm	6
98	Shale, dark gray, friable	5
97	Sandstone, weathers light yellowish gray, very coarse-grained; conglomeratic in upper 2 feet; irregular beds 2 to 3 feet thick	8
96	Covered	26
95	Sandstone and shale: sandstone, weathers light yellowish gray, medium-grained, thin-bedded; interbedded with thin layers of shale, gray, sandy, micaceous (2 feet above base: *medium sandstone; quartz-overgrowth-cemented, mature orthoquartzite;* no feldspar)	3
94	Covered	38
93	Sandstone and conglomerate: sandstone, very coarse-grained, poorly sorted, conglomeratic; interbedded irregularly with numerous thin layers of conglomerate, scattered subrounded pebbles up to 40 mm; strike N. 70° W., dip 22° NE (6 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature orthoquartzite;* no feldspar)	10
92	Covered	8

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
91	Shale, dark gray to black, slightly fossiliferous poorly exposed	3
90	Limestone and shale: limestone, dark gray, weathers dark yellowish gray, finely crystalline; nodular layers up to 8 inches thick; interbedded with thin layers of shale, black, fossiliferous	2
89	Sandstone, weathers light yellowish gray, coarse-grained, micaceous, carbonaceous	2
88	Covered, probably shale	3
87	Sandstone, weathers light yellowish gray, very coarse-grained; thin conglomeratic layers with scattered pebbles up to 20 mm (2 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, submature orthoquartzite;* no feldspar)	6
86	Conglomerate, weathers light yellowish brown, poorly sorted, sandy; common white quartzite and uncommon black chert pebbles up to 40 mm; interbedded irregularly with thin layers of coarse-grained sandstone in upper part	13
85	Sandstone, weathers light yellowish brown, very coarse-grained, poorly sorted, partly conglomeratic, with scattered pebbles up to 20 mm in upper part	27
84	Conglomerate, weathers light yellowish brown, poorly sorted; grains average 3 to 5 mm, scattered pebbles up to 20 mm	4
83	Covered	20
82	Conglomerate, weathers light yellowish brown, poorly sorted; grains average 3 to 5 mm, scattered pebbles up to 30 mm	17
81	Covered	2
80	Conglomerate, weathers light yellowish brown, poorly sorted; grains average 3 to 5 mm, scattered pebbles up to 20 mm	3
79	Covered, scattered shale talus	10
78	Sandstone, weathers light yellowish gray, coarse-grained, poorly sorted, partly conglomeratic; irregular thin layers with quartzite pebbles up to 30 mm; thick-bedded	11
77	Shale, dark gray, poorly exposed	1
76	Sandstone, weathers light yellowish brown, coarse-grained, conglomeratic; scattered pebbles up to 10 mm occurring in thin irregular layers	3
75	Covered	2
74	Sandstone, weathers light yellowish brown, coarse-grained, poorly sorted, conglomeratic; pebbles up to 10 mm occurring in thin irregular layers	8
73	Covered; probably shale or siltstone	9
72	Sandstone and conglomerate: unit weathers light yellowish brown; sandstone, coarse-grained, poorly sorted, conglomeratic; interbedded with irregular thin layers of conglomerate, poorly sorted; scattered quartzite and uncommon black chert pebbles up to 50 mm	15
	Section measurement shifted from crest of high ridge (at unit 70) southeastward about half a mile to low cliff (unit 72) about 200 yards north of a point on the highway about one half mile east of the base of the section. Units cannot be traced continuously and the thickness of unit 71 (covered interval) is approximate. Correlation is confirmed by comparison with measurement (not given here) from unit 71 eastward along poorly exposed crest of ridge to highest exposure on ridge (unit 138) and a comparison of this measurement with the better exposed sequence here given as units 72 to 138. This interval was measured on the steep face of the bluff beginning near the highway and extending northward to the crest	
71	Covered, approximate	40
70	Sandstone, dark greenish gray, weathers brown, coarse-grained, micaceous (*coarse sandstone; quartz-overgrowth-cemented, submature, muscovite-bearing orthoquartzite;* no feldspar)	2
69	Covered	4
68	Conglomerate and sandstone: unit weathers light yellowish brown; lower 4 feet of unit is sandstone, coarse-grained, poorly sorted; grading upward into conglomerate, poorly sorted; grains average 4 mm, scattered pebbles up to 20 mm (3 feet above base: *granular, very coarse sandstone; quartz-overgrowth-cemented, mature orthoquartzite;* no feldspar)	9
67	Covered; talus of shale, siltstone, and sandstone; thickness approximate	55
66	Sandstone, weathers light brown, coarse-grained, poorly sorted, silty, micaceous, partly conglomeratic (5 feet above base: *coarse sandstone; quartz-overgrowth-cemented, submature orthoquartzite;* no feldspar)	12
65	Covered; scattered talus of shale and sandstone; thickness approximate	45
64	Sandstone; medium gray, weathers light brown, medium- to coarse-grained, poorly sorted, partly conglomeratic; scattered pebbles up to 10 mm; thick-bedded	5
63	Covered; talus of dark gray shale in lower half	21
	Section shifted east about 150 yards on top of unit 62 along the south face of the hillside	
62	Sandstone and conglomerate: unit weathers light yellowish brown; sandstone, coarse-grained, poorly sorted; interbedded irregularly with thin layers of conglomerate, sandy, poorly sorted; unit cross-bedded	14
61	Covered; scattered shale talus	13
60	Sandstone, weathers light yellowish brown, coarse-grained, poorly sorted, thin-bedded	3
59	Covered	5
58	Sandstone and conglomerate: unit weathers light yellowish gray; sandstone, coarse-grained, poorly sorted; interbedded irregularly with thin to thick layers of conglomerate, poorly sorted; subangular quartzite pebbles up to 30 mm; unit cross-bedded, forms major cliff high on west end of ridge (base: *coarse sandstone; quartz-overgrowth- and calcite-cemented, submature orthoquartzite;* no feldspar; 20 feet above base: *sandy, granule conglomerate; quartz-overgrowth-cemented, submature, feldspar-bearing orthoquartzite;* feldspar 1%)	49
57	Shale, black, silty, friable	2
56	Covered	23
55	Siltstone and limestone: siltstone, dark gray, weathers light yellowish gray, calcareous; interbedded with small, tabular limestone nodules which are sparsely fossiliferous (nodule 3 feet above base: *slightly silty biomicrosparite*)	5
54	Covered	55
53	Limestone and siltstone: limestone, dark gray, weathers dark yellowish gray, finely crystalline, silty; interbedded in thin nodular layers with siltstone, calcareous, micaceous (base: *very sandy biosparite*)	6
52	Siltstone, medium gray, weathers light gray, calcareous, irregularly thin-bedded, fossiliferous; *"Protoniella"* cf. *welleri*	5½
51	Covered	46
50	Sandstone, weathers light yellowish brown, coarse-grained, poorly sorted, thick-bedded; scattered wood fragments	4
49	Covered	9
48	Siltstone and limestone: unit dark gray, weathers light yellowish brown; siltstone, calcareous; interbedded in irregular, thin, platy layers with limestone, silty (2 feet above base: *silty spiculiferous biomicrudite*)	5

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
47	Shale, dark gray, calcareous, slightly fossiliferous	1½
46	Limestone, medium gray, weathers light gray, medium crystalline, sandy, partly crinoidal (2 feet above base: *very sandy biosparudite)*	4
45	Covered; probably shale or siltstone	11
44	Sandstone, weathers moderate reddish brown, coarse-grained, poorly sorted, thick-bedded (5 feet above base: *coarse sandstone; quartz-overgrowth-cemented, immature orthoquartzite;* no feldspar)	12
43	Sandstone and covered: scattered small exposures of sandstone, fine-grained, thin-bedded; separated by covered intervals with scattered talus of siltstone and shale (10 feet above base: *fine sandstone; calcite-cemented, mature, muscovite-bearing orthoquartzite;* no feldspar)	25
42	Sandstone, weathers moderate reddish brown, coarse-grained, poorly sorted, thick-bedded (3 feet above base: *coarse sandstone; quartz-overgrowth-cemented orthoquartzite;* no feldspar)	5
41	Covered; scattered talus of sandstone	48
40	Sandstone and conglomerate: unit weathers light yellowish gray; sandstone, fine- to coarse-grained, poorly sorted, partly conglomeratic; interbedded irregularly with thinner layers of conglomerate, poorly sorted; pebbles up to 10 mm; unit thick-bedded and cross-bedded, forms first major cliff on ridge east of Tio Maes Canyon (base: *very coarse sandstone; quartz-overgrowth-cemented, immature, biotite-bearing orthoquartzite;* no feldspar; 15 feet above base: *medium sandstone; quartz-overgrowth- and calcite-cemented, mature, biotite-bearing orthoquartzite;* no feldspar)	20
39	Covered	33
38	Limestone, medium dark gray, weathers light gray, finely crystalline, partly crinoidal, partly sandy (top: *slightly sandy biomicrosparudite); Spirifer* n.sp. D?, *"Buxtonia"* n.sp. A, *Ovatia nodosus?, Schizophoria oklahomae, Antiquatonia coloradoensis*	2
37	Limestone, medium gray, weathers light yellowish gray, fragmental, very sandy; conglomeratic in lower half, scattered limestone and quartz pebbles up to 20 mm (base: *very sandy biosparudite)*	7
36	Covered; scattered limestone talus	22
35	Limestone and siltstone: limestone, medium gray, weathers light yellowish gray, finely to medium crystalline, partly crinoidal, partly silty; interbedded in thin layers with siltstone, calcareous, unit sparsely fossiliferous (base: *sandy bryozoan biomicrosparudite;* top: *slightly sandy bryozoan biosparudite)*	17
34	Covered	18
33	Limestone, dark gray, weathers light yellowish gray, fragmental, thin- and medium-bedded, nodular, partly sandy, sparsely fossiliferous; unit fractured and mineralized	3
32	Covered	13
31	Limestone, medium gray, weathers light gray, finely to coarsely crystalline, partly crinoidal; unit locally folded (4 feet above base: *very slightly sandy crinoidal biomicrudite)*	7
30	Covered	3
29	Conglomerate, medium gray, weathers light yellowish brown, poorly sorted	3
28	Covered	33
27	Conglomerate, medium gray, weathers light yellowish brown, poorly sorted; grains average 2 to 4 mm; layers one-half to 1 foot thick; unit forms poorly exposed ledge on hill overlooking Tio Maes Canyon; strike N. 40° W., dip 24° NE	4
26	Limestone, medium gray, weathers light yellowish gray, fragmental, very crinoidal, thick-bedded, partly sandy (2 feet above base: *sandy, algal and bryozoan biosparudite); Antiquatonia* cf. *morrowensis, Schizophoria texana*	5
25	Covered	4
24	Siltstone, medium gray, weathers moderate reddish brown, cherty, calcareous, banded (3 feet above base: *very fine sandstone; calcite-cemented, mature orthoquartzite;* no feldspar)	5
23	Covered	35
22	Sandstone, medium gray, weathers light yellowish gray, fine- to very coarse-grained, poorly sorted; scattered pebbles to 5 mm, thick-bedded (4 feet above base: *granular, very coarse sandstone; quartz-overgrowth- and calcite-cemented, submature orthoquartzite;* no feldspar)	5
21	Covered; talus of siltstone, shale, sandstone, and conglomerate	49
20	Sandstone, weathers light yellowish brown; basal 3 feet conglomeratic, cross-bedded; overlain by alternating layers of fine-grained and very coarse-grained, poorly sorted sandstone; unit forms lowest ledge on hill; base of unit located on trail up Tio Maes Canyon, at National Forest gate (10 feet above base: *medium sandstone; quartz-overgrowth-cemented, submature orthoquartzite;* no feldspar)	17
19	Covered, approximate	105

