STRATIGRAPHY AND PETROLOGY OF MISSISSIPPIAN, PENNSYLVANIAN, AND PERMIAN ROCKS IN THE MAGDALENA AREA, SOCORRO COUNTY, NEW MEXICO

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by

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ABSTRACT

Areally restricted beds of the Mississippian and Pennsylvanian periods occur in the Magdalena Mountains of west-central New Mexico. In surrounding areas, some sections previously considered Pennsylvanian in age are now believed to be of Permian age. The conglomerates and sandstones of the Caloso Formation are a typical transgressive sequence. The gray, crinoidal wackestones and packstones of the Kelly Formation represent subtidal deposition on a shallow marine shelf. Dark, carbonaceous shales, coarse-grained quartzites, and thin, gray fossiliferous, micritic limestones found in the Sandia Formation represent deposition on a shoreline complex. The Sandia nomenclature of Loughlin and Koschmann (1942) is difficult and impractical to use and its further use is not supported. The homogenous, micritic limestones of the Madera Limestone are thought to have accumulated on a shallow, marine, carbonate shelf characterized by local, deeper, more restricted areas. Mississippian and Pennsylvanian rocks in the Magdalena Mountains provide an example of ancient marine shelf sedimentation similar to models presented by various authors representing sedimentation on modern marine shelves.

INTRODUCTION

Area of Study

The area of investigation embraces the west-central portion of Socorro County, New Mexico and centers in the Magdalena Mountains where Mississippian and Pennsylvanian rocks are well exposed. The type section of the Magdalena Group is located in the northern Magdalena Mountains. At the type section, the Pennsylvanian sequence is about 1,200 feet thick. Loughlin and Koschmann (1942) divided the Magdalena Group into the Sandia Formation below and the Madera Limestone above.

The underlying Mississippian strata are about 125 feet thick. Armstrong (1958) divided the Mississippian in the Magdalena Mountains into an underlying Caloso Formation and an overlying Kelly Limestone.

Purpose of Study

The primary objectives of the present study are:

1. definition of practical stratigraphic units for mapping
2. observation of facies changes within units
3. description of the petrologic character of the units
4. interpretation of the environments of deposition of the units in the Mississippian and Pennsylvanian Systems.

Method of Study

Five outcrop areas were chosen for sampling and section measurement by the brunton and tape method. Locations of the sections are shown on plate 1. They are:

1. North Fork Canyon, Magdalena Mountains
2. North Baldy, Magdalena Mountains
3. Tip Top Mountain, Magdalena Mountains
4. Olney Ranch, Magdalena Mountains
5. Tres Montosas, Gallinas Mountains

Samples from the five sections (Appendix I) and from a drill hole south of Tres Montosas were analyzed petrographically with some supplementary x-ray diffraction analyses. Data accumulated from thin section analysis may be found in Appendix II. All classification systems used in this study are located in Appendix III.

Location and Accessibility

The Magdalena Mountains lie about 20 miles west of Socorro and 70 miles south of Albuquerque in west-central Socorro County, New Mexico. Tres Montosas is located about 15 miles west of the Magdalena Range (fig. 1).

Magdalena, New Mexico, a village of about 650 people, is the principle settlement of the region. Magdalena is located 26 miles west of Socorro on State Highway 60. From Magdalena, the sections in the Magdalena Mountains are reached by mining and Forest Service roads that provide access up the rugged slopes and along the crest of the range

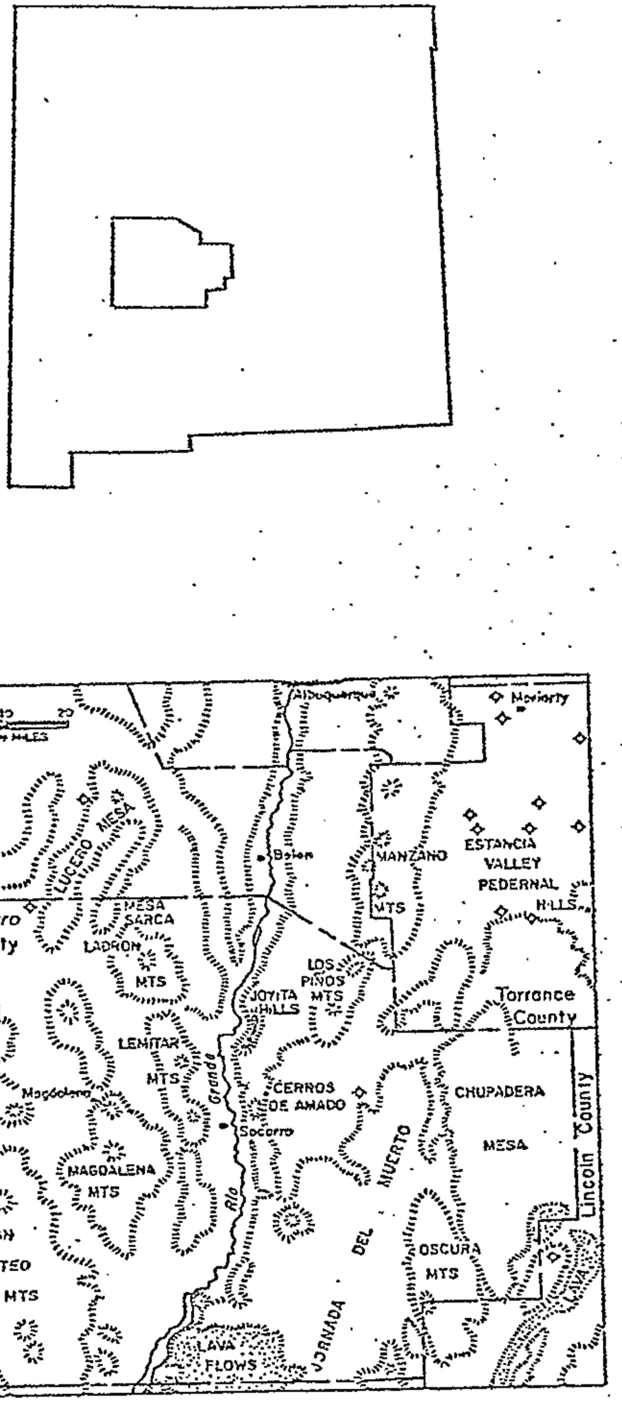

Figure 1. Index Maps of New Mexico (after Kottlowski and Stewart, 1970).

for 4-wheel-drive vehicles. The Tres Montosas section is reached by traveling 5 miles west of Magdalena along Highway 60, then north.

ACKNOWLEDGMENTS

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PALEOTECTONIC SETTING

Several Precambrian land masses, collectively referred to as the Ancestral Rocky Mountains, are known to have existed throughout the Late Paleozoic. Included among these are the Peñasco-Uncompahgre positive area centered in north-central New Mexico, the Zuni-Defiance uplift of northwestern New Mexico and northeastern Arizona, the Pedernal uplift in central New Mexico, the Kaibab Arch of north-central Arizona, the Florida landmass of southwestern New Mexico, the Joyita uplift north of the present Joyita Hills of west-central New Mexico, and the Sierra Grande Arch in northeastern New Mexico and southeastern Colorado (fig. 2).

A tectonic pattern initiated in early Osage time affected Mississippian sedimentation in southwestern New Mexico throughout the period (Armstrong, 1962). Three elements were important in this tectonic pattern (fig. 3):

1. the Peñasco uplift
2. a slowly sinking shelf to the south
3. a rapidly subsiding shelf region in the extreme south.

The Peñasco uplift was a low island that remained barely awash throughout the early and middle Paleozoic. Available evidence (Kelley and Silver, 1952; Kottlowski, et al., 1956; Armstrong, 1958 and 1962) indicates that it was a major source of clastic material only in the late Cambrian Period and was, by early Mississippian time, only a peneplaned surface cut on Precambrian metamorphic and igneous rocks.

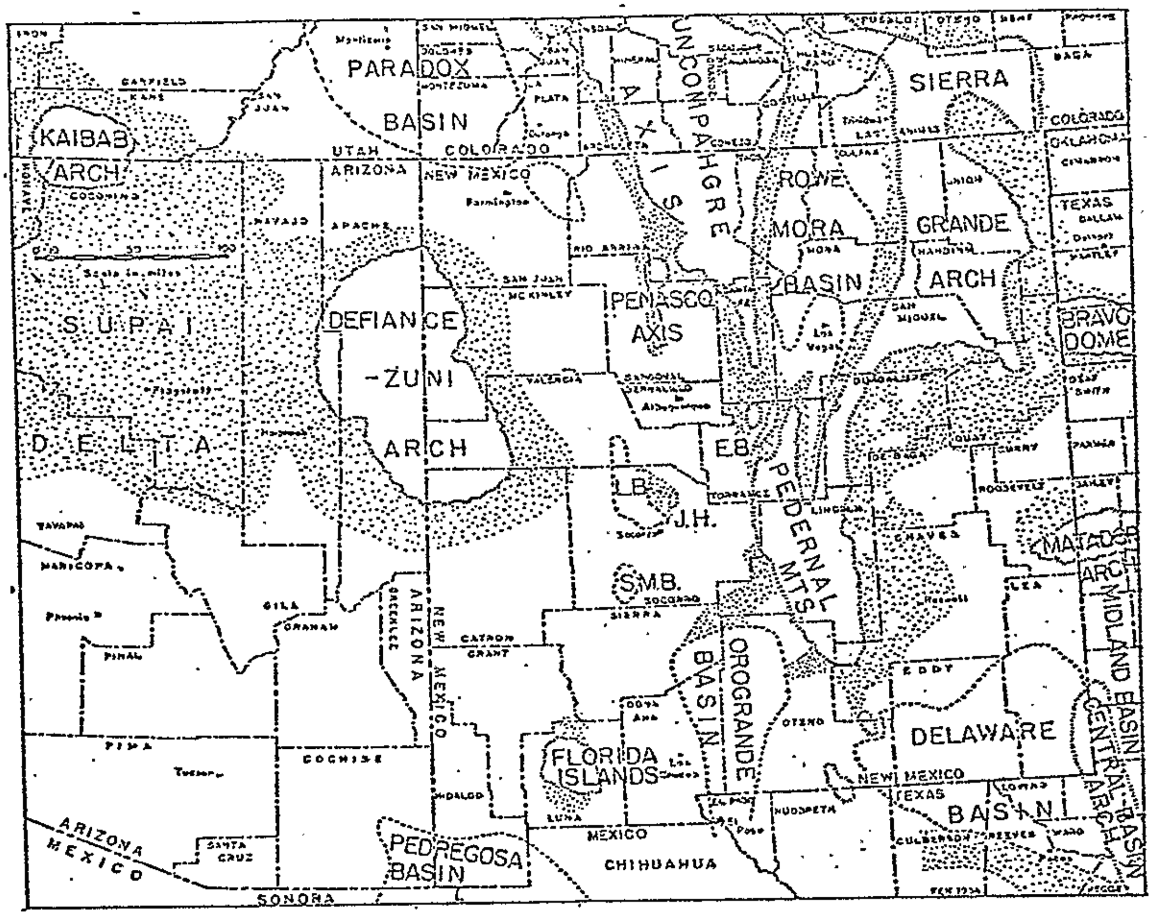

Figure 2. Pennsylvanian Paleogeographic Map of New Mexico (after Kottlowski, 1962).

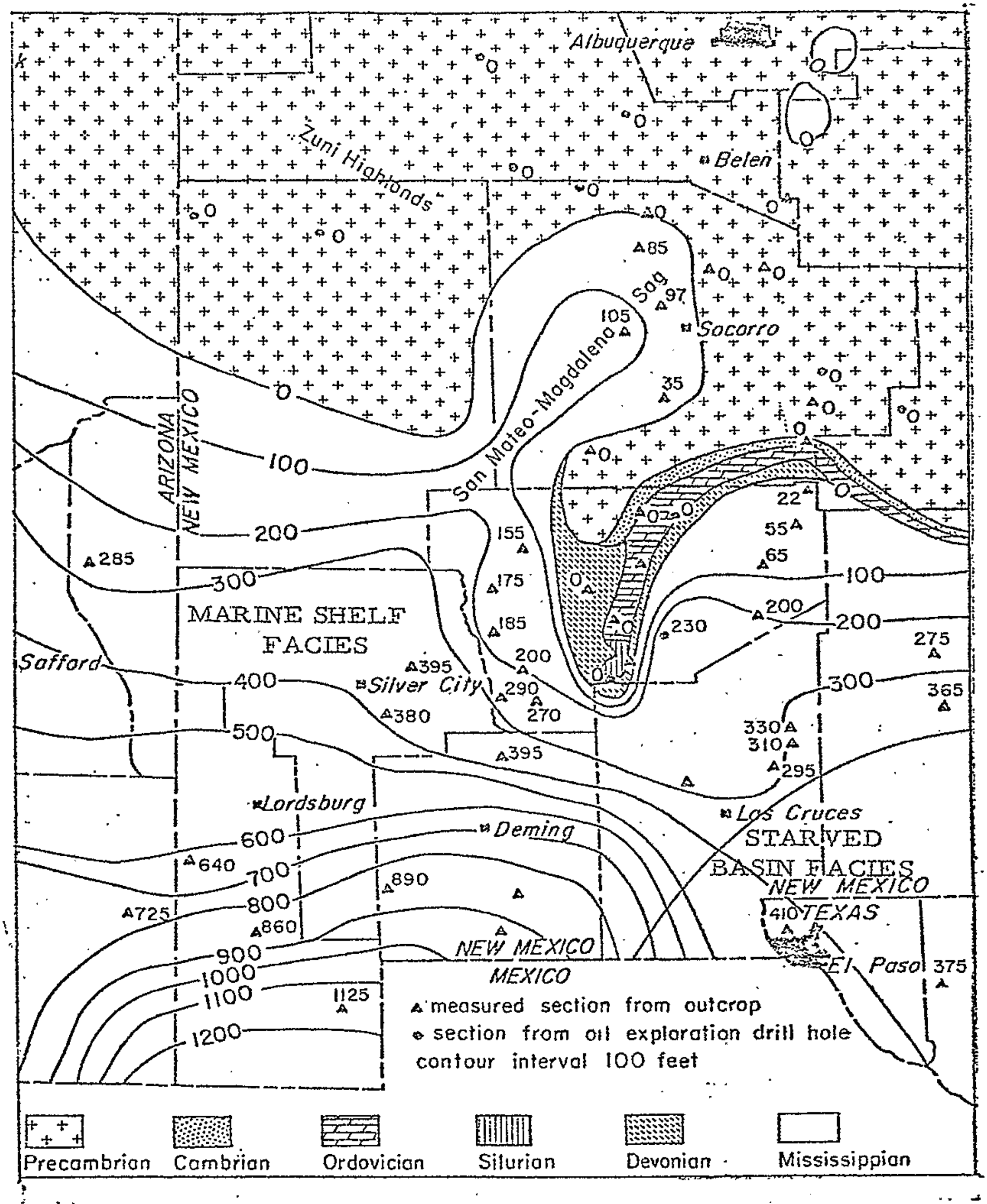

Figure 3. Isopach and Facies Map of Mississippian Strata (modified after Armstrong, 1962).

South of the Peñasco uplift, a shallow shelf area developed and subsided at a slow rate until the end of Meramec time. Subsidence of the gently sloping shelf was more rapid in the southern part of the state. In south-central New Mexico and the Trans-Pecos region of Texas, Armstrong (1962) noted the development of a starved basin facies with an open marine shelf carbonate facies to the west in southwestern New Mexico and southeastern Arizona.

The maximum inundation began in Kinderhookian time and was affected by an eastward transgression from the Cordilleran miogeosyncline through the Paradox Basin, around the north flank of the Zuni-Defiance uplift, and into portions of the present San Juan Basin. Coming from the south, another transgression passed between the Pedernal highlands and the Zuni-Defiance uplift. By late Osage time, the seas covered north-central New Mexico, reduced the Zuni-Defiance uplift to a mere island and completely covered the weakly developed Transcontinental Arch (Armstrong, 1967).

Following a period of uplift at the end of the Mississippian, all of the Paleozoic positive areas became contributors of debris to Pennsylvanian sediments in New Mexico. The Joyita highlands and the Florida highlands never gained more than local importance and the Zuni-Defiance landmass was periodically awash beneath the shallow Pennsylvanian seas. Parts of the Pedernal uplift became important contributors of debris while the Kaibab uplift was important only as a local source for the Supai Delta in northwestern Arizona (Kottlowski, 1960).

A number of areas that tended to remain more negative than the surrounding shelf areas also played important roles in Pennsylvanian sedimentation. Among these basins were the Estancia, Lucero, and San Mateo basins of central New Mexico, the Orogrande basin of south-central New Mexico, the Delaware basin in the southeast corner of the state, and the Pedregosa basin of extreme southwestern New Mexico and southeastern Arizona.

MISSISSIPPIAN PERIOD

Previous Work

In the Magdalena Mountains, Herrick (1904) named a Mississippian section consisting of crystalline light-colored limestone with an interbedded dense, dolomitic lime, the Graphic-Kelly Limestone. The name was derived from two major mines in the district. Three years later, Gordon (1907) revised the nomenclature and called the same section the Kelly Limestone after nearby Kelly, New Mexico.

Loughlin and Koschmann (1942), while studying the geology and ore deposits of the Magdalena mining district, collected a small number of fossils near the base and near the top of the Mississippian section. A study of these by G. H. Girty suggested they were of different geologic age. Additional work in the area, along with observations in the Lemitar and Ladron Mountains, led Armstrong (1958) to divide the Mississippian section into a lower Caloso Formation and an upper Kelly Formation. Armstrong (1955) had previously named the Caloso Formation for the basal part of the Mississippian section in the Ladron Mountains.

Regional Stratigraphy

In New Mexico, Mississippian rocks represent a period of time extending from Late Kinderhook through Middle Chester (fig. 4); however, Late Mississippian and Early Pennsylvanian erosion extensively removed Mississippian sediments from large portions of the state making reconstruction of the different Mississippain facies difficult.

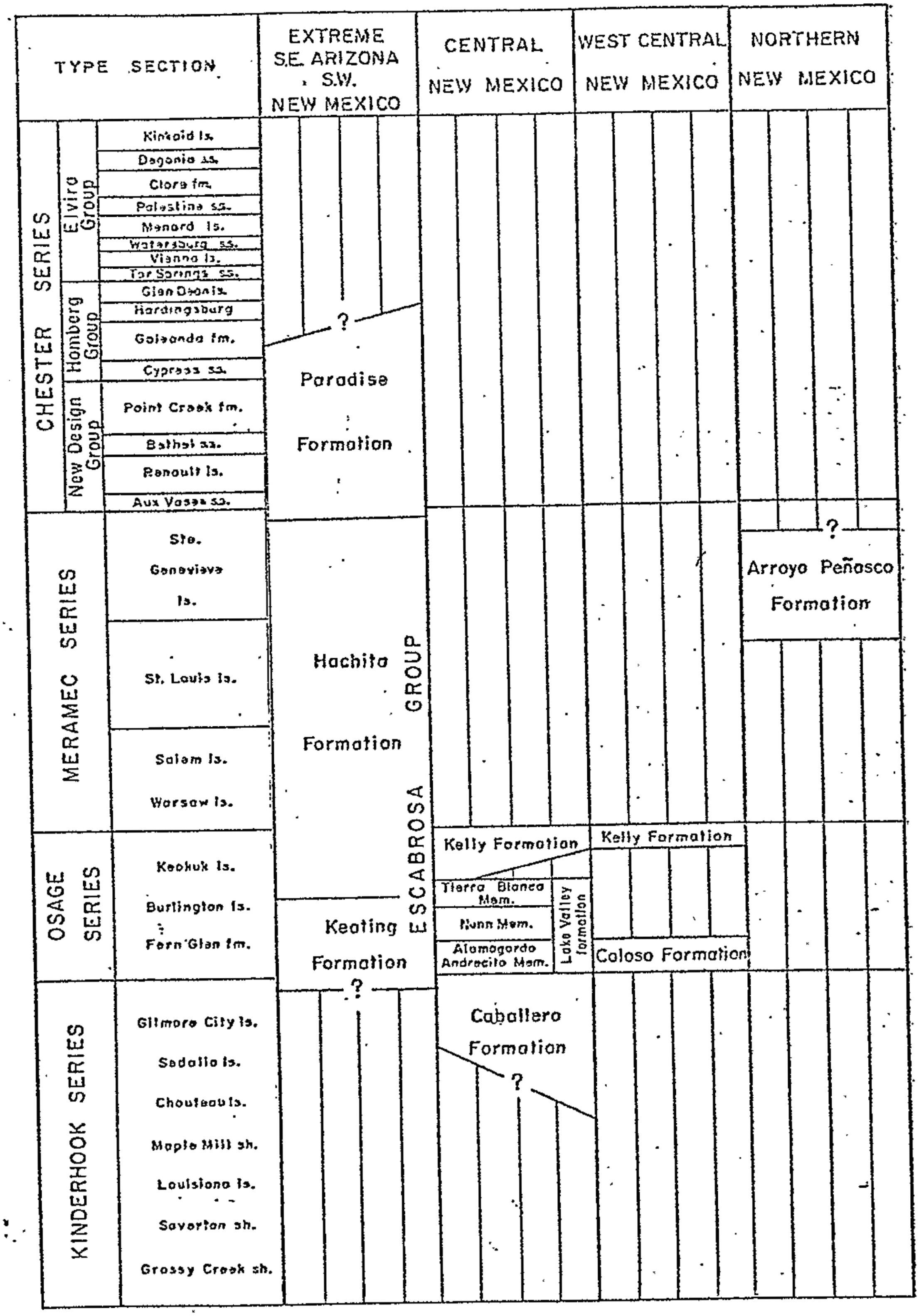

Figure 4. Correlation of Mississippian Sections in New Mexico (modified after Armstrong, 1962).

