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BIOSTRATIGRAPHY OF THE ARROYO PENASCO GROUP, LOWER CARBONIFEROUS (MISSISSIPPIAN), NORTH-CENTRAL NEW MEXICO*

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INTRODUCTION

A section of pre-Pennsylvanian predominantly carbonate rock of Paleozoic age in the San Pedro Mountain, Nacimiento, Jemez, Sandia, and Sangre de Cristo Mountains of northern New Mexico (Figs. 1, 2) has been studied by several workers since the end of World War II.

Read and others (1944) first recognized the distinctness of these rocks in north-central New Mexico and mapped them as the lower limestone member of the Pennsylvanian Sandia Formation, Magdalena Group. The lower gray limestone member was mapped and described by Wood and Northrop (1946) in the San Pedro Mountain and Nacimiento Mountains and by Northrop and others (1946) in the southeastern foothills of the Sangre de Cristo Mountains.

In 1955 Armstrong proposed the name Arroyo Penasco Formation for the lower gray limestone member of the Sandia Formation in the San Pedro, Nacimiento, Sandia, and Sangre de Cristo Mountains of north-central New Mexico. He designated its type section in SW 1/4 SW 1/4 sec. 5, T. 16 N., R. 1 E., in Pinos and Penasco Canyons, Nacimiento Mountains and reported that the unit contained a Meramecian endothyrid fauna.

Fitzsimmons, Armstrong, and Gordon (1956) listed a fauna of megafossils from the Arroyo Penasco Formation in exposures on the northwestern side of the San Pedro Mountains and from its type section. Armstrong (1958a) described part of the Meramecian endothyrid fauna of the Arroyo Penasco Formation and demonstrated that at the type section and in the Sangre de Cristo Mountains the rocks had the same lithologies and endothyrid species and were thus of the same (Meramecian) age.

Armstrong (1955, 1958a) indicated that the basal carbonate rocks in the Sangre de Cristo Mountains were Meramecian in age and restated this view in 1962 (p. 14). Because of the discovery of the *Spinoendothyra spinosa* (Chernysheva) microfauna in cherts of the basal carbonate rocks by Lee Holcomb of the Shell Oil Company, Armstrong (1963, p. 115; 1965, p. 133; Armstrong and Holcomb, 1967) determined the age of the Arroyo Penasco Formation as late Osagean and Meramecian.

In 1960 Baltz and Read divided the pre-Pennsylvanian sandstone and carbonate rocks of the Sangre de Cristo Mountains into two newly named formations, the Espiritu Santo and the Tererro. The Tererro Formation was divided into three members—in ascending order, the Macho, Manuelitas, and Cowles Members.

Sutherland (1963) studied pre-Pennsylvanian rocks of the Pecos River Canyon and Rio Pueblo region of the Sangre de Cristo Mountains. He adopted, in general, Baltz and Read's 1960 nomenclature for these rocks but added major revisions. He removed the basal sandstone of the pre-Pennsylvanian carbonate rocks in the Pecos River Canyon from Baltz and Read's Espiritu Santo Formation and named it the Del Padre Sandstone. He assigned the 230 m of conglomeratic sandstone in his Rio Chiquito section (p. 25-26), north of Truchas Peak, to his Del Padre Sandstone. He considered his unfossiliferous Del Padre Sandstone to be any age from late Precambrian (postmetamorphic) to Early Mississippian, although he believed that the Del Padre probably interfingers laterally with the Espiritu Santo Formation. He restricted the Espiritu Santo to the carbonate rocks below the breccia zone.

Armstrong (1967) studied the petrography of the carbonate rocks and described and illustrated the Foraminifera of the Mississippian rocks of north-central New Mexico. Armstrong (1967, p. 5-8) considered Baltz and Read's (1960) Espiritu Santo and Tererro Formations of the Sangre de Cristo Mountains to be laterally equivalent parts of his (Armstrong, 1955) Arroyo Penasco. He recognized the Arroyo Penasco over northern New Mexico. Because of its extent and the formations it includes, the Arroyo Penasco is raised to group rank in north-central New Mexico. Armstrong (1967) differentiated three incomplete carbonate depositional cycles in the Arroyo Penasco and outlined the following depositional history:

The Arroyo Penasco, 3 to 40 m thick, rests on a peneplained surface of Precambrian rocks. It contains a late Osagean, Meramecian, and Chesterian marine fauna. It is overlain unconformably by sandstone of Pennsylvanian age. The Arroyo Penasco crops out in the Nacimiento Mountains, its type area, as well as in the San Pedro Mountain, Jemez, Sandia, Manzanita, Manzano, and Sangre de Cristo Mountains of north-central New Mexico.

The basal unit, 0.5 to 18 m thick—named the Espiritu Santo Formation by Baltz and Read (1960) in the Sangre de Cristo Mountains—is transgressive and is composed of siltstone, sandstone, and thin shale. Three incomplete carbonate depositional cycles were recognized. The lowest, cycle 1, consists of dolomite, dedolomite, and coarse-grained poikilotopic calcite with corroded dolomite rhombs. These rocks contain gray nodular chert with a microfauna of Zone 9 (late Osagean age): *Endothyra* (now *Spinoendothyra) spinosa* (Chernysheva), *Endothyra* (now *Latiendothyra) skippae* (Armstrong), and *Septabrunsiina parakrainica* Skipp, Holcomb, and Gutschick. The lowest cycle reflects initial deposition of a shallow-marine lime mud followed by stromatolitic intertidal to supratidal carbonate deposits.

