The Stratigraphy, Petrology, and Paleoenvironments of the Pennsylvanian System of the Socorro Region, West-Central New Mexico

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SHEETS

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ABSTRACT

As much as 839 m of Pennsylvanian sediment were deposited in a shallow, epicontinental seaway (the Magdalena prong of the Orogrande Basin) which extended in a northerly direction between the Pedernal uplift to the east and the Zuni uplift to the west. The beds are part of the Magdalena Group which is subdivided in ascending order into the Sandia Formation and Madera Limestone of Pennsylvanian age and the Bursum Formation of Permian age. The Madera Limestone is further subdivided into a lower gray limestone member and an upper arkosic limestone member.

The Sandia Formation is mostly Atokan in age. A lower sandy interval, comprised of quartz sandstones, conglomerates, and interbedded mud-shales and carbonate mudstones, was deposited under nearshore conditions as an Atokan sea transgressed a Late Mississippian-Early Pennsylvanian erosion surface. These lower units grade upward into inner shelf mud-shales and carbonate wackestones which characterize the upper part of the Sandia Formation.

The gray limestone member of the Madera Limestone is mostly Desmoinesian in age and consists mainly of dark, cherty, carbonate mudstones and wackestones that were deposited in an outer shelf environment. The arkosic limestone member of the Madera Limestone is Late Pennsylvanian (Missourian and Virgilian) in age. Within this member, nearshore and inner shelf deposits (feldspathic

sandstones, terrigenous mudrocks, limestones) that characterize the eastern part of the Socorro region grade toward the west into dark, cherty, outer shelf carbonate mudstones and terrigenous mudrocks.

Most of the terrigenous material in the Pennsylvanian System of the Socorro region was shed from the Pedernal uplift to the east; some fine-grained material may have originated from the more distant Zuni uplift to the west. The small Joyita uplift in the northeastern part of the Socorro region supplied some terrigenous debris locally, but was probably only a small emergent feature that was most active during late Virgilian time. Much of the gravel at the base of the Sandia Formation is reworked debris from a pre-Atokan erosion surface.

The type section for the Magdalena Group in the northern Magdalena Mountains is incomplete because of complex faulting and erosion along cauldron margins. No single stratigraphic section in the Socorro region adequately illustrates the diverse character of the Pennsylvanian System; therefore, several localities are suggested where the different aspects of Pennsylvanian strata can be observed. The Sandia Formation is well exposed in the Ladron Mountains and Joyita Hills. Good outcrops of Desmoinesian Madera strata occur in the northern Oscura Mountains and Late Pennsylvanian Madera beds are well exposed at Abo Pass and on the eastern flank of the northern Oscura Mountains.

INTRODUCTION

Geography and Physiography

The study area is located in west-central New Mexico and important villages, cities, and physiographic features are shown in fig. 1. Socorro, a city of about 6,500 people is the principal settlement of the region. The Socorro region is part of the Mexican Highland section of the Basin and Range Province and the Datil section of the Colorado Plateau Province (Fenneman, 1938). Outcrops of Pennsylvanian rocks are located in widely separated fault-block mountains along the Rio Grande rift (fig. 2). The location of sections measured for this study (table 1) are shown in fig. 3.

Statement of the Problem

The purpose of this project is to determine the stratigraphic and lithologic characteristics of the Pennsylvanian System in the Socorro region and to reconstruct the environments of deposition. Geologic work on Pennsylvanian rocks to date has been chiefly of a reconnaissance nature that has produced a gross picture of Pennsylvanian stratigraphy and sedimentation. Most geologists, however, still think of the Pennsylvanian System in the Socorro region as a monotonous sequence of limestone which includes some shale and sandstone near the

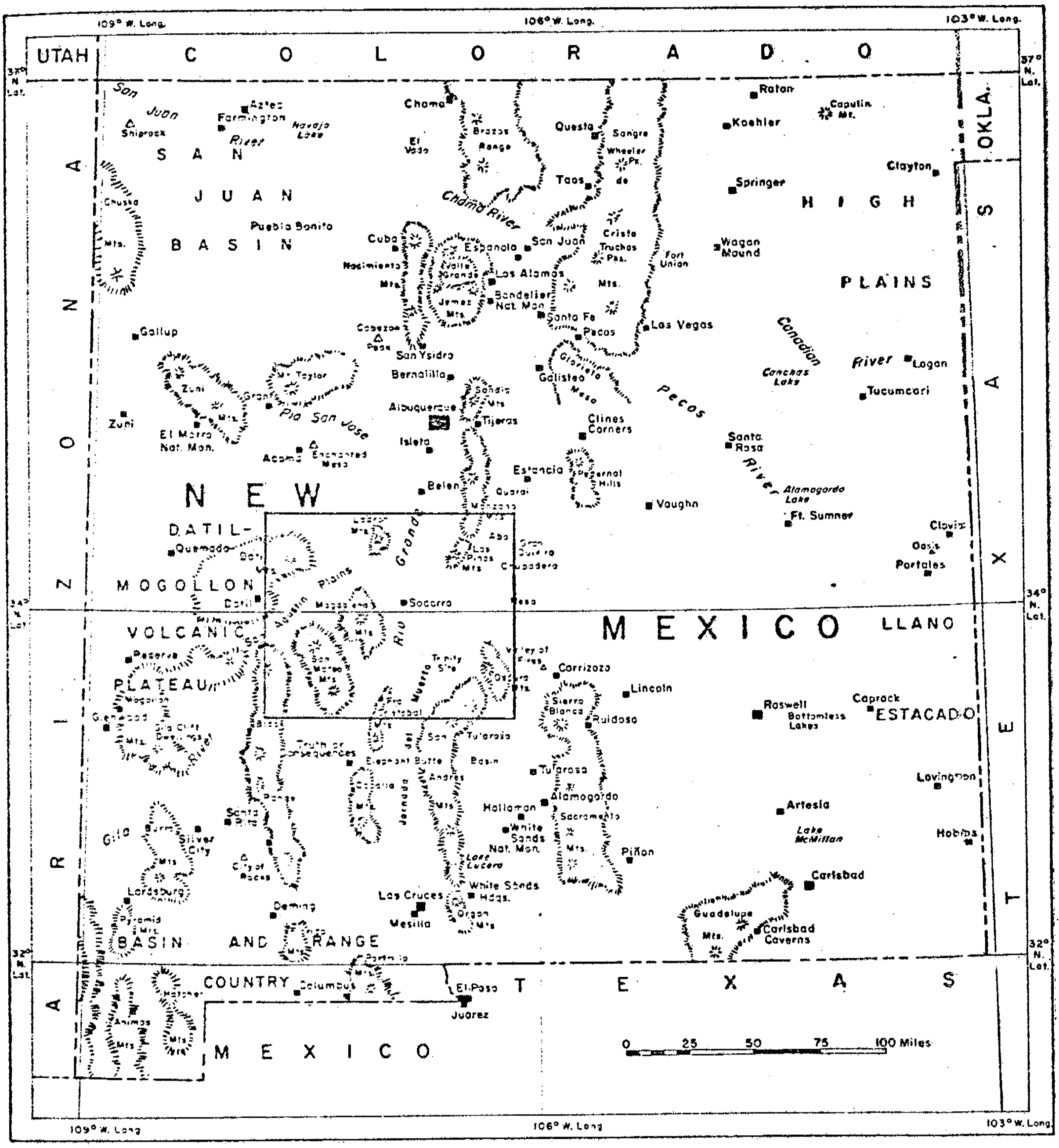


Figure 1. Index map showing the location of the study area, physiographic features, and important towns.

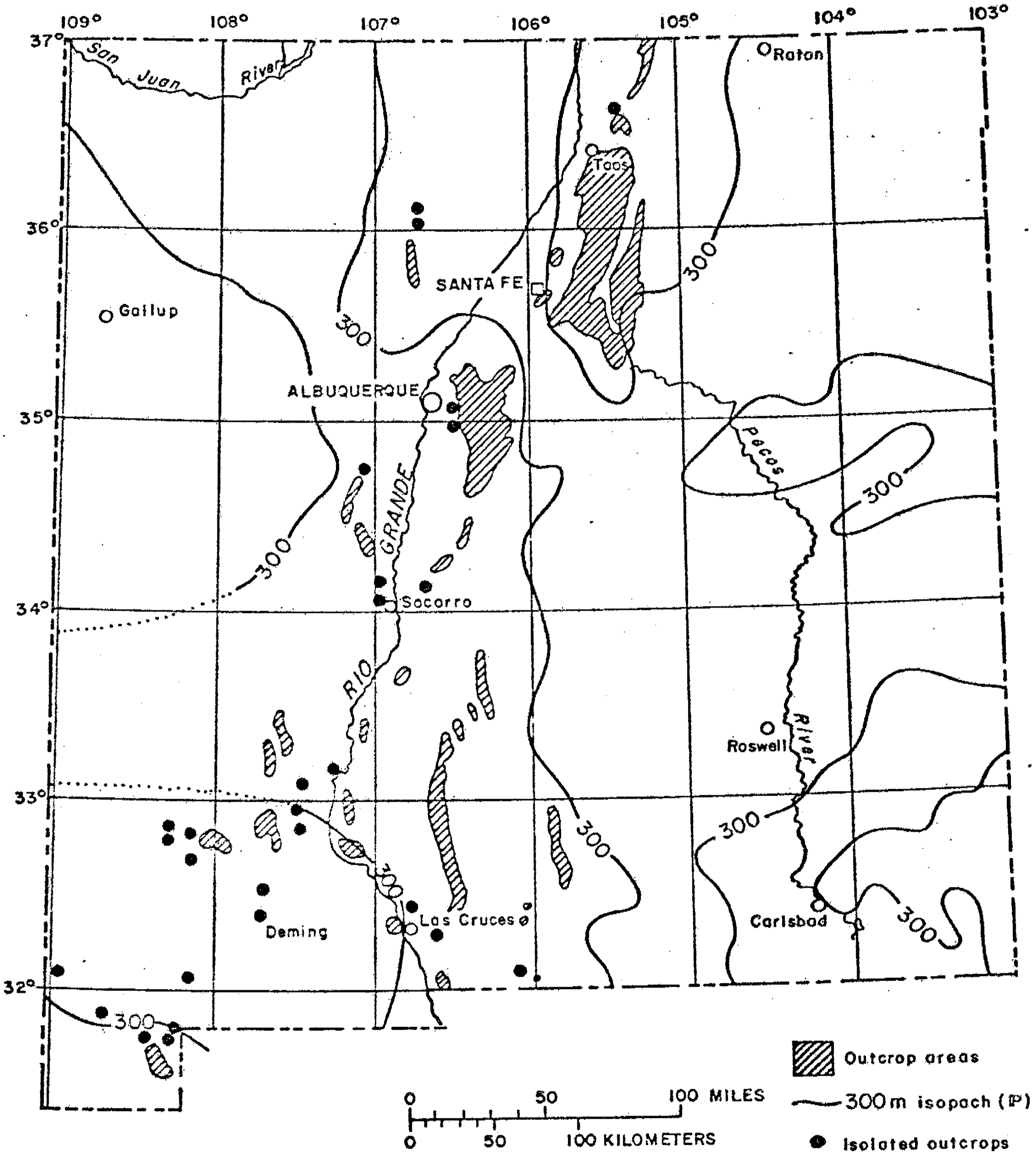


Figure 2. A map of New Mexico showing outcrop areas of Pennsylvanian rocks and areas of Pennsylvanian rocks more than 300 m in thickness.

Table 1. Locations of measured sections.

Section Number	Section Name	Section Location
1	Ladron Mountains	
	Sandia Formation (1a)	Sec.14-T.3N.-R.3W.
	Madera Limestone (1b)	Sec.24,26-T.2N.-R.3W.
2	Joyita Hills	Sec.23-T.1N.-R.1E.
3	Abo Pass	
	Sandia Formation - missing due to faulting	
	Madera Limestone	Sec.25-T.3N.-R.4E.
4	Magdalena Mountains	Sec.31-T.2S.-R.3W.
5	Lemitar Mountains	
	Sandia Formation	Sec.18-T.2S.-R.1W.
	Madera Limestone	Sec.11-T.2S.-R.2W.
6	Cerros de Amado	Sec.23-T.3S.-R.1E. Sec.26,35-T.2S.-R.1E.
7	Southeastern San Mateo Mts	Sec.17-T.8S.-R.4W.
8	Little San Pasqual Mountain	Sec.4,5-T.7S.-R.1E.
9	Northern Oscura Mountains	Sec.36-T.5S.-R.5E. Sec.30,31-T.5S.-R.6E.

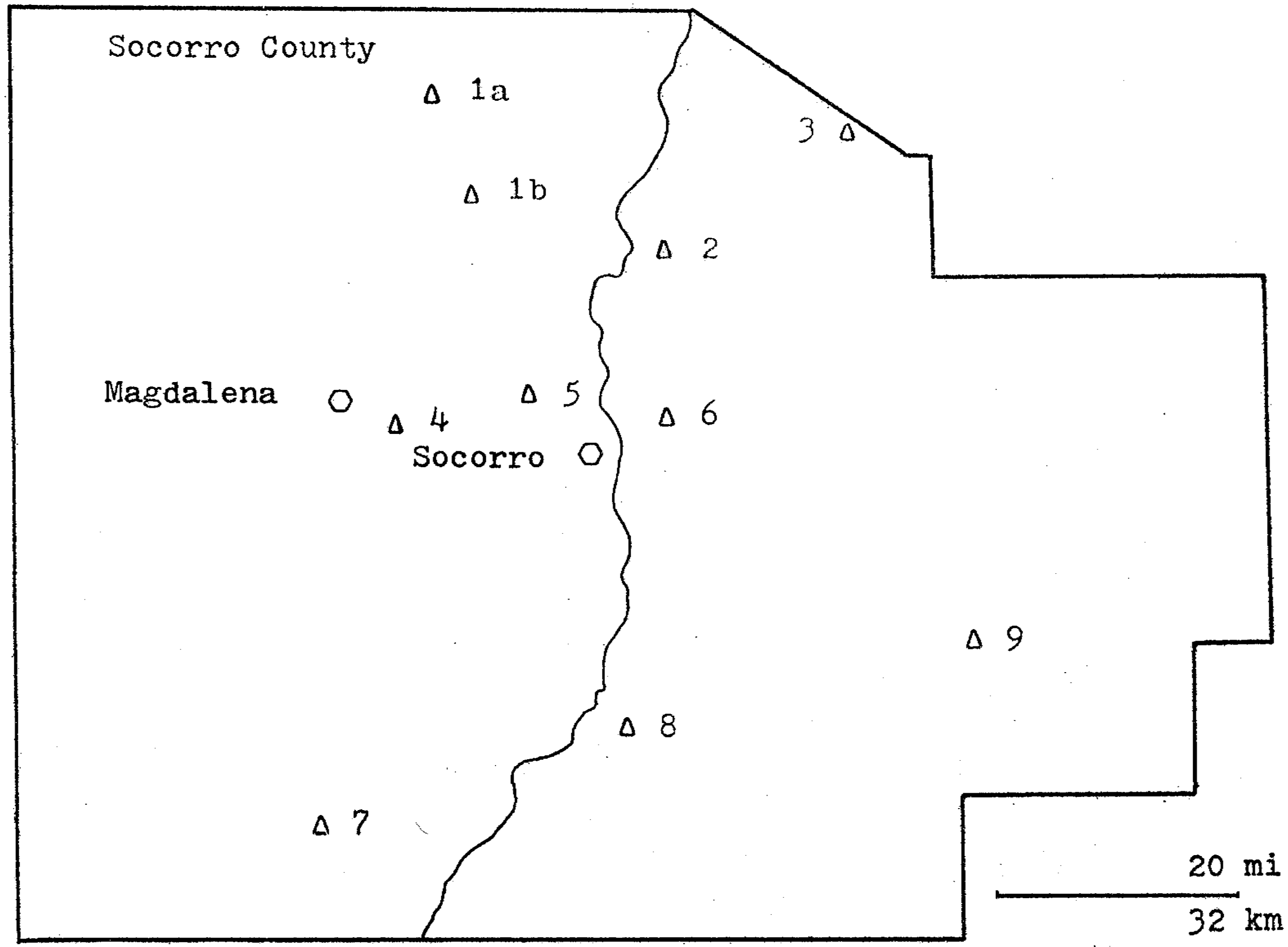


Figure 3. Location of measured sections (see table 1).

bottom and top of the section. Many facets of the Pennsylvanian System had to be considered during the course of this study; the more important of these are outlined below.

1. Nomenclature. Most previous studies were restricted to local, isolated areas, with each worker devising a nomenclature scheme to suit his needs and giving little attention to integration with other nomenclature systems. As a result, the naming of formations within the Pennsylvanian System has become so confusing that merely unraveling the nomenclature becomes a major part of any study. Seven different nomenclature systems have been used within the study area (Gordon, 1907; Thompson, 1942; Read, and others, 1944; Kelley and Wood, 1946; Read and Wood, 1947; Wilpolt and Wanek, 1951; Myers, 1973). It is, therefore, necessary to determine, describe and name mappable stratigraphic units which can be discussed within one integrated nomenclature framework.

2. Type area. The type locality of the Magdalena Group was established by Gordon (1907) in the northern Magdalena Mountains. The type section is locally metamorphosed, silicified and mineralized; it is also interrupted by many faults and is known to be stratigraphically incomplete (Krewedl, 1974). Much of the faulting within the section is probably related to its location on the eastern boundary of the Magdalena cauldron (Chapin and others, 1978). These complexities are accentuated by an

absence of chronologic data. For these reasons, the Pennsylvanian section in the northern Magdalena Mountains was a poor choice for the type locality of the Magdalena Group. One of the objectives of this study is the location of stratigraphic sections where the characteristics of the Pennsylvanian System are best represented and are well exposed.

3. Chronology. Good time control is necessary in regional studies dealing with units characterized by repetition of similar lithologies, rapid facies changes, widely separated and isolated exposures, and an absence of marker beds. Pennsylvanian time units are usually based on fusulinid biozones established for the midcontinent region of the United States. Some fusulinid data regarding the Socorro region have been published (Kottlowski, 1960; Myers, 1971; Needham, 1937; Stewart, 1970; Thompson, 1942), but at many localities within the region, time boundaries are poorly defined or there is no data available. Therefore, an important part of this study is to establish adequate time control for Pennsylvanian sections.

4. Thickness. The general thickness of the Pennsylvanian System in southwestern New Mexico is well established in the literature (Kottlowski; 1960). However, with improved control on the chronology of the Pennsylvanian System, the thicknesses of Pennsylvanian

units within the region can be recorded more accurately. For example, it was discovered that the thickness of some sections has been exaggerated by faulting; whereas, other sections have been thinned by faulting and/or erosion. Therefore, it is necessary to update and correct thicknesses that had been reported for Pennsylvanian rocks in the Socorro region.

5. Petrology. Most studies of Pennsylvanian rocks to date have been of a preliminary nature, with emphasis on field mapping conducted largely on the basis of topographic expression and the use of photogeology. The lithology of Pennsylvanian rocks has been recorded with little detail. Only a few of the Pennsylvanian rocks have been studied petrographically, and the few studies that have been published are relatively cursory. There are even fewer accounts of the sedimentologic characteristics of rocks within the Pennsylvanian System; paleoenvironmental interpretations of poorly defined facies are on such a large scale that they are of limited use. Therefore, the primary objectives of this study are to determine and describe mappable stratigraphic units and sedimentary facies patterns within the Pennsylvanian System; to present for the first time detailed descriptions of the petrographic and sedimentologic characteristics of the various lithologies; and to intrepret the depositional environments in which the rocks were deposited.

Method of Investigation

The scope of this study is regional, with control points located as much as 30 miles apart. Information was acquired from the field and petrographic description of 13 selected surface exposures and from published data on other outcrop areas and subsurface sections within the study area. Sections were selected for description on the basis of: (1) the degree to which they provided good lateral control, (2) their completeness, (3) how well they were exposed, and (4) their accessibility.

After a section had been selected for description, data were collected on about 35 different parameters through field study and petrographic analysis. The complete description of a section involved the following six steps.

Step one involved a reconnaissance study of the locality in order to put together a composite section that was representative of the Pennsylvanian System in that area. Step two involved division of the section into rock units with generally uniform, distinctive characteristics. The most commonly used parameters in the determination of unit boundaries were significant changes in lithologic character or major changes in bedding type. In step three, the strike, dip, bearing, slope angle, and slope distance were determined. Depending on the attitude of the beds and the terrane, either a Brunton compass and tape or a Brunton compass and Jacob staff were used for this part of the study. From the above data, the true thickness of each unit was calculated and the total thickness of the section determined.

In step four, each unit was described and sampled. Step five involved an additional field check on the lateral and vertical continuity of each unit. Step six concerned the preparation and description of hand specimens and thin sections. Selected sandstone samples were stained with sodium cobaltinitrite to differentiate alkali feldspar from quartz (Gabriel and Cox, 1929). Selected limestone samples were stained for dolomite using alizarine red S (Friedman, 1959). Abundances reported here are based on visual estimates periodically checked by point counting 300 grains per thin section using the Glagolev-Chayes method (Carver, 1971). Classification and nomenclature systems used in describing the rocks may be found in Appendix I. Description of the units and samples involved the following parameters.

General Field Characteristics. These are the thickness of each unit, topographic expression, nature of the basal contacts, color of fresh and weathered surfaces, and the breaking characteristics of the rock.

Bedding Characteristics. Included here are the thickness, vertical and lateral uniformity, surface shape, and internal structure of the bedding. Sedimentary structures (primary, secondary, organic, chemical) were described in detail. Transport directions that could be determined were also recorded.

Granular Constituents. The abundance and nature of monocrystalline and polycrystalline quartz, chert, potassium feldspar, plagioclase, mica, lithoclasts, intraclasts, and chemical and skeletal allochems were studied. In describing the various types of quartz, the types of inclusions and extinction were noted for monocrystalline grains, and crystal number, shape, size distribution, and contacts were examined for polycrystalline grains. Textural parameters that were considered include the size, sorting, shape, orientation, and contacts of the various granular constituents. Descriptions of fossil debris included an abundance of taxonomic groups, mode of preservation, orientation, and location within the unit.

Matrix and Cement. The use of textural names based upon stated proportions of grains versus matrix and cement met with little success in this study. In both the classification and interpretation of rocks, the major obstacle to the use of such terminology is the inherent implication of a particular genetic origin, i.e., cement is chemically precipitated, whereas matrix has clastic, detrital, and diagenetic connotations. The diverse types of cement and matrix have been admirably discussed by Dickenson (1970) who offers several criteria concerning their recognition; nevertheless, the genetic character of groundmass constituents can seldom be determined with any degree of certainty. Since the ambiguity of the cement-matrix problem remains unresolved, the granular fraction of the rocks is relied upon for classification of terrigenous rocks. The nature of the interstitial material (cement and matrix) is considered separately.

The general framework of Pennsylvanian sedimentation that has evolved through the efforts of previous workers, is little changed by this study. Nevertheless, much information regarding the nature of the various facies that are present in this complex system has been acquired, and the sedimentology and petrology of the Pennsylvanian System in west-central New Mexico are better understood. It is believed that the regional stratigraphic and sedimentologic interpretations suggested here will find later application in more detailed lithofacies mapping and environmental analysis.

Previous Work

The nomenclature presently applied to the Pennsylvanian System in New Mexico by the U. S. Geological Survey (Read and Wood, 1947) was first suggested by Gordon (1907). Gordon referred to the rocks as the Magdalena Group, which he divided into a lower terrigenous unit, the Sandia Formation, and an upper limestone unit, the Madera Limestone. In the Magdalena Mountains, the type locality for the Magdalena Group, Loughlin and Koschmann (1942) divided the Sandia Formation into six members: (1) a lower quartzite, (2) a lower limestone, (3) a middle quartzite, (4) a medial shale, (5) an upper limestone, and (6) an upper quartzite. Within the Madera Limestone, they identified a lower bluish-black limestone member and an upper bluish-gray limestone member.

In the Oscura Mountains, Thompson (1942) divided the Pennsylvanian strata into four series on the basis of fusulinid biozones. In ascending order they are the Derry, Des Moines, Missouri, and Virgil. He further subdivided these into eight groups, 15 formations, and one member. This nomenclature has been used recently for Pennsylvanian rocks in the hills east of Socorro (Rejas, 1965; Jaworksi, 1973) and in the Los Pinos Mountains (Stark and Dapples, 1946).

On the Lucero uplift, Kelley and Wood (1946) divided the Magdalena Group into the Sandia Formation and the Madera Limestone, and identified within the Madera Limestone three members: (1) a lower Gray Mesa Member, (2) a medial Atrasado Member, and (3) an upper Red Tanks Member. In the same general region and in areas to the north, Read and Wood (1947) subdivided the Sandia Formation into a lower limestone member and an upper clastic member; they also subsdivided the Madera Limestone into a lower gray limestone member and an upper arkosic limestone member. It has since been demonstrated that the lower limestone member of the Sandia Formation is Keokuk (Late Osage, Early Mississippian) in age (Armstrong, 1958).

Wilpolt and Wanek (1951) mapped the geology of regions to the south and east of Socorro on a reconnaissance scale and divided the Magdalena Group into a lower Sandia Formation and an upper Madera Limestone. Within the Madera Limestone, they too defined a lower gray limestone and an upper arkosic limestone. Sidwell and Warn (1951) described the nature of some Madera beds in northeastern Socorro County. They concluded that Madera beds resulted from a period of long, continuous deposition in a sea less than 600 feet deep that was bordered by four positive areas of low to moderate relief.

The most important regional study of the Pennsylvanian System was conducted by Kottlowski in the late 1950's (Kottlowski, 1960). His summary of Pennsylvanian sections throughout southwestern New Mexico and southeastern Arizona demonstrated that most of the Pennsylvanian sequence in central New Mexico was deposited on a shallow marine shelf of an epicontinental sea situated between the Zuni-Defiance and Pedernal uplifts (fig. 4).

Hambleton (1962) studied the carbonate rock fabrics of three Missourian (Late Pennsylvanian) sections in Socorro County and concluded that epineritic and infraneritic conditions existed throughout the area during most of Missourian time. Martin (1971) suggested that the Lucero region was a depositional shelf or a structural basin of differential subsidence with thick Pennsylvanian sections along the axis; however, deposition on this shelf was always in nearshore, shallow-water environments.

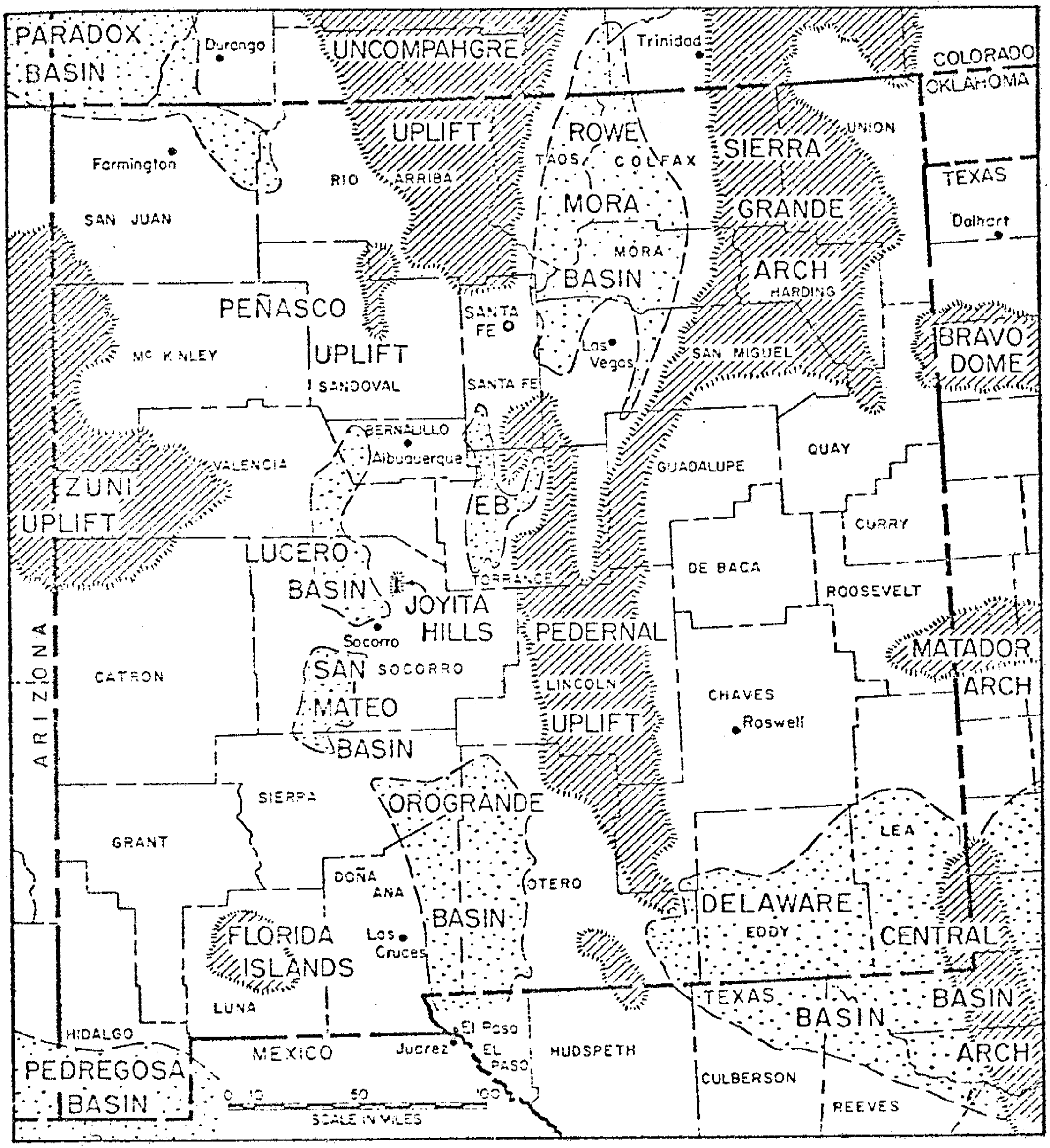


Figure 4. Pennsylvanian paleogeographic map of New Mexico. Uplifts (diagonal pattern) grade through areas of moderate deposition (white areas) into areas of thick sedimentation (stippled pattern). Modified from Kottlowski and Stewart (1970). E.B. = Estancia Basin.

In the Manzano and Los Piños mountains, Myers (1973) raised the Madera Limestone to group rank and then subdivided it into, in ascending order: (1) the Los Moyos Limestone, (2) the Wild Cow Formation, including the Sol se Mete, Pine Shadow, and La Casa members, and (3) the Bursum Formation of Permian age. Below the Madera Group, Myers also recognized the Sandia Formation.

In summary, the basic nomenclature of Gordon (1907) is still generally followed in the region (table 2), but numerous authors have changed the rank of his terms and named various members within his formations. Consequently, the Pennsylvanian has become riddled by a host of names converging from all directions so that merely coping with the nomenclature becomes a major problem in any study of the System. The problem is further complicated by the variety of rock types and the rapid changes in facies and thicknesses that make correlation from one area to another exceedingly difficult.

Paleotectonic Setting

Several land masses, collectively called the Ancestral Rocky Mountains, existed in the southern Rocky Mountain region throughout the late Paleozoic. During Pennsylvanian time, the Colorado Plateau region was subjected to tectonic forces which caused the breakup of the Mississippian Peñasco uplift and its associated shelf area (Armstrong, 1962) into a number of tectonic elements that defined a north- to northwest-trending seaway

Table 2. Summary of nomenclature for Pennsylvanian rocks of the Socorro region.

Author	Group / Series	Formation / Group	Formation / Member
Gordon (1907)	Magdalena group	Madera ls	
		Sandia fm	
Loughlin & Koschmann (1942)	Magdalena group	Madera ls	bluish-black member
			bluish-gray member
		Sandia fm	upper quartzite
			upper limestone
			shale
			middle quartzite
			lower limestone
			lower quartzite
Thompson (1942)	Virgil	Fresnal group	Bruton fm
			Moya fm
			Del Cuerto fm
	Missouri	Hansonberg group	Story fm
			Burrego fm
		Veredas group	Council Springs fm
			Adobe fm
			Coane fm
	Des Moines	Bolander group	
		Armendaris group	Garcia fm
			Whiskey Canyon ls
			Elephant Butte fm
	Derry	Mud Springs group	Cuchillo Negro fm
			Hot Springs fm
		Green Canyon group	Apodaca fm
			Arroy fm
Kelley & Wood (1946)	Magdalena group	Madera ls	Red Tanks memb
			Atrasado member
			Gray Mesa member
		Sandia fm	
Read & Wood (1947)	Magdalena group	Madera ls	upper arkosic limestone member
			lower gray ls member
		Sandia fm	clastic member
			limestone memb
Myers (1973)	Madera Group	Wild Cow Fm	La Casa Memb
			Pine Shadow Memb
			Sol Se Mete Member
		Los Moyos Ls	
		Sandia fm	

(Kottlowski, 1960; fig. 4). Depocenters formed in the Paradox basin of northwestern New Mexico, in the Estancia, Lucero, and San Mateo basins of central New Mexico, and in the Orogrande, Pedregosa, and Delaware basins of southern New Mexico. The seaway was bounded on the west by the Zuni-Defiance uplift and on the east by the Uncompahgre axis and Pedernal uplift. The Florida and Joyita highlands never gained more than local importance as source areas (Kottlowski, 1960).

The present structural elements of the region are dominated by fault-block uplifts and basins of late Cenozoic age. Most of these elements, however, appear to be closely associated with older structural elements of Laramide and late Paleozoic age. Rio Grande rift structures were superimposed during late Cenozoic time upon a north-trending tectonic belt that was intensely deformed during late Paleozoic time (Ancestral Rocky Mountains) and again during the Laramide Orogeny. Chapin and Seager (1975, fig. 2) demonstrate how well the tectonic elements of these three periods are superimposed and how earlier deformations influenced later ones. Thus, the late Paleozoic was an important period of time in the tectonic and stratigraphic development of the region.

STRATIGRAPHY

Two different approaches have been used in describing Pennsylvanian rocks in New Mexico. One approach has been to divide the system into observable rock-stratigraphic units that can be mapped in the field. Numerous rock-stratigraphic classifications have been proposed (table 2), but all of them center around a simple framework which recognizes three, thick, generalized subdivisions within the Pennsylvanian sequence: (1) a lower predominantly terrigenous rock unit, (2) a middle carbonate rock unit, and (3) an upper mixed carbonate and terrigenous rock unit.

The second approach has been to subdivide the Pennsylvanian into a number of time-stratigraphic units on the basis of faunal zones. In North America, Van Eysinga (1975) divides the Pennsylvanian into five series which in ascending order include the Morrowan, Atokan/Derryan, Desmoinesian, Missourian, and Virgilian. Beds that are Morrowan in age are generally defined by the *Paramillerella*, *Millerella*, and *Nankinella* fusulinid biozones (Thompson, 1964). In New Mexico, the upper boundary of the Morrowan is drawn at the upper limit of beds containing numerous brachiopod species similar to those which occur in Morrowan formations of northwestern Arkansas and northeastern Oklahoma (Miller and others, 1963).

Atokan beds are defined by the biozone which includes the fusulind genera *Profusulinella* and *Fusulinella*, with abundant occurrences of several other fusulinid genera. The term Derryan was proposed by Thompson (1942) for rocks in south-central New Mexico between the base of the Pennsylvanian and the base of the Desmoinesian. However, use of the term Derryan is not widespread because its stratigraphic relationship to the Morrowan and Atokan is poorly understood and needs additional study. Therefore, the term Atokan, rather than Derryan, will be used here for beds considered to be post-Morrowan and pre-Desmoinesian in age.

The *Beedeina* (*Fusulina*) biozone extends from lowermost to uppermost Desmoinesian, and the Lower Desmoinesian (Cherokeean) is defined by the biozone *Wedekindellina*. Stewart (1968) also identified several other fusulinid genera within the Desmoinesian series including *Plectofusulina* *Frumentella*, *Pseudostaffella*, and *Eostafella*; however, these genera are not restricted to the Desmoinesian.

Numerous species of the *Triticites* biozone occur in the lower part of the Missouri series and extend into the Lower Permian (Wolfcampian). The *Eowaeringella* biozone marks the base of the Missourian, but does not extend far up into the stage. Species of the genus *Triticites* are also the most common faunal elements of the Virgilian series; however, widespread representatives of the genus *Dunbarinella* occur in the Lower Virgilian.

There are advantages and disadvantages to both approaches in dealing with regions in which there is repetition of similar lithologic types, rapid facies changes, a general absence of marker beds, and isolated exposures. The use of names for thick, generalized units is advantageous because it provides a simple stratigraphic framework that is easily recognizable and mappable in the field. However, such generalized units often obscure local and regional stratigraphic relationships and make difficult the interpretation of geologic history. The alternative time-stratigraphic approach is useful in reconstructing geologic history, but necessitates identification of time divisions which are difficult to establish and even more difficult to recognize in the field. In studying the Pennsylvanian in central New Mexico, the time stratigraphic approach has been used mostly by the biostratigrapher-paleontologist, and seldom has enough detailed mapping been done to determine if the units within the fusulinid biozones have formational significance. Little data have been published to demonstrate the cartographic continuity of Thompson's (1942) units; most of his formations could not be recognized as lithologic entities throughout the study area.

The stratigraphic framework that will be used here is based on rock-stratigraphic units (fig. 5) that are recognizable in the field, but time lines and their

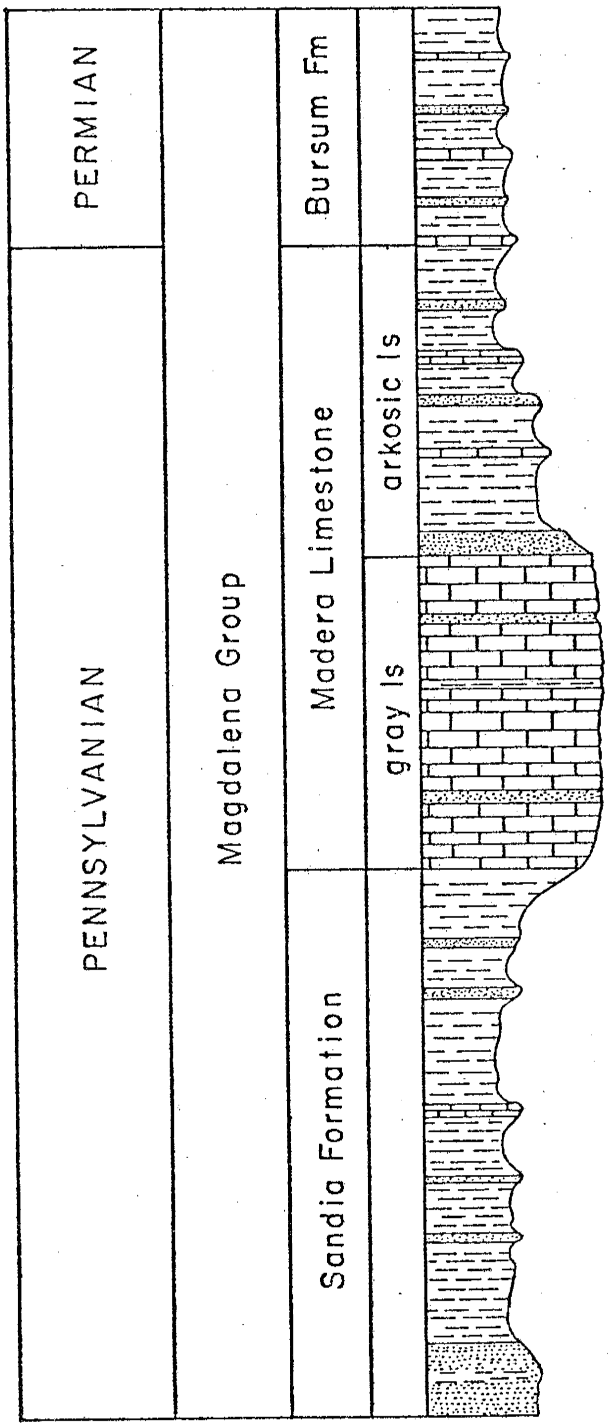


Figure 5. A classification of Pennsylvanain rocks in the Socorro region, New Mexico (modified from many sources, see table 2).

relationships with the rock units have been determined through faunal studies of the rocks. Therefore, the study is based on mappable rock units that are tied into fusulinid faunal zones in order to facilitate correlations between sections and determination of geologic history.

The only consistant lithologic breaks recognized within the Pennsylvanian System throughout the Socorro region are between a lower terrigenous unit, a medial limestone unit, and an upper mixed limestone-terrigenous unit. In this study, the lower terrigenous unit is called the Sandia Formation and the two upper units are referred to as the Madera Limestone. The lower limestone unit of the Madera Limestone is called the gray limestone member and the mixed unit is called the arkosic limestone member.

The definition of the Sandia Formation used here is similar to that proposed by Read and Wood (1947), who noted that the Sandia Formation is: (1) a predominantly clastic deposit of early Pennsylvanian age, and (2) a transgressive suit of sediments that, in a regional sense, vary slightly in age limits. The lower boundary of the formation coincides with the base of the Magdalena Group, and is placed at the top of rocks interpreted to be Mississippian or older in age.

The transition from the terrigenous nature of the underlying Sandia Formation to the calcareous nature of the overlying Madera Limestone is gradational, and therefore, the position of the boundary is somewhat arbitrary. In this study, the boundary is placed at the top of a terrigenous unit, preferrably a prominant sandstone, below which terrigenous strata predominate and above which limestones are dominant. The boundary is in no way linked to time surfaces, and it is the only subdivision of the Pennsylvanian sequence that can be easily recognized in the field.

The Madera Limestone is stratigraphically overlain by the Wolfcampian (Lower Permian) Bursum Formation or by the Abo Formation. The Bursum Formation is a transitional unit consisting of alternating limestones and redbeds that grade upward into the predominantly continental mudstones and sandstones of the overlying Abo Formation. The trend is to abolish the term Magdalena Group because in most classification systems, it is synonymous with the systemic term Pennsylvanian (Miller and others, 1965). It is believed, however, that since the Sandia Formation, the Madera Limestone, and the Bursum Formation represent a transgressive-regressive cycle beneath the continental redbeds of the Abo Formation (D.A. Myers, personal communication, 1974), it is logical to consider them as one group. It is suggested that the term Magdalena Group be retained for these three formations.

This approach affords an opportunity to describe and discuss on a regional scale isolated, widely separated Pennsylvanian outcrops among which correlation is virtually impossible because of rapid facies changes and an absence of marker beds. This approach also avoids adding new units to an already bewildering collection of names proposed by various authors in their attempts to deal with units whose vertical and lateral relationships were, and still are, only partially understood.

AGE AND CORRELATION

On the basis of fusulinid faunal zones characteristic of the midcontinental United States, the Pennsylvanian System is divided in ascending order into rocks of Atokan, Desmoinesian, Missourian, and Virgilian age. The positions of the boundaries between time-stratigraphic units within the sections of Pennsylvanian rocks studied here, were determined on the basis of published information, unpublished data provided by Exxon Corporation and Texaco, Incorporated, and on fusulinid identifications made on samples collected during the course of this study by Donald Myers, United State Geological Survey, and Wendell Stewart, Texaco, Incorporated.

Control still remains somewhat inadequate, however, and a procedure described by Adams (1962), and used extensively by Martin (1971) in the Lucero region, was used to "pick" some of the time-stratigraphic boundaries. In employing this technique, boundaries are based on fusulinid biozones, but actual contacts are placed to coincide with the limit of a lithologic entity. At localities where fusulinid control is poor, lithologic and stratigraphic similarities are used to demonstrate continuity in correlation among sections. Though inexact, the method is useful in the absence of precise fusulinid determinations, and boundaries are probably as accurately determined as those recognized elsewhere over equally extensive areas with as widely spaced control.

No Morrowan faunas have been reported in literature pertaining to Pennsylvanian beds in west-central New Mexico. Kottlowski (1965) believes that during Morrowan time, areas to the south were undergoing some limestone deposition, but that most of west-central New Mexico lay just above sea level.

Most of the Sandia Formation in the Joyita Hills (Kottlowski and Steward, 1970) the Ladron Mountains (Cheetham, 1950; Martin, 1971) the Magdalena Mountains (Needham, 1937); the Cerros de Amado (Needham, 1937) the northern Oscura Mountains (Kottlowski, 1952, 1960) and at Little San Pasqual Mountain (Geddes, 1963) is Atokan in age. At Abo Pass, the Sandia Formation is faulted out of the section; however, to the north Myers (1973) states that the entire Sandia is Atokan in age. No work has been done on the age of Sandia beds in the Lemitar Range, but Kottlowski (1960) reports an Atokan age for the Sandia on Socorro Peak about 5 miles south of sections in the Lemitar Range. Therefore, it appears that throughout most of the Socorro Region, Sandia beds are generally Atokan in age (fig. 6).

Disagreement exists as to the age of the Sandia Formation in the San Mateo Mountains. G.L. Wilde (Kottlowski, 1960) believes there is some faunal evidence to indicate that much of the unit is Atokan in age, whereas W.J. Stewart (personal communication, 1977) believes the Sandia Formation is Desmoinesian in age.

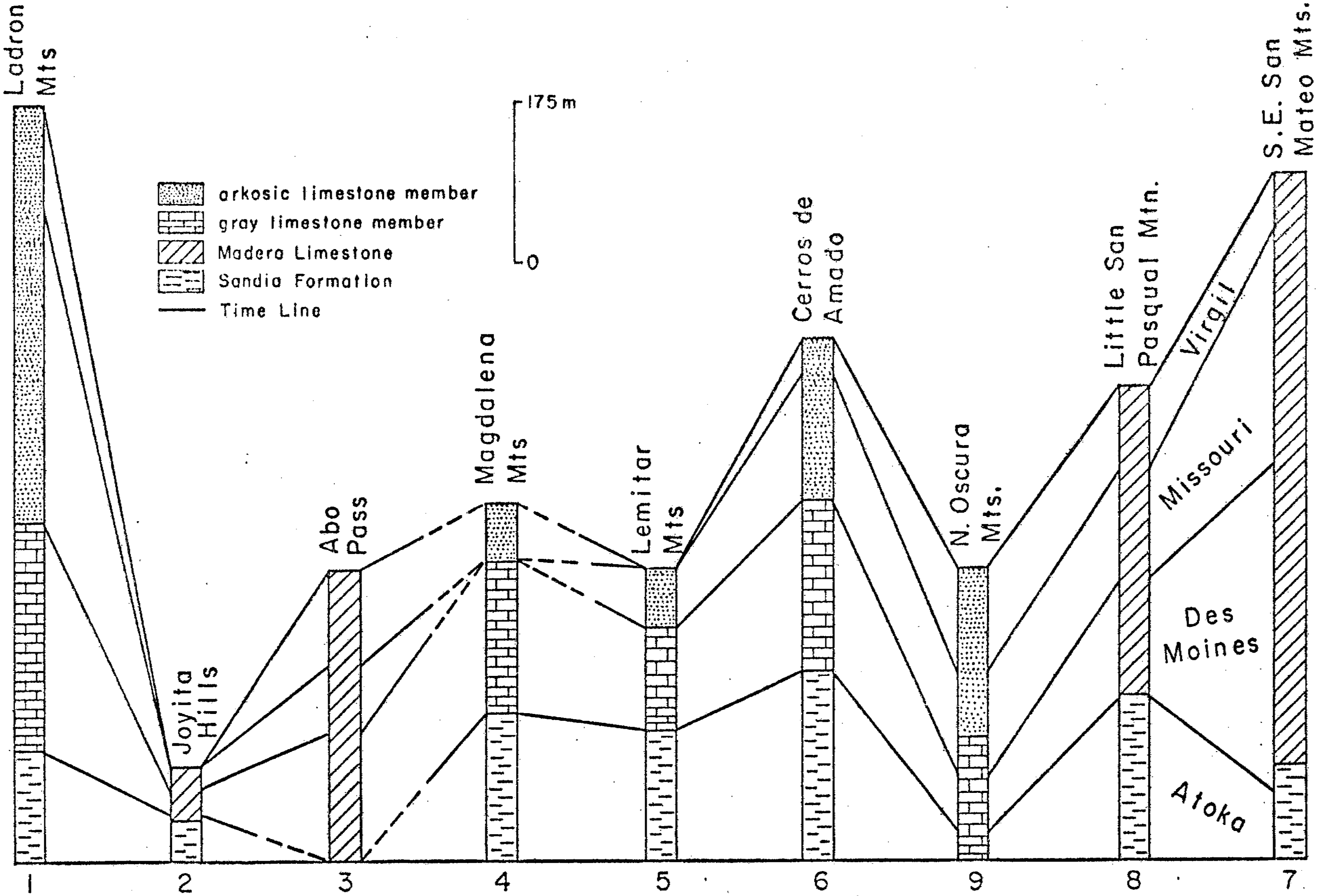


Figure 6. Correlation of rock-stratigraphic and time-stratigraphic units in the Socorro region. Base line is the base of the Pennsylvanian.

Fusulinid faunas characteristic of the Madera Limestone range from Atokan to Desmoinesian in age (fig. 6). At Abo Pass and Little San Pasqual Mountain, and in the Magdalena, Ladron, and Lemitar mountains, the base of the Desmoinesian coincides closely with the base of the Madera Limestone. In the Joyita Hills and in the northern Oscura Mountains, however, the basal 10 to 35 m of the gray limestone member of the Madera formation are Atokan in age. The top of the Desmoinesian often occurs near the top of the gray limestone member, but again exceptions occur. In the Joyita Hills, the Cerros de Amado, the San Mateo Mountains, and the northern Oscura Mountains, the uppermost 10 to 40 m of the gray limestone member are Missourian in age. Throughout the region, the arkosic member of the Madera formation is Missourian and Virgilian in age.

Time-stratigraphic units are conceptually distinct from rock-stratigraphic units and their boundaries need not coincide. Nevertheless, in the Socorro region, the positions of time-stratigraphic boundaries within the Pennsylvanian System often occur in about the same stratigraphic position as do major rock-stratigraphic boundaries. Notable exceptions to this generalization are discussed above, but generally, Sandia beds are Atokan in age, the gray limestone member of the Madera Limestone is Desmoinesian in age, and the arkosic limestone member is Missourian and Virgilian in age.

DESCRIPTIVE SEDIMENTOLOGY

Sandia Formation

Basal Relationships

Basal Pennsylvanian age beds overlie Lower Mississippian, Devonian, Silurian, Ordovician, Cambrian, and Precambrian rocks, in New Mexico (Kottlowski, 1960). In the Socorro region the Sandia Formation rests with erosional unconformity on Precambrian granitic and metamorphic rocks, or on Lower Mississippian (Osagian) or Ordovician limestones that survived periods of erosion during the Devonian, Mississippian, and Early Pennsylvanian-Morrowan (fig. 7).

In the southeastern San Mateo Mountains, basal beds of the Sandia Formation rest unconformably on the Upham Dolomite of Ordovician age. Kottlowski (1960) suggested that removal of the lower Paleozoic units probably occurred sometime during a period of widespread erosion in the Devonian and Early Mississippian. The Cambro-Ordovician section was not recognized by early workers in the vicinity, but Kelley and Furlow (1965) believed that more than 60 meters of pre-Pennsylvanian section was present in the area. Identification of some brachiopod and trilobite pieces collected from the lower 60 meters of the section later verified the presence of Cambrian and Ordovician formations beneath the Pennsylvanian (Kottlowski, 1965).

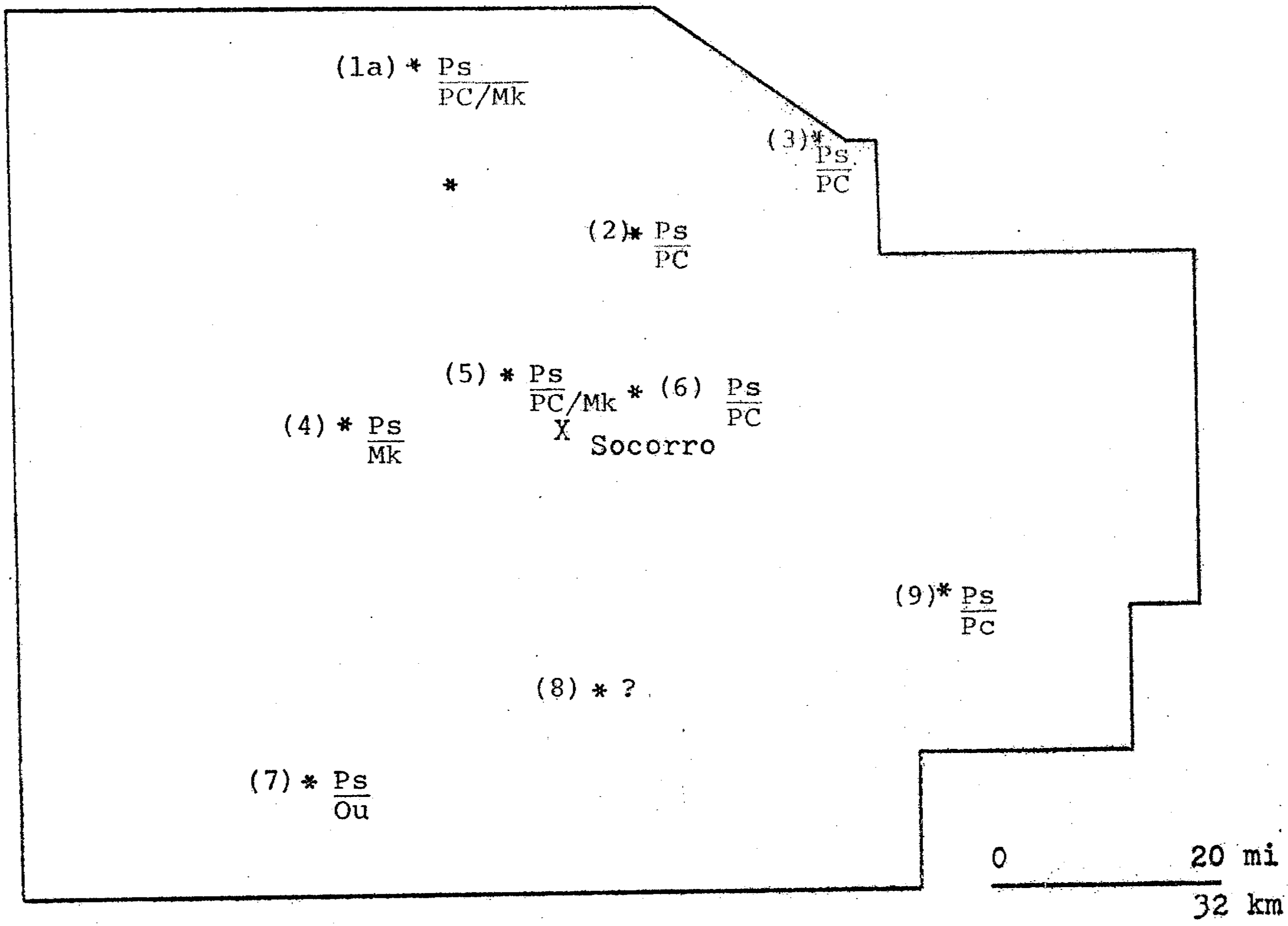


Figure 7. Relationships of the Sandia Formation in the Socorro region with underlying rocks. Precambrian (PC), Upham Dolomite (Ou), Kelly Ls. (Mk), Sandia Fm. (Ps).