NORTHERN NEW MEXICO. The thin Upper Meramec limestones of the Arroyo Peñasco Formation are the only known Mississippian rocks in northern New Mexico and, along with the upper part of the Hachita Formation in the southwestern part of New Mexico, represent the only rocks of known Meramec age within the state. Armstrong (1967), in discussing the Arroyo Peñasco Formation, described a 2- to 60-foot-thick basal unit consisting of quartz conglomerate, sandstone, and thin shale. He divided the overlying carbonates into three incomplete cycles. In ascending order these are: 1) a lower dolomite; 2) a medial wackestone to lime mudstone; and 3) a wackestone to oolitic packstone overlain by lime mudstone or intertidal dolomite.

SOUTH-CENTRAL NEW MEXICO. The extent and faunal assemblages of the earliest Mississippian rocks in the central part of the state are not clearly known. These rocks, first named the Caballero Formation by Laudon and Bowsher (1941), are indicated by a large invertebrate fauna to be Late Kinderhookian (Chouteau to Gilmore City) in age. The rocks disconformably overlie various Devonian formations.

The Caballero Formation varies from a feather-edge to 60 feet in thickness and is a gray, mottled, nodular, shaly limestone with interbedded thin, calcareous shales. Locally, a thin, fissile, black, basal shale is present. The overlying Osage rocks in south-central New Mexico are divided into the Lake Valley Formation, representing Early and Middle Osage (Fern Glen and Burlington) times, and the Kelly Formation representing Late Osage (Keokuk) time.

Laudon and Bowsher (1949) recognized six members in the Lake Valley Formation. In ascending order they are: 1) 35 feet of gray, fossiliferous limestones of the Andrecito Member; 2) 30 to 50 feet of massive, cherty, poorly fossiliferous, cliff-forming, black limestones of the Alamogordo Member; 3) 1 to 100 feet of soft, blue-gray marls and nodular, crinoidal limestone of the Nunn Member; 4) 10 to 125 feet of medium-bedded, cherty, gray to brown, crinoidal coquinas of the Tierra Blanca Member; 5) 25 to 230 feet of soft, thin-bedded, gray, calcareous siltstones and shales of the Arcente Member; and 6) 175 feet of medium-bedded to massive, gray to black, cherty, crinoidal coquinas of the Dona Ana Member. The Kelly Formation, of Keokuk age consists of as much as 125 feet of somewhat-massive, gray to tan, cherty, crinoidal limestone (Laudon and Bowsher, 1949).

SOUTHWESTERN NEW MEXICO. Armstrong (1962), while working in Cochise County, Arizona and in Luna, Hidalgo, and Grant Counties of Southwestern New Mexico, named the Mississippian rocks the Escabrosa Group. The Escabrosa Group has a minimum thickness of 650 feet in the Peloncillo Mountains and a maximum thickness of 1, 000 feet in the Big Hatchet Mountains of New Mexico. Armstrong also divided the Escabrosa Group into a lower 350- to 590-foot-thick Keating Formation and an upper 250- to 350-foot-thick Hachita Formation.

The oldest Mississippian rocks found in southwestern New Mexico are the Early Osage (Burlington) limestones of the Keating Formation. Armstrong (1962) divided the Keating Formation into a lower member A and an upper member B. The lower part of member A consists of about 50 feet of well-sorted, crinoidal limestone. Above this is 20 to 50 feet of massive, dark-gray, nodular limestone with an abundant and varied fauna of corals, brachiopods, endothyrids, blastoids, bryozoans, crinoids, and occasional trilobites and gastropods. Member B consists of dark-gray, thin-bedded, lithographic, pelletoidal limestones that grade into crinoidal calcarenites with a sparse brachiopod, coral, and bryozoan fauna.

The overlying Hachita Formation ranges in age from Late Osage (Keokuk) to Late Meramec (St. Genevieve). The lower part of the Hachita Formation is primarily light-gray massive, crinoidal limestone with irregularly occuring chert nodules. Above this pure crinoidal limestone, the proportion of brachiopods, bryozoans, and endothyrid foraminifera becomes greater.

The Paradise Formation is present above the Hachita Formation. The 250- to 300-foot-thick Paradise Formation is comprised of thin, interbedded limestones, shales and fine sandstones. The Paradise Formation is Late Meramec (St. Genevieve) to Middle Chester (Homberg) in age and is the only formation known to be of this age in New Mexico.

Present evidence demonstrates continuous deposition from Osage through Meramec time and if there is a hiatus present it is completely masked in the field (Armstrong, 1962). The regressive Chester sequence, however, reflects a distinct departure from the widespread environment of stability that prevailed through most of the Mississippian. The structural and sedimentation patterns that were to dominate the Pennsylvanian Period were clearly defined by this time (Kottlowski, 1960).

Local Stratigraphy

Armstrong (1955), working in west-central New Mexico divided the Mississippian into a lower Caloso Formation and an upper Kelly Formation. He defined the 0 to 30 foot, pre-Keokuk, Caloso Formation as a sequence of basal sands, arkoses, and shales overlain by a fine-grained, cherty, algal, massive, gray limestone. The Caloso fauna included brachiopods, corals, gastropods, and several pelecypod genera (table 1).

The overlying Kelly Formation is comprised of crinoidal, medium-crystalline, gray limestone with white to light-gray chert. The brachiopod, endothyrid, and blastoid fauna (table 2) suggests a Keokuk age for the Kelly Formation.

In the Magdalena Mountains, the oldest Paleozoic rocks are Mississippian strata that rest on a truncated Precambrian surface. In the northern part of the range, the Mississippian System is well exposed as a winding, undulating band along the narrow, knife-edged crest of the range (fig. 5). Of the five sections measured, Mississippian rocks were exposed at three: Tip Top Mountain, North Baldy, and North Fork Canyon.

<u>TIP TOP MOUNTAIN.</u> At Tip Top Mountain, the basal 3 feet of the Caloso Formation is a greenish-black limestone with poorly sorted,

CALOSO FORMATION

Brachiopoda
Schuchertella? sp.
Camarotoechia tuta (Miller)
Rhynchotreta? sp.
Spirifer louisianensis Rowley
Spirifer centronarus ladronensis, n. subsp.
Composita? sp.
Syringothyris? sp.
Streptorhynchus? sp.

Mollusca
Pelecypods, several genera
Straparolus luxus (White)

Coelenterata
Michelinia sp.
Aulopora sp.
Cyathophyllum? sp.

Table 1. Fauna of the Caloso Formation, Magdalena Mountains (modified after Armstrong, 1958).

KELLY FORMATION

Brachiopoda
"*Orthotetes?*" sp.
Streptorhynchus? sp.
Rhipidomella sp.
Linoproductus sp.
Productus, sensu lato, several species
Echinoconchus? sp.
Tetracamera cf. *subtrigona* (Meek and Worthen)
Tetracamera subcuneata (Hall)
Spirifer tenuicostatus Hall
Spirifer grimesi Hall
Spirifer? sp.
Brachythyris suborbicularis (Hall)
Athyris aff. *lamellosa* (Leveille)
Cleiothyridina hirsuta (Hall)
Cleiothyridina? parvirostris (Meek and Worthen)
Cleiothyridina obmaxima (McChesney)

Blastoidea
Pentremites conoideus Hall
Orbitremites floweri, n. sp.

Mollusca
Platyceras sp.
Straparolus spp.
Pelecypods, several genera

Coelenterata
Zaphriphyllum casteri, n. sp.
Rare fragments of an indeterminable genus

Bryozoa
Large fauna

Arthopoda
"*Phillipsia*" sp.

Vertebrata
Shark's tooth

Protozoa
Plectogyra sp.

Table 2. Fauna of the Kelly Formation, Magdalena Mountains (modified after Armstrong, 1958).

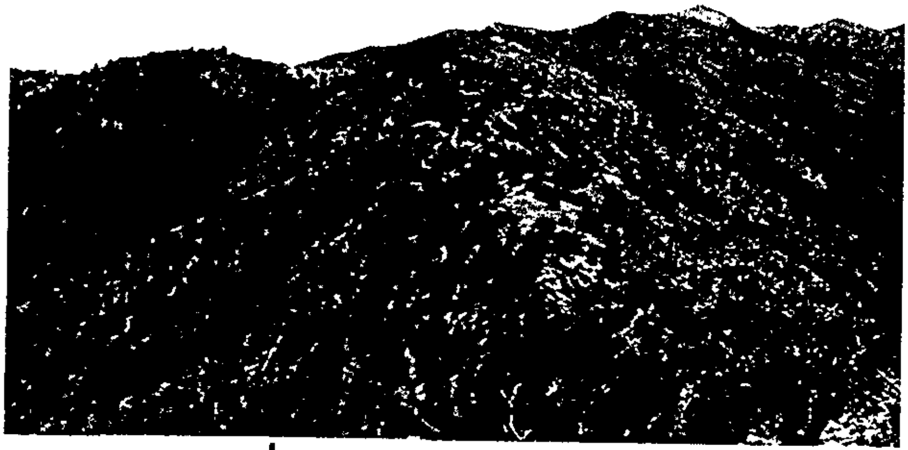

Figure 5. View from Tip Top Mountain looking southward along the crest of the Magdalena Range. North Baldy is the high peak at upper right. The Kelly Limestone crops out boldly in the center foreground and forms the dip-slope towards the west.

angular to round, coarse-grained sand- to pebble-size fragments of Precambrian quartz, microcline quartz, granite, and greenschist. It is in this lower arkosic limestone bed that Armstrong (1955) has identified the following brachiopods: Spirifer Louisanesis Rowley, Camarotoechia tuta (Miller), Schuchertella ? sp., Conposita ? sp., and a possible Spirifer centronatus ladronesis, n. subsp. Above this basal bed is about 12 feet of sandy limestone with granules and pebbles of angular to well-rounded poorly-sorted Precambrian quartz and quartzite. The absence of feldspar and large Precambrian fragments probably indicates deeper water and a farther removed source area. Overlying this bed is about 15 feet of medium-gray limestone containing medium- to very coarse-grained sand, limestone clasts and quartzite fragments (fig. 6). Total thickness of the Caloso Formation at Tip Top Mountain is about 30 feet.

Upper beds of the Mississippian section include 95 feet of light-gray, medium-bedded, crinoidal limestone of the Kelly Formation (fig. 7). White, nodular chert increases in size until, in the thinner bedded upper strata, lenticular masses attain thicknesses of 6 inches and lengths of 4 feet. Fenestellid bryozoans are quite numerous near the top of the section. Echinoderms, brachiopods and horn corals are also present.

NORTH BALDY MOUNTAIN. On North Baldy Mountain, about a mile and a half south-southeast of the Tip Top section, the basal 7 feet of Mississippian is intensly silicified. Within the silicified matrix are grains of moderately sorted, subangular, medium-grained quartzose

Figure 6. Basal coarse-grained, conglomeratic strata of the Caloso Formation overlain by well-sorted, sandy limestones of the upper Caloso at Tip Top Mountain.

Figure 7. Crinoidal limestone in the Kelly Limestone near Tip Top Mountain. The large crinoid fragments are very conspicuous in this Kelly grainstone which consists primarily of reworked crinoid fragments.

sand. Here the Caloso is very light-gray in color and weathers a moderate yellowish-brown to black.

Above the basal, silicified, terrigenous Caloso Formation is 81 feet of poorly-cemented, medium- to thick-bedded, crinoidal Kelly Limestone. White chert lenses are present throughout (fig. 8). Near the center of the unit is 1 to 2 feet of very thin-bedded, gray micrite.

Another silicified zone overlies the crinoidal limestone. This 25-foot-thick zone beautifully displays the jasperoid "ribbon rock" that is so common in the Kelly Formation throughout the Magdalena district (fig. 9). Megascopically, the original composition and texture are masked; in thin section, however, relict textures indicate the rock is a crinoidal limestone.

<u>NORTH FORK CANYON</u>. In North Fork Canyon the Mississippian section is a slope former and crops out poorly. At this location, the Caloso Formation is not present and the 64-foot-thick Kelly Limestone unconformably overlies the Precambrian. The lower 10 feet of Kelly Limestone is a micrite to sparite with a very small amount of medium-grained, well-sorted, well-rounded, detrital quartz sand. Echinoderm fragments are also found, but are very limited in this lower unit. Above this 10 foot unit is 54 feet of cherty, light- to medium-dark-gray, crinoidal limestone. Echinoderms are abundant in the lower and middle parts of this unit, but become very scarce in the highest parts. At the very top only a finely laminated micritic limestone is present. As in the sections

Figure 8. White chert in crinoidal Kelly Limestone at North Baldy. The chert occurs as large lenticular masses 3 or 4 feet long and 1 to 3 inches thick. Armstrong (1962) suggests these chert masses result from diagenetic accumulation of silica that was disseminated through the calcareous muds.

Figure 9. Sharp contact between unaltered limestone and intensely silicified limestone within the Kelly Formation. From Tip Top Mountain southward, the Kelly Formation has been extensively silicified and often these "ribbon-like" structures are produced with remarkably sharp contacts with relatively unaltered limestone. Silicification is most persistant in the upper beds, but may also be present in the lower beds. Drusy quartz, sometimes accompanied by barite, fluorite, and galena, line the voids between bands of dense jasperoid.

at Tip Top Mountain and North Baldy, white nodular and lenticular chert is abundant in the middle and upper parts of the section.

STRATIGRAPHIC SUMMARY. The Mississippian System in the Magdalena Mountains ranges in thickness from 64 feet in the North Fork Canyon area to about 125 feet in the northern part of the range. The system can generally be divided into a 7- to 30-foot lower clastic unit and an upper 54- to 95-foot crinoidal limestone.

The basal terrigenous unit consists of about 5 feet of poorly sorted, angular to round, coarse-grained sand to pebble-size fragments of Precambrian detritus in a carbonate matrix. Overlying the terrigenous base is as much as 25 feet of massive, medium-gray limestone with abundant rounded to angular, medium- to coarse-grained, quartz sand and sporadic Precambrian lithic fragments. Sparsely scattered throughout the unit are brachiopods, corals, bryozoans, and echinoderms.

The present study is in agreement with other studies of the Mississippian by Armstrong (1955 and 1958) and the continued use of the Caloso and Kelly nomenclature is suggested. The Caloso is limited to the lower 0 to 30 feet of pebbly, sandy arkosic limestones which contain pre-Keokuk fossils. The Kelly Formation is identified as the 0 to 95 feet of crinoidal limestone of Keokuk age that rests disconformably on the Caloso Formation and unconformably underlies the Sandia Formation of Pennsylvanian age. I suggest, however, that due to the thinness and limited exposure of the Caloso Formation, that the Caloso and Kelly formations should be mapped as Caloso-Kelly Formation undifferentiated unless mapping on a very large scale.

Petrography

The objectives of petrographic study were the description of the petrologic character of the units and an assessment, in terms of mineralogy and texture, of probable environments in which the units were deposited. Thin section study was supplemented by x-ray diffraction analysis.

CALOSO FORMATION. The Caloso Formation is dominated by carbonates that contain a high percentage of detrital debris. Quartz is the most abundant terrigenous constituent, with microcline, chert, and heavy minerals comprising less than 50 percent of the total detritus. In the Caloso, the detrital content ranges from 2 to 80 percent and averages about 35 percent. Although the fossil content is very limited, occasional echinoderm fragments are present. The orthochem content ranges from 40 to 98 percent and averages about 70 percent. It occurs as microspar that is considered to be recrystallized micrite. Detrital grains usually fall in the medium-grained sand range, but commonly vary as much as 2.1 Wentworth grades toward the coarser sizes or 2.8 Wentworth grades toward the finer sizes. The grains are poorly to moderately sorted, subrounded in shape, and have a sphericity coefficient of about .6. Diagenetic textures occurring within the limestones are predominantly neomorphic. Included are porphyroid and coalessive aggrading neomorphism and degrading neomorphism. Neomorphic grain shapes are fibrous to equant and grain sizes range from 1 to 5. Feldspars, quartz grains, and chert fragments display varying degrees of replacement by calcite. Most thin sections exhibit small fractures that are filled with sparry calcite or, less commonly, silica.

Almost all of the Caloso limestones are quartz micrites; however, they range from quartz micrite through quartz, feldspar, echinoderm pelmicrite depending on the varying quantity of these additional constituents. Using Dunhams classification (1962) most of the rocks are wackestones, or packstones. Figures 10, 11 and 12 are representative of lithologies characteristic of the Caloso Formation.

KELLY LIMESTONE. The Kelly Limestone is composed primarily of crinoidal limestone. The terrigenous content ranges from 0 to 25 percent and averages about 3.7 percent. This small percentage is usually comprised of reworked terrigenous spar or rounded grains of fine-grained, terrigenous, quartz sand. The organic allochem content averages about 36 percent, but may range from 0 to 95 percent. The most abundant fossils are echinoderms. Lesser numbers of brachiopods, bryozoans, corals, and ostracods are present. The taxonomic groups are restricted, for the most part to the echinoderms near the base of the formation but become increasingly diversified upward in the section. The fossil debris is generally broken and well-sorted. Calcite is the predominant orthochemical mineral. The orthochemical content averages

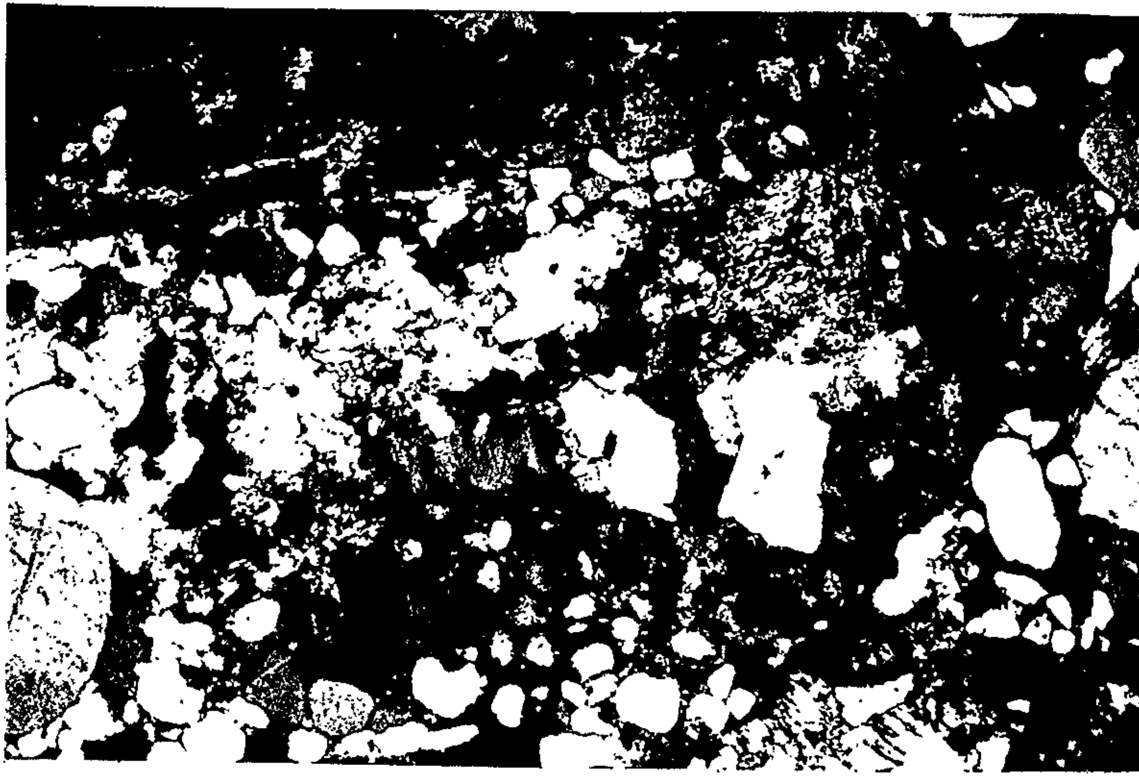

Figure 10. Photomicrograph of a highly terrigenous micrite in the lower part of the Caloso Formation at Tip Top Mountain. Coarse, angular to subrounded, poorly sorted quartz grains are the most abundant terrigenous constituents. In the upper left corner is a large microcline fragment that is undergoing replacement by calcite. The matrix material is micrite. X31.25. Name: Calcareous, Conglomeratic, Quartz Wacke.