Cycle 2 is shallow-marine to intertidal echinoderm wacke-

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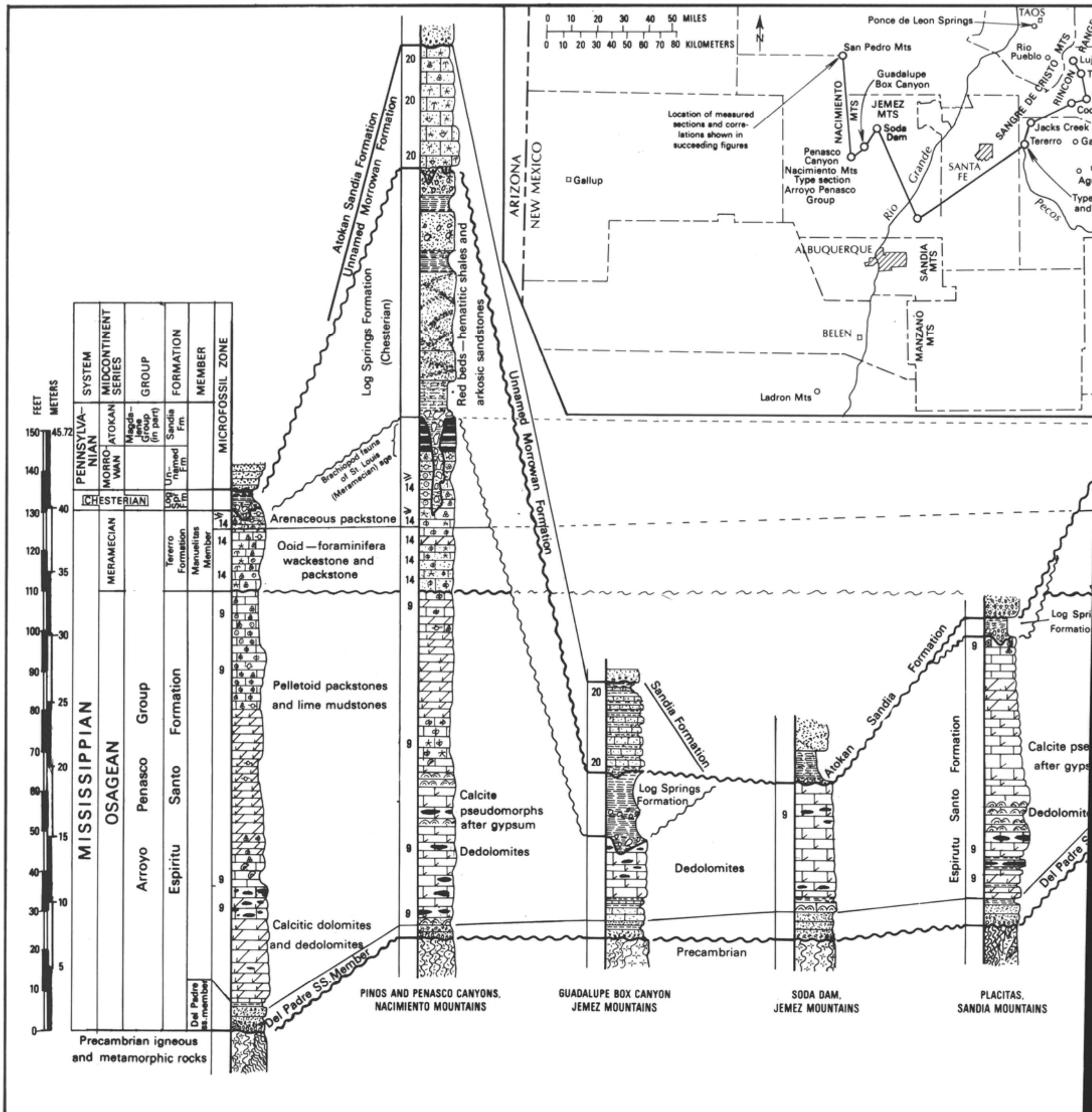
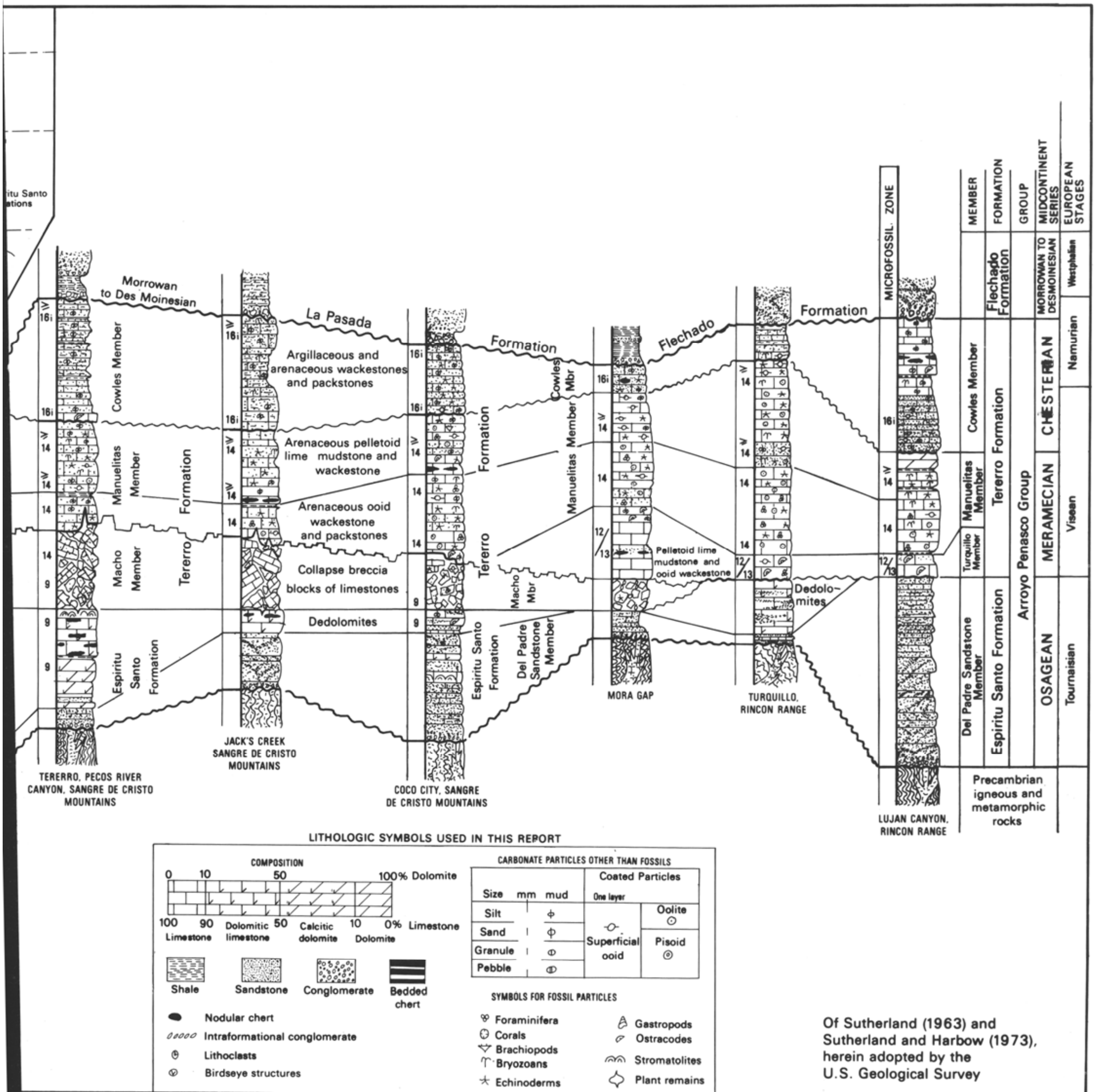


Figure 1. Regional Mississippian biostratigraphy correlation chart, and index map of north-central New Mexico showing the locatio[n of] sections shown in Appendix, Figures 9 through 17.

stone to lime mudstone and dolomite containing a sparse fauna of *Endothyra* (now *Spinoendothyra)* aff. *S. spinosa* (Chernysheva), *Endothyra irregularis* (Zeller), and *Endothyra* (now *Eoendothyranopsis) spiroides* (Zeller) (an identification error; in this report referred to the Tournayellidae).

Cycle 3 is shallow-marine wackestone to arenaceous oolitic to ooid-echinoderm packstone ending as subtidal lime mudstone to intertidal dolomite. The ooid facies contains a rich microfauna of Meramecian age: *Endothyra* (now *Eoendothyranopsis) prodigiosa* (Armstrong), *Endothyra* (now *Eoenclothyranopsis) macra* (Zeller), *Endothyra irregularis* (Zeller), and *Tournayella* sp. (in this report referred to as *Eoforschia).* Cycles 2 and 3 are present in Baltz and Read's (1960) Tererro Formation in its type area, the Sangre de Cristo Mountains.



type sections of the Espiritu Santo and Tererro Formations and the Arroyo Penasco Group. Detailed location maps of measured

Late Mississippian and Early Pennsylvanian uplift resulted in extensive erosion and removal of the Arroyo Penasco Formation. A solution limestone collapse breccia, 1.5 to 9 m thick, rests on a smooth surface of stromatolitic dedolomite in the Sangre de Cristo Mountains. The breccia—Baltz and Read's (1960) Macho Member of the Tererro Formation—resulted from movement of meteoric ground waters in Late Mississippian or Early Pennsylvanian time. These waters dissolved a 1.5- to 9-m-thick gypsum bed and caused the subsequent collapse of adjacent overlying lower Meramecian carbonate rocks. Solution activity was extensive, and sinkholes developed.

In "The Geologic Atlas of the Rocky Mountain Region," Johnson (1972, figs. 1, 2, 4-6) followed the Mississippian age assignments of Baltz and Read (1960) on his part of the cor-