Units 20 to 62 measured eastward up poorly exposed ridge beginning on trail in Tio Maes Canyon at National Forest gate about 200 yards north of State Highway 3. The underlying covered interval (unit 19), in the bottom of Tio Maes Canyon, conceals the lowest Pennsylvanian beds, the Mississippian Terrero Formation, and the pre-Mississippian(?) Espiritu Santo Formation. The still older pre-Mississippian(?) Del Padre Formation is well exposed in the north bank of the Rio Pueblo near the mouth of Tio Maes Creek (*see* pl. 9-B). In the south bank of the Rio Pueblo east of the mouth of Tio Maes Creek, the covered sequence just mentioned was partly exposed before being covered in the summer of 1961 by the rerouted State Highway 3. Units 16 to 18, as here given, were described at that now-concealed locality. The thickness of unit 19 (covered interval) is based on a measurement of the covered interval from the top of the Del Padre Formation north of the river to the base of unit 20, less the thickness, south of the river, from the top of the Del Padre Formation to the top of unit 18

UNIT NO.	DESCRIPTION	THICKNESS (FEET)
18	Limestone, dark gray, weathers yellowish gray, finely to coarsely crystalline, sandy; nodular and irregularly bedded; unit now covered by rerouted highway; *"Buxtonia"* n.sp. A?, *Antiquatonia* cf. *morrowensis, Schizophoria texana;* strike N. 30° W., dip 22° NE	4
17	Covered	30
16	Sandstone, medium gray weathers light reddish brown, fine-grained, calcareous	10
15	Covered	16
	Total thickness of Flechado Formation	2586½

Tererro Formation (Mississippian), strike N. 30° W., dip 22° NE

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PLATES 1-13

WITH EXPLANATIONS

PLATE 1

(in pocket)

GEOLOGY OF PART OF THE SOUTHERN SANGRE DE CRISTO MOUNTAINS,
NEW MEXICO

PLATE 2

VIEW OF TRUCHAS PEAKS

Winter view, looking north, showing Truchas Divide (bottom, center) formed on Pennsylvanian rocks, then northward into high massif of Truchas Peaks (South Truchas Peak is first sharp summit; Middle Truchas Peak is following broad summit; North Truchas Peak has snow streamer) eroded on Precambrian quartzite. Jicarilla fault crosses Divide where steep rocky rise begins. Great cirques cut out of massif on northwest side are well shown. Rio Grande depression spreads out to north and west, except for isolated spur of Picuris Range (near top, right). *Air photo by David N. Rodgers*

PLATE 3

VIEW OF TRUCHAS AND SANTA FE RANGES

Looking southward toward Sandia Mountains (top, skyline). Winter view showing north slopes of Jicarilla Peak (lower left) connected by low ridge westward with North Truchas Peak (all snow), thence Middle Truchas Peak (two rocky summits, east and west), thence South Truchas Peak (snow streamers, center), thence along Truchas Divide followed by massive curving ridge of Pecos Baldy (left center). Low forested gap in summit ridge follows (Picuris—Pecos fault crosses here and is responsible for gap and offset in range crest). Santa Fe Range rises in middle distance, crested by sharp summits of Capulin, Santa Fe Baldy (highest), and Lake Peaks. *Air photo by David N. Rodgers*

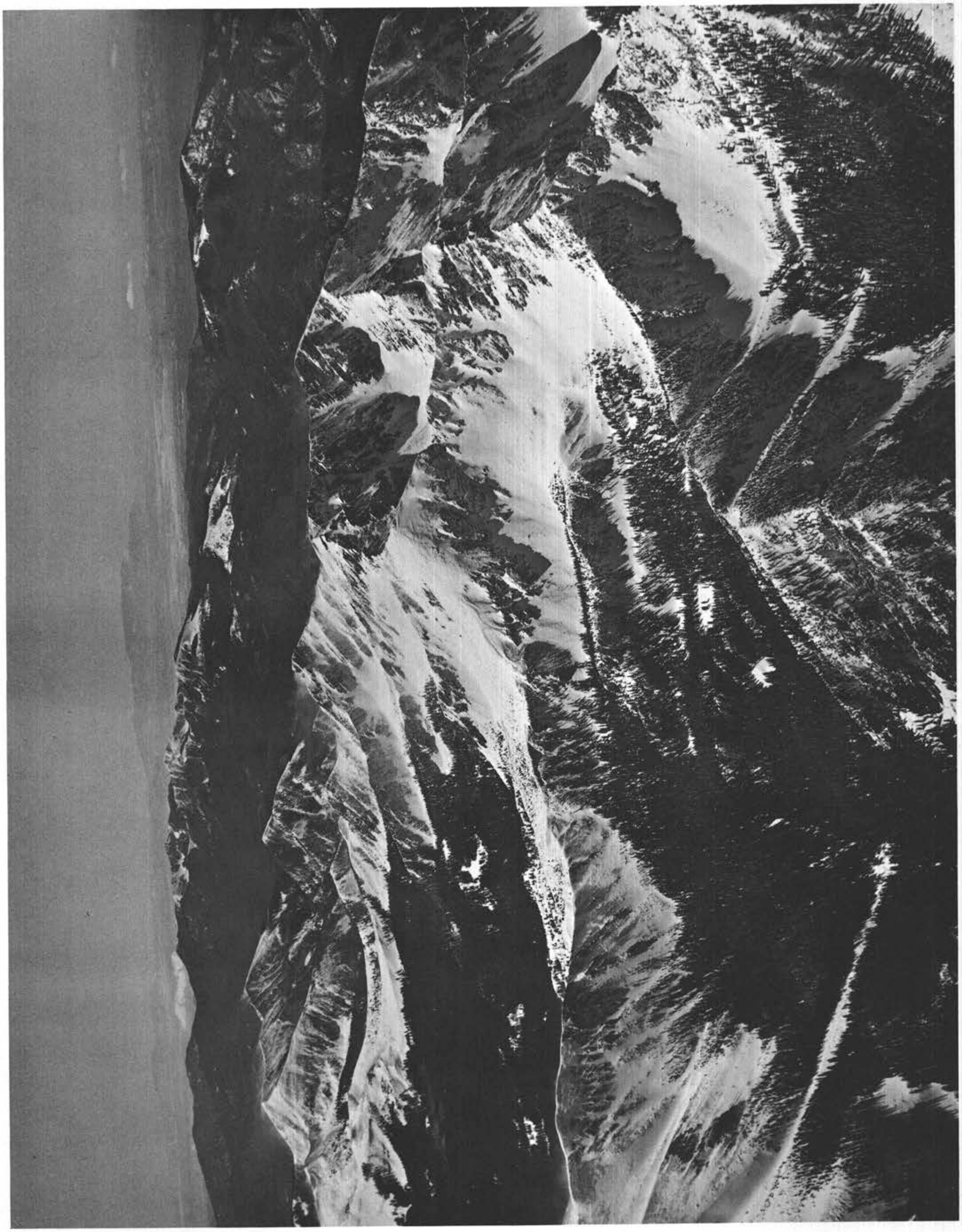


PLATE 4

VIEW OF MIDDLE TRUCHAS PEAK

Winter scene looking west across Rio Grande Valley toward Jemez Mountains on far horizon. Rocky mass of Middle Truchas Peak, with its east and west summits, towers at left of center. Great cirque of Rincon Grande drops off westward at center. Broad snow summit of North Truchas Peak rises at right of center.

Air *photo by David N. Rodgers*

PLATE 5

PANORAMA OF THE TRUCHAS PEAKS

Looking west from south slopes of Jicarilla Peak to the three Truchas Peaks (South, Middle, and North). All four peaks consist of resistant Precambrian quartzite and the Middle Truchas Peak is marked by a zone of snow-white micaceous quartzite. The peaks have been uplifted along west side of the Jicarilla fault which here runs northeast-southwest across the lower left part of photograph and separates quartzite from poorly exposed Pennsylvanian sedimentary rocks east of fault (bottom, left).