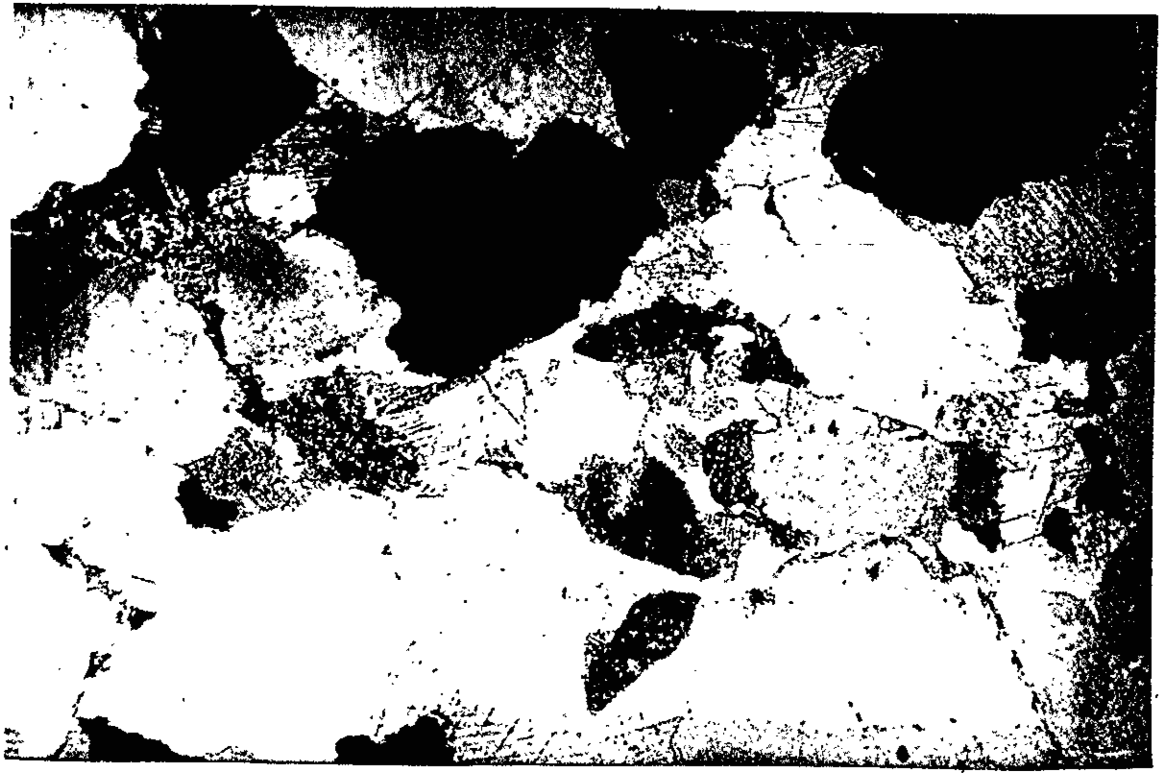

Figure 11. Photomicrograph of a quartz arenite in the upper part of the Caloso Formation at Tip Top Mountain. Terrigenous grains are well-sorted, subrounded, medium-grained quartz cemented by sparry calcite. The sparry cement is partially replacing quartz to form irregular grain boundaries. X31.25.
Name: Quartz Arenite.

Figure 12. Photomicrograph of a crinoidal limestone in the Kelly Limestone at Tip Top Mountain. Large rounded crinoid fragments are the most distinctive features. Microspar, interpreted as neomorphosed micrite is the most abundant orthochemical constituent. Crinoid fragments are undergoing degrading neomorphism. X31.25.
Name: Crinoid Biosparudite.

about 58 percent and usually occurs as micrite or microspar. Most of the microspar results from neomorphism of micrite. Some spar was formed by the same process but is erratic in its distribution and is in only limited quantities.

Neomorphic diagenetic textures are abundant in most thin sections. Both aggrading and degrading neomorphism are common and their form may be either coalessive or porphyroid. Grain shape is fibrous, bladed, or equant and sizes range from 2 to 6 but are most commonly 2 to 3. Replacement by silica is common throughout the Kelly Formation and, as a result of silicification and neomorphism, fossil "ghosts" are common occurrences in thin section. Fracturing, with later infilling by calcite and silica, is also quite common. It appears as if two periods of silicification occurred. The first was a period of limestone replacement which was followed by fracturing and in-filling of the fractures by silica.

The limestones in the Kelly Formation are predominantly biomicrudites. However, lithologies are rather varied and biosparites, biomicrites, and micrites are also found. Using Dunham's classification, most of the rocks are wackestones or packstones. Grainstones and mudstones are relatively uncommon.

	Caloso Formation	Kelly Limestone
Lithology	Conglomeratic lower unit overlain by a sandy limestone. Lower unit contains large fragments of Precambrain granite, greenschist, quartzite, and detrital quartz sand. Grains are poorly sorted, subangular, and medium sand size. Micrite and neomorphic microspar are the predominating orthochemical constituents and they comprise 65 to 70% of the rock.	Gray, crinoidal limestone. Crinoid fragments are rounded and well-sorted. Quartz grains are well-rounded, fine-grained, and seldom exceed 5%. The orthochemical content averages 58% and consists of micrite and neomorphic microspar. Biomicrudites, wackestones, and packstones are dominant lithologies. Chert nodules (white) are characteristic of upper beds. Silicification is common throughout the formation.
Fossils	The present study demonstrated the presence of limited numbers of crinoids. Armstrong (1958) found sparse mollusks, brachiopods, and coelenterates (corals) (table 2).	Fossil content averages 36% and ranges from 0 to 95%. Included are crinoid, brachiopod, bryozoan, coral, and ostracod fragments. Fenestelled bryozoans are abundant in the highest beds. The well-rounded, well-sorted fossil fragments indicate transportation and deposition in a high-energy environment.
Structures	Medium-bedded, channel scours at the base.	The limestones are medium-bedded. They exhibit small-scale, low-angle cross-bedding and planar-bedding at the North Fork Canyon section.

Table 3. Summary of Mississippian Sections.

PENNSYLVANIAN PERIOD

Previous Work

The nomenclature presently applied to the Pennsylvanian System in New Mexico by the U. S. Geological Survey and others was first used by Gordon (1907). Gordon referred to the Pennsylvanian System as the Magdalena Group, which he then divided into a lower terrigenous unit, the Sandia Formation, and an upper limestone unit, the Madera Limestone (fig. 13).

Thompson (1942), in a statewide study of Pennsylvanian rocks, divided each Pennsylvanian series into two groups on the basis of fusulinid faunal zones. These included: 1) a lower Green Canyon Group and an upper Mud Springs Group for the Derry Series; 2) a lower Armendaris Group and an upper Bolander Group for the Des Moines Series; 3) a lower Veredas Group and an upper Hansonburg Group for the Missouri Series; and 4) a lower Keller Group and an upper Fresnal Group for the Virgin Series. He further subdivided these groups into 16 formations and 1 member. Reflecting on the marked variation in Pennsylvanian lithologies around the state, Thompson suggested that his fusulinid faunal zones might not be recognizable in other lithic sequences.

Loughlin and Koschmann (1942), in describing the Magdalena Group at its type locality in the Magdalena Mountains, retained the Sandia and Madera formations of Gordon; however, they divided the Sandia Formation into six members. In ascending order these are: 1) a lower

Authors	HERRICK and BENDRAT	KEYES	KEYES	GORDON	KEYES	PAIGE	SCHMITT	SPENCER and PAIGE	NELSON
Date	1900	1903	1906	1907	1915	1916	1933	1935	1940
Area	Sandia Mts.	Sandia Mts.	Central New Mexico	Rio Grande Valley	New Mexico	Silver City area	Central Mining area	Santa Rita area	Franklin Mts.
PENNSYLVANIAN ROCKS	Limestone and Red Sandstone COYOTE SANDSTONE LIMESTONE Carbonaceous Limestone and Shale SANDIA SERIES	MADERA LIMESTONE PLACITOS LIMESTONE SANDIA QUARTZITE	MANZANAN: MOSCA LIMESTONE COYOTE SANDSTONE MONTOSA LIMESTONE LADRONESIAN: SANDIA SHALE ALAMITO SHALE	MAGDALENA: MADERA LIMESTONE SANDIA BEDS	MADERAN: TELLERA LIMESTONE GALLEGOS SANDSTONE ANTONITO LIMESTONE LUNASAN: MOSCA LIMESTONE COYOTE SANDSTONE MONTOSA LIMESTONE SANDIA SHALE LADRONESIAN: ALAMITO SHALE	FIERRO LIMESTONE (Includes Mississippian above and Permian below)	UPPER MAGDALENA: Humboldt "formation" Mountain Home shale LOWER MAGDALENA: (not named) "parting shale"	MAGDALENA: SYRENA OSWALDO	MAGDALENA: MAGDALENA: Bishops Cap Berino La Tuna

Figure 13a. Nomenclature of Pennsylvanian units (after Kelley and Silver, 1952).

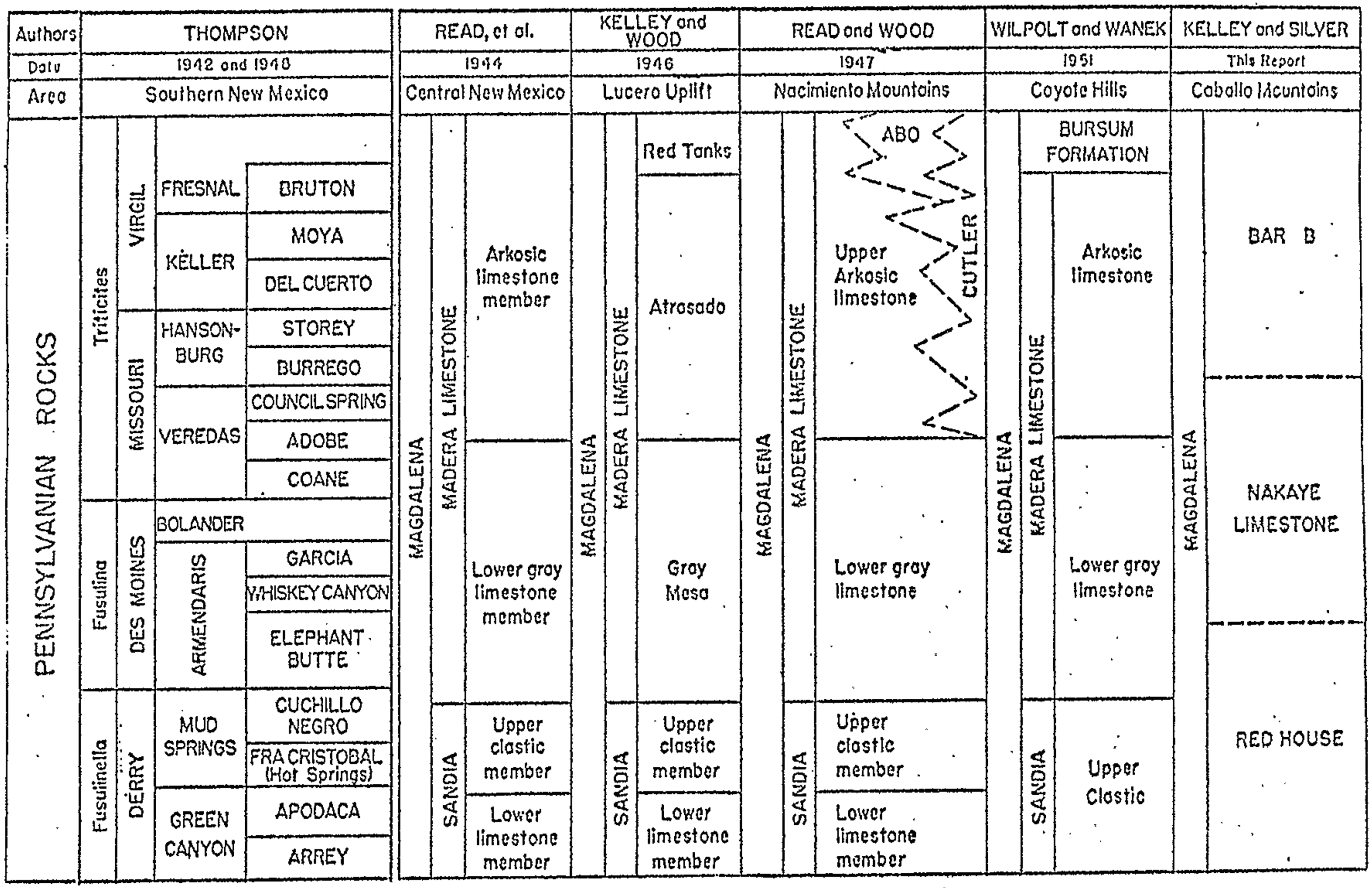

Figure 13b. Nomenclature of Pennsylvanian units continued (after Kelley and Silver, 1952).

quartzite member; 2) a lower limestone member; 3) a middle quartzite member; 4) a shale member; 5) an upper limestone member; and 6) an upper quartzite member. Within the Madera Limestone, they described a lower bluish-black, thin-bedded limestone, and an upper more massive, bluish-gray limestone, but the two were not separated for mapping purposes.

Kottlowski (1960) summarized Pennsylvanian sections throughout southwestern New Mexico and southeastern Arizona. In Kottlowski's summary, he discussed lithofacies, thicknesses, and depositional environments within the Pennsylvanian System. Kottlowski noted that northwestern Socorro County was dominated by a shale-lime facies. The southwestern part of Socorro County was found to be predominantly a lime-shale facies and the southeastern part of Socorro County varied from a lime-shale to a shale-lime facies. In the northeastern part of Socorro County, the detrital debris was slightly coarser grained and a sand-lime to lime-sand lithofacies was more dominant.

Kottlowski's isopach maps indicate that the thickness of the Pennsylvanian in Socorro County ranges from less than 250 feet, as the Pedernal Uplift is approached on the east, to more than 2,500 feet in the Lucero and San Mateo basins in the north-central and south-central parts of the county. In most of Socorro County, the Pennsylvanian is 1,000 to 2,500 feet thick and consists of shallow marine, continental shelf deposits of limestone and terrigenous rocks. Kottlowski points out that on this shallow shelf region were areas of low relief that were periodically emergent. These, along with the Lucero and San Mateo basins, were the primary features affecting the shallow marine shelf environment in which Pennsylvanian sediments were deposited.

The present literature review is restricted to Socorro County and the Magdalena area. For an excellent review of Pennsylvanian literature with a more regional perspective, the interested reader may refer to Kottlowski (1960, p. 15-24).

Regional Stratigraphy

The Pennsylvanian System in New Mexico is a complex sequence of marine and continental strata derived from several Pennsylvanian highlands with a rather irregular geographic distribution. Read and Wood (1947) used lithologic features to divide the Pennsylvanian in central New Mexico into a lower Sandia Formation and an upper Madera Limestone. The Sandia Formation is a complex basal suite of transgressive shales, siltstones, sandstones, and limestones. The overlying Madera Limestone constitutes the limestones and arkosic limestones of a period of maximum transgression prior to regression. A brief summary of the lithologic character of the Pennsylvanian throughout New Mexico follows. A more detailed discussion is given in an excellent review of the Pennsylvanian by Kottlowski (1960).

NORTHERN NEW MEXICO. To become acquainted with the Pennsylvanian of the northern part of the state, the areas of the Zuni, Jemez, Nacimiento, San Pedro, and Sangre de Cristo mountains were reviewed. In northern New Mexico, the Sandia Formation is considered to be Early Pennsylvanian (Morrowan) in age (Read and Wood, 1947). The thickness of the formation ranges from 0 feet along the Zuni Arch to more than 2,000 feet in the Sangre de Cristo Mountains. Lithologically, the Sandia Formation is mostly coarse-grained conglomeratic sandstones, siltstones, carbonaceous shales, and thin limestones, with lenses of impure coal not uncommon to the lower beds.

The Madera is composed of two lithologically distinct units (Baltz and Bachman, 1956). A lower gray limestone consists of thin- to thick-bedded, crystalline and granular, fossiliferous limestone interbedded with black shale, siltstone, and thin sandstone. Limestone becomes more dominant to the south. Thickness ranges from 0 feet along the Zuni Arch to more than 3,000 feet in the Sangre de Cristo Mountains. The upper part of the Madera is an arkosic limestone with beds of gray and olive siltstone and shale, thin purple and red shale, coarse-grained, conglomeratic, arkosic sandstone, and gray, fossiliferous limestone. This arkosic limestone represents a transition from dominantly marine conditions, indicated by the lower gray limestone, to the nonmarine environment of the overlying Sangre de Cristo Formation. Age of the Madera Limestone is Atokan to Missourian.

CENTRAL NEW MEXICO. Areas examined and reviewed in this part of the state include the Estancia Basin, Sandia Mountains, Manzano Mountains, Lucero Mesa, Los Pinos Mountains, Joyita Hills, Ladron Mountains, Socorro-Lemitar Mountains, Sierra Oscura, and the San

Mateo Mountains. In central New Mexico the Sandia Formation varies in thickness from 100 to more than 600 feet. It contains a diverse assemblage of rock types ranging from limestone, chert, and quartz-pebble conglomerates to pebbly, arkosic sandstones, siltstones, and shales through thin nodular and ledgy limestones. Sand-shale/lime ratios vary from 1.3 to 1.8 with sand-shale ratios of .54 to .98 (Kottlowski, 1960). Coarser grained lithologies are slightly more abundant in the northern part of the area. Also included in some sections are dark shales, sands, and coals of continental origin. Faunal assemblages contain brachiopods, corals, echinoderms, gastropods, foraminifera, and plant remains. Although the lithologic boundaries are time transgressive, Atokan age is suggested for most of the Sandia.

The Madera Limestone, over most of central New Mexico, is from 80 to more than 2,000 feet thick and is divisible into several local members. On the Lucero uplift, Kelley and Wood (1946) divided the Madera into the lower Gray Mesa, medial Atrasado, and upper Red Tanks members. In the mountain ranges east of the Rio Grande, a lower gray limestone member and an upper arkosic limestone member have been mapped (Wilpolt and others, 1946). Thompson (1942) used a six-fold division of the Madera in this part of the state that was based on faunal assemblages of Atokan, Desmoinesian, Missourian, and Virgilian ages.

Common to most Madera Limestone sections is a lower, ledgy, massive to thin-bedded, medium- to dark-gray limestone with subordinate amounts of gray and green shale, siltstone, sandstone, and conglomerate. Above this is frequently observed a medium- to light-gray limestone with a low chert content and a much higher proportion of gray, black, and red shales; green, brown and gray sandstones; and arkosic sandstones. An upper unit of reddish and buff sandstone, siltstone, shale, and limestone pebble conglomerates, interbedded with thin-bedded, gray limestones, gray shales, and arkosic sandstones is locally present. Some geologists correlate these strata with the Bursum Formation (early Wolfcampian), but this third unit is probably equivalent to the Bruton Formation (late Virgilian) to the south (Kottlowski, 1960).

<u>SOUTHWESTERN NEW MEXICO.</u> The Pennsylvanian of southwestern New Mexico is Morrowan to Virgilian in age and is generally 1,000 to 2,000 feet in thickness. In some local areas, the thickness of Pennsylvanian strata may approach 3,000 feet (Kottlowski, 1960). Throughout most of the southern part of the area, the section is dominated by limestone, while to the north, sand and shale become important.

In southwestern New Mexico, different names have been assigned to units within Pennsylvanian sections in the various mountain ranges. In southwesternmost New Mexico, Quaide (1953) and Gillerman (1950) put the Pennsylvanian sediments into the Naco Group containing a lower Horquilla Formation and an upper Earp Formation. Both of these names are related to nomenclature presented by Gilluly and others (1954) for Pennsylvanian strata in southeastern Arizona. In the Sacramento Mountains, Pray (1961) divided the Pennsylvanian into a lower Gobbler Formation, a medial Beeman Formation, and an upper Holder Formation. Kottlowski and others (1956) referred to the Virgil Series in the San Andres Mountains as the Panther Seep Formation. Slightly to the west, in the Sierra Caballos, Kelley and Silver (1952) defined the Red House, Nakaye, and Bar B formations.

The Pennsylvanian in southwestern New Mexico is generally a lime-shale lithofacies. A limestone lithofacies predominates in the extreme southwest and a sand-lime lithofacies is found in the vicinity of areas that were topographically high during Pennsylvanian time. The basal Morrowan and Atokan deposits are usually sandy and shaly except in the south. Desmoinesian strata are dominantly marine limestones and the upper Pennsylvanian (Missourian and Virgilian) beds range from massive marine limestones with interbedded redbeds to clastic continental deposits.

Local Stratigraphy

The type section for the Magdalena Group is in the Magdalena Mountains. It is here, in the northern part of the range, that Loughlin and Koschmann (1942) named the lower part of the Pennsylvanian section the Sandia Formation and the upper part of the section the Madera Limestone. Loughlin and Koschmann further subdivided the Sandia Formation into six members with a total thickness of about 600 feet. The six members are: 1) lower quartzite member; 2) lower limestone member; 3) middle quartzite member; 4) shale member; 5) upper limestone member; 6) upper quartzite member.

Lower quartzite member: The lower quartzite member is about 90 feet thick. It consists of brown, gray, and greenish-gray quartzite with subordinate interbedded shale and limestone. The quartzite beds are fine- to coarse-grained, sometimes conglomeratic, sands cemented by calcareous and siliceous material.

Lower limestone member: The thickness of the lower limestone is approximately 65 feet. This member consists of fossiliferous, medium-grained, bluish-gray, argillaceous limestone with interbedded shales and quartzites. Thin, fossiliferous, shaly beds constitute a large portion of the lower part of the unit.