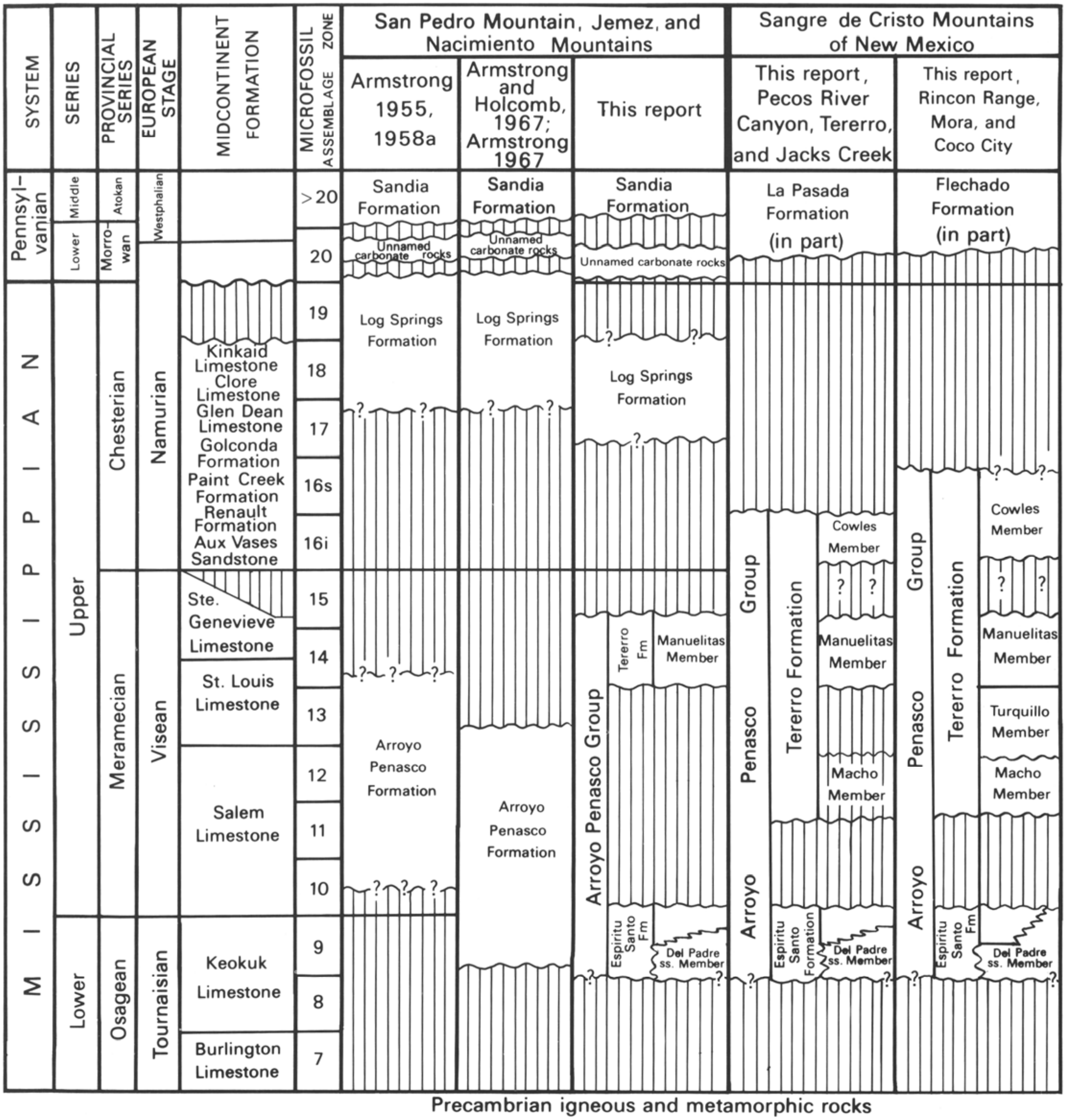


Figure 2. Stratigraphic nomenclature and age assignments of lower Carboniferous rocks in north-central New Mexico.

relation chart (fig. 1), sub-Mississippian paleogeologic map (fig. 2) and Kinderhookian, Osagean, and Meramecian lithofacies maps (figs. 4-6). He showed the Espiritu Santo Formation as Devonian(?) on the sub-Mississippian paleogeologic map, the Macho Member as Kinderhookian, the Manuelitas Member as Osagean, and the Cowles Member as Meramecian on the lithofacies maps.

RECENT ADVANCES IN DATING AND CORRELATING MISSISSIPPIAN ROCKS IN NORTH AMERICA ON THE BASIS OF MICROFAUNAL ZONATION

The knowledge of Mississippian microfossils has greatly increased, and more refined zonation is now possible since the publication of Armstrong's 1967 paper. Taxonomic changes have been rapid, and more than 60 new generic taxa have been proposed in 5 years.

Mamet (1968a, 1968b, 1970), Mamet and Gabrielse (1969), and Mamet and Mason (1968) used microfossils to zone the Mississippian of Canada. Armstrong, Mamet, and Dutro (1970) and Mamet and Armstrong (1972) divided the Carboniferous Lisburne Group of arctic Alaska into faunal zones based on microfossils. Mamet and Skipp (1970) used calcareous Foraminifera for a zonation of the lower Carboniferous of North America. Sando, Mamet, and Dutro (1969), Skipp and Mamet (1970), and Mamet, Skipp, Sando, and Mapel (1971) used microfossils in regional zonation and biostratigraphy of the Mississippian of the northern Cordilleran of the United States. The Redwall Limestone of northern Arizona was zoned by Skipp (1969). Brencle (1973) described the smaller Mississippian and Early Pennsylvanian calcareous Foraminifera of Nevada and determined their stratigraphic ranges.

Armstrong in 1972 and 1973 re-examined and recollected the Mississippian outcrops of north-central New Mexico. A large number of new thin sections were examined by Mamet for both petrography and microfossils.

THE ARROYO PENASCO GROUP

The Arroyo Penasco Formation of Armstrong (1955) is raised to group rank in north-central New Mexico and contains two formations, the Espiritu Santo and the Tererro of Baltz and Read (1960). These two formations are now recognized in the Nacimiento Mountains and San Pedro Mountain. The Espiritu Santo Formation is recognized in the Sandia and Jemez Mountains.

The basal unit, 0.5 to 15 m thick—originally named the Espiritu Santo Formation by Baltz and Read (1960) in the Sangre de Cristo Mountains—is transgressive and is composed of quartz conglomerates, sandstone, siltstones, and thin shale. This basal unit was subsequently removed by Sutherland (1963) from the Espiritu Santo Formation and named the Del Padre Sandstone. No microfossils have been found in this unit, and as Sutherland suggested, its age may be anything from post-Precambrian to Mississippian. The Del Padre Sandstone, herein adopted as the basal member of the Espiritu Santo Formation, interfingers with the Espiritu Santo carbonate rocks and should be considered as the basal unit of a normal transgression; thus it is probably late Tournaisian in age.

A similar unit is observed at the base of the transgressive upper Tournaisian (Zone 8) Caloso Formation by Armstrong (1958b) in west-central New Mexico. In the Front Range, south of Pueblo, Colorado, a calcareous siltstone named the Williams Canyon Limestone forms a similar blanket arenite at the base of the upper Tournaisian Hardscrabble Limestone.

The Del Padre Sandstone Member of the Espiritu Santo constitutes the lower 1.2 m of the Arroyo Penasco Group in the Nacimiento Mountains. It has been observed in all the sections investigated during this study in north-central New Mexico. Its maximum known thickness is 15 m at Lujan Canyon.

The carbonate rocks of the Espiritu Santo Formation consist of dolomites, dedolomites, and coarse-grained poikilotopic calcite with corroded dolomite rhombs. Where the rocks are not dolomitized, stromatolitic algal mats, Spongiostromata mats, echinoderm wackestones, kamaenid mudstones rich in birdseyes, oncolitic-bothrolitic mats, and related features are visible. This association suggests very shallow water sedimentation with intertidal to supratidal carbonate blankets. The unit is 26.2 m thick in the Nacimiento Mountains at the Pinos Canyon section and 8 m thick in the type Tererro section in the Sangre de Cristo Mountains.

The microfauna is usually unrecognizable in the dolomites and dedolomites; however, cherts usually preserve the outline of foraminiferal tests, and stratigraphically useful microfossil assemblages can be detected. The most important taxa are: abundant *Calcisphaera laevis* Williamson, *Endothyra* sensu stricto, *Latiendothyra* of the group *L. parakosvensis (Latiendothyra skippae* of Armstrong), *Septabrunsiina parakrainica* Skipp, Holcomb, and Gutschick, *Septatournayella pseudocamerata* Lipina *in* Levedeva, and *Spinoendothyra spinosa* (Chernysheva). The assemblage clearly indicates Zone 9 and is late Tournaisian in age (late Keokuk age equivalent).

Armstrong (1967) indicated that forms referrable to *Eoendothyranopsis spiroides* (Zeller) were present in the upper part of the Espiritu Santo Formation in the Nacimiento and San Pedro Mountains. Additional thin sections show that they are not endothyranopsids but should be transferred to the tournayellids. The presence of Salem fauna in the Espiritu Santo Formation is therefore to be discarded.

In the region under study, the Espiritu Santo carbonate rocks rest everywhere on the Del Padre Sandstone Member. The maximum thickness of the Espiritu Santo is 29 m at the Pinos Canyon section.