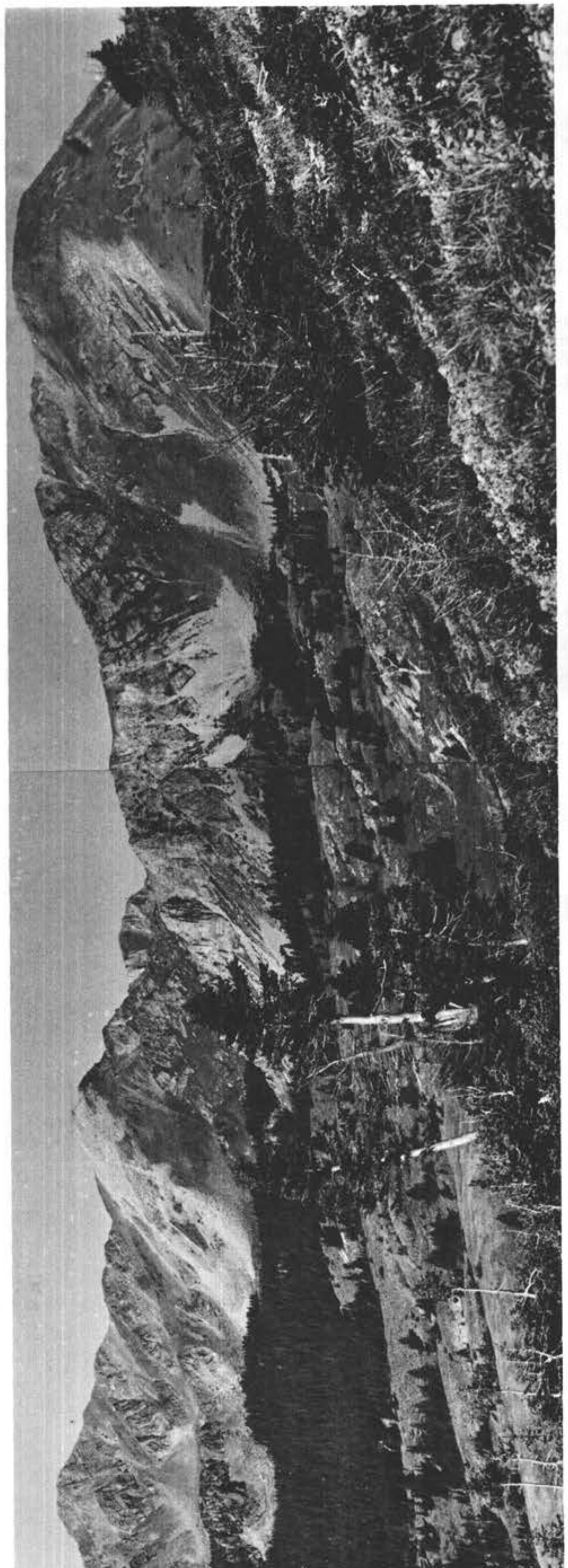


PLATE 6

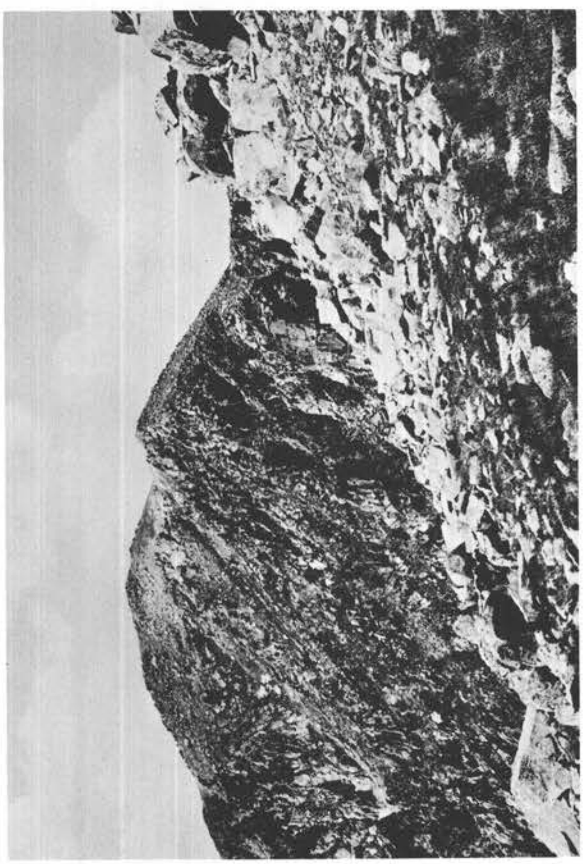
VIEWS OF PRECAMBRIAN ROCKS

A. Granite summit ridge of Santa Fe Baldy. Looking southwest toward highest summit (12,600 feet) from ridge top north of Lake Katherine.

B. Dumps of Pecos Mine two miles north of Terrero. Low cliffs on west side of valley expose Mississippian and older Paleozoic rocks at base of outcrop. Sporadic exposures of Pennsylvanian limestone and shale are visible higher up on valley side (site of Pennsylvanian part of Paleozoic section 22).

C. Slabby jointing in Precambrian quartzite of the Ortega Formation. Looking northwest along summit ridge of Middle Truchas Peak (13,00o feet). Joint surfaces dip 4o degrees southeastward and are parallel to bedding.

D. Lake Katherine. One of the most beautiful glacial lakes of Pecos Wilderness Area. Located at I 1,700 feet in large cirque cut in Precambrian granite on east side of Santa Fe Baldy. Looking east toward Pecos Valley, past moraine which dams lake at eastern edge.



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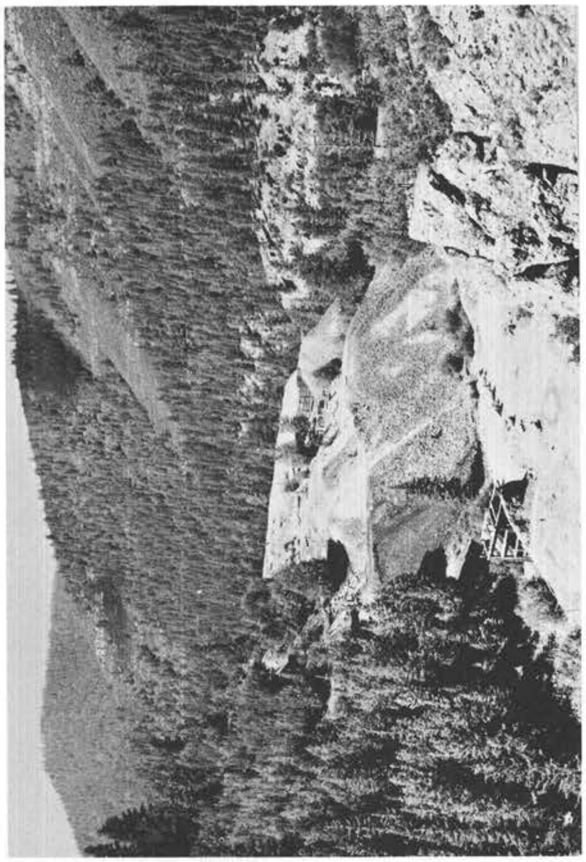

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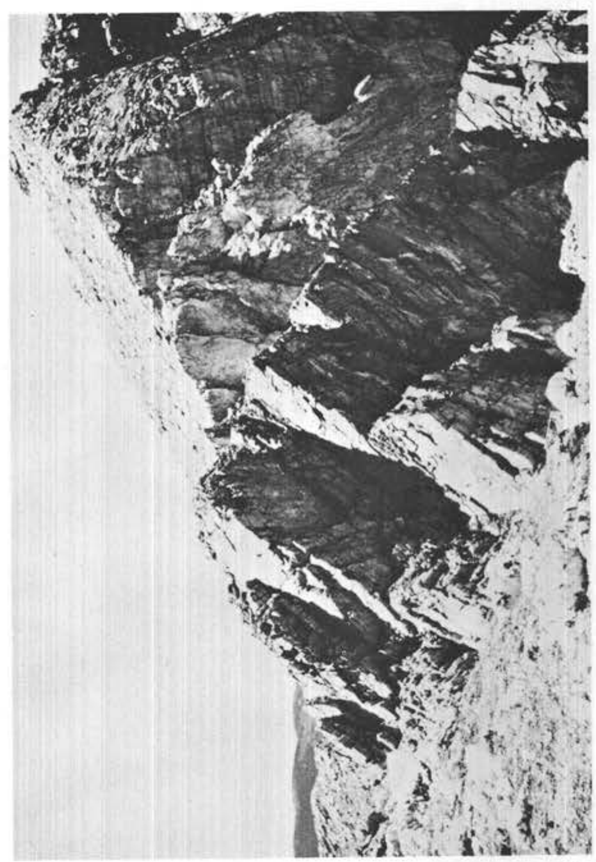

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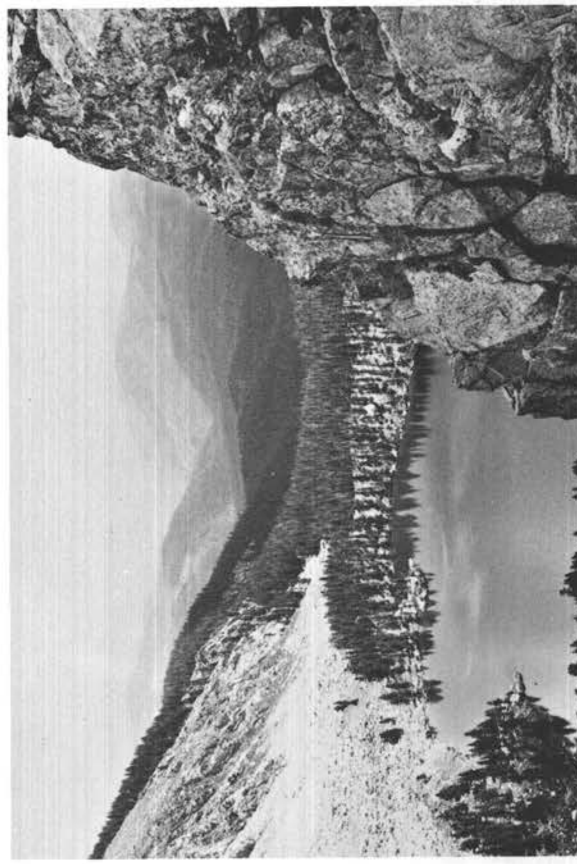

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PLATE 7

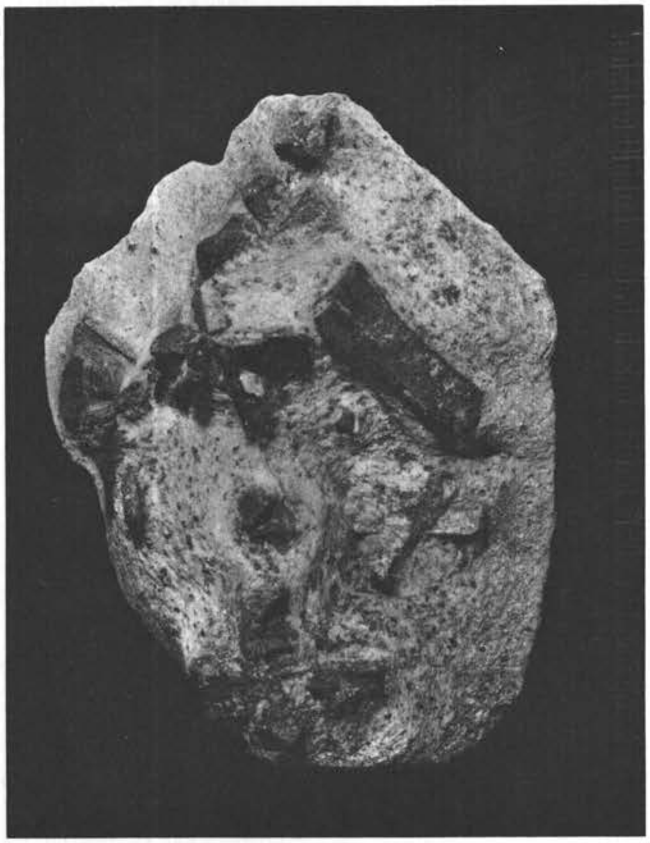
PHOTOGRAPHS OF PRECAMBRIAN ROCKS *(by Laura Gilpin)*

A. Staurolite schist of the Rinconada Schist Member of the Ortega Formation, from site two miles below head of Rio Mora.

B. Smooth, silvery muscovite-quartz-biotite phyllite of the Rinconada Schist Member of the Ortega Formation, from point five miles below head of Rio Mora.