Middle quartzite member: The middle quartzite is defined as the 18 feet (maximum) of quartzite that separates the lower limestone from the overlying shale member. It consists of lenticular, medium-grained, brown to gray quartzite.

Shale member: The 300-foot-thick shale member constitutes more than one half of the Sandia Formation. It is a black, locally carbonaceous, fossiliferous shale with interbedded quartzite and limestone.

Upper limestone member: The thickness of the upper limestone is as much as 300 feet. This member consists of lenticular, bluish-gray, medium-gray limestone characterized by spherical, concentric algal growths that are as much as 2 inches in diameter.

Upper quartzite member: The lenticular upper quartzite member has a maximum thickness of about 65 feet. The member is composed of gray quartzite beds with interbedded limestone and shale.

Fossils collected from the Sandia Formation by Loughlin and Koschmann and identified by G. H. Girty are listed in Table 4. Stein and Ringland (1913) report the following plant fossils were identified by David White: Neuropteris aldrich (Lesquereux); ferns represented indeterminable species of rachises; Lepidophyllum lucidum (Lesquereux); Sigillara spl; and Cordaites sp. Faunal evidence suggests the Sandia is of Morrowan and Atokan (Pottsville) age.

Loughlin and Koschmann (1942) identified an upper member and a lower member within the 600-foot-thick Madera Limestone. The lower 300 feet consisted of bluish-black, thin-bedded limestone with interbedded, bluish-gray, fossiliferous shale, and gray, medium-grained quartzite. The general character of these beds is similar to that of the Sandia Formation. However, Loughlin and Koschmann state that, since limestone beds are dominant and are continuous upward with greater thickness of limestone, these beds should be assigned to the Madera Limestone; furthermore, they believe the upper quartzite of the Sandia is a convenient and practical horizon for placing a boundary between the gradational Sandia Formation and Madera Limestone. The present study, though not in agreement with the six-member concept of Loughlin and Koschmann, is in agreement with their general definition of the formational boundary. The writer suggests the boundary be

Fossils	Sandia formation				Madera limestone
	Lower quartzite	Lower limestone	Shale	Upper limestone	
Fusulinid, genus undetermined					17, 22
Triplophyllum sp.					15
Cyathophyllum subcaespitosum?					17
Lophophyllum profundum	1		12		15
Campophyllum torquium					18, 19, 21
Campophyllum torquium?		5			18
Campophyllum? sp.					17
Clisiophyllum sp.					17
Axophyllum rude?			12		
Syringopora sp.					15
Aulopora? sp.					17
Michelinia eugeneae		3			
Hydreionocrinus acanthophorus?		6			
Fistulipora sp.		7	9		
Anisotrypa? sp.		6			
Tabulipora aff. *T. carbonaria*			12		
Tabulipora sp.		5, 6, 8			
Fenestella sp.		3, 5, 6, 8	9		
Polypora sp.		3, 5, 6, 8			
Septopora sp.			9		
Rhombopora sp.	1	8	9		
Prismopora? sp.		6			
Cystodictya sp.		6			
Orthotetes sp.		6			
Derbya crassa		5			
Derbya crassa?	1		9		
Chonetes aff. *C. arkansanus*		6			
Chonetes mesolobus			11		19
Chonetes sp.	1	4			
Productus (Linoproductus) cora	1	5, 6, 7, 8	11, 12, 13		19
Productus aff. *P. inflatus*		6			
Productus coloradoensis	1			14	18, 20
Productus coloradoensis?					17
Productus nolani?	1		9		
Productus semistriatus?		5			
Productus semireticulatus		8		14	19
Productus semireticulatus?		5			
Productus aff. *P. gallatinensis*		3			
Productus aff. *P. morrowensis*		3			
Productus sp.	1	3, 4, 5	11		19
Productus n. sp.			12		
Productus n. sp.?			13		15
Productus (Juresania) nebraskensis		8			
Productus (Juresania) nebraskensis var.		5			
Productus (Juresania) nebraskensis?		7	11		
Productus (Pustula) aff. *P. wallacianus*		5, 6			
Productus (Pustula) n. sp.					19
Productus (Avonia) sp.		4			
Marginifera ingrata			11		
Marginifera splendens					17
Marginifera muricata					17
Marginifera muricata?			12, 13		17
Marginifera n. sp. aff. *M. splendens*			12, 13		15
Marginifera? sp.		3			
Marginifera sp.					19, 21
Schizophoria aff. *S. texana*		6			
Spirifer cameratus			11, 12, 13	14	
Spirifer cameratus?			9		
Spirifer aff. *S. goreii*		6			
Spirifer opimus var. *occidentalis*		5, 6	12, 13		15, 16

Table 4. Invertebrate fossils in the Pennsylvanian (after Loughlin and Koschmann, 1942). Numbers refer to different lots collected at places listed below.

Fossils	Sandia formation				Madera limestone
	Lower quartzite	Lower limestone	Shale	Upper limestone	
Spirifer rockymontanus var.	1	4, 7	9		20
Spirifer rockymontanus		3	11		
Spirifer triplicatus					19, 21
Spirifer triplicatus var.					19
Spirifer triplicatus?			13		
Spirifer n. sp.		5			
Spirifer sp.					18
Punctispirifer aff. *P. transversus*	1	3			
Punctispirifer kentuckyensis		6			
Punctispirifer kentuckyensis?			9		
Punctispirifer sp.					17
Squamularia perplexa					15, 17, 19
Composita subtilita	1	3, 4, 5, 6	12, 13		15, 17, 18, 20, 21
Composita sp.		6			
Cleiothyridina pecosi	1	4, 6	12, 13		
Hustedia aff. *H. miseri*		3			
Hustedia mormoni		3			
Hustedia n. sp.?		6			
Edmondia? sp.	1				
Leda aff. *L. meekana*		3			
Pseudomonotis? sp.		3			
Myalina perniformis?		5			
Aviculopecten sp.	2	3			
Aviculopecten n. sp.		3			
Deltopecten occidentalis?	1				
Streblopteria sp.		5			
Lima sp.			11		
Lima? sp.		6			
Astartella sp.		3			
Pleurophorus? sp.		6	12		
Pleurotomaria sp.		3			
Pleurotomaria? sp.		5			
Bucanopsis sp.		3			
Patellostium sp.			12		
Euphemites carbonarius					15
Euphemites carbonarius? sp.		3			
Schizostoma catilloides		3			
Diaphorostoma peoriense?					15
Naticopsis sp.					19
Naticopsis? sp.		5			
Meekospira? sp.		3			
Platyceras occidentale			12		
Platyceras occidentale?		6			
Eotrochus sp.					19
Griffithides sp.		3			

1. Lot 6804, from a shaly bed near top of the lower quartzite member south of Tip Top tunnel.
2. Lot 6805, about 100 feet east of Woodland mine.
3. Lots 6904, 6906, and 6907, east of Mistletoe tunnel on west side of range.
4. Lot 6811, about 1,000 feet northeast of Cimarron tunnel.
5. Lot 6825, about 700 feet northeast of Cimarron tunnel.
6. Lots 6828 and 6829, about 700 to 1,000 feet south of Tip Top tunnel on west side of gulch.
7. Lot 6810, on spur with saddle on east slope of range east of Kelly.
8. Lot 6807, near north end of lower limestone exposure on east slope of range due east of Kelly.
9. Lot 6809, just east of Paschal shaft.
10. Lot 6816, from thin-bedded limestone just below quartzite bed at first bend in road southwest of fork in Tip Top road.
11. Lot 6808, west of Young America mine.
12. Lots 6820 and 6823, west and north of Tri-Bullion mill.
13. Lot 6827, 500 to 800 feet southwest of Tip Top tunnel.
14. Lot 6803, 1,000 feet southeast of Young America mine.
15. Lot 6822, Basal shaly bed in gulch 700 feet west of Paschal shaft.
16. Lot 6824, 500 feet north of Cimarron tunnel.
17. Lot 6800, 800 to 1,000 feet northwest of Tri-Bullion mill.
18. Lot 6802, 600 to 700 feet west of Tri-Bullion mill.
19. Lot 6821, 700 feet west-northwest of Tri-Bullion mill.
20. Lots 6812 and 6815, west-southwest of Grand Ledge tunnel.
21. Lot 6826, 800 feet west of Tip Top tunnel.
22. Lot 6905, about 100 feet north of Mistletoe tunnel.

Table 4. Continued

placed at the top of the quartzite below which shale is dominant and above which limestone predominates. In subsequent pages, the logic of this suggestion will be evident.

The upper member of the Madera Limestone was found by Loughlin and Koschmann (1942) to be about 300 feet thick. It is consistantly a fine- to coarse-grained, homogeneous, bluish-gray limestone throughout the Magdalena district. Black, nodular chert is abundant within this unit. Interbedded with the limestone are shaly limestones, conglomeratic limestones, thin gray shales, and gray to brown quartzites. In the southern part of the district the highest beds are mottled and shaly and are stained brownish-red by iron oxides from the overlying Abo Sandstone of Permain age.

Loughlin and Koschmann state that the true thickness of the Madera Limestone cannot be determined due to erosion and faulting; they estimate it to be about 600 feet, but note thicknesses may approach 1,000 feet. Kottlowski (1960) suggests the Madera Limestone in the Magdalena area had an original thickness of at least 1,000 feet and perhaps 1,200 to 1,500 feet.

Fossils collected by Loughlin and Koschmann and identified by G. H. Girty are listed in Table 4. Girty regards these as post-Atokan (post-Pottsville) in age. Mr. J. W. Skinner indicated to Loughlin and Koschmann that fusulinids he had identified from the upper Madera were suggestive of Upper Virgilian (Wabaunsee) time.

Overlying the Madera Limestone within the district is about 175 feet of red, shaly, laminated, fine-grained, sandstones and siltstones named the Abo Formation. The Abo is of Permain age and unconformably overlies the Madera Formation. The Abo is overlain by Tertiary volcanic rocks south of Highway 60 but is in fault contact with other Permian units north of the highway. In the Granite Mountain-Olney Ranch area, a thick section of strata, previously called Pennsylvanian by Loughlin and Koschmann (1942), is believed by the writer, and other workers in the district, to be the Abo, Yeso (?), Glorieta, and San Andres Formations of Permian age. Sandstones and siltstones in Hardscarbble Valley, previously mapped as Sandia shale by Laughlin and Koschmann (1942), are now believed to be the Abo Formation of Permain age (R. B. Blakestad, oral communication, 1973). These Permian sections are overlain by Tertiary volcanic rocks.

TIP TOP MOUNTAIN. Although the top of the section has been removed by faulting, there is more than 1,200 feet of Pennsylvanian section exposed at Tip Top Mountain. The Sandia Formation and the overlying Madera Limestone each account for about one half the total thickness. The Sandia Formation crops out on the eastern side of Tip Top Mountain and comprises most of this eastern slope.

The Sandia-Madera contact is on the eastern slope just beneath the top of Tip Top Mountain, thus the cap and western dip slope are comprised of Madera Limestone. Near the base of the western dip slope, Madera Limestones are interrupted by Oligocene faulting that has uplifted Sandia quartzites and siltstones.

Sandia Formation. On the eastern slope of Tip Top Mountain, the Sandia Formation unconformably overlies Kelly Limestone of Mississippian age and dips to the west at 40° to 45° and strikes N. 10° W. The Sandia Formation is about 587 feet thick and consists of shale, quartzite, and limestone. Shale crops out poorly due to covering by talus and an immature soil. Quartzites and limestones, however, are usually well-exposed cliff-formers.

Wackes and shales constitute about 453 feet or 79 percent of the total Sandia thickness. They range in color from olive gray to black and are usually grayish black. The granular material of the wackes is poor- to well-sorted, silt- to sand-size, quartz and mica. In places, they become slightly calcareous. Most beds are homogeneous, but some low-angle cross lamination is present. In some parts of the section the shales become quite fissile. Within the wacke and shale beds, thin fossiliferous micritic limestone lenses, less than 1 foot thick, are occasionally found. Within these limestone lenses, echinoderms and brachiopods are the most abundant faunal representatives with mollusks, corals, and bryozoans as minor and infrequent constituents. These small limestone lenses exhibit thin lamination. Although most contacts with other lithologies are covered, the few that were observed indicate that both upper and lower contacts may be abrupt or gradational.

Quartzites in the Sandia Formation have a total thickness of about 73 feet. This accounts for about 13 percent of the formations total thickness. The thickness of individual quartzite units ranges from 3 feet to more than 20 feet. Colors among these quartzite units vary from olive- to brownish-light-gray; weathered surfaces have a more reddish-brown appearance. The granular material usually consists of rounded, moderately sorted, medium- to coarse-grained quartz sand. Chert and feldspar contents are consistantly very low and very sporadic through the entire Sandia section. Locally, the quartzites become quite calcareous. Quartzite units are typically internally homogeneous; however, examples of small- to medium-scale, low-angle planar cross-bedding were observed. Talus and soil cover did not permit observation of upper and lower contacts with other lithologies.

The cumulative thickness of limestone within the Sandia Formation on Tip Top Mountain is 44 feet, or is about 8 percent of the total thickness. Individual limestone units range from 1 foot to almost 30 feet in thickness. The fossiliferous, micritic limestones vary from medium-light gray to blackish-gray in color. The faunal assemblage is mostly echinoderms and brachiopods accompanied by limited numbers of bryozoans, mollusks, forams, and horn corals. The fossil content of the more fossiliferous beds may approach 75 percent. A small percentage of fine, detrital, quartz sand is also characteristic of some limestone beds. The limestone units are thin- to medium-bedded and internally exhibit thin planar lamination. As with other lithologies, upper and lower contacts may be either abrupt or gradational.

Madera Limestone. The contact between the Madera Limestone and the underlying Sandia Formation is gradational and may be observed on the eastern slope of Tip Top Mountain about 100 feet below the summit. The arbitrary boundary is placed at the top of a quartzite beneath which wacke and shale are the dominant lithologies and above which limestone is dominant.

At Tip Top Mountain, the faulted remnant of Madera Limestone is about 793 feet thick. The uniform sequence of limestones form a long dip slope that is faulted against beds of the Sandia Formation near the base of the slope. The thickness of Madera beds cut out by the faulting is not known but is believed to be at least several hundred feet on the basis of Madera thicknesses encountered in drill holes elsewhere in the district. Of the total thickness present, 79 percent (630 feet) is limestone and 20 percent (157 feet) quartzite and shale.

The limestones range from light-gray to black in color, but are usually dark gray or grayish-black. They are micrites with a limited but diverse faunal assemblage. Fossils found in the Madera Limestone include brachiopods; mollusks, echinoderms, corals, foraminifera, and bryozoans; however, none are found in large numbers. The fossil content rarely exceeds 15 percent. Small percentages of silt-size quartz grains are also found in some limestone beds. About 300 feet above the basal contact, black nodular chert becomes very abundant. These black chert nodules, along with the large horn corals, are probably the most diagnostic features of the Madera Limestone. Bedding within the Madera section is variable and ranges from thin-bedded to very-thick-bedded. The only sedimentary structures observed in the Madera Limestone were thin cross-laminations and planar laminations. Contacts between limestones and other lithologies are usually abrupt.

Madera quartzites are somewhat similar to quartzites found in the Sandia Formation. At Tip Top Mountain, they are usually only a foot or two thick and consist predominantly of rounded, poorly sorted, coarse-grained quartz grains in a calcareous matrix; some beds contain pebbles of pegmatitic, milky quartz. Feldspar, mica, and chert are sparse to absent. The quartzites are typically homogeneous, but some small- to medium-scale, low-angle, planar cross beds occur.

NORTH FORK CANYON. The North Fork Canyon section is located 1.2 miles west of the Water Canyon-North Fork Canyon intersection along the south side of the canyon. Pennsylvanian strata unconformably overlie the Kelly Limestone of Mississippian age, dip to the west at 35 to 40 degrees, and strike N 10° W. The Sandia section is predominantly shale and quartz wacke that is expressed largely as covered section. Interbedded quartzites and limestones within the Sandia Formation form ledges. Upon entering the Madera section, the slope angle increases suddenly from 20° to about 30° and the limestones crop out boldly. The Pennsylvanian section ends abruptly along the ridge crest where it is juxtaposed against down-dropped Tertiary volcanic rocks. White rhyolite dikes have been injected along the faulted contact.

Sandia Formation. The Sandia Formation in North Fork Canyon is about 554 feet thick. Thin-bedded wackes and shale, comprising as much as 75 percent (418 feet) of the section, are the most important rock types. Interbedded sandstone and limestone account respectively for only 17 percent (94 feet) and 8 percent (43 feet) of section.

The wackes and shales are usually olive-gray to olive-black in color and sometimes weather a rather light-reddish-brown. Terrigenous material consists of well-sorted quartz grains and mica; the matrix material is noncalcareous. The wackes are thinly bedded and often display internal planar laminations while the shales are usually crudely fissile. Small limestone pods (fig. 14) are also present within the shaly units and plant fossils were found along shale partings.

The more resistant quartzite beds crop out as small cliffs on the soil and talus covered slope. They range in thickness from 1 foot to more than 20 feet and are usually medium-gray to olive-gray in color. The quartzites are moderately sorted, coarse-grained, quartz arenites with calcareous cements. Many quartzites contain angular, white quartz pebbles as much as a half inch in diameter. The quartzites at North Fork Canyon are usually very-thick-bedded. Contacts are usually covered, but when observed they are abrupt and appear to be erosional.

Limestones in the North Fork Canyon section are dark-gray to black micrites that contain an abundant brachiopod and echinoderm fauna.

Figure 14. Micritic limestone pods in a noncalcareous, laminated mudstone of the Sandia Formation in North Fork Canyon. Laminations bend around the pods and are not truncated. The pods are interpreted as accumulations of carbonate in small depressions in terrigenous muds of a tidal flat.

They are thin- to medium-bedded with internal small-scale, low-angle cross lamination and planar lamination. Some of the limestones are characteristically pod-like in nature with pods of micritic carbonate encased in an envelope of more siliceous, silty material. Contacts between the limestones and other lithologies are abrupt.

Madera Limestone. The Madera Limestone crops out boldly along the upper part of the ridge bordering North Fork Canyon. Upon approaching the thick Madera section the shaly beds of the Sandia Formation end abruptly and the resistant limestone strata cause a rapid steepening of the slope. At this location, the faulted remnant of Madera beds is approximately 763 feet thick. About 520 feet above the base of the section, faulting and intrusion of white-rhyolite dikes may have significantly affected section thickness. The top of the section ends abruptly against down-faulted Tertiary volcanic rocks; the thickness of Madera beds cut out by the faulting may be in excess of 1,000 feet judging from Madera thicknesses encountered in drill holes elsewhere in the district. Of the exposed 763 feet, 94 percent (718 feet) is limestone and 6 percent (45 feet) is interbedded coarse-grained quartzite.

The Madera Limestone at North Fork Canyon consists of medium- to dark-gray, fossiliferous, medium-bedded, dense micrites. Fossils include brachiopods, bryozoans, echinoderms, horn corals, mollusks, and foraminifera. The foraminifera are rather unique, with respect to other fossil groups, in that they are very localized. They are either absent or abundant. The whole faunal assemblage consists of broken, transported fragments. In places, the limestone beds become slightly sandy and in other beds the pod-like texture is well-developed. Black, nodular chert is again present through most of the formation (fig. 15). The micrites exhibit planar-lamination and occasional small-scale, low-angle cross-lamination.

The thickness of all the interbedded quartzites within the Madera section is only 45 feet. Individual units range in thickness from 2 feet to more than 20 feet and are usually light-olive-brown. The homogeneous quartzites are very-thick-bedded, coarse-grained, moderately sorted, micaceous, quartz arenites. Many of the units contain milky-white, pegmatitic quartz pebbles that are as much as .75 inches in diameter. The cementing material of these quartzites may be either silica or calcite. Contacts with underlying limestone beds are abrupt and appear erosional.

NORTH BALDY. Pennsylvanian strata at North Baldy strike N 25° W and dip to the southwest at about 40°. Faulting within the Sandia Formation and the Madera Limestone has greatly reduced the section, leaving only 326 feet of Sandia and 35 feet of Madera Limestone (fig. 16). The lithologies at North Baldy are not unlike those found at Tip Top Mountain and North Fork Canyon. The Sandia Formation consists primarily of shale, expressed largely as covered section, and interbedded quartzite and limestone that form small cliffs and ledges on the otherwise covered slope. Shales account for 250 feet of section, while limestone accounts for 24 feet and quartzite 52 feet.

Figure 15. Black chert nodules in the Madera Limestone in North Fork Canyon. The Madera limestones are homogeneous, unfossiliferous micrites. However, in some exposures, the Madera limestones are quite fossiliferous and well-laminated.

Figure 16. View of the Sandia and Madera sections on the north side of North Baldy. A fault that greatly reduces the thickness of the section occurs in the Sandia Formation just above the resistant limestone beds about half way up the mountain. Above the fault, another 55 feet of Sandia shale, quartzite, and limestone is present. Resistant Madera limestones cap North Baldy and form the western dip slope.