The basal beds of the Sandia Formation rest unconformably above 3-30 m of Kelly Limestone (Osagian) in the Magdalena Mountains, southern Lemitar Mountains, and in the Ladron Mountains. In the northern part of the Lemitar Range and locally in the Ladron Mountains, however, and throughout the eastern part of the Socorro region, the Kelly Limestone has been removed by Late Mississippian or Early Pennsylvanian erosion and the Sandia Formation rests on Precambrian granite.

The lower part of the Pennsylvanian section at Little San Pasqual Mountain is faulted and original basal relationships cannot be determined. At Abo Pass, faulting and erosion have obscured the basal Sandia contact, but in the nearby Los Piños and Manzano mountains, Sandia beds directly overlie Precambrian rocks.

Thickness

The thickness of the Sandia Formation ranges from 10 to 211 m (table 3, fig. 8) within the same region. The absence of Sandia beds in the Gallinas Mountains (Kottlowski, 1960) to the east in Lincoln County and in the Sun No. 1 San Agustin Plains hole to the west, demonstrates that the formation eventually wedges out against the Zuni and Pedernal uplifts. On the western flank of the Pedernal uplift, in the northern Oscura Mountains, the unit is only about 10 m thick (Kottlowski, 1960). In the Joyita Hills, near the Pennsylvanian Joyita uplift, the formation is also

	Thickness				Lithology				
Location	Ss (m)	Mr (m)	Ls (m)	Total	Ss%	Mr%	Ls%	CR	SMR
Abo Pass	-	-	-	60	-	-	-	-	-
Cerros de Amado	63.7	96.6	50.4	210.0	30	46	24	3.2	0.66
Joyita Hills	9.8	38.2	0	48	20	80	0	-	0.26
Ladron Mts	21.2	95.9	6	123.1	17	78	5	19.5	0.22
Lemitar Mts	37.3	90.8	17	145.1	26	62	12	7.5	0.41
L. San Pasqual Mtn.	19.8	115.1	46.5	181.4	11	63	26	2.9	0.17
Magdalena Mts	26.2	135.9	4.8	166.9	16	81	3	33.8	0.19
N. Oscura Mts	-	-	-	10 ?	-	-	-	-	-
S. E. San Mateo Mts	0	85	17.6	102.6	0	83	17	4.8	0

Table 3. Summary of thickness and lithology for the Sandia Formation. Sandstone (Ss), Mudrock (Mr), Limestone (Ls), Clastic Ratio (CR), Sandstone-mudrock Ratio (SMR).

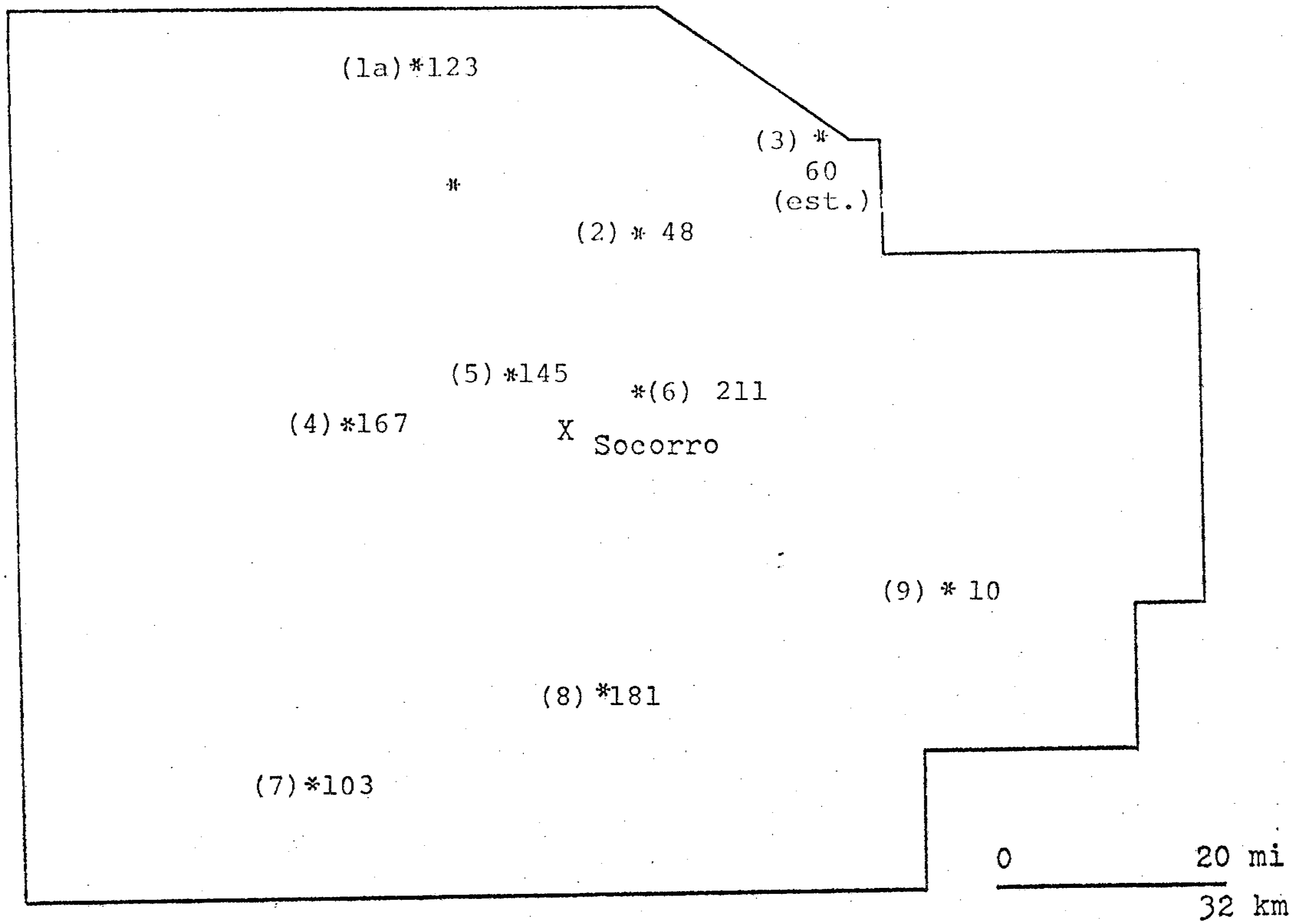


Figure 8. Map showing the thickness (in meters) of the Sandia Formation in the Socorro region. Mean Thickness = 126 m (413 ft).

thin (only about 48 m are present). Northwest of Socorro, 145 m of Sandia strata were measured in the Lemitar Mountains, but recent mapping by Chamberlin (personal communication, 1977) has shown that rapid thickening and thinning of the unit occurs within the area due to penecontemporaneous faulting.

In Abo Pass, where Sandia beds are faulted out of the section, the original thickness of the formation is inferred to be about 60 m, based on Myers' (1973) observation of about 55 m of the unit to the north in Priest Canyon in the southern Manzano Mountains, and on the presence of about 100 m of the unit to the south on Turret Mesa in the northern Los Pinos Mountains.

At Little San Pasqual Mountain, the base of the Sandia Formation is faulted and covered (Geddes, 1963). The true thickness of the formation cannot be ascertained, but 181 m of the formation was measured near the northern end of the uplift. This thickness is similar to thicknesses recorded for the formation throughout the region, and is somewhat greater than the thickness of the Sandia section in the northern Oscura and southeastern San Mateo Mountains. Therefore, 181 m probably closely approximates the true thickness of the Sandia section in the Little San Pasqual Mountain area.

It has been shown that the Sandia-Madera contact coincides closely with the upper limit of Atokan strata in the Socorro region. Average thickness for the Sandia Formation and the Atokan Series bears this out. The average thickness of the Sandia Formation within the region is 116 m, and Atokan faunas extend on the average, about 117 m into the Pennsylvanian System.

In summary, the thickest part of the Sandia Formation is positioned along a generally north- to northwest-trending axis located in the central part of the Socorro region, where the unit may be as much as 211 m thick. Local, rapid changes in thickness probably related to penecontemporaneous faulting, occur in some areas, and thinning of a more regional nature is apparent nearer the Pedernal and Zuni highlands. The formation eventually wedges out against the Zuni and Pedernal uplifts.

Lithologic Character

General Statement. The Sandia Formation in the Socorro region is composed of a wide variety of terrigenous mudrocks, granular terrigenous rocks, and carbonates. High clastic ratios (mean of 12.0) and low sandstone-mudrock ratios (mean of 0.27) demonstrate the terrigenous nature of the formation. The ratios (table 3, fig. 9) also point out the dominance of terrigenous mudrocks whose abundance within the section accounts for the conspicuous slope-forming character of the unit at every locality.

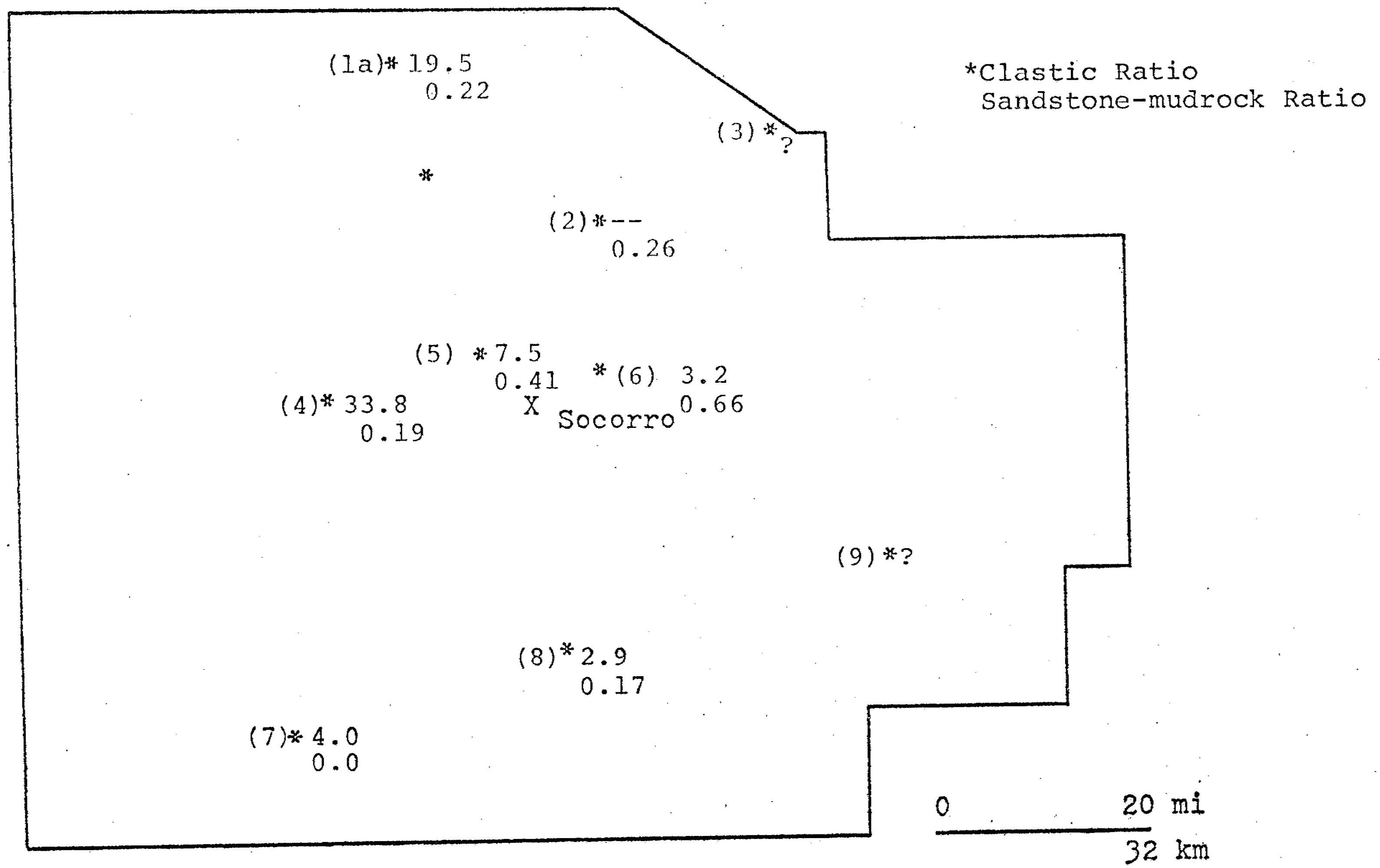


Figure 9. Map showing clastic ratios and sandstone-mudrock ratios for the Sandia Formation in the Socorro region.

Higher clastic ratios toward the west reflect an increasing abundance of terrigenous rocks in the western part of the region. However, the sandstone-mudrock ratio in the section decreases toward the west as the volume of mudrock increases (fig. 9). Clastic ratios and sandstone-mudrock ratios are generally lower in the southern part of the region, signifying the growing importance of limestone towards the south.

Sandstone is commonly more abundant in the lower part of the Sandia Formation, with shale and limestone predominating in the middle and upper parts of the unit. The lower sandy interval varies considerably in character from section to section, depending on the abundance of interbedded mudrock and limestone. At localities where the base of the section is exposed, a basal sandstone ranging from 1 to 20 m in thickness can be observed. Where this sandstone overlies Precambrian rocks, it is commonly a white to light-gray, siliceous, quartzose unit with a pebbly zone near the base. In areas where the sandstone rests on the Kelly Limestone (Mississippian), its composition is more variable and colors are usually drab.

The base of the Sandia Formation could not be observed at two localities within the study area. At Abo Pass, faulting has disrupted the base of the section, but in the northern Los Piños Mountains, a light-gray sandstone with a quartz pebble zone at its base overlies Precambrian granite (Stark and Dapples, 1946; Wilpolt, and others, 1946). Slope debris covers the base of the section in the northern Oscura Mountains; however, farther south in the range Kottlowski (1960) noted that lower Sandia beds consist of black shales, sandstones, and conglomerates that unconformably rest on Precambrian granite.

The basal sandstone interval is not present in the southeastern San Mateo Mountains where the lowermost beds are mudrocks and limestones. The lower part of the section at this locality is poorly exposed, but since a shale-limestone lithofacies dominates this part of the region (fig. 9) the apparent absence of the lower sandstone interval is not unreasonable.

In the southeastern San Mateo Mountains, some upper Sandia beds are Desmoinesian in age (Garner Wilde, personal communication, 1976). Lithologic ratios and rock characteristics do not change across the Atokan-Desmoinesian boundary and no major changes occur in the type of sedimentation until the Sandia-Madera contact is reached.

In summary, mudrock-producing environments generally dominated deposition of both Atokan and Desmoinesian Sandia beds throughout the Socorro region. Nevertheless, sandstone-producing environments gained some influence to the north and east, and limestone-producing environments became somewhat more important to the south.

Terrigenous Mudrocks. Fissile and less commonly nonfissile terrigenous rocks with less than 25 percent granular material (mudrocks) comprise 46 to 83 percent (mean 70 percent) of the Sandia Formation (table 3). They are seldom seen at the surface because they are usually covered by talus, soil, and vegetation. The only outcrops of mudrock (fig. 10) that can be described in detail are those found along road cuts and steep-sided arroyos, or those that are protected beneath a more resistant, ledge-forming sandstone or limestone bed. Individual mudrock units range from less than one meter to more than 65m in thickness, with the thicker intervals generally occurring in the middle and upper parts of the section. Thin shaly intervals and partings are also present in limestone and sandstone units. The color of the mudrocks is variable, including various shades of gray, green, and brown, with some shade of gray being the most common. The color of the weathered surface may be similar to that of a fresh surface, but more often is somewhat lighter and generally much duller in appearance.

Most of the mudrocks in the Sandia Formation feel gritty when chewed and in the field were identified as mud-shales; however, thin section analysis (fig. 11) revealed that most of the mudrocks are actually clay-shales with grain-to-mud ratios of less than one to three. Mudrock lithologies are somewhat variable within and among the various sections but

Figure 10. Poorly exposed outcrop of a slope-forming Sandia shale along the north-facing side of an arroyo in the Lemitar Mountains (5). As this photograph shows, Sandia shales are typically gray to black in color and commonly contain thin limestone and sandstone beds. Sec. 23, T. 1 N., R. 1 E.

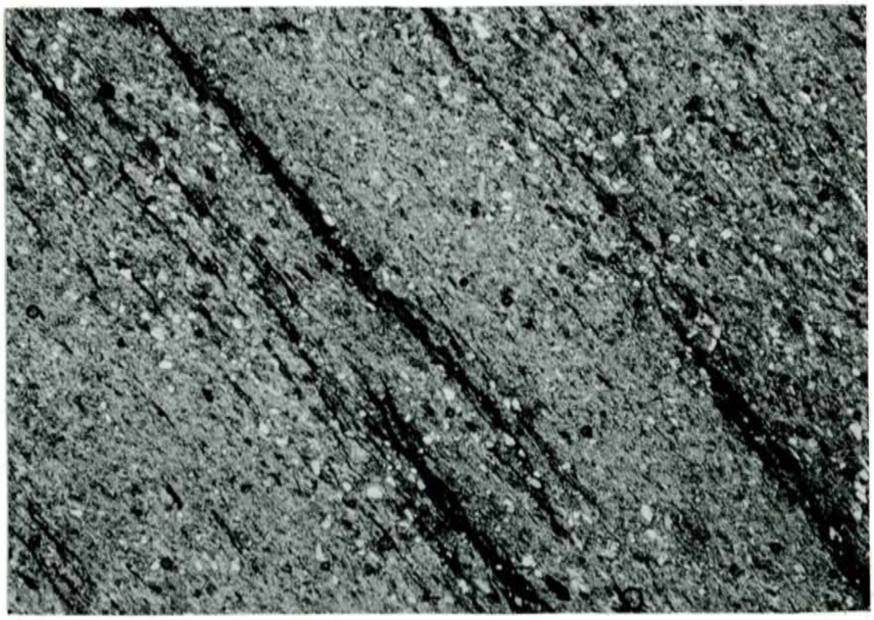


Figure 11. Photomicrograph of a typical mudrock from the Sandia Formation showing subangular, coarse silt-size grains of quartz and mica floating in a calcareous, siliceous, recrystallized clayey groundmass. The dark, linear patches consist of carbonaceous material and iron oxide. X25

commonly consist of subangular, poor- to well-sorted, coarse silt-size grains of quartz and muscovite floating in a calcareous, siliceous, generally recrystallized clayey groundmass. Porosity is negligible and usually occurs as microscopic fractures, vugs, or channels.

Small plant impressions are commonly found along parting planes and pieces of permineralized wood were found in shaly intervals in the Cerros de Amado. Marine invertebrates are extremely uncommon, but rare occurrences of brachiopods, crinoids, fusulinids, bryozoans, gastropods, and pelecypods are reported in the literature (Loughlin and Koschmann, 1942; Stark and Dapples, 1946) and were noticed occasionally during the present study. Stark and Dapples (1946) note that where plant forms are common in the northern Los Piños Mountains, marine fossils are absent. The most abundant occurrence of marine fossils in Sandia mudrocks witnessed by the writer, was the presence of brachiopods in black, carbonaceous shales in the Magdalena Mountains.

A summary of bedding parameters for nonfissile mudrocks is somewhat tenuous because they ordinarily are very poorly exposed, and their abundance in the section is limited. The available data suggest variations in bedding thickness ranging from thin to very thick. The beds are normally uneven and irregular, and frequently display thin, discontinuous to continuous, parallel to nonparallel, wavy and planar lamination, or thin, low-angle, small-scale cross-lamination that may be disturbed by small-scale soft-sediment deformation. Minor burrowing is associated with some mudstones, and gypsum occurs within some intervals in the Joyita Hills, but is not common within the Sandia Formation throughout most of the study area.

Granular Terrigenous Rocks. Terrigenous rocks composed of more than 25 percent sand and gravel constitute approximately 18 percent of the Sandia Formation. Their abundance in the section may be as much as 30 percent at some localities, whereas they are absent at others (table 3, fig. 12). The thickness of individual units ranges from less than a meter to as much as 20 m, and they crop out as low ledges that break the monotony of the covered shaly slopes (fig. 13). Due to changes in slope, the base of the more resistant sandstone intervals is a favorable site for the accumulation of slope debris and the nature of contacts with underlying units is seldom seen. Basal contacts that were observed are usually abrupt and there is seldom any evidence to suggest erosion or channeling into underlying units.

The various granular terrigenous lithologies are typically light- to medium-gray in color, but a wide range of browns and greens are found. The color of weathered surfaces is generally the same as that of fresh surfaces.

Classification. Quartz sandstones are the most common granular terrigenous rocks in the Sandia Formation (table 4), but a wide variety of other types are present, including subarkoses and arkoses, sublithic and lithic sandstones and

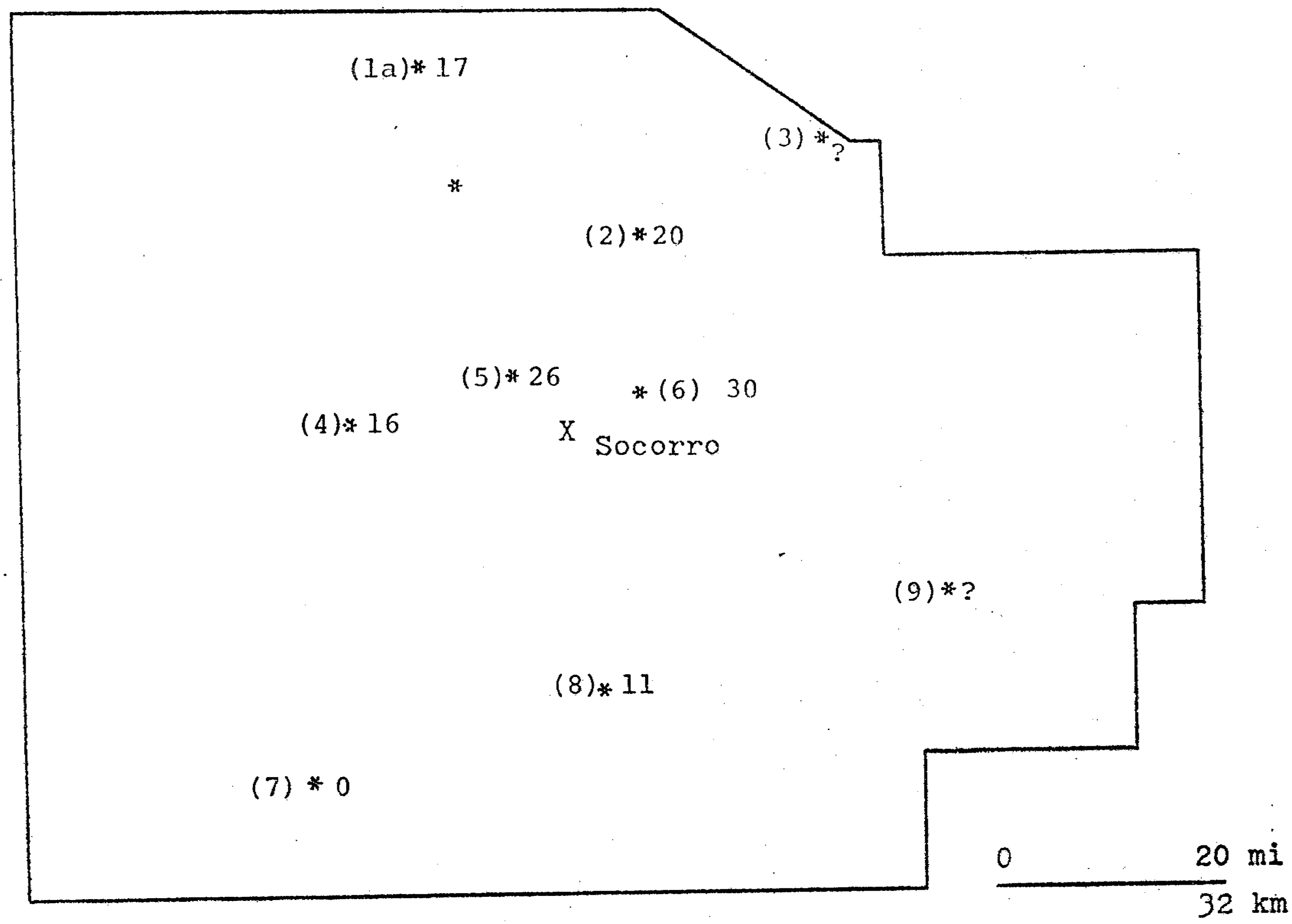


Figure 12. Map shows percentages of granular terrigenous rocks in the Sandia Formation in the Socorro region.

Figure 13. West-facing view of a low ridge in the Cerros de Amado (6) illustrating the ledgy nature of sandstone and limestone outcrops among the slope-forming shales of the Sandia Formation. Sec. 23, T. 3 S., R. 1 E.

Location	Rock Name	Grain Size	Sorting	Grain Shape	Induration
Ladron Mts	Qtz. sandstone	coarse sand	poor	angular to subangular	well indurated
Joyita Hills	Subarkose	very coarse sand	poor	angular	well indurated
Abo Pass	The Sandia Formation has been faulted out.				
Magdalena Mts	Qtz. sandstone	very coarse sand	poor	angular	well indurated
Lemitar Mts	Qtz. sandstone	coarse sand	poor	angular	very well indurated
Cerros de Amado	Qtz. sandstone	coarse sand	poor	subangular	well indurated
S.E. San Mateo Mt.	No sandstones are exposed.				
L. San Pasqual Mtn	Qtz. sandstone	fine to medium sand	well sorted	angular	well indurated
N. Oscura Mts	No Sandia Formation is exposed.				

Table 4. General lithology of granular terrigenous rocks in the Sandia Formation.

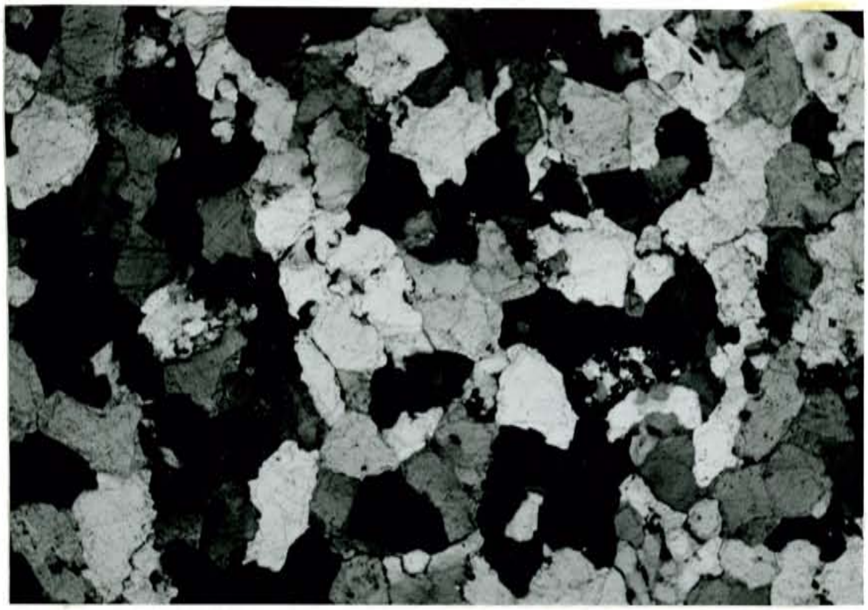
sedlithic conglomerates (Appendix II). Feldspathic sandstones are somewhat more abundant in the Joyita Hills; whereas, lithic conglomerates are common in the lower part of the section in the Lemitar Mountains.

Petrography. Figure 14 illustrates the mineralogic and textural characteristics typical of sandy terrigenous rocks in the Sandia Formation. Quartz is the most abundant constituent of these sandstone units, with both monocrystalline and polycrystalline grains present in thin section. Monocrystalline quartz is the more abundant of the two forms; these grains are commonly subequant and exhibit slightly undulatory or undulatory extinction. Vacuoles are the most common inclusions, but minor occurrences of microlites and hairlike inclusions (Folk, 1962) were also noted.

Polycrystalline quartz is present in most sandstones, but seldom constitutes more than 5 or 10 percent of a thin section. Polycrystalline grains commonly consist of five or more elongate crystals in line and sutured contact. Individual grains show slight to strong undulatory extinction; the distribtuion of crystal sizes within grains is generally bimodal.

Feldspar constitutes 2 to 5 percent of the sandstones in the Joyita Hills; whereas feldspar is typically absent in the rest of the region, except for sporadic occurrences in the Ladron Mountains and in the Cerros de Amado. Potassium feldspar, the most abundant feldspar, is often replaced by, or altered

A



B

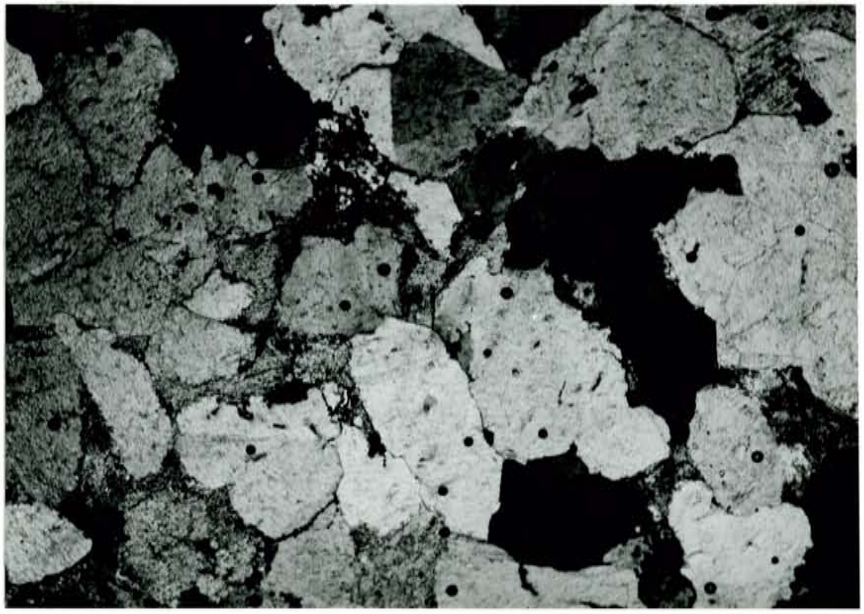


Figure 14. Photomicrographs of typical quartz sandstones from the Sandia Formation. The granular material consists of coarse- to very- coarse-grained, poorly sorted, angular to subangular grains of quartz cemented together by silica (A) and calcite (B). X25

to, calcite, clay, or fine-grained white mica (sericite). In hand specimen, potash feldspars commonly appear as bleached, chalky, rectangular patches; in thin section, badly altered relict grains are frequently the only clue to its presence. Plagioclase is seldom abundant, but a few grains usually occur in every feldspathic sandstone. They are characteristically less altered than the potassium feldspars nevertheless, they also show replacement by, or alteration to, calcite or sericite.

Detrital muscovite is the only common accessory mineral and is most abundant in fine-grained sandstones with a high proportion of matrix material. Long axes of muscovite are typically longer than the average grain size of the associated quartz and feldspar. The flakes are usually bent and deformed by pressure from adjacent grains; nevertheless, they tend to be aligned with their long axes parallel to bedding.

Lithic fragments are rare in Sandia sandstones and are usually restricted to fine-to coarsely crystalline chert grains. In the Lemitar Mountains, the few lithic conglomerate units in the lower part of the section contain clasts of siltstone, carbonate mudstone, and Precambrian argillite.

Heavy minerals were not examined in detail during the course of this study; however, a few of the more stable types (including tourmaline, garnet, and zircon) were noted in thin sections. Small opaque grains of magnetite, usually altered to hematite, sometimes occur in the matrix. Other opaque grains that do not have the typical reddish-brown color of hematite in reflected light also occur in trace amounts, but their composition is uncertain.

Most sandstone beds are free of any fossil material, but some of the more calcareous units in the lower Sandia in the Joyita Hills section are fairly fossiliferous and contain crinoid columnals and gastropods. The less resistant fossil material has been preferentailly removed by weathering so that molds on weathered surfaces are the only suggestion of the fossiliferous nature of the beds. In the Joyita Hills, the Lemitar Mountains, and the Ladron Mountains, woody plant impressions, accentuated by iron oxide staining, commonly occur on weathered surfaces. Some of the fragments are as much as 10 cm wide and 50 cm long.

Matrix material usually constitutes less than 10 percent of the sandstones in the Sandia Formation. On this basis, a majority of the sandstones would be called arenites in most of the textural nomenclature systems. Matrix material typically consists of detrital silt and a cloudy recrystallized interstitial paste of clay and diagenetic material. It is recognized that in a strict sense, the diagenetic fraction of the interstitial paste should not be called matrix, but because of the inhomogeneity and indistinct character of interstitial paste, detrital and diagenetic distinction was virtually impossible and it became necessary to lump the two components under the title of matrix.

Silica is the most common cementing agent and occurs as quartz overgrowths on detrital grains, quartz pore filling, or cherty pore filling. The end result is frequently an interlocking mosaic in which original grains are outlined by a faint border of dust-like inclusions. In many cases, it is difficult to determine whether interlocking line and sutured boundaries are the result of pressure solution or simply the product of interference between overgrowths.

Calcite is the next most abundant cement in many sandstones and occurs as finely crystalline pore filling, single-crystal pore filling, and large poikilitic patches that may enclose many sand grains. The finely crystalline pore filling variety is especially common in finer grained sandstones with somewhat higher concentrations of matrix material. Finely crystalline calcite frequently etches and embays detrital feldspar and quartz, with almost complete replacement of large orthoclase grains being very common. Cementation of Sandia sandstones is fairly complete and results in well-indurated units with negligible interparticle porosity.

The granular fraction of most sandstone is generally angular to subangular, poorly sorted, coarse- to very-coarse-grained sand with a sphericity coefficient of about 0.5 to 0.7. Vertically within the Sandia section, the textural character of sandstones is fairly consistent, but some minor variations exist between the sections and among various sandstone types. The few sandstone beds that occur in Sandia sections in the southern part of the county, where mudrocks and limestones are dominant, are finer grained and well sorted. Sandstones in the central and northern parts of the county, especially in the Magdalena Mountains and Joyita Hills, tend to be more coarsely grained and poorly sorted. Wackes and feldspathic sandstones generally show less rounding and are more poorly sorted than are quartzose arenite lithologies.

Bedding and Structures. Sandia sandstones are characteristically highly variable with bedding thicknesses ranging from thin to very thick, but with most beds in the medium to thick range. In most instances a sandstone unit is composed of multiple beds without vertical consistency in bedding thickness within the unit, i.e., bedding is generally uneven. Units may also consist of only one bed. Bedding regularity is usually difficult to establish laterally owing to the poorly exposed nature of many units. Most beds, however, appear to be fairly continuous and have subparallel, planar to wavy bedding surfaces. Entire units may show some lateral thinning, but most are laterally continuous within the areas examined.

A determined effort was made to study the suite of sedimentary structures characterizing Sandia sandstones because they are sensitive indicators of environmental conditions during deposition and reflect paleotransport directions. However, the effort met with little success because of inadequate exposures. In actual practice, description and classification of internal structures are further complicated by weathering and varnishing, that often remove any surface expression of existing internal structure. Therefore, many sandstones appear to be massive.

Available data indicate that a rather limited suite of sedimentary structures, restricted to various types of lamination and cross lamination, is typical of Sandia sandstones. Very thin to thin, subparallel, fairly continuous, planar and wavy lamination (fig. 15) is common in most sandstone units throughout the study area, and is especially visible in the Cerros de Amado. Cross lamination (fig. 16) is also common and occurs as solitary, concordant or discordant small- to medium-scale, tabular- and wedge-shaped sets with planar surfaces. Individual laminae are thin, straight or concave up, and usually dip less than 20 degrees. Strike and dip of cross laminations in Sandstones suggest that the bulk of the sediment was being transported in a southerly direction (see Appendix I).

Most of the sandstone units in the Magdalena Mountains section have a massive appearance, but similar sandstones in other parts of the range are laminated and cross laminated. Therefore, the massive "look" is believed to be an illusion related to weathering phenomena described above.

Carbonate Rocks. Carbonate rocks constitute 3 to 26 percent of the Sandia Formation in the Socorro region; they are most abundant in the Cerros de Amado-Little San Pasqual Mountain area (table 3, fig. 17). Most carbonate units are five meters or less in thickness, but some attain thicknesses

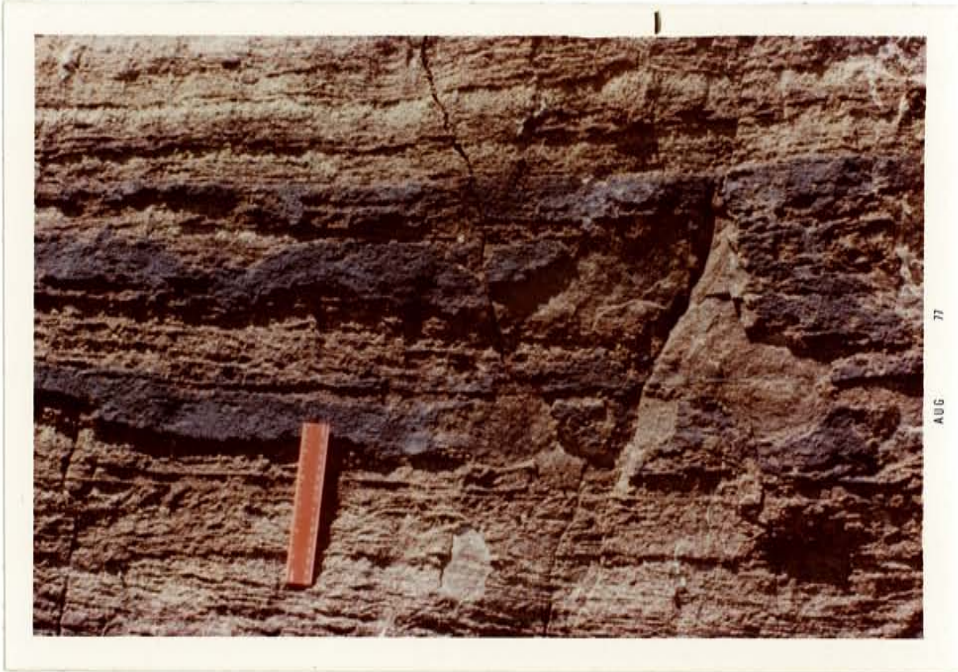


Figure 15. Laminated sandstone from the Sandia Formation in the Cerros de Amado (6) showing the fairly continuous, subparallel, planar and wavy lamination common in most Sandia sandstones and especially common in the Cerros de Amado. Sec. 23, T. 3 S., R. 1 E.

Figure 16. Cross-laminated Sandia sandstone from the Sandia Formation in the Cerros de Amado (6) showing the small- to medium-scale, low-angle, planar cross-lamination that is common in the Sandia Formation. Sec. 23, T. 3 S., R. 1 E.

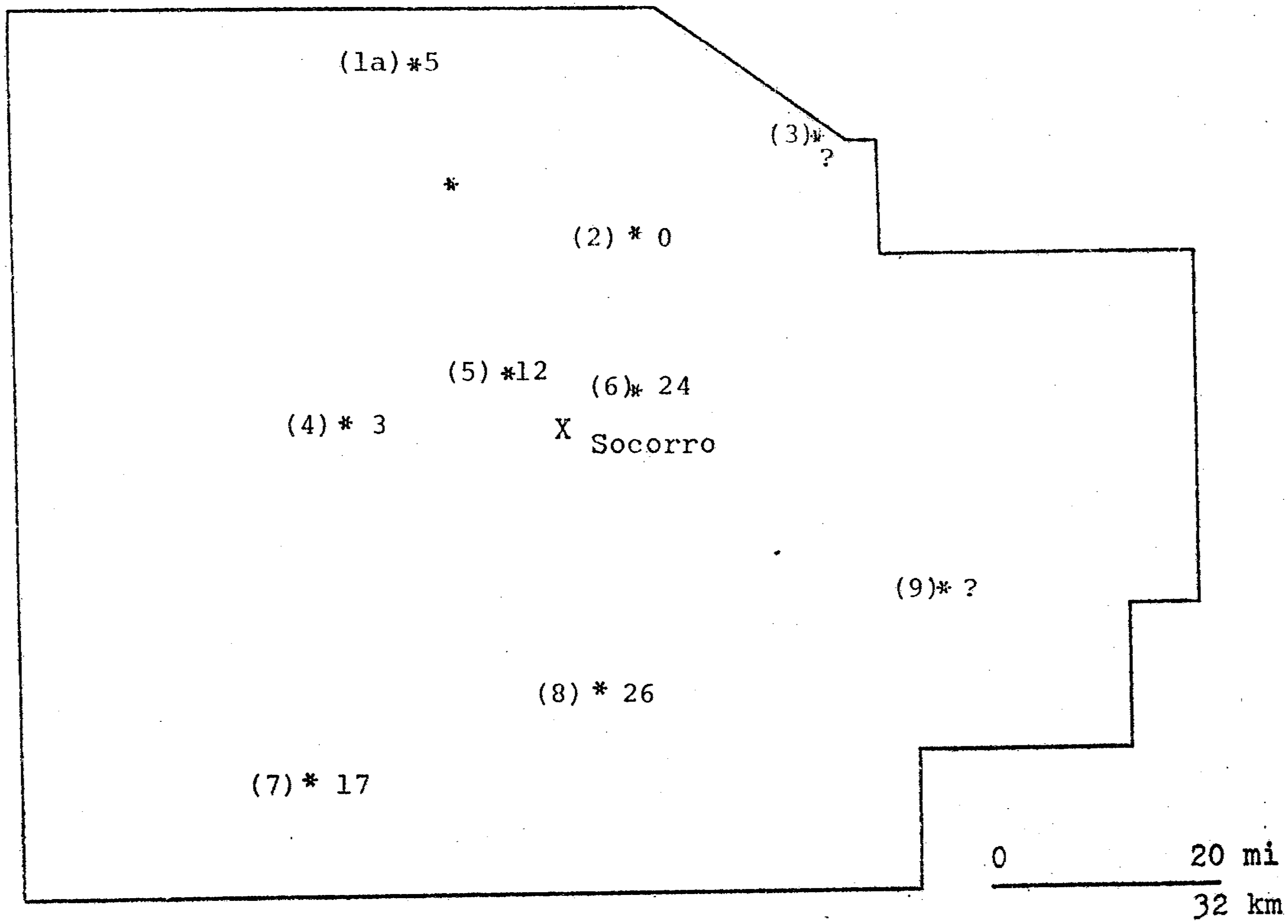


Figure 17. Map showing the percentage of carbonate rocks in the Sandia Formation in the Socorro region.

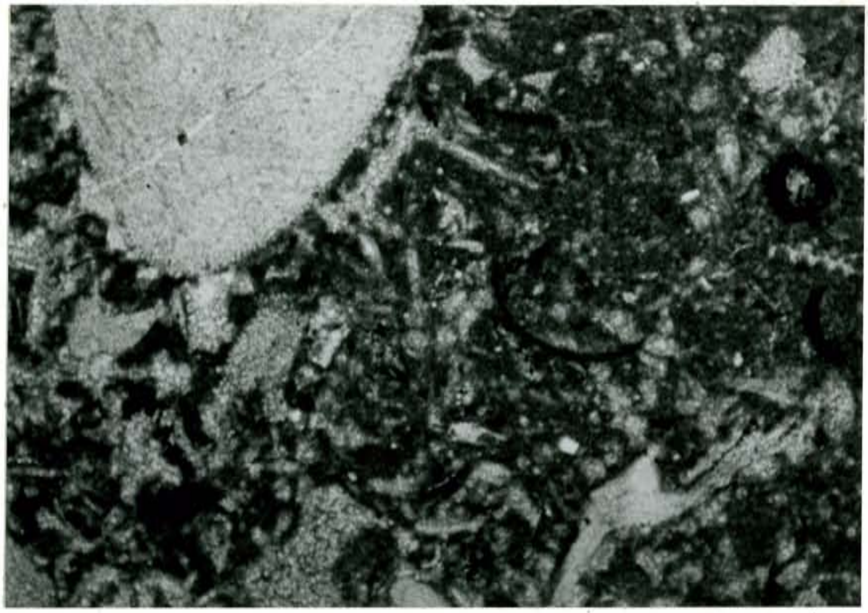
of as much as 40 m. The various types of Sandia limestone commonly range from medium-gray to black in color and crop out as low ledges separated by the slope-forming Sandia shales. Weathered surfaces are typically lighter in color than fresh surfaces.

Classification. Two carbonate nomenclature systems (Folk, 1959; Dunham, 1962) are used to name carbonate rocks in this study. Folk's (1959) system is based on composition and texture, whereas Dunham's system relies mostly on depositional fabric; by using both systems, the reader will have a clearer concept of the character of the limestones that have been studied.

Carbonate mudstones, wackestones, and packstones are all present in most Sandia sections, but wackestones are decidedly the most abundant. Mudstones, however, acquire some importance in the Magdalena Mountains. By Folk's (1959) nomenclature system, most Sandia limestones are biomicrites or biomicrudites. Frequent occurrences of micrite are also common.

Petrography. Photomicrographs of limestones that are representative of the Sandia Formation are shown in fig. 18. Terrigenous grains may be common in some limestone beds, but are generally absent or rare. They usually occur as angular, subspherical, variably sorted, silt and fine sand-size grains of quartz floating in a microcrystalline calcite groundmass. Sporadic traces of muscovite and microcline also occur, but

A



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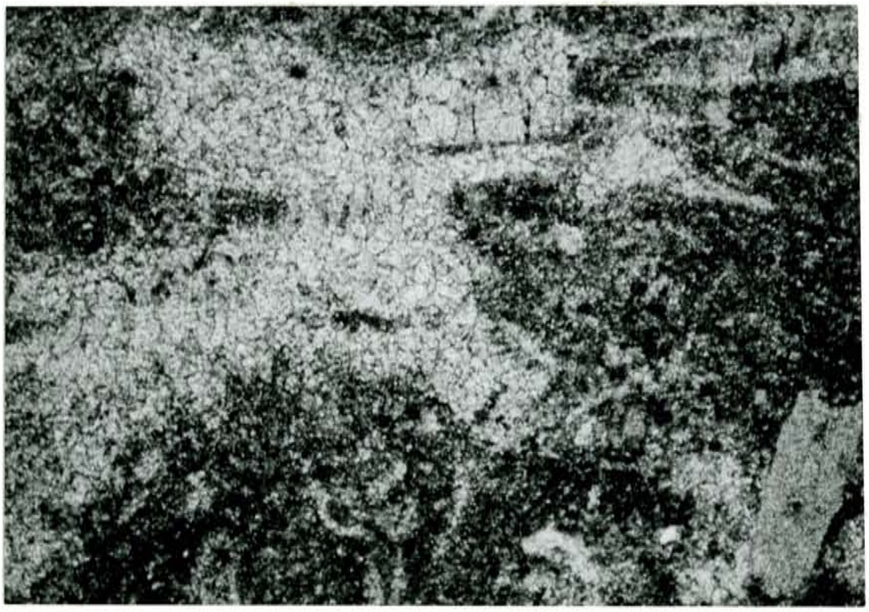


Figure 18. Photomicrographs of typical limestones from the Sandia Formation. The wackestone (A) consists of crinoid and brachiopod debris floating in a micrite groundmass that shows minor aggrading neomorphism. The mudstone (B) consists of some crinoid debris floating in a micrite groudmass that has undergone considerable aggrading neomorphism. X25

they seldom constitute more than one percent of the rock volume. Quartz grains are monocrystalline and slightly undulatory. Additional textural detail is generally lacking because most grains are corroded by the enclosing calcareous groundmass and original textures have been destroyed.

Almost every limestone contains some skeletal debris that includes in decreasing order of abundance crinoids, brachiopods, bryozoans, calcareous algae, solitary and colonial corals, mollusks, and fusulinids; crinoids and brachiopods are certainly the most abundant faunal representatives. Fossil material is characteristically fragmentary and poorly sorted, but shows little evidence of abrasion. The distribution of fossil debris is fairly uniform in most beds, with the more linear fragments usually oriented with their long axes parallel to bedding surfaces. Skeletal debris is most commonly preserved as finely to coarsely crystalline calcite. Both calcite and aragonite were no doubt constitutents of the original fossil debris but the original character of the material has been destroyed by neomorphic processes such as inversion and recrystallization. Fragment borders are frequently ill-defined and gradational as a result of micritization. In other cases boundaries are sharp and show well developed micritic envelopes suggesting boring and colonization by algae prior to burial (Bathurst, 1971). Internal micritization of fossil fragments is also common and often results in the complete destruction of internal structures. Fossil cavities are filled with micrite and coarsely crystalline calcite. Often micrite, neomorphic spar (microspar and pseudospar; Folk, 1959), and sparry calcite (spar precipitated from solution) occur in the same cavity. Silicification of fossil material is unusual in the Sandia Formation.

Inorganic allochemical constituents (Folk, 1959) are very rare in Sandia carbonates, but occasional occurrences (usually less than 5 percent) of intraclastic debris, peloidal material, and ooids are noted. Intraclasts consist of carbonate sediment that was eroded and redeposited while in a weakly consolidated state. Such fragments are irregular in shape and their borders are indiscriminantly cut by terrigenous grains and other allochem grains. Intraclasts range in size from coarse sand to pebbles and are commonly similar in composition to the bulk of the rock in which they are enclosed.

Ooids are nonbioclastic grains that show evidence of either concentric of radial structure. The few examples of ooids in Sandia limestones are comprised of a calcite core surrounded by a thin concentrically layered coat which is partially destroyed by micritization. The core now consists of single crystal of calcite spar. The diameter of the entire structure seldom exceeds 0.2 mm.

Peloidal material consists of spherical to irregularly-shaped aggregates of microcrystalline calcite, devoid of any internal structure. There is little uniformity in size, but most range between 0.5 and 1.0 mm in diameter and often occur in patchy clusters. Their origin is uncertain. They lack many of the characteristics associated with fecal pellets and may represent auto-agglutination of calcareous mud or small neomorphosed skeletal fragments that have been replaced by micrite (Folk, 1962).

Most carbonate rocks in the Sandia Formation are composed of microcrystalline calcite which occurs as a faintly brownish, subtranslucent material comprised of subequant to equant crystals of calcite that are generally less than 30 microns in diameter. Folk (1959) divides neomorphic calcite into micrite, microspar, and pseudospar primarily on the basis of crystal size. No attempt was made in this study to determine the precise abundance of the types of microcrystalline calcite, but in most samples much of the micrite is neomorphosed to microspar. In a majority of thin sections, some patches of microspar have undergone additional aggrading neomorphism to finely to very coarsely crystalline pseudospar, giving the rocks a porphyroid texture. The patches commonly are more coarsely crystalline near the center with crystal sizes becoming smaller toward the edges of the patch where pseudospar appears to invade the enclosing micrite or microspar.

Precipitated sparry calcite also constitutes part of the groundmass. Its precipitation in the original open spaces of the rock has reduced the porosity of most units to only a trace; nevertheless, higher porosities (three or four percent) occur in some beds. Higher porosities, however, are commonly related to secondary vugs, channels, caverns, and fractures. The sparry calcite ranges from finely to very coarsely crystalline and occurs as pore-filling material between allochems, within fractures, within fossil cavities, and in some pores that were very large due to "umbrella" effects by brachiopods and other large, flat fossil fragments. Some sparry calcite also occurs as overgrowths on crinoid fragments.