The third mappable unit is a collapse breccia that Baltz and Read (1960) named the Macho Member of the Tererro Formation. The mode of formation of this unit is difficult to assess. It could have been formed by subaerial exposure after deposition of the Espiritu Santo Formation, or it could be the result of dissolution by meteoric ground water during the late Carboniferous (Armstrong, 1967). In the Tererro section the lower 4.5 m of the Macho Member contains blocks of foraminiferal pelletoidal wackestone that yield Tournaisian *Spinoendothyra* assemblages, while the matrix of the blocks yields Viséan *Eoendothyranopsis,* notably *Eoendothyranopsis macra* (Zeller) and *Eoendothyranopsis* of the group *E. ermakiensis* (Lebedeva). In this section, the formation of the breccia coincides with a hiatus that spans the entire Salem time equivalent. In other sections, such as the Lujan Canyon and Turquillo, the breccia is overlain by algal mudstones that contain Zone 12/13 microfossils. In these areas, the hiatus spans only the lower part of the Salem time equivalent. At all localities, the upper parts (Fig. 1) of the breccia contains collapsed blocks derived from the overlying Turquillo Member; these blocks contain a middle Viséan microfauna.

Most of the blocks observed in the base of the Macho Member have late Tournaisian Espiritu Santo microfossils. The matrix is much younger—middle to late Viséan in age. It is possible that some early Visdan fauna will be found some day, thus filling the hiatus, as has been done recently in a similar collapse breccia of the Bighorn Mountains in Wyoming and Montana (Sando and Mamet, 1974). At this time, no proof of early Salem age equivalent has been found.

The Macho Member is not present in the Nacimiento Mountains or San Pedro Mountain where the upper Viséan Manuelitas Member rests directly on the upper Tournaisian Espiritu Santo Formation. In the Sandia and Jemez Mountains only the

Espiritu Santo Formation of the Arroyo Penasco Group is present beneath the Pennsylvanian unconformity.

The fourth recognized unit in this report is a thick-bedded mudstone-wackestone, rich in foraminifers and bothrolites. This unit is here designated the Turquillo Member. In its type section at Turquillo, section 65A-16 (Fig. 1), the sequence consists of stromatolitic-spongiostromid wackestones only 2 m thick. The type section (section 65A-16) is on the east side of the Rincon Range, Mora County, 4 miles south of the village of Turquillo on New Mexico State Highway No. 38 and half a mile west on a logging road into a deep canyon. It rests with disconformity on the eroded Espiritu Santo Formation. The same relationship is observed at the Ponce de Leon Springs section east of Taos, where the unit is 2.5 m thick. It is 2.5, 1.2, 3, and 4.5 m thick at Agua Zarca, Lujan Canyon, Gallinas Canyon, and Mora Gap, respectively; in these four localities, the Turquillo Member rests on the Macho breccia. At the Mora Gap section, the member includes widespread intraformational conglomerates.

Foraminifers are abundant in the Turquillo Member. In particular *Eoendothyranopsis* of the group *E. spiroides* (Zeller), *Eoendothyranopsis scitula* (Toomey), *Eoendothyranopsis hinduensis* (Skipp *in* McKee and Gutschick), *Eoendothyranopsis prodigiosa* (Armstrong), and primitive *Endothyranopsis* and biseriamminids are present. The dasyclad *Koninckopora* is widespread. The fauna indicates the passage of Zone 12/13, which is the Salem-St. Louis boundary age equivalent.

The Manuelitas Member of Baltz and Read (1960), the fifth lithographic unit, is composed of two readily identifiable units: a thick-bedded oolitic-bothrolitic grainstone, and a silty pelletoidal fine-grained grainstone-packstone with minor calcareous silts. The oolitc ranges in thickness from zero to one meter (at Agua Zarca, Lujan Canyon and Jacks Creek) to 6 m and even 10 m (at Turquillo and Gallinas Canyon, respectively). The oolite is clearly transgressive and rests on the Espiritu Santo Formation or the Macho or Turquillo Members of the Tererro Formation.

The finer grained pelletoidal unit is considered here to be a lateral equivalent of the oolitic unit as they interfinger and their thicknesses are complementary; where the oolite unit is poorly developed, the pelletoidal facies is thick. The pelletoidal facies reaches a maximum thickness of 8.5 m at the Dalton picnic ground section and at the Turquillo section.

The oolitic unit is rich in foraminifers. The association of *Eoendothyranopsis macra* (Zeller), *Eoendothyranopsis* of the group *E. ermakiensis* (Lebedeva), *Eoendothyranopsis prodigiosa* (Armstrong), *Endothyranopsis* of the group *E. compressa* (Rauzer-Chernoussova and Reitlinger), and *Globoendothyra paula* (Vissarionova) clearly indicates a St. Louis age equivalent (Zone 14). *Banffella,* usually present in Zone 14, appears to be the only taxon of that zone absent in New Mexico. Foraminifers vary greatly in state of alteration; some are completely mud filled, abraded, and broken; some are free of mud and show no sign of abrasion. Algae are abundant and numerous broken thalli of the dasyclad *Koninckopora* are present. Stachein algae are represented by *Stacheia, Stacheoides,* and A *oujgalia.*

The pelletoidal facies is poorer in foraminifers as most of the microfossils are sieved and distributed by size; hence the foraminifers are mostly minute archaediscids (notably *Archaediscus krestovnikovi* Rauzer-Chernoussova, and *Archaediscus? pachytheca* Petryk). Young forms of *Eoendothyranopsis, Endothyranopsis,* and *Globoendothyra* are also found and are very scarce. It is difficult to give a precise age on such a material; characteristic foraminiferal assemblages of Zones 14 and 15 are composed of quite large indexes, which are not present as adult forms in the pelletoidal sieved fauna. As we have already suggested, the pelletoidal facies is probably a lateral equivalent of the oolitic facies (Zone 14). Moreover, the St. Louis megafauna listed by Fitzsimmons, Armstrong, and Gordon (1956) comes from that level, and it is therefore certain that the unit is not much younger than Zone 14.

A sixth unit, the Cowles Member of Baltz and Read (1960), consists of recessive silts, calcareous silts, shales, pelletoidal fine-grained silty limestones, and fine-grained ostracod mudstone. The Cowles Member is known only in the Sangre de Cristo Mountains and rests everywhere in that region on the Manuelitas Member, and the contact appears paraconformable. The top of the formation is eroded everywhere and unconformably overlain by Pennsylvanian clastic rocks. Its apparent thickness is 0.5 m at Turquillo, 2.5 m at Rio Pueblo, 3 m at Mora Gap, 4.5 m at Coco City, 10 m at Jacks Creek, and 10.1 m at Lujan Canyon.

Like the Manuelitas Member, the sieved Cowles microfauna is composed almost exclusively of very small, rolled, abraded and often mud-filled foraminifers; these are mostly Archaediscidae with few Endothyridae and Eostaffellidae. The presence of primitive *Neoarchaediscus* and of *Zellerina* clearly indicates that the formation is younger than Meramecian and should be regarded as early Chesterian age equivalent. There is therefore no proof of the existence of Ste. Genevieve fauna between the Manuelitas Member and the Cowles Member.

A distinct and easily recognizable carbonate unit at the top of the Cowles Member is observed in the Lujan Canyon section, where its apparent minimum thickness is 4 m, and in the Manuelitas Creek section where it is at least 3 m thick. The top of this unit is eroded by Pennsylvanian arenites, and the true thickness of the unit cannot be determined. This carbonate rock unit is composed of dark, very fine grained ostracod mudstones. Aside from ostracods, the unit is very poor in fossil remains.

The Log Springs Formation of Armstrong (1955, 1967) herein adopted, is known only in the Sandia, Jemez, and Nacimiento Mountains, and San Pedro Mountain. It is 2 to 25 m thick and rests with a marked unconformity on various beds of the Arroyo Pcnasco Group. It is composed of continental clastic red beds and is post-Zone 16i. Since it is overlain, with hiatus, by Zone 20, it must be a Chesterian age equivalent.

The last Foraminifera-bearing rocks are Morrowan age equivalents; in the Arroyo Penasco section limestones are found that yield very abundant Ozawainellidae *(Millerella pressa* Thompson) associated with *Zellerina, Planoendothyra, Asteroarchaediscus, Biseriella,* and the earliest *Globivalvulina* sensu stricto.

PALEOGEOGRAPHY

Although deceptively thin, the Arroyo Penasco Group spans a considerable part of the Carboniferous time and is, in this respect, comparable to the condensed Amsden Formation of Wyoming.

The paleogeographic history of the succession is exceedingly complex and may be summarized, if not oversimplified, as follows:

1) The Del Padre transgression occurred from south to north on a peneplained Precambrian craton. Few basal con-

glomerates are present. The sandstones and silts are clean and have little detrital feldspar. These arcnites filled all the fractures and depressions and transformed the region to a uniformly flat platform, which was immediately changed into a carbonate sebkha.