Quartzites are moderately sorted, rounded, medium- to coarse-grained, siliceous to calcareous quartz arenties. They are thin-bedded to very-thick-bedded and internally display planar lamination, and small-scale cross lamination, and cross bedding. In one of the thicker quartzites, medium-scale, low-angle, trough cross bedding was witnessed (fig. 17). Contacts with other lithologies are abrupt and basal contacts appeared to be erosional.

About 250 feet of micaceous silty shale is present at North Baldy (fig. 18). The coarse-silt-size quartz grains are angular in shape and poorly to moderately sorted. Bedding is thin and sedimentary structures are limited to planar laminations and small-scale cross laminations.

Limestones are dark-gray to black, fossiliferous micrites. The faunal assemblage includes brachiopods, echinoderms, mollusks, and sparse bryozoans. Locally, the thin-bedded micrites are slightly sandy.

About 247 feet above the base of the Sandia Formation, normal faulting has faulted out more than 200 feet of the formation. Above the fault, about 55 feet of upper Sandia material grades into the Madera Limestone. Again, the coarse-grained quartzite above which limestone is the dominant lithology is used as a reference point for the Sandia-Madera contact. In the Magdalena Mountains, 5 to 10 feet of shale may separate this quartzite from the overlying limestones.

Figure 17. Coarse-grained quartzite in the Sandia Formation at North Baldy. Large, white quartz fragments are abundant and there is some suggestion of trough cross-bedding. The basal contacts of these quartzites are erosional and their geometry seems lenticular.

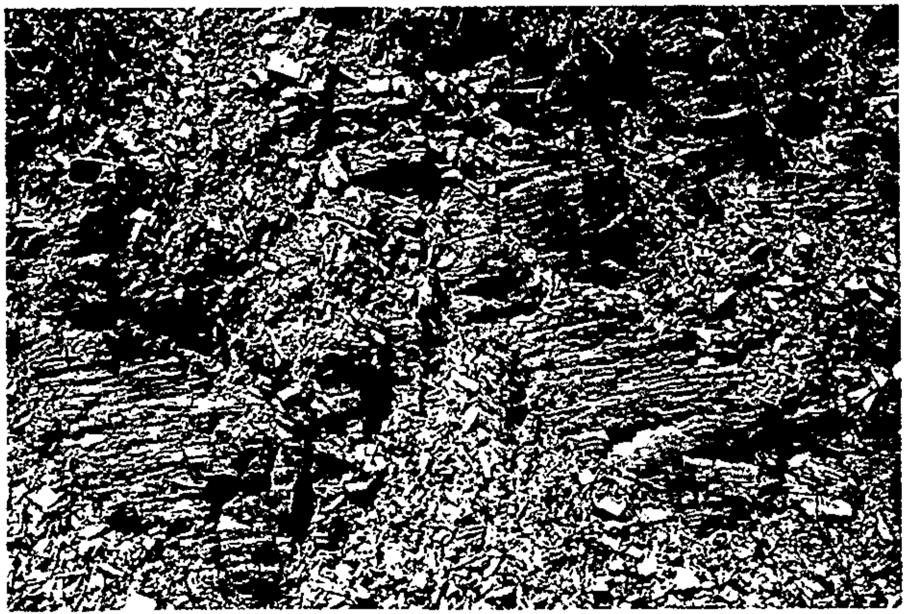

Figure 18. Black, fissile shale in the Sandia Formation at North Baldy. The shales contain silt-size quartz grains and mica. Invertebrate marine fossils were not observed in the shales; however, plant fossils are often abundant.

The 35 feet of Madera Limestone consists of dark-gray to black micrite that weathers a lighter gray. The limestones are medium-bedded to very-thick-bedded and display a faunal assemblage containing abundant brachiopods, horn corals, mollusks, echinoderms, and fusulinids.

Summary of Pennsylvanian Sections. In the Magdalena Mountains, the Sandia Formation unconformably overlies the Kelly Limestone of Mississippian age and is from 550 to 600 feet thick. It consists of more than 75 percent shale and wacke with subordinate amounts of interbedded, medium- to coarse-grained, quartzite and dark-gray to black, fossiliferous micritic limestone. Brachiopods, echinoderms, mollusks, bryozoans, and horn corals are included in the faunal assemblage. Bedding is thin-bedded to very-thick-bedded. The limestones exhibit planar lamination and small-scale cross lamination while quartzites are cross bedded on a small to medium scale. Contacts are usually abrupt. The six members of Loughlin and Köschmann (1942) were found obscure and impractical to use in the field. The writer suggests that the use of these subdivisions be discontinued and that the Sandia Formation in the Magdalena Mountains be described as a shale unit with interbedded quartzite and limestone.

The Sandia Formation grades into the overlying Madera Limestone that is about 750 to 800 feet thick in exposed sections but more than 2,000 feet thick in some drill cores. It is predominantly dark-gray to black, medium-bedded to very-thick-bedded, fossiliferous, micritic limestone. Subordinate amounts of coarse-grained, poorly to moderately sorted, calcareous quartzite and interbedded shales and wackes are present. Fossils include brachiopods, horn corals, echinoderms, mollusks, bryozoans, and foraminifera, with large horn corals and large, black chert nodules being the most distinctive features of the formation. Internally, the medium- to very-thick-bedded limestones locally display thin planar laminations.

Petrography

SANDIA FORMATION. The Sandia section is dominated by terrigenous rocks. Most of the shales were found to be borderline wackes. Sand- and silt-size grains comprise about 35 percent of these silty shales; quartz with subordinate mica are the dominant minerals. The matrix material consists of silica, calcite, and clay and comprises about 65 percent of most shales; matrix minerals are usually found to be replacing detrital quartz grains. I believe that the detrital quartz content may have been much higher than is presently indicated. These rocks are classified as micaceous quartz shales or wackes. The average grain size is coarse silt, but sizes may be as much as 1.5 Wentworth grades larger or 2.1 Wentworth grades smaller. Grains are angular to subangular and have a sphericity coefficient of about .58. Sorting is poor to moderate with a tendency toward poor sorting. Structures witnessed in thin section are limited to small fractures filled with secondary calcite or silica. Occasionally, the long axes of mica or quartz grains are aligned parallel to each other and parallel to fissility.

Quartz is the predominant mineral in Sandia arenites (fig. 19). Polycrystalline quartz is abundant in some thin sections and mica and feldspar are usually absent. Granular material constitutes about 75 to 80 percent of most thin sections. Mica, quartz, clay and fine authigenic chert constitute the primary matrix constituents. Cement occurs primarily as siliceous overgrowths in optical continuity with the detrital quartz grains. Calcite cement is abundant in some arenites where it occurs as pore filling by single calcite crystals or as large "poikilitic" patches that enclose several quartz grains. It is not uncommon to find quartz grains highly embayed by matrix or cementing material.

Most of the grains are very coarse sands but may occur as much as 1 Wentworth grade toward larger sizes or 3 Wentworth grades toward smaller sizes. Pressure solution and siliceous overgrowths cause a degree of uncertainty when describing textures; however, grains appear to be moderately to well-sorted, rounded to subrounded, and to have a sphericity coefficient of about .6. Almost all of the Sandia quartzites are quartz arenites.

The terrigenous content of Sandia limestones (fig. 20) may be as high as 30 percent, but rarely exceeds 5 percent. Quartz is the most abundant terrigenous constituent. The grains usually fall in the coarse silt to fine sand range, are angular, and have a sphericity coefficient of about 0.5. Sorting is variable. The fossil content of Sandia limestones is about 32 percent, but may be as high as 75 percent. The faunal assemblage contains a large number of taxonomic groups including

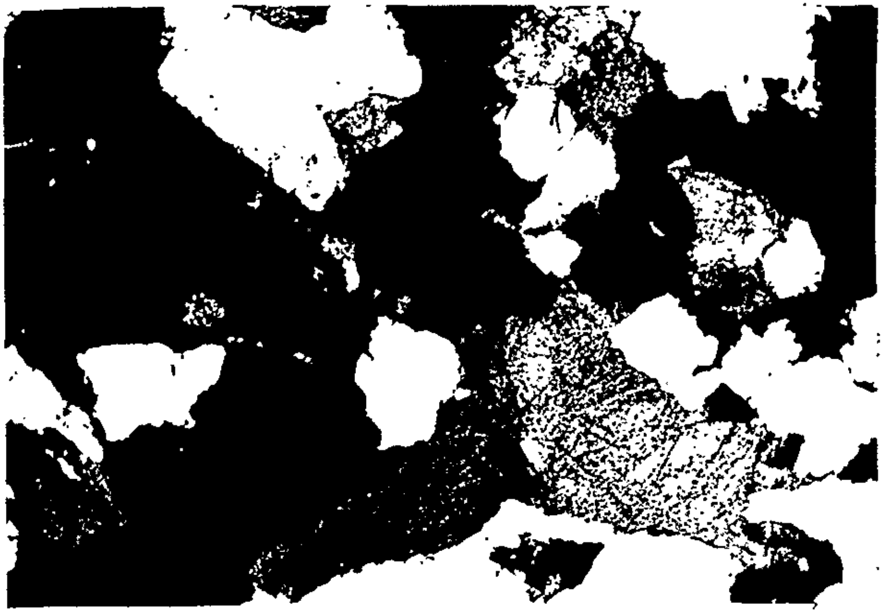

Figure 19. Photomicrograph of a Sandia quartzite at Tip Top Mountain. Quartz is the dominant mineral and the coarse grains seem to be moderately sorted. Sutured grain boundaries and silica overgrowths are conspicuous and make descriptions of grain shapes uncertain. X31.25.
Name: Quartz Arenite.

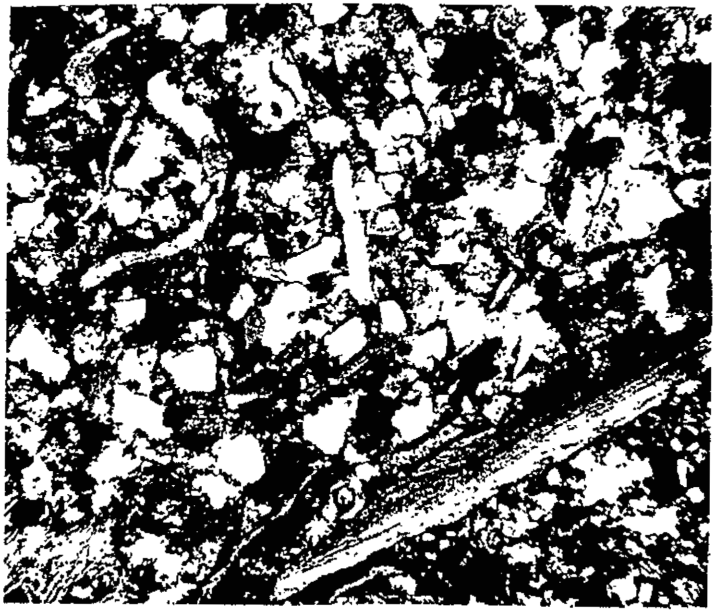

Figure 20. Photomicrograph of a Sandia limestone with a high detrital quartz and fossil content in a matrix of micrite. The most abundant fossils are brachiopods. Lesser numbers of crinoids, pelecypods, and gastropods are present. Medium-size quartz grains are angular to subangular in shape and are embayed by the matrix. Location: Tip Top Mountain. X31.25. Name: Quartz, Brachiopod, Mollusk, Crinoid Biomicrudite; Packstone.

echinoderms, brachiopods, bryozoans, mollusks, forams, and sponges. The fossil material is broken and rounded suggesting transportation prior to deposition. Matrix material, comprising more than 60 percent of most thin sections, occurs as micrite or microspar. Pseudospar is present, but is not common. Both microspar and pseudospar are interpreted as recrystallized micrite.

In the Sandia Formation, the most common diagenetic textures (See Appendix III) are the result of various types of neomorphism. Most aggrading neomorphism was found to be coalescive. Degrading neomorphism is also quite common. The neomorphic grain shapes are fibrous to equant and range from 1 to 3 in size. Small fractures filled with secondary sparry calcite occur in thin section.

All of the limestones studied in thin section are classified as biomicrites. Using Dunham's (1962) classification scheme, the biomicrites range from mudstone to packstone.

MADERA LIMESTONE. Quartzite accounts for about 6 percent of the Madera Limestone. A typical arenite in the Madera Limestone (fig. 21) consists of about 80 percent granular material and about 20 percent matrix and cement. Quartz and polycrystalline quartz are the primary terrigenous components. Feldspar and mica are not common; although, mica is more abundant in wackes. Carbonate is the major orthochemical component; in arenites it occurs as a sparry cement.

The grain size of arenites is predominantly coarse sand. Deviation may be as much as 1.5 Wentworth grades toward coarser

Figure 21. Photomicrograph of a Madera quartzite from North Fork Canyon composed of coarse, poorly sorted quartz sand grains cemented by sparry calcite. X31.25.
Name: Quartz Arenite.

sizes or 3.5 Wentworth grades toward finer sizes. Grains are round to subround and have a sphericity coefficient of about .6. Sorting is variable and ranges from poor- to well-sorted. The quartz arenites of the Madera Limestone typically contain more matrix than do those of the Sandia arenites.

Micritic limestones (fig. 22) dominate Madera lithology. Allochems constitute less than 20 percent of the limestone and terrigenous material is seldom present in thin section; however, detrital quartz sometimes constitutes as much as 10 percent of the rock. Allochemical constituents include intraclasts, lithoclasts, and pellets. The fossil content of the micrites averages about 8 percent. The faunal assemblage includes brachiopods, echinoderms, mollusks, fusulinids, horn corals, bryozoans, and ostracods. As in Sandia limestones, the fragmented fossils indicate transportation to the depositional site.

Calcite is the dominant orthochem. The orthochem content is ordinarily greater than 80 percent and occurs as micrite, microspar, or less commonly pseudospar. Both pseudospar and microspar are interpreted as neomorphosed micrite.

Neomorphism dominates diagenetic textures. Degrading neomorphism is most common, but both prophyroid and coalescive aggrading neomorphism occur. Neomorphic grain shapes are fibrous, bladed, and equant and grain sizes range from 2 to 6. Small fractures in some limestones are filled with secondary calcite spar.

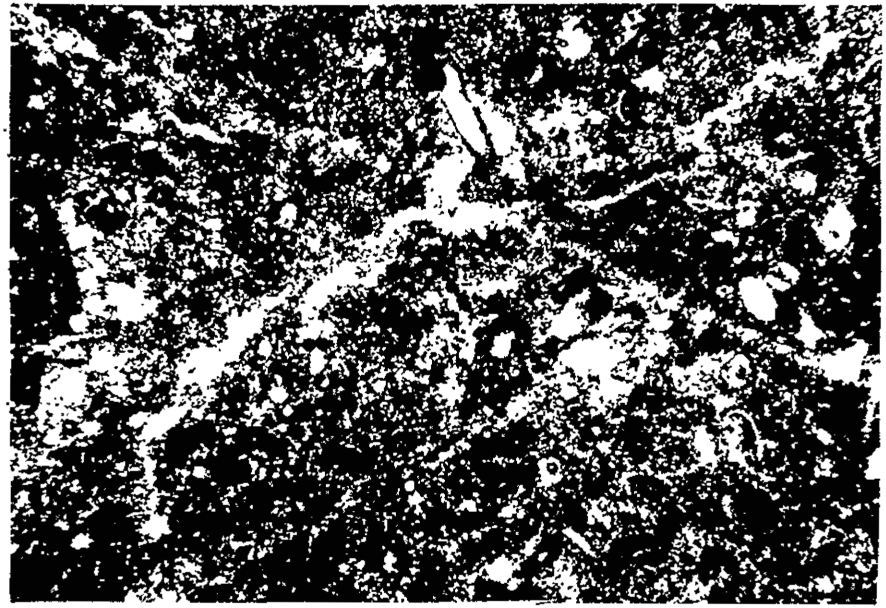

Figure 22. Photomicrograph of a micrite in the Madera Limestone at Tip Top Mountain. Fossils are limited to a few brachiopod fragments or spines. The light patches are coarser calcite formed by porphyroid, aggrading neomorphism. X31.25.
Name: Fossiliferous micrite; mudstone.

The number of fossil groups represented is large, but the fossil content is consistantly small. Since the fossil content is less than 10 percent, the limestones are classified as fossiliferous micrites. Using Dunham's (1962) terminology, most are classified as mudstones. Occasionally, the granular content becomes high enough to apply the names biomicrite and wackestone.

ROCKS OF QUESTIONED AGE

The present study leads the writer to question earlier workers who feel the sections at Olney Ranch (Granite Mountain) and Tres Montosas are of Pennsylvanian age. Loughlin and Koschmann (1942) mapped a Paleozoic section north of Highway 60 and east of Granite Mountain in which they interpreted the sequence to be: Precambrian argillite, Kelly Limestone, Sandia Formation, and Madera Limestone. They were puzzled, however, by the anomalous thickness of the Sandia which was estimated to be about 2,300 feet. Kottlowski (1960) described a 50 to 100 foot section located about two miles east of Tres Montosas which consists of limestone-pebble and boulder conglomerate interbedded with fine-grained quartzites. Although Kottlowski did not name the rocks, he thought they were similar to parts of the Pennsylvanian System in the Magdalena Mountains.

The pronounced similarity of the quartzites in the Tres Montosas and Olney Ranch indicate that they belong to the same stratigraphic unit. However, comparison of these sections with the Mississippian and Pennsylvanian in the Magdalena Mountains indicates that they are not of Pennsylvanian age. Moreover, comparisons of these rocks with Permian sections elsewhere in Socorro County suggest that the rocks in question are of Permian age. Before discussing the evidence supporting this conclusion, a brief review of the Permian units in Central New Mexico is needed for purposes of comparison.

Rocks of Permian age are well exposed in Socorro County. In ascending order, formations of Permian age include the Bursum, Abo, Yeso, Glorieta, and San Andres formations (fig. 23). A brief description of each follows:

BURSUM FORMATION. The type Bursum (Lloyd, 1949) in and near the Oscura Mountains, consists of lower interbedded dark-purplish-red and grayish-green shale, pinkish-gray arkose, and gray to greenish-gray limestones capped by a thick, massive, light-gray, biostromal limestone (Wilpolt and Wanek, 1951; Kottlowski, 1952). This massive limestone is overlain in some places by limestone pebble-conglomerate and elsewhere by algal calcarenite with lenses of pebble conglomerate. In Rhodes Canyon and northward, the Bursum Formation contains lenses of grayish, red to purple shale and sandstone and near the top of the formation sporadic limestone boulder-conglomerates (Kottlowski and others, 1956). Regionally, thicknesses of the Bursum Formation are variable and range from 50 to as much as 400 feet.

ABO FORMATION. The Abo Formation (Needham and Bates, 1943) consists of fine-grained, brownish-red, calcareous sandstone, siltstone, and shale. At its type section in Abo Canyon, the Abo consists of about 60 percent shale and about 40 percent sandstone, arkose, and conglomerate (Needham and Bates, 1943). This ratio holds approximately true for most exposures in central New Mexico. Locally, limestone pebble-conglomerates occur in the basal parts of the Abo Formation (Loughlin and Koschmann, 1942; Kottlowski and others, 1956; Jaworski,

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<tr><td colspan="2">1928</td><td colspan="2">1943</td><td colspan="2">1944</td><td colspan="3">1946</td></tr>
<tr><td colspan="2">Central New Mexico</td><td colspan="2">Central New Mexico</td><td colspan="2">Central New Mexico</td><td colspan="3">Lucero Uplift</td></tr>
<tr><td rowspan="9">PERMIAN (lower)</td><td rowspan="7">LEONARD</td><td rowspan="7">CHUPADERA FORMATION</td><td rowspan="3">SAN ANDRES LIMESTONE</td><td rowspan="8">MANZANO GROUP</td><td rowspan="2">SAN ANDRES FORMATION</td><td rowspan="3">SAN ANDRES FORMATION</td><td>Upper member</td><td rowspan="3">SAN ANDRES FORMATION</td><td colspan="2">Upper member</td></tr>
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<tr><td>GLORIETA SANDSTONE</td><td>Glorieta sandstone member</td><td colspan="2">Glorieta sandstone member</td></tr>
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<tr><td>Cañas member</td></tr>
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<tr><td>VIRGIL</td></tr>
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Figure 23. Summary of nomenclature for Permian units (modified after Kelley and Silver, 1952).

1973). The majority of the clastic units are laminated or cross-laminated and may exhibit ripple marks, mudcracks, and burrowing. The Abo Formation may be as much as 1,100 feet thick, but in the Magdalena Mountains only thin remnants, as much as 175 feet thick, are preserved beneath the late-Eocene erosion surface on which the mid-Tertiary volcanic rocks were deposited.

YESO FORMATION. Four members are recognized in the Yeso Formation (Needham and Bates, 1943). In ascending order, the four members are: 1) Meseta Blanca Sandstone (Lower member), 2) Torres Member (Evaporite member), 3) Cañas Gypsum, and 4) Joyita Sandstone (Needham and Bates, 1943). The total thickness of the Yeso Formation may be more than 1,600 feet and limestones in the middle part have yielded a large faunal assemblage indicating a Leonardian age (Kottlowski and others, 1956). The Meseta Blanca Sandstone is characterized by pink or orange sandstone which in the San Andres Mountains is about 350 feet thick. The overlying Torres Member is about 900 feet thick and consists of interbedded friable sandstone; calcareous, sandy siltstone; arenaceous to argillaceous limestone; and gypsum. The Cañas Gypsum member is about 200 feet thick and is composed chiefly of mottled, light- to medium-gray gypsum with interbedded, reddish-brown and friable sandstone. Silty limestones occur near the base. The Joyita Sandstone is less than 100 feet thick and consists of soft, cross-bedded, reddish-brown, calcareous sandstone.