Some difficulty is associated with the distinction between precipitated spar and neomorphic spar, but on the basis of clarity, uniformity of crystal sizes, crystal orientations, and the nature of crystal boundaries and contacts (Folk, 1965; Bathurst, 1971), some degree of distinction is achieved. Generally, sparry caclite is clear and consists of randomly oriented crystals of uniform size with sharp, straight, interlocking boundaries. Neomorphic spar is more cloudy and is composed of crystals of varying sizes with gradational, curved, simple boundaries. Other characteristics of neomorphic calcite are: 1) it "nibbles" into the surrounding micrite, usually with euhedral faces; 2) it transects allochems, such as skeletal grains, oolites, intraclasts, and pellets; 3) silt, clay, or organic matter often remains between crystals of neomorphic spar, or is trapped within neomorphic crystals; and 4) neomorphic spar typically occurs in the midst of homogeneous micrite and is associated with lithologies in which packing is abnormally loose.

Clay-size noncarbonate material constitutes a small part of the matrix in the carbonate rocks, but estimates of its abundance were indeterminant because of the difficulty in distinguishing it from cloudy, micritic matrix. This fraction of the rock is generally composed of clay minerals and organic or carbonaceous matter.

Bedding and Structures. Bedding thicknesses among Sandia limestones range from thin to very thick, with most localities showing much diversity throughout the vertical extent of the section. Both even and uneven bedding are common and beds are typically regular with continuous, parallel, planar bedding surfaces. The beds in the southern part of the study area tend to be somewhat thicker and more evenly bedded than are those examined in the central and northern part of the region.

Most limestone beds show zones of thin, parallel to nonparallel, continuous to discontinuous, planar and wavy lamination (fig. 19). The observation of these laminated zones is commonly enhanced on weathered surfaces because they weather a light brown or very pale orange and are more resistant to weathering than nonlaminated areas. This may result from somewhat higher concentrations of terrigenous material in these zones. Many other beds are massive, showing no hint of any internal structure.

Madera Limestone

Basal Relationships

The change from the terrigenous nature of the Sandia Formation to the thick, massive-looking, gray limestones of

Figure 19. Outcrop of a Sandia limestone in the Magdalena Mountains (4) showing thin, parallel to nonparallel, planar and wavy lamination. The laminated zones often weather a lighter color than the rest of the rock and frequently contain higher concentrations of terrigenous material. Sec. 21, T. 2 S., R. 3 W.

the Madera Formation is usually conspicuous and the selection of a boundary between the two formations is not difficult. At many localities, however, limestones become more abundant and more thickly bedded in the upper part of the Sandia Formation; in these cases, the choice of a Sandia-Madera contact can become a disconcerting problem. A widely used and practical solution is placement of the boundary at the top of a prominent limestone unit, below which terrigenous strata dominate and above which limestone units dominate (Loughlin and Koschmann, 1942).

It has been noted that Madera beds range from Atokan to Virgilian in age, but that in much of the Socorro region the base of the Desmoinesian roughly coincides with the base of the Madera Limestone. Basal Desmoinesian beds are generally parallel to those of the underlying Atokan Series and there is little physical evidence to suggest an unconformity between the two series. Geddes (1963), however, described and illustrated a slight angular unconformity of local extent between Atokan and Desmoinesian strata at Little San Pasqual Mountain. The unconformity is apparently restricted to the southern part of the uplift because it could not be found in the northern part of the range where the section was measured for this study. Thompson (1942) also identified, on the basis of faunal evidence, a discontinuity between the two series throughout central and southern New Mexico.

Apparently, a hiatus exists between the Atokan and Desmoinesian series, but the interruption in sedimentation probably involved a relatively short interval of time with only minor, local diastrophism.

The lowermost beds of the Missourian Series are essentially parallel to those of the underlying Desmoinesian Series. However, faunal studies by Thompson (1942) demonstrated a disconformity of some magnitude at this boundary. In addition, he noted the occurrence of reworked Desmoinesian fusulinids in the basal terrigenous beds of the overlying Missourian units. Field evidence also supports the presence of a disconformity between the two series, for the base of the Missourian is marked by a conglomeratic sandstone and local channeling in some areas.

The base of the Virgilian is also marked by an unconformity. Faunal investigations by Thompson (1942) led him to conclude that Missourian and Virgilian beds in central New Mexico were separated by a short break in time. Conglomerates and sandstones at the base of some Virgilian sections further support the presence of an inconformity between the two series. For example, just north of Abo Pass in the southern Manzano Mountains, Myers (1973) observed that the basal unit of the Virgil Series is an arkosic conglomerate of cobble-sized, poorly sorted metamorphic rocks. The unit also contains fossilized wood fragments. Within most of the Socorro region, however, the basal unit of the Virgil Series consists mostly of shale, siltstone, and some fine- to medium-grained sandstone.

The Permo-Pennsylvanian contact is disconformable throughout the region. In central New Mexico, uppermost Virgilian beds carry a fusulinid fauna that is nearly identical to the fauna at the top of the Virgil Series in Kansas (Thompson, 1942). Basal Permian beds that occur immediately above these Virgilian strata in central New Mexico, however, carry a fusulinid fauna that is slightly younger than the basal Permian fusulinid faunas of Kansas. Furthermore, fusulinid faunas from uppermost Virgilian strata in central New Mexico are considerably more primitive than the fusulinid fauna at the top of Virgilian sections in the southern part of the state. Virgilian strata in central New Mexico, however, are superceded by Permian beds with a fusulinid fauna identical to Permian fusulinid faunas of basal Permian limestones in the southern part of the state. In summary, uppermost Virgilian beds in central New Mexico are time equivalent to uppermost Virgilian beds in Kansas, but lowermost Permian beds in New Mexico are not time equivalent to lowermost Permian beds in Kansas. They are slightly younger. Moreover, basal Permian strata in central New Mexico are time equivalent to basal Permian beds in southern New Mexico but uppermost Virgilian beds in central New Mexico are not time equivalent to uppermost Virgilian beds in southern New Mexico. Age discontinuities such as these clearly suggest a widespread disconformity of considerable magnitude between the Pennsylvanian and Permian systems throughout central New Mexico.

Thickness

The thickness of the Madera Limestone ranges from 64 to 716 m in the Socorro region (table 5, fig. 20). Thickest sections occur along a north-south trending axis through the southern Ladron, Magdalena, and southeastern San Mateo mountains, where the formation may be as much as 716 m thick. Only 232 m of the Madera Limestone were measured in the Magdalena Mountains, but normal faulting has cut out all of the Missourian, and parts of the Desmoinesian and Virgilian in North Fork Canyon where the section was measured. Recent subsurface studies (Krewedl, 1974) and stratigraphic reconstructions (Siemers, 1975) have demonstrated that original thickness of the Madera Limestone in the Magdalena area were probably about 500 to 550 m.

The Madera Limestone is from 300 to 375 m thick throughout most of the eastern Socorro region. In Abo Pass about 40 m of the lower Madera Limestone has been removed by faulting. Myers (1973), however, estimated that the true thickness of the unit in the area is about 375 m. Madera beds are absent in the Gallinas Mountains in westernmost Lincoln County (Kottlowski, 1960), which suggests that the formation eventually wedges out eastward against the Pennsylvanian Pedernal uplift.

The two thinnest Madera sections found in the Socorro region occur north of Socorro, only a short distance east of the axis of maximum thickness. Thinning of Desmoinesian and Missourian intervals and the complete removal of Virgilian strata by Wolfcampian (Early Permian) erosion (Kottlowski

Location	Thickness Ss(m)	Mr(m)	Ls(m)	Total	Lithology Ss%	Mr%	Ls%	CR	SMR
Abo Pass	21.3	172.8	138	332.1	6	52	42	1.4	0.12
Cerros de Amado	19.5	161.4	186.7	367.6	5	44	51	0.97	0.12
Joyita Hills	0	11.9	52.1	64	0	19	81	0.23	0
Ladron Mts	28.0	178.4	509.8	716.2	4	25	71	0.40	0.16
Lemitar Mts	0	29.5	155.2	184.7	0	16	84	0.19	0
L. S. Pasqual Mtn	10.6	49.6	284.2	344.4	3	14	83	0.21	0.21
Magdalena Mts	11.2	54.7	166.4	232.3	5	23	72	0.40	0.20
N. Oscura Mts	22.9	41.1	265.8	329.8	7	12	81	0.14	0.56
S. E. San Mateo Mts	17.1	166.8	479.6	663.5	3	25	72	0.38	0.10

Table 5. Summary of thickness and lithology for the Madera Limestone. Sandstone (Ss), Mudrock (Mr), Limestone (Ls), Clastic Ratio (CR), Sandstone-mudrock Ratio (SMR).

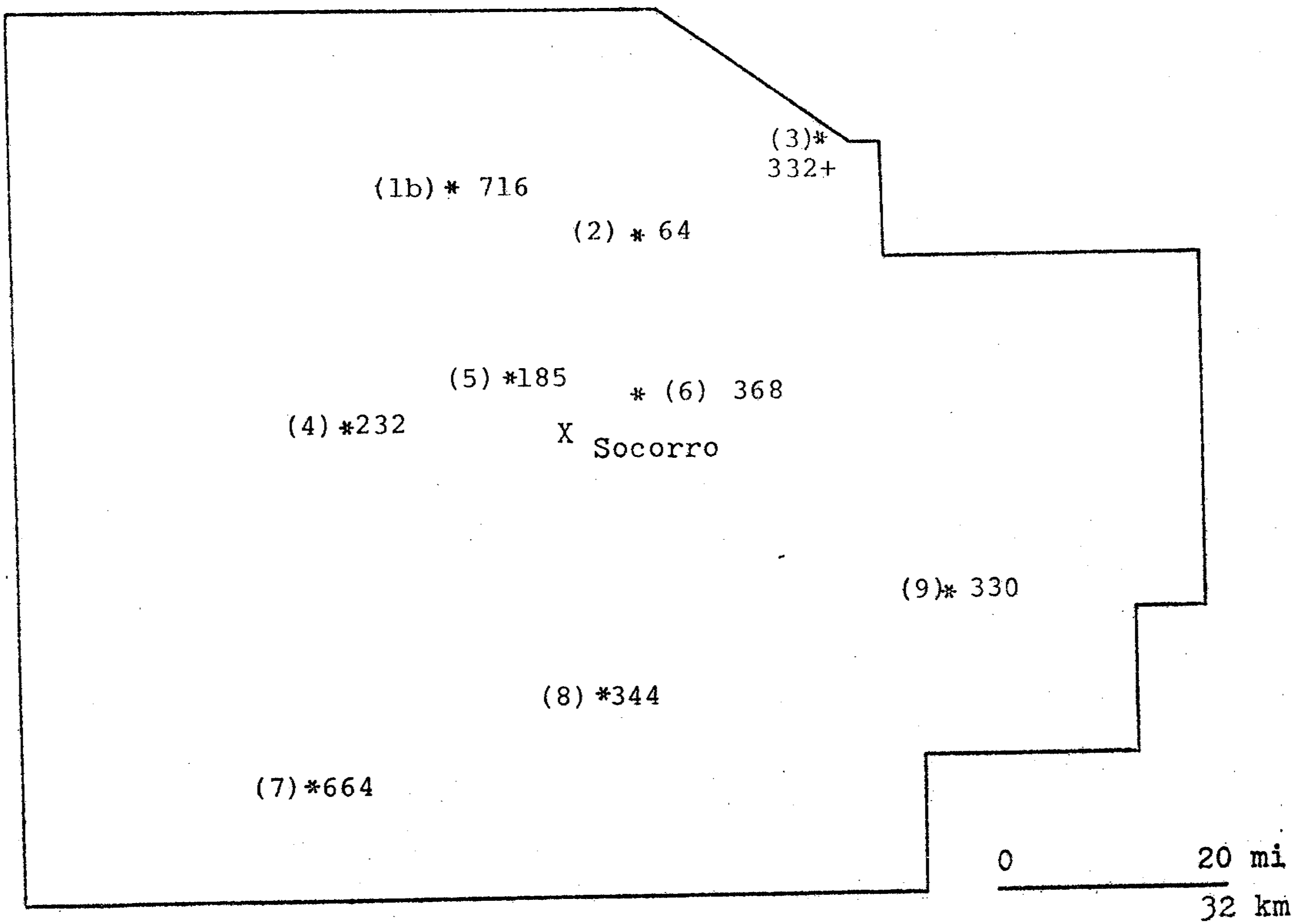


Figure 20. Map showing the thickness (in meters) of the Madera Limestone in the Socorro region.

and Stewart, 1970) has reduced the thickness of the formation to only 64 m in the Joyita Hills. In the Lemitar Mountains, Wolfcampian redbeds overlie Madera beds that are late Missourian in age. Thinning in this area, therefore, is also related to a period of late Virgilian or early Wolfcampian erosion that removed Virgilian and uppermost Missourian beds.

Lowermost Madera Limestone beds of Atokan age attain thicknesses of 11 m and 34 m in the Joyita Hills and the northern Oscura Mountains respectively (table 6, fig. 21). Throughout the rest of the region, basal Madera beds are Desmoinesian in age. Desmoinesian Madera strata range from 18 to 237 m in thickness, with the thickest preserved deposits occurring in the Ladron and southeastern San Mateo Mountains.

Madera beds of Missourian age range from 31 to 361 m in thickness (table 6). The thickest sections again occur in the Ladron and southeastern San Mateo Mountains and the thinnest section is in the Joyita Hills (fig. 21). Virgilian beds, however, attain their greatest thickness in the northern Oscura Mountains where they are about 121 m thick (fig. 21). The Virgilian series is completely missing from the sections in the Joyita Hills and Lemitar Mountains.

The average original thickness of the Madera Limestone must have been about 400 m with somewhat thicker sections located along a north-trending axis west of Socorro, and considerably thinner sections located in the Joyita Hills and

Table 6. Summary of the thickness of Pennsylvanian series in the Madera Limestone. Sandstones (Ss), Mudrock (Mr), Limestone (Ls).

Atokan Madera Limestone

Location	Ss (m)	Mr (m)	Ls (m)	Total
Abo Pass	0	0	0	0
Cerros de Amado	0	0	0	0
Joyita Hills	0	0	11	11
Ladron Mts	0	0	0	0
Lemitar Mts	0	0	0	0
L. S. Pasqual Mtn	0	0	0	0
Magdalena Mts	0	0	0	0
N. Oscura Mts	0	8.6	24.9	33.5
S. E. San Mateo Mts	0	0		0

Desmoinesian Madera Limestone

Location	Ss (m)	Mr (m)	Ls (m)	Total
Abo Pass	0	64.6	79.9	144.5
Cerros de Amado	10.4	81.6	97.4	189.4
Joyita Hills	0	3.6	18.3	21.9
Ladron Mts	4.6	13.7	237.4	255.7
Lemitar Mts	0	0	115.7	115.7
L. S. Pasqual Mtn	3.0	13.7	119.6	136.3
Magdalena Mts	11.2	34.7	125.7	171.6
N. Oscura Mts	0	1.8	65.0	66.8
S. E. San Mateo Mts	17.1	89.5	233.6	340.2

Missourian Madera Limestone

Location	Ss (m)	Mr (m)	Ls (m)	Total
Abo Pass	16.7	48.8	9.7	75.2
Cerros de Amado	8.2	70.7	69.2	148.1
Joyita Hills	0	8.3	22.8	31.1
Ladron Mts	23.4	123.2	214.3	360.9
Lemitar Mts	0	29.5	39.5	69.0
L. S. Pasqual Mtn	0	41.8	71.8	113.6
Magdalena Mts	-	-	-	-
N. Oscura Mts	4.6	15.0	88.9	108.5
S. E. San Mateo Mts	0	64.9	202.5	267.4

Virgilian Madera Limestone

Location	Ss (m)	Mr (m)	Ls (m)	Total
Abo Pass	4.6	59.4	48.4	112.4
Cerros de Amado	0.9	9.1	20.1	30.1
Joyita Hills	0	0	0	0
Ladron Mts	0	41.5	58.1	99.6
Lemitar Mts	0	0	0	0
L. S. Pasqual Mtn	7.6	24.1	62.8	94.5
Magdalena Mts	0	20.0	40.7	60.7
N. Oscura Mts	18.3	24.3	78.4	121.0
S. E. San Mateo Mts	3.5	19.8	39.8	63.1

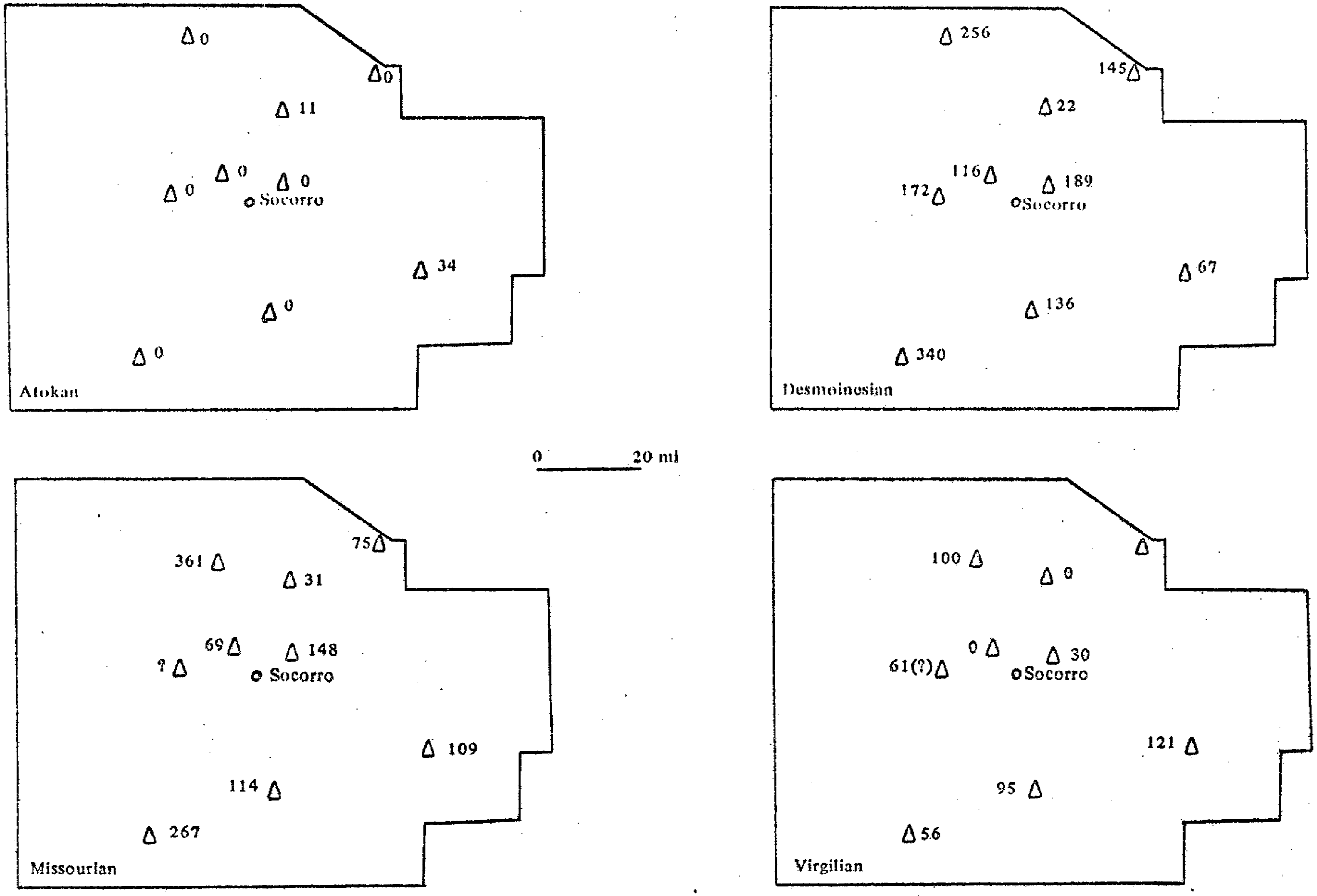


Figure 21. Maps showing the thickness of Pennsylvanian Series within the Madera Limestone. Thicknesses are given in meters.

Lemitar Mountains. The lower part of the Madera is Atokan in age in the Joyita Hills and in the northern Oscura Mountains; elsewhere lowermost Madera beds are Desmoinesian in age. Madera beds of Desmoinesian, Missourian, and Virgilian ages average about 160, 140, and 85 m in thickness, respectively.

Lithologic Character

General Statement. The Madera Limestone in the Socorro region is composed of diverse carbonate and terrigenous lithologies. The mean clastic ratio is about 0.45, which illustrates the dominance of carbonate rocks (table 5, fig. 22). Low sandstone-mudrock ratios (mean of 0.16) indicate that terrigenous beds are chiefly mudrocks. Sandstones, in fact, seldom comprise more than about 5 percent of the section.

All Madera beds of Atokan age in the Joyita Hills are limestone (table 7, fig. 23). Atokan Madera beds in the northern Oscura Mountains are also limestones, but are frequently separated by shaly partings 1 to 10 cm thick. Shaly partings are common among limestone units in the area and it is, therefore, suspect that most covered intervals in the section are probably shale or shaly limestone.

Clastic ratios of Desmoinesian Madera beds range from 0 to 0.94 (table 7, fig. 23). Values near the lower end of the spectrum occur at Little San Pasqual Mountain and in the Lemitar, northern Oscura, and northern Ladron Mountains. High values were noted at Abo Pass and in the Cerros de Amado. Medial values, ranging from 0.2 to 0.5, are representative of Desmoinesian beds in the Joyita Hills, Magdalena Mountains,

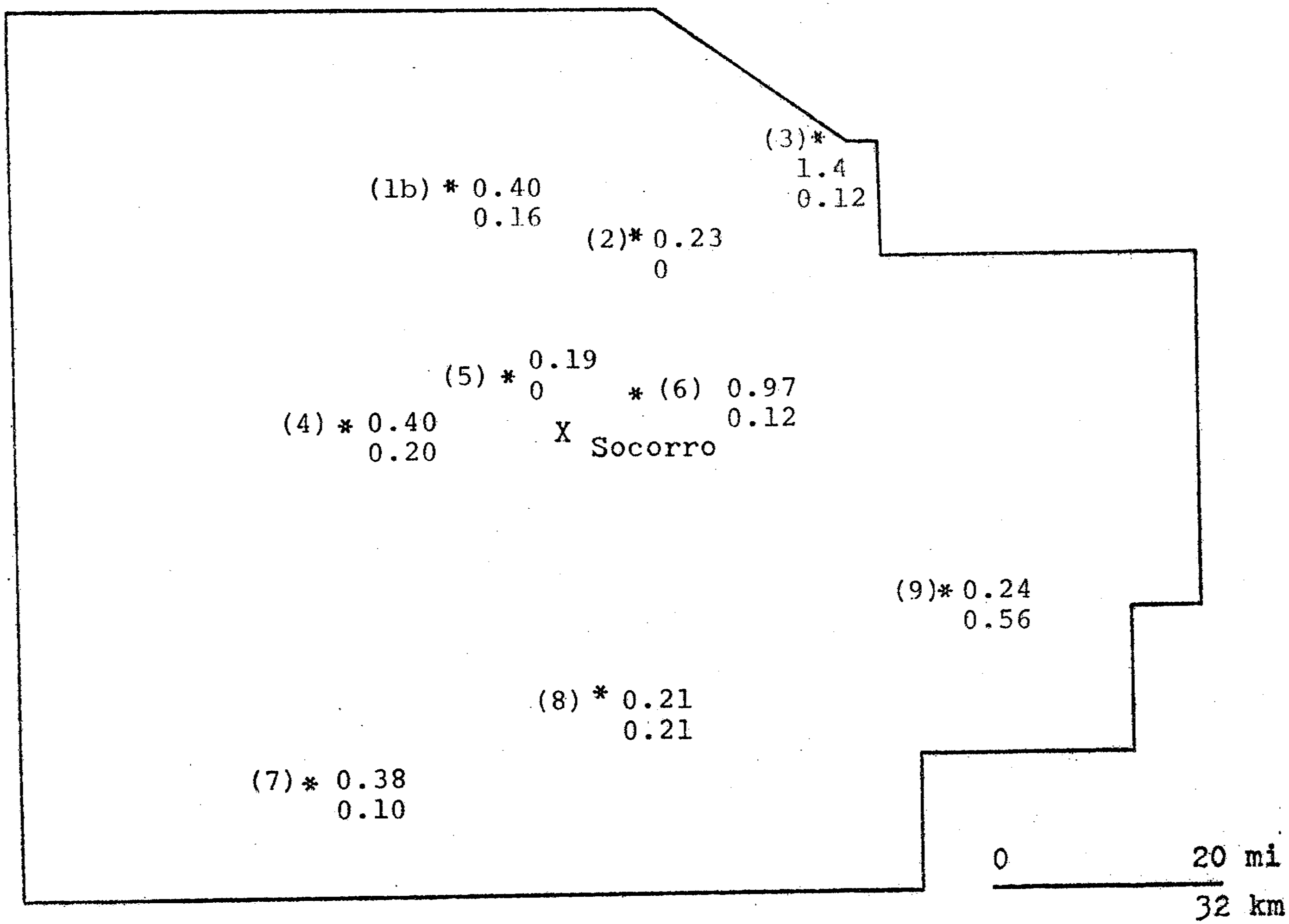


Figure 22. Map showing the lithology of the Madera Limestone in the Socorro region.

Table 7. Lithologic summary of Pennsylvanian series in the Madera Limestone. Sandstone (Ss), Mudrock (Mr), Limestone (Ls), Clastic Ratio (CR), Sandstone-mudrock Ratio (SMR).

Atokan Madera Limestone

Location	Ss%	Mr%	Ls%	CR	SMR
Abo Pass	0	0	0	-	-
Cerros de Amado	0	0	0	-	-
Joyita Hills	0	0	100	0	-
Ladron Mts	0	0	0	-	-
Lemitar Mts	0	0	0	-	-
L. S. Pasqual Mtn	0	0	0	-	-
Madalena Mts	0	0	0	-	-
N. Oscura Mts	0	26	74	0.34	-
S. E. San Mateo Mts	0	0	0	-	-

Desmoinesian Madera Limestone

Location	Ss%	Mr%	Ls%	CR	SMR
Abo Pass	0	45	55	0.81	0
Cerros de Amado	6	43	51	0.94	0.13
Joyita Hills	0	16	84	0.20	0
Ladron Mts	2	5	93	0.08	0.34
Lemitar Mts	0	0	100	0	-
L. S. Pasqual Mtn	10	88	0.14	0.22	
Magdalena Mts	7	20	73	0.37	0.32
N. Oscura Mts	0	3	97	0.03	0
S. E. San Mateo Mts	5	26	69	0.47	0.19

Missourian Madera Limestone

Location	Ss%	Mr%	Ls%	CR	SMR
Abo Pass	22	65	13	6.8	0.34
Cerros de Amado	6	48	46	1.1	0.11
Joyita Hills	0	27	73	0.36	0
Ladron Mts	7	34	59	0.68	0.19
Lemitar Mts	0	43	57	0.75	0
L. S. Pasqual Mtn	0	37	63	0.58	0
Magdalena Mts	-	-	-	-	-
N. Oscura Mts	4	14	82	0.22	0.31
S. E. San Mateo Mts	0	24	76	0.32	0

Virgilian Madera Limestone

Location	Ss%	Mr%	Ls%	CR	SMR
Abo Pass	4	53	43	1.3	0.07
Cerros de Amado	3	30	67	0.50	0.10
Joyita Hills	-	-	-	-	-
Ladron Mts	0	42	58	0.71	0
Lemitar Mts	-	-	-	-	-
L. S. Pasqual Mtn	8	26	66	0.50	
Magdalena Mts	0	33	67	0.49	0
N. Oscura Mts	15	20	65	0.54	0.75
S. E. San Mateo Mts	0	0	100	0	-

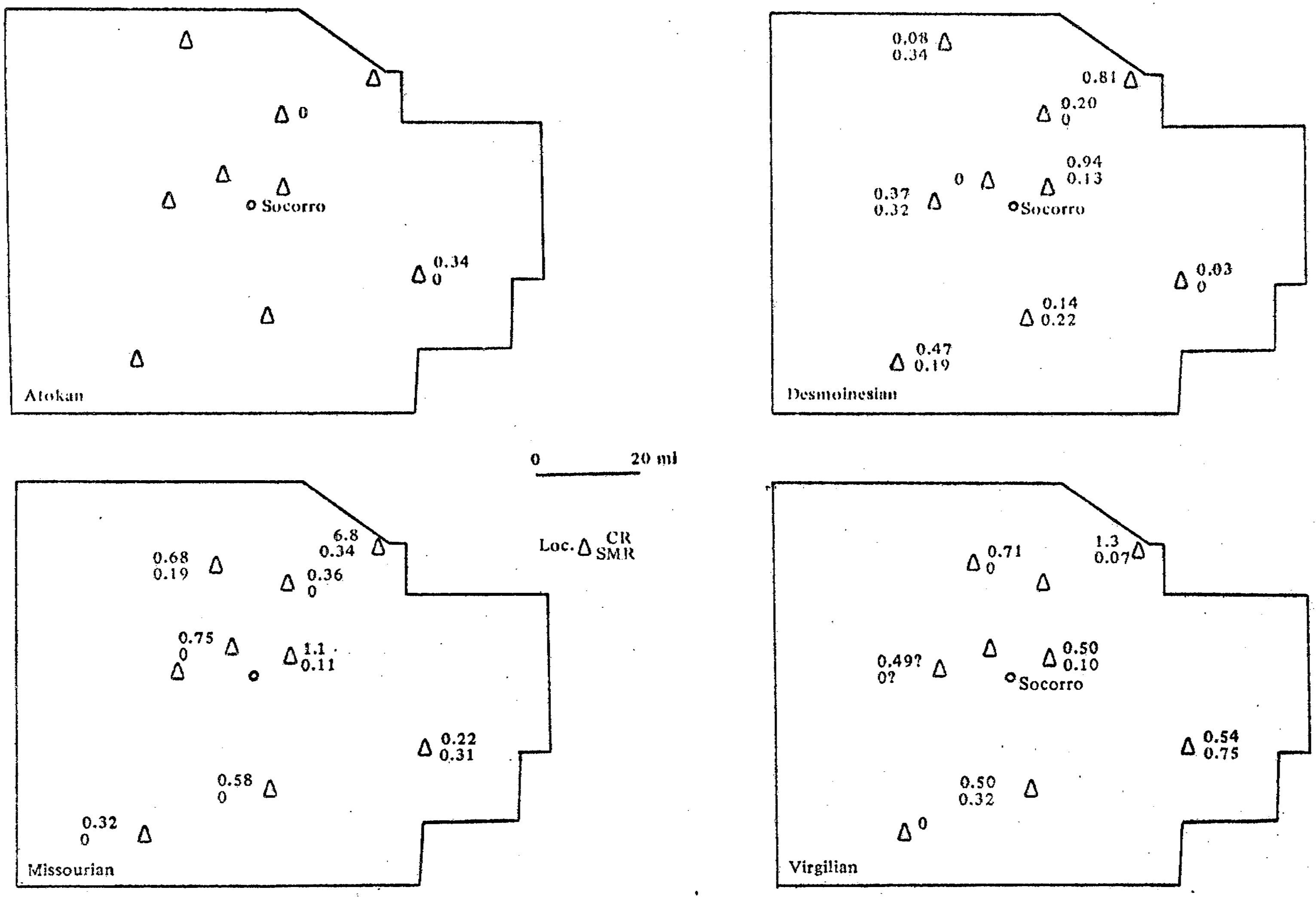


Figure 23. Maps showing the lithology of the Pennsylvanian Series associated with the Madera Limestone.

and southeastern San Mateo Mountains. The resistance of the thickly bedded Desmoinesian limestones to erosion in the semi-arid climate of New Mexico makes it a prominant ridge-former (fig. 24) throughout the region. The series constitutes most of what is generally called the gray limestone member of the Madera Limestone.

Clastic ratios determined for Missourian beds range between 0.22 and 6.8 (table 7, fig. 23). The unusually high upper limit of 6.8 reflects an extremely terrigenous Missourian sequence at Abo Pass, where mudrock and sandstone constitute 87 percent of the section. Discounting the Abo Pass area, clastic ratios in the Missourian Series average about 0.7 and are seldom more than 1.0. Missourian sandstone-mudrock ratios are low, suggesting that the paucity of sandstone in the underlying Desmoinesian Series continues through the Missourian and into the Virgilian.

Clastic ratios of Virgilian beds range from 0 to 1.3 (table 7, fig. 23), with the most terrigenous section again occurring at Abo Pass. At other localities, values are commonly between 0.5 to 0.7. No terrigenous rocks occur among Virgilian strata in the southeastern San Mateo Mountains. Sandstone-mudrock ratios are somewhat higher in the Virgilian Series than they were in the Missourian Series; however, they are still low and attain an average value of only 0.18. The most abundant occurrences of granular terrigenous rocks are restricted to the eastern part of the

Figure 24. A southwest-facing view in the western Lemitar Mountains (5) which illustrates the slope-forming nature of the Sandia Formation and the ledgy, ridge-forming character of the Desmoinesian gray limestone member of the Madera Limestone. Sec. 11, T. 2 S., R. 2 W.

region. In that area, they may constitute as much as 15 percent of the Virgilian section.

These data show that the Madera Limestone is dominantly a carbonate unit, but shows considerable geographic and stratigraphic diversity in the amount of terrigenous strata that it contains. Terrigenous beds are generally more abundant at Abo Pass and in the Cerros de Amado than they are in the rest of the Socorro region, and tend to become more abundant upward from the base of the formation.

Carbonate Rocks. Limestones constitute 42 to 84 percent, and average about 69 percent of the Madera Limestone (table 5, fig. 25). Carbonates are most abundant in Atokan and Desmoinesian Madera beds, where they account for about 80 percent of the section (table 7), whereas, in the Missourian and Virgilian series, carbonate rocks account for about 62 percent of the section. In the Joyita Hills and the Lemitar Mountains, carbonates make up an uncommonly large part of the Madera section. This may be related to the removal of more terrigenous Missourian and Virgilian beds in these areas by late Virgilian or early Wolfcampian erosion. Carbonate rocks are also uncommonly abundant at Little San Pasqual Mountain, but at this locality, most of the Upper Pennsylvanian is part of a valley-forming sequence in which exposures are limited. In mapping the area, Geddes (1963) thought that most of the

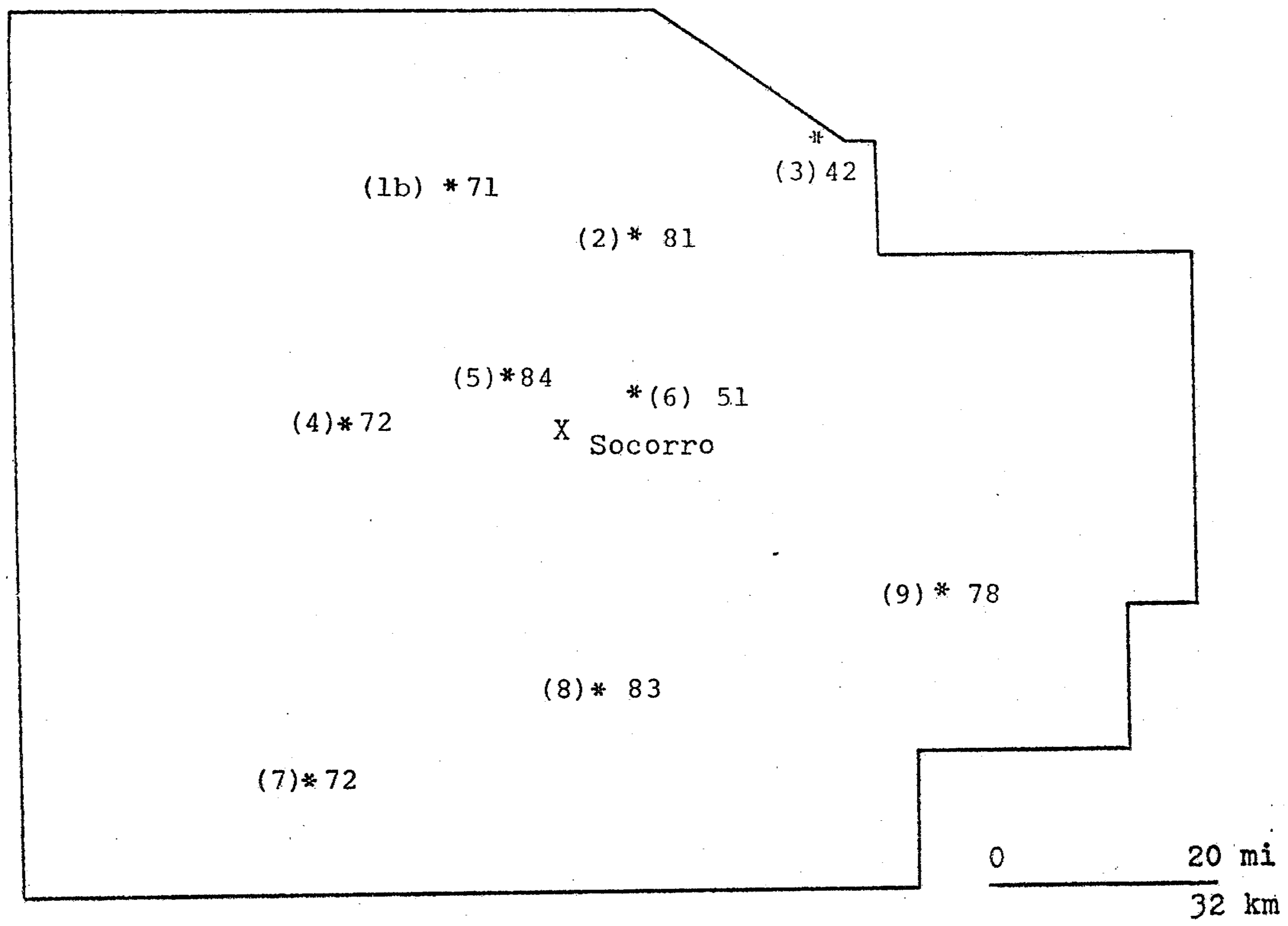


Figure 25. Map of the percentage of carbonate rocks in the Madera Limestone of the Socorro region.

covered intervals were limestone. However, much of the covered Upper Pennsylvanian section may be terrigenous in nature. Therefore, estimates reported for the amount of limestone in the Madera section at Little San Pasqual Mountain may be somewhat inflated.

Carbonate rocks constitute only 42 percent of the section at Abo Pass, and in a strict sense, one could question whether or not it is appropriate to call all these beds the Madera Limestone. Atokan beds and 40 to 50 m of the Desmoinesian Series have been faulted out of the section. Complexly faulted outcrops elsewhere in the area, and in the southern Manzano Mountains (Myers, 1973) suggest that the missing Desmoinesian beds are dominantly limestones. If this is the case, the presence of this interval at the base of the section would increase the abundance of limestone in the section to almost 50 percent. This, along with the thickly bedded, massive, cliff-forming nature of many of the limestone units in the area, suggests that even though the Abo Pass section is unusually terrigenous, it is not unreasonable to include these beds in the Madera Limestone.

The average thickness of carbonate intervals at most sections usually ranges between 5 and 15 m. Thin carbonate mudstones, only a few centimeters thick, however, frequently occur within shaly intervals. Limestone intervals in the Ladron Mountains, Lemitar Mountains, and Abo Pass sections consist of 90 to as much as 140 m of limestone which are virtually uninterrupted except for a few thin calcareous shales.

Limestone intervals in the Madera Limestone are durable in the semi-arid climate of the region, and units that attain thicknesses of more than 2 or 3 m typically form prominant ledges. Thicker units are likely to be cliff-formers, and intervals of section in which limestones are unusually abundant are often prominant ridge formers.

The color of carbonate rocks is almost always some shade of gray, with darker hues dominating. A few beds acquire a greenish cast, and some uppermost Pennsylvanian carbonate units become brownish-gray or grayish-red. The color of weathered surfaces generally reflects the fresh color of the rock, but is usually somewhat lighter. If a bed is dolomitic, it is likely to weather yellowish-orange or yellowish-brown (fig. 26).

Classification. The majority of Madera limestones are mudstones and wackestones (table 8) by Dunham's classification. Only occasionally are carbonate packstones and grainstones noted among Madera limestones.

Mudstones completely dominate Missourian and Virgilian carbonates and are the predominate limestone type in Desmoinesian Madera beds in the Ladron and Magdalena mountains (northwestern and west-central areas). Mudstones also are

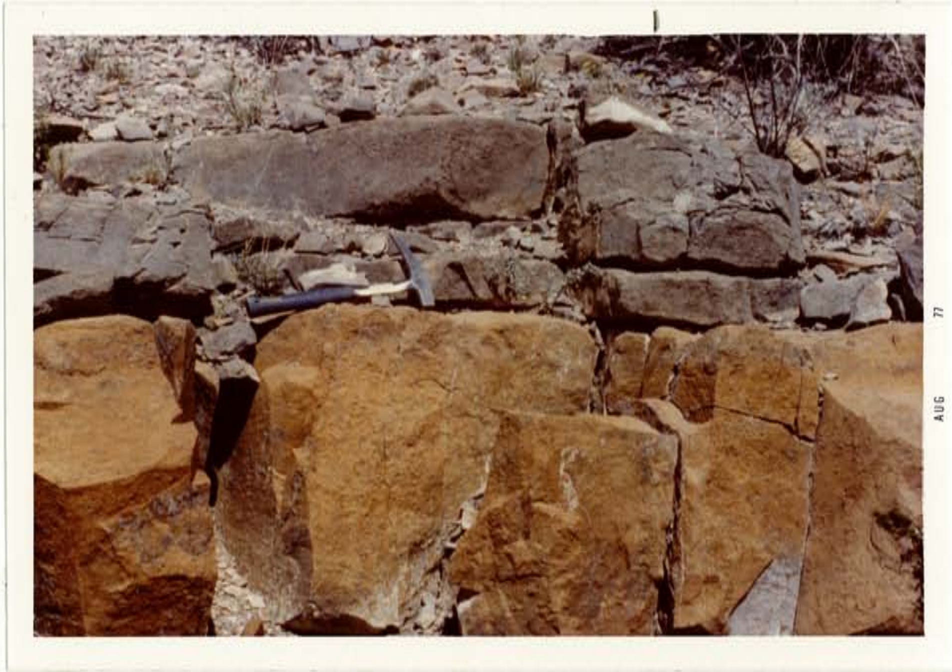


Figure 26. An outcrop of a dolomitic limestone in the Madera Limestone at Abo Pass (3). Dolomitic beds are not very common in the Madera Limestone, but when they do occur, they are very noticeable because they weather yellowish-orange or yellowish-brown. Sec. 25, T. 3 N., R. 4 E.

Location	Rock Name	Terrigenous Grains	Nonskeletal Allochems	Fossils	Bedding
Ladron Mts	Mudstone	very rare	very rare	common	thin-very thick, e, r
Joyita Hills	Mudstone & Wackestone	very rare	very rare	very common	thin-very thick, e, r
Abo Pass	Wackestone	very rare	none	very common	thin-very thick, e, r
Magdalena Mts	Mudstone	none	none	common	medium-thick ue, r
Lemitar Mts	Mudstone	none	none	common	medium-thick ue, r
Cerros de Amado	Mudstone & Wackestone	very rare	rare	very common	thin-very thick, r
S. E. San Mateo Mts	Mudstone	very rare	very rare	common	medium-very thick, r
L. San Pasqual Mtn	Mudstone	none	very rare	common	thin-very thick, e, r
N. Oscura Mts	Mudstone & Wackestone	very rare	very rare	very common	thin-very thick, e, r

Table 8. General description of carbonate rocks in the Madera Limestone in the Socorro region. even (e), uneven (ue), regular (r), irregular (ir).

the most abundant Desmoinesian limestone type in the southeastern San Mateo and northern Oscura mountains of southwestern and southeastern Socorro County. Desmoinesian limestones northeast of Socorro in the Lemitar Mountains and at Little San Pasqual Mountain, however, are commonly wackestones.

After Folk (1959, 1962), most Madera limestones are fossiliferous micrites and biomicrites or biomicrudites, which suggests that most of the non-mud material in the mudstones and wackestones is comprised of skeletal material. Except for a few rare occurrences at Abo Pass and in the southeastern San Mateo Mountains, surface exposures of Pennsylvanian dolomites in the Socorro region are virtually nonexistant.

Petrography. Figures 27 and 28 illustrate the typical petrographic characteristics of limestones encountered in the Madera Limestone. Occurrences of granular terrigenous material in Madera limestones are rare (table 8). In some samples, however, as much as 5 to 10 percent detrital, monocrystalline quartz may occur. The silt- to fine-sand-size grains are fairly well sorted, angular to subangular in shape, and show straight to undulatory extinction. Detrital muscovite also occurs in some thin-sections, but its abundance seldom exceeds one percent.

The abundance of fossil debris in Madera limestones ranges from rare to very abundant, but in most units,

Figure 27. Photomicrograph of typical wackestone from the Madera Limestone. The wackestone consists of crinoid, bryozoan, brachiopod, and fusulinid debris in a micrite matrix. X25

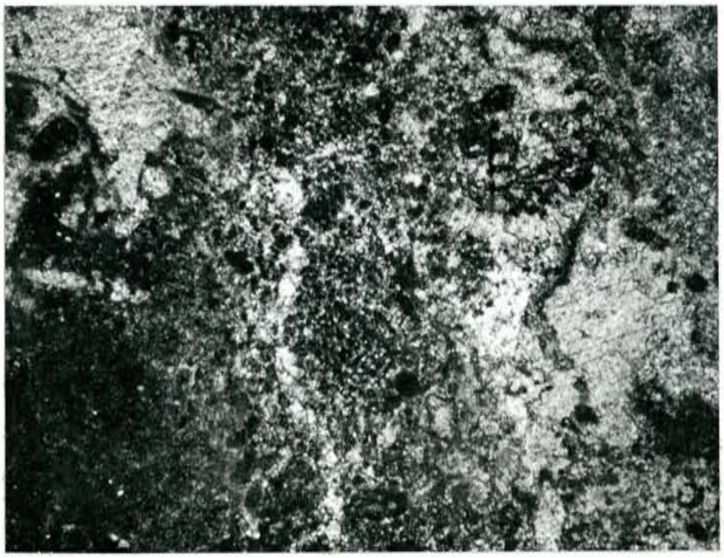


Figure 28. Photomicrograph of typical mudstone from the Madera Limestone. The mudstone shows some crinoid and algal debris floating in a micrite matrix that shows aggrading neomorphism. X25

skeletal material constitutes about 5 to 15 percent of the rock. In the field, it appears that brachiopods and crinoids are the most frequently occurring fossils. Thin section descriptions, however, suggest that the contribution actually made by brachiopod debris to the total volume of fossil material in the rock is relatively small. The bulk of the skeletal debris is bryozoan, and crinoid material. Less commonly occurring taxonomic groups, in order of generally decreasing abundance, include: brachiopods, algae fusulinds, corals, gastropods, and pelecypods. An important point to make here is that the more durable taxonomic groups, like brachiopods, corals, and fusulinids, in which the preservation of more intact examples is more likely, are much more catching to the eye on the outcrop than are genera that are less durable. Thus, their importance is often exaggerated. Close observation usually shows that the bulk of the fossil fraction of the rock is composed of smaller fragments of bryozoans and crinoids that often go unnoticed without the aid of a microscope.

The distribution of bioclastic material among the various beds of a unit is somewhat variable, whereas within the boundaries of any one bed, the distribution of skeletal debris is fairly uniform. Fusulinids, however, are a notable exception. The isolated, sporadic occurrence of this chronologically significant taxon can even dampen the spirits of the most inspired fossil collector.

Preserved bioclastic material is typically finely to coarsely crystalline calcite. Neomorphic inversion of original aragonite and recrystallization of original calcite has destroyed most original skeletal textures and complicates taxonomic identification. In some instances, micritization has reduced the boundaries of skeletal fragments to weakly defined, gradational features, whereas, in other cases, boundaries are distinct and characterized by a well developed micritic envelope. Taxonomic identification is further complicated by negligible to almost complete degrading neomorphism of skeletal debris. Internal pores in the fossils are filled with either micrite, neomorphic spar, or sparry calcite all of which may occur in the same opening. Some silicification of fossil material occurs in the Madera Limestone, but it is not common.

Every type of inorganic allochem occurs in the Madera Limestone, but none occurs with widespread abundance. In only a few thin sections do nonskeletal allochems comprise more than three percent of the rock, and in the large majority of thin sections, nonskeletal allochems were not observed. The occurrence of peloidal material is sporadic; nevertheless, it is the most commonly observed type of nonskeletal allochem.

Peloidal material seldom makes a significant contribution to the bulk of the rock, but locally it may constitute as much as 25 percent of a limestone bed. Individual peloids are uniformly shaped, structureless, ovoid, micritic aggregates that are about 0.05 mm in diameter. Occasional uniformity in size and shape suggest that some peloids may be invertebrate fecal pellets (Hatch and Rostall, 1938). In most cases, however, and especially in instances where peloidal material constitutes a significant proportion of the rock, peloidal bodies are more irregular in shape and size, suggesting that genesis by a recrystallization process may be more likely.

Penecontemporaneous, generally weakly consolidated carbonate sediment that was eroded from adjoining parts of the sea bottom and redeposited as intraclasts may constitute as much as 50 to 75 percent of some Missourian and Virgilian beds in the southern Ladron Mountains. In most limestone units intraclasts are absent and when they do occur, abundances seldom exceed more than a few percent of the rock. Their size is variable, ranging from sand-size particles to irregularly-shaped fragments as much as 2 or 3 cm long. The genesis of these bodies by reworking of semi-consolidated sediment from within the surrounding area is suggested by their smoothly irregular shape, their intricate relationship with other components of the rock, their compositional similarity to the enclosing rock type, and by the occurrence of terrigenous grains and skeletal fragments that cut their borders.

Ooids are seldom witnessed in thin section, and are often altered almost beyond recognition. Ooids in which the original texture can be distinguished are composed of a calcite core surrounded by a concentrically layered envelope. Some radially structured envelopes also occur, but never in great abundance. Slight to extreme deterioration of the envelope owing to micritization is common. If a core is visible, it typically consists of one crystal of calcite that is apparently a diagenetic feature related to dissolution of the original nucleus and part of the envelope, followed by precipitation of clear sparry calcite in the ensuing void space.

Brownish, subtranslucent, microcrystalline calcite forms the greater part of most Madera limestones, and occurs as micrite or microspar which constitutes 75 to more than 90 percent of the rock.

Sparry calcite is from very rare to common in these limestones; its origin, however, is often obscure. Criteria used in distinguishing sparry calcite cement and neomorphic spar were reviewed previously. Yet in practice, distinction is seldom clear-cut and it frequently became necessary to use the following approach in distinguishing the two types of spar. If there was no conclusive evidence of neomorphism, such as loosely packed allochems in a sparry calcite groundmass, or transection of allochems by calcite spar, or gradational relationships between sparry calcite and matrix, then the simpler view that the spar is precipitated cement was assumed. General textures (Dunham, 1962) and abundances of micrite in Madera limestones suggest that most of the coarsely crystalline calcite is neomorphic in origin. Other petrographic observations also support such an origin and include: (1) allochems are loosely packed, but they lie in a micritic groundmass characterized by porphyroid calcite spar, (2) allochems are seldom but may be transected by calcite spar, (3) gradational contacts between spar and matrix are most common, although sharp contacts do occur, and (4) all of the preceding are likely to occur in the same thin section. It is concluded, therefore, that some passive precipitation of calcite into open voids occured in Madera limestones, but most coarsely crystalline calcite is neomorphic in character. Crystal size ranges from fine to very coarse and crystal shape is typically equant. If sparry calcite occurs, it is usually observed as polycrystalline or monocrystalline overgrowths on some type of nucleus, the most common of which are skeletal grains, especially crinoid fragments.

Variable amounts of silicification occurs among Madera beds and is concentrated in the more thickly bedded, dark-gray limestones of the Desmoinesian. The silica occurs as disseminated "blebs", as nodules and lenses, and as small pods of chalcedony. Chert nodules range from light-gray to black in color, and typically weather light- to medium-brown. Their size and shape are extremely variable. Inclusion of fossil material within the nodules suggests that they are probably secondary replacement features.

Dolomite is rare in surface exposures, but some thin sections exhibit small dolomite crystals and rhombs. Disseminated clay-size material, generally believed to be organic material and clay minerals, also occurs in carbonate thin sections, but estimates of its abundance were not attempted because it was so difficult to distinguish in a blurry background of micrite.

Bedding and Structures. Limestones are thin to very thickly bedded throughout the vertical extent of every Madera Limestone section (table 8). Desmoinesian carbonate units, however, are generally more thickly bedded than are Upper Pennsylvanian carbonate units. In a vertical sense, the bedding of limestones within the Madera ranges from uneven to even. Desmoinesian limestone intervals, which are typically thick and thickly bedded, are ususally more evenly bedded than the rest of the Pennsylvanian section. In a lateral sense, limestone beds are distinguished by subparallel, regular, planar to wavy bedding planes.

Characteristically, two types of rock surfaces are developed by weathering. One is generally smooth, the other is rough and pitted by solution. Rough, pitted surfaces are commonly associated with more thickly bedded, massive units, whereas, smooth surfaces are chiefly related to more thinly bedded, dark-gray, laminated limestone units.

Most of the more thickly bedded limestones in the Madera show no surface expression of internal structure and are believed to be massive. Many of the more thinly bedded limestones are likewise massive, however, some show thin, subparallel to nonparallel, continuous and discontinuous, wavy and planar laminations (fig. 29). Small-scale, low-angle cross lamination occurs sporadically in some of the limestone beds.