2) The Espiritu Santo Formation represents a succession of tidal flats and sebkhas leading to evaporites. Dolomites and dedolomites are abundant. Abundant chert or calcite pseudomorphs of gypsum blades indicate hypersaline conditions. Algae such as spongiostromids, stromatolites, kamaenid filaments *(Ka maena, Pseudokamaena, Palaeoberesella),* calcisphere cysts, and orthonellid bushes are present in all the limestones.

3) The early Viséan Macho regression left this 30.4-m-thick sequence of evaporites and carbonate deposits exposed to subaerial erosion. Percolation of ground water through these deposits formed a karst with a thick, continuous blanket of collapse breccia. This breccia was probably exposed during the whole length of the early Viséan and formed a chaotic land surface. The Turquillo Member transgression coming from the south shows this chaotic surface by erratic patterns of deposition.

The Turquillo and Espiritu Santo seas must have been quite similar as shown by the proliferation of spongiostromid-stromatolite limestones. However, the Turquillo sea remained entirely normal marine where foraminifers thrived, associated with abundant red algae (Stacheins) and dasyclads *(Koninckopora).*

4. The Manuelitas transgression overlapped the Turquillo, and the whole platform was covered by turbulent oolite banks. As in the preceding facies, the fauna and flora thrived; abundant blue-green algae thalli are observed as oolite nuclei or filled with mud. The sieved fauna and flora are characteristic of the associated pelletoidal fine-grained facies. Some silt, shale, and fine-grained grainstone with abundant algal pellets were also deposited.

It is difficult to assess if a regression occurred after the Manuelitas Member was deposited. Ste. Genevieve age equivalents have not been found. However, the basal part of the Cowles Member consists of calcareous silts and shales devoid of foraminifers, and the uppermost Meramecian could be condensed there. If Zone 15 is present, it is no more than a few meters thick. If it is absent, a paraconformity is plausible.

5) Like most of the Chesterian formations of the American and Canadian Cordillera, the upper Visean Cowles is composed of recessive facies. The end of this clean Visean carbonate platform is too abrupt and too widespread to be caused only by a regression and a change of source material; a climatic change must have also occurred.

6) The paleogeography of the Cowles Member in the Sangre de Cristo Mountains is difficult to assess as the unit was deeply gouged by overlying units. The same holds true for the Log Springs conglomerates and the Morrowan carbonate rocks in the Nacimiento and Jemez Mountains whose outcrops are now isolated.

LOWER CARBONIFEROUS SECTIONS IN THE FIELD TRIP AREA, NACIMIENTO, SAN PEDRO, JEMEZ, AND SANDIA MOUNTAINS

Pinos and Penasco Canyons, Nacimiento Mountains

The stratigraphic section in Penasco and Pinos Canyons, Nacimiento Mountains, displays (Fig. 1) the complex depositional sequence of events from Keokuk, late Osagean through Morrowan time. The Espiritu Santo Formation is 27.5 m thick. The Del Padre Sandstone Member rests on a peneplained surface of Precambrian granites, is 1 to 1.5 m thick, and is composed of clean well-sorted quartz conglomerates and calcareous sandstone that grade upward into the coarse-grained dedolomites which form the lower 12.2 m of the formation. The remainder of the section to 2.75 m is crinoid wackestones and mudstones capped by calcitic dolomites that have undergone dcdolomitization.

The Manuclitas Member of the Tererro Formation from 22.3 m to 39.6 m, is composed of arenaceous lime mudstones, pelletoid-ooid wackestones, and packstones.

The following microfossils were obtained from the Arroyo Penasco Group and the unnamed Morrowan, Pennsylvanian limestone in Penasco and Pinos Canyons.

Pinos and Penasco Canyons, 66A-2 and 72 N-17; 66A-2B, 72 N-17 and 73 N-17: and a collection made with Lee Holcomb in 1962.

Arroyo Penasco Group

Espiritu Santo Formation

Basal part, 3 to 3.7 m

Latiendothyra ghosts
Spinoendothyra ghosts

Age: Zone 9(?) (late] Keokuk age equivalent(?), late Tournaisian(?)

Middle part, 8.5 to 16.8 m

Calcisphaera sp.
Calcisphaera laevis Williamson
Earlandia sp.
Earlandia of the group *E. clavatula* (Howchin)
Earlandia of the group *E. elegans* (Rauzer-Chernoussova)
Earlandia of the group *E. moderato* (Malakhova)
Endothyra sp.
"Globoendothyra" trachida (Zeller)
Inflatoendothyra sp.
Kamaena sp.
Latiendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina) *[L. skippae* (Armstrong)]
Medioendothyra sp.
Parathurammina sp.
Proninella sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Septatournayella sp.
Spinoendothyra spinosa (Chernysheva)
Tournayella sp.
Tournayella aff. *T. discoidea* Dain
cf. *Uslonia?* sp.

Age: Zone 9, late Keokuk age equivalent, late Tournaisian N.B. The report of *Eoendothyranopsis spiroides in* Armstrong (1967, fig. 24) is to be discarded.

Upper part, 22.3 to 27.4 m*Anatolipora*

Anatolipora sp.
Calcisphaera sp. *Calcisphaera laevis* Williamson
Earlandia sp.
Earlandia clavatula (Howchin)
Endothyra sp.
"Globoendothyra" trachida (Zeller)
Infiatoendothyra sp.
/n f la to nd o thy ra ''/n flata" Lipina OB J *(Inflatoendothyra eospiroides* Skipp *in* McKee and Gutschick)
Karnaena sp.
Latiendothyra sp.
"Nostocites" sp.
Orthriosiphon sp.
Palaeoberesella sp.
Parathurammina sp.
Proninella sp.
Radiosphaerina sp.

Septabrunsiina sp.
Septaglomospiranella sp.
Septatournayella sp.
Spinoendothyra sp.
Spinoendothyra spinosa (Chernysheva)
Vicinesphaera sp.
Age: Zone 9, late Keokuk age equivalent, late Tournaisian N.B. Report of *Eoendothyranopsis spiroides in* Armstrong (1967, fig. 24) is to be discarded.

Tererro Formation, Manuelitas Member
Lower part (oolitic facies), 28.1 to 33 m
Aoujgalia sp.
Aoujgalia variabilis Termier and Termier
Archaediscus sp.
Archaediscus krestovnikovi Rauzer-Chernoussova
Archaediscus koktjubensis Rauzer-Chernoussova
cf. *Banffella?* sp.
Brunsia sp.
Brunsia lenensis Bogush and Yuferev
Calcisphaera laevis Williamson
Calcisphaera pachysphaerica (Pronina)
Diplosphaerina sp.
Earlandia clavatula (Howchin)
Earlandia of the group *E. vulgaris* (Rauzer-Chernoussova and Reitlinger)
Endothyra sp.
Eoendothyranopsis of the group *E. ermakiensis* (Lebedeva)
Eoendothyranopsis macro (Zeller)
Eoendothyranopsls prodigiosa (Armstrong)
Eoendothyranopsis of the group *E. pressa-rara* (Grozdilova *in* Lebedeva) *[Eoendothyranopsis scitula* (Toomey)]
Eoendothyranopsis cf. *E. thompsoni* (Anisgard and Campau)
Eoforschio sp.
Epistacheoides sp.
Globoendothyra sp.
Globoendothyra paula (Vissarinova)
Intextullella sp.
Irregularina sp.
Koninckopora sp.
Koninckopora inflata (de Koninck)
Paracalligelloides sp.
Parathurammlna sp.
Priscella sp.
Pseudocomuspira sp.Pseudoissinella
Psemdoissinella sp.
Rectangulina sp.
Skippella sp.
Stacheia sp.
Stachela tenuis Petryk and Mamet
Age: Zone 14, late Meramecian age equivalent, late Visean

Upper part, 33.5 to 37.2 m
Aoujgalia sp.
Archaediscus sp.
Archaediscus krestovnikovi Rauzer-Chernoussova
Brunsia sp.
Brunsia lenensis Bogush and Yuferev
Calcisphaera laevis Williamson
Calcisphaera pachysphaerica (Pronina)
Earlandia clavatula (Howchin)
Endothyra of the group *E. bowman/* Phillips *emend* Brady *[E. Irregularis* (Zeller)]
juvenile form of *Eoendothyranopsis macro* (Zeller)
juvenile forms of *Eoendothyranopsis prodigiosa* (Armstrong)
Eoforschia sp.
Epistacheoides sp.
juvenile forms of *Globoendothyra* sp.
Koninchopora sp.
Koninckopora inflata (de Koninck)
Priscella prisca (Rauzer-Chernoussova and Reitlinger)
"Septabrunsiina" sp.
Stacheoides sp.
Stacheoides tenuis Petryk and Mamet
Tetrataxis sp.
Age: Zone > 14, sieved fauna, late Meramecian age equivalent, late Visean.