GLORIETA SANDSTONE. The Glorieta Sandstone (Needham and Bates, 1943) attains its maximum thickness in northern New Mexico where it is less than 300 feet thick. The Glorieta consists of light-gray, medium-grained, cross-bedded sandstone. In the San Andres Mountains, the Glorieta is comprised of yellowish-brown sandstones, with interbedded limestones, that grade down into the reddish sandstones of the Yeso Formation. The quartzitic character of the Glorieta makes it highly resistant to erosion.

SAN ANDRES FORMATION. The San Andres Formation (Needham and Bates, 1943) is as much as 1,000 feet thick. The limestones of the San Andres are gray to dark-gray, medium-bedded to very-thick-bedded, fetid, petroliferous, fossiliferous, and dolomitic. Many limestones throughout the formation contain laminae of calcareous siltstone and scattered quartz grains. Locally, Glorieta-like sandstones are found near the base. In the Joyita Hills the Glorieta and San Andres are separated by 3 inches of pink shale (Needham and Bates, 1943). The San Andres Formation is overlain by the pale reddish-brown siltstone, claystone, and mudstone of the Dockum (Chinle) Formation of Triassic age, or by the Bernal or Artesia red beds of Permian age.

Comparison of Olney Ranch and Tres Montosas Sections with Permian and Pennsylvanian Formations

Thickness. Major problems with thickness are encountered with the so-called Sandia Formation at Olney Ranch. The Sandia

Formation in the Magdalena Range is from 550 to 600 feet thick but the Sandia section at Olney Ranch, as mapped by Loughlin and Koschmann (1942), is 2,300 to 2,400 feet thick. If correct, this would require that the thickness of the section be increased approximately 1,750 feet in a little more than 3 miles. Facies changes, along with pene-contemporaneous faulting, might possibly explain the abrupt thickening of the unit. However, these factors should be reflected in the lithologies and structures of the sedimentary rocks. To evaluate the possibility of primary thickening by facies changes, the rocks of the Olney Ranch and Tres Montosas sections are compared in the following paragraphs with rocks of unquestioned Sandia affinity in the Magdalena Mountains.

<u>Sedimentary Structures</u>. In the main part of the Magdalena Range Sandia quartzites are typically homogeneous, but some small- to medium-scale, low-angle, trough cross beds occur. At the Olney Ranch and Tres Montosas sections, internal sedimentary structures in the quartzites are conspicuous and are typically thin lamination and small scale cross-lamination. The laminations are present throughout this unit. Blakestad (personal communication, 1973) has observed the same thin laminations and cross-laminations in a fine-grained quartzite section along the east side of Stendel Ridge, about two miles to the south. Loughlin and Koschmann (1942) mapped these outcrops as Sandia shale. It is important to note that the sedimentary structures found in the quartzites of these three localities are quite unlike those of the thin Sandia quartzites of the main part of the Magdalena Range.

Lithology. Lithologically, the sections at Olney Ranch and Tres Montosas are not similar to the Pennsylvanian sections in the Magdalena Mountains. In the main part of the Magdalena Range, the Pennsylvanian System consisted of the Sandia Formation (predominantly shale with subordinate interbedded, thin coarse-grained, poorly to moderately sorted, angular to subangular quartzite and fossiliferous micrite) and the overlying Madera Limestone (predominantly fossiliferous, micritic limestones with thin, interbedded, coarse-grained, poorly to moderately sorted, angular to subangular quartzites and silty shales).

The Paleozoic section at Olney Ranch is underlain by Precambrian argillite. Above the argillite is about 1,300 feet of faulted and hydrothermally altered limestone that strikes N 33° E and dips about 60° to the northwest. Replacement of limestone by silica has destroyed original textures; however, in some samples replacement is incomplete and it appears that the limestone was originally a dark-gray, fossiliferous micrite. Fossil identification is almost impossible, but echinoderm fragments are identifiable in some fresher samples as is a small percentage of detrital quartz. Loughlin and Koschmann (1942) map these beds as Kelly Limestone and lower Sandia Limestone but they more closely resemble the uniform fossiliferous micrites of the Madera Limestone and are interpreted herein as a down-faulted block of Madera.

Above this limestone unit is 689 feet of section that Loughlin and Koschmann (1942) mapped as Sandia shale. The beds crop out poorly, but the present study shows that these beds are predominantly fine-grained, laminated quartzite with subordinate shale and limestone. The quartzites are not similar in bedding characteristics, internal structures, grain size, lithology or color to those found in the Sandia Formation of the Magdalena Range (table 5). In the following descriptions, the characteristics of the Sandia Formation in the Magdalena Mountains are given in parentheses. The granular content of the Olney Ranch quartzites (fig. 24). averages about 80 percent (Sandia - 75 to 80%) and consists of coarse-silt to fine-sand-size, (Sandia - very-coarse-sand), well-sorted (Sandia - poor-to well-sorted), subround to round (Sandia - subround to round) quartz and subordinate feldspar (Sandia - quartz). Grain sizes vary as much as 1.5 Wentworth grades toward smaller or larger sizes (Sandia - 1 to larger, 3 to smaller) and grain sphericity is about .6 (Sandia - .6). In the cementing material, calcite is subordinate to silica. Color ranges from light reddish-brown through light-gray and green. The weathered surface is always a reddish brown (Sandia - gray). Due to poor exposure and significant alteration, shale and limestone characteristics are uncertain. The quartzites are classified as quartz arenites or subarkoses.

A comparison of these quartzites with those of the Abo Formation of Permian age show strong similarities in everything but color. The Olney Ranch section is within a zone of strong propylitic alteration (Chapin, oral communication, 1973) and I interpret the quartzites to be Abo beds bleached of their normal reddish coloration by hydrothermal

	Sandia Quartzites (Magdalena Mountains)	Abo Quartzites (Olney Ranch)
Composition	Granular Material: 75%. Quartz is dominant, mica, feldspar, and chert subordinate. High degree of pressure solution and quartz overgrowth. Matrix & Cement: 25%. Predominantly silica, subordinate calcite and clay. Color: Olive-gray to gray. Weather gray. Name: Quartz Arenites.	Granular Material: 80%. Quartz and subordinate feldspar. Matrix & Cement: Calcite is subordinate to silica and clay. Color: Light-reddish-brown, light-grays, and greens. Weather red. Name: Quartz Arenite.
Texture	Grain Size: Very coarse sand. Sorting: Poor- to well-sorted. Roundness: Uncertain, subround to round. Sphericity: Uncertain, 0.6	Grain Size: Coarse-silt to fine sand. Sorting: Well-sorted. Roundness: Round to subround. Sphericity: 0.6
Bedding & Structures	Thickness: The Sandia Fm. in the Magdalena Mts. is 550 to 600 feet thick. Bedding: Very-thick-bedded, homogeneous. Sedimentary Structures: Generally homogeneous, but with some small- to medium-scale, low-angle trough cross-bedding and planar cross-bedding. Erosional lower contacts.	Thickness: Loughlin and Koschmann (1942) estimate the thickness of the Sandia Formation to be about 2,300 feet. Bedding: Thin-bedded, thick sequence. Sedimentary Structures: Abundant, thin lamination and cross-lamination.

Table 5. Comparison of Sandia and Abo quartzites.

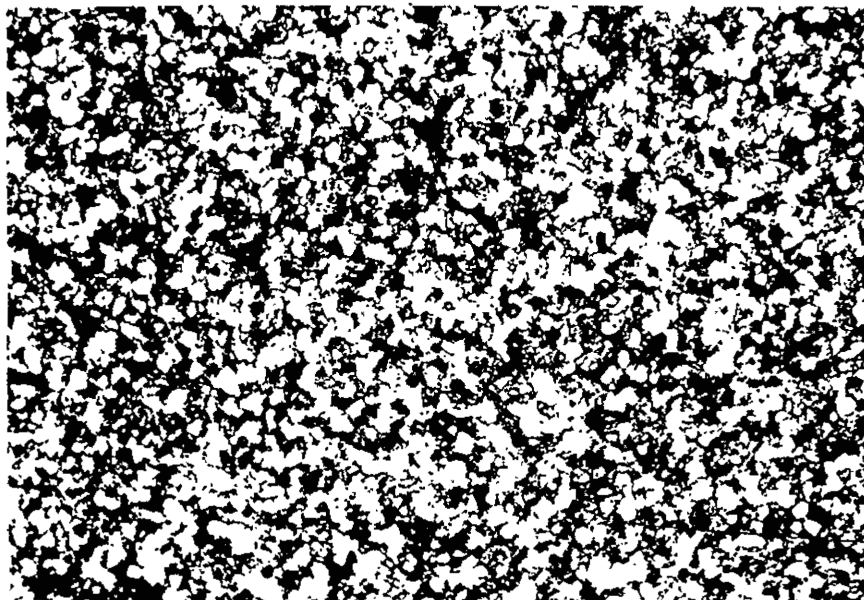

Figure 24. Photomicrograph of an Abo quartzite at Olney Ranch. The fine-grained sands are subrounded, well-sorted quartz. Contrast this texture with that of the Sandia quartzite shown in figure 22. Some sutured grain boundaries and quartz overgrowths are also present in the Abo quartzites. X31.25.
Name: Quartz Arenite.

fluids. L. P. Entwistle of the American Smelting and Refining Company reached the same conclusion for similar beds along the east side of Stendel Ridge and at depth in the Waldo mine (Chapin, oral communication, 1973). The overlying latitic conglomerates of the Spears Formation have been affected in a similar manner. When fresh, the Spears conglomerates are reddish brown but in the Granite Mountain area they have been pervasively altered to a greenish gray. If the red pigmentation were restored to the quartzites in question, they would be unmistakably Abo.

Overlying the fine-grained quartzites is a valley-forming unit that is about 523 feet thick. A few thin limestones crop out through the alluvium that covers most of the 523 feet. These limited exposures occur as dark-gray, unfossiliferous, dolomitic micrites that may locally become sandy. Loughlin and Koschmann (1942) mapped this part of the section as the upper limestone of the Sandia Formation. If the underlying quartzites are Abo, then this unit may be a faulted, incomplete section of the Yeso Formation, also of Permian age.

Along the western slope of the valley, Loughlin and Koschmann (1942) mapped 135 feet of quartzite and interbedded limestone as upper Sandia quartzite. The limestones are subordinate and similar to those found in the valley below. The quartzites (fig. 25) are light- to medium-gray in color. The medium quartz sand grains in these very-well-sorted quartz arenites are well-rounded and have a sphericity coefficient of about 0.7 to 0.8. Cementing material is dominated by calcite and usually comprises 10 to 20 percent of the rock. Sedimentary structures were

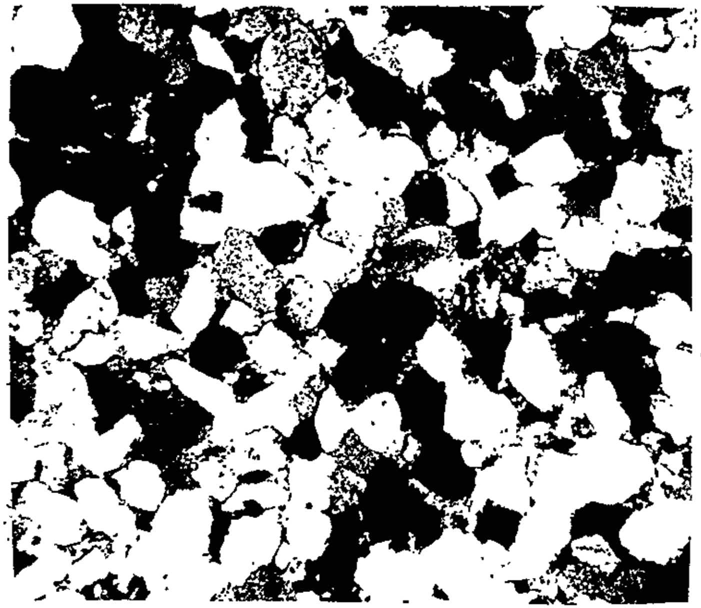

Figure 25. Photomicrograph of a medium-grained quartz arenite in the Glorieta Sandstone at Olney Ranch. The grains are well-sorted and well-rounded quartz. The cement is not conspicuous but is calcite microspar. Note the suturing of some grain boundaries. X31.25.
Name: Quartz Arenite.

not conspicuous, but some small- to medium-scale, low-angle cross-bedding occurs in the quartzite (table 6).

A comparison of these quartzites with those of the Glorieta Sandstone on Lucero Mesa showed striking similarities. Both are light-gray, well-sorted, medium-grained, well-rounded, thick-bedded quartz arenites. The quartzites at Olney Ranch are more highly indurated, but this is probably a consequence of hydrothermal alteration. The lithology and stratigraphic position of these quartzites, above the Abo and Yeso formations and below a massive dolomitic limestone interpreted below as the San Andres Limestone, makes a Glorieta assignment reasonable.

Overlying the Glorieta is 658 feet of dolomitic limestone that caps the ridge and forms the westward-facing dip slope east of the Olney ranch house (fig. 26). Loughlin and Koschmann (1942) mapped this part of the section as Madera Limestone. These limestones (fig. 27) are relatively unfossiliferous with less than 5 percent fossil fragments; the only group represented is the crinoids. The remaining 95 percent of the rock is comprised of micrite and neomorphic microspar. The predominate diagenetic textures are fibrous to equant neomorphism and degrading neomorphism. Neomorphic calcite sizes range from 2.0 to 4.0. The limestones are medium-bedded to very-thick-bedded, and characteristically produce a rough-, hackly weathered surface, and yield a strong fetid odor when freshly broken. The upper contact is a fault contact with overlying Tertiary volcanics.

	Sandia Quartzites (Magdalena Mountains)	Glorieta Sandstone (Olney Ranch)
Composition	Granular Material: 75%. Quartz is dominant; mica, feldspar, and chert subordinate. High degree of pressure solution and quartz overgrowth. Matrix & Cement: 25%. Predominantly silica overgrowths, subordinate calcite and clay. Color: Olive-gray to gray, Weather gray. Name: Quartz Arenites.	Granular Material: 80 to 90 percent. Quartz grains. Matrix & Cement: Calcite spar. Color: Light- to medium-gray. Name: Quartz Arenite.
Texture	Grain Size: Very-coarse-sand. Sorting: Poor- to well-sorted. Roundness: Uncertain, subround to round. Sphericity: Uncertain, 0.6	Grain Size: Medium-sand. Sorting: Very-well-sorted. Roundness: Well-rounded. Sphericity: 0.7 to 0.8.
Bedding & Structures	Thickness: The Sandia Fm. in the Magdalena Mts. is 550 to 600 feet thick. Bedding: Very-thick-bedded, homogeneous. Sedimentary Structures: Generally homogeneous, but with some small- to medium-scale, low-angle trough cross-bedding and planar cross-bedding. Erosional lower contacts.	Thickness: Uncertain, 100 to 150 feet. Bedding: Very-thick-bedded, homogeneous. Sedimentary Structures: Small- to medium-scale, low-angle cross-bedding.

Table 6. Comparison of Sandia quartzite and Glorieta sandstone.

Figure 26. Contact between the Glorieta Sandstone and the overlying San Andres Formation at Olney Ranch. The white quartzites of the Gloriety Formation are well-sorted, cross-bedded, quartz arenites (see fig. 25). The overlying San Andres limestones are sparsely fossiliferous, medium- to very-thick-bedded, dolomitic limestones which characteristically display a rough, hackly weathered surface.

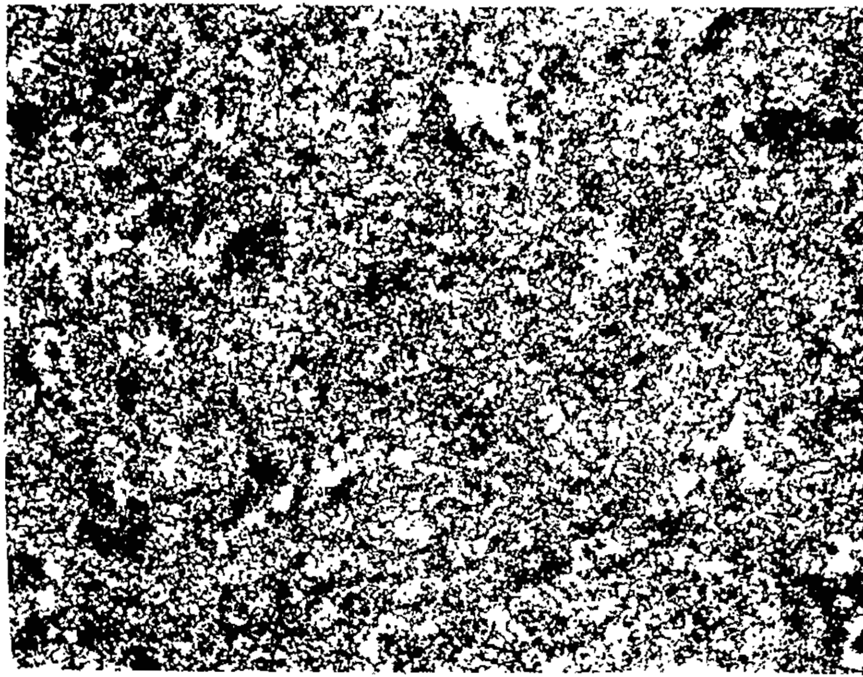

Figure 27. Photomicrograph of a dolomitic micrite in the San Andres Limestone at Olney Ranch. This homogeneous, texture is common throughouth the formation. As much as 5 percent crinoids are present in some thin sections, but they are absent here. This contrasts with the more fossiliferous, non-dolomitic limestones found in the Pennsylvanian. X31.25. Name: Dolomitic micrite; mudstone.

A comparison of these limestones with the San Andres Limestone revealed many similarities. Both are sparsely fossiliferous, very-thick-bedded, black dolomitic limestones with rough, hackly weathered surfaces. The San Andres Formation on Lucero Mesa is predominantly gypsum but the thin, interbedded limestones are similar to those in question and a transition from evaporites to dolomitic limestone is a common facies change within the San Andres Formation. The Madera limestones in the Magdalena Mountains are not dolomitic, are relatively fossiliferous with a wide range of faunal types, are lighter in color, are not fetid, and do not develop such a hackly fracture upon weathering (table 7). Considering the lithologic similarities to the San Andres and their stratigraphic position above beds reasonably interpreted as Abo and Glorieta, the assignment of the upper limestone unit of the Olney Ranch section to the San Andres Limestone seems a likely correlation.

Kottlowski (1960) briefly discussed a 50- to 100-foot section of poorly exposed Paleozoic rocks near Tres Montosas. He found no fossils indicating Pennsylvanian age; however, he did note that the beds were similar to parts of the Pennsylvanian in the Magdalena Mountains.

The rocks at the Tres Montosas section are very poorly exposed and it was not possible to accurately measure the section; however, a rough measurement indicates the section may be as much as 150 feet thick. The lower half of the section consists of limestone and quartzite boulder and pebble conglomerates interbedded with calcareous quartzites. The conglomerates contain poorly sorted, angular to rounded, sand- to

	Madera Limestone (Magdalena Mountains)	San Andres Formation (Olney Ranch)
Orthochems	80 percent of the rock. Calcite is dominant and it occurs as micrite or neomorphic microspar.	95 percent of the rock. Dolomite is dominant and calcite is subordinate. Minor neomorphism.
Allochems	Less than 10 percent of the rock. Occur as intraclasts, lithoclasts, and pellets. Fossil content averages 8 percent. Includes: brachiopods, crinoids, mollusks, horn corals, bryozoans, fusulinids, and ostracods.	No inorganic allochems. Fossil content averages about 5 percent. Only crinoids were observed.
Terrig. Deb.	Less than 10 percent of the rock. Detrital quartz grains. Grains are moderately sorted, angular, and silt-size. Interbedded coarse-grained quartzite beds.	None.
Bed. & Struct.	Medium- to very-thick-bedded, homogeneous. Thin laminations. 750 to 800 feet thick in the Magdalena Mountains. Gray, weathers gray.	Very-thick-bedded, homogeneous. 658 feet thick. Black, fetid, weathers brown or black and has a rough, hackly weathered surface.

Table 7. Comparison of Madera and San Andres limestones.

boulder-size clasts of dark-gray, micritic limestone and reddish-brown, medium-grained quartzite (internally planar and cross laminated) in a calcareous matrix (fig. 28). The interbedded calcareous quartzites are moderately sorted, subrounded, fine- to medium-grained, olive-gray, and weather a pale reddish brown.