C. Tightly folded layers of the lower quartzite member of the Ortega Formation from cirque north of Middle Truchas Peak. Folded layers are separated by thin films of muscovite.

D. Xenoliths of amphibolite in Embudo Granite from north fork of Willow Creek. Partial assimilation of amphibolite by granite has produced here a "dark granite" of quartz-diorite composition.



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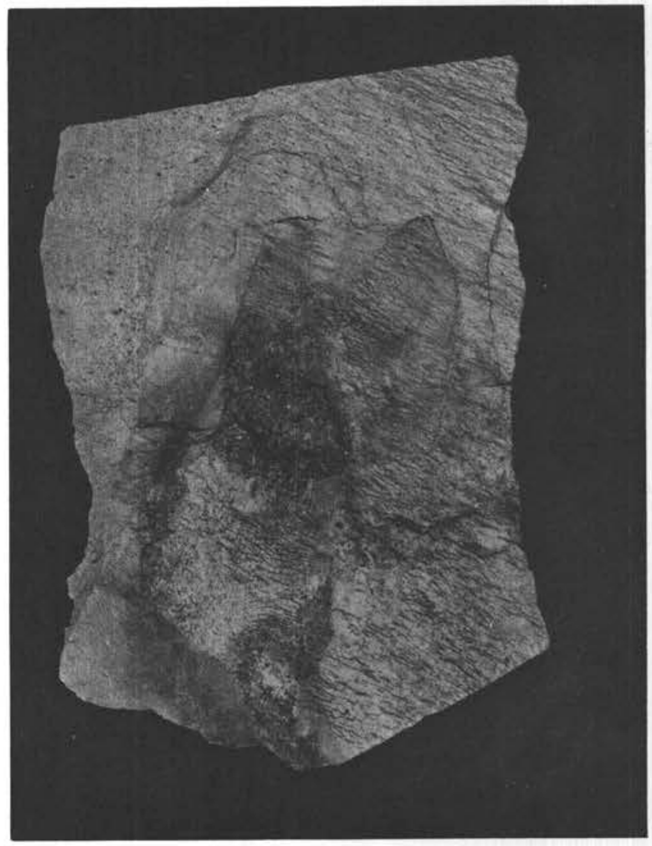

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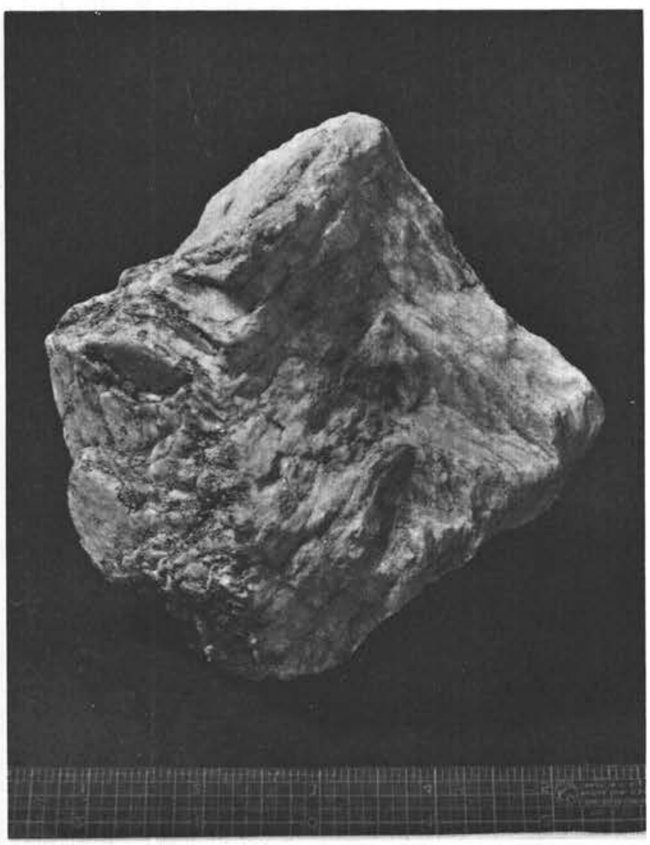

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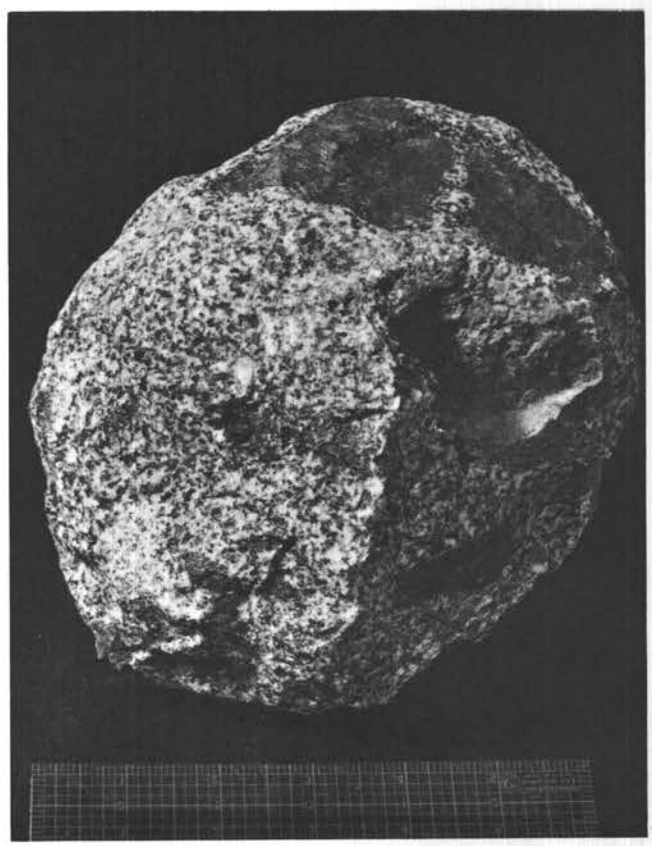

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PLATE 8

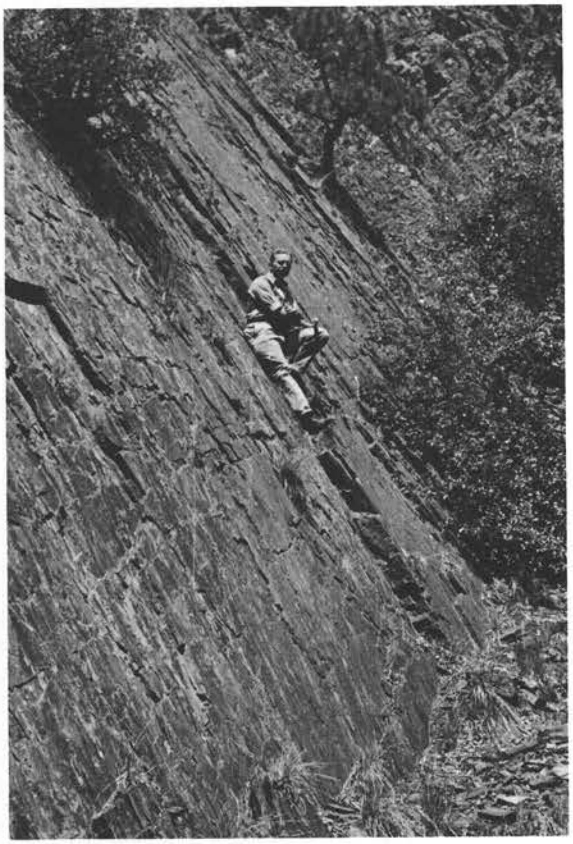
VIEWS OF PRECAMBRIAN ROCKS AND THE BASAL PALEOZOIC UNCONFORMITY

A. Looking east along cliff outcrop of black carbonaceous Pilar Phyllite northeast of Pilar in the Picuris Range. Slaty character of rock and steep southerly dip of foliation are well shown.

B. Looking north past Brazos Cabin on upper Rio Medio at ribs of granite standing vertical tens of feet above hillside. Ribs run parallel to, and stand one-quarter mile west of Picuris—Pecos fault. Ribs consist of silicified brecciated rock that is very resistant to erosion.

C. Irregularly bedded, coarse conglomerates of Del Padre Sandstone unconformable on Precambrian quartzite. Boulders of quartzite in Del Padre are more than one foot in diameter. Sloping, irregular quartzite surface seen in foreground. Del Padre was here deposited in valley on old erosional surface; compare with Plate 9-A which shows Del Padre Sandstone with no conglomerate where deposited on Precambrian quartzite depositional high. Location on high slope east of upper Rio Mora, north of Rociada trail.

D. Unconformity of Del Padre Sandstone on nearly flat erosional surface of Precambrian amphibolite. Regolith one foot thick on amphibolite is overlain by six feet of the Del Padre Sandstone, which in turn is overlain conformably, in upper-middle part of photograph, by Espiritu Santo Formation. Location is at entrance to abandoned mine tunnel above Pecos mine dumps on north side of Willow Creek, one-quarter mile east of Pecos Valley. Tunnel entrance six feet high.