N.B. Report of *Tournayella* from that level by Armstrong (1967, fig. 24) should be transferred to *Eoforschia* sp.

Unnamed Pennsylvanian limestone
66A-2B, 0.3 to 7.6 m, and 72 N-17, 89 to 103.6 m
Apterrinellids
Archaediscus sp.
Asphaltina sp.
Asphaltina cordillerensis Mamet
Asteroarchaediscus sp.
Biseriella sp.
Biseriella of the group *B. parva* (Chernysheva)
Calcisphaera sp.
Climacammina sp.
Earlandia sp.
Endothyra sp.
Eolasiodiscus sp.
Globivalvulina sensu stricto (scarce)
Millerella sp.
aff. *M. marblensis* Thompson emend.
Millerella pressa Thompson
Neoarchaediscus sp.
Planoendothyra sp.
Pseudoglomospira sp.
Tetrataxis sp.
Zellerina sp.
Age: Zone 20, Morrowan age equivalent

Log Springs Formation

The Log Springs Formation is found only in the Sandia, Jemez, and Nacimiento Mountains, and San Pedro Mountain. It rests unconformably on the Arroyo Penasco Group, and beds of Morrowan age rest with an angular unconformity on it (Figs. 1, 3, 4). The Log Springs Formation is a red bed sequence of continental clastic sediments from 2 to 25 m thick. The lower 2 to 4 m are red to dusky red, silty, hematitic shales. The contact with the Arroyo Penasco Group is very irregular and contains abundant solution-rounded pebbles and cobbles of limestone and chert. The deep red shales contain numerous 1- to 5-mm oolites or pisolites of dark-red hematite. The shale appears to be a terra rossa soil that has been slightly reworked. Above the shale lies 10 to 20 m of arkosic to conglomeratic, crossbedded, argillaceous dusky red to mottled

Figure 3. Type section of the Arroyo Penasco Group as viewed from New Mexico State Highway 44. View is to the east, just north of Warm Springs, New Mexico. Arrow 1 points to an excellent outcrop of the Espiritu Santo Formation dedolomites with chert that contains microfossils. Arrow 2 points to outcrop and base of measured section. Section is measured down the slope due north along the fence line (see Figure 4).

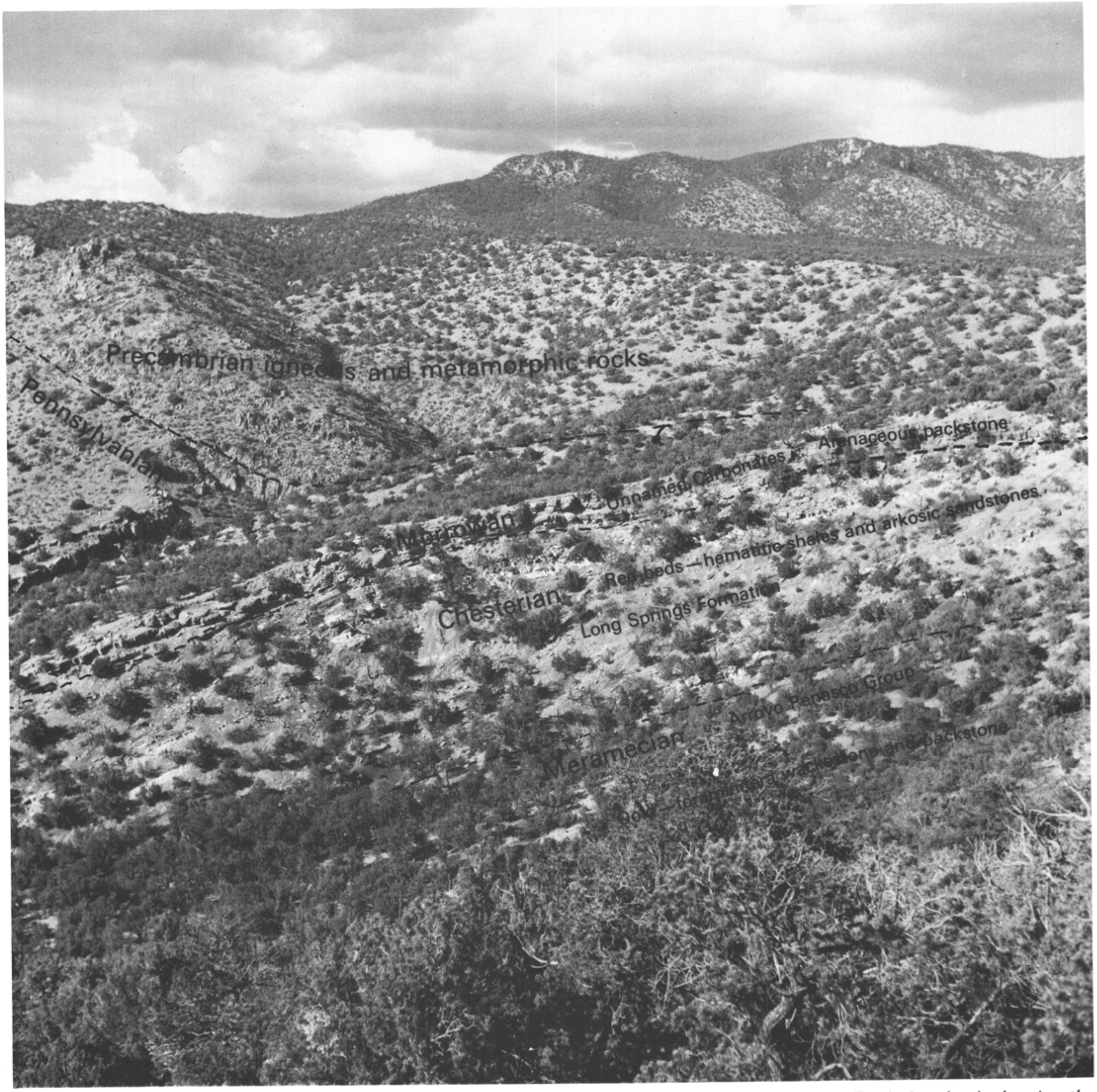


Figure 4. View across Pinos Canyon, Nacimiento Mountains, with fence line separating Jemez and Zia Indian lands showing the Arroyo Penasco Group, followed by the red beds of the Log Springs Formation which are unconformably overlain by the unnamed, Morrowan age, arenaceous limestones. The top of the Arroyo Penasco Group is highly silicified.

pale-orange sandstones. The beds are a few centimeters to 3 m thick and are crossbedded, and both sandstones and shales are lenticular in shape. Within these beds are numerous rounded pebbles and cobbles from the Arroyo Penasco Group and an assorted mixture of Precambrian gneiss, granites, schists, and quartz. Clastic material tends to become coarser in the higher beds of the Log Springs Formation. The Log Springs Formation is truncated by an angular unconformity and is overlain by argillaceous, arenaceous, bioclastic packstones of Morrowan age. The unconformity is marked by abundant conglomerate channel fill. No Foraminifera have been found in the Log Springs Formation. R. M. Kosanke (written commun., 1972) found the formation to be devoid of spores.

The unnamed, Morrowan, Pennsylvanian arenaceous wackestones and grainstones carbonate rocks unconformably overlie the red bed and conglomerates of the Log Springs Formation. The Morrowan beds are in turn unconformably overlain by arkosic sandstones of Middle Pennsylvanian age (Figs. 1, 3).

San Pedro Mountain

The Arroyo Penasco Group outcrop at the northwestern end of the San Pedro Mountain (Figs. 1, 5) is 39.6 m thick and lithologically similar to the section in Pinos and Pcnasco Canyons, Nacimiento Mountains.

The microfossils found in the San Pedro section are given in the following list.

The red shales and sandstones of the Log Springs Formation unconformably overlie the Manuelitas Member. The Log Springs Formation is less than 4 m thick and is poorly exposed; it in turn is unconformably overlain and truncated by sandstones of the Sandia Formation.