The pebble and boulder conglomerates are not present in the upper part of the section and only quartzite beds are observed. The calcareous quartzites are moderately sorted, subangular to subrounded, medium grained, olive gray, and weather a light reddish brown. Sedimentary structures in the quartzites are dominantly thin planar laminations and small scale, low angle cross-laminations. The characteristics of these quartzites are similar to those in the thick quartzite section at Olney Ranch. Contacts with other pre-Teritary units are not exposed because alluvium and blow-sand completely cover lower contacts. The upper contact is a depositional contact with the overlying Tertiary volcanics of the Spears Formation. Similarities with Abo quartzites, at Olney Ranch, and the presence of limestone conglomerates elsewhere in the Abo make a correlation of this section with the Abo Formation reasonable.

If the reader compares the sections at Olney Ranch and Tres Montosas with the Permian stratigraphic sequence, many similarities may be noted. The lithologies are more like the Permian than the Pennsylvanian. The sedimentary structures found in the Olney Ranch and Tres Montosas beds are more similar to those found in Permian rocks than to those in Pennsylvanian rocks. In the light of these similarities

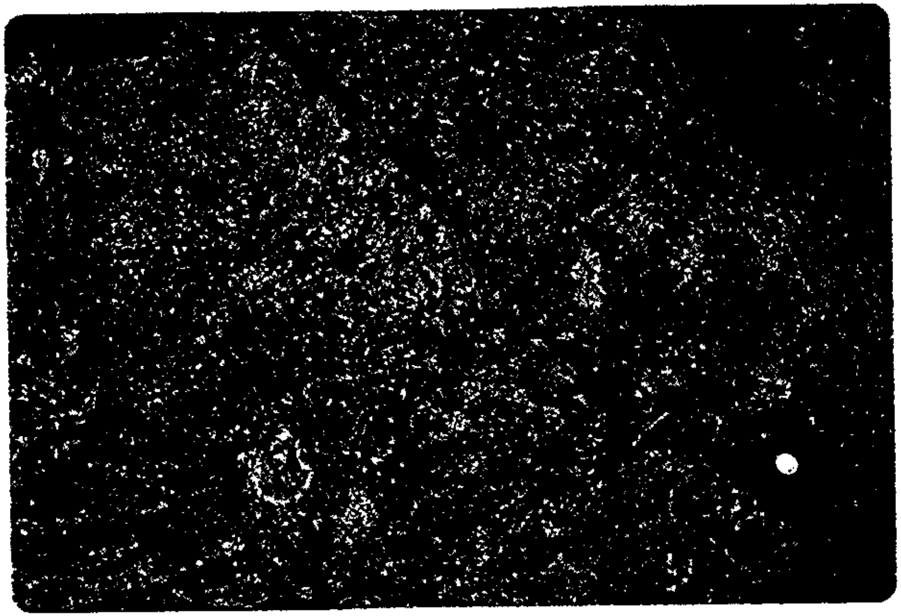

Figure 28. Limestone pebble to boulder conglomerate in the Abo Formation at Tres Montosas. The clasts are sand- to boulder-size fragments of dark-gray micritic limestone in a calcareous matrix. Armstrong identified brachiopods and ostracods in the limestone clasts (Chapin, oral communication, 1973). Other conglomerates in this section contain both quartzite and limestone clasts. The conglomerates are interbedded with Abo quartzites.

with the Permian System, and the previously discussed conflicts with rocks of known Pennsylvanian age, the following revisions in stratigraphic nomenclature are suggested:

1. The units mapped by Loughlin and Koschmann (1942) at Olney Ranch as Kelly Limestone and lower Sandia Limestone are part of the Madera Limestone of Pennsylvanian age. The Mississippian and Lower Pennsylvanian have been faulted out.
2. The unit mapped by Loughlin and Koschmann (1942) at Olney Ranch and Stendel Ridge as Sandia shale is part of the Abo Formation of Permian age.
3. The unit at Olney Ranch which was mapped by Loughlin and Koschmann (1942) as the upper limestone member of the Sandia Formation is of uncertain Permian age, but is probably Yeso Formation.
4. The upper quartzite member of the Sandia Formation, as mapped by Loughlin and Koschmann (1942) at Olney Ranch, is the Glorieta Sandstone of Permian age.
5. The limestone at Olney Ranch which was previously mapped as Madera Limestone (Loughlin and Koschmann, 1942) is the San Andres Formation.

Recognition and proper correlation of these units has solved many of the problems encountered with earlier interpretations. This model eliminates the abrupt thickening of the Sandia Formation, it adequately explains the discrepencies in grain sizes and sedimentary structures of the quartzites, and it explains the dolomite and sparsely fossiliferous character of the upper limestone unit. In short, a degree of order is achieved in a heretofore problematic area.

ENVIRONMENTS OF DEPOSITION

This chapter integrates the rock characteristics presented in preceeding chapters and discusses a modern environment of deposition in which sediments with similar characteristics occur. A correlation with large-scale modern environments, rather than small-scale modern equivalents, is attempted because of limitations on the data imposed by poorly exposed sections and limited lateral control.

Caloso Formation: The lower Caloso (table 3), a calcareous, arkosic sandstone with quartzite, granite and greenschist fragments, reflects terrigenous debris derived from the beveled Precambrian rocks over which the Mississippian sea transgressed. The angularity, poor sorting, and large size of the Precambrian debris suggest negligible distances of transportation prior to deposition. This lower 15-foot part of the Caloso is probably comprised of debris that was lying on the eroded Precambrian surface and then reworked by transgressing seas. This material was presumably supplemented by debris of similar composition that was shed from nearby, low-lying highlands. Although no modern analogs are known, Krumbein and Sloss (1963, p. 563) discuss similar deposits under the heading "basal arkose association."

The lower Caloso is overlain by well-sorted sandy limestones. These probably reflect continued transgression that resulted in sedimentation in deeper, quieter water with a more distant source area. The sources still provided detrital quartz, but deeper, quieter water prevented the incorporation of coarser material into these upper Caloso beds. The paucity of fossils and fossil fragments and significant accumulations of carbonate mud suggest that Caloso beds were probably deposited in somewhat restricted portions of a shallow, marine shelf. Summaries of modern shelves have been given by Curray (1960 and 1965), Belderson and Stride (1966), Emery (1966), Swift (1970), Stride (1963), and Uchupi (1968).

Kelly Limestone: A hiatus exists between the Caloso and Kelly formations that represents at a minimum, all of middle Osage (Burlington) time. Deposition in late Osage (Keokuk) time, characterized by an abundant and varied fauna (table 2), took place in an environment conducive to organic growth. The origin of crinoidal wackestones, packstones, and occasional grainstones (table 3), however, is not easily explained. In areas of modern carbonate accumulation, crinoids are uncommon or absent (Bathurst, 1971), As a result, little is known concerning their habitat. The model proposed here for deposition of Kelly beds is similar to, and in agreement with, the regional model proposed and discussed by Armstrong (1962 and 1963). The crinoidal limestones of the Kelly Formation probably accumulated on a broad, shallow, marine shelf. The abundant crinoid gardens that must have been present probably indicate well-circulated waters and probable access to open seas. The crinoidal gardens were a ready source of the bioclastic sands that paleocurrents reworked and spread across the shelf floor. Chert in the Kelly Formation shows evidence of a replacement origin (partial silicification of fossils and relict textures in the matrix). Armstrong (1962) suggests the silica was originally disseminated throughout the unconsolidated calcareous muds and sands and was then concentrated into nodules during diagenesis.

Sandia Formation: During latest Mississippian and early Pennsylvanian time the Magdalena area was subjected to erosion. Prior to Pennsylvanian transgression, the Peñasco dome, so prominant through most of Mississippian time, along with the smaller Joyita uplift, became the most important contributors of detritus to shallow Pennsylvanian seas (Kottlowski, 1960). The characteristics of Sandia rocks, presented on page 59, are similar to those of sediments accumulating in a modern shoreline complex. Selley (1970) reviews modern shoreline environments and offers an excellent bibliography concerning shoreline sedimentation. Very-coarse sands and gravels often are observed in channel deposits. Cross-bedding formed by megaripples is common in channel deposits and lenticular bedding and wavy lamination are common in finer lithologies. Small-scale erosional features are very common. Carbonates are fossiliferous and micritic in nature. They exhibit thin lamination or cross-lamination. The rock types of the Sandia Formation are interpreted to represent various subenvironments associated with a shoreline complex.

Quartzite: The properties of Sandia quartzites (table 5) are similar to channel sands. These properties include: 1) texture--very-coarse-sand size, poorly to well-sorted, rounded shape; 2) structures--small- to large-scale planar and trough crossbedding; 3) erosional basal contacts, and 4) geometry--lensoid (uncertain in Magdalena Mountains due to limited exposures but some suggestion of lateral thinning). Wackes probably represent overbank equivalents of the channel facies and were deposited in nearby interchannel areas.

Shale: The properties of Sandia shales (page 59) indicate deposition out of suspension in a low energy environment such as a marsh, swamp, deltaic platform, or tidal flat. They are characterized by plant growth and a dearth of marine fossils. Sedimentary structures are restricted to wavy, lenticular lamination and cross lamination. The deposits consist of silty muds with small amounts of sand and are usually carbonaceous.

Limestone: The characteristics of Sandia limestones suggest the rocks originated in a nearshore marine or lower tidal flat type of environment. This conclusion is supported by: 1) the presence of marine fossils, 2) abundant micrite, 3) fine laminations, and 4) their association with shale and quartzite. Similar limestones in modern nearshore and tidal flat environments are described by Shinn, Lloyd, and Ginsburg (1969), Illing, Wells, and Taylor (1965), and Bathurst (1971). They are also observed in the ancient record by Laporte (1967) and Mater (1967).

Madera Limestone: Madera limestones are the result of a long period of subtidal deposition on a shallow marine shelf. Uniform accumulations of micrite with relatively sparse fossil debris interrupted by occasional beds of quartzite indicate periods of higher energy periodically occurred. Thin lamination indicates that some horizons accumulated in an environment with sufficient circulation to winnow micrite. Occasional high-energy regimes produced coarse-grained quartzite beds, nodular limestone beds, and the comminution of skeletal debris.

SUMMARY AND CONCLUSIONS

This paper has discussed the Mississippian and Pennsylvanian strata of the Magdalena area in terms of:

1. Regional Stratigraphy
2. Local Stratigraphy
3. Petrology and Petrography
4. Depositional Environments.

Evidence was cited to support the following conclusions:

1. The Mississippian System in the Magdalena area is 64 to 125 feet thick. The basal Caloso Formation is about 30 feet thick and is comprised of a lower terrigenous unit containing poorly-sorted, coarse-grained sand to pebble-size fragments of Precambrian detritus and an upper unit of sandy limestone. The overlying Kelly Formation is as much as 95 feet thick and is predominantly a crinoidal limestone. The Caloso beds were deposited as early Mississippian seas transgressed over a surface of low relief carved on Precambrian rocks. Limestones of the Kelly Formation accumulated on a broad, shallow, well-circulated marine shelf containing abundant crinoid gardens.

2. Exposed sections of Pennsylvanian rocks in the Magdalena Mountains are 1,300 to 1,400 feet thick. The Sandia Formation is 550 to 600 feet thick and consists predominantly of shale with subordinate amounts of interbedded coarse quartzite and fossiliferous, micritic limestone. The Sandia beds were deposited as facies of a shoreline complex. The Madera

Limestone is 750 to 800 feet thick in exposed sections but as much as 1,200 feet of the upper Madera has been faulted out. Homogeneous Madera micrites were probably deposited in local depressions on a shallow marine shelf in which circulation and organic activity was inhibited.

3. The six members in the Sandia Formation, as described by Loughlin and Koschmann (1942), are lenticular, local units impractical to use in regional mapping or stratigraphic studies. It is suggested that their use be discontinued and the Sandia Formation be described as a shale unit with thin, interbedded quartzites and limestones.

4. It is suggested that the sections at Olney Ranch and Tres Montosas are of Permian age rather than Pennsylvanian age as previously thought. Permian units at Olney Ranch are, in ascending order, the Abo, Yeso (?), Glorieta, and San Andres formations. Permain strata at Tres Montosas are restricted to about 100 to 150 feet at the Abo Formation.

In conclusion, Mississippian and Pennsylvanian sedimentary rocks in central New Mexico provide an example of ancient shallow marine shelf environments. Relationships between numerous and diverse sub-environments in the Pennsylvanian rocks are poorly understood at present. Continued study of facies distrubutions and an analysis of paleotransport directions are needed before a detailed understanding of the Pennsylvanian will be achieved.

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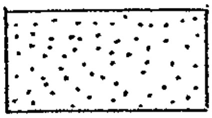
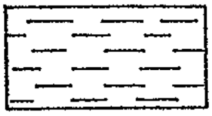
APPENDICES

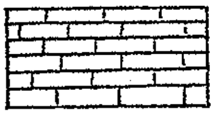
APPENDIX I

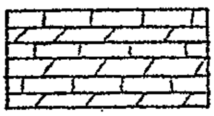
STRATIGRAPHIC COLUMNS

LEGEND

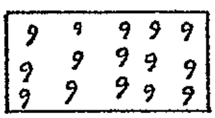

Sandstone

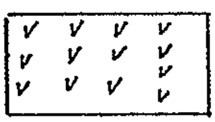

Shale

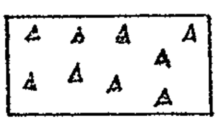

Limestone


Dolomitic Limestone

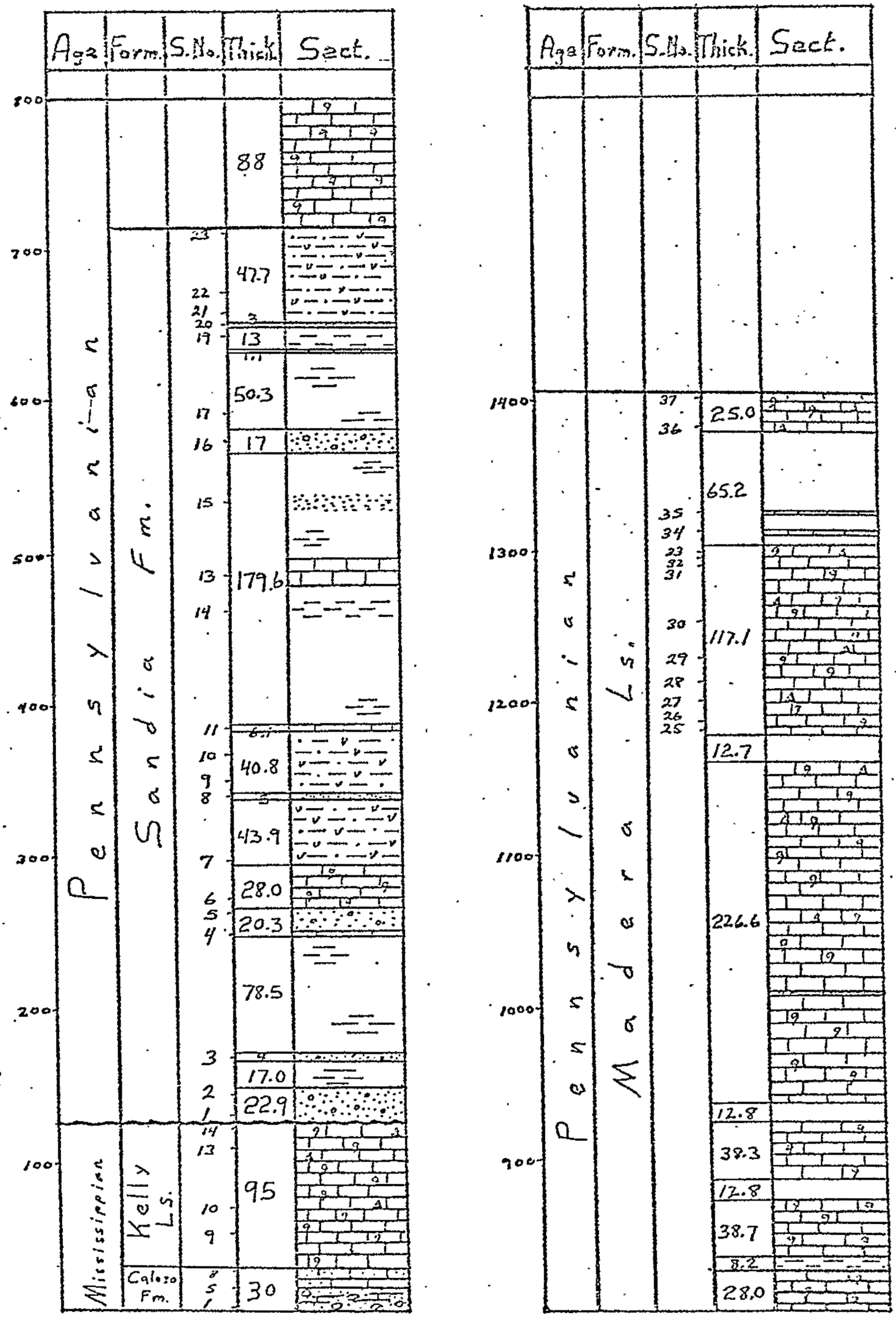

Precambrian


Fossils

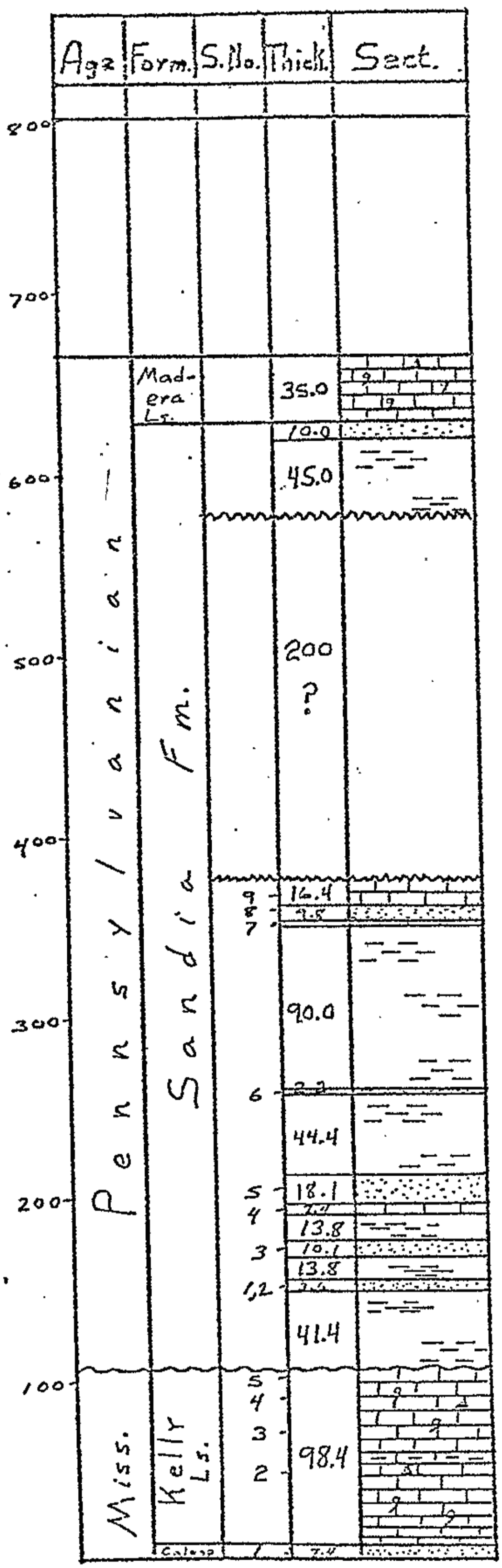

Mica

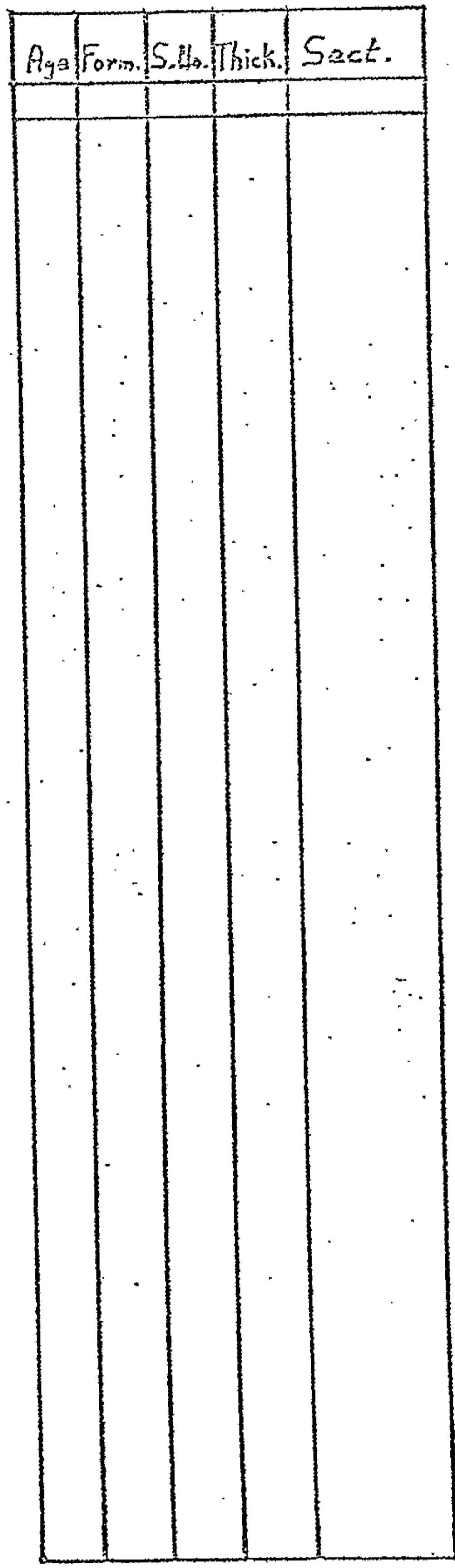

Chert Nodules

TIP TOP MOUNTAIN 1" = 100'