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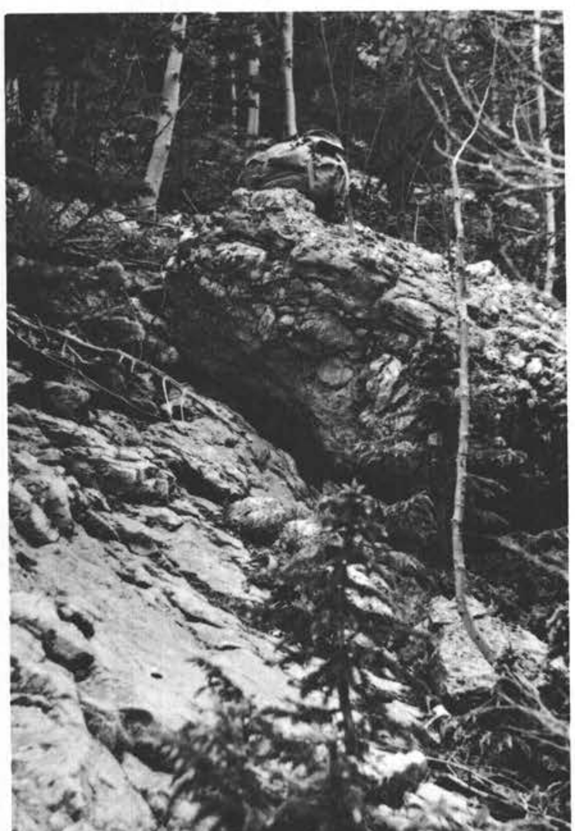

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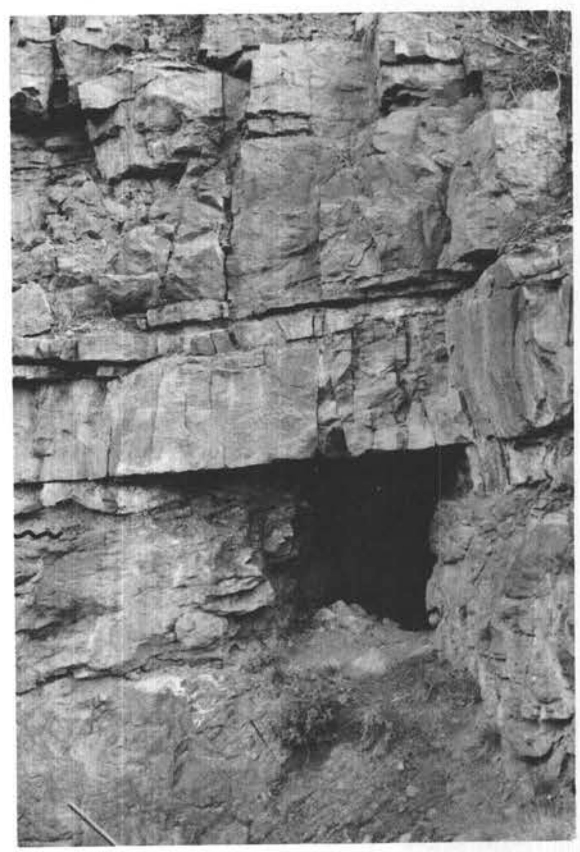

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PLATE 9

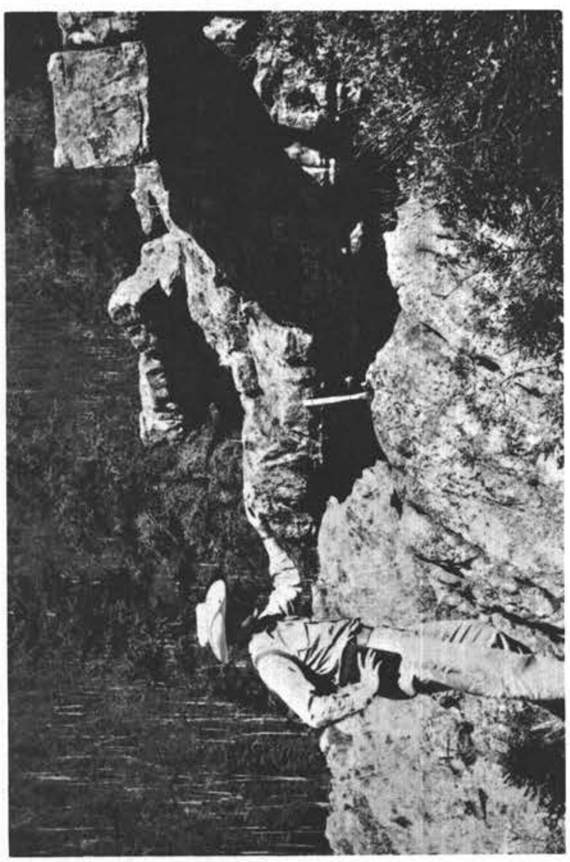
VIEWS OF DEL PADRE AND ALAMITOS FORMATIONS

A. Unconformity of Del Padre Sandstone on steeply dipping Precambrian quartzite, marked by geologic hammer. Del Padre here deposited on depositional high; irregularly bedded conglomerates occur at base in depositional depression near by. Compare with Plate 8-C. Location is on cliff top on east side of Pecos Canyon one and one-half miles south of Beatty's Cabin.

B. Del Padre Sandstone. Note even bedding and vertical jointing. Top of formation about at head-level of figure; contact with overlying Espiritu Santo Formation is covered. Lower contact (covered) with Precambrian Rio Pueblo Schist located about 5o yards to left of photograph. Location is on north side Rio Pueblo, Paleozoic locality 6o.

C. Alamitos Formation. Cross-bedded arkosic sandstone lenses interbedded with maroon and green shale in unit 33 of Paleozoic section 96 *(see* fig. 14). Location is in abandoned railroad cut on east side of Alamitos Valley two miles north of Alternate U.S. Highway 84-85.

D. Alamitos Formation. Cross-bedded, arkosic sandstone and conglomerate in unit 171 of Paleozoic section 6o. Note figure at roadside for scale. Location is on north side Rio Pueblo Valley about six miles east on State Highway 3 from junction with State Highway 75.



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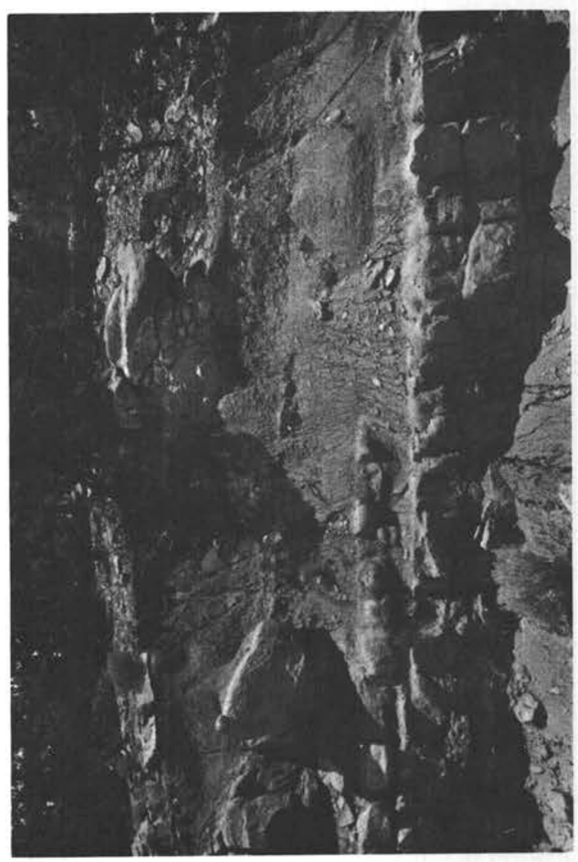

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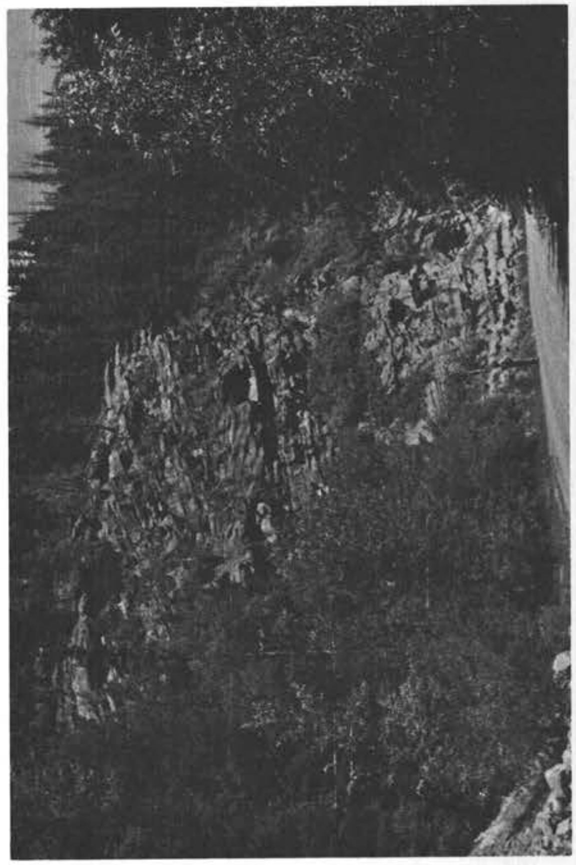

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PLATE 10

VIEWS OF DEL PADRE, ESPIRITU SANTO, AND TERERRO FORMATIONS

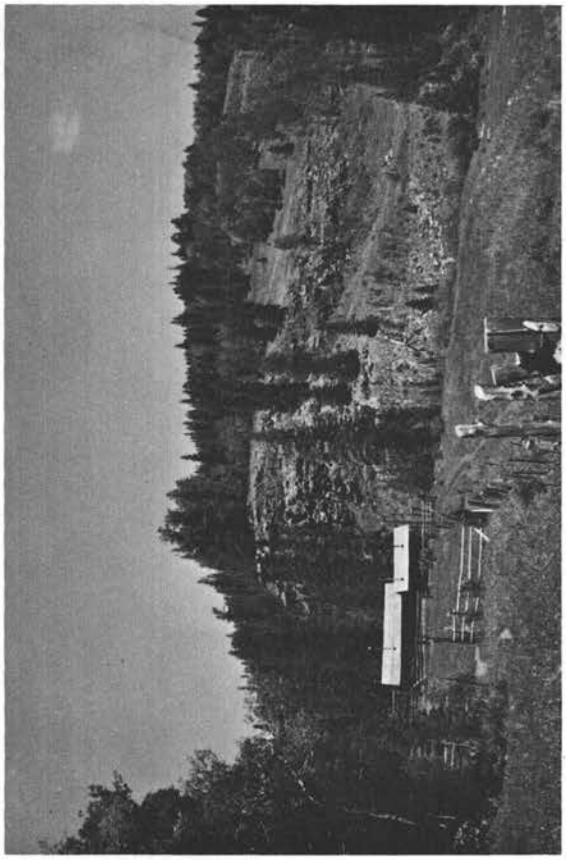
A. Limestone boulder conglomerate, Macho Member of Tererro Formation. Exposure in bluff on north side of junction of Mora and Pecos Rivers, showing irregular, unsorted pattern of rounded limestone boulders. One-foot rule supplies scale.

B. Type locality of Del Padre Sandstone. Site is at bluff north of Beatty's Cabin, here shown at junction of Rito del Padre and Pecos River (at right). Paleozoic section 4.

C. Irregular, unconformable contact of the Macho Member of the Tererro Formation on Espiritu Santo Formation. Note truncation of Espiritu Santo Formation and vertical fractures in that formation which do not extend above unconformity. Also note bedded limestone lens at base of Macho boulder conglomerate at center of photograph. Bluff is on north side of Pecos River near mouth of Jacks Creek. Site of Paleozoic section 13, here showing detail of lower-middle part of bluff designated in Plate I 1-A.

D. Well-rounded boulder of partly recrystallized quartzite over four feet in length contained in the Macho Member of the Tererro Formation. Exposure near beginning of Hamilton Mesa road at site of Paleozoic section 5. Five-foot staff supplies scale.