San Pedro Mountain section, 65A-11, 72 A-11
Espiritu Santo Formation
.Middle part, 8.2 to 14.6 m
Calcisphaera laevis Williamson
Carbone/la sp.
Eotuberitina sp.
Kamaena sp.
Latiendothyra of the group *L. parakosvensis* (Lipina) *[L. skippae* (Armstrong)]
Palaeoberesella sp.
Palaeocancellus sp.
Parathurammina of the group *P. cushmani* Suleimanov
Parathurammina of the group *P. suleimanovi* Lipina
Proninella sp.
Radiosphaerina sp.
Septaglomospiranella sp.
Septatournayella sp.
Spinoendothyra spinosa (Chernysheva)
Tournayella sp.
Vicinesphaera sp.
Age: Zone 9, late Keokuk age equivalent, late Tournaisian
N.B. Record of *Endothyra spiroides* by Armstrong (1967, fig. 26) in these strata is to be discarded.
tipper part, 26.8 to 33 m
Calcisphaera laevis Williamson
Kamaena sp.
Latiendothvra so.
Latiendothyra of the group *L. parakosvensis* (Lipina) *[L. skippae* (Armstrong)]
Ortonella sp.
Palaeocancellus sp.
Parathurammina of the group *P. cushmani* Suleimanoy
Parathurammina of the group *P. suleimanovi* Lipina
Septaglomospiranella sp.
Spinoendothyra sp.
Vicinesphaera sp.
Age: Zone 9, late Keokuk age equivalent, late Tournaisian
N.B. Attribution to the Meramecian by Armstrong (1967, fig. 16) is to be modified.

Tererro Formation, Manuelitas Member
Lower part, 33 to 38.5 m
Aoujgalia sp.
Calcisphaera sp.
Earlandia vulgaris (Rauzer-Chernoussova and Reitlinger)
Endothyra of the group *E. bowman'* Phillips *emend* Brady *[E. irregular's* (Zeller)]
Endothyranopsis sp.
Eoendothyranopsis sp.
Eoendothyranopsis of the group *E. ermakiensis* (Lebedeva)
Eoendothyranopsis macra (Zeller)
Eoendothyranopsis prodigiosa (Armstrong)
Globoendothyra sp.
Koninckopora inflata (de Koninck)
Stacheia sp.
Stacheoides tenuis Petryk and Mamet
Age: Zone 14, late Meramecian age equivalent, late Viscan
Upper part, 39 m
A rchaediscus sp.
Brunsia sp.
Calcisphaera sp.
Calcisphaera pachysphaerica (Pronina)
Earlandia sp.
Endothyra sp.
juvenile *Globoendothyra* sp.
Age: Probably > Zone 14(?) (sieved fauna), late Meramecian age equivalent, late Visean.

Jemez Mountains

The Arroyo Penasco Group in the Jemez Mountains outcrops at Soda Dam and Guadalupe Box (Figs. 1, 6, 7) has been extensively -removed by pre-Pennsylvanian erosion, with only 10 to 12 m left of the Espiritu Santo Formation. This is unconformably overlain by 2 to 4 m of the Log Springs Formation, which in turn is unconformably overlain by unnamed Morrowan age arenaceous limestones.

Figure 5. Outcrop of the Arroyo Penasco Group along the crest of the northwestern side of San Pedro Mountain. View is to the east.

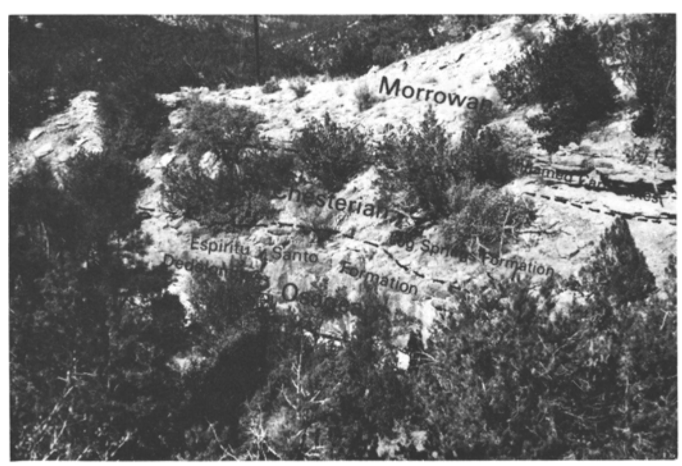


Figure 6. Outcrop of the Espiritu Santo Formation in the Arroyo Penasco Group at Guadalupe Box Canyon, Jemez Mountains.

Figure 7. A large, enigmatic, circular, radial form found by S. A. Northrop, October 1973, on the northeast side of Guadalupe Box Canyon on the upper surface of the Espiritu Santo Formation and overlain directly by the Log Springs Formation. Its shape is suggestive of a colonial coral or jelly fish but may represent calcite pseudomorphs after gypsum. It is preserved by coarse-grained dedolomite crystals.

Microfossils found in the dark-gray and brown nodular cherts within the coarse-grained dedolomites have yielded a well-preserved fauna of Keokuk, Zone 9, age.

Soda Dam section, 65A-20
Espiritu Santo Formation
10.7 m

Calcisphaera sp.
Cakisphaera laevis Williamson
Earlandia sp.
"Globoendothyra" trachida (Zeller)
Inflatoendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina) *[(L. skippae* (Armstrong)]
Parathurammina sp.
Septabrunsiina sp.
Septaglomospiranella sp.
Spinoendothyra spinosa (Chernysheva)
Age: Zone 9, late Keokuk age equivalent, late Tournaisian

Sandia Mountains

The Arroyo Penasco Group at the north end of the Sandia Mountains is 22 m thick and is the Osagean Espiritu Santo Formation (Figs. 1, 8). It consists of about 2 m of the Del Padre Sandstone Member and 10 m of stromatolitic dedolomites followed by lime mudstones and dolomites and minor amounts of wackestones. The nodular dark-gray cherts in the lower part of the section have yielded well-preserved microfossils, and the lime mudstones have yielded microfossils in the upper parts of the section.

Placitas section, 65A-1 and 72 N-1
Espiritu Santo Formation

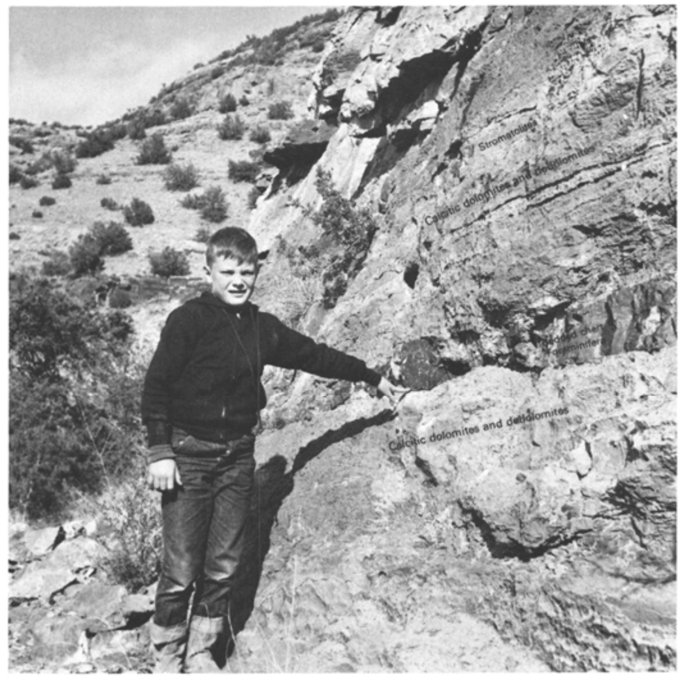


Figure 8. Fossiliferous chert beds surrounded by dedolomites in the Espiritu Santo Formation, Sandia Mountains. The chert beds are 3.7 m above the Precambrian contact.

Base, 3.7 to 4.6 m
Calcisphaera laevis Williamson
Earlandia clavatula (Howchin)
Endothyra sp.
cf. *Endospiroplectammina?* sp.
Inflatoendothyra sp.
Latiendothyra sp.
Latiendothyra of the group *L. parakosvensis* (Lipina) *[L. skippae* (Armstrong)]
Parathurammina of the group *P. cushmani* Suleimanov
Parathurammina of the group *P. suleimanovi* Lipina
Septatournayella sp.
Septaglornospiranella sp.
Spinoendothyra sp.
Age: Zone 9, late Keokuk age equivalent, late Tournasian

Middle part of the section, 12.8 m
Calcisphaera laevis Williamson
Latiendothyra sp.
Palaeocancellus sp.
Parathurammina sp.
Radiosphaerina sp.
Septaglornospiranella sp.
Vicinesphaera sp.
Age: As above.