Terrigenous Mudrocks. Terrigenous mudrocks constitute from 12 to 52 percent of the Madera Limestone and average about 27 percent of the formation (table 5, fig. 30). Their abundance ranges from 0 to 26 percent in Atokan Madera beds and averages about 18 percent in Desmoinesian Madera strata (table 7, fig. 23). In Missourian and Virgilian beds, mudrock abundances average about 30 to 35 percent of the section. Mudrocks are most abundant in the sections at Abo Pass and in the Joyita Hills (table 5, fig. 30).

Mudrock intervals are usually covered at the surface; consequently, their description is based on data from a few good exposures which occur at Abo Pass and in the Cerros de Amado. These, along with limited descriptions obtained from exposures in gullys and roadcuts at other localities, provide a reasonable estimate of the nature of fine-grained terrigenous units within the area.

Figure 29. An outcrop of a Madera Limestone in the Cerros de Amado (6) which illustrates the massive, cherty character that is typical of most limestone beds in the Madera Limestone. Subparallel, wavy lamination, which occurs in some Madera limestones, can be observed near the bottom of the photograph. Sec. 35, T. 2 S., R. 1 E.

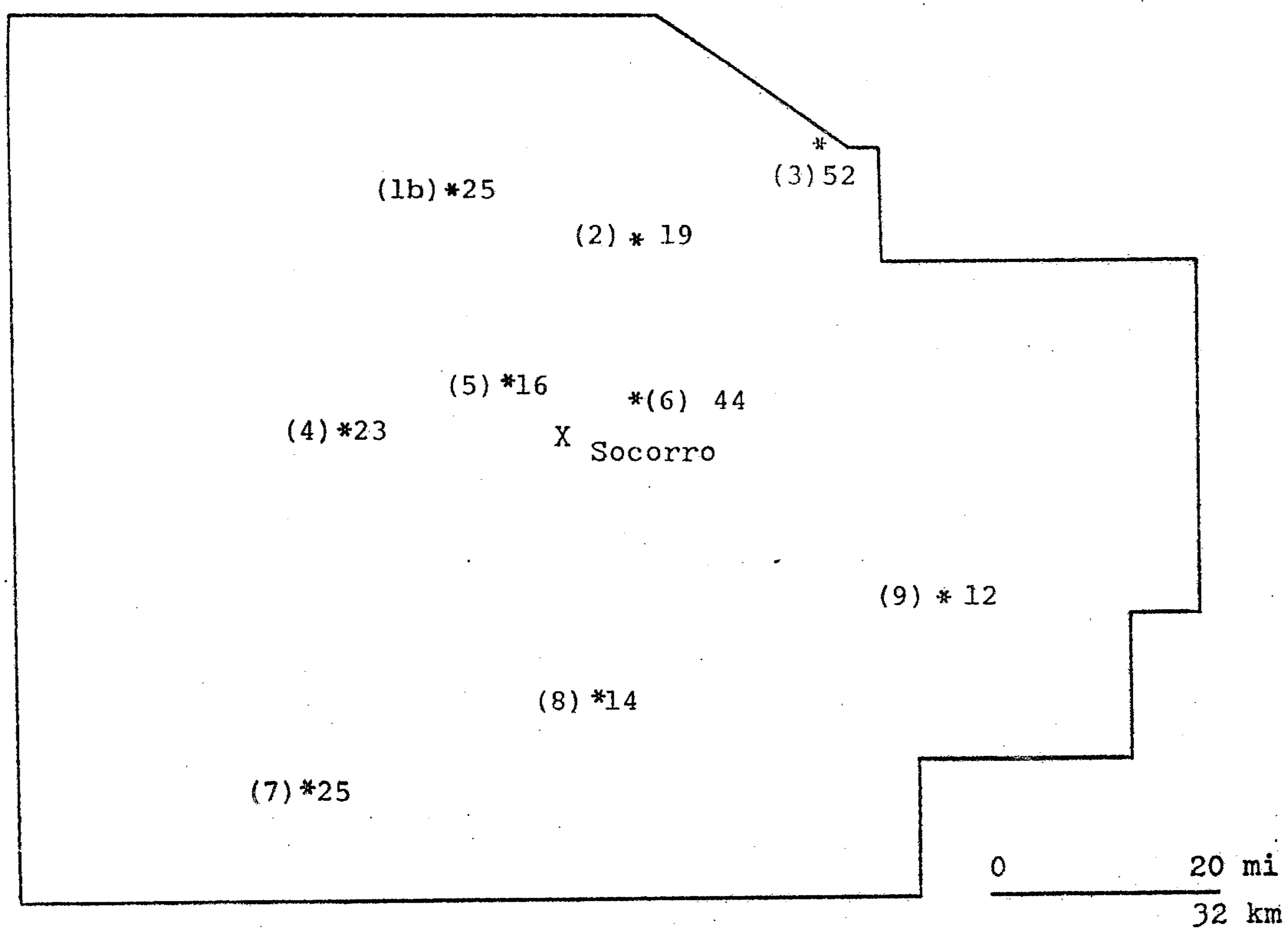


Figure 30. Map showing the percentage of terrigenous mudrock in the Madera Limestone in the Socorro region.

Mudrocks throughout the region occur mostly as light- to dark-gray, slope-forming, mudstones and mud-shales or siltstones and silt-shales. Mud-shales are decidedly the most abundant. Atokan Madera strata are known to occur only in the Joyita Hills and in the northern Oscura Mountains. Atokan Madera beds in the Joyita Hills are all limestone, and Atokan Madera mudrock intervals are covered in the northern Oscuras. Black, calcareous, micaceous mud-shale partings between limestone beds provides some insight as to the nature of these units, but the true character of mudrocks in the Atokan part of the Madera Limestone is still not well known.

Madera mudrocks of Desmoinesian age are mostly mud-shales. Mudrock lithologies in the upper part of the Desmoinesian Series in the Cerros de Amado, however, are chiefly silt-shale and siltstone; silt-shales also occur sporadically in the section at Abo Pass. The granular, fraction of mudrocks is comprised of angular, fine silt to very fine sand-sized grains of quartz and muscovite. The beds are almost always calcareous and carbonaceous plant impressions are often observed along parting planes. Burrows are frequently visible in Madera mudrocks in the Cerros de Amado, but are not common elsewhere in the region.

Except in the Lemitar Mountains, where clay-shales are common, mud-shales are also the most abundant mudrock type in the Missourian Series. Granular material is again comprised of angular, fine- to medium-silt-sized quartz and muscovite, but grain sizes are somewhat smaller than those that characterize mudrocks in the Desmoinesian Series. The Missourian units are also calcareous and plant impressions occur along parting planes.

Exposures of Virgilian-age mudrocks are infrequent. Some mudstone and clay-shale outcrops were observed at Abo Pass and in the Cerros de Amado, but these do not provide enough evidence to characterize Virgilian mudrocks of the region. The mudrocks at the above localities are calcareous and contain angular, well sorted, fine- to medium-silt-size grains of quartz and mica. Micritic limestone nodules occur in some mudstone units in the Cerros de Amado and plant impressions are again common along parting planes.

In conclusion, terrigenous mudrocks generally constitute about 10 to 25 percent of the Madera Limestone, with the Upper Pennsylvanian being somewhat more terrigenous in nature than the Middle Pennsylvanian. Mud-shale, the dominant mudrock lithology, typically consists of angular, well sorted, silt-size grains of quartz and muscovite embedded in a calcareous, clayey groundmass. Carbonaceous plant impression are common along parting planes, and some Desmoinesian mudrocks show extensive burrowing. The lithologic character of the mudrock facies remains fairly consistent through the vertical extent of the Madera Limestone and throughout the Socorro region.

Granular Terrigenous Rocks. Sandstones and conglomerates do not constitute more than about 7 percent of the Madera Limestone (table 5, fig. 31). No granular terrigenous rocks were encountered in the Joyita Hills or Lemitar Mountains.

Although some sandstone units may be as much as 14 m thick, most are no more than about 5 m thick. They outcrop as low ledges or breaks in slope, and are much more obscure among the resistant limestones of the Madera Limestone than they are among the slope-forming shales of the Sandia Formation.

The basal contact of sandstone units is often poorly exposed and difficult to characterize. However, basal Missourian sandstones and Virgilian sandstones in the northern and eastern parts of the region often lie on surfaces cut into underlying beds, whereas in the central, western, and southern areas there is little evidence of erosion into underlying strata. Erosional bases are also uncommon among Desmoinesian sandstone units. Particularly striking examples of the nonerosional nature of surfaces beneath sandstone units may be witnessed in the Magdalena Mountains were coarse-grained, quartzose sandstones are in depositional contact, both above and below, with carbonate

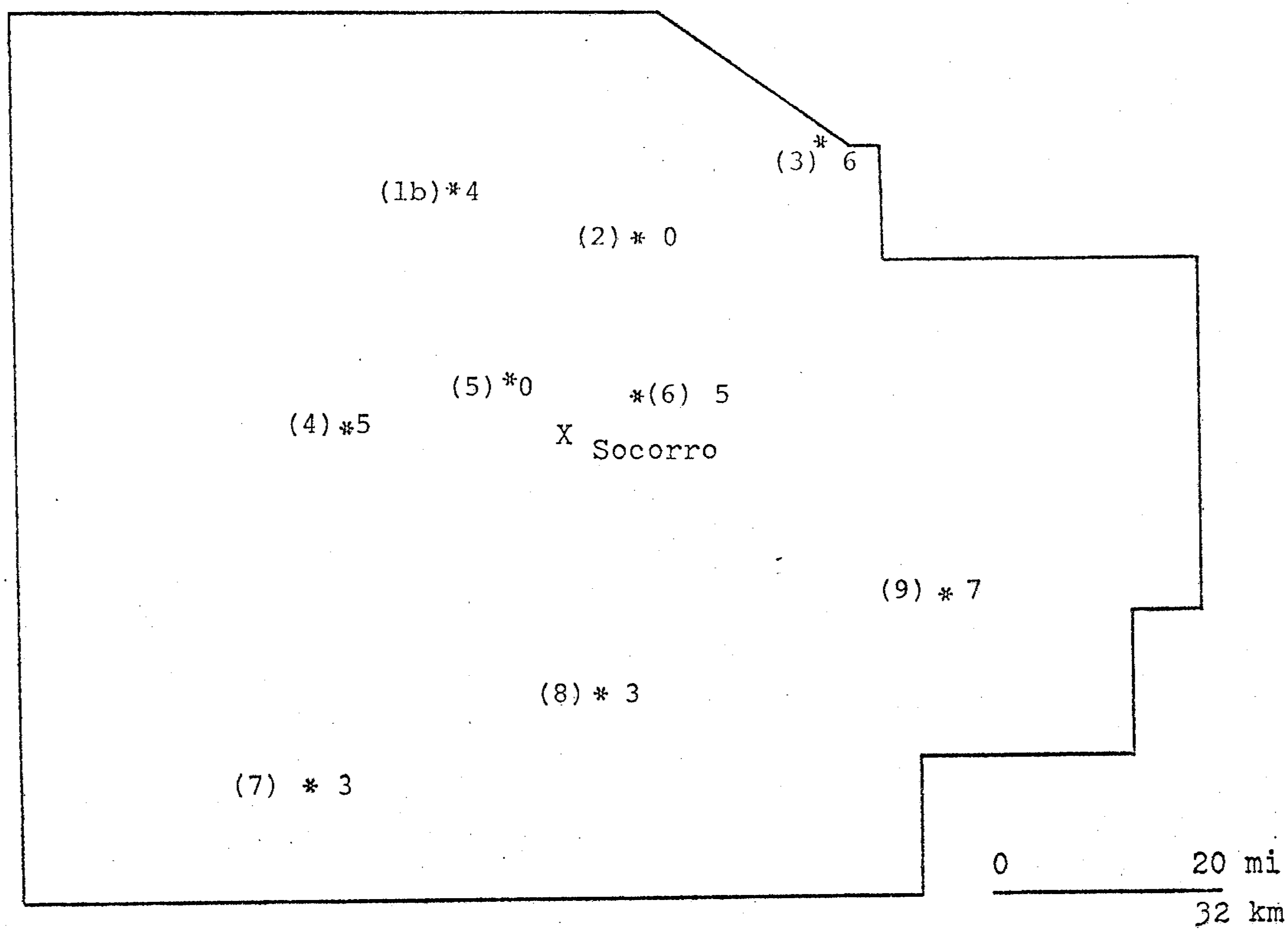


Figure 31. Map showing the percentage of granular terrigenous rocks in the Madera Limestone of the Socorro region.

mudstones. The contacts between the two lithologies are abrupt, with no evidence to suggest any erosion of the underlying limestone.

The color of terrigenous grainstones is quite variable within the study area, and only a few generalizations are valid. In the central and westernmost sections, Madera sandstones are invariably light- to medium-gray in color. In the three easternmost sections (Abo Pass, Cerros de Amado, northern Oscura Mountains) various shades of brown and green are more common. At Abo Pass, there are many yellowish- to greenish-gray beds, with the greenish colors becoming very prominent in the Virgilian part of the section. Brownish-gray is commonly the color of sandstone units through most of the section in the Cerros de Amado, but near the top of the Virgilian, they become more grayish-red. Virgilian sandstones in the northern Oscura Mountains are likewise more red in color.

Classification. A wide range of granular terrigenous lithologies, including quartz sandstones, subarkoses, and sublithic sandstones, occur in the Madera Limestone. Most units appear to be quartz sandstones in the field, but thin-section analysis proves that subarkoses are the dominant sandstone lithology (table 9). Quartz sandstones, however, do dominate the Madera section in the Magdalena Range. Only one sandstone unit was found in the Pennsylvanian section in the southeastern San Mateo

Location	Rock Name	Grain Size	Sorting	Grain Shape	Induration
Abo Pass	Subarkose	fine to medium sand	moderate	angular to subangular	poor to well indurated
Cerros de Amado	Subarkose	very coarse sand	very poor to well	angular to subangular	well indurated
Joyita Hills	No sandstone is present in the Madera Limestone.				
Ladron Mts	Subarkose	very coarse sand	poor	angular	well indurated
Lemitar Mts	No sandstone is present in the Madera Limestone.				
L. San Pasqual Mtn	Subarkose	medium to very coarse sand	poor to moderate	angular to subround	well indurated
Magdalena Mts	Qtz. sand-stone	very coarse sand	poor	angular	well indurated
N. Oscura Mts	Arkose	fine sand	moderate	angular	poor
S. E. San Mateo Mts	Qtz. sand-stone	very fine sand	well sorted	subangular	moderate

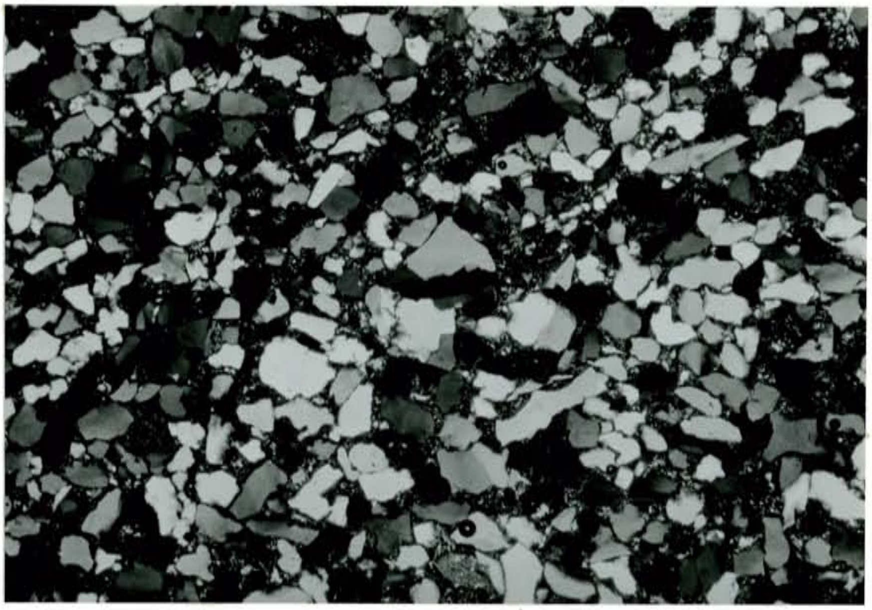
Table 9. A general description of the granular terrigenous rocks in the Madera Limestone.

Mountains and it, too, is a quartz sandstone. In the northern Oscura Mountains, sandstones are limited to the Upper Pennsylvanian, and at this locality arkoses are the most abundant sandstone. The only conglomerates in the Madera Limestone within the sections studied occur at Little San Pasqual Mountain as poorly exposed, quartzitic, sedlithic conglomerates that crop out in a valley-forming interval that is Missourian in age. However, Laughlin and Koschmann (1943) and Blakestad (1977) also describe some quartz-pebble conglomerates in the Madera Limestone near Kelly.

Petrography. Photomicrographs in fig. 32 illustrate the petrographic character of Madera sandstones. Quartz, feldspar, chert, and mica are the most frequently occurring granular constitutents. Quartz is the most abundant grain type with monocrystalline quartz usually predominating over polycrystalline quartz. Monocrystalline quartz grains are typically elongate to subequant in shape and exhibit slightly undulatory to undulatory extinction. The most common inclusions are vacuoles, but microlites and hairlike inclusions also occur in many of the quartz, grains. Grain boundaries are, in most cases, relatively sharp, but apparent etching of the grains by calcite is commonly visible.

Polycrystalline quartz constitutes more than 50 percent of some thin sections; in most cases, however, it is limited to 5 or 10 percent of the rock volume and in a very few samples it is absent. Composite quartz grains are most abundant in the more coarsely grained sandstone units of the Magdalena

A



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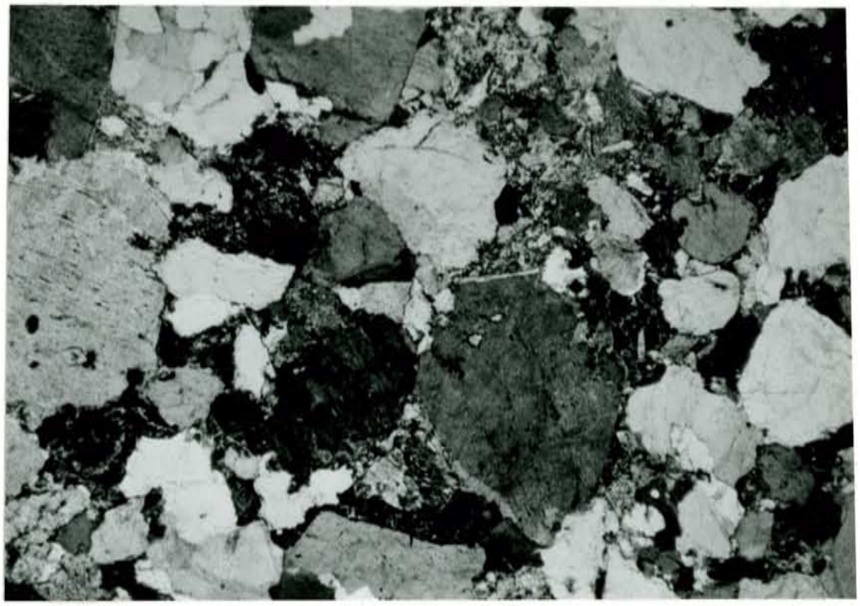

Figure 32. Photomicrographs of typical sandstones from the Madera Limestone. The quartz sandstone (A) consists of angular, poorly sorted, medium-grained monocrystalline and polycrystalline quartz and chert grains cemented by calcite and silica. The arkose (B) is composed of angular to sub-angular, poorly sorted, very coarse-grained, altered, potash feldspar and monocrystalline and polycrystalline quartz grains cemented by calcite and silica. X15

Mountains and the Cerros de Amado. Such grains are usually composed of five or more elongate crystals in line or sutured contact. Quartz grains are typically fresh, but various stages of replacement of the grains (especially the borders) by calcite is also observed. Polycrystalline grains are also susceptible to deformation and fracturing as a result of compaction.

The abundance of feldspar in Madera sandstones ranges from 0 to 25 percent. Abundances in most feldspathic sandstones, however, are limited to less than 15 percent. Among sandstones that are Middle Pennsylvanian in age, feldspar abudances are somewhat higher in the Ladron Mountains and at Abo Pass (the northern part of the area): whereas, in Late Pennsylvanian sandstones, feldspar is more plentiful in the southeastern part of the Socorro region. Sandstones also tend to be more arkosic in the Desmoinesian and Virgilian than in the Missourian.

Potash feldspar is the most abundant of feldspar, but is often extremely altered to, or replaced by, calcite, sericite, and clay. Microcline is fairly common in many thin sections and it is usually much fresher than the accompanying orthoclase. Plagioclase is seldom present in more than trace amounts, and like microcline, is usually relatively fresh.

Muscovite commonly constitutes 1 or 2 percent of sandstone grains in the Madera Limestone and, in some of the finer-grained units, its abundance may increase to 10 or 15 percent. Muscovite grains are typically oriented with their flat sides more or less parallel to bedding, but they commonly show some deformation and bending as a result of pressure from adjacent grains.

Lithic fragments are virtually absent in Madera sandstones. The few units in which they do occur are restricted to the Cerros de Amado and a conglomerate unit in the Missourian Series at Little San Pasqual Mountain. In the Cerros de Amado, many of the sandstone beds in the upper part of the section contain as much as 2 percent chert. Some of the uppermost units also contain carbonate mudstone intraclasts. The conglomeratic unit at Little San Pasqual Mountain is characterized by limestone, chert, and siltstone gravels in a calcareous, sandy, clayey groundmass.

Invertebrate fossils are rare in sandstone outcrops and thin sections, but may occur as a few fragments of brachiopod, crinoid, or bryozoan debris. Woody plant fragments are common at Abo Pass and in the Ladron Mountains and Cerros de Amado. In the Manzano Mountains north of Abo Pass, Myers (1973) reports that the basal sandstone of the Missourian Series locally contains petrified logs that may be as much as 2.5 m or more in length.

Matrix material typically constitutes only 5 to 10 percent of a sandstone thin section, thus most units are characterized by an arenite texture. Matrix material is usually comprised of silt-size quartz and mica in a cloudy, interstitial paste of recrystallized clay-size material. Unfortunately, it is seldom possible to determine the origin of the clay-size material in thin section.

Calcite and silica are the most common kinds of cement with calcite being the most abundant. Calcite occurs as finely crystalline interstitial material, single pore-filling crystals, and poikilitic patches that encompass many sand grains. Silica usually occurs as quartz overgrowths on detrital quartz grains or as simple pore filling. Cementation is so complete that Madera sandstones are typically well indurated and characterized by negligible porosity.

The grain size of Madera sandstones ranges from fine to very coarse sand (table 9). Field observation suggests that a majority of the sandstones are very coarse-grained, whereas thin section data shows most of them to be medium-grained sandstones. The difference may be due to sampling bias or inherent problems of determining grain size by thin section analysis (Carver, 1971). Very coarsely grained sandstones are characteristic of the Ladron Mountains, the Magdalena Mountains, and the Cerros de Amado. Finer grained sandstones are common in the northern Oscura and southeastern San Mateo Mountains. Desmoinesian sandstones are consistently more coarsely grained than are sandstones that are Late Pennsylvanian in age.

Thin-section analysis also shows that sandstones are commonly less well sorted than they appear to be in the field. Most units are poorly sorted, but the occurrence of moderate to well sorted sandstones is not uncommon. It is interesting to note in table 9 the apparent correlation between grain size and sorting. Fine-grained sandstones are usually fairly well sorted, whereas more coarsely grained sandstones tend to be more poorly sorted.

Angular grains with sphericity coefficients of about 0.5 are characteristic of most sandstone beds. Roundness, however, ranges from angular to subround and sphericity coefficients range from 0.3 to 0.9.

Bedding and Structures. Bedding thickness among Madera sandstones is variable and ranges from thin to very thick. There is a tendency for bedding thickness to decrease upward from the base of the Madera section with thick bedding being typical of Desmoinesian sandstones, medium bedding characteristic of Missourian sandstones, and thin bedding most common among Virgilian sandstones. Thicker bedding is common in the Magdelana and Ladron mountains, whereas thinner bedding is common in the southeastern San Mateo and northern Oscura mountains.

The vertical and lateral continuity of sandstone bedding is generally variable. In a vertical sense, most units are unevenly bedded. Bedding regularity is more difficult to establish because of the nature of many exposures. It appears, however, that both irregular and regular bedding are common in most sections. Desmoinesian beds are typified by more regular bedding, whereas irregular bedding is more prevalent among Missourian and Virgilian sandstones.

As with the Sandia Formation, weathering has often removed much of the surface expression of any internal structures that may be present in these sandstones. However, the effort to collect this type of information on Madera sandstones was much more rewarding than it was in dealing with Sandia sandstones.

Most sandstone units in the region are thinly laminated and many are cross-laminated. The nature of most exposures does not permit a detailed description of lamination and cross-lamination. Available information, however, suggests that most lamination is continuous to discontinuous, subparallel, and wavy to sub-planar in shape (fig. 33). Cross-lamination typically occurs in solitary, concordant and discordant, small- to medium-scale, tabular- and wedge-shaped sets with planar surfaces (fig. 34). Trough cross-bedding occurs in basal Missourian sandstones at Abo Pass and in the southern Ladron Mountains. Strikes

Figure 33. An outcrop of a sandstone from the Madera Limestone in the Cerros de Amado (6) showing the continuous, parallel, planar lamination that is found in some Madera sandstones. Sec. 35, T. 2 S., R. 1 E.

A

B

Figure 34. Outcrops of cross-laminated sandstones showing the small- to medium-scale, low-angle, tabular-wedge-shaped sets with planar surfaces that are typical of some Madera sandstones. A - a Missourian sandstone from the Cerros de Amado (6). B - a Virgilian arkose from the northern Oscura Mountains (9). Sec. 35, T. 2 S., R. 1 E. and Sec. 31, T. 5 S., R. 6 E.

and dips of cross-lamination in sandstone units suggest that the direction of sediment transport was generally toward the south (see Appendix II). Paleotransport directions that were measured, however, ranged from southeast to southwest.

Ripple marks occur on the bedding surfaces of a Virgilian sandstone unit in the section at Abo Pass. They are shown and described in fig. 35. Burrowing was noted in a number of Desmoinesian and Virgilian sandstones in the Cerros de Amado area. The only other sedimentary structures commonly witnessed in Madera sandstones are restricted to load casts and interruptions of internal features due to penecontemporanceous deformation or post-depositional compaction.

Sandstone beds in North Fork Canyon are typically massive, but as was noted earlier, the massive appearance in this area may be only a weathering phenomena since sandstones in other areas of the Magdalena Mountains are laminated and cross-laminated. Madera sandstones in the southeastern San Mateo Mountains also appear to be massive, but exposures are so poor in this area that little is known of their true character.

Figure 35. An outcrop of Virgilian ripple marks at Abo Pass (3). As in this photo, ripple marks are usually assymmetrical and lunate. The amplitude of the ripple marks is usually less than 5 cm, and their wavelength ranges between 10 and 25 cm. Sec. 25, T. 3 N., R. 4 E.

SEDIMENTOLOGIC SYNTHESIS AND INTERPRETATION

Sedimentary environments are three-dimensional spaces characterized by processes (physical, biological, and chemical) that operate at certain rates and intensities. The processes control deposition and impart a distinctive imprint on accumulating sediments. The environmental processes at a depositional site, however, change with time and stratigraphic sections are usually composed of several types of deposits. The complexity of stratigraphic sections is merely the manifestation of changing environment. This last section is devoted to a search for the rationale behind Pennsylvanian sedimentation in the Socorro region.

Depositional Model

Many authors (see Introduction - Previous Work) have demonstrated that the Pennsylvanian System of west-central New Mexico was deposited on the southwestern flank of the North American craton in a shallow marine seaway that was interrupted and bounded by several long, narrow uplifts (fig. 4). Lithologic associations, faunal assemblages, and regional stratigraphic relationships provide evidence for these interpretations. This study substantiates such a model. Improvements in the general concepts of sedimentation in an epicontinental seaway, however, now permit a more refined interpretation of Pennsylvanian sedimentation.

Epicontinental subenvironments and accompanying lithofacies are a function of many tectonic and climatic variables, but the nature of such deposits basically reflects the rate at which terrigenous material is injected into the system and the ability of marine processes to distribute this material. If the influx of terrigenous material is high, carbonate deposition is inhibited; if the terrigenous sediment supply is slowed, carbonate production is enchanced and limestone-producing environments migrate toward the strandline.

Under shallow marine conditions, the effects of small environmental fluctuations are considerable and intricate lithofacies relationships are likely to develop. In order to grasp the significance of such relationships in a region where integration of data is hampered by widely spaced, isolated control points, related subenvironments and their concomitant lithofacies have been grouped into four major environments: (1) nearshore, (2) inner shelf, (3) outer shelf, and (4) deeper basin. This grouping (modified from many sources for the purposes of this study) is somewhat oversimplified, but keeps the sedimentary framework as detailed as possible, yet general enough to be practical for use under the constraints of this study.

Nearshore Environment. The nearshore environment, as defined here, extends from just above the strandline down to wave base. It is situated adjacent to land areas and grades seaward into the inner shelf environment. Depending on the amount of terrigenous material entering the nearshore sedimentary regime, nearshore systems are classified as terriginous, mixed carbonate-terrigenous, or carbonate (Selley, 1970). Clastic ratios that characterize the Pennsylvanian System in the Socorro region (table 3, table 5) are indicative of mixed terrigenous-carbonate systems. Diverse lithologies are common as a result of the interaction of many different subenvironments. Deposits included within this lithofacies include:

(1) swamp and marsh deposits consisting of dark-colored, organic-rich, redundant, bioturbated claystones containing occasional silt laminae and well-preserved plant debris.

(2) dune deposits comprised of well-rounded, well-sorted, fine-to medium-grained, quartzitic sands which commonly show large-scale, high-angle cross lamination.

(3) tidal flat deposits in which muddy sediments of the mud flat (upper tidal flat) grade through the mixed flat into the sandy sediments of the sand flat (lower tidal flat).

(4) muds and sands indicative of overbank and channel deposition associated with small, nearshore deltaic complexes.

(5) bioturbated, muddy sediments with intercalated sandy layers which imply lagoonal conditions.

(6) laminated, and cross-laminated backshore, foreshore, and shoreface sands (Reinick and Singh, 1973).

With a declining supply of terrigenous sediment, owing to a low-lying hinterland or a dry climate, nearshore carbonate sedimentation may occur. Shaw (1964) and Irwin (1965) concluded that epeiric carbonate sedimentation occurs in three distinct zones oriented approximately parallel to the strandline. The most seaward zone lies below wave base and will be considered later. Landward of this zone is a high energy belt where waves and currents touch bottom and clean-washed carbonate sands accumulate. In the most landward belt, water aggitation is greatly diminished by dissipation of energy across the outer belt. In this zone, low-energy lagoonal conditions prevail and the sediments typically consist of micritic carbonate sands that grade landward into laminated, burrowed, tidal-flat muds. If salinites are high, dolomites and evaporites may accumulate.

In summary, the diversity of nearshore subenvironments produces many types of deposits. In mixed nearshore systems, the sediments are characteristically terrigenous. If the influx of terrigenous material becomes sufficiently low, a succession of carbonate-producing subenvironments may develop. Terrigenous mudrocks and carbonate mudstones are typically deposited in low-energy subenvironments such as swamps, marshes, tidal mud flats, and lagoons. Granular terrigenous rocks and carbonate packstones and wackestones reflect higher energy conditions associated with channels, or areas where wave base impinges on the sea floor.

Inner Shelf Environment. The inner shelf, as defined here, extends seaward from the nearshore area down to a depth of a few tens of meters. Quiet, moderately circulated, generally open marine conditions prevail on the inner shelf, but waters are periodically roiled by storms. Salinity is somewhat variable, ranging from normal marine to slightly higher. In a mixed system, the prevailing rock types are various types of limestone and terrigenous rocks.

Carbonate rocks of the inner shelf are typically wackestones and mudstones (micrites, fossiliferous micrites, biomicrites); terrigenous rocks are mudstones or mud-shales and claystones or clay-shales. Thin, mature, quartz sandstones occur in association with many shelf carbonates (Pettijohn and others, 1972), but little is known of the processes that are responsible for such lithologic associations. Inner shelf sediments are typically medium-bedded and often show fine lamination; however, they may be massive as a result of bioturbation.

The faunal assemblage of the inner shelf environment is diverse. Stenohaline forms (e.g. echinoderms, brachiopods, cephalopods) occur in inner shelf sediments, but they are not as abundant as they are on the outer shelf. Mollusks, sponges, arthropods, foraminifera, and algae are also associated with inner shelf deposits.

Shoal areas and patch reefs commonly occur on the inner shelf. Their occurrence may be sporadic, and they are commonly located along the outer margin of the inner shelf. Offshore shoal areas develop when the depositional interface rises too near the water surface. The relief may be inherited from old erosion surfaces, related to tectonic activity, or related to submerged bars and banks. Such features range from well above sea level to 5 or 10 meters below sea level (Wilson, 1975).

Sediments deposited in shoal areas are subject to constant wave and current action, so that mud is removed by winnowing. Owing to a constantly shifting substrate, shoal areas are relatively inhospitable to most forms of marine life. Therefore, deposits are grainstones and packstones (biosparites, biomicrites) comprised of well-sorted, well-rounded, skeletal fragments (Martin, 1971). In mixed systems, quartz sand may also be included in shoal deposits. The strata commonly show planar and trough cross lamination. If shoal areas, or organic buildups, become well-developed along the outer edge of the inner shelf, the inner shelf environment may occur as straits, open lagoons, and bays behind the shelf-margin sands.

Outer Shelf Environment. The outer shelf environment lies seaward of the inner shelf area and attains water depths of a few tens of meters to more than a hundred meters. Indolent marine currents keep the water well circulated and maintain normal marine salinities. Such currents promote sluggish, large-scale movements of water masses, but their effect on bottom sediments is almost nil. Intermittent large storms, however, may have a considerale effect on bottom sediments. Faint water movement and a fineness of sediment, reflecting remoteness from a terrigenous source, are the outstanding characteristics of this environment (Rich, 1951). The outer shelf is generally considered the typical realm of deeper neritic sedimentation, with deposits consisting of limestone and shale. Such shelves are generally wide and sedimentation is usually quite uniform.

The prevailing carbonate lithologies are bioclastic and whole fossil wackestones and interbedded mudstones. Thorough burrowing produces massive beds that range from thin to very thick. The beds contain a diverse shelly fauna in which the presence of stenohaline forms, such as brachiopods, corals, echinoderms, and cephalopods are notable (Wilson, 1975). The remains of larger benthonic forms are often scattered through the deposit like plums in a pudding. The limestones are often cherty, with the chert possibly being derived during diagenesis from opaline organisms and, later, from solution and replacement of wind-blown quartz silt by carbonate.

Claystones and clay-shales are the most common terrigenous sediments of the outer shelf environment, and thin shale partings commonly separate the thick limestone beds. The partings are thought to have originated either from the cessation of carbonate deposition and very slow accumulation of suspended detritus, or from a rapid influx of terrigenous material into an environment of slow carbonate accumulation.

Deeper Basin Environment. The depth of water in deeper basins is at least 30 meters and is commonly several hundred meters. Sediment is deposited under restricted, euxinic conditions developed below oxygenation level. Deposition is dependent up on the influx of fine argillaceous and siliceous material and a rain of decaying plankton, for the water is too deep and dark for benthonic production of carbonate (Wilson, 1975). Much of the terrigenous material incorporated in the sediment is wind blown. Few burrowers can exist in the stagnant, reducing milieu and thin-to medium-bedded, finely laminated sediment results. The prevailing rock types are thin, even beds of dark carbonate mudstone, with dark clay-shale admixed with carbonate or occurring as thin, distinct layers. Chert is very common.

The deeper basin biota consists of nektonic-pelagic organisms that often accumulate in local abundance on bedding planes as a result of mass mortality (Wilson, 1975). In some cases, deeper basin deposits may resemble deposits of deeper parts of the outer shelf, which at times may be near or slightly below the oxygen level. Deeper basin deposits, however, are typically more argillaceous, thinner bedded, darker colored, and more thinly laminated.

The Mudrock Problem. From the foregoing, it can be concluded that low-energy conditions may occur in any of the four sedimentary environments that have been defined. In the deeper basin environment, and most of the time in the shelf environment, low-energy conditions are the general rule. Low-energy conditions, likewise, prevail in many subenvironments of the nearshore system. It is, therefore, reasonable to expect terrigenous or carbonate muds to accumulate in any of these environments. Carbonate rocks are generally sensitive environmental indicators and pose no major problem. This is not, however, the case with terrigenous mudrocks, for it is often difficult to clearly distinguish between nearshore, shelf, and deeper basin deposits of this nature. As a result, much emphasis has been placed on lithologic associations, with interpretation being founded on the more definitive characteristics of associated carbonates and granular terrigenous rocks.

Pennsylvanian Tectonics and Sedimentation

Before Pennsylvanian time, the Socorro region was part of a structural highland which remained barely awash throughout the early and middle Paleozoic. Available evidence suggests that it was a major source of terrigenous material only in the late Cambrian and was, by early Mississippian time, only a beveled surface cut on Precambrian metamorphic and igneous rocks (Kelley and Silver, 1952; Kottlowski, and others, 1956; Armstrong, 1958 and 1962). South of the Penasco uplift, a shallow shelf area developed and subsided at a slow rate until the end of Meremec time (Middle Mississippian). Subsidence of the gently sloping shelf was more rapid in the southern part of the state. The maximum inundation began in Kinderhookian time (Early Mississippian) as an eastward transgression from the Cordilleran miogeosyncline around the north flank of the Zuni-Defiance uplift. Coming from the south, another transgression passed between the Pedernal highlands and the Zuni-Defiance uplift. By late Osage time, the seas covered central New Mexico, reduced the Zuni-Defiance uplift to an island, and completely covered the weakly developed Transcontinental Arch (Armstrong, 1967).

Following a period of uplift at the end of the Mississippian, several positive areas (fig. 4) became contributors of terrigenous debris to Pennsylvanian sediments in central New Mexico. An isopach map of the Mississippian system shows the beginning of the tectonic pattern that was to dominate Pennsylvanian sedimentation (fig. 36). The Zuni highlands, which were to become an important Pennsylvanian structural element, developed as a low-relief feature with the retreat of the late Mississippian seas. The Mississippian rocks preserved in the San Mateo-Magdalena sag (Armstrong, 1962) mark the beginning of differential subsidence along the Magdalena prong of the Oro Grande basin.

The Zuni uplift has long been known from outcrops in the Zuni Mountains where Permian strata overlie Precambrian rocks. Kelley (1967) believed that Mississippian inundation was followed by epeirogenic warping of the Zuni region. Subsequent stripping, through early Pennsylvanian time, was followed by domal uplift, which shed sediment to Desmoinesian seas in adjacent areas. Kelley (1967) suggested that throughout the remainder of the Pennsylvanian period, most of the region was overlapped and buried during broad regional subsidence. Martin (1971) noted a tendency for the uppermost strata of each of the Pennsylvanian series to extend farther onto the flank of the Zuni uplift than the strata of the preceding series.

The presence of the Joyita uplift during Pennsylvanian time is suggested by the occurrence of an anomalously thin Pennsylvanian section in the Joyita Hills. Wengerd (1959) interpreted such thinning to reflect the existence of a

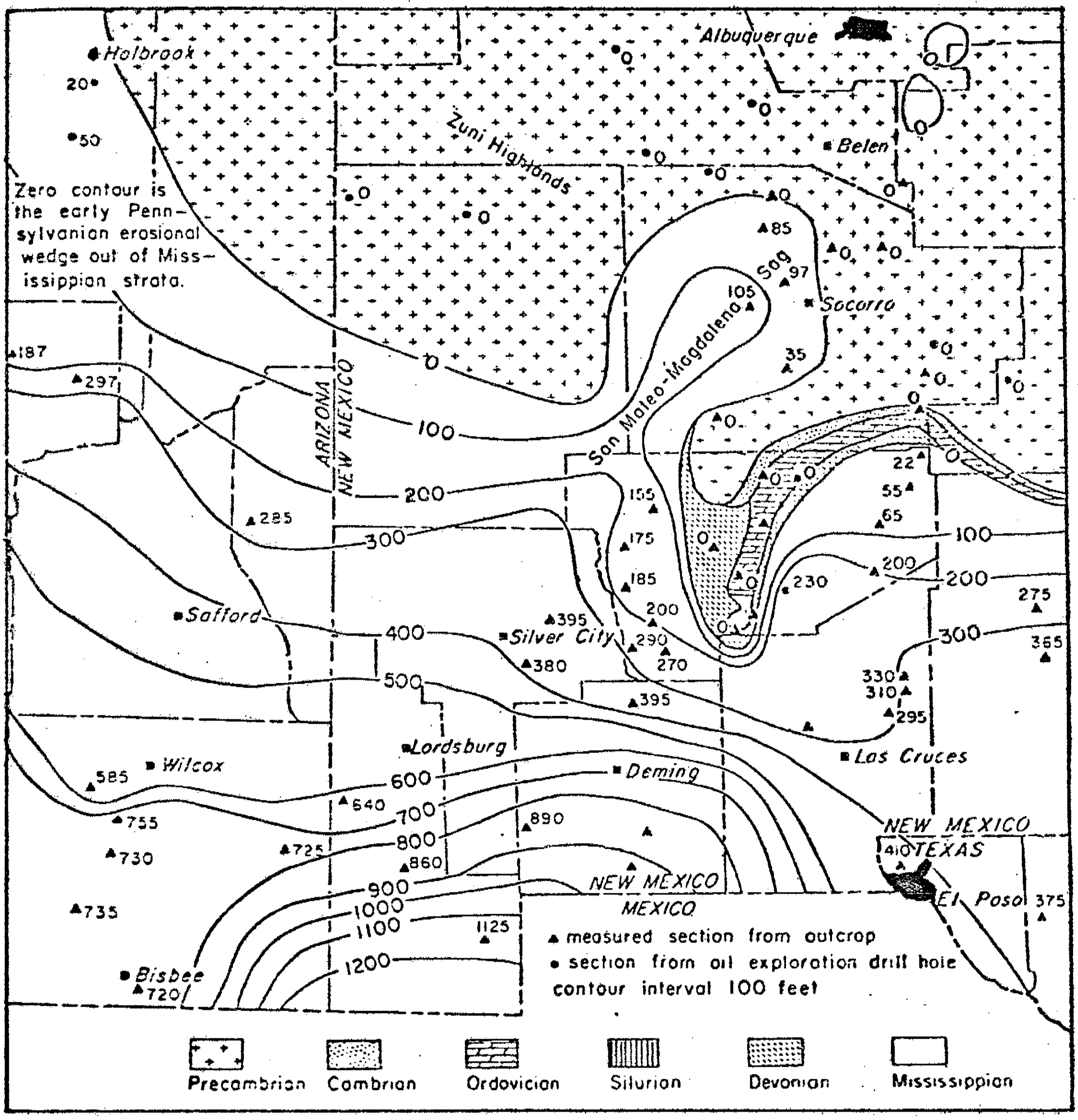

Figure 36. Isopach map of Mississippian strata in southwestern New Mexico (after Armstrong, 1962).

north-trending platform (Manzanita platform) which separated the Lucero basin on the west from the Estancia trough on the east (fig. 4). Kottlowski and Stewart (1970) and Martin (1971) provided additional evidence that the Joyita uplift was a submarine platform with small, low islands rather than a large landmass. The local positive areas of the Joyita uplift supplied some terrigenous material to the Socorro region and provided topographically higher areas that influenced sedimentation throughout the Pennsylvanian period. The fusulinid data of Kottlowski and Stewart (1970), however, suggest that the major period of uplift in the area occurred during late Virgilian and early Wolfcampian time. Hambleton (1962) concluded that the Joyita uplift was also an active positive area that greatly affected sedimentation during Missourian time. Kottlowski (1963), however, believed that the abundance of terrigenous material in the Missourian sequence suggested that most of the material must have been derived from a larger emergent feature, and maintained that the Joyita uplift was merely a small group of islands and shoal areas that barely interrupted the general north-south trend of basins, shelves, and highlands.

The Pedernal uplift (fig. 4) was named by Thompson (1942) and has since been discussed by many writers. Thompson noted that Permian redbeds rest directly on rocks of Precambrian age from the eastern flank of the Sacramento

Mountains (Otero County) to northern Torrance County. Thompson concluded that the Precambrian masses represent the buried remnants of a large land area of the Ancestral Rocky Mountains which extended almost unbroken from Colorado across central New Mexico to near the southern border of the state. The maximum uplift of the Pedernal landmass occurred in late Pennsylvanian and early Permian time (Kottlowski, 1960). The evidence consists of truncation of older rocks beneath Wolfcampian (Lower Permian) strata along the flanks of the Pedernal landmass, and the thick, late Pennsylvanian and early Permian, terrigenous deposits in the Orogrande and Estancia basins west of the landmass. The low clastic ratios and low sandstone-mudrock ratios of Atokan and Desmoinesian strata in the Socorro region suggest that the Pedernal area was low-lying and perhaps only a group of scattered, hilly islands during most of the Middle Pennsylvanian.

An isopach map of the Pennsylvanian System in west-central New Mexico (fig. 37) shows that during Pennsylvanian time the Socorro region was a broad depocenter between the Zuni uplift to the west and the Pedernal uplift to the east. Stratigraphic reconstructions by Kottlowski (1960) and Siemers (1974) demonstrated that the original thickness of the Pennsylvanian section in the Magdalena area (fig. 37, site 52) was as much as 550 to 600 m. Drill-hole data from the Magdalena Mountains has since proven the true thickness of the Pennsylvanian section in the area to be at least 715 m

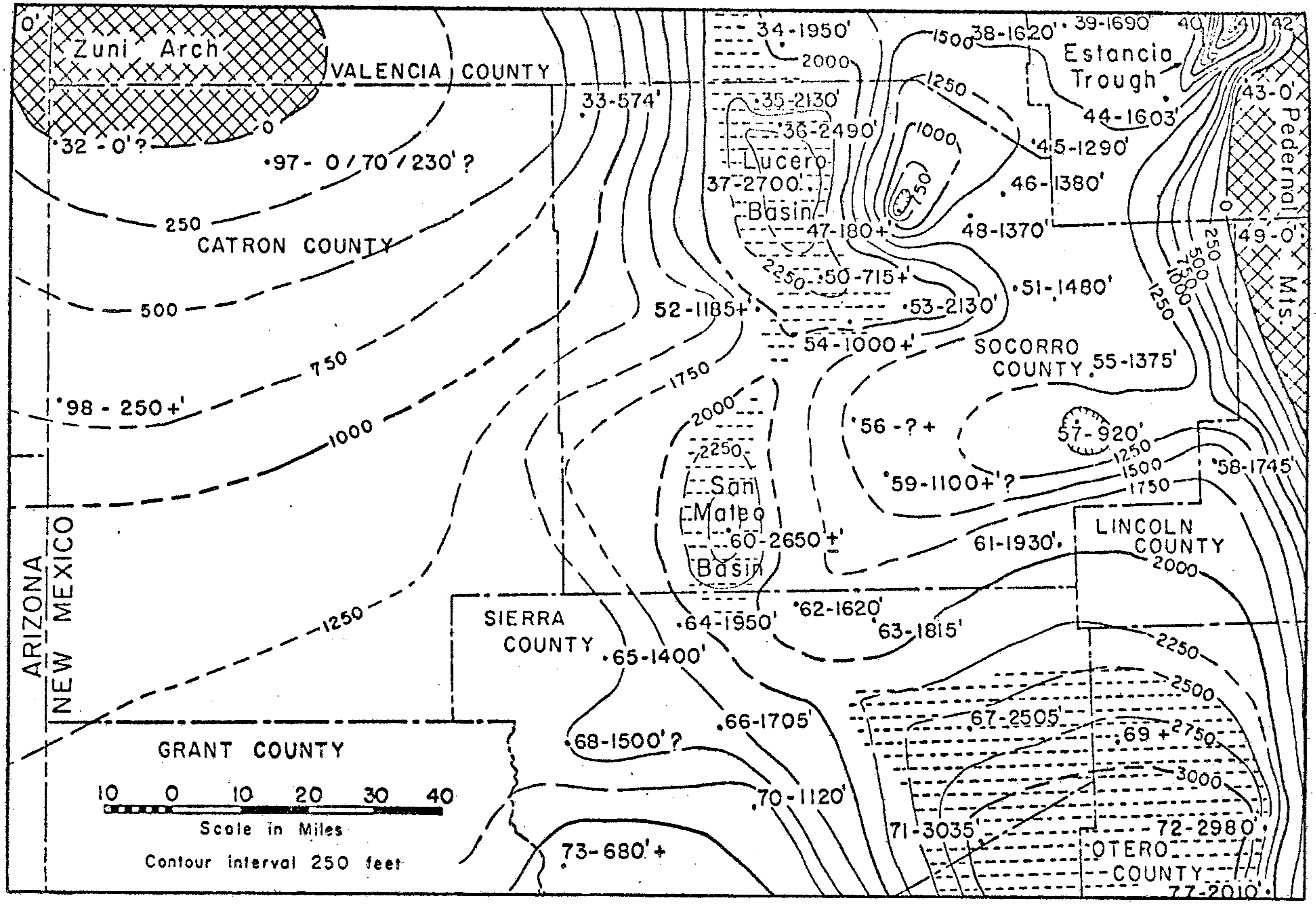

Figure 37. Isopach map for the Pennsylvanian System of west-central New Mexico (from Kottlowski, 1960).

(Krewedl, 1974). This thickness is similar to the thickness of Pennsylvanian sediments to the south in the San Mateo Basin and to the north in the Lucero Basin. It is concluded, therefore, that the San Mateo-Lucero downwarp was probably one continuous, north-trending axis of sedimentation extending northward from the Orogrande Basin. This postulated axis of sedimentation is here informally called the Magdalena prong of the Orogrande Basin. Within this sedimentary framework, more than 900 m of Pennsylvanian sediment accumulated in the Orogrande Basin and as much as 839 m of Pennsylvanian sediment was deposited along the axis of the Magdalena prong. On either side of the Magdalena prong, thinner sequences of Pennsylvanian sediments accumulated on broad shelf areas bounded by the Zuni uplift on the west and the Pedernal uplift on the east.

Morrowan Sedimentation. Morrowan sediments were deposited south of the Socorro region in the Orogrande Basin (Pray, 1961), but are apparently absent in the Socorro region. Morrowan clastic sediments were also deposited in the Delaware (Myer, 1966), Rowe-Mora (Sutherland, in Miller, and others, 1963), Paradox (Wengerd, 1962), and Pedregosa (Zeller, 1975) basins. Much of central New Mexico, however, was a low-lying positive element during Morrowan time (Kottlowski and Stewart, 1970).

Atokan Sedimentation. Periods of erosion during the Late Mississippian and Early Pennsylvanian stripped the thin Paleozoic cover from much of the Socorro region. Early and

Middle Paleozoic beds were completely removed from the eastern part of the region; whereas, west of Socorro as much as 40 m of the Mississippian System were preserved in the San Mateo-Lucero downwarp. In the southwestern part of the Socorro area, this erosion surface was carved upon the Ordovician Montoya Group. In Atokan time, seas inundated the Socorro region and spread their deposits across the Late Mississippian-Early Pennsylvanian erosion surface. An area of greater accumulation developed in the central part of the Socorro region where the thickness of the Atokan Series in places exceeds 200 m. To the east and west of this region of thicker accumulation, Atokan strata thin, and eventually pinch out against the Pedernal and Zuni uplifts.

High clastic ratios and low sandstone-mudrock ratios suggest that Atokan beds were deposited under mixed nearshore and inner shelf conditions as the marine environment transgressed across the Socorro region onto the Pedernal and Zuni uplands and the smaller Joyita uplift. Cross-sections from the northern, central, and southern parts of the region (sheet 1) show a sandy interval in the lower part of the Sandia Formation at some localities but not at others. The sandstones within this interval are generally massive, laminated, or cross-laminated, very thickly bedded, coarse-grained, submature, silica- or calcite-cemented quartz sandstones with arenite textures. This type of sandstone, though common in the geologic record, is exceptional in the sense that it is not known to be forming in any modern environment (Pettijohn, and others, 1972). However, these authors suggest that such sandstones are probably related to dunes, beaches, or bars. The fauna of associated lithologies clearly attests to the marine nature of the lower sandy interval, and it is probable these lower Atokan sands are related to nearshore bar and beach environments, in which rather intense abrasion, weathering, and winnowing are likely to occur.

The quartz pebble conglomerates frequently observed at the base of the sandy interval often occur in local, shallow depressions or channels in the underlying strata. The absence of feldspar and predominance of pebble-size quartz and chert suggest that the basal conglomeratic zones most likely represent simple reworking of local, weathered detritus that was present on the Late Mississippian-Early Pennsylvanian erosion surface. Some of the quartz and chert may have been derived from the Mississippian Caloso and Kelly formations; Mississippian rocks undoubtedly supplied the calcareous siltstone and limestone lithoclasts for the sedlithic conglomerate in the Lemitar Mountains because all other beds had been removed by erosion. Most of the quartz, especially in the eastern part of the region, however, was probably derived from Precambrian rocks, since Mississippian beds had been stripped from this area by earlier erosion.

The sparse crinoid, brachiopod, and bryozoan fauna which characterizes the thin, interbedded limestones and shales of the lower sandy interval verifies the marine nature of these finer-grained deposits. The absence of distinctive marsh characteristics (burrows, root casts, mud cracks) and tidal mudflat features (bioturbation; limited, but abundant fauna) suggests that most of the terrigenous mudrocks and carbonate mudstones were deposited under lagoon-type conditions. When fine-grained terrigenous sediment was available, lagoon bottoms provided ideal conditions for mud-shale deposition. During periods when the supply of terrigenous material was low, the deposition of thin, slightly fossiliferous carbonate mudstones could occur.