A



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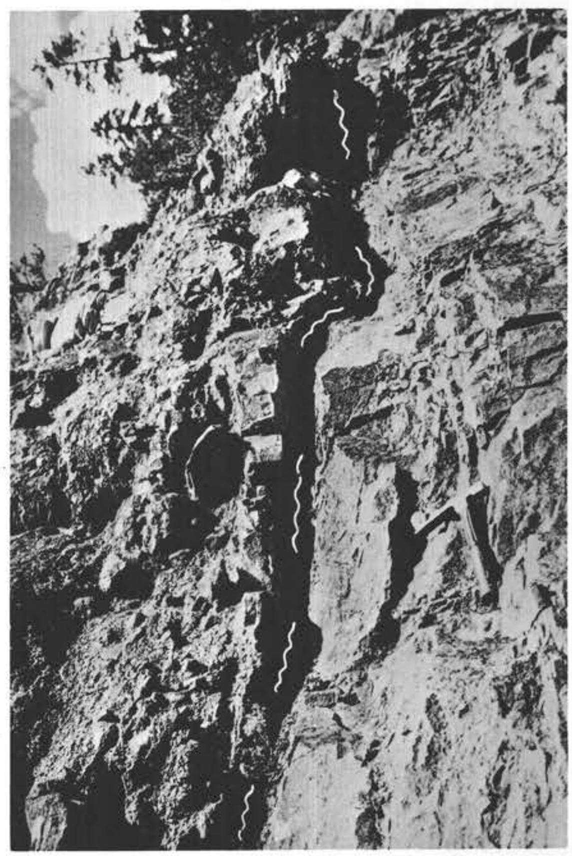


C

D

PLATE 11

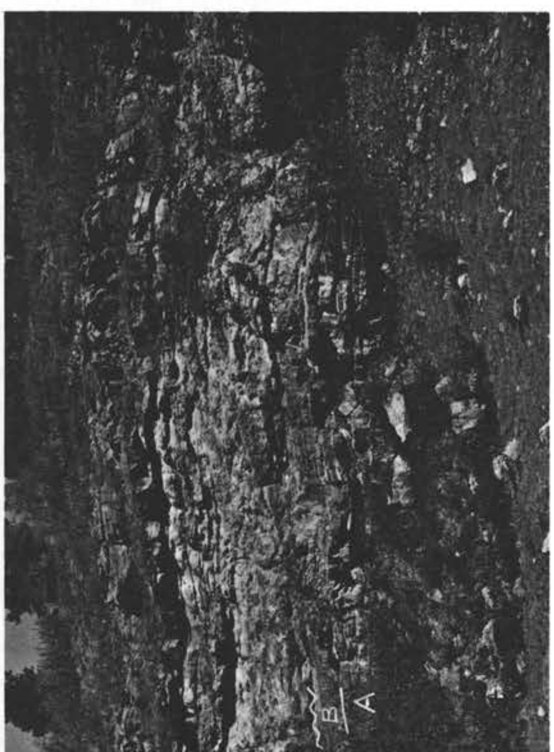
VIEWS OF PALEOZOIC FORMATIONS

A. Mississippian and older Paleozoic formations exposed in bluff on northwest side of Pecos River near mouth of Jacks Creek. Compare letters at left of photograph with diagram in Plate Site of Paleozoic section 13. Bluff is about 5o feet high. A close-up of lower-middle part of bluff is shown in Plate 10-C.

B. Diagram explaining Plate 11-A. Zigzag line marks upper limit of vegetation at base of cliff.

C. Dalton Bluff, type locality of the La Pasada Formation. Site of Paleozoic section 36, located on west side of Pecos River six and one-half miles north of town of Pecos. Bluff stands I zoo feet high above river level.

D. Diagram explaining Plate 11-C. Numbered cliffs are indicated on Figure 12.


E
D
C
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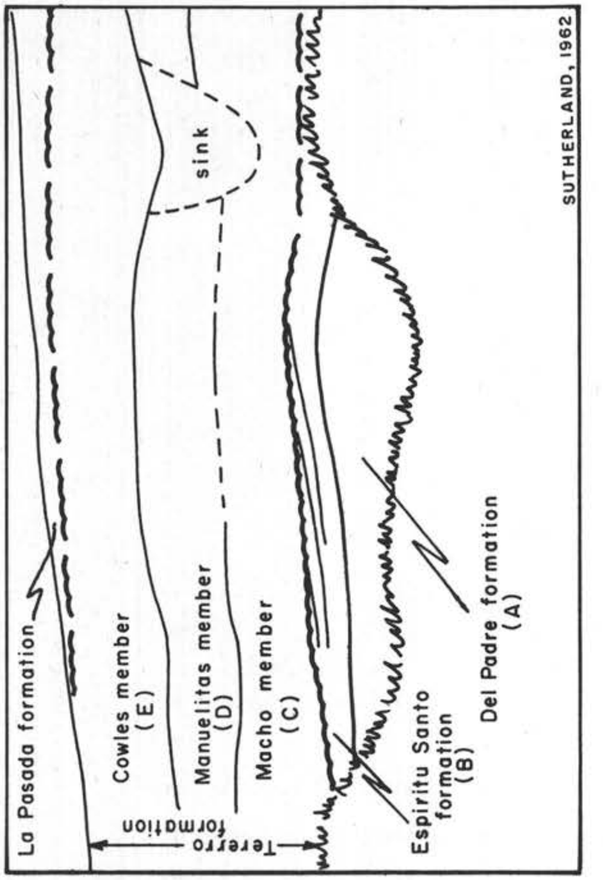
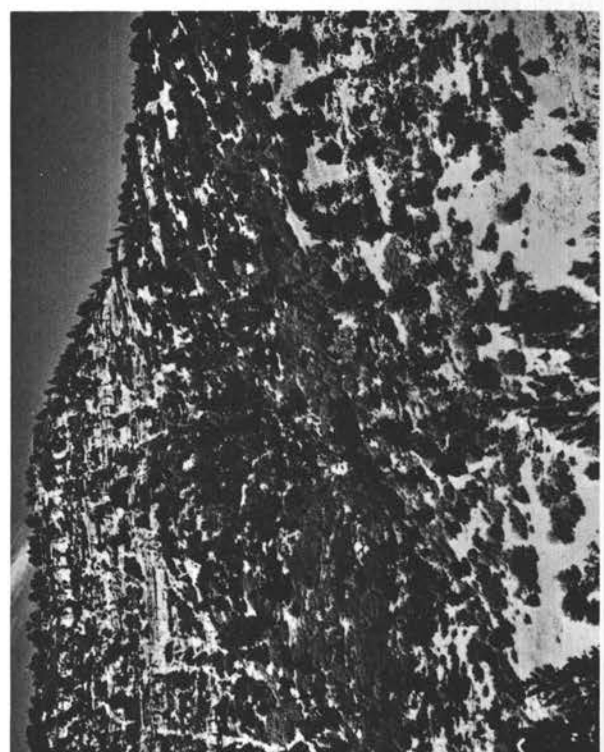
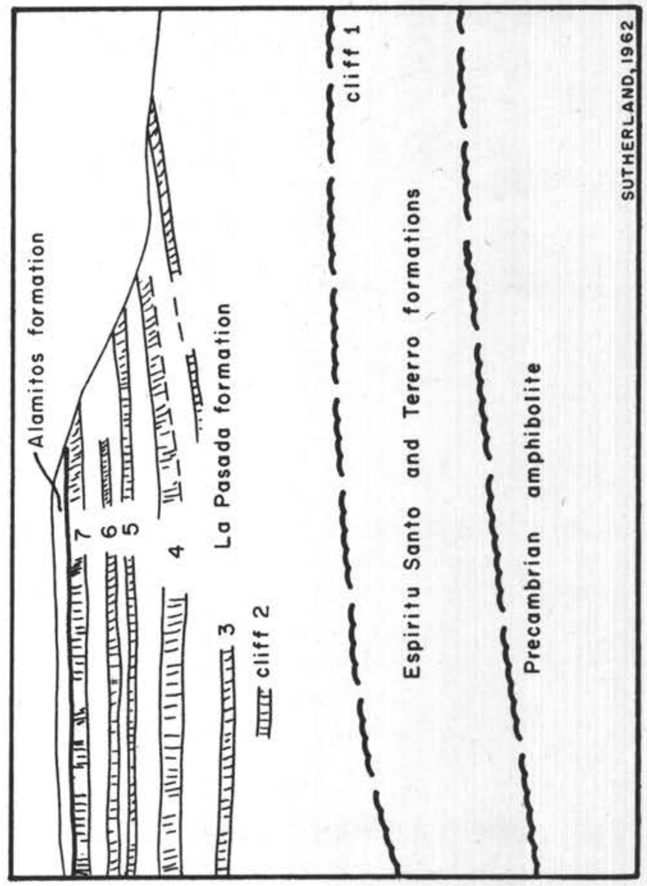
A


La Pasada formation
Cowles member
(E)
Manuelitas member
(D)
Macho member
(C)
Tererro formation
Espiritu Santo formation
(B)
Del Padre formation
(A)
sink
SUTHERLAND, 1962

B


7
6
5
4
3

C


Alamitos formation
7
6
5
4
3
La Pasada formation
cliff 2
cliff 1
Espiritu Santo and Tererro formations
Precambrian amphibolite
SUTHERLAND, 1962

D

PLATE 12

JICARILLA FAULT

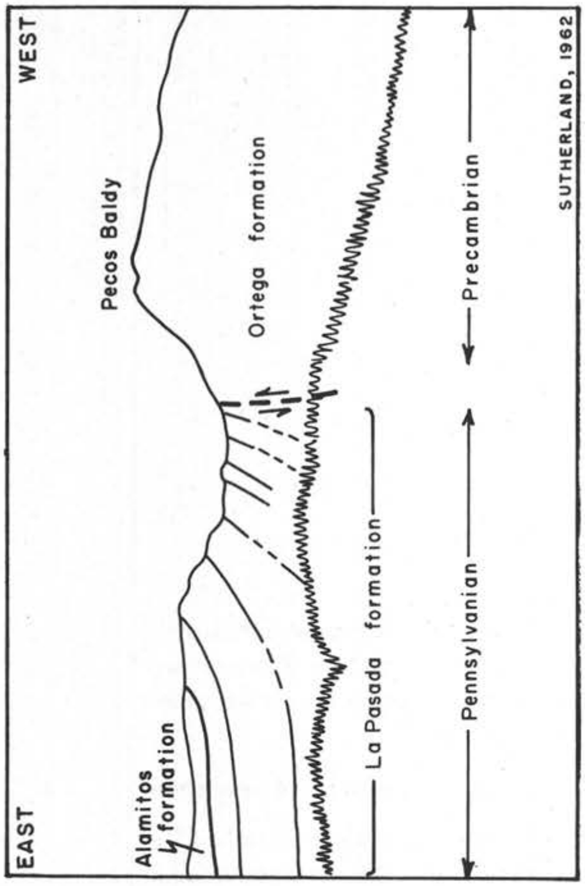
A. Jicarilla fault. Looking south toward northeast shoulder of Pecos Baldy (at right) across upper drainage of Rio Medio. Pecos Baldy Lake is located immediately south of low saddle in ridge trending east from fault at base of shoulder. Paleozoic section I o measured along crest of this ridge. Compare with *Frontispiece* which shows same ridge looking northward from south of Pecos Baldy Lake.