Upper part of the section, 21 m
Calcisphaera loevis Williamson
Parathurammina of the group *P. cushmani Suleimanov*
Parathurammina of the group *P. suleimanovi* Lipina
Septatournayella sp.
Tournayella sp.
Vicinesphaera sp.
Age: As above.

N.B. The report of Endothyra prodigiosa, E. irregularis, and *E. macre* at that level (Armstrong, 1967, fig. 40) must be discarded. The horizon is Osagean age equivalent, not Meramecian.

The Espiritu Santo Formation is unconformably overlain by 2 to 3 m of red shales and siltstone of the Log Springs Formation, which are unconformably overlain by the coarse-grained crossbedded sandstones of the Sandia Formation.

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APPENDIX

Location maps of outcrop sections shown in Figure 1

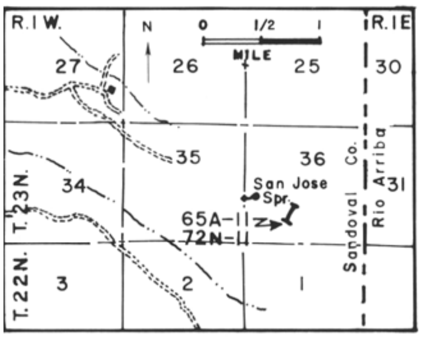

Figure 9. San Pedro Mountain section, 65A-11, 72N-11.

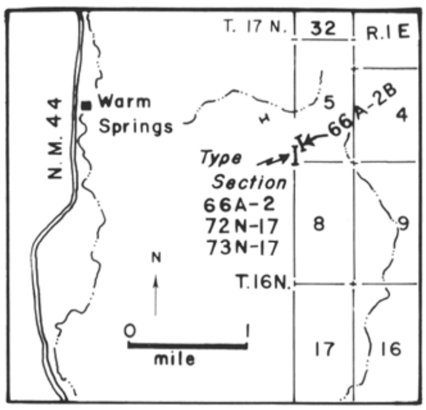

Figure 10. Pinos and Penasco Canyon, Arroyo Penasco Group, type section Log Springs Formation, Nacimiento Mountains, sections 66A-2, 72N-17, 66A-2B, and 73N-17.

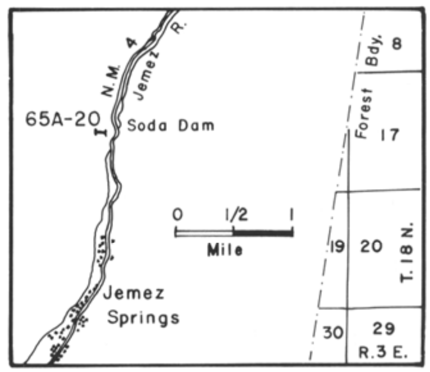

Figure 11. Soda Dam section, Jemez Mountains, 65A-20.

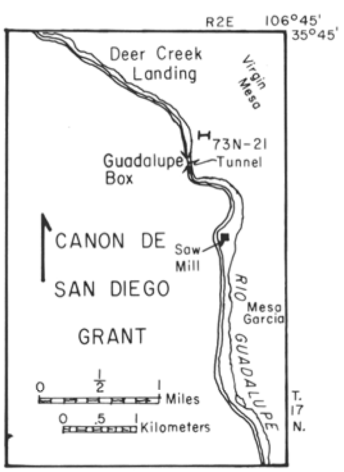

Figure 12. Guadalupe Box Canyon section, Jemez Mountains, 73N-21.

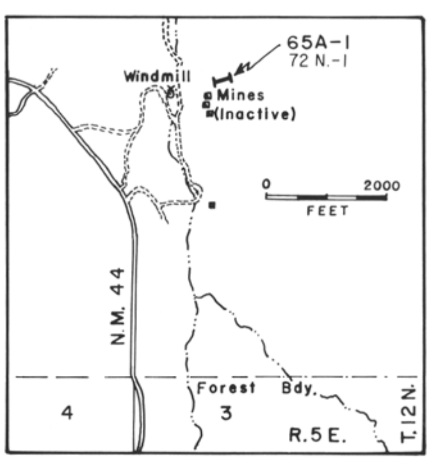

Figure 13. Placitas, Sandia Mountains, sections 65A-1, 72N-1.

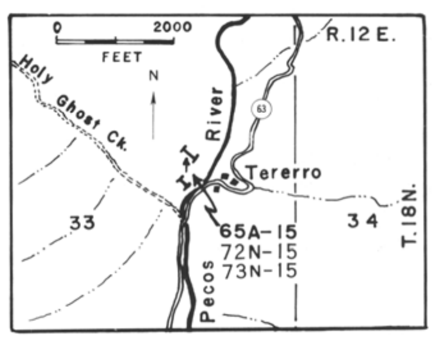

Figure 14. Tererro, Pecos River Canyon, Sangre de Cristo Mountains, sections 65A-15, 72N-15, 73N-15.

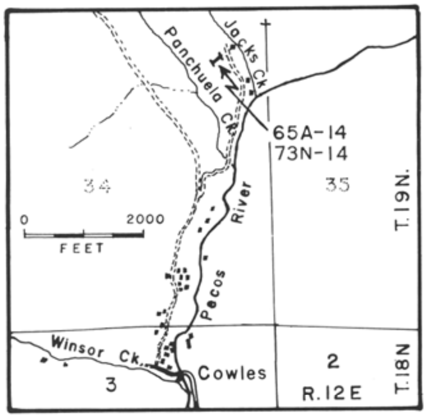

Figure 15. Jacks Creek, Sangre de Cristo Mountains, 65A-14, 73N-14.

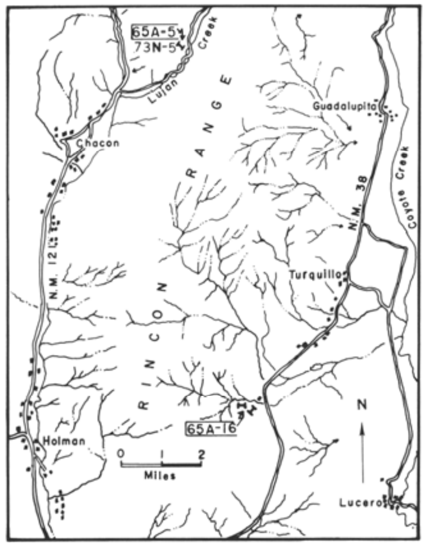

Figure 16. Lujan Canyon 65A-5, 73N-5 and Turquillo 65A-16 sections, Rincon Range, Sangre de Cristo Mountains. Lujan Canyon section 3.9 miles northeast of Chacon Presbyterian Day School. Turquillo section 4 miles south of Turquillo village on N. Mex. Highway 38, then east to small ranch and up canyon on old logging road 0.5 mile. Mississippian outcrop is along south side of the canyon wall. Index map from N. Mex. State Highway Commission, Black Lake quadrangle (1952 edition).

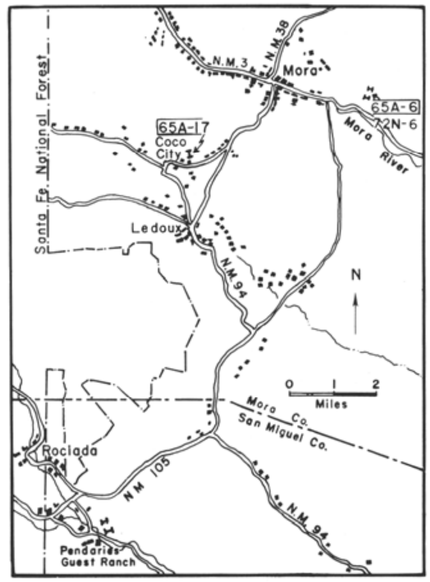

Figure 17. Coco City 65A-17, 73N-17 and Mora Gap 65A-6, 72N-6 sections, Sangre de Cristo Mountains. Coco City section was measured on the north side of the dirt road east of Coco City village. Mora Gap section, on the north side of Mora River 1.9 miles east of Mora town limits, was measured at two locations; basal part well exposed 100 yards north of main outcrop. Index map from N. Mex. State Highway Commission, Las Vegas quadrangle (1951 edition).