The stratigraphic cross sections in sheet 1 show that most of the middle and upper Atokan is dominated by shale and limestone. The gray carbonates generally occur as wackestones that carry a diverse marine fauna, which suggests normal, open marine conditions. The thickness of most beds is variable, but bedding is regular with continuous, generally parallel bed surfaces. Most beds show planar or wavy lamination. These combined characteristics are indicative of deposition under the shallow, quiet but well circulated, inner shelf conditions. It is difficult to distinguish inner shelf and nearshore terrigenous mudrocks, but in the case of the middle and upper Atokan parts of the Sandia

Formation, the association of mud-shales with inner shelf limestones suggests that most of the mud-shales are probably also inner shelf deposits.

In the Joyita Hills, middle and upper Atokan beds are dark-gray to black, carbonaceous clay- and mud-shales. Gypsum laminae and thin, black, silty carbonate mudstones occur in the upper part of the unit and Kottlowski and Stewart (1970) noted bone coal within these beds. These characteristics indicate that nearshore environments prevailed during middle Atokan time in the Joyita Hills area, and that many of the beds were laid down under very restricted, possibly euxinic, lagoon-type conditions.

In the Cerros de Amado, the clastic ratio is considerably lower than other clastic ratios throughout most of northern and central Socorro County (fig. 9), but the sandstone-mudrock ratio is considerably higher. The dark colored limestones are carbonate wackestones and commonly contain brachiopods, crinoids, bryozoans, and horn corals. These limestones are indicative of inner shelf conditions, but the abundance of coarse-grained, sometimes pebbly, often cross laminated, quartz sandstone and dark, carbonaceous, calcareous mud-shale in the section implies a rather steady influx of terrigenous material into the area throughout Atokan time. The Cerros de Amado are only about 15 miles south of the Joyita Hills, where nearshore environments prevailed during the middle and late Atokan.

Transport data, based on cross lamination in sandstones, indicate that most of the terrigenous debris originated from source areas to the north and east. Some of the sand and mud may have been derived from small islands with moderate relief in the vicinity of the Joyita uplift, but the large volume of sediment suggests that much of the detritus must have been derived from the larger Pedernal landmass. The deposits in the Cerros de Amado area may have been associated with small nearshore deltaic complexes along the western margin of the uplift, which would explain the anomalous thickness and the terrigenous and sandy nature of the Atokan Series in the vicinity.

In conclusion, most of the Atokan Sandia Formation was deposited under nearshore and inner shelf conditions. A lower Atokan sandy interval was deposited discontinuously in the Socorro region as Atokan seas transgressed low-lying Early Mississippian-Ordovician-Precambrian terrane that had been exposed by Late Mississippian-Early Pennsylvanian erosion. Most of the sediment was derived from local reworking of Precambrian and Mississippian detritus and from the weakly developed Zuni and Pedernal uplands. Nearshore sedimentation continued to be important in the Joyita Hills and apparently had some influence on the Cerros de Amado area, but with continued transgression, most of the Socorro region came under the influence of inner shelf environments during the middle and late Atokan. Under these conditions mud-shales and carbonate wackestones were spread over the region, with fine-grained terrigenous material coming from the low-lying, more distant Pedernal and Zuni land masses. During periods of low terrigenous influx, clear water, epeiric inner shelf conditions prevailed and deposition of fossiliferous carbonate wackestones occurred.

Desmoinesian Sedimentation. A small disconformity separates Atokan and Desmoinesian beds, but the interruption in sedimentation was of short duration and involved only minor local diastrophism. As Desmoinesian seas spread their deposits over the Socorro region, the area of maximum accumulation was again along the axis of the Magdalena prong of the Orogrande Basin, where as much as 340 m of carbonate and terrigenous material were deposited.

Low clastic ratios (fig. 23) and graphic sections across northern, central, and southern Socorro County (sheet 1) document the abundance of limestone in the Desmoinesian Series throughout most of the Socorro region. Cherty carbonate mudstones and wackestones are the most common carbonate lithologies, with the beds typically showing thick to very thick, even or uneven, regular bedding. The fauna of the wackestones consists of crinoids, brachiopods, corals, bryozoans, and fusulinids. These characteristics imply deposition under predominantly outer shelf conditions. Chert is known to accumulate in both outer shelf and deeper basin environments (Wilson, 1975), but the fairly fossiliferous nature of Desmoinesian limestones does not substantiate deposition under the restricted, often euxinic conditions of deeper basins. Wilson (1975) notes that in the outer shelf environment, dark to light carbonate mudstones are frequently related to the more landward regions of the outer shelf, whereas, cherty, bioclastic and whole fossil wackestones are suggestive of more offshore outer shelf areas. At most sections, the dominance of carbonate mudstones over wackestones suggests that most of the Desmoinesian strata were deposited on the inner, more landward portion of the outer shelf.

Thin terrigenous units occur in the Desmoinesian section in the Magdalena and Ladron Mountains, and terrigenous beds are common in the Desmoinesian Series at Abo Pass and in the Cerros de Amado, where clastic ratios approach one. Little is known of the terrigenous mudrocks that occur in the Desmoinesian section in the Magdalena and Ladron mountains sections, for most of the intervals are covered. Wilson (1975), however, noted that well-segregated beds of shale and siltstone are common among outer shelf limestones.

Granular terrigenous rocks interbedded with outer shelf limestones are somewhat of an enigma. Pettijohn and others (1972) noted that geologists have long noticed the occurrence of thin sandstones in association with shelf carbonates, but pointed out that little is known of processes that concentrate mud-free sandstones on carbonate shelves. Whether these features are related to persistant longshore and tidal currents or to occasional, intense storms is uncertain. Such sandstones that occur in the Desmoinesian Series are coarse-grained, poorly sorted, angular, low sphericity quartz sandstones that occasionally show medium-scale, low-angle, planar cross lamination. As a consequence of their poor exposure, little data have been acquired regarding spatial relationships of various lithologic parameters within these sandstones; therefore, little is known as to their origin.

Figure 23 shows that at Abo Pass and in the Cerros de Amado, terrigenous rocks constitute nearly one-half of the Desmoinesian Section. Very little sandstone, however, is observed in the Desmoinesian Series at these localities and most of the terrigenous units are olive- to dark-gray mud-shales. The associated carbonate units are typical outer-shelf-type limestones that are observed in the Desmoinesian throughout the rest of the Socorro region. These lithologic associations and the small amount of terrigenous material in the sections toward the west suggest that these eastern localities may have been offshore from small delta complexes fed by detritus from the Pedernal landmass. During intervals of time when terrigenous supply was low, cherty carbonate mudstones and wackestones were deposited in an outer shelf environment. With periodic increases in the supply of fine-grained terrigenous material, calcareous mud-shales were deposited. The cross lamination in a few thin sandstones in the Cerros de Amado indicates that most of the terrigenous material was derived from a low-lying landmass to the northeast.

The source of Desmoinesian terrigenous material was apparently a relatively distant, low-relief feature for most of the terrigenous detritus deposited in the Socorro region during Desmoinesian consists of silt and mud. Considering the weakly positive nature of the Joyita uplift during the Atokan Epoch and the fine-grained nature of Desmoinesian sediments in sections that surround the Joyita axis, it is doubtful that the Joyita uplift acquired enough relief during the Desmoinesian to contribute much detritus to the Socorro region. Some of the debris may also have come from the distant Zuni landmass, but since most of the terrigenous material is concentrated in the eastern part of the study area, and since limited paleocurrent data suggests a southwesterly direction of transport, a source area to the east or northeast (the Pedernal Uplift) is more likely.

The small Penasco uplift was tectonically active during Desmoinesian time and supplied some detritus to the Lucero area (Martin, 1971). Some of the fine-grained material in the Socorro region may have filtered into the area from this small feature, but its small size and remote position suggest that its influence would have been limited.

In conclusion, Desmoinesian deposition occurred across a low energy, marine shelf between the low-lying Zuni and Pedernal uplifts. Throughout most of the study area, cherty limestones and dark mud-shales were deposited under normal, outer marine shelf conditions. In the northeast and east-central parts of the region, terrigenous mudrocks were deposited under inner shelf conditions, possibly offshore from small deltaic complexes. Outer shelf cherty limestones, however, were deposited in this area during periods of low terrigenous influx or slightly deeper water conditions.

Late Pennsylvanian Sedimentation. A disconformity involving considerable time is present at the base of the Missourian Series. The area of maximum sediment accumulation during the late Pennsylvanian was again along the axis of the Magdalena prong where more than 450 m of carbonate and terrigenous strata were laid down. Clastic ratios are still less than one, but they are generally higher than clastic ratios that characterize the Desmoinesian Series. An examination of stratigraphic sections (sheet 1) clastic ratios, and sandstone-mudrock ratios (fig. 23) across northern, central, and southern Socorro region shows that limestone generally increases and terrigenous rocks become finer grained toward the west and south. Late Pennsylvanian deposits are thin in the Joyita Hills and Lemitar Mountains. Faulting has made reconstruction of Late Pennsylvanian stratigraphy very difficult in the Magdalena Mountains.

Higher clastic ratios and the presence of cross-bedded, coarse-grained, immature to submature, arkosic and subarkosic sandstones that contain petrified logs more than two meters long, reflect the frequent occurrences of nearshore, possibly deltaic, conditions in the eastern part of the study area near the Pedernal uplift. Carbonate mudstones and wackestones carrying a normal open-marine fauna are also common at Abo Pass and in the northern Oscura Mountains, which suggests that the shelf conditions that were present to the west frequently spread over eastern Socorro County.

Upper Pennsylvanian beds in the southern Ladron and southeastern San Mateo Mountains are dominated by regular, fairly even, medium- to thick-bedded, cherty, carbonate mudstones and poorly exposed mud-shales. This suggests that Late Pennsylvanian sedimentation in the western part of the study area, along the axis of the Magdalena prong, was accomplished predominantly under outer shelf conditions. The large amount of fine-grained terrigenous material that occurs in the lower part of the Missourian section in the southern Ladron Mountains is unusual in an outer shelf environment. Inner shelf and outer shelf mudrocks are difficult to distinguish, but the thin, interbedded, sparsely fossiliferous, cherty carbonate mudstones suggests that these mud-shales may actually be related to terrigenous sedimentation in an outer shelf system.

Between the outer shelf area, along the axis of the Magdalena prong, and the inner shelf-nearshore environments in the eastern part of the study area, most of the Upper Pennsylvanian was deposited under inner shelf conditions. Owing to Virgilian-Wolfcampian erosion, the Late Pennsylvanian sections in the Joyita Hills and Lemitar Mountains are unusually thin. The noncherty carbonate wackestones and mudstones and terrigenous mud-shales that escaped erosion, however, are indicative of inner shelf conditions. In the Cerros de Amado, carbonate wackestones and mudstones and small bioherms (Jaworski, 1973; Hambleton, 1962), also indicate inner shelf conditions. The Late Pennsylvanian section at Little San Pasqual Mountain is poorly exposed and offers little evidence on which to base environmental interpretation. Nevertheless, the limestones that crop out at this locality are typically dark, cherty, sparsely fossiliferous, carbonate mudstones which were most likely deposited on a wide outer marine shelf that extended into the area of the southeastern San Mateo Mountains.

Hambleton (1962) studied Missourian carbonate lithologies from three scattered localities (northern Oscura Mountains, Cerros de Amado, Mesa Sarca) and concluded that the Joyita axis was an active positive area from which most of the late Paleozoic terrigenous detritus was derived. Kottlowski (1963) refuted most of Hambleton's evidence and maintained that most of the terrigenous clastics came from the Pedernal uplift to the east and the Zuni upland to the west. The thrust of Kottlowski's argument was that the large amounts of terrigenous material that occur in the Late Pennsylvanian could not have been supplied from a small emergent feature like the Joyita uplift, but rather must have come from larger positive elements such as the Pedernal or Zuni landmasses.

The stratigraphic and sedimentologic data acquired in this study support Kottlowski's conclusions. Based on: (1) higher clastic ratios in eastern sections, (2) the concentration of subarkosic and arkosic sandstones in eastern areas, and (3) a few scattered southwesterly paleotransport readings, it is believed that most of the Late Pennsylvanian detritus was derived from the Pedernal uplift. Some of the fine terrigenous material in the western part of the region may have come from the distant Zuni landmass.

Composite Stratigraphic Section

The type section of the Magdalena Group is in the northern Magdalena Mountains (Jicha and Balk, 1958) where Loughlin and Koschmann (1942) divided the Magdalena Group into the Sandia Formation below and the Madera Limestone above. The Pennsylvanian section in the Magdalena Mountains, however, is incomplete and is generally a poor choice for a type section. In fact, owing to either inaccessibility, incompleteness, faulting, or unusual lithologic characteristics, there is no one section which adequately represents the general nature of the entire Pennsylvanian sequence as discussed in foregoing pages. For this reason a number of localities have been selected (table 11) where one may witness the typical features of various parts of the Pennsylvanian System in the Socorro region.

Sandia Formation. I believe the best exposures of the Sandia Formation are in the northern Ladron Mountains and in the Joyita Hills. At these localities, a well-developed sandy interval near the base of the section grades upward into a sequence of dark-colored mud-shales and thin limestones. The section in the Ladron Mountains is complete and accessible, but exposures are sometimes less than satisfactory. The section in the Joyita Hills is thin, but it is complete and exposures are good. There is, however, a problem with accessibility because the section is now within the Sevilleta Game Refuge and permission must be obtained before entering. Also, the Joyita section is remote and must be reached by poorly mapped, unmaintained, jeep trails.

Madera Limestone. Excellent exposures of the gray, cherty, outer-shelf limestones, which generally characterize Desmoinesian Madera strata, occur in the northern Ladron, western Lemitar, and northern Oscura

Table 10. Locations of sections which best illustrate the general characteristics of the Pennsylvanian System in the Socorro region.

Sandia Formation
northern Ladron Mountains
Joyita Hills
Madera Limestone
Desmoinesian
northern Ladron Mountains
western Lemitar Mountains
northern Oscura Mountains
Late Pennsylvanian (Missourian-Virgilian)
Abo Pass
northern Oscura Mountains

Mountains. The sections at these localities are readily accessible, complete, and relatively undisturbed by faulting. The section in the western Lemitar Mountains is somewhat thinner than normal, but fusulinids collected for this study indicate that the Desmoinesian section is complete.

Complete, well-exposed Late Pennsylvanian Madera Limestone sections occur at Abo Pass and in the northern Oscura Mountains. These sections illustrate the terrigenous nature of the arkosic limestone member of the Madera Limestone and nearby roads permit easy access. The best exposures of Late Pennsylvanian outer shelf deposits occur in the southern Ladron Mountains, but the section is badly faulted and is accessible only by poorly maintained jeep trails.

SUMMARY AND CONCLUSIONS

This study has investigated the stratigraphy and petrology of Pennsylvanian rocks in the Socorro region of west-central New Mexico. The major conclusions are:

1. One integrated nomenclature system can be adequately used to describe and discuss Pennsylvanian units within the Socorro region. The lower terrigenous interval of the Pennsylvanian System is called the Sandia Formation. The Sandia Formation is overlain by a calcareous unit called the Madera Limestone, which is divided into a lower gray limestone member and an upper arkosic limestone member. The Sandia Formation, Madera Limestone, and overlying Bursum Formation (Wolfcampian) represent a transgressive-regressive cycle beneath the continental redbeds of the Abo Formation (Wolfcampian), and are thus referred to as the Magdalena Group; a term that is well established in the literature.

2. Improved faunal control indicates that within the Socorro region, litho-stratigraphic and time-stratigraphic boundaries show close spatial relationships. The Sandia Formation is generally Atokan in age, the gray limestone member of the Madera Limestone is generally Desmoinesian in age, and the arkosic limestone is Missourian and Virgilian in age. The Pennsylvanian series are separated by unconformities of small magnitude.

3. The thickness of Pennsylvanian sections is now more accurately known as a result of better time control. The thickness of Pennsylvanian sections that have not been thinned by later tectonic events ranges from 112 to 839 m, with the thickest sections occurring along a north-trending line through the southeastern San Mateo Mountains, Magdalena Mountains, and Ladron Mountains. Along this axis of sedimentation, named the Magdalena prong of the Orogrande Basin, Pennsylvanian beds attain a maximum thickness of as much as 839 m, and thin regionally toward the east and west, where they wedge out against the Pedernal and Zuni uplifts respectively. Local, rapid changes in thickness may occur as a result of penecontemporaneous faulting. Local thinning also occurs in the Joyita Hills where the thickness of Pennsylvanian strata measures only 112 m.

4. No Morrowan sediments are known in the study area and it is concluded that much of central New Mexico was a low-lying positive region during Morrowan time.

5. Atokan sedimentation occurred under nearshore and inner shelf conditions as marine environments transgressed low-lying Mississippian, Ordovician, and Precambrian terranes exposed by Late Mississippian and Early Pennsylvanian erosion. The basal Sandia Formation contains a discontinuous sandy interval comprised of massive to cross-laminated, very thickly

bedded, coarse-grained, submature, silica or calcite cemented, quartz sandstones that were deposited in a nearshore environment. Inner shelf mud-shales and gray, carbonate wackestones are typical of the upper part of the Sandia Formation in most areas. Nearshore conditions, however, prevailed in the Joyita Hills and Cerros de Amado, with the latter probably coming under the influence of small deltaic complexes associated with the western margin of the Pedernal uplift.

6. The Desmoinesian beds of the gray limestone member of the Madera Limestone consist of dark-colored, cherty, thick, regularly bedded carbonate mudstones and wackestones and dark-colored mud-shales that were deposited under outer shelf conditions at most localities. Higher clastic ratios in the Cerros de Amado and at Abo Pass suggest that these areas may have periodically been under the influence of more nearshore conditions.

7. Late Pennsylvanian sedimentation was associated with complex and shifting nearshore, inner shelf, and outer shelf environments. Arkosic sandstones, terrigenous mudrocks, and limestones, in the eastern part of the region, along the flanks of the Pedernal uplift, were deposited under nearshore and inner shelf conditions. Small deltaic complexes along the margin of the Pedernal uplift may have locally supplied much of the sediment to these eastern areas. To the west, along the axis of

the Magdalena prong, cherty carbonate mudstones, and terrigenous mud-shales accumulated in an outer shelf environment.

8. Most of the terrigenous material in the Pennsylvanian System of the Socorro region was shed from the east. Thick sections along the axis of the Magdalena prong, increasing clastic ratios toward the east, increasing sandstone-mudrock ratios toward the east, the more arkosic nature of eastern sandstone, and prevailing southerly to westerly paleotransport directions suggest that most of the debris was derived from the Pedernal uplift. Much of the gravel in the basal sandy interval of the Sandia Formation may be reworked debris that was present on a weathered, pre-Atokan erosion surface. Some fine-grained material may have been flushed in from the Zuni uplift, and the Joyita uplift may have contributed some material locally. The major uplift in the Joyita area occurred during late Virgilian time, when Missourian and Virgilian strata were stripped from the area.

9. The above support a basic concept of Pennsylvanian sedimentation centering around a marine, epicontinental seaway trending northward through the central part of the Socorro region that was bounded to the west by the Zuni highlands, to the east by the Pedernal landmass. The Joyita uplift was only a small emergent feature or shoals area

that was most active during late Virgilian time. In this paleogeographic setting, diverse terrigenous and carbonate sediments were deposited under complex and shifting environmental conditions that ranged from nearshore through inner and outer shelf. No significant accumulation of deeper basin deposits has been recognized; if deeper conditions did develop in the Magdalena prong, they were most likely restricted to small, local depressions on the outer shelf. Most of the thick Pennsylvanian deposits along the axis of the Magdalena prong do not reflect deep water conditions, but rather persistent differential subsidence and more continuous sedimentation on an outer marine shelf.

10. The type section for the Magdalena Group in the northern Magdalena Mountains is a poor choice for a type section because it is faulted and incomplete, and rocks are locally silicified and metamorphosed. The original thickness of the Pennsylvanian section in the Magdalena area was probably about 700 to 725 m; not 365 m as previously reported. Because no single stratigraphic section adequately illustrates the diverse character of Pennsylvanian rocks, a number of localities are suggested where the typical features of various parts of the Pennsylvanian System occur. The best Sandia sections are located in the northern Ladron Mountains and in the Joyita Hills. Good exposures of Demoinesian strata occur in the

northern Oscura Mountains; Late Pennsylvanian units crop out well at Abo Pass and in the northern Oscura Mountains.

Many problems remain to be studied, but the integrated stratigraphic framework, thickness values, chronologic data, petrologic data, and paleoenvironmental interpretations presented here provide a solid base for future work in the region.

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APPENDICES

Appendix I

Classification Systems and Abbreviations

Abundance Terminology

Trace (t)	0-1%	Abundant	26-50%
Very Rare (vr)	2-5%	Very Abundant	51-90%
Rare (r)	6-10%	Extremely Abundant	91-100%
Common (c)	11-25%		

Porosity (Levorsen, 1967)

Negligible (n)	0-5%	Good	15-20%
Poor (p)	5-10%	Very Good	20%
Fair (f)	10-15%		

Grain Size (Wentworth, 1922)

Boulder (b)	>256mm
Cobble (c)	64-256mm
Pebble (p)	4-64mm
Granule (g)	2-4mm
Very Coarse Sand (vcs)	1-2mm
Coarse Sand (cs)	0.5-1mm
Medium Sand (ms)	0.25-0.5mm0
Fine Sand (fs)	0.125-0.25mm
Very Fine Sand (vfs)	0.0625-0.125
Coarse Silt (csl)	0.031-0.0625mm
Medium Silt (msl)	0.0156-0.031mm
Fine Silt (fsl)	0.007-0.0156mm
Very Fine Silt (vfsl)	0.0039-0.007mm
Clay (cl)	<0.0039mm

Sorting (Folk, 1974)

	Diameter Ratio
Very Well Sorted (vw)	1.0-1.6
Well Sorted (w)	1.6-2.0
Moderately Sorted (m)	2.0-4.0
Poorly Sorted (p)	4.0-16.0
Very Poorly Sorted (vp)	>16.0

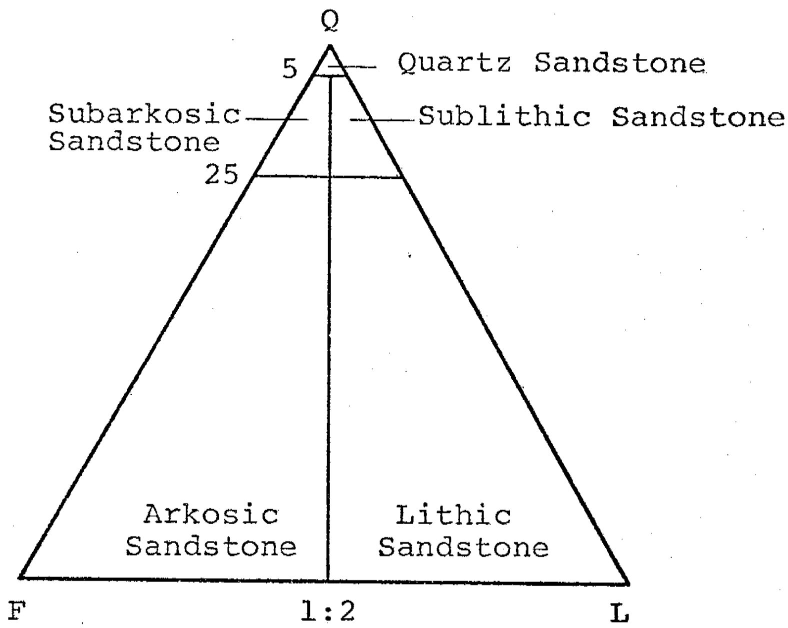
Grain Shape

(Krumbein & Sloss, 1963, p. 111)

Chart for visual estimation of roundness and sphericity of sand grains.

Rock Classification

Limestones: Folk (1959) and Dunham (1962)
Mudrocks: Blatt, Middleton, and Murray (1974)
Conglomerates: Folk (1974)
Sandstones: modified from Pettijohn, Potter, and Siever (1972)



Sandstone Classification

Bed Size (modified after McKee & Weir, 1953; Ingram, 1954; Campbell, 1967)

Very Thickly Bedded	>1 meter
Thickly Bedded	30-100 centimeters
Medium Bedded	10-30 centimeters
Thinly Bedded	1-10 centimeters
Very Thinly Bedded	<1 centimeter

Bed Uniformity (modified after Dunbar & Rogers, 1953; McKee & Weir, 1953)

Regular: beds do not vary in thickness laterally
Irregular: beds do vary in thickness laterally
Even: all beds in vertical succession similar in size
Uneven: vertically adjacent beds not similar in size

Bed/Lamina Surface Shapes (modified from Campbell, 1967)

Planar: bed or lamina surface lies in one plane
Wavy: bed or lamina surface is undulatory
Curved: bed or lamina surface is continuously bent

Internal Structure of Beds (modified from McKee & Weir, 1963; Campbell, 1967; Pettijohn, Potter, & Siever, 1972; Jacob, 1973)

Massive: no distinguishable lamination

Laminated:

Surface Shape: see bed/laminae surface shapes

Thickness:	Very Thick Laminae	>30 mm
	Thick Laminae	10-30 mm
	Medium Laminae	3-10 mm
	Thin Laminae	1-3 mm
	Very Thin Laminae	<1 mm

Cross-laminated:

Magnitude:	Small Scale	>0.05 m
	Medium Scale	0.05-5.0 m
	Large Scale	<5.0 m
Dip:	Low Angle	2-15 degrees
	High Angle	>15 degrees

Relation to lower bounding surface:

Concordant-cross lamination is essentially parallel to the lower bounding surface of the set

Tangential-cross lamination is tangential to the lower bounding surface of the set

Discordant-cross lamination is at angle to the lower bounding surface of the set.

Grouping:

Solitary-unit consists of a single set of cross lamination which succeeds and is succeeded by non-cross-laminated deposits or cross-laminated units of a different type.

Grouped-unit is comprised of two or more vertically adjoining similar sets of cross-lamination.

General Shape:

Tabular-sets bounded by parallel planar surfaces

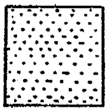
Wedge-sets bounded by converging planer surfaces

Trough-sets bounded by curved surfaces

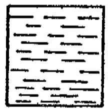
Appendix II

Measured Stratigraphic Sections

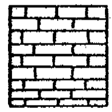
Explanation



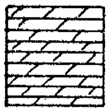
Sandstone



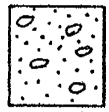
Mudrock



Limestone



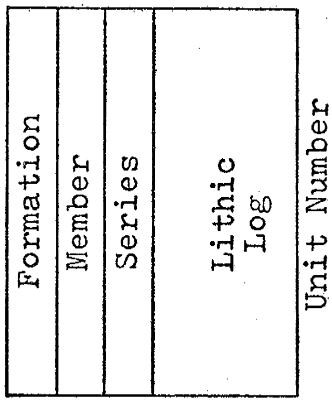
Dolomite



Conglomerate

9 Fossils ▲ Chert

Graphic Section



Unit Description Format

Unit Number — Unit Thickness; Rock Type; Topographic Expression; Rock Color; Terrigenous Grains; Allochemical Materials; Fossil Material; Interstitial Material; Primary Structures; Organic Structures; Chemical Structures; Bedding; Internal Structure of Beds; Transport Directions; Other Data; Sample Numbers.

Abo Pass Section (3)

Abo Pass is located about 35 mi northeast of Socorro in northeastern Socorro and southeastern Valencia counties. Pennsylvanian rocks measured for this study crop out on the west-facing slope of a mesa along Abo Canyon; SE¼ sec. 26, T.3N., R.4E., Scholle Quadrangle. Lowermost Pennsylvanian beds are not exposed at this section because of faulting. Section measurement proceeded from the lowest outcrops found 200 yards north-northeast of the Atchison, Topeka, and Santa Fe Railroad line. Work began in July, 1977.

Measured Section

Location: Abo Pass   Total Thickness: 1091 feet
332.1 meters

Top of Section

Unit

36 65 ft (19.8 m); Limestone (wackestone); cliff former; medium-gray; fairly fossiliferous (crinoids, brachiopods, fragments); cherty; uneven, regular, thin-very thick bedding; generally massive, with some thin, continuous, subparallel wavy lamination. Pap - 36

35 18 ft (5.5 m); Covered slope.

34 15 ft (4.6 m); Limestone (mudstone); ledge former; medium dark-gray; slightly fossiliferous (crinoids, fragments); even, irregular, medium bedding; generally massive, some thin, discontinuous, nonparallel, wavy lamination. Pap - 34

33 13 ft (4 m); Covered slope.

32 30 ft (9.1 m); Limestone (mudstone); cliff former; medium-gray; slightly fossiliferous (crinoids, brachiopods, fusulinids, fragments); brown-weathering, light-gray chert; uneven, regular, thin to thick bedding; generally massive, with some thin, discontinuous, nonparallel, wavy lamination. Pap - 32

31 50 ft (15.2 m); Covered slope.

30 45 ft (13.7 m); Limestone (wackestone); prominent cliff former; medium-gray; fairly fossiliferous (brachiopods, fragments); uneven, regular, medium-very thick bedding; massive. Pap - 30

29 24 ft (7.3 m); Covered slope; float indicates a light olive gray, micaceous shale.

28 4 ft (1.2 m); Limestone (mudstone); ledge former; pale yellowish-brown; slightly fossiliferous (brachiopods, fragments); even, regular, thick bedding; massive.

27 15 ft (4.6 m); Subarkosic sandstone; ledgy slope former; light olive-gray; subangular, moderately sorted, moderately indurated, medium sand; slightly calcareous; subparallel catenary, symmetrical ripple marks; uneven, regular, thin-thick bedding; concordant, straight-concave; low angle, small-scale planar cross-lamination; transport to southwest. Pap - 27

26 90 ft (27.4 m); Clay-shale; slope former; light olive-gray; angular, well-sorted, medium silt; plant impressions;

calcareous. Some interbedded medium-gray, slightly fossiliferous, carbonate mudstone. Base of Virgilian Series. Pap - 26

25 25 ft (7.6 m); Limestone (mudstone); ledge former; medium-gray, slightly fossiliferous (bivalve fragments); even, regular, medium bedding; massive. Top of Missourian Series. Pap - 25

24 20 ft (6.1 m); Covered slope.

23 10 ft (3 m); Quartz sandstone; slope former; light olive-gray; angular, well-sorted, poorly indurated, coarse silt-fine sand; calcareous; even, irregular, thin bedding; thin, continuous, parallel lamination. Pap - 23

22 45 ft (13.7 m); Covered slope; float indicates a yellowish-gray, silty shale.

21 10 ft (3 m); Subarkosic sandstone; ledge former; light olive-gray, weathers moderate-brown; subangular, moderately sorted, well-indurated, fine-medium sand; calcareous; uneven, irregular, thin-very thick bedding; concordant-tangential, straight-convex, low angle, small-large scale, planar and trough cross-lamination. Pap - 21

20 95 ft (29 m); Micaceous, quartz silt-shale; slope former; yellowish gray; angular, well sorted, fine-medium silt; plant impressions; calcareous. Pap - 20

19 7 ft (2.1 m); Dolostone; ledge former; light olive gray, weathers dark yellowish orange; very finely crystalline; even, irregular thin bedding; massive. Pap - 19

18 35 ft (10.7 m); Subarkosic sandstone; slope former; yellowish gray; angular, poorly sorted, poorly indurated, fine-coarse sand; calcareous; uneven, irregular, medium-thick bedding; straight, low-angle, small-large scale, wedge-planar and tabular-planar cross lamination; transport toward northeast. Base of Missourian Series. Pap - 18

17' 50 ft (15.2 m); Covered slope.

17 110 ft (33.5 m); Limestone (wackestone); ledge former; black; fairly fossiliferous (brachiopods, crinoids, fragments); black to brown chert; even, regular, thin-medium bedding; generally massive, some thin, discontinuous, parallel to nonparallel, wavy lamination. Top of Desmoinesian Series. Pap - 17

16 33 ft (10.1 m); Covered slope.

15 8 ft (2.4 m); Limestone (wackestone); ledge former; medium dark-gray; fairly fossiliferous (brachiopods, crinoids);

even, regular, medium bedding; massive. Pap - 15

14 14 ft (4.3 m); Covered slope; appears to be a medium-gray mud-shale.

13 6 ft (1.8 m); Limestone (packstone); ledge former; medium-gray; very fossiliferous (crinoids, brachiopods, hash); even, regular, medium bedding; thin-medium, discontinuous, nonparallel, wavy lamination, sometimes massive. Pap - 13

12 30 ft (9.1 m); micaceous quartz mud-shale; slope former; medium-gray; calcareous. Some interbedded, angular, poorly sorted, coarse-grained, fossiliferous, conglomeratic sub-arkosic sandstone. Pap - 12

11 6 ft (1.8 m); Limestone (mudstone); small cliff former; medium-gray; fairly fossiliferous (brachiopods, crinoids, bryozoans, fusulinids); even, regular, medium bedding; generally massive with some thin-medium, discontinuous, nonparallel, wavy lamination. Pap - 11

10 20 ft (6.1 m); micaceous quartz silt-shale; slope former; light olive-gray; angular, well-sorted, silt-very fine sand; calcareous; interbedded olive-gray, fine-medium grained, fossiliferous; muddy, quartz sandstones. Pap - 10

9 42 ft (12.8 m); Limestone (wackestone); ledge, cliff former; black; fairly fossiliferous (brachiopods), crinoids, bryozoans); black chert; even, regular, thin-medium bedding; generally massive. Pap - 9

8 29 ft (8.8 m); Quartz mud-shale; slope former; greenish gray; well-sorted, fine silt; calcareous; carbonate nodules; interbedded olive-gray, coarse-grained sandstone beds. Pap - 8

7 8 ft (2.4 m); Limestone (wackestone); ledge former; medium-gray; slightly to moderately fossiliferous (brachiopods, crinoids); uneven, regular, thin-medium bedding; generally massive with some medium, discontinuous, nonparallel wavy lamination. Pap - 7

6 13 ft (4 m); mud-shale; slope former; olive-gray; well-sorted fine silt; slightly calcareous. Pap - 6

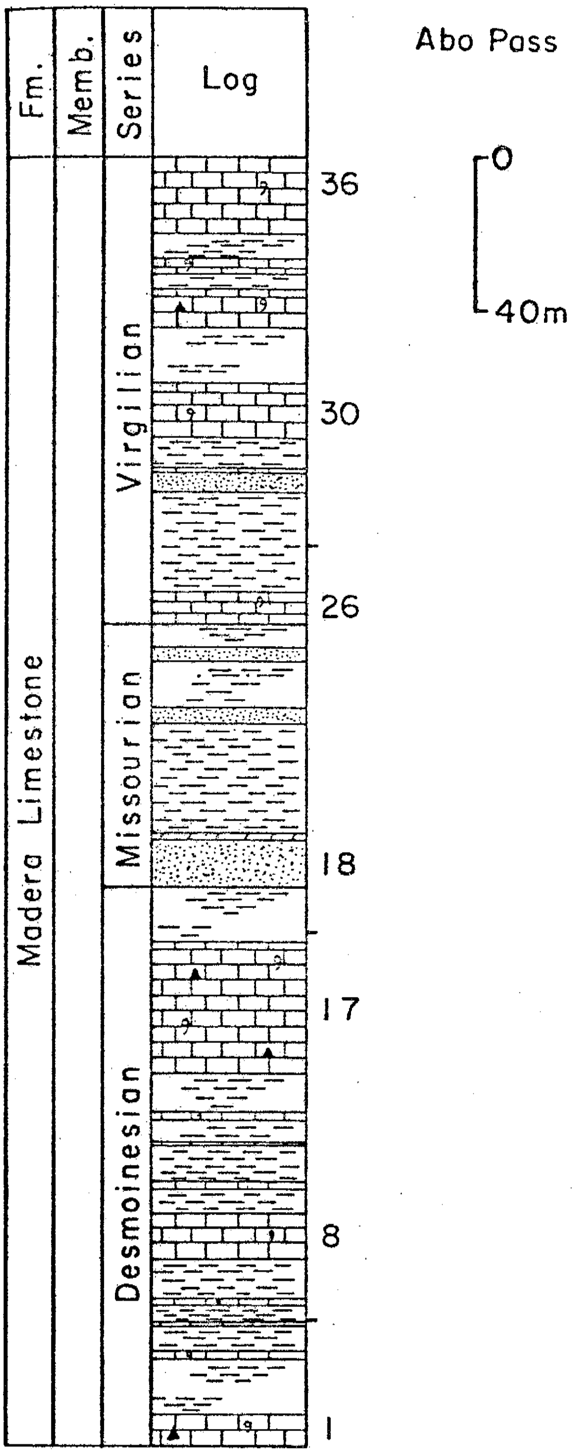
5 3 ft (0.9 m); Limestone (wackestone); ledge former; medium-gray; rare, angular, poorly sorted, coarse-grained sand; moderately fossiliferous (crinoids, brachiopods); black chert; even, regular, thin bedding; medium-thick, discontinuous, nonparallel, wavy lamination, often massive. Pap - 5

4 22 ft (6.7 m); mud-shale; slope former; light olive-gray; well-sorted, fine silt; calcareous. Pap - 4

3 5 ft (1.5 m); Limestone (wackestone); ledge former; medium-gray; fairly fossiliferous (brachiopods, crinoids, bryozoans, gastropods?); uneven, regular, thin-medium bedding; generally massive with some thin, discontinuous, parallel-nonparallel wavy lamination. Pap - 3

2 51 ft (15.5 m); Covered slope, possibly a greenish gray shale.

1 25 ft (7.6 m); Limestone (wackestone to grainstone); ledgy slope former; medium-gray; moderately to very fossiliferous (crinoids, brachiopods); light-gray, brown-to black-weathering chert; uneven, regular, thin-medium bedding; medium, continuous, parallel, planar and wavy lamination, some beds massive. Base covered by alluvium; the Sandia Fm. and about 40 meters of the Madera Ls. have been removed by faulting.


Fm.
Memb.
Series
Log
Abo Pass
0
40m
Madera Limestone
Virgilian
Missourian
Desmoinesian
36
30
26
18
17
8
1

Cerros de Amado Section (6)

The Cerros de Amado are located about seven mi east of Socorro in Socorro County. The Pennsylvanian rocks measured for this study crop out among low hills about 0.75 mi west of Cerros de Amado; NE¼ sec. 3, T.3S., R.1E; NW¼ sec. 2, T.3S., R.1E.; W½ sec. 35, T.2S., R.1E.; W½ sec. 26, T.2S., R.1E., Loma de Las Canas Quadrangle. The base of the section is well exposed and section measurement proceeded from a point near the head of Arroyo de Tio Bartolo. Work began in October, 1975.

Measured Section

Location: Cerros de Amado   Total Thickness: 1902 feet (578.3 m)

Top of Section

Unit

94 8 ft (2.4 m); Limestone (mudstone); forms a dip slope; light-gray; slightly fossiliferous (brachiopods); even, regular, medium bedding; massive. Pca - 94

93 3 ft (0.9 m); Subarkosic Sandstone; slope former; grayish red; angular, moderately sorted, well-indurated, medium sand; very rare, rounded, pebble-size, micritic intraclasts; slightly fossiliferous (brachiopods, crinoids); thin-medium bedding; crops out poorly. Pca - 93

92 15 ft (4.6 m); Limestone (wackestone); caps a small ridge; medium light-gray, fairly fossiliferous (brachiopods, crinoids, bryozoans, colonial corals); birdseye structures, nodular; brown-weathering, light-gray chert; nodular; uneven, reguar, thin-medium bedding; thin-medium, discontinuous, nonparallel, wavy lamination. Indistinct interbeds of arkosic limestone and mudrock.

91 5 ft (1.5 m); Limestone (wackestone); similar to unit 90.

90 23 ft (7.0 m); Limestone (wackestone); small ridge former; medium light-gray; fairly fossiliferous (brachiopods, crinoids, bryozoans, colonial corals); birdseye structure; brown-weathering light-gray chert; nodular; uneven, regular thin-medium bedding; thin, discontinuous, nonparallel, wavy lamination. Pca - 90

89 20 ft (6.1 m); Mudstone; slope former; dusky red; calcareous; micritic nodules; crops out poorly.

88 15 ft (4.6 m); Sandy limestone (wackestone); caps a ridge; medium-gray; rare, subangular, moderately sorted, medium sand; poorly sorted, subrounded, micritic intraclasts; fairly fossiliferous (crinoids, brachiopods, fusulinids, fragments); brown-weathering chert; uneven, regular, thin-medium bedding; thin-medium, continuous, parallel, planar lamination in lower part of unit, upper part massive. Pca - 88

87 10 ft (3.0 m); Covered slope. Base of Virgilian Series.

86 25 ft (7.6 m); Limestone (wackestone); caps a small ridge; medium light-gray; slightly fossiliferous (brachiopods, crinoids); even, regular, thin-medium bedding. Top of Missourian Series. Pca - 86

85 25 ft (7.6 m); Covered slope, Float indicates reddish brown shales, limestones, and siltstones.

84 45 ft (13.7 m); Limestone (mudstone); ledgy slope former; medium dark-gray; slightly fossiliferous (brachiopods, crinoids, fusulinids); uneven, regular, thin-medium bedding; generally massive with some thin, discontinuous, subparallel, wavy lamination. Pca - 84

83 27 ft (8.2 m); Subarkosic sandy mudrock; ledgy slope former; yellowish gray to reddish brown; angular, well-sorted, medium sand; calcareous; uneven, irregular, very thin- thin bedding; abundant, grouped, tangential to concordant, concave up, low-angle, small-large scale, wedge-planar cross lamination. Pca - 83

82 18 ft (5.5 m); Limestone (mudstone); ledge former; light-gray, weathers pale yellowish brown; slightly fossiliferous (brachiopods, gastropods, crinoids, fragments); uneven, regular, thin-medium bedding; generally massive with some thin, discontinuous, parallel, planar lamination; highly fractured. Pca - 82

81 30 ft (9.1 m); Mud-shale; slope former, olive gray; well-sorted, fine-medium silt; slightly fossiliferous (plant impressions). Pca - 81

80 16 ft (4.9 m); Limestone (mudstone); ridge former, medium-gray; slightly fossiliferous (mostly hash); light-gray chert; uneven, regular, medium-very thick; generally massive with some thin, discontinuous, nonparallel, wavy lamination; highly fractured. Pca - 80

79 90 ft (27.4 m); mud-shale; ledgy slope former; black; slightly fossiliferous (brachiopods, gastropods, plant fragments, silicified wood fragments); interbedded medium light-gray, subangular, poorly sorted fine-medium, discontinuous, subparallel planar lamination; and interbedded olive-gray, medium-bedded, fairly massive, sandy limestones. Pca - 79a, 79b, 79c

78 20 ft (6.1 m); Limestone (mudstone); caps a ridge; medium light-gray; slightly fossiliferous (brachiopods, fragments); even, regular, thick bedding; generally massive with some thin, discontinuous, subparallel, planar lamination; highly fractured.

77 35 ft (10.7 m); Covered slope, with a few medium-gray, fairly fossiliferous; uneven, regular, thin-medium bedded; wavy-laminated and cross-laminated (low-angle, small-scale) limestone beds cropping out; transport toward southwest. Pca - 77

76 35 ft (10.7 m); Limestone (wackestone); ledgy slope former; greenish gray-medium light-gray; fairly fossiliferous (brachiopods, crinoids, horn corals); light-gray chert; even, regular, thick bedding, generally massive with some thin-medium, discontinuous, parallel lamination and solitary,

concordant, straight, low-angle, small-scale, tabular-planar cross lamination. Pca - 76

75 35 ft (10.7 m); Limestone (mudstone); ridge former; medium-gray; slightly fossiliferous (brachiopods); even, regular, thin-medium bedding; generally massive with some thin-medium, discontinuous, parallel, planar-wavy lamination. Pca - 75

74 85 ft (25.9 m); Shale and interbedded ledge forming; slightly fossiliferous (brachiopods); even, regular, thin-medium bedding; generally massive with some thin-medium, discontinuous, parallel, planar-wavy lamination. Pca - 74

73 A zone of faulting not included in the measured section.

72 35 ft (10.7 m); Limestone (mudstone); ridge former; medium-gray; fairly fossiliferous (brachiopods, horn corals, crinoids); brown-weathering gray chert; uneven, regular, medium bedding; generally massive with some thin, discontinuous, subparallel, wavy lamination. Top of Desmoinesian Series.

71 34 ft (10.4 m); Covered slope

70 5 ft (1.5 m); Limestone (mudstone); ledge former; moderate yellowish brown; slightly fossiliferous (crinoids, hash); even, regular, medium bedding, massive. Pca - 70

69 34 ft (10.4 m); Silt-shale; slope former, light olive-gray; slightly fossiliferous (brachiopods, plant fragments); interbedded yellowish brown, slightly fossiliferous; even, regular, medium bedded limestone (mudstone).

68 10 ft (3 m); Limestone (wackestone); ledge former; medium-gray; rare, subangular, moderately sorted, very coarse sand; fairly fossiliferous (brachiopods, crinoids); uneven, regular, thin-medium bedding; generally massive with some thin, discontinuous, subparallel, planar and wavy lamination. Pca - 68

67 12 ft (3.7 m); Subarkosic sandstone; cliff former; light brownish gray, weathers moderate-brown; angular-well-rounded, very poorly sorted, medium sand to cobbles; intraclastic; some burrowing in finer grained beds; uneven, irregular, thin-thick bedding; thin-thick, continuous-discontinuous, nonparallel-parallel planar lamination, and solitary and grouped, concordant and tangential, straight and concave up, low-angle, small-medium-scale, tabular-planar and wedge-planar cross lamination. Pca - 67a, 67b

66 60 ft (18.3 m); Clay-shale; mostly covered slope; light olive-gray; slightly fossiliferous (brachiopods, plant impressions); calcareous. Pca - 66

65 12 ft (3.7 m); Subarkosic sandstone; ledge former brownish-gray; angular, poorly sorted, medium sand; slightly fossiliferous (brachiopods in more calcareous beds); fairly calcareous; extensive burrowing; even, regular, thin bedding; thin-medium, continuous, subparallel, planar lamination. Pca - 65

64 47 ft (14.3 m); Silt-shale, slope former; olive-gray; slightly fossiliferous (brachiopods, plant impressions); calcareous. Pca - 64

63 20 ft (6.1 m); Limestone (wackestone); caps a ridge; medium dark-gray; some poorly sorted, coarse sandy beds; fairly fossiliferous (brachiopods, crinoids, horn corals); uneven, regular, medium bedding; generally massive with some thin, continuous, subparallel planar and wavy lamination in some beds. Pca - 63

62 6 ft (1.8 m); Silty limestone (mudstone); poorly exposed slope former; olive-gray, very rare, angular, moderately sorted, coarse silt. Pca - 62

61 5 ft (1.5 m); Limestone (wackestone); ledge former; medium dark-gray; abundant, rounded, well-sorted, pebble-size lithoclasts; fairly fossiliferous (brachiopods, crinoids, solitary and colonial corals), some silicification of fossils; uneven, regular, medium-thick bedding; thin discontinuous-continuous, nonparallel-parallel lamination. Pca - 61

60 15 ft (4.6 m); mostly covered slope with a few gray, fossiliferous, thinly bedded limestones cropping out.

59 45 ft (13.7 m); Limestone (wackestone); cliff former; medium-gray; fairly fossiliferous (crinoids, brachiopods); cherty; uneven, regular, medium-thick bedding; generally massive with some thin-medium, discontinuous, subparallel, wavy lamination. Pca - 59

58 50 ft (15.2 m); Silt-shale; poorly exposed slope former; light olive-gray; micaceous; interbedded gray, thinly bedded, massive or laminated limestone and light olive-gray; angular, poorly sorted, very coarse-grained, medium-bedded, subarkosic sandstones.

57 33 ft (10.1 m); Limestone (mudstone); ledgy slope former; grayish black; nodular; uneven, regular, very thin-thick bedding; thin-medium, discontinuous, subparallel, planar and wavy lamination. Pca - 57

56 10 ft (3.0 m); Siltstone; slope former, olive-gray; plant fragments along parting planes; calcareous; burrowed; very thinly bedded; interbedded grayish orange, angular-subangular, well-sorted, fine-medium grained, calcareous, thin-thick bedded, cross-laminated (solitary, concordant,

straight and concave, low-angle, small-scale, tabular and wedge-planar), subarkosic sandstone; transport toward southwest. Pca - 56a, 56b

55 5 ft (1.5 m); Covered slope

54 10 ft (3.0 m); Sandy limestone (wackestone); slope former; medium-gray; common, subangular, moderately sorted, coarse-grained sand; fairly fossiliferous (brachiopods, horn corals, crinoids); medium bedded. Pca - 54

53 10 ft (3.0 m); Limestone (wackestone); poorly exposed slope former; medium-gray; fairly fossiliferous (algae, crinoids, horn corals, brachiopods); even, regular, thin bedding; generally massive. Pca - 53

52 6 ft (1.8 m); Limestone (packstone); ledgy slope former; medium light-gray; moderately fossiliferous (crinoids, brachiopods); even, regular, thin-medium bedding; generally massive with some thin, discontinuous, nonparallel-parallel, wavy lamination. Pca - 52

51 10 ft (3.0 m); Subarkosic sandstone; ledge former; light brownish gray; subround, poorly sorted, well-indurated, medium sand; rounded, poorly sorted, pebble-size, limestone intraclasts; slightly fossiliferous (bivalve hash); calcareous; burrowed; even, regular, medium bedding, thin-medium, continuous, parallel lamination. Pca - 51

50 28 ft (8.5 m); Siltstone; ledgy slope former; olive-gray; slightly fossiliferous (brachiopods); even, regular, thin bedding; generally massive; interbedded gray to black, silty, slightly fossiliferous (brachs and crinoids), thinly bedded, generally massive limestone (mudstone) and light olive-gray, angular, poorly sorted, coarse-grained, thin-bedded, generally massive, subarkosic sandstone. Pca - 50a, 50b, 50c

49 120 ft (36.6 m); Limestone (mudstone); low ridge former medium light-gray-black; fairly fossiliferous (brachiopods, crinoids, horn corals, bryozoans, fusulinids, algae), some silicification of fossil debris; brown-weathering chert; uneven, regular, medium-thick bedding; generally massive with some thin, continuous-discontinuous, parallel-nonparallel, wavy and planar lamination. Base of Desmoinesian Series, base of Madera Ls. Pca - 49a, 49b

48 10 ft (3.0 m); Quartz sandstone; poorly exposed slope former; mottled light-gray; subangular, poorly sorted, poorly indurated, coarse sand, fairly calcareous; uneven, irregular, thin-medium bedding; some straight, low angle, small-scale, planar cross lamination; transport to southwest. Top of Atokan, top of Sandia Fm. Pca - 48

47 14 ft (4.3 m); Limestone (wackestone); ledge former;

medium-gray, weathers yellowish brown; fairly fossiliferous (crinoids, brachiopods, horn corals); uneven, regular, thin-medium bedding; sparse thin, continuous, subparallel, wavy lamination. Pca - 47

46 10 ft (3.0 m); Subarkosic sandstone; slope former, partially covered; olive-gray, weathers dusky-brown; subangular, poorly sorted, very coarse sand; calcareous. Pca - 46

45 15 ft (4.6 m); Limestone (mudstone); small cliff former; medium light-gray; slightly fossiliferous (brachiopods, horn corals, crinoids, bryozoans); uneven, regular, medium-thick bedding; thicker beds are massive, thinner beds show thin, discontinuous, parallel to nonparallel, wavy lamination. Pca - 45

44 15 ft (4.6 m); olive-gray to medium-gray, subangular, poorly sorted medium-grained, calcareous, subarkosic sandstones grade upward into light olive-gray-medium gray, subangular, well-sorted, very coarse-grained, calcareous, quartz muddy sandstones. Pca - 44a, 44b

43 10 ft (3.0 m); Limestone (wackestone); ledge former; medium-gray to grayish black; fairly fossiliferous (algae, brachiopods, crinoids, bryozoans, horn corals); uneven, regular and irregular thin to medium bedding; generally massive. Pca - 43

42 10 ft (3.0 m); Covered slope

41 6 ft (1.8 m); Limestone (wackestone); ledge former; dark-gray; fairly fossiliferous (algae, brachiopods, crinoids, bryozoans, horn corals); brown-weathering light-gray chert; uneven, regular and irregular, thin to medium bedding; massive.

40 13 ft (4.0 m); Covered slope

39 9 ft (2.7 m); Limestone (wackestone); ledge former; medium-gray to grayish black; fairly fossiliferous (brachiopods, crinoids, algae, bryozoans, horn corals, some silicification of fossil debris; uneven, regular and irregular, thin to medium bedding; generally massive with some thin to medium, continuous and discontinuous, parallel and nonparallel, planar and wavy lamination. Pca - 39

38 7 ft (2.1 m); Quartz sandstone; ledge former; light-gray; angular, poorly sorted, well-indurated, very coarse sand; slightly calcareous; uneven, irregular, thick bedding; solitary, concordant, straight to concave, low-angle, small-to medium-scale, planar cross lamination; transport toward west-southwest. Pca - 38

37 10 ft (3.0 m); Covered slope

36 7 ft (2.1 m); Limestone (mudstone); ledge former; grayish black; slightly fossiliferous (brachiopods, crinoids, horn corals); nodular; uneven, irregular, medium bedding; thin to medium, discontinuous, nonparallel, wavy lamination. Pca - 36

35 9 ft (2.7 m); Covered slope.