B. Diagram explaining Plate 12-A. Zigzag line marks upper limit of vegetation.

C. Jicarilla fault. Looking southwest across upper drainage of the west fork of Rio Santa Barbara toward east face of Jicarilla Peak. Sharp folding evident in Pennsylvanian strata of the La Pasada Formation, east of fault. Site of Paleozoic section 40.

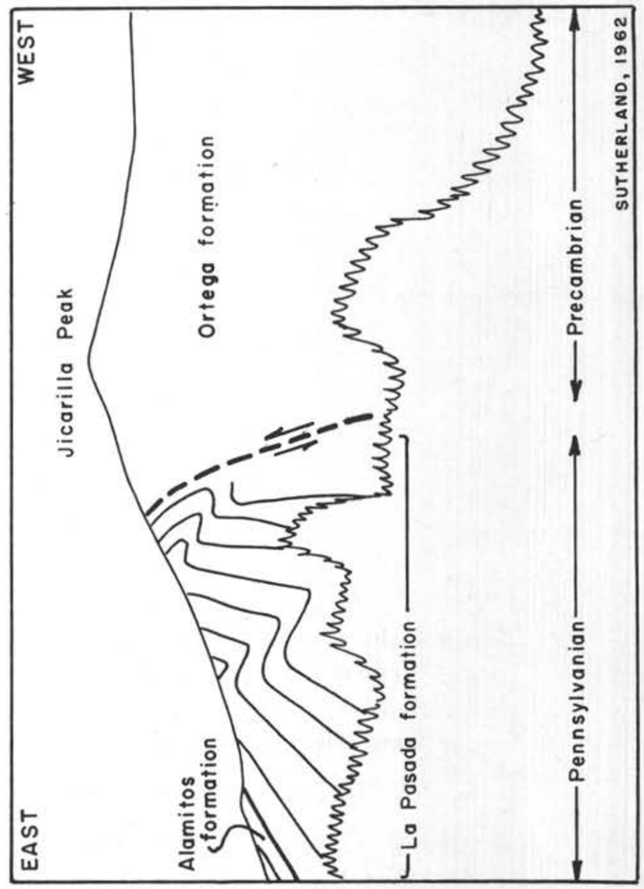
D. Diagram explaining Plate 12-C. Zigzag line marks upper limit of vegetation.

A


EAST
WEST
Alamitos formation
Pecos Baldy
Ortega formation
La Pasada formation
Pennsylvanian
Precambrian
SUTHERLAND, 1962

B

C


EAST
WEST
Alamitos formation
Jicarilla Peak
Ortega formation
La Pasada formation
Pennsylvanian
Precambrian
SUTHERLAND, 1962

D

PLATE 13

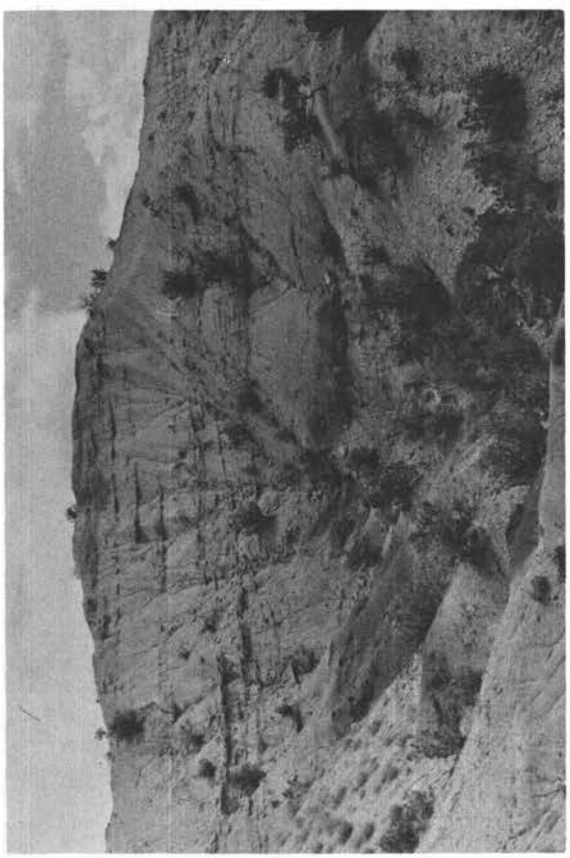
VIEWS OF CENOZOIC DEPOSITS AND FEATURES

A. Westward-tilted beds of Tesuque Formation exposed in steep hillside near Chupadero.

B. Nearly horizontal beds of Ancha Formation in thick exposure one-half mile west of town of Truchas.

C. Dissected alluvial fan of glacial origin along Rio Santa Barbara in the broad expanse of the Penasco—Rodarte—Llano area. Fan composed of poorly sorted gravel and boulders in a sand matrix with a total thickness of more than zoo feet.

D. Stone nets developed on Pennsylvanian arkosic sandstone of the Alamitos Formation over the large, gentle dip slope which comprises the high part of the ridge between the middle and west forks of the Rio Santa Barbara. Diameter of rings is about eight to ten feet.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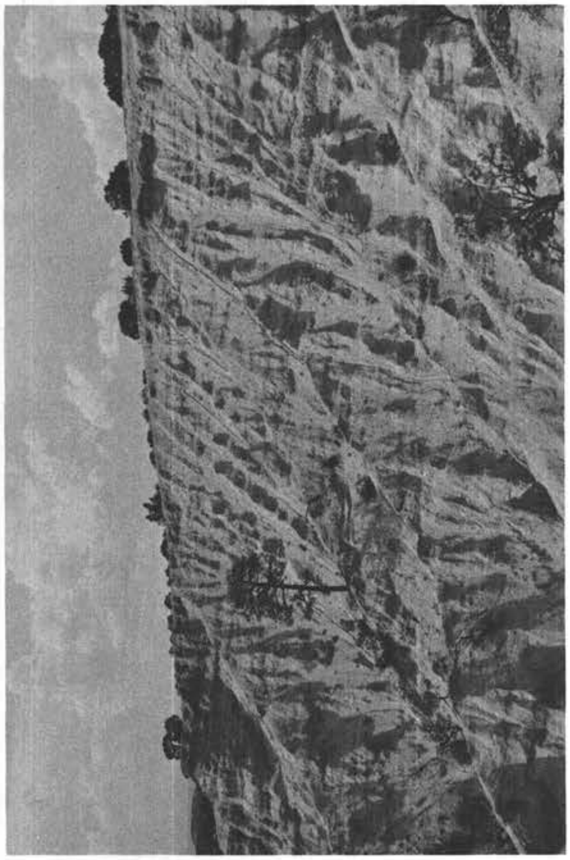
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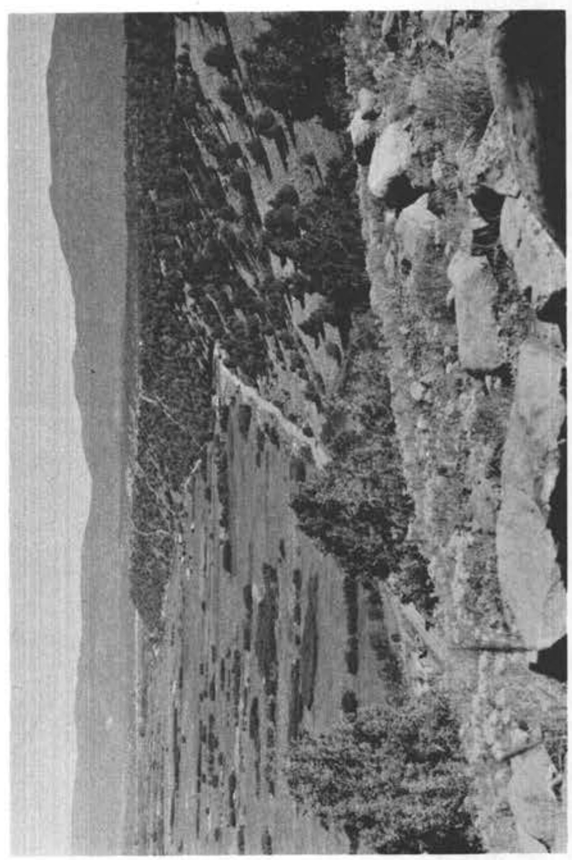
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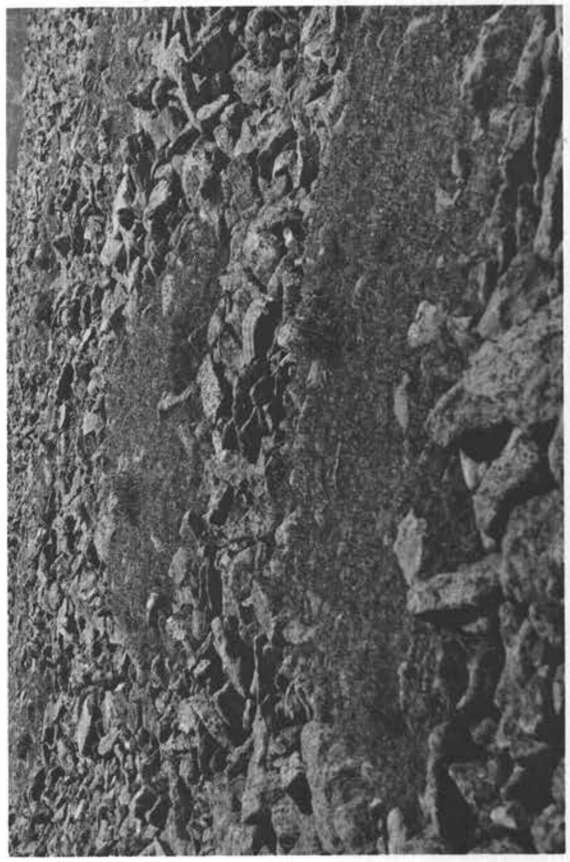
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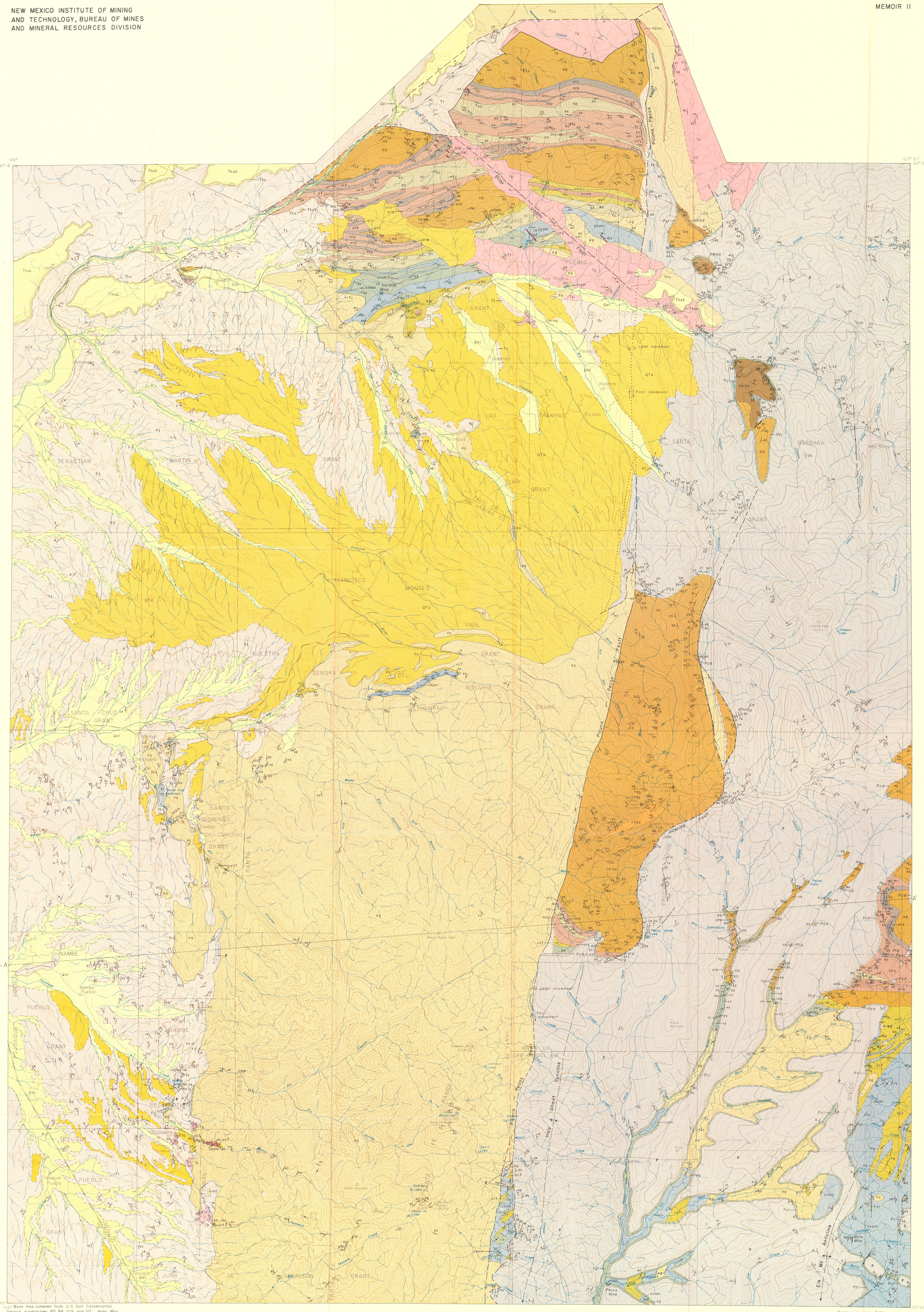
Index