34 3 ft (0.9 m); Limestone (wackestone); ledge former; medium-gray; fairly fossiliferous (brachiopods; crinoids, bryozoans, fragments); even, regular, thin-medium bedding; thin, discontinuous, subparallel, lamination. Pca - 34

33 6 ft (1.8 m); Covered slope.

32 5 ft (1.5 m); Quartz, sandstone; ledge former; pale olive; subangular, poorly sorted, very coarse sand; wood, plant impressions; calcareous; medium to thick bedding; solitary, concordant, straight to convex, low-angle, small-scale, planar cross lamination, transport toward southwest. Pca - 32

31 9 ft (2.7 m); Covered slope.

30 20 ft (6.1 m); Limestone (mudstone); ledge former; medium-gray; slightly fossiliferous (brachiopods, crinoids, hash); uneven, regular, thin-thick bedding; thin, discontinuous, nonparallel, wavy and curved lamination. Pca - 30

29 7 ft (2.1 m); Quartz sandstone; ledge former, medium light-gray; subangular, poorly sorted, well-indurated, very coarse sand; weakly calcareous; medium to thick bedding; solitary and grouped, concordant, straight, low-angle, small-scale, planar cross lamination; transport toward west. Pca - 29

28 29 ft (8.8 m); silt-shale; slope former; grayish black; coarse silt, plant impressions; calcareous; limestone concretions. Pca - 28

27 22 ft (6.7 m); Limestone (wackestone); ledgy slope former; medium-gray to grayish black; very rare, subangular, moderately sorted, coarse sand; slightly fossiliferous (crinoids, brachiopods; fragments); uneven, regular, thin to medium bedding; thin to medium, discontinuous, subparallel, wavy lamination. Pca - 27

26 10 ft (3.0 m); Quartz sandstone; ledge former, light olive-gray; subangular, very poorly sorted, very coarse sand; calcareous; even, regular, thick bedding; medium continuous, parallel lamination and solitary, concordant, straight and concave, low-angle, small-scale, planar cross lamination. Pca - 26

25 17 ft (5.2 m); Silt-shale; slope former; light olive-gray; angular, moderately sorted, medium silt; strongly calcareous. Pca - 25

24 7 ft (2.1 m); Quartz sandstone, ledge former; light olive-gray; angular, poorly sorted; well-indurated, very coarse sand; common plant impressions and fragments; thick bedding; solitary, concordant straight to concave, low-angle, small-scale, planar cross lamination; transport toward southwest. Pca - 24

23 21 ft (6.4 m); Covered slope.

22 7 ft (2.1 m); Quartz sandstone; ledge former; pale olive-gray; angular to well-rounded, poorly sorted; coarse sand to pebble; strongly calcareous; uneven, regular, thin to thick bedding; medium to thick, continuous, parallel, planar lamination. Pca - 22, 226

21 21 ft (9.4 m); Covered slope, from float it seems to be grayish orange mud-shale.

20 28 ft (8.3 m); Quartz sandstone; ridge former; light olive-gray; subangular, poorly sorted, very coarse sand; woody plant fragments; calcareous; uneven, irregular, thin-medium bedding; solitary, concordant, straight, low-angle, small-to medium-scale, planar cross lamination. Pca - 20

19 35 ft (10.7 m); Mud-shale; slope former; grayish orange, medium silt. Pca - 19

18 21 ft (6.4 m); Quartz sandstone; forms a small rise; yellowish brown to medium light-gray; angular, poorly sorted; moderately indurated, very coarse sand; calcareous, uneven, irregular, thin to medium bedding; solitary, straight, concordant, low-angle, small-to medium-scale, planar cross lamination; transport toward southwest.

17 70 ft (21.3 m); Mud-shale; slope former, poorly exposed; yellowish gray; interbedded yellowish brown, fossiliferous thinly bedded limestone beds.

16 7 ft (2.1 m); Quartz sandstone; ledge former, very light-gray; subround, well-sorted, well-indurated, coarse sand; siliceous; even, regular, very thick bedding; medium to very thick, continuous, parallel, planar lamination and solitary, concordant, straight, low-angle, small-to medium-scale planar cross lamination. Pca - 16

15 9 ft (2.7 m); Limestone (wackestone); ledge former; light yellowish brown; fairly fossiliferous (crinoids, brachiopods); uneven, irregular, thin bedding; thin to medium, discontinuous, nonparallel to parallel lamination; some

beds contain very rare, subangular, poorly sorted, silt and very fine sand. Pca - 15

14 23 ft (7.0 m); Quartz sandstone; ledge former; very light-gray; angular, very poorly sorted, well-indurated, coarse sand to pebbles; siliceous, even, regular, very thick bedding; solitary, concordant, straight, low-angle, small-medium scale planar cross lamination, and medium, continuous, parallel, planar lamination. Pca - 14

13' 14 ft (4.3 m); Limestone (packstone); slope former; olive gray, weathers moderate yellowish brown; moderately fossiliferous (crinoids, brachiopods, fragments); even, regular, thin to medium bedding; generally massive. Pca - 13'

13 35 ft (10.7 m); Covered slope.

12 7 ft (2.1 m); Limestone (wackestone); slope former; medium gray; common, angular, poorly sorted, fine sand; abundant, rounded, poorly sorted, sandy limestone (wackestone) intraclasts; slightly fossiliferous.

11 5 ft (1.5 m); Quartz sandstone; ledge former; olive-gray, weathers dark reddish brown; angular, well-sorted, coarse silt; subround limestone intraclasts; siliceous, uneven, subparallel, wavy lamination. Pca - 11

10 3 ft (0.9 m); Limestone (packstone); slope former, outcrops poorly; medium-gray; abundant, medium sand-size oolites; slightly fossiliferous (brachiopods; crinoids, hash); thin to medium bedding; generally massive. Pca - 10

9 20 ft (6.1 m); Quartz sandstone; small ridge former; dark reddish brown; angular, poorly sorted, well-indurated, very coarse sand; fossiliferous (woody plants); siliceous; uneven, irregular, thick-very thick bedding, abundant, thin to medium, discontinuous and continuous, nonparallel and parallel lamination, and solitary, concordant, straight and concave, low-angle, small-scale, planar cross lamination. Pca - 9

8 4 ft (1.2 m); Covered slope.

7 13 ft (4.0 m); Quartz sandstone; small ridge former; light-gray, angular, poorly sorted, well-indurated, very coarse sand, fossiliferous (woody plants); siliceous; uneven, irregular, thick to very thick bedding; abundant, thin to medium, discontinuous and continuous, nonparallel and parallel lamination, and solitary, concordant, straight and concave, low angle, small-scale, planar cross lamination. Pca - 7

6 17 ft (5.2 m); Limestone (packstone); small ledge former; light brownish gray; very rare, subangular, well-sorted,

medium quartz sand; slightly intraclastic, moderately fossiliferous (brachiopods, crinoids, hash); uneven, regular, thin-medium bedding; thin, discontinuous, nonparallel, wavy lamination. Pca - 6

5 7 ft (2.1 m); Quartz sandstone; ledge former; light gray to light greenish gray; subangular, moderately sorted, medium sand, weakly calcareous; even, regular, medium bedding; some solitary, concordant; straight, low-angle, small-scale, planar cross lamination; transport toward southwest. Pca - 5

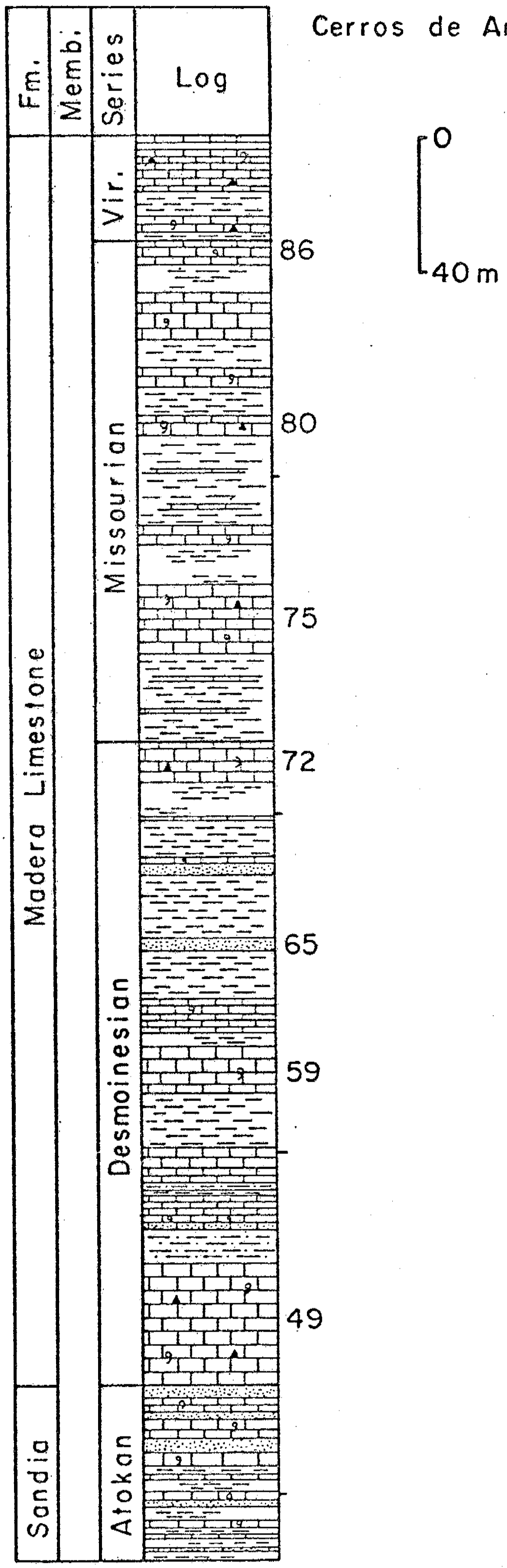
4 9 ft (2.7 m); Covered slope, possibly an olive-gray shale.

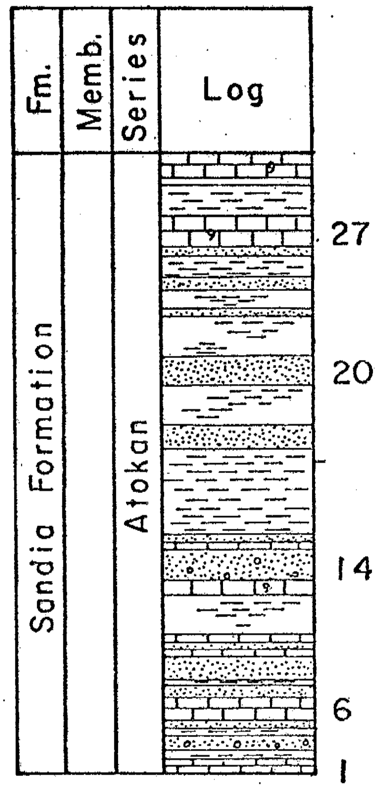
3 9 ft (2.7 m); Quartz granule conglomerate; ledge former; grayish red; subangular, moderately sorted, well-indurated granule-size clasts; fossiliferous (woody plants); weakly calcareous; uneven, irregular, medium to thick bedding; solitary, concordant, straight, low-angle, small-to medium-scale, planar cross lamination; transport toward southwest. Pca - 3

2 10 ft (3.0 m); Covered slope.

1 10 ft (3.0 m); Silicified limestone; ledge former; light-brown to dark-gray; quartz filled vugs; even, thin to medium bedding; generally massive with some faint, thin, continuous, nonparallel, wavy lamination.

Cerros de Amado





Joyita Hills Section (2)

The Joyita Hills, or Los Cañoncitos as labeled on the La Joya quadrangle map, are located about 15 mi north-northeast of Socorro in Socorro County. The Pennsylvanian rocks measured for this study are located on the east-facing slope of the prominant ridge cut by the southernmost branch of Cañada Ancha. The base of the section is well-exposed and section measurement proceeded from a point just east of a series of four prospects near the head of the canyon. Work began in August, 1974.

Measured Section

Location: Joyita Hills   Total Thickness: 267 feet
                                              112 meters

Top of Section

Unit

13 20 ft (6.1 m); Limestone; slope former; medium light-gray; slightly fossiliferous (brachiopods, crinoids); very thick, even, regular bedding; massive.

12 24 ft (7.3 m); Covered section.

11 25 ft (7.6 m); Limestone (wackestone); slope former; medium light-gray; fairly fossiliferous (brachiopods, crinoids, fusulinids); thick, even, regular bedding; massive.

10 30 ft (9.1 m); Limestone (mudstone); ledgy slope former; light-gray; slightly fossiliferous (brachiopods, crinoids); very thick, even, regular bedding; massive.

9 15 ft (4.6 m); Covered reddish brown mudrocks. Desmoinesian-Missourian contact is near the top of this unit.

8 60 ft (18.3 m); Limestone; ridge former; medium-gray; abundant, subround, moderately sorted, quartz and intraclast pebbles; fairly fossiliferous (brachiopods, crinoids, horn corals); very thick, regular bedding; massive. Base of Desmoinesian Series. Pj - 8a, 8b, 8c

7 36 ft (11 m); Limestone (wackestone); cliff former; medium-gray; very fossiliferous (brachiopods, solitary and colonial corals, crinoids); cherry; thin-medium, regular bedding; fine planar to wavy lamination. Top of Atokan Series, base of gray limestone member of Madera Ls. Pj - 7

6 42 ft (12.8 m); Shale; slope former; dark-gray to black; micaceous; calcareous. Top of Sandia Fm.

5 11 ft (3.4 m); Mudstone; ledge former; light olive-gray; very thin to thin, regular bedding; massive. Pj - 5

4 41 ft (12.5 m); Shale; slope former; dark-gray to black; micaceous; calcareous. Pj - 4

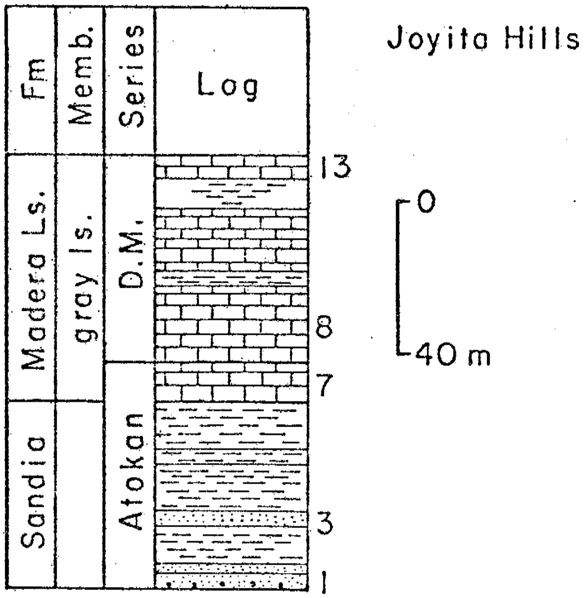
3 13 ft (4 m); Quartz sandstone; ledge former; grayish brown; angular, poorly sorted, very coarse sand; thick regular bedding; indistinct cross lamination. Pj - 3

2 31 ft (9.5 m); Shale; slope former; dark-gray to black; micaceous; calcareous. Pj - 2a, 2b

1 4 ft (1.2 m); Subarkosic sandstone; ridge former; yellowish-gray; angular to subangular, poorly sorted, very coarse

sand to granule; fairly fossiliferous (crinoids, gastropods); calcareous; medium-bedded. Pj - 1

1' 15 ft (4.6 m); Quartz sandstone; ridge former; light-gray; rounded, well-sorted, very coarse sand; well-indurated; slightly fossiliferous (brachiopods, crinoids, woody fragments); siliceous, iron-stained; regular, even, medium bedding with internal thick, planar lamination and straight, low-angle, small-scale, planar cross lamination; southerly transport direction.


Fm
Memb.
Series
Log
Madera Ls.
gray ls.
D.M.
Sandia
Atokan
13
8
7
3
1
Joyita Hills
0
40 m

Ladron Mountains Section (1a, 1b)

The Ladron Mountains are located about 25 mi north-northwest of Socorro in Socorro County. The Sandia Formation and the gray limestone member of the Madera Limestone were measured in the northern Ladron Mountains at the northwest end of a prominant ridge that trends northwest from Ladron Peak; SE¼ sec. 14, T.3N., R.3W., Riley Quadrangle. The base of the section is well exposed and section measurement proceeded from a point immediately to the west of a low distinctive hill of Precambrian granite near the center of the section.

The arkosic member of the Madera Limestone was measured among low hills to the east of a prominant south-trending ridge east of Cerro Colorado in the southern Ladron Mountains; sec. 24 and sec. 26, T.2N., R.3W., Riley Quadrangle. Section measurement proceeded from a point about 0.25 mi east of a large stock tank near the center of the section. Work began in August, 1975.

Measured Section

Location: Ladron Mts. Total Thickness: 2747 ft
839.3 m

Top of Section

Unit

71 20 ft (6.1 m); Limestone (mudstone); cliff former, medium light-gray; slightly fossiliferous (brachiopods, crinoids, bryozoans, debris); very light-gray, brown-weathering, lenticular to nodular chert; uneven, regular, thin to thick bedding; generally massive with some thin to medium, discontinuous, subparallel, wavy lamination. Pl - 71

70 18 ft (5.5 m); Talus covered slope.

69 5 ft (1.5 m); Limestone (mudstone); ledge former; medium dark-gray; slightly fossiliferous (crinoids, brachiopods, bryozoan debris); uneven, regular and irregular, thin to thick bedding; generally massive. Pl - 69

68 5 ft (1.5 m); Limestone (mudstone); slope former; light olive-gray; uneven, irregular, thin bedding; continuous, parallel to subparallel, planar and wavy lamination. Pl - 68

67 8 ft (2.4 m); Limestone (mudstone); small ledge former; medium-gray; slightly fossiliferous (brachiopods, bryozoans, crinoids); light-gray, nodular chert; uneven, regular, thin bedding; some discontinuous, subparallel, wavy lamination. Pl - 67

66 30 ft (9.1 m); Covered slope.

65 60 ft (18.3 m); Limestone (mudstone); ledge former; medium-gray; slightly fossiliferous (brachiopods, bryozoans, crinoids, fusulinids); light-gray, nodular chert; uneven, regular, thin-very thick bedding; thin, continuous to discontinuous, subparallel, wavy lamination. Pl - 65

64 15 ft (4.6 m); Covered slope, possibly a medium gray, fossiliferous, limestone.

63 3 ft (0.9 m); Limestone (mudstone); small ledge former; medium light-gray; slightly fossiliferous (brachiopods, bryozoans, crinoids, forams); one, regular, thick bed; massive. Pl - 63

62 23 ft (7.1 m); Covered slope.

61 8 ft (2.4 m); Limestone (mudstone); mostly covered slope; olive gray.

60 5 ft (1.5 m); Limestone (mudstone); ledge former; medium

dark-gray; slightly fossiliferous (bryozoa, debris); uneven, regular, thin to medium bedding; generally massive. Pl - 60

59 29 ft (8.8 m); Covered slope with a few gray, nodular, thin-bedded limestone cropping out.

58 20 ft (6.1 m); Limestone (mudstone); small ledge former; light-gray; slightly fossiliferous (brachiopods, debris); light-gray, brown-weathering, nodular to lenticular chert; uneven, regular, thin-medium bedding; generally massive. Pl - 58

57 45 ft (13.7 m); Covered slope.

56 13 ft (4.0 m); Limestone (mudstone); ledge former; medium light-gray; slightly fossiliferous (brachiopods, debris); light-gray, brown-weathering, nodular chert; thick bedding; massive.

55 20 ft (6.1 m); Covered slope; one small exposure of interbedded mud-shale and thin-bedded lime-mudstone. Possible fault at the base of this unit. Base of Virgilian Series.

54 3 ft (0.9 m); Limestone (mudstone); small ledge former; yellowish gray; slightly fossiliferous (horn corals, crinoids, brachiopods, debris); even, regular, thick bedding; thin discontinuous, nonparallel, wavy lamination. Top of Missourian Series. Pl - 54

53 5 ft (1.5 m); Limestone (packstone); ledge slope former; medium dark-gray; very fossiliferous (crinoids, brachiopods, bryozoans); even, regular, medium bedding, thin, discontinuous, nonparallel, wavy lamination. Pl - 53

52 10 ft (3.0 m); Limestone (packstone); small cliff former; medium-gray; abundant, angular, poorly sorted, moderately indurated, very coarse sand to pebbles; pebble-size limestone lithoclasts or intraclasts; moderately fossiliferous (crinoids, brachiopods, bryozoans, fusulinids); uneven, irregular, thick to very thick bedding; solitary, concordant, straight to concave, low-angle, large-scale, wedge-planar cross lamination, and medium, continuous, parallel, planar lamination; transport toward the south. Pl - 52

51 25 ft (7.6 m); Limestone (mudstone); ridge former; medium light-gray, slightly fossiliferous (crinoids, brachiopods, horn corals, gastropods); black, brown-weathering, irregular chert masses; uneven, regular, medium to thick bedding; massive. Pl - 51

50 22 ft (6.7 m); Quartz sandstone; ledgy slope former; medium-gray, weathers yellowish gray; angular, poorly sorted, well-indurated, very coarse sand; rounded, pebble-size,

carbonate intraclasts; very calcareous; even, regular medium bedding; generally massive, with some medium continuous, parallel, planar and wavy lamination. Pl - 50,50'

49 10 ft (3.0 m); Limestone (mudstone); small ledge former; medium-gray; even, regular, thick bedding; generally massive, with some thin, discontinuous, subparallel, wavy and planar lamination. Pl - 49, 49'

48 20 ft (6.1 m); Diabasic intrusive; slope former; brown, weathers greenish gray.

47 5 ft (1.5 m); Intraclastic limestone (packstone); poorly exposed slope former; mottled medium-gray; irregular, very poorly sorted, pebble- to cobble-size limestone (mudstone) intraclasts. Pl - 47

46 10 ft (3.0 m); Subarkosic sandstone; poorly exposed slope former; white to very light-gray; subround, very well-sorted, well-indurated, fine sand, calcareous; uneven, irregular, thin to medium bedding. Pl - 46

45 35 ft (10.7 m); Limestone (mudstone); small ledge former; medium dark-gray, weathers yellowish gray; slightly fossiliferous (brachiopods, bryozoans, debris); even, regular, medium bedding; thin, discontinuous, nonparallel, wavy lamination. Pl - 45

44 40 ft (12.2 m); Limestone (mudstone); small cliff former; light-gray; slightly fossiliferous (brachiopods, bryozoans, crinoids, fragments); minor, light-gray, brown-weathering, nodular chert; even, regular, very thick bedding; massive. Pl - 44

43 75 ft (22.9 m); Covered slope; probably interbedded gray, mud-shale and black, thin bedded, carbonate mudstones. Pl - 43

42 8 ft (2.4 m); Limestone (mudstone); ledge former; medium light-gray; slightly fossiliferous (brachiopod and crinoid debris); uneven, regular, medium to very thick bedding; generally massive, with some thin, discontinuous, subparallel, wavy lamination. Pl - 42

41 50 ft (15.2 m); Covered slope, seems to be interbedded carbonate mudstone and light gray mud-shale.

40 300 ft (91.5 m); Limestone (mudstone); ridge former; medium light-gray to medium dark-gray; slightly fossiliferous (brachiopods, crinoids, debris); minor, light-gray, brown-weathering, nodular chert; uneven, regular, thin to medium bedding; generally massive, with some thin, discontinuous to continuous, subparallel, wavy and planar lamination. Pl - 40a, 40b, 40c

39 120 ft (36.6 m); Covered slope, appears to be interbedded gray, mud-shale and interbedded black, carbonate mudstones. Pl - 39

38 15 ft (4.6 m); Limestone (mudstone); small ledge former; medium light-gray; slightly fossiliferous (brachiopods, fusulinids, crinoids, bryozoans, debris); gray, brown-weathering, nodular chert; even, regular, medium bedding; generally massive; fractured. Pl - 38

37 105 ft (32 m); Covered slope.

36 35 ft (10.7 m); Limestone (mudstone); small ledge former; light-gray, slightly fossiliferous (bryozoans, crinoids, debris); even, regular, medium bedding; generally massive. Pl - 36

35 50 ft (15.2 m); Covered slope; possibly interbedded shale and thin-bedded limestone.

34 5 ft (1.5 m); Limestone (mudstone); ledge former; medium light-gray; slightly fossiliferous (bryozoans, brachiopods, crinoids, fusulinids, horn corals); black, brown-weathering, nodular to lenticular chert; medium to thick bedding. Pl - 34

33 15 ft (4.6 m); Covered slope.

32 10 ft (3.0 m); Limestone (mudstone); small ledge former; medium light-gray; slightly fossiliferous (brachiopod and crinoid debris); dark-gray, brown-weathering, nodular chert; even, regular, medium bedding, generally massive. Pl - 32

31 10 ft (3.0 m); Covered slope.

30 9 ft (2.7 m); Limestone (mudstone); ledge former; medium dark gray-yellowish brown; slightly fossiliferous (brachiopods, crinoids, bryozoans); gray, brown-weathering, lenticular to nodular chert; uneven, regular, medium to thick bedding; thin, continuous to discontinuous, parallel to nonparallel, wavy and curved lamination. Pl - 30

29 125 ft (38.1 m); Covered slope.

28 28 ft (8.5 m); Sandy limestone (wackestone); ledge former; light-gray; abundant, angular, moderately sorted, very coarse sand; slightly fossiliferous (brachiopods, crinoids, horn corals, bryozoans); uneven, regular, medium bedding; low-angle, small-scale, planar cross lamination. Pl - 28

27 15 ft (4.6 m); Covered slope; a few scattered outcrops of gray, thinly bedded limestone (mudstone). Pl - 27

26 45 ft (13.7 m); Calcareous, intraclastic, subarkosic sandstone; slope former; light-gray; angular, moderately sorted, poorly indurated, very coarse sand, rounded, granule-size, limestone intraclasts; woody plant impressions; uneven, irregular, thick to very thick bedding; planar lamination and small-scale, low-angle, cross lamination. Base of Missourian, base of arkosic limestone member of Madera Ls. Pl - 26

25 35 ft (10.7 m); Limestone (mudstone); ledge, cliff former; medium-gray; slightly fossiliferous (horn corals, brachiopods, crinoids, gastropods, bryozoans); light-gray, nodular chert; even, regular, thick bedding; generally massive. Top of Desmoinesian, top of gray limestone member of Madera Ls.

24' 20 ft (6.1 m); Covered slope.

24 45 ft (16.5 m); Limestone (mudstone); ledge former; medium-gray; slightly fossiliferous (horn corals, brachiopods, crinoids, bryozoans); light-gray, nodular chert; even, regular, thick bedding; massive. Pl - 24

23 20 ft (6.1 m); Covered slope, seems to be a gray, thinly bedded limestone. Pl - 23

22 65 ft (19.8 m); Limestone (mudstone); ledgy slope former; medium-gray; slightly fossiliferous (horn corals, brachiopods, gastropods, crinoids); light-gray, nodular chert; uneven, regular, thick to very thick bedding; massive. Pl - 22

21 25 ft (7.6 m); Covered slope.

20 55 ft (16.8 m); Limestone (mudstone); prominant cliff former; medium-gray; slightly fossiliferous (horn corals, brachiopods, algae, bryozoans, fusulinids, gastropods); minor, gray, nodular chert; even, regular, very thick bedding; generally massive. Pl - 20

19 55 ft (16.8 m); Limestone (wackestone); ledgy slope former; medium-gray; fairly fossiliferous (brachiopods, crinoids, forams, bryozoans, horn corals); gray, lenticular and nodular chert; even, regular, medium bedding, generally massive, with some indistinct, thin, discontinuous, nonparallel, wavy lamination. Pl - 19

18 25 ft (7.6 m); Covered slope.

17 10 ft (3.0 m); Limestone (mudstone); ledge former; medium dark-gray; slightly fossiliferous (crinoids, forams, brachiopods); even, regular, very thick bedding; thin, continuous to discontinuous, parallel and nonparallel, wavy lamination. Pl -17

16 25 ft (7.6 m); Covered slope.

15 70 ft (21.3 m); Limestone (mudstone); ledgy cliff former; medium-gray, slightly fossiliferous (horn corals, brachiopods, crinoids); abundant, gray, brown- to black-weathering, chert; even, regular, very thick bedding; generally massive with some discontinuous, nonparallel, planar and wavy lamination. Pl - 15

14 30 ft (9.1 m); Limestone (mudstone); ledge, cliff former; medium-gray, slightly fossiliferous (brachiopods, crinoids, horn corals); gray, brown-weathering chert; even, regular, thick bedding, generally massive, with some discontinuous, nonparalel, wavy lamination. Pl - 14

13 50 ft (15.2 m); Limestone (mudstone); small ledgy cliff former, medium-gray; slightly fossiliferous (brachiopods, crinoids, horn corals), uneven, regular, very thick bedding; generally massive with some discontinuous, nonparallel, wavy and planar lamination. Pl - 13

12 115 ft (35.1 m); Limestone (mudstone); outcrops alternating with small covered sections; the limestone outcrops are medium dark-gray to black, fairly fossiliferous (horn corals and brachiopods, bryozoans, crinoids); medium- to thick-bedded, and generally massive, with some thin, discontinuous, nonparallel, wavy lamination. Pl - 12

11 15 ft (4.6 m); Subarkosic sandstone; ledge former; light-gray; subangular, poorly sorted, well-indurated, very coarse sand; calcareous, uneven, irregular, medium to thick bedding; thin, continuous, parallel, planar lamination, and solitary, concordant, straight and concave, low-angle, small scale, planar cross lamination; transport toward the southeast. Pl - 11

10 45 ft (13.7 m); Limestone (mudstone); ledge former; medium dark-gray; slightly fossiliferous (colonial corals, horn corals, brachiopods, gastropods, crinoids); gray, nodular chert; even, regular, very thick bedding, generally massive. Pl - 10

9 60 ft (18.3 m); Limestone (wackestone); ledge former; medium dark-gray; slightly fossiliferous (horn corals, colonial corals, gastropods, bryozoans, brachiopods), gray, brown- to black-weathering, nodular, chert; even, regular, medium bedding; generally massive with some thin; discontinuous, nonparallel, wavy lamination. Pl - 9

8 35 ft (10.7 m); Limestone (mudstone); small cliff former; black, weathers medium-gray; slightly fossiliferous (colonial corals, bryozoans, brachiopods, fusulinids); even, regular, medium bedding; generally massive.

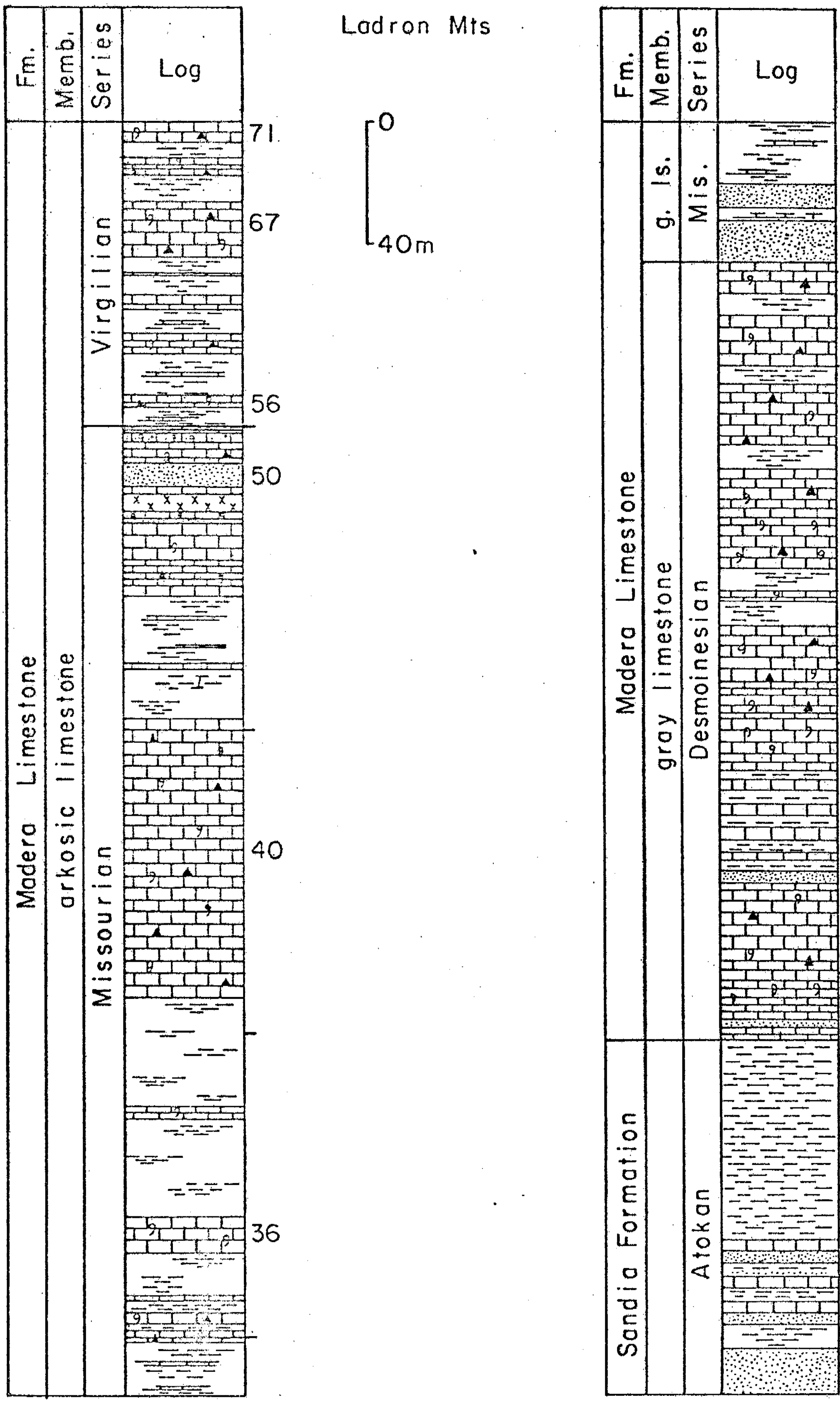
7 30 ft (9.1 m); Limestone (wackestone); ledge former; grayish black; slightly fossiliferous (colonial corals, crinoids, brachiopods, horn corals, bryozoans); even, regular, very thick bedding; massive. Near the center of the unit there is a very poorly exposed yellowish gray, angular, poorly sorted, very coarse-grained, quartz sandstone bed that is about 1 meter thick. Base of Desmoinesian, base of gray limestone member of Madera Ls. Pl - 7

6 215 ft (65.5 m); Silt-shale; slope former; dusky yellow to black; minor interbedded gray, argillaceous, slightly fossiliferous (brachiopods, bryozoans, crinoids, colonial corals); thinly bedded, carbonate mudstones. Top of Atokan Series, top of Sandia Fm. Pl - 6

5 95 ft (28.7 m); A series of very poorly exposed, interbedded olive-gray to yellowish brown, fairly fossiliferous (crinoids, brachiopods, bryozoans, debris); uneven, irregular, thin-medium bedded, massive and thin, planar-laminated, sandy limestones; grayish brown to grayish red, angular, poorly sorted, medium- to very coarse-grained, uneven, irregular, medium-bedded, laminated and cross laminated, quartz sandstones; and covered slopes that are probably shales. Pl - 5a, 5e, 5f, 5i

4 45 ft (13.7 m); Covered slope.

3 50 ft (15.2 m); Siliceous quartz sandstone; low ledge former; light-gray, weathers mottled dark brownish red; subangular, poorly sorted, very well-indurated, coarse sand; uneven, regular and irregular, thick bedding; some indistinct, solitary, concordant, straight, low-angle, large-scale, tabular- and wedge-planar cross lamination; transport toward southeast. Base of Pennsylvanian System. Pl - 3a, 3b


Ladron Mts
0
40m
Fm.
Memb.
Series
Log
Madera Limestone
arkosic limestone
Virgilian
Missourian
71
67
56
50
40
36
Fm.
Memb.
Series
Log
Madera Limestone
g. ls.
Mis.
gray limestone
Desmoinesian
Sandia Formation
Atokan
26
22
16
11
6
3

Lemitar Mountains Section (5)

The Lemitar Mountains are located about 12 mi northeast of Socorro in Socorro County. The Sandia Formation was measured near the mouth of a small northeast-trending drainage that empties into Cañoncito del Puertocito del Lemitar; NW¼ NW¼ sec. 18, T.2S., R.1W., Lemitar Quadrangle. The base of the section is well exposed and section measurement proceeded from a point located near the top of the east side of the drainage.

The Madera Limestone was measured in the western part of the Lemitar Range; NW¼ sec. 2, T.1S., R.2W., Magdalena Quadrangle. The base of the section is well exposed and section measurement proceeded from a point about 0.25 mi west of the stock tank in the northeastern part of section 2. Work began on these sections in August, 1974.

Measured Section

Locations: Lemitar Mts. Total Thickness: 1083 feet
329.8 meters

Top of Section

Unit

32 51 ft (15.5 m); Limestone (Mudstone); medium-gray, sometimes light-red in the upper beds; fairly fossiliferous (crinoids, brachiopods, bryozoans); uneven, regular, thick to very thick bedding; generally massive, with occasional discontinuous, subparallel, planar or wavy lamination.

31 23 ft (7.0 m); Clay-shale; very light-gray, weathers dusky red; calcareous.

30 10 ft (3.0 m); Limestone (mudstone); medium light-gray; slightly fossiliferous (brachiopods, crinoids, colonial corals, fusulinids), some chert; thin-medium, uneven, irregular bedding; generally massive.

29 35 ft (10.7 m); Covered slope, believed to be a clay-shale.

28 51 ft (15.5 m); Limestone (mudstone); medium light-gray; slightly fossiliferous (brachiopods, crinoids, fusulinids); some chert; thin to medium, uneven, regular bedding (upper and lower part thicker bedded); generally massive.

27 11 ft (3.6 m); Covered slope, believed to be a clay-shale.

26 18 ft (5.5 m); Limestone (mudstone); ledge former; medium-gray, mottled weathered surface; slightly fossiliferous (horn corals); brown-weathering chert; very thick, even, regular bedding; massive.

25 27 ft (8.2 m); Clay-shale; slope former, yellowish gray, calcareous. Base of Missourian Series.

24 17 ft (5.2 m); Limestone (wackestone); ridge former, light-gray, weathers with a dusky red cast; fairly fossiliferous (crinoids, brachiopods, fusulinids, horn corals); light-gray to black, brown-weathering, nodular chert; thick to very thick uneven, irregular, bedding; generally massive, with some thin, discontinuous, subparallel, planar and wavy lamination. Top of Desmoinesian Series.

23 16 ft (4.9 m); Silicified limestone; crops out poorly; weathers light-red.

22 346 ft (105.6 m); Limestone (wackestone); ridge former, medium light-gray; fairly fossiliferous (crinoids, brachiopods, fusulinids, horn corals); light-gray to black, brown weathering, nodular chert; thick to very thick, uneven, regular bedding; generally massive, with some thin continuous

and discontinuous, subparallel, planar and wavy lamination. Base of Desmoinesian Series, base of gray limestone member of Madera Ls. Pc - 24, 28

21 48 ft (14.6 m); Clay-shale, mostly covered, slope former. medium-gray. Top of Atokan Series, top of Sandia Fm.

20 15 ft (4.6 m); Limestone (wackestone); ledge former; black, weathers medium-gray or moderate-brown; fairly medium to thick, uneven, regular bedding; generally massive. Pc - 20

19 21 ft (6.4 m); Quartz sandstone; low ledge former; light olive-brown; angular, poor, well-indurated, medium to very coarse sand; calcareous; medium to thick bedding; massive. Pc - 19

18 28 ft (8.5 m); Limestone (wackestone); ledge former; dark-gray; moderately fossiliferous (brachiopods, crinoids); thin to medium, uneven, regular bedding; generally massive. Pc - 18, 18b, 18c

17 27 ft (8.2 m); Quartz sandstone; ledge former, very light-gray, weathers pale greenish yellow; angular, very well-sorted, medium sand; calcareous; medium to thick, uneven, regular bedding; medium-scale, low-angle, planar cross bedding. Pc - 17

16 111 ft (33.8 m); Clay-shale; valley former, medium light-gray; calcareous; interbedded, angular, poorly sorted, calcareous, thin to medium bedded, wavy-laminated, muddy sublithic sandstones. P - 16a, 16b, 16c

15 29 ft (8.8 m); Quartz sandstone; forms dip slope; light olive-brown; subangular, poorly sorted, poorly indurated, very coarse sand; calcareous; thick to very thick bedding. Pc - 15

14 5 ft (1.5 m); Limestone (packstone); medium-gray; very fossiliferous (crinoids, brachiopods, fragments); medium to thick, uneven bedding; generally massive. Pc - 14

13 23 ft (7.0 m); Quartz sandstone; low, prominant ridge former; very light-gray, weathers dusky-red to moderate reddish brown; well-rounded, well-sorted, very well-indurated, coarse sand; siliceous; very thick, uneven, regular bedding; low-angle, small-scale, planar cross bedding; wood fragments; southerly transport direction indicated. Pc - 13a, 13b, 13c

12 2 ft (0.6 m); Limestone (wackestone); medium-gray; common angular, moderately sorted, coarse, quartz sand; slightly fossiliferous (crinoids, fragments); medium, regular bedding; generally massive. Pc - 12

11 2 ft (0.6 m); Quartz sandstone; light olive-brown; angular, poorly sorted, very well-indurated, fine to coarse sand; calcareous; medium bedding; laminated. Pc - 11

10 24 ft (7.3 m); Covered slope, believed to be clay-shale.

9 6 ft (1.8 m); Limestone (wackestone); dark yellowish brown; abundant, angular, moderately sorted, coarse, quartz sand; slightly fossiliferous (brachiopods, crinoids, gastiopods); medium bedding. Pc - 9

8 48 ft (14.6 m); Covered slope, believed to by clay-shale.

7 6 ft (1.8 m); Lithic conglomerate; color variable; round, poorly sorted, pebble-to cobble-size siltstone lithoclasts and quartz fragments; carbonate mudstone matrix; medium bedding. Pc - 7

6 13 ft (4.0 m); Mud-shale; light olive-gray; calcareous. Pc - 6

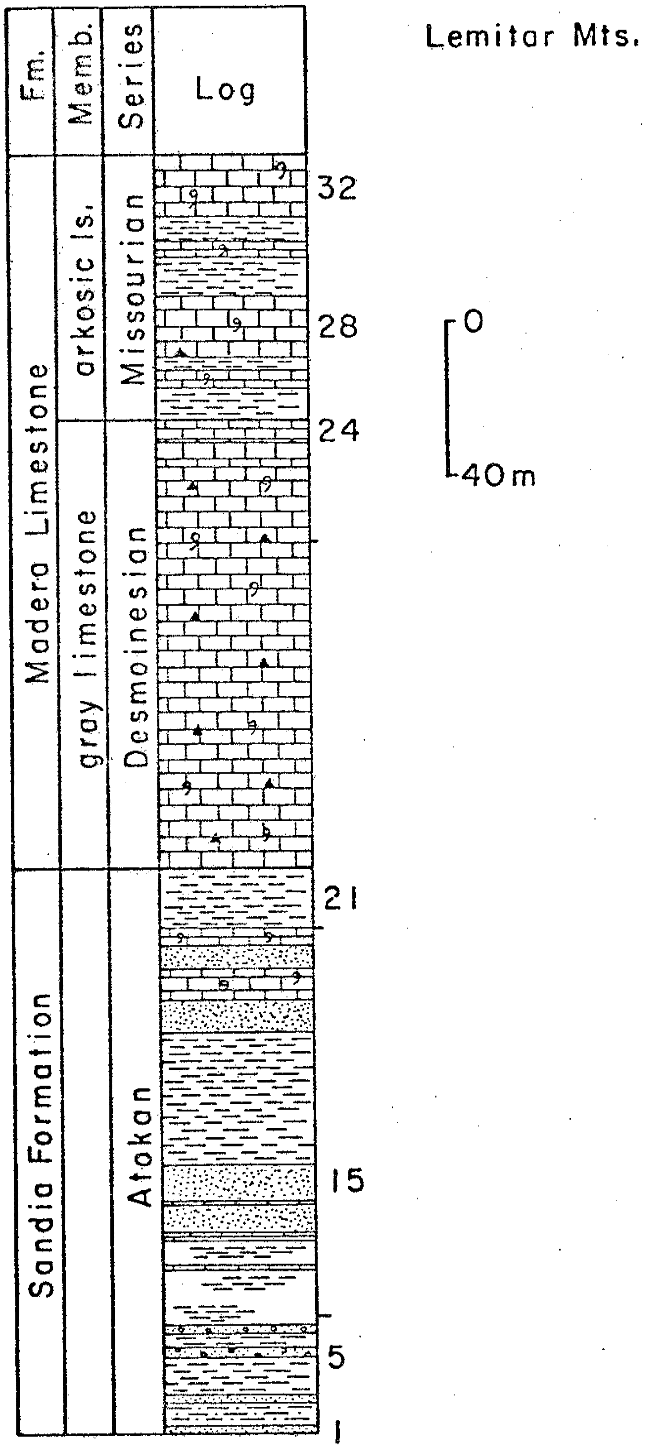
5 5 ft (1.5 m); Sandy lithic conglomerate; small break in slope; variagated light olive-gray; angular to round, poorly sorted, pebble-to cobble-size carbonate mudstone and argillite lithic fragments and quartz gravels; carbonate cement; medium to thick bedding. Pc - 5

4 34 ft (10.4 m); Clay-shale; slope former, crops out poorly; medium gray. Pc - 4

3 7 ft (2.1 m); Quartz sandstone; break in slope; very light-gray, weathers black; angular, moderately sorted, very well-indurated, coarse sand; siliceous, ferruginous; very thick bedding; massive. Pc - 3

2 20 ft (6.1 m); Siltstone; slope former; dusky brown, weathers reddish brown; well-sorted, well-indurated, coarse silt; micaceous; siliceous; medium, regular bedding; massive. Pc - 2a, 2b

1 3 ft (0.9 m); Quartz sandstone; slope former; dusky brown; angular, poorly sorted, very well-indusrated, coarse sand, siliceous; thick bedding; massive. Pc - 1


Lemitar Mts.
Fm.
Memb.
Series
Log
Madera Limestone
arkosic ls.
gray limestone
Missourian
Desmoinesian
Sandia Formation
Atokan
32
28
24
21
15
5
1
0
40m

Little San Pasqual Mountain Section (8)

Little San Pasqual Mountain is located about 25 mi south of Socorro in Socorro County. The Pennsylvanian rocks measured for this study crop out in the northern part of the uplift, on and to both sides of the prominant north-trending ridge off of the uplift; sec. 4 and sec. 5, T.7S., R.1E., Val Verde Quadrangle. The base of the section is covered and believed to be faulted. Section measurement proceeded from a point beneath a distinctive brown sandstone on the west side of the prominant north to northwest-trending drainage along the west side of the uplift. Work began in July, 1975.

Measured Section

Location: Little San Pasqual Mtn. Total Thickness: 1726 feet / 525.8 meters

Top of Section

Unit	
43	75 ft (22.9 m); Limestone (mudstone); ridge former, medium-gray; rounded, pebble-size, limestone intraclasts; slightly fossiliferous (brachiopods, crinoids, corals, bryozoans, fusulinids); medium-gray, brown-weathering, lenticular and nodular chert; even, regular, thick to very thick bedding; massive.
42	30 ft (9.1 m); Covered slope with a few outcrops of mottled medium-gray, slightly fossiliferous (crinoids, hash), slightly silty (angular, poorly sorted, coarse silt) limestone (wackestone). Psp - 42
41	25 ft (7.6 m); Limestone (mudstone); ridge former; medium dark-gray; slightly fossiliferous (crinoids, algae, debris); even, regular, very thick bedding; generally massive. Psp - 41
40	140 ft (42.7 m); Generally covered slope with scattered outcrops of grayish black, yellowish brown-weathering, fairly fossiliferous (horn corals, brachiopods, crinoids, debris); uneven, regular, thin-to medium-bedded; thinly laminated limestone (wackestone). Psp - 40
39	15 ft (4.6 m); Limestone (mudstone); medium dark-gray; slightly fossiliferous (brachiopods, crinoids, debris); medium-gray, brown-to black-weathering, nodular chert; uneven, regular, medium to thick bedding; generally massive. Psp - 39
38	15 ft (7.6 m); Arkosic sandstone; part of a poorly exposed valley forming sequence; grayish orange, weathers light-brown; angular, poorly sorted, medium sand, calcareous; burrowed; bedding uncertain. Base of Virgilian Series. Psp - 38
37	10 ft (3.0 m); Limestone (mudstone); small rise in a valley forming sequence; grayish black; slightly fossiliferous (brachiopods, bryozoans, crinoids, debris); medium-gray, brown-weathering, nodular chert); even, regular, medium to thick bedding; generally massive. Top of Missourian Series. Psp - 37
36	80 ft (24.4 m); Covered slope with a few outcrops of medium dark-gray, slightly fossiliferous, medium-to thick-bedded, laminated limestone. Variable dips indicate some faulting in this part of the section.

35 50 ft (15.2 m); Limestone (mudstone); low ridge former; medium dark-gray; slightly fossiliferous (horn corals, brachiopods, bryozoans, crinoids, debris); medium-gray, brown-weathering, nodular chert; even, regular, medium- to thick-bedded; generally massive, with some thin, discontinuous, subparallel, wavy lamination. Common calcite filled fractures. Psp - 35

34 15 ft (4.6 m); Covered section

33 15 ft (4.6 m); Limestone (mudstone); ledgy rise in a valley forming sequence; grayish black; slightly fossiliferous (bryozoans, brachiopods, crinoids, debris); even, regular, thin to medium bedding; thin, discontinuous, subparallel, wavy and planar lamination. Psp - 33

32 120 ft (36.6 m); Covered valley forming sequence with a few isolated exposures of (1) medium dark-gray, intraclastic, moderately fossiliferous, thinly bedded limestone, and (2) olive-gray, angular, very poorly sorted, thinly bedded, quartz granule muddy conglomerate. Psp -32a, 32b

31 30 ft (9.1 m); Limestone (wackestone); small rise in a valley forming sequence; light olive-gray; fairly fossiliferous (brachiopods, crinoids, bryozoans, debris); medium dark-gray, brown-weathering, nodular chert; even, regular, thin to medium bedding; massive. Psp - 31

30 19 ft (5.8 m); Covered slope with small exposures of medium dark-gray, slightly fossiliferous, cherty, thickly bedded, massive, carbonate wackestones.

29 5 ft (1.5 m); Limestone (wackestone); part of a small ridge; medium dark-gray; slightly fossiliferous (brachiopods, crinoids, bryozoans, fusulinids); medium dark-gray, brown-weathering, irregular chert masses; even, regular, thick bedding; generally massive. Psp - 29

28 29 ft (8.8 m); Covered slope. Base of Missourian Series.

27 80 ft (24.4 m); Limestone (wackestone); ridge former; mottled medium-gray; fairly fossiliferous (crinoids, brachiopods, bryozoans, horn corals, fusulinids); medium-thick bedding; generally massive, with some thin, discontinuous, parallel, wavy lamination. Top of Desmoinesian Series. Psp - 27

26 45 ft (13.7 m); Covered slope; possibly a thin bedded limestone.

25 10 ft (3.0 m); Subarkosic sandstone; gully former; white; subround, moderately sorted, well-indurated, very coarse sand, siliceous, slightly calcareous; uneven, irregular, medium to thick bedding; convex to straight,

low-angle, small-to large-scale, planar cross lamination; southeasterly transport direction. Psp - 25

24 10 ft (3.0 m); Limestone (packstone); small ledge former; dark-gray, weathers dark yellowish brown, very fossiliferous (crinoids, brachiopods, bryozoans, coral debris); even, regular, medium bedding; generally massive. Psp - 24

23 140 ft (42.7 m); Limestone (wackestone); ridge forming unit that caps the north-trending ridge off Little San Pasqual Mtn.; medium dark-gray; some beds slightly intra-clastic; slightly fossiliferous (brachiopods, crinoids, fusulinids, bryozoans, horn corals); even, regular, medium to thick bedding; generally massive with some thin, discontinuous, nonparallel, wavy lamination. Psp - 23a, 23b

22 63 ft (19.2 m); Limestone (packstone); ledgy slope former; medium dark-gray; moderately fossiliferous (crinoids, bryozoans, brachiopods, horn corals); even, regular, thin to medium bedding; thin, discontinuous, parallel and nonparallel, wavy lamination. Shaly interbeds. Psp 22

21 12 ft (3.7 m); Limestone (mudstone); small cliff former; medium-gray; slightly fossiliferous (crinoids, brachiopods, horn corals); light gray, brown weathering, irregular chert masses; even, regular, thick to very thick bedding; generally massive. Psp - 21

20 15 ft (4.6 m); Limestone (wackestone); ledgy slope former; medium-gray; rounded, pebble size, carbonate intraclasts; slightly fossiliferous (crinoids, bryozoans, fusulinids, gastropods); even, regular, thin to medium bedding; generally massive, with some thin, discontinuous, nonparallel, wavy lamination. Shaly interbeds. Psp - 20

19 13 ft (4.0 m); Limestone (wackestone); major cliff former, medium dark-gray; fairly fossiliferous (brachio-pods, horn corals, crinoids, fusulinids); even, regular, very thick bedding; generally massive. Psp - 19

18 15 ft (4.6 m); Limestone (wackestone); ledgy slope former; grayish black; moderately fossiliferous (brachiopods, fusulinids, horn corals, crinoids, bryozoans); even, regular, medium bedding; thin, discontinuous, parallel and non-parallel, wavy lamination. Shaly interbeds. Psp - 18

17 7 ft (2.1 m); Limestone (wackestone); ledge former; grayish black; fairly fossiliferous (brachiopods, fusu-linids, crinoids); even, regular, thick bedding; thin, discontinuous, parallel and nonparallel, wavy lamination. Psp - 17

16 25 ft (7.6 m); Limestone (mudstone); ledgy slope former; grayish black; slightly fossiliferous (brachiopods, crinoids, horn corals, fusulinids); even, regular, medium bedding, thin, discontinuous to discontinuous, parallel to nonparallel, wavy lamination. Shaly interbeds. Psp - 16

15 12 ft (3.7 m); Limestone (wackestone); ledge former; medium dark-gray; moderately fossiliferous (brachiopods, horn corals, crinoids, fusulinids, gastropods); even, regular, thick bedding; generally massive. Base of Desmoinesian Series, base of Madera Ls. Psp - 15

14 48 ft (14.6 m); Limestone (wackestone); slope former; dark greenish gray; rare, angular, well-sorted, medium silt; slightly fossiliferous (crinoids, brachiopods, debris); even, regular, thin bedding; massive; interbedded greenish gray, micaceous, calcareous, mud-shale. Top of Atokan Series, top of Sandia Fm.