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, BUREAU OF MINES AND MINERAL RESOURCES DIVISION

MEMOIR II

PLATE I



Base map compiled from U.S. Soil Conservation Service quadrangles 85, 86, 109, and 110; Army Map Service Santa Fe quadrangle and the following U.S. Geological Survey quadrangles: Velarde, Trampas, Chimayo, Truchas, Cundiyo, Sierra Mosca, Tesuque, and Aspin Basin.

Geology by John P. Miller, Arthur Montgomery, and Patrick K. Sutherland. Mapped in 1954-1959. Geologic Cartography by Bob Price.

EXPLANATION

CENOZOIC

Qal — Alluvium
Sand and silt deposits of modern floodplains and post-glacial stream terraces.

UNCONFORMITY

QTa — Ancha Formation
Sand and gravel of several different ages but distinguished from recent alluvium by position and consolidation.

Ths, Thsb — Servilleta Formation
Gravels and micaceous sand (Ths); in part covered by surface or near-surface basalt flows (Thsb).

UNCONFORMITY

Tt, Ttb — Tesuque Formation
Sand, silt, gravel, volcanic ash, clay, and intraformational breccia, mostly buff colored and slightly consolidated; locally contains thin basalt flows (Ttb).

Tp — Picuris Tuff
Coarse basal conglomerate; brick-red, yellow, green, and white clay; volcanic breccia; water-laid volcanic tuff with interbedded coarse and fine gravels and thin basalt flows, compact marl beds and thin shales.

UNCONFORMITY

PALEOZOIC

IP — Pennsylvanian undifferentiated
Includes La Pasada Formation; limestone, gray shale, and primarily nonarkosic sandstone; Flechado Formation; coarse-grained nonarkosic sandstones, conglomerates, gray shales, and minor limestones; Alamitos Formation; coarse-grained arkosic sandstones, conglomerates, limestones, and gray and red shales; Sangre de Cristo Formation (basal part only); coarse-grained arkosic sandstones, conglomerates, and red shales.

SOUTH	NORTH
	Sangre de Cristo Formation (basal part)
Alamitos Formation	Alamitos Formation
La Pasada Formation	Flechado Formation

UNCONFORMITY

Pzl, Pzd
Pzl *where Tererro, Espiritu Santo, and Del Padre formations are present;* Pzd *where only Del Padre Sandstone is present.*

Mississippian, Tererro Formation, gray limestones, silty limestones, calcareous siltstones, and limestone boulder conglomerates.

Mississippian or pre-Mississippian, Espiritu Santo Formation; sandy recrystallized limestones, sandy dolomitc limestones, and sandy dolomite; Del Padre Sandstone; quartz sandstone and local quartzite conglomerate.

UNCONFORMITY

PRECAMBRIAN

dd — Diabase Dikes
Relatively unmetamorphosed, cutting all other igneous and metamorphic Precambrian rocks.

eg, egam — Embudo Granite
Gray to tan, medium- to coarse-grained partly porphyritic, partly gneissic, microcline-biotite granite or quartz monzonite; also, locally, dark-gray, medium- to coarse-grained, partly gneissic, quartz diorite or granodiorite; also locally, tan to pinkish, mostly fine-grained, partly gneissic leucogranite. The leucogranite locally contains zones of amphibolite gneiss (egam).

Vadito Formation

vs, vsam — Schist member
Quartz-muscovite schist, quartz-muscovite phyllite, and quartz-biotite granulite (vs), interbedded with flows and containing sills and dikes of partly porphyritic plagioclase amphibolites (vsam).

vc, vcam, vcf — Conglomerate member
Coarse quartz conglomerate and fine-grained muscovite-specked quartzite (vc), locally with minor quartz-muscovite phyllite, interbedded with flows and containing sills of metafelsites, chiefly metarhyolites and metadacites (vcf), but also of minor meta-andesites and plagioclase amphibolites (vcam).

Ortega Formation

op — Pilar Phyllite Member
Gray-black carbonaceous quartz-muscovite phyllite with a slaty cleavage.

orp, orq, ors — Rinconada Schist Member
Quartz-muscovite-biotite phyllite and schist with thin calcareous beds (orp); discontinuous quartzite (orq); staurolite-rich schist and gneiss interbedded with thin beds of quartzite, underlain locally by a discontinuous bed of andalusite-biotite gneiss (ors).

oq, oqgg, oqrps — Lower quartzite member
Coarse-grained quartzite (oq); with thin beds of sillimanite-kyanite gneiss, quartz-feldspar-biotite granulite gneisses, and gray to black, chiefly metasedimentary amphibolites (oqgg). Locally near its exposed base may contain a thick zone of schistose feldspathic quartzite (Rio Pueblo Schist- oqrps).

Contact
Dashed where approximately located.

Fault
Showing relative movement. Dashed where approximately located; dotted where concealed. U, upthrown side; D, downthrown side.

Thrust or reverse fault
Saw-teeth on side of upper plate.

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

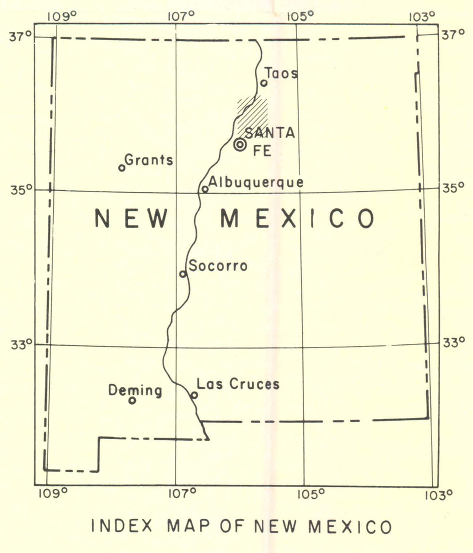
Strike and dip of foliation

Strike of vertical foliation

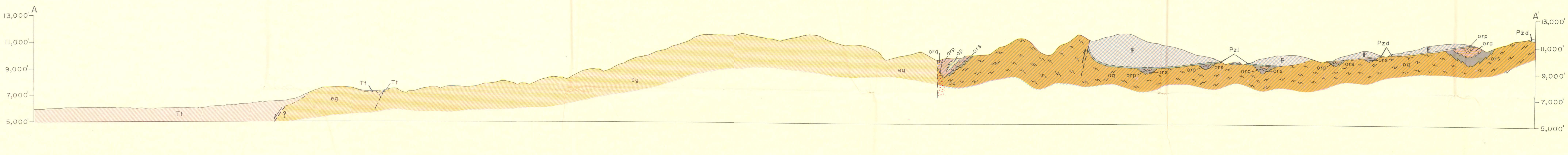
Strike and dip of foliation and plunge of lineation

Mine

Silicified zone



INDEX MAP OF NEW MEXICO



GEOLOGIC MAP AND SECTION OF PART OF THE SOUTHERN SANGRE DE CRISTO MOUNTAINS

by John P. Miller, Arthur Montgomery, and Patrick K. Sutherland

1:63,360

0 1 2 3 4 5 Miles

Contour interval: 200 feet

Datum-mean sea level

1963