13 10 ft (3.0 m); Limestone (wackestone); ledge former; grayish black; fairly fossiliferous (brachiopods, crinoids, horn corals, fusulinids); even, regular, medium bedding; massive. Psp - 13

12 132 ft (40.2 m); Limestone (wackestone); slope former; dark greenish gray; often fairly lithoclastic; rare, angular, well-sorted, medium silt; slightly fossiliferous (brachiopods, crinoids); even, regular, thin bedding; generally massive; interbedded, greenish gray, micaceous, calcareous mud-shale. Psp - 12a, 12b

11 34 ft (10.4 m); Mud-shale; mostly covered slope; greenish gray; medium silt; micaceous; calcareous. Psp - 11

10 9 ft (2.7 m); Limestone (mudstone); ledge former; dusky yellowish brown; rounded, irregularly shaped carbonate intraclasts; slightly fossiliferous (crinoids, brachiopods, bryozoans); even, regular, medium bedding; generally massive. Psp - 10

9 60 ft (18.3 m); Mud-shale; mostly covered slope; medium gray; micaceous; calcareous. Psp - 9

8 9 ft (2.7 m); Limestone (mudstone); ledge former; black, weathers light-brown; slightly fossiliferous (crinoids, debris); even, regular, medium bedding; generally massive. Psp - 8

7 10 ft (3.0 m); Covered slope

6 3 ft (0.9 m); Limestone (wackestone); small ledge former; light olive-gray, weathers grayish orange; common rounded, pebble-size carbonate intraclasts; fairly fossiliferous (crinoids, fusulinids, brachiopods); even, regular,

medium bedding; thin, discontinuous, subparallel, wavy lamination. Psp - 6

5 32 ft (9.8 m); Covered slope; probably a shale with interbedded limestone.

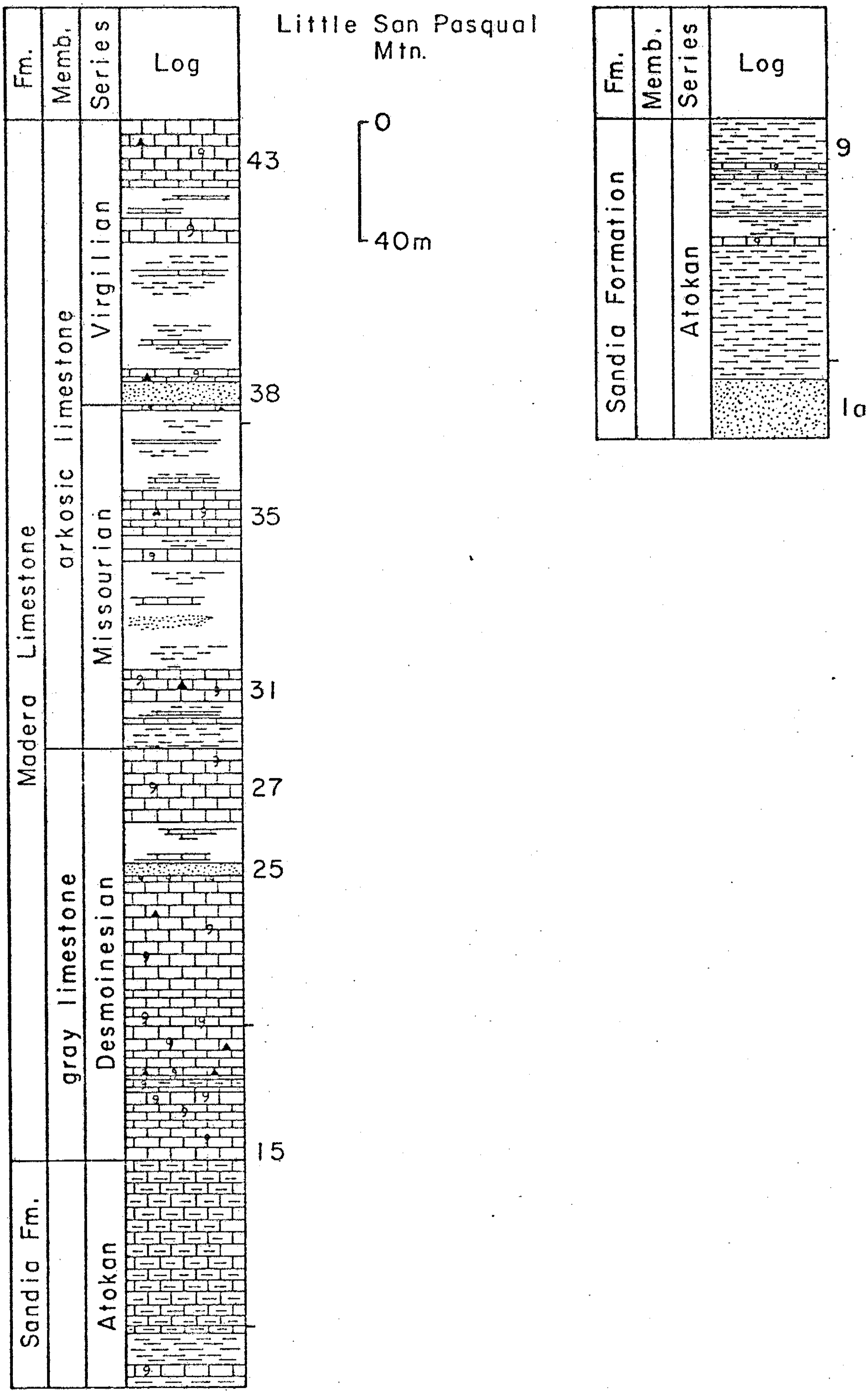
4 9 ft (2.7 m); Mudstone; slope former; angular, well-sorted, very coarse silt; micaceous; calcareous; uneven, irregular, thin bedding; thin continuous to discontinuous, parallel and nonparallel, wavy lamination; minor cross lamination. Psp - 4

3 22 ft (6.7 m); Mud-shale; mostly covered slope; black; micaceous; calcareous. Psp - 3

2 8 ft (2.4 m); Limestone (wackestone); ledge former; medium dark-gray; fairly fossiliferous (brachiopods, crinoids, horn corals, colonial corals, fusulinids); uneven, regular thin to very thick bedding; massive, with thin, wavy lamination and cross lamination in the upper 0.5 meters. Psp - 2a, 2b

1b 145 ft (44.2 m); Mud-shale; valley former; black, micaceous, sometimes calcareous; interbedded black, brown-weathering, fossiliferous, thin-to medium-bedded, carbonate mudstones and wackestones; interbedded, olive gray, thinly bedded siltstones.

1a 65 ft (19.8 m); Quartz sandstone; caps the dip slope of a ridge; grayish brown; angular, well-sorted, well-indurated, fine to medium sand; sometimes calcareous; uneven, fairly regular, medium to thick bedding, massive or laminated and cross-laminated. Faulting at base of unit.


Little San Pasqual Mtn.
Fm.
Memb.
Series
Log
0
40m
Madera Limestone
Sandia Fm.
arkosic limestone
gray limestone
Virgilian
Missourian
Desmoinesian
Atokan
43
38
35
31
27
25
15
Fm.
Memb.
Series
Log
Sandia Formation
Atokan
9
1a

Magdalena Mountains Section (4)

The Magdalena Mountains are located about 15 mi west of Socorro in Socorro County. Pennsylvanian beds measured for this study crop out in North Fork Canyon; SE¼ sec. 21, T.3S., R.3W.; NE¼ sec. 28, T.3S., R.3W., Magdalena Quadrangle. The base of the section is well exposed and section measurement proceeded from a point on the south side of North Fork Canyon about 1.25 mi from the junction of North Fork and Water canyons. Work began in July 1973.

Measured Section

Location: Magdalena Mts. Total Thickness: 1310 feet
399.2 meters

Top of Section

Unit

38 199 ft (60.7 m); Faulted sedimentary section above the white rhyolite intrusion containing a few outcrops of gray, fossiliferous, carbonate mudstones; gray to black, calcareous, terrigenous mud-shales, and several thin, white rhyolite and grayish green mafic dikes or sills. Late Virgilian Fusulinids were collected from limestone about 125 feet (38.1 m) above the base of the unit. Section overlain by Tertiary volcanics.

37 50 ft (15.2 m); White rhyolite intrusive believed to be fault controlled.

36 91 ft (27.7 m); Limestone (mudstone); ledgy ridge former; medium light-gray; slightly fossiliferous (brachiopods, crinoids, bryozoans); uneven, regular, medium to very thick bedding; thin, wavy lamination. Pnfm - 9, 10

35 2 ft (0.6 m); Quartz sandstone; small ledge; yellowish gray; angular, poorly sorted, poorly cemented, coarse sand; calcareous; thick bedded; massive. Pnfm - 8

34 51 ft (15.4 m); Limestone (mudstone); ledgy ridge former; dark gray; slightly fossiliferous (brachiopods, crinoids, bryozoans); black, brown weathering, nodular chert; very thick bedding; generally massive, with some thin, planar and wavy lamination.

33 53 ft (16.2 m); Covered slope, based on a few small, isolated exposures, unit appears to be interbedded gray shales and thinly bedded carbonate mudstones.

32 36 ft (11.0 m); Limestone (mudstone); ledgy ridge former; mottled dark-gray; slightly silty; slightly fossiliferous (brochiopods, crinoids, bryozoans, debris; very thick bedding; generally massive, with some fine, planar and wavy lamination. Pnfm - 7

31 3 ft (0.9 m); Quartz sandstone; small ledge; medium-gray; angular, poorly sorted, well-indurated, very coarse sand; common, rounded, granule-size, carbonate mudstone intraclasts; calcareous, thick bedding; massive.

30 24 ft (7.3 m); Limestone (mudstone); ledgy ridge former; dark-gray; slightly fossiliferous (brachiopods, crinoids); very thick bedding; generally massive with some fine wavy lamination.

29 10 ft (3.0 m); Quartz sandstone; ledge former, medium-gray; angular, poorly sorted, well-indurated, very coarse sand; rounded granule-size, carbonate mudstone intraclasts; calcareous, very thickly bedded, massive. Pnfm - 6

28 84 ft (25.6 m); Limestone (wackestone); ledge ridge former; dark-gray; fairly fossiliferous (mollusks, brachiopods, bryozoans, foraminifera, crinoids); black, brown-weathering, chert nodules; regular; very thick bedding; generally massive, with some thin, planar and wavy lamination. Pnfm - 5

27 52 ft (15.8 m); Covered slope.

26 22 ft (6.7 m); Quartz sandstone; ledge former; light-gray to olive-green; angular, poorly sorted, poor- to well-indurated, medium to very coarse sand; fines upward; calcareous; thick to very thick bedding; massive. Pnfm - 3, 4

25 9 ft (2.7 m); Covered slope.

24 127 ft (38.7 m); Limestone (mudstone); ledgy ridge former; medium dark-gray; slightly fossiliferous (brachiopods, crinoids, bryozoans, horn corals); black, brown-weathering, nodular chert; regular, thick to very thick bedding; generally massive, with some thin, planar and wavy lamination. Base of Desmoinesian Series; base of Madera Ls. Pnfm - 1, 2

23 4 ft (1.2 m); Mostly covered slope with a few small isolated exposures of gray, mud-shale. Top of Atokan Series, top of Sandia Fm. Pnfs - 23

22 6 ft (1.8 m); Quartz sandstone; small ledge former; light gray; subangular, moderately sorted, well-indurated, very coarse sand; calcareous; very thick bedding; massive. Pnfs - 11

21 54 ft (16.5 m); Covered slope, probably shale and interbedded, thin limestone.

20 14 ft (4.3 m); Rhyolite intrusion.

19 94 ft (28.7 m); Covered slope, believed to be shale and thin interbeds of limestone and sandstone.

18 4 ft (1.2 m); Limestone (mudstone); small ledge; black.

17 54 ft (16.5 m); Covered slope, believed to be shale and thin, interbedded limestone and sandstone.

16 13 ft (4.0 m); Mud-shale; slope former; olive-gray; common, subround, well-sorted, coarse silt; calcareous. Pnfs - 9

15 16 ft (4.9 m); Quartz sandstone; ledge former, light-gray; subangular, poorly sorted, well-indurated, coarse sand; calcareous; very thick-bedded, massive. Pnfs - 8

14 11 ft (3.4 m); Covered slope, probably gray to black mud-shales.

13 12 ft (3.6 m); Limestone (mudstone); ledge former; black; slightly fossiliferous (crinoids, brachiopods, debris); thick bedded; generally massive, with some wavy lamination that is more common toward the base. Pnfs - 8

12 20 ft (6.1 m); Covered slope, believed to be gray to black shale.

11 5 ft (1.5 m); Quartz sandstone; ledge former; medium-gray; angular, poorly sorted, well-indurated, fine sand to pebbles; calcareous; very thick-bedded; massive. Pnfs - 7

10 58 ft (17.7 m); Covered slope; possibly gray to black shale and thin interbedded limestone and sandstone.

9 10 ft (3.0 m); Quartz sandstone; prominant ledge; very light-gray; angular, poorly sorted, well-indurated, very coarse sand; calcareous; very thick bedding; massive.

8 27 ft (8.2 m); Mudstone, slope former; greenish gray; contains medium light-gray, carbonate mudstone pods; thick bedding; continuous, subparallel, wavy lamination.

7 18 ft (5.5 m); Covered slope, possibly a mud-shale.

6 21 ft (6.4 m); Quartz sandstone; mostly covered slope; light-gray, brown iron oxide stain on weathered surface; angular, very poorly sorted, coarse sand; calcareous; thick bedded; generally massive. Pnfs - 6

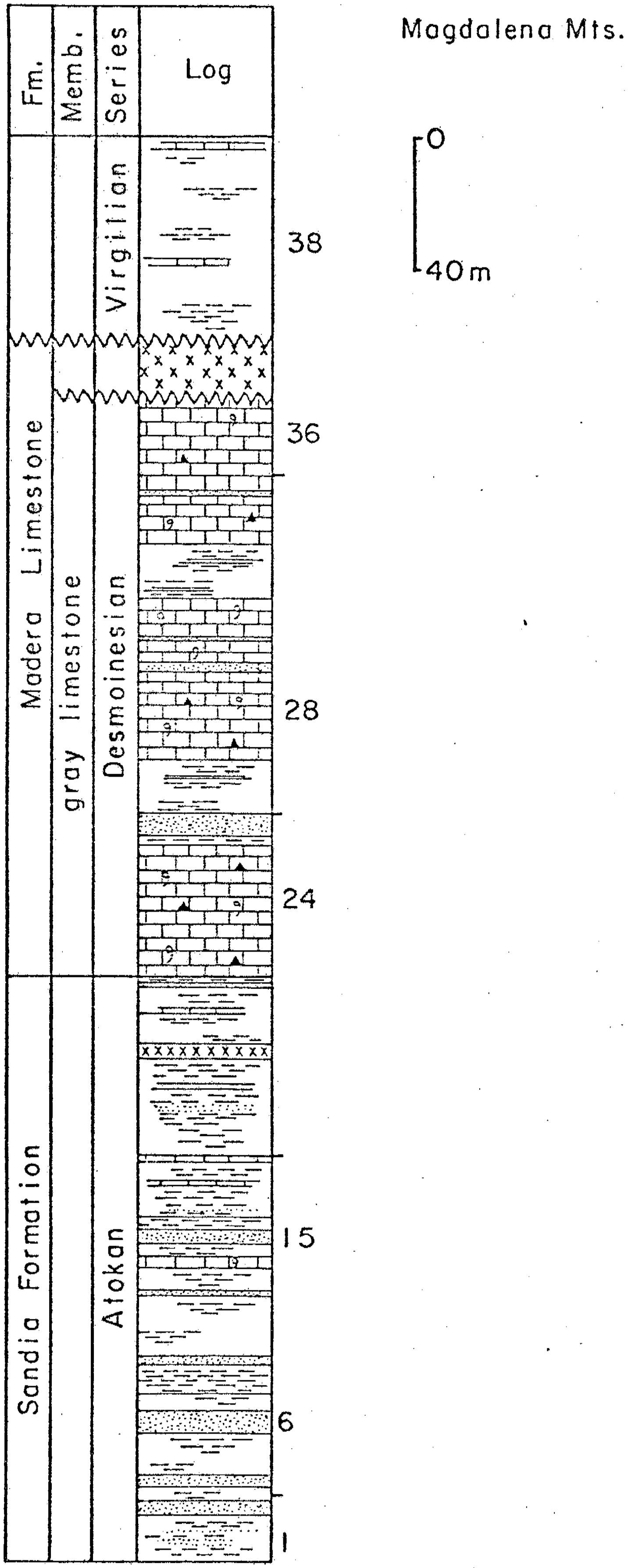
5 35 ft (10.7 m); Covered slope, believed to be gray to black mud-shale and thin, interbedded limestone and sandstone.

4 14 ft (4.3 m); Quartz sandstone; poorly exposed slope former; mottled brownish black; angular, poorly sorted, very coarse sand; calcareous. Pnfs - 4, 5

3 16 ft (4.9 m); Covered slope, possibly gray to black mud-shales with interbedded limestone and sandstone.

2 14 ft (4.3 m); Quartz sandstone; ledge former; very light-gray; subangular, well-sorted, coarse sand; very thick bedding; generally massive. Pnfs - 3

1 41 ft (12.5 m); Mostly covered slope with a few small isolated exposures of dark-gray mud-shale and thinly bedded, micaceous terrigenous mudrooks. Pnfs - 8


Fm.
Memb.
Series
Log
Madera Limestone
Sandia Formation
gray limestone
Virgilian
Desmoinesian
Atokan
38
36
28
24
15
6
1
Magdalena Mts.
0
40m

Northern Oscura Mountains Section (9)

The Oscura Mountains are located about 45 mi southeast of Socorro in Socorro County. Pennsylvanian rocks measured for this study crop out in the northern part of the range; SE¼ sec. 36, T.5S., R.5E.; Sec. 31, SE¼ sec. 30, T.5S., R.6E., Bingham Quadrangle. The base of the section is covered. Section measurement proceeded from a point just northwest of a small barite prospect on the northeast wall of the prominant, steep canyon in the extreme southeastern part of section 36. Work began in June , 1975.

Measured Section

Location: Northern Oscura Mts. Total Thickness: 1082 feet
329.8 meters

Top of Section

Unit

32 59 ft (18 m); Limestone (wackestone); mostly covered slope; light brownish gray or grayish purple; rare, angular, well-sorted, fine silt; fairly fossiliferous (brachiopods, gastropods, crinoids; fusulinids); no bedding data; laminated. Po - 32

31 17 ft (5.2 m); Arkosic sandstone; small ledge former; angular, poorly sorted, very coarse sand; some beds fine sand; calcareous; thin to very thick bedding; straight and concave, low-angle, small- to large-scale; planar cross lamination; grades laterally into fine grained sandstone. Po - 31a, 31b

30 22 ft (6.7 m); Limestone (wackstone); small ledge former; medium-gray, weathers light olive-gray; fairly fossiliferous (crinoids, brachiopods, gastropods, fusulinids); sometimes nodular; even, regular, thin to medium bedding; generally massive. Po - 30

29 20 ft (6.1 m); Arkosic sandstone; cliff former; reddish brown; angular, poorly sorted, crumbly, fine sand; rounded, pebble-size, carbonate lithoclasts near base; uneven, irregular, thin to very thick bedding; thin to medium, planar, wavy, and curved lamination; discordant straight to concave, low-angle, small- to large-scale, planar cross lamination; southwesterly transport direction. Po - 29

28a 17 ft (5.2 m); Limestone (mudstone); small ledge former; greenish gray; rare, well-sorted fine to medium silt; micaceous; slightly fossiliferous (brachiopods, fusulinids, crinoids); uneven, regular, medium bedding; generally massive. Po - 28a

28 87 ft (26.5 m); Limestone (wackestone); forms a long, gentle dip slope; medium-gray to medium dark-gray; fairly fossiliferous (brachiopods, crinoids, gastropods, corals, fusulinids); even, regular, thick to very thick bedding; generally massive. Po - 28

27 8 ft (2.4 m); Covered slope.

26 5 ft (1.5 m); Limestone (wackestone); small ledge former; light olive-gray, weathers medium-gray; slightly fossiliferous (brachiopods, crinoids, horn corals, gastropods); even, regular, medium bedding, generally massive.

25 10 ft (3.0 m); Covered slope.

24c 18 ft (5.5 m); Limestone (wackestone); prominant ledge former; mottled medium dark-gray; fairly fossiliferous (brachiopods, crinoids, gastropods, fusulinids); even, regular, very thick bedding; generally massive. Po - 24c

24b 19 ft (5.8 m); Covered slope.

24a 33 ft (10.1 m); Limestone (wackestone); cliff former; medium dark-gray, mottled weathered surface; fairly fossiliferous (brachiopods, crinoids); even, regular, very thick bedding; massive. Po - 24a, $24a_2$

23 23 ft (7.0 m); Arkosic sandy mudrock; slope former; reddish brown to olive-gray; subangular, moderately sorted, fine sand; calcareous, glauconitic; uneven, irregular, thin bedding; appears massive; clay galls in some beds. Po - 23a, 23b

22 16 ft (4.9 m); Limestone (wackestone); ledge former; medium-gray; slightly fossiliferous (brachiopods, horn corals, crinoids, fusulinids); even, regular, very thick bedding; generally massive. Po - 22

21 43 ft (13.1 m); Covered slope. Base of Virgilian Series.

20 34 ft (10.4 m); Limestone (wackestone); cliff former, light gray; fairly fossiliferous (brachiopods, crinoids, fusulinids); even, regular, very thick bedding; generally massive. Top of Missourian Series.

19 15 ft (4.6 m); Arkosic sandy mudrock; mostly covered slope; moderate-brown; subangular, moderately sorted, fine sand; calcareous; uneven, irregular, thin bedding; thin, continuous, parallel, planar lamination, and straight, low-angle, small-scale wedge-planar and tabular-planar cross lamination. Po - 19

18b 28 ft (8.5 m); Limestone (wackestone); ledge former; medium gray; fairly fossiliferous (brachiopods, crinoids, fusulinids); even, regular, very thick bedding; generally massive. Po - 18b

18a 6 ft (1.8 m); Limestone (wackestone); slope former; medium-gray; slightly fossiliferous (brachiopods, crinoids); even, regular, thin to medium bedding; generally massive. In some places this unit is underlain by a reddish brown, fine-grained, thin- to thick-bedded, laminated and cross-laminated channel sandstone in which transport was southwesterly. Po - 18a

17 6 ft (1.8 m); Limestone (grainstone); small ledge former; grayish red; common, subangular, well-sorted, fine-grained, quartz and feldspar sand; very fossiliferous (crinoids); thick bedding; thin, discontinuous, nonparallel, wavy lamination. Po - 17

16b 17 ft (5.2 m); Limestone (grainstone); slope former; medium light-gray, very fossiliferous (crinoids, brachiopods); even, regular, thick bedding; generally massive. Po - 16b

16a 12 ft (3.7 m); Limestone (wackestone); slope former; light olive gray; rare, irregularly rounded, pebble-size, carbonate intraclasts; slightly fossiliferous (brachiopods, crinoids, bryozoans); even, irregular, thin to medium bedding; very thin, continuous, parallel, wavy lamination. Po - 16a

15 28 ft (8.5 m); Dolomitic limestone (mudstone); small cliff former; medium light-gray; very rare fossil debris; even, regular, very thick bedding; massive. Po - 15

14 78 ft (23.8 m); Covered slope, with a few exposures of medium dark-gray, fairly fossiliferous limestones (wackestones), and olive-gray, angular, poorly sorted, fine-grained, arkosic sandstones.

13 132 ft (40.2 m); Limestone (wackestone); ledgy ridge former; mottled, medium dark-gray, weathers dark yellowish orange; slightly to fairly fossiliferous (brachiopods, crinoids, horn corals, bryozoans, fusulinids); white, orangish yellow- to black-weathering, nodular chert; even, regular, thick to very thick bedding; generally massive, with some thin, continuous to discontinuous, parallel to nonparallel, planar and wavy lamination. Base of Missourian Series. Po - 13

12 11 ft (3.4 m); Limestone (mudstone); distinctive ledge former; medium dark-gray; slightly fossiliferous (brachiopods, crinoids, debris); white, lenticular and nodular chert; even, regular, very thick bedding; massive. Top of Desmoinesian Series. Po - 12

11 59 ft (18.0 m); Limestone (wackestone); ledgy ridge former, medium light-gray; fairly fossiliferous (brachiopods, crinoids, horn corals, fusulinids); white to medium-gray, nodular chert; uneven, regular, thin to medium bedding; generally massive, with some thin, continuous, nonparallel, wavy and planar lamination. Po - 11

10 18 ft (5.5 m); Limestone (wackestone); prominant cliff former; medium light-gray; slightly fossiliferous (crinoids, brachiopods, fusulinids); even, regular, very thick bedding; massive. Po - 10

9 51 ft (15.5 m); Limestone (wackestone); ledgy ridge former; light-gray; slightly fossiliferous (crinoids, Brachiopods, bryozoans); white to black, nodular chert; uneven, regular, medium to very thick bedding; generally massive, with some thin, discontinuous, nonparallel, wavy lamination. Upper limit is a continuous white chert zone. Po - 9

8 16 ft (4.9 m); Limestone (mudstone); prominant ledge former; medium dark-gray, mottled weathered surface; slightly fossiliferous (crinoids, brachiopods); even, regular, very thick bedding; massive. Po - 8

7 40 ft (12.2 m); Limestone (mudstone); ledgy ridge former; grayish black; slightly fossiliferous (brachiopods, crinoids, fusulinids, debris); black nodular and bedded chert; uneven, regular, medium to very thick bedding; massive. Po - 7

6 6 ft (1.8 m); Covered slope.

5 18 ft (5.5 m); Limestone (mudstone); ledgy ridge former; medium dark-gray; slightly fossiliferous (brachiopods, horn corals, colonial corals, crinoids, fusulinids); dark-gray to black, nodular to bedded chert; even, regular, thick to very thick bedding; some thin, discontinuous, nonparallel, wavy lamination. Base of Desmoinesian Series. Po - 5

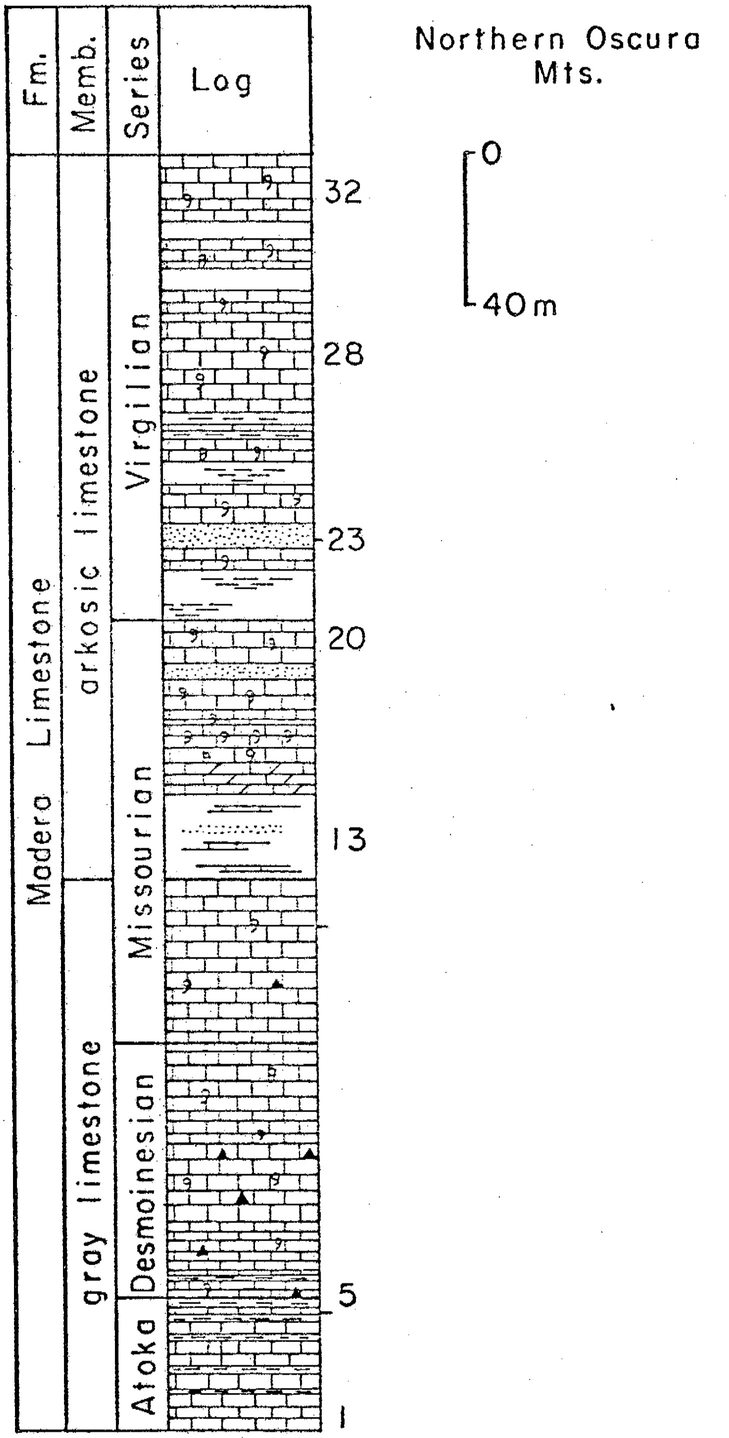
4 6 ft (1.8 m); Covered slope. Top of Atokan Series.

3 4 ft (1.2 m); Limestone (mudstone); small ledge former; medium-gray, distinctive, dark yellowish orange weathered color; rare, irregularly rounded, pebble-size, carbonate mudstone intraclasts; slightly fossiliferous (brachiopods, horn corals, fusulinids, crinoids); even, regular, thick bedding; thin, continuous, nonparallel, wavy lamination. Po - 3

2 12 ft (3.7 m); Covered slope. Possibly a thinly bedded, shaly limestone based on a couple of poor, small exposures.

1 88 ft (26.8 m); Interbedded medium-gray to black, calcareous, mud-shales and medium-gray, silty, slightly fossiliferous (brachiopods, fusulinids); thin to thickly bedded, massive, carbonate mudstones.

Note: Sandia Fm. is not exposed.


Northern Oscura
Mts.
Fm.
Memb.
Series
Log
0
40m
Madera Limestone
arkosic limestone
gray limestone
Virgilian
Missourian
Desmoinesian
Atoka
32
28
23
20
13
5
1

Southeastern San Mateo Mountains Section (7)

The San Mateo Mountains are located about 55 mi southwest of Socorro in Socorro County. Pennsylvanian rocks measured for this study crop out among low hills along the southeastern edge of the range, northwest of Bell Hill; sec. 17, T.8S., R.4W., Steel Hill Quadrangle. The base of the section is poorly exposed. Section measurement proceeded from a point about 250 yards west-southwest of the junction of the east-trending drainage that transverses the northern part of section 17 and the road along the eastern boundary of section 17. Work began in August, 1974.

Measured Section

Location: Southeastern San Mateo Mts.

Total Thickness: 2512 feet
766.1 meters

Top of Section

Unit

68 60 ft (18.3 m); Limestone (mudstone); ledge former; gray to dark-gray; slightly fossiliferous (crinoids, brachiopods, bryozoans, debris); uneven, regular, medium to thick bedding; generally massive with some wavy and planar lamination, and some small-scale, planar cross lamination. Pe - 68a, 68b, 68c

67 27 ft (8.2 m); Limestone (wackestone); ledge former; medium-gray; moderately fossiliferous (crinoids, brachiopods, forams; debris); uneven, regular, thick to very thick bedding; generally massive with some planar and wavy lamination and small-scale, planar cross lamination. Pe - 67a, 67b

66 93 ft (28.4 m); Limestone (mudstone); slope former, very poorly exposed; dark-gray, weathers brownish gray; slightly fossiliferous (debris); bedding uncertain; planar and wavy lamination. Base of Virgilian Series. Pe - 66a

65 45 ft (13.7 m); Limestone (mudstone); ledge former; light-gray; slightly fossiliferous (debris); even, regular, very thick bedding; massive. From float, the unit may become moderately sandy (subangular, very poorly sorted, very coarse-grained) toward the top. Top of Missourian Series. Pe - 65a, 65b

64 34 ft (10.4 m); Covered slope

63 174 ft (53.0 m); Limestone (wackestone); ledgy slope former; dark-gray; fairly fossiliferous (brachiopods, colonial corals, crinoids, fusulinids); even, regular, very thick bedding; generally massive. Pe - 53a, 63b, 63c, 63d, 63e

62 26 ft (7.9 m); Covered slope, possibly thin bedded limestone.

61 27 ft (8.2 m); Limestone (wackestone); ledgy break in slope; dark-gray; fairly fossiliferous (brachiopods, corals; crinoids, fusulinids); even, regular, very thick bedding, generally massive with some thin, planar and wavy lamination. Pe - 61a, 61b

60 34 ft (10.4 m); Covered slope, thought to be interbedded shale and thin bedded limestone.

59 135 ft (41.2 m); Limestone (mudstone); ledge former; medium dark-gray; slightly fossiliferous (brachiopods, crinoids, algae); black chert; even, regular, very thick bedding; generally massive, some local thin, wavy lamination. Pe - 59a, 59b, 59c, 59d

58 35 ft (10.7 m); Covered slope with a few outcrops of gray limestone.

57 17 ft (5.2 m); Limestone (Mudstone); ledgy break in slope; dark-gray; slightly fossiliferous (brachiopods, crinoids, fusulinids, debris); even, regular, very thick bedding; thin, planar and wavy lamination. Pe - 57a, 57b

56 28 ft (8.5 m); Limestone (mudstone); ledge former, medium gray; slightly fossiliferous (brachiopods, crinoids, bryozoans); even, regular, thick bedding; massive. Pe - 56a

55 16 ft (5 m); Covered slope with a few outcrops of thinly bedded, gray, limestone (mudstone).

54 6 ft (1.8 m); Limestone (wackestone); small ledge former; dark-gray; slightly fossiliferous (crinoids, debris); black chert; even, regular, thick bedding; thin, planar and wavy lamination. Pe - 54a

53 264 ft (80.5 m); Covered section; valley former.

52 39 ft (11.9 m); Limestone (packstone); dip slope on a ridge; dark-gray; very fossiliferous (corals, crinoids, brachiopods, bryozoans, forams, algae); even, regular, thick bedding; generally massive. Base of Missourian Series. Pe - 52a

51 57 ft (17.4 m); Limestone (wackestone); ridge former; dark gray to black; slightly fossiliferous (brachiopods, crinoids, forams); even, regular, very thick bedding; massive. Top of Desmoinesian Series. Pe - 51a

50 75 ft (23.0 m); Limestone (mudstone); ridge former; dark gray; slightly fossiliferous (horn corals, colonial corals, crinoids, brachiopods, bryozoans); even, regular, very thick bedding; massive. Pe - 50a

49 13 ft (4.0 m); Covered slope.

48 4 ft (1.0 m); Limestone (mudstone); ridge former; dark-gray; slightly fossiliferous (coral, crinoid, bryozoan, brachiopod debris); cherty; even, regular, very thick bedding; massive. Pe - 48a

47 5 ft (2.0m); Covered section

46 7 ft (2.0 m); Limestone (mudstone); ridge former; dark-gray; slightly fossiliferous (brachiopods, crinoids, corals, bryozoans); cherty; even, regular, very thick bedding; massive. Pe - 46a

45 10 ft (3.0 m); Covered section

44 5 ft (2.0 m); Limestone (mudstone); ridge former; dark-gray; slightly fossiliferous (brachiopods, crinoids, bryozoans, corals); even, regular, thick bedding; massive. Pe - 44a

43 11 ft (3.0 m); Covered section

42 23 ft (7.0 m); Limestone (mudstone); ridge former, dark-gray; slightly fossiliferous (crinoids, bryozoans, brachiopods, corals); cherty; even, regular, very thick bedding; massive. Pe - 42a

41 27 ft (8.2 m); Covered section; a 2 foot (0.61 m) gray limestone bed near the top of the unit.

40 104 ft (31.7 m); Limestone (mudstone); ridge dip slope; dark-gray to black; slightly fossiliferous (brachiopods, crinoids, horn corals, fusulinids); black chert; even, regular, very thick bedding; massive. Pe - 40

39 6 ft (1.8 m); Covered slope

38 26 ft (7.9 m); Limestone (mudstone); part of a group of ridge-forming limestones; dark-gray to black; slightly fossiliferous (brachiopods, crinoids, horn corals, fusulinids); black chert; even, regular, very thick bedding, massive. Pe - 40

37 18 ft (5.5 m); Covered slope

36 5 ft (1.5 m); Limestone (mudstone); within a limestone ridge; medium-gray; slightly fossiliferous (brachiopods, crinoids, forams, algae); even, regular, very thick bedding, massive. Pe - 36a

35 11 ft (3.4 m); Covered slope, believed to be calcareous shale and interbedded thin limestone.

34 6 ft (1.8 m); Limestone (wackestone); part of a limestone ridge; dark-gray; slightly fossiliferous (brachiopod, crinoids, horn corals); even, regular, very thick bedding; massive. Pe - 34a

33 43 ft (13.1 m); Mostly covered section with a few outcrops of gray limestone.

32 4 ft (1.2 m); Limestone (mudstone); part of a limestone ridge; medium-gray; very rare, angular, well-sorted, medium sand; slightly fossiliferous (debris); nodular and lenticular, gray chert; even, regular, medium bedding; thin planar and wavy lamination and small-scale, planar cross lamination. Pe - 32a

31 16 ft (4.9 m); Covered section, seems to be shale and interbedded limestone.

30 12 ft (3.7 m); Limestone (mudstone); part of a limestone ridge; medium dark-gray; slightly fossiliferous (brachiopods, crinoids, horn corals, debris); black chert; uneven, regular, thick to very thick bedding; massive. Pe - 30a

29 30 ft (9.1 m); Covered section.

28 3 ft (0.9 m); Limestone (mudstone); ledge former; dark-gray; slightly fossiliferous (brachiopods, bryozoans, horn corals); even, regular, thick bedding; generally massive. Pe - 28a

27 11 ft (3.4 m); Covered slope

26 32 ft (9.8 m); Limestone (wackestone); part of a group of ridge forming limestones; dark-gray; slightly fossiliferous(brachiopods, bryozoans); black chert; uneven, regular, medium to thick bedding; generally massive with some thin, planar and wavy lamination. Pe - 26a, 26b

25 42 ft (12.8 m); Covered gully forming unit; a few small outcrops of thinly bedded, gray limestone.

24 64 ft (19.5 m); Limestone (wackestone); ridge former; medium dark-gray; fairly peloidal; fairly fossiliferous (brachiopods, horn corals, crinoids, debris); black chert; even, regular, thick bedding; generally massive, some thin, wavy lamination. Pe - 24a, 24b

23 64 ft (19.5 m); Covered section; gully former, seems to be mostly shale with a few outcrops of thin bedded limestone.

22 91 ft (27.7 m); Limestone (mudstone); caps a spur of a larger limestone ridge; medium-gray; slightly fossiliferous(brachiopods, crinoids, bryozoans, horn corals); black chert; uneven, regular, thick to very thick bedding; massive. Pe - 22a, 22b, 22c

21 9 ft (2.7 m); Covered slope.

20 3 ft (0.6 m); Limestone (mudstone); ledge former; medium-gray; slightly fossiliferous (bryozoans, algae, debris); nodular; even, regular, thick bedding; massive. Pe - 20a

19 18 ft (5.5 m); Covered slope.

18 2 ft (0.6 m); Limestone (packstone); ledge former; dark-gray; very rare, angular, poorly sorted, coarse sand; very fossiliferous (brachiopods, crinoids, bryozoans, horn corals); even, regular, medium bedding; thin, wavy lamination. Pe - 18a

17 3 ft (0.9 m); Limestone (mudstone); ledge former; medium- to dark-gray; slightly fossiliferous (brachiopods, crinoids); even, regular, thick bedding; generally massive. Pe - 17a

16 56 ft (17.1 m); Quartz sandstone; gully former; olive-gray; well-sorted, very fine sand; thin bedded; massive. Pe - 16a

15b 163 ft (49.7 m); Limestone (mudstone to packstone); caps a limestone ridge; medium-gray to black; fairly to very fossiliferous (crinoids, brachiopods, horn corals, bryozoans, fusulinids, algae); uneven, regular, thick to very thick bedding; generally massive with some thin, planar and wavy lamination. Pe - 15b1, 15b2, 15b3, 15b4

15a 36 ft (11 m); Limestone (mudstone); part of a limestone ridge; medium-gray, weathers brown; slightly fossiliferous(horn corals, colonial corals, crinoids, brachiopods); gray, nodular chert; even, regular, thick bedding; thin, wavy lamination and small-scale, low-angle cross lamination. Base of Madera Ls. Pe - 15a

14 49 ft (14.9 m); Covered slope with a few outcrops of thinly bedded, gray, limestone (mudstones) cropping out on the slope. Top of Sandia Fm.

13 17 ft (5.2 m); Limestone (wackestone); low ledge former, medium-gray; abundant, angular, poorly sorted, coarse sand to granules; slightly fossiliferous (brachiopods); uneven, regular, medium to thick bedding; low-angle, small- to medium-scale, planar cross lamination. Pe - 13a

12 15 ft (4.6 m); Covered slope

11 14 ft (4.3 m); Limestone (packstone); low ledge former; medium-gray; moderately fossiliferous (brachiopods, horn corals, crinoids, debris); even, regular, thick bedding. Base of Desmoinesian Series. Pe - 11

10 20 ft (6.1 m); Covered slope. Top of Atokan Series.

9 4 ft (1.2 m); Limestone (wackestone); low ledge former; medium-gray; rare, ellipsoidal, granule-size, limestone (mudstone) intraclasts; slightly fossiliferous (brachiopods, crinoids, debris); even, regular, thick bedding; generally massive. Pe - 9a

8 63 ft (19.2 m); Covered slope.

7 7 ft (2.1 m); Limestone (packstone); low ledge former; medium-gray; very fossiliferous (brachiopods, crinoids, small horn corals, debris); even, regular, thick bedding; generally massive. Pe - 7a

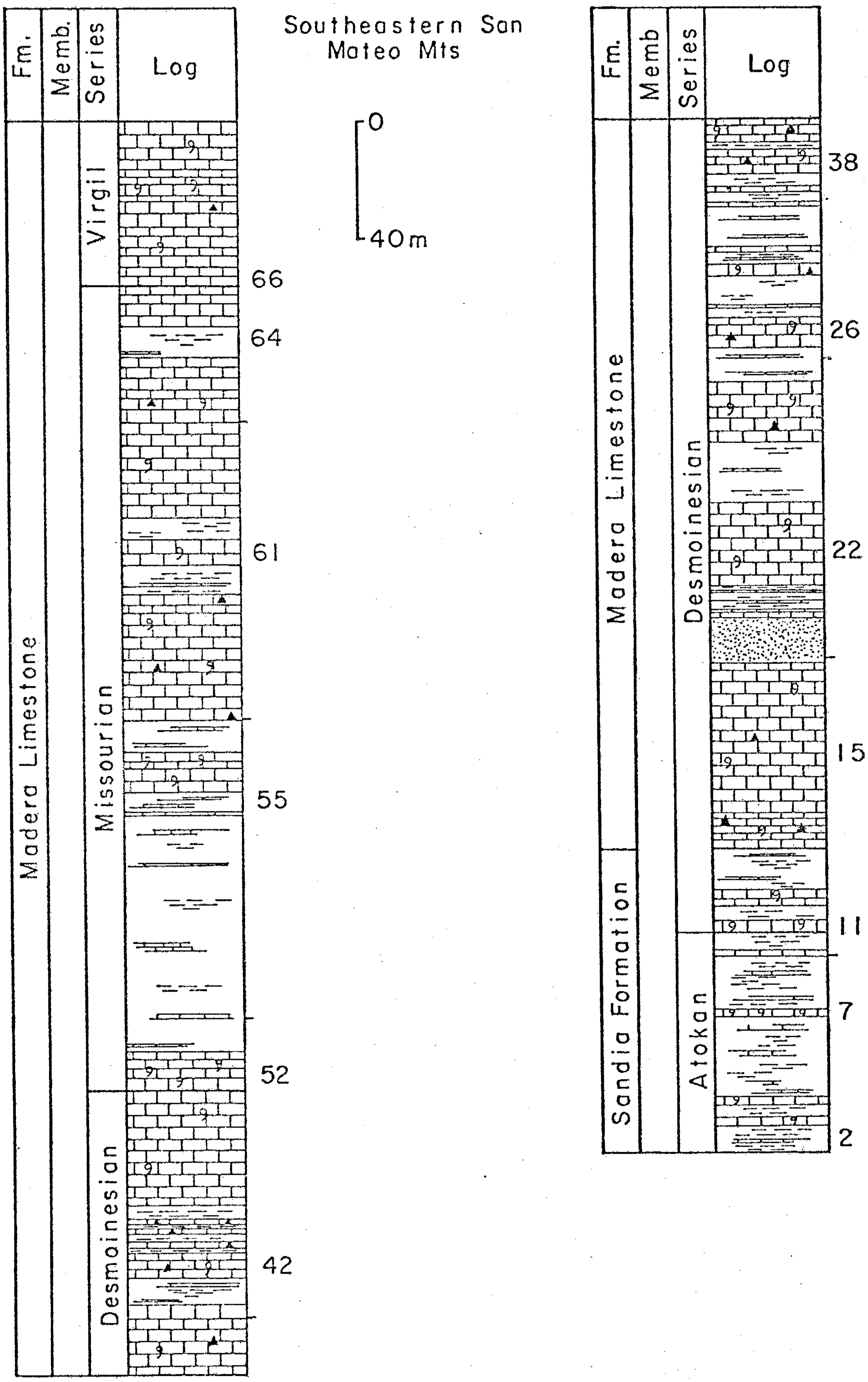
6 89 ft (27.1 m); Covered slope with a few outcrops of gray, fossiliferous limestone.

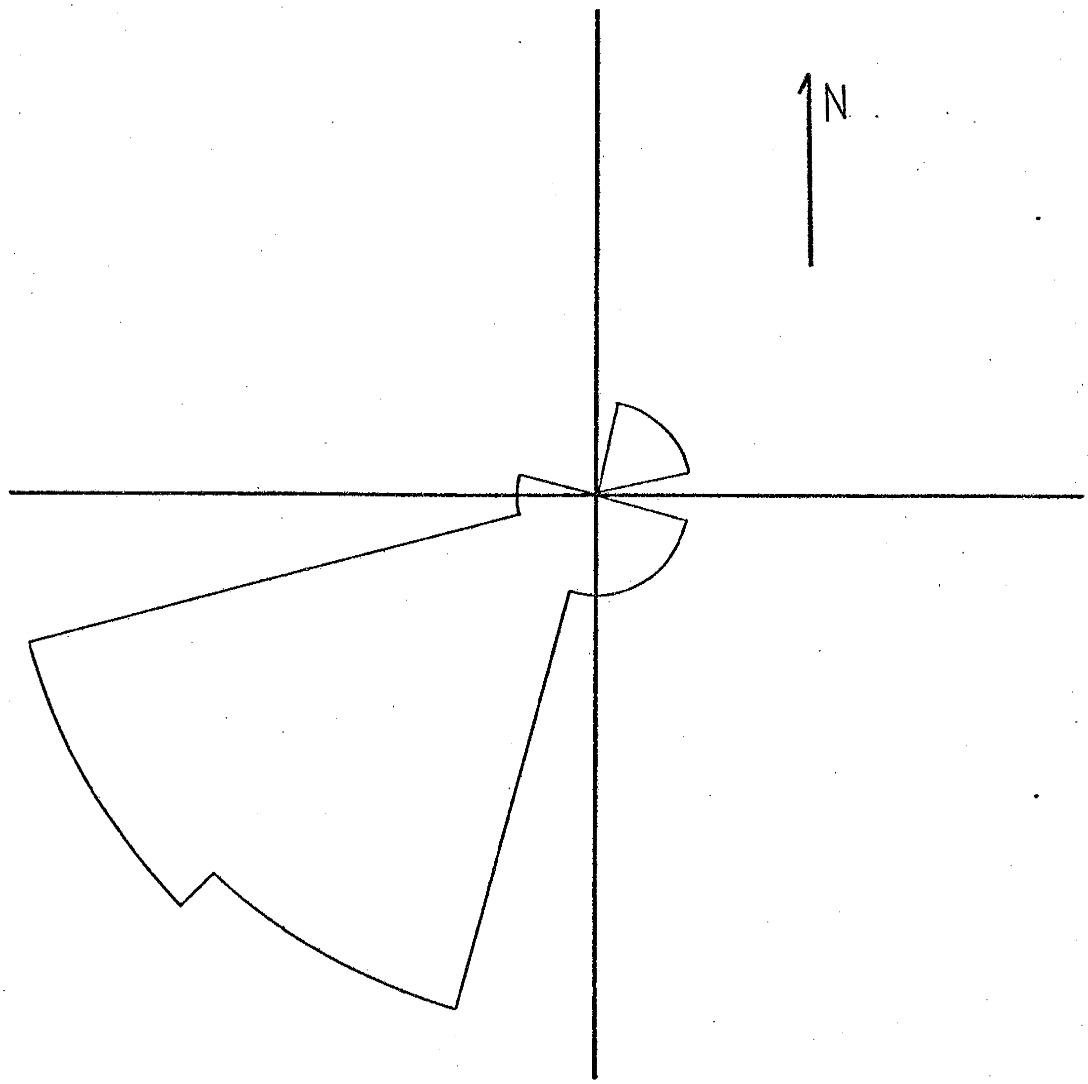
5 8 ft (2.4 m); Limestone (wackestone); low ledge former; dark-gray to black; slightly fossiliferous (fusulinids, crinoids, brachiopods); brown-weathering resistant patches; uneven, regular, medium to thick bedding; massive. Pe - 5a

4 15 ft (4.6 m); Covered slope.

3 8 ft (2.4 m); Limestone (wackestone); low ledge former; mottled dark-gray to black; fairly fossiliferous (horn corals, fusulinids, crinoids, debris); even, regular, very thick bedding; massive. Pe - 3a

2 28 ft (9.5 m); Covered slope.


Southeastern San Mateo Mts
0
40m
Fm.
Memb.
Series
Log
Madera Limestone
Virgil
Missourian
Desmoinesian
66
64
61
55
52
42
Fm.
Memb
Series
Log
Madera Limestone
Sandia Formation
Desmoinesian
Atokan
38
26
22
15
11
7
2



A rose diagram summarizing the frequency of paleotransport directions that were measured in Pennsylvanian rocks of the Socorro region of west-central New Mexico.

Appendix III

Petrographic Data

CODE

Abundance
Trace (t)
Very Rare (vr)
Rare (r)
Common (c)
Abundant (a)
Very Abundant (va)
Extremely Abundant (ea)

Porosity
Negligible (n)
Poor (p)
Fair (f)
Good (g)
Very Good (vg)

Grain Size
Boulder (b)
Cobble (c)
Pebble (p)
Granule (g)
Very Coarse Sand (vcs)
Coarse Sand (cs)
Medium Sand (ms)
Fine Sand (fs)
Very Fine Sand (vfs)
Coarse Silt (csl)
Medium Silt (msl)
Fine Silt (fsl)
Very Fine Silt (vfsl)
Clay (cl)

Sorting
Very Well Sorted (vw)
Well Sorted (w)
Moderately Sorted (m)
Poorly Sorted (p)
Very Poorly Sorted (vp)

Roundness
Angular (a)
Subangular (sa)
Subround (sr)
Round (r)
Well Rounded (wr)

Limestone Classification
Mudstone (cm)
Wackestone (cw)
Packstone (cp)
Grainstone (cg)
Boundstone (cb)
Crystalline Carbonate (cc)

Conglomerate Classification
Sedlithic (sc)
Volcanilithic (vc)
Metalithic (mc)

Sandstone Classification
Quartz Sandstone (qs)
Subarkosic Ss. (sas)
Sublithic Ss. (sls)
Arkosic Ss. (as)
Lithic Ss. (ls)

Terrigenous Mudrock Classification
Mudrock (m)

Section	Abo Pass - Pap													
Sample Number	1	3	5	7	9	10	11	12	13	15	17	18	19	21
Porosity	n	n	n	n	n	n	n	g	n	n	n	n	n	n
Ter. Grains	-	-	vr	-	-	a	-	va	t	-	-	va	t	a
Quartz	-	-	vr	-	-	c	-	a	t	-	-	a	t	a
Feldspar	-	-	t	-	-	t	-	c	-	-	-	vr	-	-
Mica	-	-	-	-	-	r	-	t	-	-	-	c	t	r
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	t	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	r
Size	-	-	ms	-	-	vfs	-	cs	fs	-	-	fs	csl	fs
Sorting	-	-	vp	-	-	p	-	vp	m	-	-	m	vw	m
Foundness	-	-	sa	-	-	a	-	a	sr	-	-	sa	-	sa
Sphericity	-	-	0.7	-	-	0.7	-	0.7	0.7	-	-	0.5	-	0.7
Allochems	-	-	t	vr	t	-	-	-	-	t	t	-	-	-
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	t	vr	t	-	-	-	-	t	t	-	-	-
Peloids	-	-	t	-	-	-	-	-	-	-	-	-	-	-
Fossils	va	vr	va	c	vr	-	t	-	c	vr	vr	-	-	-
Algae	-	-	-	-	-	-	-	-	x	-	x	-	-	-
Brachiopoda	x	-	x	x	x	-	x	-	x	x	-	-	-	-
Bryozoa	x	-	x	x	x	-	x	-	x	x	x	-	-	-
Echinodermata	x	-	x	x	-	-	-	-	x	x	-	-	-	-
Foraminifera	-	-	-	x	-	-	x	-	-	-	x	-	-	-
Mollusca	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	-	-	-	-	-	x	-	-	x	-	-	-	-
Int. Material	c	ea	a	va	ea	va	ea	c	va	ea	ea	a	ea	va
Carbonate	c	ea	a	va	ea	va	ea	c	va	ea	ea	t	ea	va
Silica	-	-	-	-	-	vr	-	t	t	-	t	c	-	-
Clay	-	-	-	-	-	vr	-	t	t	-	t	c	-	-
ROCK NAME	cg	cm	cp	cw	cm	cw	cm	sas	cp	cm	cm	qs	d	cw

Section	Abo Pass Cont.							
Sample Number	23	25	26	27	30	32	34	36
Porosity	n	n	n	n	n	n	n	n
Ter. Grains	va	-	r	va	-	-	-	-
Quartz	va	-	r	va	-	-	-	-
Feldspar	vr	-	-	vr	-	-	-	-
Mica	vr	-	vr	vr	-	-	-	-
Chert	vr	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-
Size	fs	-	csl	ms	-	-	-	-
Sorting	p	-	m	p	-	-	-	-
Roundness	a	-	a	sa	-	-	-	-
Sphericity	0.5	-	0.5	0.5	-	-	-	-
Allochems	-	-	-	-	-	-	t	-
Intraclasts	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	t	-
Peloids	-	-	-	-	-	-	-	-
Fossils	-	r	-	-	c	t	vr	vr
Algae	-	-	-	-	-	-	-	-
Brachiopoda	-	x	-	-	x	x	x	x
Bryozoa	x	-	-	-	-	-	-	-
Echinodermata	x	-	-	x	x	x	x	x
Foraminifera	-	x	-	-	x	-	-	-
Mollusca	-	-	-	-	x	x	-	-
Zoantharia	-	-	-	-	-	-	-	-
Fragments	-	-	-	-	-	-	x	x
Int. Material	c	ca	va	a	va	va	ea	ea
Carbonate	r	ea	r	r	va	va	ea	ea
Silica	r	-	c	vr	-	-	-	-
Clay	r	-	va	-	-	-	-	-
ROCK NAME	sas	cm	qm	sas	cw	cm	cm	cm

Section	Cerros de Amado - Pca													
Sample Number	1b	3	7	10	11	12	13	15	16	18	19	20	22a	24
Porosity	n	vg	p	n	n	n	n	n	p	f	n	g	n	p
Ter. Grains	-	va	va	t	va	c	vr	vr	a	a	vr	va	c	a
Quartz	-	va	va	t	va	r	vr	vr	a	a	vr	va	c	a
Feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mica	-	t	-	-	t	vr	-	t	t	t	t	t	-	-
Chert	-	-	-	-	-	-	-	-	-	vr	-	-	t	t
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	-	g	vcs	fs	fs	fs	fs	vfs	cs	cs	ms	cs	fs	cs
Sorting	-	vp	p	m	vp	p	vp	p	w	vp	p	p	vp	p
Roundness	-	sa	sr	sa	a	a	a	sa	sr	sa	a	sa	a	sa
Sphericity	-	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.7	0.7	0.7
Allochems	-	-	-	a	r	a	t	t	-	-	-	-	t	-
Intraclasts	-	-	-	-	r	a	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	a	-	t	t	t	-	-	-	-	t	-
Peloids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	t	-	-	r	-	r	va	c	-	-	-	-	c	-
Algae	-	-	-	x	-	-	-	x	-	-	-	-	-	-
Brachiopoda	-	-	-	x	-	x	x	x	-	-	-	-	x	-
Bryozoa	-	-	-	x	-	c	x	x	-	-	-	-	x	-
Echinodermata	-	-	-	x	-	x	x	x	-	-	-	-	x	-
Foraminifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	x	-	-	x	-	x	x	x	-	-	-	-	x	-
Int. Material	ea	r	a	a	a	a	a	va	a	a	ea	a	va	a
Carbonate	-	vr	-	a	-	a	a	va	-	-	-	-	va	c
Silica	ea	r	a	-	c	t	-	-	a	a	vr	a	-	a
Clay	-	-	-	-	vr	-	-	-	-	t	va	-	-	t
ROCK NAME	-	qs	qs	cp	sls	cw	cp	cw	qs	qs	qm	qs	cw	qs

Section	Cerros de Amado Cont.													
Sample Number	25	26	27	28	29	30	32	34	36	38	39	43	44a	45
Porosity	n	f	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	vr	va	r	vr	va	-	va	-	-	va	-	-	c	-
Quartz	t	va	r	vr	va	-	va	-	-	va	-	-	c	-
Feldspar	-	-	-	-	vr	-	-	-	-	-	-	-	-	-
Mica	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chert	t	-	t	t	-	-	vr	-	-	r	-	-	vr	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	msl	cs	cs	csl	cs	-	vcs	-	-	vcs	-	-	fs	-
Sorting	vp	vp	vp	p	p	-	vp	-	-	vp	-	-	fs	-
Roundness	a	sa	a	a	sa	-	a	-	-	sa	-	-	a	-
Sphericity	0.7	0.5	0.7	0.5	0.5	-	0.7	-	-	0.7	-	-	0.5	-
Allochems	-	-	-	-	-	-	-	-	-	-	vr	vr	-	-
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	vr	vr	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	-	-	-	-	-	-	vr	-	-
Fossils	-	-	r	t	-	vr	-	c	vr	-	r	vr	-	t
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	x
Brachiopoda	-	-	x	-	-	-	-	x	-	-	x	x	-	x
Bryozoa	-	-	-	-	-	-	-	x	-	-	x	x	-	x
Echinodermata	-	-	x	-	-	x	-	x	x	-	x	x	-	x
Foraminifera	-	-	x	-	-	-	-	-	x	-	x	-	-	x
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	-	-	x	-	x	-	-	-	-	-	x	-	-
Int. Material	ea	c	va	ea	c	ea	c	va	ea	c	va	ea	va	ea
Carbonate	-	r	va	va	t	ea	vr	va	ea	vr	va	ea	va	ea
Silica	vr	vr	-	vr	v	-	r	-	-	c	-	-	vr	-
Clay	ea	-	-	-	t	-	-	-	-	-	r	-	-	t
ROCK NAME	qm	qs	cw	cm	qs	cm	qs	cw	cm	qs	cw	cm	cw	cm

Section	Cerros de Amado Cont.													
Sample Number	46	47	48	49a	50a	50c	51	52	53	54	56b	57	59	61
Porosity	n	n	g	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	va	-	va	-	r	va	a	t	t	a	a	vr	-	-
Quartz	va	-	va	-	r	va	a	t	t	c	a	vr	-	-
Feldspar	r	-	vr	-	-	r	r	-	-	r	c	t	-	-
Mica	t	-	-	-	vr	-	-	-	-	-	-	t	-	-
Chert	-	-	vr	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	vcs	-	cs	-	fs	vcs	ms	fs	fs	cs	ms	vfs	-	-
Sorting	vp	-	vp	-	vp	vp	vp	m	m	p	p	p	-	-
Roundness	a	-	sa	-	a	sa	a	a	a	sa	a	a	-	-
Sphericity	0.7	-	0.5	-	0.7	0.5	0.5	0.7	0.5	0.5	0.7	0.5	-	-
Allochems	-	r	-	-	vr	-	vr	-	-	t	-	t	-	-
Intraclasts	-	-	-	-	vr	-	vr	-	-	t	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	t	-	-	t	-	-	-	-	t	-	t	-	-
Peloids	-	r	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	-	vr	-	t	c	-	vr	va	vr	r	-	t	c	t
Algae	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Brachiopoda	-	x	-	x	x	-	x	x	-	-	-	-	x	x
Bryozoa	-	-	-	-	x	-	-	x	x	x	-	-	x	x
Echinodermata	-	-	-	x	-	-	x	x	x	x	-	x	x	-
Foraminifera	-	x	-	x	-	-	-	-	-	x	-	-	-	-
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	x	-	x	-	-	-	-	x	x	-	x	x	x
Int. Material	c	va	r	ea	va	c	a	a	ea	va	a	ea	va	ea
Carbonate	c	va	r	ea	va	c	a	a	ea	va	a	va	va	ea
Silica	-	-	-	-	-	-	t	-	-	-	-	vr	r	-
Clay	-	-	-	-	-	-	t	-	-	-	-	vr	r	-
ROCK NAME	sas	cm	sls	cm	cw	sas	as	cp	cm	cw	sas	cm	cw	cm

Section	Cerros de Amado Cont.													
Sample Number	62	63	65	66	67a	68	69	70	72	74	76	79b	82	83b
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	vr	t	a	vr	va	t	vr	vr	-	t	-	a	-	a
Quartz	vr	t	c	vr	va	t	vr	vr	-	t	-	c	-	a
Feldspar	-	-	c	-	vr	-	-	-	-	-	-	r	-	r
Mica	t	-	t	t	t	-	t	-	-	-	-	vr	-	vr
Chert	-	-	-	-	t	-	-	-	-	-	-	-	-	-
Lithics	-	-	vr	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	t	-	-	vr	-	-	-	-	-	-	-
Size	csl	csl	ms	csl	vcs	fs	msl	vfs	-	msl	-	ms	-	fs
Sorting	m	-	p	p	vp	-	p	p	-	w	-	m	-	p
Roundness	a	-	a	sa	a	-	sa	a	-	a	-	a	-	a
Sphericity	0.5	-	0.5	0.7	0.7	-	0.5	0.5	-	0.5	-	0.7	-	0.5
Allochems	-	t	-	-	vr	r	-	a	t	-	t	t	-	-
Intraclasts	-	-	-	-	vr	vr	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	t	-	-	-	-	t	t	-	-
Peloids	-	t	-	-	-	t	-	a	t	-	-	-	-	-
Fossils	-	c	vr	-	vr	c	-	vr	vr	-	c	r	-	vr
Algae	-	x	-	-	-	x	-	-	x	-	-	-	-	-
Brachiopoda	-	x	x	-	x	x	-	-	-	-	x	x	-	-
Bryozoa	-	x	-	-	x	x	-	-	x	-	x	-	-	-
Echinodermata	-	x	x	-	x	x	-	-	x	-	x	x	-	-
Foraminifera	-	-	x	-	x	-	-	-	x	-	x	-	-	-
Mollusca	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	-	-	-	-	x	-	-	-	-	-	-	-	x
Int. Material	ea	va	va	ea	c	va	ea	va	ea	ea	va	va	ea	a
Carbonate	ea	va	va	a	c	va	a	va	ea	a	va	a	ea	a
Silica	vr	-	-	a	-	-	a	-	-	-	-	-	-	-
Clay	vr	-	-	a	-	-	a	-	-	a	-	vr	r	-
ROCK NAME	cm	cw	cw	qm	sas	cw	qs	cw	cm	cm	cw	as	cm	sas

Section	Cerros de Amado Cont.					
Sample Number	84	86	88	90	93	94
Porosity	n	n	n	n	n	n
Ter. Grains	-	-	t	-	va	-
Quartz	-	-	t	-	a	-
Feldspar	-	-	-	-	c	-
Mica	-	-	-	-	vr	-
Chert	-	-	-	-	t	-
Lithics	-	-	-	-	-	-
Other	-	-	-	-	-	-
Size	-	-	vfs	-	ms	-
Sorting	-	-	m	-	p	-
Roundness	-	a	-	a	-	-
Sphericity	-	-	0.7	-	0.5	-
Allochems	-	-	c	t	vr	-
Intraclasts	-	-	c	-	vr	-
Lithoclasts	-	-	-	-	-	-
Ooids	-	-	t	t	-	-
Peloids	-	-	-	-	-	-
Fossils	r	c	c	c	-	-
Algae	x	-	x	-	-	x
Brachiopoda	x	x	x	x	-	-
Bryozoa	x	x	x	x	-	-
Echinodermata	x	x	x	x	-	x
Foraminifera	x	x	x	-	-	-
Mollusca	x	-	-	x	-	-
Zoantharia	-	-	-	-	-	-
Fragments	-	-	-	-	-	x
Int. Material	va	va	va	va	c	ea
Carbonate	va	va	va	va	c	ea
Silica	-	vr	-	-	-	-
Clay	vr	vr	-	-	-	-
ROCK NAME	cm	cw	cw	cw	as	cm

Section	Joyita Hills - Pj						
Sample Number	1	2b	3	4	5	7	8
Porosity	p	n	p	n	n	n	n
Ter. Grains	c	va	va	c	r	-	-
Quartz	c	va	va	vr	vr	-	-
Feldspar	vr	vr	vr	-	-	-	-
Mica	t	-	-	c	vr	-	-
Chert	-	-	t	-	-	-	-
Lithics	-	-	-	-	-	-	-
Other	-	-	t	-	-	-	-
Size	cs	cs	vcs	msl	csl	-	-
Sorting	vp	p	m	w	w	-	-
Roundness	a	r	sr	sa	r	-	-
Sphericity	0.7	0.7	0.7	0.7	0.7	-	-
Allochems	-	-	-	-	-	t	-
Intraclasts	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	t	-
Peloids	-	-	-	-	-	-	-
Fossils	-	-	-	-	-	vr	-
Algae	-	-	-	-	-	-	-
Brachiopoda	-	-	-	-	-	x	-
Bryozoa	-	-	-	-	-	x	-
Echinodermata	-	-	-	-	-	x	-
Foraminifera	-	-	-	-	-	x	-
Mollusca	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-
Fragments	-	-	-	-	-	x	-
Int. Material	va	c	c	va	ea	ea	ea
Carbonate	r	vr	t	-	-	ea	ea
Silica	va	c	c	vr	-	-	-
Clay	vr	-	-	va	ea	-	-
ROCK NAME	sas	sas	qs	qm	qm	cm	cm

Section	Ladron Mountains - P1													
Sample Number	3b	4	5b	5f	5i	6	7	8	9	11	12	13	14	15
Porosity	g	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	va	vr	-	va	a	c	-	t	-	va	t	t	t	t
Quartz	va	vr	-	a	c	c	-	t	-	va	t	t	t	t
Feldspar	-	-	-	c	vr	-	-	-	-	c	-	-	-	-
Mica	t	-	-	vr	-	vr	-	-	-	-	-	-	-	-
Chert	-	-	-	vr	vr	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	cs	csl	-	vcs	cs	csl	-	ms	-	vcs	msl	msl	csl	msl
Sorting	p	p	-	vp	vp	p	-	w	-	vp	w	m	m	w
Roundness	sa	a	-	sa	a	sa	-	-	-	sa	a	a	sa	-
Sphericity	0.7	0.3	-	0.5	0.5	0.7	-	-	-	0.7	0.3	0.7	0.7	-
Allochems	-	-	-	-	vr	-	-	-	t	-	-	-	-	-
Intraclasts	-	-	-	-	vr	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	-	-	-	t	-	-	-	-	-
Fossils	-	-	r	t	vr	-	c	-	r	-	vr	vr	r	r
Algae	-	-	-	-	-	-	x	-	-	-	-	-	-	-
Brachiopoda	-	-	x	-	x	-	x	-	x	-	x	x	x	x
Bryozoa	-	-	x	-	x	-	x	-	x	-	x	x	x	x
Echinodermata	-	-	-	x	x	-	x	-	x	-	x	x	x	x
Foraminifera	-	-	x	-	x	-	-	-	x	-	-	-	x	x
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Int. Material	r	ea	ea	a	va	va	va	ea	va	r	ea	ea	ea	va
Carbonate	-	ea	ea	a	a	a	va	ea	va	vr	ea	ea	ea	va
Silica	r	-	-	vr	t	a	-	-	-	r	-	-	-	-
Clay	-	vr	-	vr	-	-	-	-	-	t	-	-	-	-
ROCK NAME	qs	cm	cm	sas	cw	qs	cw	cm	cw	asa	cm	cm	cw	cm

Section	Ladron Mountains Cont.													
Sample Number	17	19	20	22	23	24	25	26	28	30b	32	34	36	38
Porosity	n	n	n	n	n	n	n	p	p	n	n	n	n	n
Ter. Grains	t	-	-	-	t	-	t	a	a	-	t	t	-	t
Quartz	t	-	-	-	t	-	t	c	c	-	t	t	-	t
Feldspar	-	-	-	-	-	-	-	r	r	-	-	-	-	-
Mica	-	-	-	-	t	-	-	-	-	-	-	-	-	-
Chert	-	-	-	-	-	-	-	vr	vr	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	r	r	-	-	-	-	-
Size	msl	-	-	-	csl	-	msl	vcs	vcs	-	csl	csl	-	csl
Sorting	w	-	-	-	w	-	m	p	p	-	w	p	-	m
Roundness	a	-	-	-	a	-	a	sa	sa	-	a	a	-	a
Sphericity	0.5	-	-	-	0.7	-	0.7	0.7	0.7	-	0.7	0.7	-	0.7
Allochems	t	-	t	t	t	-	-	c	c	t	-	-	-	t
Intraclasts	-	-	-	-	-	-	-	c	c	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	t	-	t	t	t	-	-	-	-	t	-	-	-	t
Peloids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	t	a	c	r	vr	r	vr	vr	vr	vr	vr	r	vr	vr
Algae	-	x	x	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	-	x	x	x	-	-	x	x	x	x	-	x	x	x
Bryozoa	-	-	x	x	x	x	x	x	x	x	-	x	x	x
Echinodermata	-	x	x	x	x	x	x	x	x	x	x	x	x	x
Foraminifera	-	-	x	x	x	x	-	-	-	-	-	x	-	x
Mollusca	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	x	-	-	-	-	-	-	-	-	-	x	-	x	x
Int. Material	ea	va	va	va	ea	va	ea	a	a	ea	ea	va	ea	ea
Carbonate	ea	va	va	va	ea	va	ea	a	a	a	va	va	ea	ea
Silica	-	-	-	-	-	-	-	-	-	a	t	t	t	-
Clay	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ROCK NAME	cm	cw	cw	cm	cm	cw	cm	sas	cg	cm	cm	cm	cm	cm

Section	Ladron Mountains Cont.													
Sample Number	39	40d	42	43	44	45	46	47	49	50	51	52	53	54
Porosity	n	n	p	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	t	t	vr	t	-	t	va	vr	vr	a	t	r	vr	t
Quartz	t	t	vr	t	-	t	va	vr	vr	a	t	r	vr	t
Feldspar	-	-	-	-	-	-	r	t	t	vr	t	t	t	-
Mica	-	-	-	-	-	-	vr	-	vr	-	-	-	t	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	csl	csl	csl	csl	-	msl	ms	vfs	csl	vcs	csl	vcs	fs	csl
Sorting	m	m	p	m	-	m	m	vp	p	vp	w	vp	vp	w
Roundness	a	a	a	sa	-	a	sa	a	sa	a	a	a	sa	-
Sphericity	0.5	0.7	0.5	0.7	-	0.7	0.7	0.5	0.5	0.7	0.7	0.7	0.5	-
Allochems	-	vr	vr	-	t	-	-	va	-	c	-	c	t	-
Intraclasts	-	-	-	-	-	-	-	va	-	c	-	c	t	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	vr	vr	-	t	-	-	-	-	-	-	-	-	-
Fossils	-	r	vr	-	r	vr	-	t	vr	r	vr	a	a	vr
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	-	-	-	-	x	-	-	-	x	-	x	x	x	x
Bryozoa	-	-	-	-	x	-	-	-	-	x	-	x	x	x
Echinodermata	-	-	-	-	x	-	-	-	-	x	x	x	x	x
Foraminifera	-	x	-	-	-	-	-	-	-	x	x	x	-	-
Mollusca	-	-	-	-	x	-	-	-	-	-	x	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	x	x	-	x	-	-	-	x	-	x	-	-	x
Int. Material	ea	va	va	ea	va	ea	c	a	ea	a	ea	a	a	ea
Carbonate	ea	va	va	ea	va	ea	c	a	ea	a	ea	a	a	ea
Silica	t	t	-	-	t	-	r	r	-	vr	t	-	-	-
Clay	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ROCK NAME	cm	cm	cm	cm	cm	cm	sas	cp	cm	cp	cm	cp	cp	cm

Section	Ladron Mountains Cont.							
Sample Number	56	60	63	65	67	68	69	71
Porosity	n	n	n	n	n	n	n	n
Ter. Grains	-	t	t	t	t	c	-	-
Quartz	-	t	t	t	t	c	-	-
Feldspar	-	-	-	-	-	-	-	-
Mica	-	-	-	-	-	vr	-	-
Chert	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-
Size	-	csl	csl	csl	csl	vfs	-	-
Sorting	-	-	-	-	-	p	-	-
Roundness	-	-	-	-	-	sa	-	-
Sphericity	-	-	-	-	-	0.7	-	-
Allochems	-	-	r	r	t	-	va	-
Intraclasts	-	-	-	-	-	-	va	-
Lithoclasts	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	t	-	-	-
Peloids	-	-	r	r	-	-	-	-
Fossils	vr	vr	vr	vr	t	-	vr	vr
Algae	-	-	-	-	-	-	-	-
Brachiopoda	x	-	x	x	-	-	x	x
Bryozoa	x	x	x	x	x	-	x	x
Echinodermata	x	-	x	x	x	-	x	-
Foraminifera	-	-	x	x	-	-	-	x
Mollusca	-	-	-	-	x	-	-	-
Zoantharia	-	-	-	-	-	-	-	-
Fragments	x	-	x	x	-	-	-	x
Int. Material	ea	ea	va	va	ea	va	c	ea
Carbonate	ea	ea	va	va	ea	a	c	ea
Silica	-	-	-	-	-	-	-	t
Clay	-	-	-	-	-	a	t	-
ROCK NAME	cm	cm	cm	cm	cm	cw	cp	cm

Section	Lemitar Mountains - Pc													
Sample Number	1a	2b	3	5	7	8	9b	11	12	13a	13b	14	15	16a
Porosity	g	n	g	n	n	-	t	t	t	p	n	p	p	n
Ter. Grains	va	va	va	va	a	-	a	va	r	va	va	t	va	c
Quartz	va	va	va	va	a	-	a	va	r	a	a	t	va	c
Feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mica	t	t	-	t	-	-	t	t	t	t	t	-	t	-
Chert	-	-	-	-	t	-	-	-	-	r	r	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	t	-	t	t	-	-	-
Size	vcs	fs	ms	ms	ms	-	ms	fs	ms	vcs	cs	ms	vcs	csl
Sorting	vp	p	m	vp	m	-	vp	vp	m	w	w	vw	w	w
Roundness	a	a	sa	a	a	-	sa	sa	sa	wr	wr	a	sr	sa
Sphericity	0.5	0.7	0.5	0.5	0.5	-	0.7	0.5	0.7	0.7	0.7	0.5	0.7	0.7
Allochems	-	-	-	vr	vr	-	vr	-	vr	-	-	-	-	-
Intraclasts	-	-	-	vr	vr	-	vr	-	vr	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	t	-	-	t	vr	-	r	-	a	-	-	va	-	-
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	-	-	-	x	x	-	x	-	x	-	-	x	-	-
Bryozoa	-	-	-	-	-	-	x	-	x	-	-	x	-	-
Echinodermata	-	-	-	x	x	-	x	-	x	-	-	x	-	-
Foraminifera	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Mollusca	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	x	-	-	x	x	-	x	-	x	-	-	x	-	-
Int. Material	c	a	c	a	va	ea	a	c	a	c	c	c	c	va
Carbonate	-	t	-	a	a	ea	a	c	a	-	-	c	-	c
Silica	vr	-	c	-	-	t	t	-	t	r	r	-	r	r
Clay	-	-	-	-	-	t	-	-	-	vr	vr	-	-	va
ROCK NAME	qs	qs	qs	qs	cp	cm	qs	qs	cp	qs	qs	cp	qs	qm

Section	Lemitar Mountains Cont.					
Sample Number	17	18	19	20	24	28a
Porosity	n	n	n	t	n	n
Ter. Grains	va	-	ea	t	-	-
Quartz	va	-	ea	t	-	-
Feldspar	vr	-	-	-	-	-
Mica	t	-	-	-	-	-
Chert	vr	-	t	-	-	-
Lithics	-	-	-	-	-	-
Other	vr	-	-	-	-	-
Size	ms	-	ms	csl	-	-
Sorting	p	-	p	vw	-	-
Roundness	sa	-	a	a	-	-
Sphericity	0.5	-	0.7	0.7	-	-
Allochems	-	vr	-	-	-	t
Intraclasts	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-
Ooids	-	vr	-	-	-	t
Peloids	-	-	-	-	-	-
Fossils	-	vr	-	r	r	vr
Algae	-	-	-	-	-	-
Brachiopoda	-	x	-	x	-	-
Bryozoa	-	-	-	-	-	-
Echinodermata	-	x	-	x	x	-
Foraminifera	-	-	-	x	x	-
Mollusca	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-
Fragments	-	x	-	x	x	x
Int. Material	c	va	r	va	ea	ea
Carbonate	c	va	t	va	a	ea
Silica	-	-	r	-	-	-
Clay	-	c	-	c	a	r
ROCK NAME	qs	cw	qs	cw	cm	cm

Section	Little San Pasqual Mountain - Psp													
Sample Number	1	1'b	2b	4	6	10	11	13	15	17	18	19	20	21
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	-
Ter. Grains	c	r	r	a	t	t	r	-	-	-	-	-	-	-
Quartz	r	vr	vr	c	t	t	r	-	-	-	-	-	-	-
Feldspar	-	-	-	vr	-	-	-	-	-	-	-	-	-	-
Mica	vr	r	vr	vr	-	-	t	-	-	-	-	-	-	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	vfs	csl	vfs	vfs	csl	msl	csl	-	-	-	-	-	-	-
Sorting	m	p	-	p	m	w	w	-	-	-	-	-	-	-
Roundness	a	sa	-	a	a	-	a	-	-	-	-	-	-	-
Sphericity	0.3	0.5	-	0.5	0.5	-	0.5	-	-	-	-	-	-	-
Allochems	-	-	t	-	-	-	-	-	-	-	-	-	-	-
Intraclasts	-	-	t	-	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	c	-	c	-	r	vr	t	t	vr	vr	vr	r	vr	r
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	x	-	x	-	-	x	-	-	x	x	x	x	-	x
Bryozoa	-	-	-	-	-	x	-	-	x	x	-	x	-	x
Echinodermata	x	-	-	-	x	x	-	-	x	x	-	x	x	x
Foraminifera	-	-	-	-	-	-	-	-	-	-	-	x	x	x
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	x	-	x	-	-	x	-	-	x	x	x	x	-	x
Int. Material	va	va	va	va	va	ea	ea	ea	ea	ea	ea	ea	ea	ea
Carbonate	a	-	va	a	va	ea	a	va	ea	ea	ea	ea	ea	ea
Silica	vr	a	r	c	-	-	a	vr	-	-	-	-	vr	vr
Clay	-	a	-	vr	-	-	-	r	-	-	-	-	-	-
ROCK NAME	cw	qm	cw	cw	cw	cm	cm	cm	cm	cm	cm	cm	cm	cm

Section	Little San Pasqual Mountain Cont.													
Sample Number	22	23a	24	25	27	29	31	32b	33	35	37	38	39	40a
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	-	vr	t	va	-	-	-	va	-	-	t	a	-	-
Quartz	-	vr	t	va	-	-	-	va	-	-	t	a	-	-
Feldspar	-	-	-	r	-	-	-	vr	-	-	-	c	-	-
Mica	-	-	-	-	-	-	-	-	-	-	-	r	-	-
Chert	-	-	-	-	-	-	-	vr	-	-	-	r	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	-	csl	fs	vcs	-	-	-	ms	-	-	csl	ms	-	-
Sorting	-	w	w	p	-	-	-	p	-	-	w	p	-	-
Roundness	-	a	sa	sa	-	-	-	sa	-	-	a	a	-	-
Sphericity	-	0.5	0.5	0.5	-	-	-	0.7	-	-	0.5	0.7	-	-
Allochems	-	-	vr	-	-	a	-	r	-	vr	-	-	-	a
Intraclasts	-	-	vr	-	-	-	-	r	-	vr	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	a	-	-	-	-	-	-	-	a
Fossils	a	r	a	-	c	r	vr	t	r	vr	-	-	-	-
Algae	-	-	-	-	x	x	-	-	-	-	-	-	-	-
Brachiopoda	x	x	x	-	x	-	-	-	x	x	x	x	x	x
Bryozoa	x	x	x	-	x	-	x	-	x	-	-	-	-	-
Echinodermata	-	x	x	-	x	-	-	x	x	-	-	-	-	-
Foraminifera	x	x	x	-	x	x	-	-	-	-	-	-	-	-
Mollusca	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	-	-	-	-	-	x	-	-	-	x	-	-	-	-
Int. Material	va	ea	a	c	va	a	ea	a	ea	ea	ea	a	ea	a
Carbonate	va	va	a	vr	va	a	ea	a	ea	va	ea	a	ea	a
Silica	t	t	-	r	-	vr	t	-	vr	vr	t	-	t	-
Clay	-	vr	-	vr	-	-	-	-	-	-	-	-	-	-
ROCK NAME	cp	cm	cw	sas	cw	cw	cm	sls	cm	cm	cm	sas	cm	cw

Section	Little San Pasqual Mountain Cont.	
Sample Number	41	42
Porosity	n	n
Ter. Grains	-	r
Quartz	-	r
Feldspar	-	t
Mica	-	t
Chert	-	-
Lithics	-	-
Other	-	-
Size	-	csl
Sorting	-	p
Roundness	-	a
Sphericity	-	0.5
Allochems	-	-
Intraclasts	-	-
Lithoclasts	-	-
Ooids	-	-
Peloids	-	-
Fossils	vr	r
Algae	-	-
Brachiopoda	-	x
Bryozoa	-	-
Echinodermata	x	x
Foraminifera	-	-
Mollusca	-	-
Zoantharia	-	-
Fragments	x	x
Int. Material	ea	va
Carbonate	ea	va
Silica	t	t
Clay	-	-
ROCK NAME	cm	cw

Section	Magdalena Mountains - Pnf													
Sample Number	s1	s2	s3	s4	s7	s8	s9	s11	s12	m1	m2	m3	m5	m6
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	va	c	va	va	va	-	c	va	c	-	-	va	-	va
Quartz	va	c	va	va	va	-	c	va	c	-	-	va	-	va
Feldspar	vr	-	-	-	-	-	-	-	-	-	-	-	-	vr
Mica	-	r	t	-	-	-	r	-	t	-	-	vr	-	-
Chert	r	-	-	-	r	-	-	-	-	-	-	t	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	t	-	-	-	-	-	-	-	-	-
Size	cs	csl	cs	vcs	vcs	-	csl	vcs	vfs	-	-	ms	-	vcs
Sorting	w	m	w	vp	m	-	w	p	m	-	-	p	-	p
Roundness	a	sa	sr	sa	a	-	sr	sa	sa	-	-	a	-	a
Sphericity	0.7	0.7	0.7	0.7	0.5	-	0.7	0.7	0.5	-	-	0.5	-	0.5
Allochems	-	-	-	-	-	-	-	-	-	-	-	-	-	c
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	c
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	-	-	-	-	-	vr	-	-	-	vr	vr	-	c	vr
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	-	-	-	-	-	x	-	-	-	-	x	-	x	-
Bryozoa	-	-	-	-	-	-	-	-	-	x	x	-	x	x
Echinodermata	-	-	-	-	-	x	-	-	-	x	x	-	x	x
Foraminifera	-	-	-	-	-	-	-	-	-	-	-	-	x	x
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	x	x
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Int. Material	a	va	a	c	c	ea	va	c	va	ea	ea	a	ea	c
Carbonate	c	vr	-	r	c	ea	r	c	-	ea	ea	c	ea	c
Silica	r	va	a	r	vr	-	a	r	a	-	-	c	-	-
Clay	-	r	vr	-	-	vr	c	-	a	-	-	vr	-	-
ROCK NAME	qs	qm	qs	qs	qs	cm	qs	qs	qm	cm	cm	qs	cw	cm

Section	Magdalena Mountains Cont.		
Sample Number	m7	m9	m10
Porosity	n	n	n
Ter. Grains	vr	-	-
Quartz	vr	-	-
Feldspar	-	-	-
Mica	-	-	-
Chert	-	-	-
Lithics	-	-	-
Other	-	-	-
Size	ms	-	-
Sorting	w	-	-
Roundness	-	-	-
Sphericity	-	-	-
Allochems	-	-	-
Intraclasts	-	-	-
Lithoclasts	-	-	-
Ooids	-	-	-
Peloids	-	-	-
Fossils	r	c	vr
Algae	-	-	-
Brachiopoda	x	x	x
Bryozoa	-	-	x
Echinodermata	-	x	x
Foraminifera	-	-	-
Mollusca	-	-	-
Zoantharia	-	-	-
Fragments	x	x	x
Int. Material	va	va	ea
Carbonate	va	va	ea
Silica	-	-	-
Clay	-	-	-
ROCK NAME	cw	cw	cm

Section	Northern Oscura Mountains - Po													
Sample Number	1	2b	3	5	7	8	9	10	11	13	14a	14b	15	16a
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	-	-	-	-	-	-	-	-	-	-	-	a	-	-
Quartz	-	-	-	-	-	-	-	-	-	-	-	c	-	-
Feldspar	-	-	-	-	-	-	-	-	-	-	-	vr	-	-
Mica	-	-	-	-	-	-	-	-	-	-	-	vr	-	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	-	-	-	-	-	-	-	-	-	-	-	fs	-	-
Sorting	-	-	-	-	-	-	-	-	-	-	-	vp	-	-
Roundness	-	-	-	-	-	-	-	-	-	-	-	a	-	-
Sphericity	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-
Allochems	-	-	-	-	-	-	-	-	-	-	t	t	-	-
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	-	-	-	-	-	-	-	-	-	t	t	-	-
Peloids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fossils	-	vr	vr	r	c	a	vr	c	vr	c	c	-	-	vr
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	-	-	x	x	x	x	x	x	x	x	x	-	-	x
Bryozoa	-	-	-	-	x	-	-	x	x	x	-	-	-	x
Echinodermata	-	-	x	-	x	x	x	x	x	x	x	-	-	x
Foraminifera	-	-	x	x	x	x	x	x	x	x	x	-	-	x
Mollusca	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Fragments	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Int. Material	ea	ea	ea	va	va	va	ea	va	ea	va	va	va	ea	ea
Carbonates	ea	ea	va	va	va	va	va	va	ea	va	va	a	ea	ea
Silica	-	-	-	-	-	-	vr	-	-	a	-	a	-	-
Clay	-	-	-	-	-	-	-	-	-	-	-	r	-	-
ROCK NAME	cm	cm	cm	cw	cw	cp	cm	cw	cm	cw	cw	sas	cm	cm

Section	Northern Oscura Mountains Cont.													
Sample Number	17	18a	19	20	22	23a	24a	28-1	28	29	30	31-1	31-2	32
Porosity	n	n	n	n	n	n	n	n	n	f	n	n	n	n
Ter. Grains	-	-	va	-	-	va	-	-	-	va	-	a	va	t
Quartz	-	-	va	-	-	a	-	-	-	a	-	a	va	vr
Feldspar	-	-	r	-	-	c	-	-	-	r	-	vr	c	-
Mica	-	-	vr	-	-	t	-	-	-	r	-	vr	t	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	-	-	ms	-	-	cs	-	-	-	ms	-	fs	cs	vfs
Sorting	-	-	p	-	-	vp	-	-	-	vp	-	p	vp	vp
Roundness	-	-	a	-	-	sa	-	-	-	a	-	a	a	a
Sphericity	-	-	0.5	-	-	0.5	-	-	-	0.5	-	0.5	0.7	0.5
Allochems	-	t	-	-	-	-	vr	-	r	-	-	-	-	-
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	t	-	-	-	-	-	-	-	-	-	-	-	-
Peloids	-	-	-	-	-	-	vr	-	r	-	-	-	-	-
Fossils	r	r	-	vr	r	-	t	r	r	-	vr	-	-	vr
Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopoda	x	x	-	x	x	-	-	x	-	-	-	-	-	x
Bryozoa	x	x	-	-	-	-	-	-	-	-	-	-	-	-
Echinodermata	x	x	-	-	-	-	-	-	-	-	-	-	-	x
Foraminifera	x	x	-	x	x	-	-	x	x	-	-	-	-	-
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragments	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Int. Material	ea	va	c	ea	ea	a	ea	ea	va	c	ea	a	c	ea
Carbonate	ea	va	r	-	ea	vr	ea	-	va	vr	ea	a	r	ea
Silica	-	vr	r	-	-	a	-	-	-	vr	t	t	r	-
Clay	-	-	t	-	-	t	-	-	-	vr	-	-	-	-
ROCK NAME	cw	cw	sas	cm	cm	as	cm	cm	cw	as	cm	sas	as	cm

Section	Southeastern San Mateo Mountains - Pe													
Sample Number	1	1a	3a	5a	7a	9a	11a	13a	15a	15b2	15b6	17a	18a	20a
Porosity	f	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	vr	-	t	-	-	t	t	c	t	vr	-	vr	vr	vr
Quartz	vr	-	t	-	-	t	t	c	t	vr	-	vr	vr	vr
Feldspar	-	-	-	-	-	-	-	vr	-	-	-	-	-	t
Mica	-	-	-	-	-	-	-	t	-	t	-	t	-	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	fs	-	fs	-	-	csl	csl	fs	msl	ms	-	vfs	cs	vfs
Sorting	p	-	m	-	-	m	p	vp	p	vp	-	p	vp	m
Roundness	sa	-	-	-	-	-	-	a	-	a	-	a	a	a
Sphericity	0.7	-	-	-	-	-	-	0.7	-	0.7	-	0.7	0.5	0.7
Allochems	va	t	-	t	t	t	r	t	t	t	-	c	t	r
Intraclasts	va	-	-	t	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	t	-	t	-	t	vr	t	t	t	-	-	t	-
Peloids	-	-	-	-	t	t	r	-	-	-	-	c	-	r
Fossils	vr	r	r	c	a	t	c	c	r	va	c	vr	a	vr
Algae	-	-	-	-	x	-	x	x	x	x	-	-	-	-
Brachiopoda	x	x	x	x	x	-	x	x	x	x	x	-	x	x
Bryozoa	x	x	x	x	x	x	x	x	x	x	x	-	x	-
Echinodermata	-	x	x	x	x	-	x	x	x	x	x	-	x	-
Foraminifera	x	x	x	x	x	-	x	x	x	x	-	-	x	-
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	x	-	x	-	-	x	-	-	-	-	-	-	-
Fragments	-	-	x	-	-	-	-	-	x	-	-	x	-	x
Int. Material	r	ea	ea	va	va	ea	va	va	ea	c	va	ea	a	va
Carbonate	r	ea	ea	va	va	ea	va	va	ea	c	va	ea	a	va
Silica	-	-	-	t	t	-	t	-	-	t	-	-	t	t
Clay	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ROCK NAME	cp	cm	cm	cw	cw	cm	cw	cw	cm	cp	cw	cm	cp	cm

Section	Southeastern San Mateo Mountains Cont.													
Sample Number	22	22b	24a	26b	28a	30a	32a	34a	36b	38a	40a	40c	42a	44a
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	-	t	-	-	-	-	-	-	-	-	-	-	-	-
Quartz	-	t	-	-	-	-	-	-	-	-	-	-	-	-
Feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mica	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	-	csl	-	-	-	-	-	-	-	-	-	-	-	-
Sorting	-	m	-	-	-	-	-	-	-	-	-	-	-	-
Roundness	-	sa	-	-	-	-	-	-	-	-	-	-	-	-
Sphericity	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-
Allochems	t	-	a	r	r	t	vr	c	t	t	t	-	vr	c
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	t	-	-	t	r	t	t	t	t	-	t	-	-	-
Peloids	-	-	a	r	-	-	vr	c	-	t	-	-	vr	c
Fossils	r	r	vr	va	vr	r	c	c	r	t	t	t	vr	vr
Algae	x	-	-	x	-	x	x	x	x	-	-	-	x	-
Brachiopoda	-	-	-	x	-	x	x	x	x	-	-	-	x	-
Bryozoa	x	-	-	x	-	x	-	x	-	-	x	-	x	-
Echinodermata	x	-	-	x	-	x	x	x	x	-	x	-	x	x
Foraminifera	-	-	-	-	-	x	x	x	x	-	x	-	x	x
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	x	x	-	-	-	-	-	-
Fragments	-	x	x	-	x	-	-	-	-	x	x	x	-	-
Int. Material	ea	ea	va	a	ea	ea	va	va	ea	ea	ea	ea	va	va
Carbonate	ea	c	va	a	ea	ea	va	va	ea	ea	ea	ea	va	va
Silica	-	c	-	-	-	-	-	-	-	-	-	-	-	-
Clay	-	va	-	-	-	-	-	-	-	-	-	-	-	-
ROCK NAME	cm	qs	cw	cp	cm	cm	cw	cw	cm	cm	cm	cm	cw	cw

Section	Southeastern San Mateo Mountains Cont.													
Sample Number	46a	48a	50a	51a	52a	54a	56a	57a	59a	59d	61b	63c	65a	65b
Porosity	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ter. Grains	-	-	-	r	t	t	-	-	-	-	-	-	-	a
Quartz	-	-	-	r	t	t	-	-	-	-	-	-	-	a
Feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mica	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chert	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithics	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Size	-	-	-	fs	vfs	cls	-	-	-	-	-	-	-	vcs
Sorting	-	-	-	p	p	-	-	-	-	-	-	-	-	vp
Roundness	-	-	-	a	sa	-	-	-	-	-	-	-	-	sa
Sphericity	-	-	-	0.5	0.7	-	-	-	-	-	-	-	-	0.7
Allochems	-	vr	-	t	-	-	-	t	a	t	-	t	-	vr
Intraclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	vr
Lithoclasts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ooids	-	vr	-	t	-	-	-	t	-	t	-	-	-	-
Peloids	-	vr	-	-	-	-	-	-	a	-	-	-	-	-
Fossils	r	r	vr	va	va	vr	vr	r	vr	vr	vr	vr	vr	t
Algae	-	-	-	-	x	-	-	-	-	-	x	x	-	-
Brachiopoda	x	x	x	x	x	-	x	x	x	x	-	x	-	x
Bryozoa	x	x	x	-	x	-	x	-	-	-	-	x	-	-
Echinodermata	x	x	x	x	x	x	xx	x	x	x	x	x	-	x
Foraminifera	x	-	-	x	x	-	-	-	-	x	x	x	-	-
Mollusca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zoantharia	-	-	-	-	-	-	-	-	x	x	-	-	-	-
Fragments	-	-	-	-	-	x	-	-	x	x	-	-	x	-
Int. Material	ea	va	ea	a	a	ea	ea	ea	va	ea	ea	ea	ea	a
Carbonate	va	va	va	a	a	ea	ea	ea	va	ea	ea	ea	ea	a
Silica	r	-	vr	t	-	-	-	-	-	-	-	-	-	vr
Clay	-	-	r	-	-	t	-	t	-	-	-	-	-	-
ROCK NAME	cm	cw	cm	cp	cp	cm	cm	cm	cw	cm	cm	cm	cm	cw

Section	Southeastern San Mateo Mountains Cont.		
Sample Number	66a	67a	68a
Porosity	n	n	n
Ter. Grains	t	-	-
Quartz	t	-	-
Feldspar	-	-	-
Mica	-	-	-
Chert	-	-	-
Lithics	-	-	-
Other	-	-	-
Size	csl	-	-
Sorting	w	-	-
Roundness	sa	-	-
Sphericity	0.7	-	-
Allochems	-	t	-
Intraclasts	-	-	-
Lithoclasts	-	-	-
Ooids	-	t	-
Peloids	-	-	-
Fossils	-	-	t
Algae	-	-	-
Brachiopoda	-	-	x
Bryozoa	-	-	x
Echinodermata	-	-	x
Foraminifera	-	-	-
Mollusca	-	-	-
Zoantharia	-	-	-
Fragments	-	-	-
Int. Material	ea	ea	ea
Carbonate	ea	ea	ea
Silica	-	t	-
Clay	-	-	vr
ROCK NAME	cm	cm	cm

This dissertation is accepted on behalf of the faculty of the

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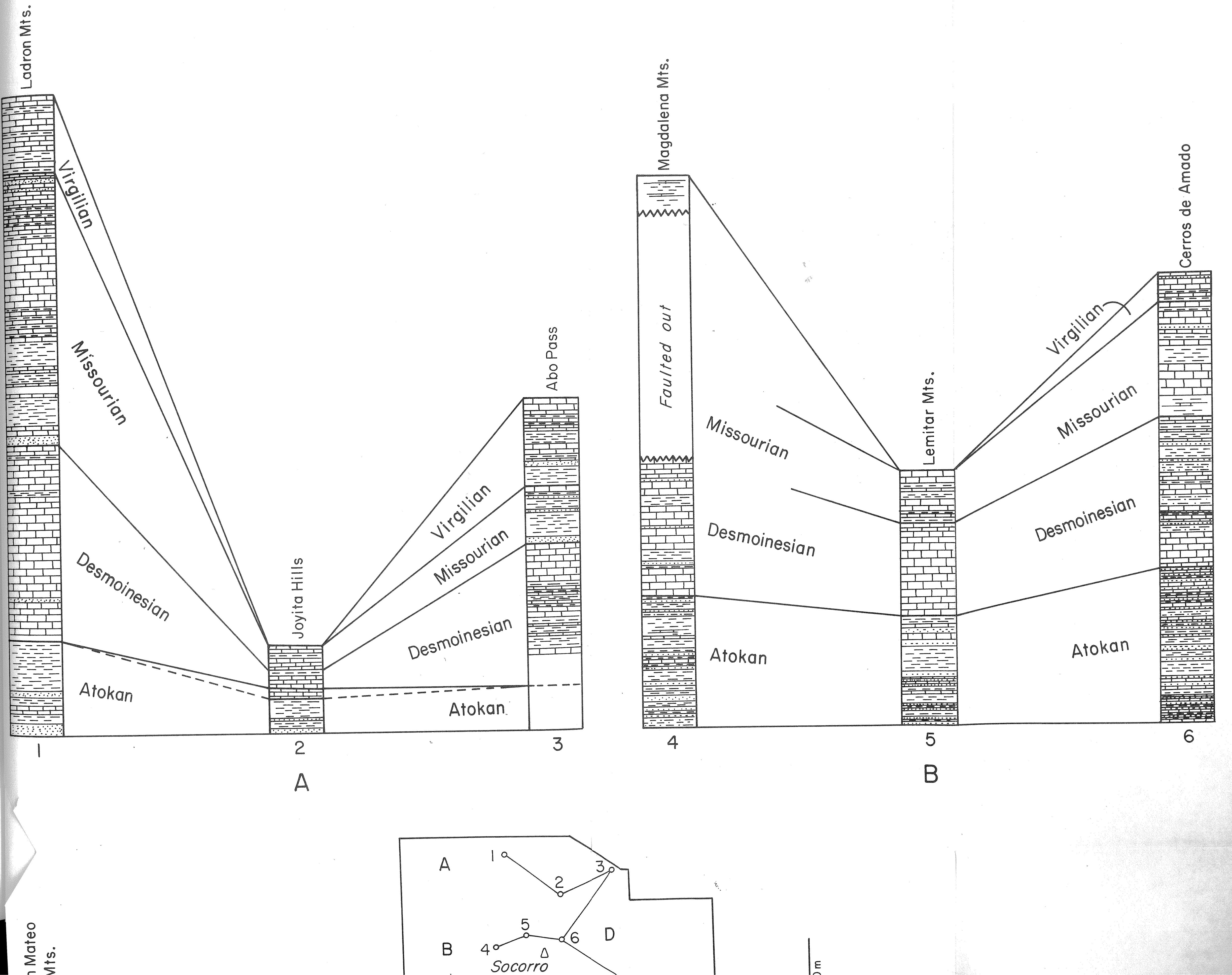
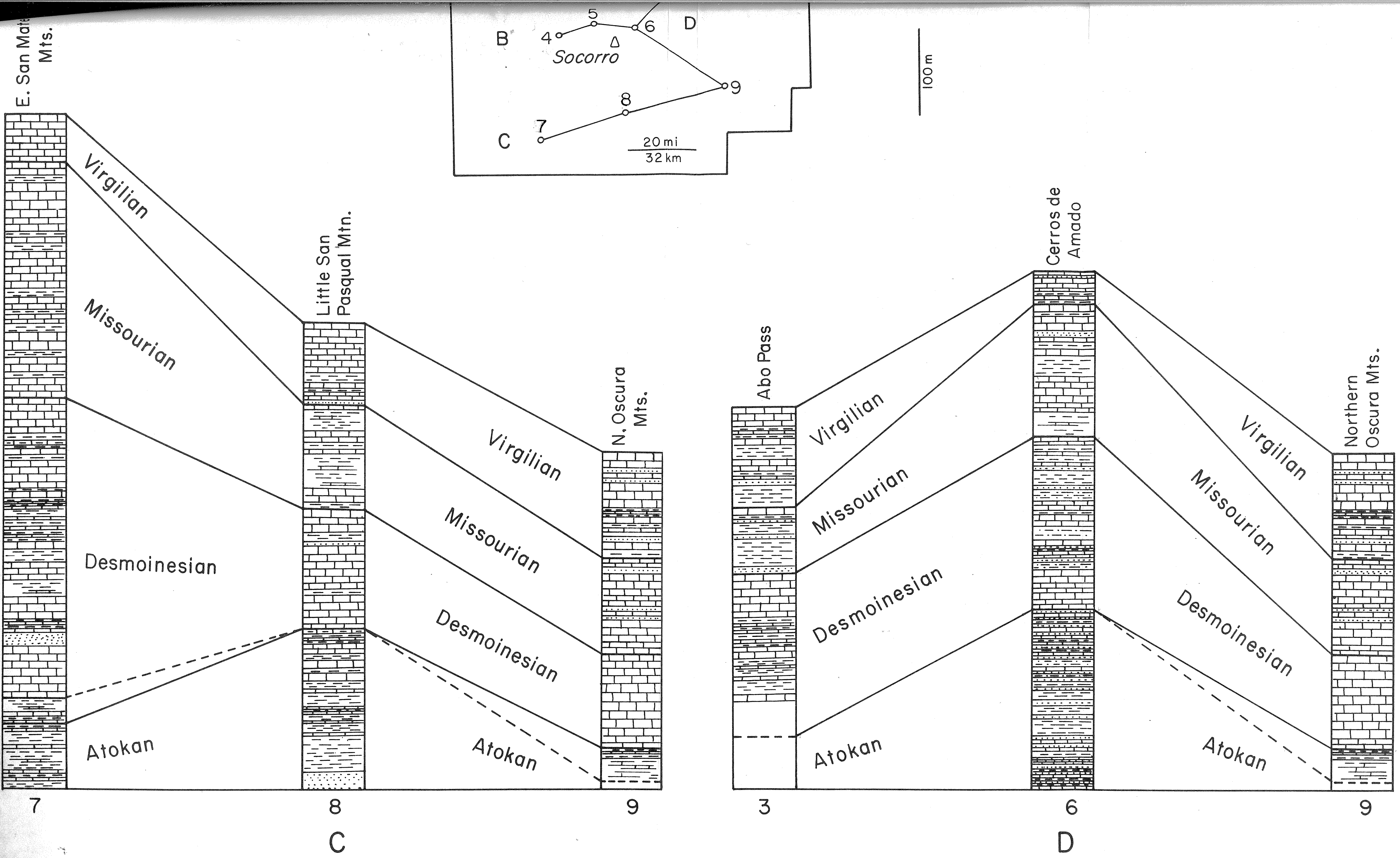
Sept 25, 1978

Date



Ladron Mts.
Virgilian
Missourian
Desmoinesian
Atokan
Joyita Hills
Abo Pass
Virgilian
Missourian
Desmoinesian
Atokan
1
2
3
A
Magdalena Mts.
Faulted out
Missourian
Desmoinesian
Atokan
Lemitar Mts.
Cerros de Amado
Virgilian
Missourian
Desmoinesian
Atokan
4
5
6
B
A
B
D
Socorro



Sheet I.-- Stratigraphic cross-sections across the Socorro region

Series boundary ——— Sandia-Madera contact - - - - - - - -