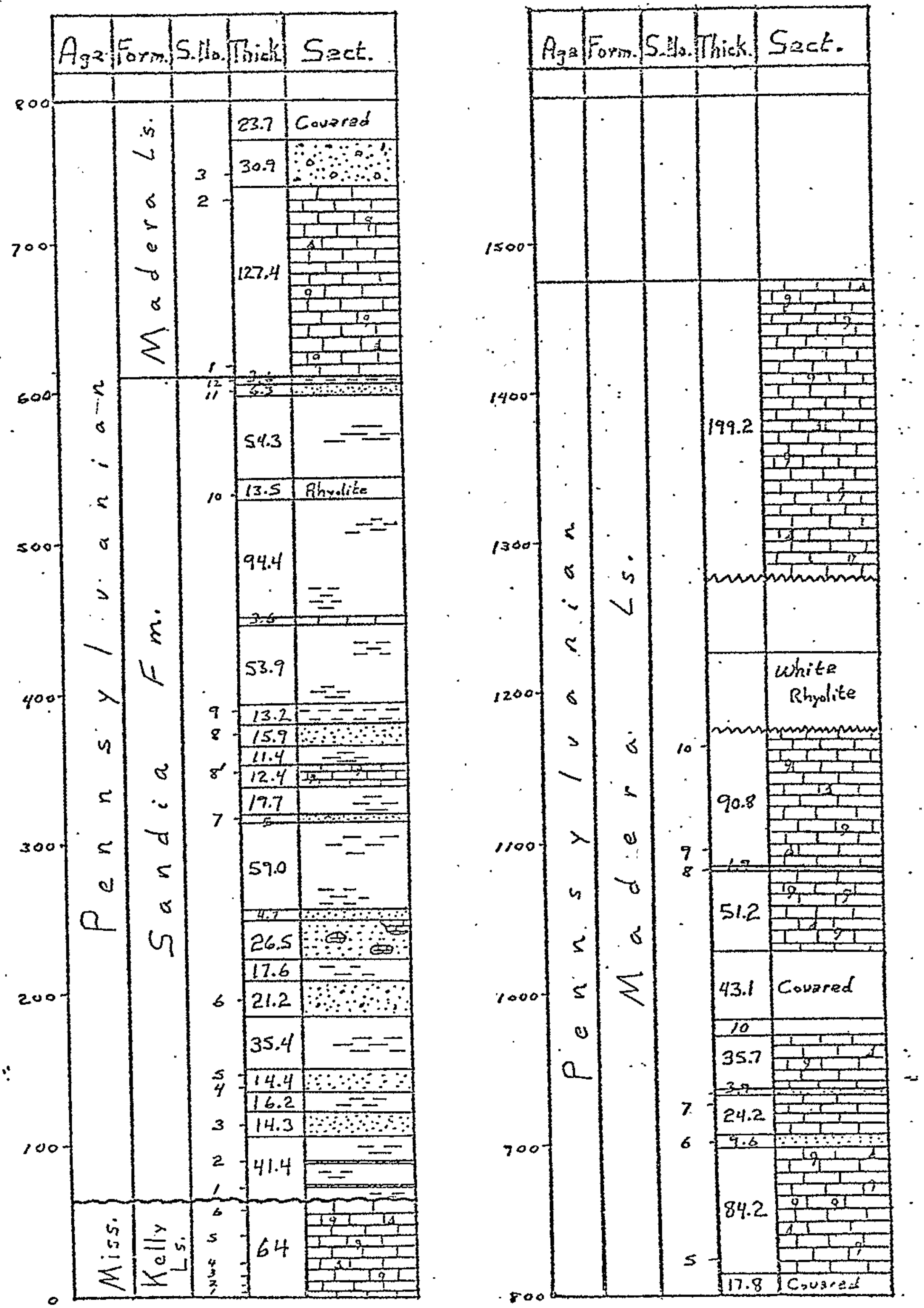


NORTH BALDY 1" = 100'

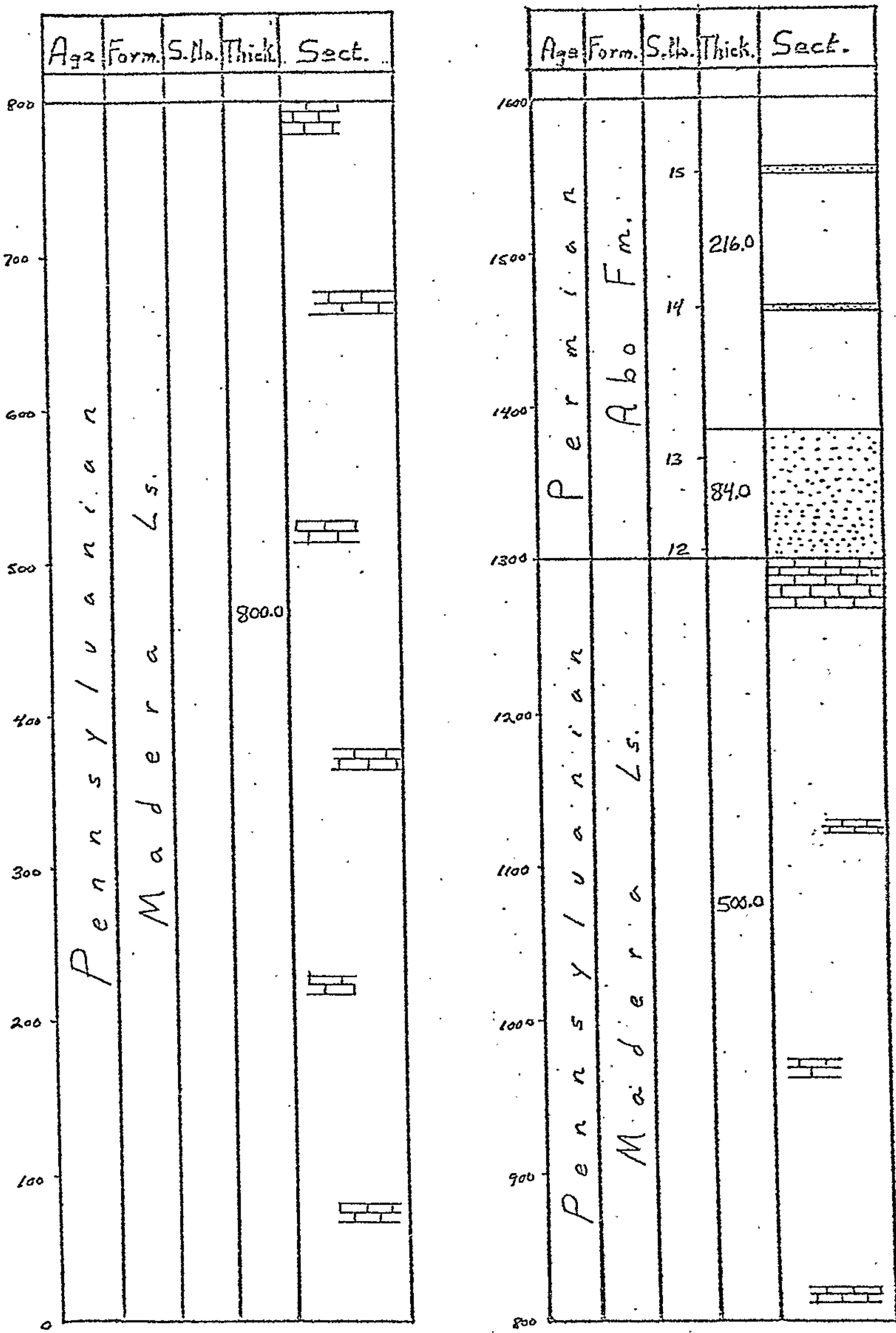




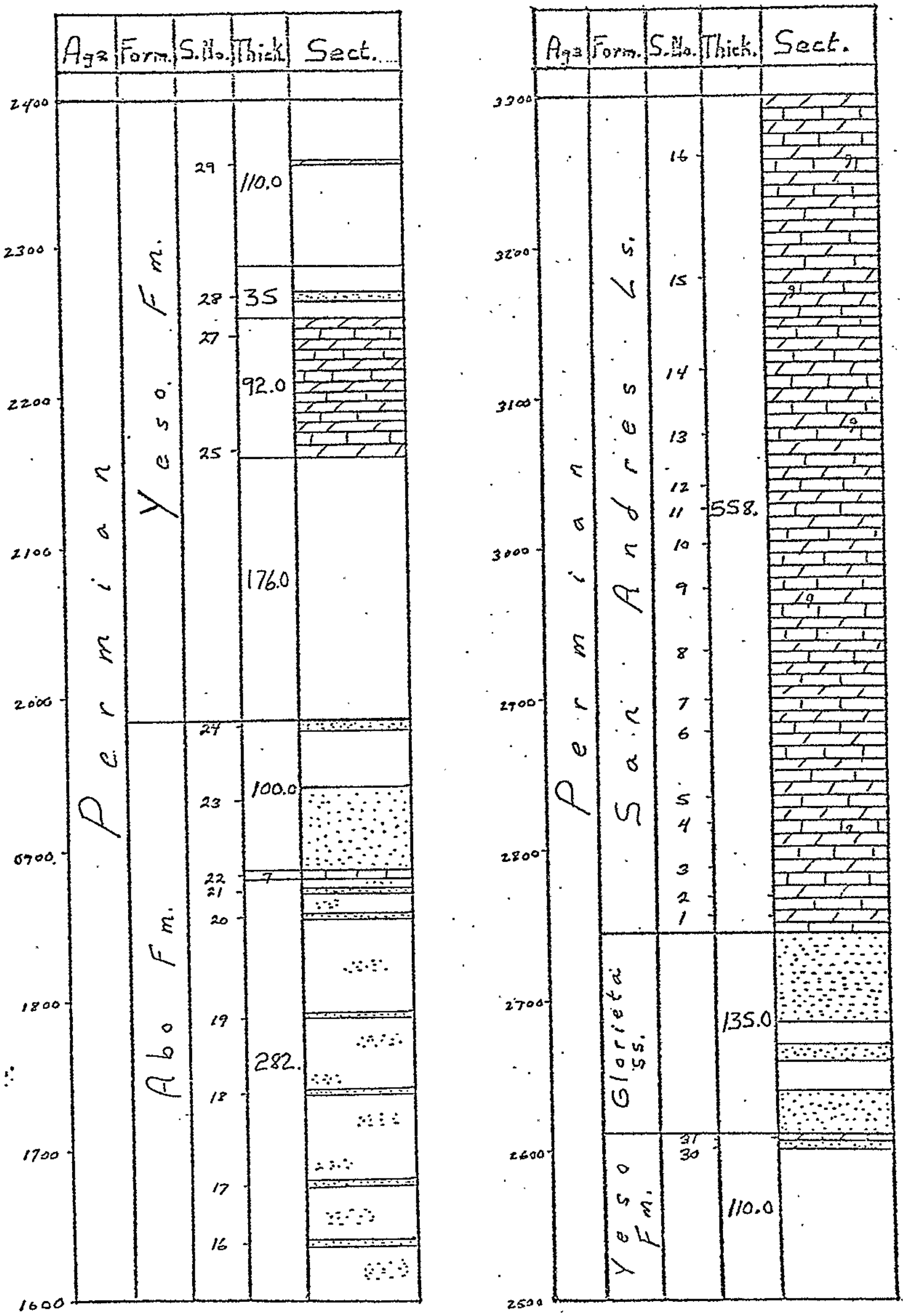
NORTH FORK CANYON 1" = 100'



OLNEY RANCH 1" = 100'



OLNEY RANCH (continued)



OLNEY RANCH (continued)

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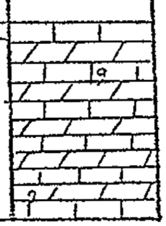
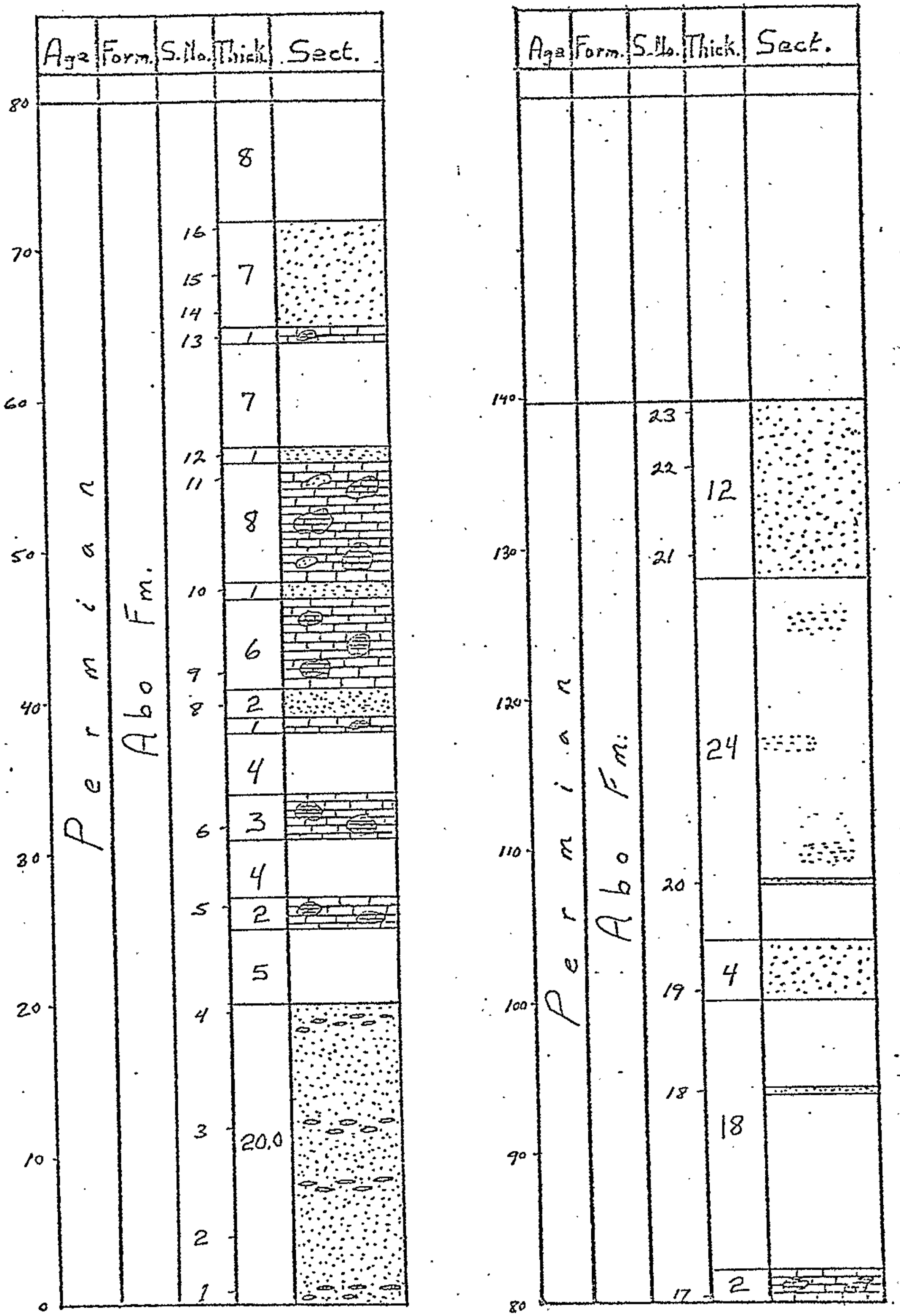
3900	Permian	San Andres Ls.	17	100.0	

Age	Form.	S. No.	Thick.	Sect.

TRES MONTOSAS 1" = 10'



APPENDIX II

SEDIMENTARY PETROLOGY

Age: Mississippian	Thickness: 125'								Location: Tip Top Mountain				
Formation:	Caloso Fm. Code: TTk								Kelly Fm. Code: TTk				
Sample Number:	1	2	3	4	5	6	7	8	9	10	12	13	14
% Matrix:	40	65	65	80	60	90	98	60	99	15	60	55	50
Carbonate	40	65	65	80	60	90	98	60	99	15	60	55	50
Silica													
Clay													
% Terrigenous Grains:	60	35	34	20	25	9	2	1					
Quartz	40	30	30	15	25	9	2	1					
Feldspar	20	3	2										
Other: Chert		2	2	5									
Other: Mica													
% Allochems:					15			39					
Pellets								39					
Oolites													
Intraclasts					15								
Lithoclasts													
Composites													
% Fossils:			1			1			1	85	40	45	50
Brachiopods												C	
Bryozoans												R	A
Algae													
Corals													
Echinoderms			R			R			R	A	A	A	A
Foraminifera													
Mollusks										R		R	A
Sponges													
Ostracods													?

Age: Pennsylvanian	Thickness: 587'						Location:					Tip Top Mountain									
Formation:	Sandia Fm.																				
Sample Number:	1	2	3	4	5	6	7	8	9	10	11	13	15	16	17	18	19	20'	21	22	23
% Matrix & Cement	20	15	20	35	15	25	95	10	45	90	40	99	15	15	90	25	90	20	60	45	60
Carbonate	5			35		25					40	99	10	10	90	25				45	50
Silica	10	10	15		10		55	7	40	80			5	5			80	10	25		10
Clay	5	5	5		5		40	3	5	10							10	10	35		
% Terrigenous Grains:	80	85	80	60	85	1	5	90	55	10	25	1	85	85		1	10	80	40	10	40
Quartz	80	80	75	60	80	1	3	90	50	9	25	1	82	82		1	9	80	39	10	39
Feldspar		3	3		3																
Other: Mica		1	1		1		2		5	1							1		1		1
Other: Chert		1	1		1								3	3							
% Allochems:				1		1														20	
Pellets																					
Oolites				1		1															
Intraclasts																				10	
Lithoclasts																				10	
Composites																					
% Fossils:				4		73					35				10	74				25	
Brachiopods				R		A					A				R	A				C	
Bryozoans				R		C					A				?	R				C	
Algae				R																	
Corals																					
Echinoderms						A					A				R	A				C	
Foraminifera						R									R	C					
Mollusks						R					C				R	C				C	
Sponges (Spicules)																?A					
Ostracods															R						

Age: Pennsylvanian	Thickness: 793					Location: Tip Top Mountain						
Formation:	Madera Ls.											
Sample Number:	1	2	4	5'	6	7	8	10	20	21'	27	36
% Matrix & Cement:	95	25	80	99	85	25	85	95	35	65	20	65
Carbonate	95	23		99	85	24	85	95	33	65	2	65
Silica		1	45			1			2		10	
Clay		1	35								8	
% Terrigenous Grains:		75	20		10	75		3	65		80	
Quartz		73	15		10	70		2	63		75	
Feldspar		1	1			2			1		1	
Other: Mica			3					1			3	
Other: Chert		1	1			3			1		1	
% Allochems:										20		25
Pellets										20		25
Oolites												
Intraclasts												
Lithoclasts												
Composites												
% Fossils:	5			1	5		15	2		15		10
Brachiopods	C			R	C		C	R		A		R
Bryozoans							?			R		
Algae												
Corals	R											
Echinoderms	C						C					R
Foraminifera							R			R		R
Mollusks	R				R		A					R
Sponges										?		?
Ostracods							C					R

Age: Mississippian Thickness: 106' Location: North Baldy

Formation: #1 is Caloso Fm. Code: MNBk, 2-5 Kelly Fm. Code: MNBk

Sample Number:	1	2	2a.	3	5																	
% Matrix:	20	5	100	5	?																	
Carbonate	20	5	100	5																		
Silica																						
Clay																						
% Terrigenous Grains:	80																					
Quartz	80																					
Feldspar																						
Other:																						
Other:																						
% Allochems:																						
Pellets																						
Oolites																						
Intraclasts																						
Lithoclasts																						
Composites																						
% Fossils:		95		95	?																	
Brachiopods																						
Bryozoans																						
Algae																						
Corals																						
Echinoderms		A		A																		
Foraminifera																						
Mollusks																						
Sponges																						
Ostracods																						

Age: Pennsylvanian Thickness: 274 Location: North Baldy

Formation:	Sandia Fm.								
Sample Number:	1	2	3	4	5	6	7	8	9
% Matrix:	90	75	20	20	85	50	90	35	85
Carbonate				20			90	25	85
Silica	50	70	20		85	50		10	
Clay	40	5							
% Terrigenous Grains:	10	25	80	5	15	50		65	
Quartz	7	23	75	5	14	40		60	
Feldspar									
Other: Mica	3				1	10			
Other: Chert		2	5					5	
% Allochems:									
Pellets									
Oolites									
Intraclasts									
Lithoclasts									
Composites									
% Fossils:				75			10		15
Brachiopods				A			R		?
Bryozoans				R					
Algae									
Corals									C
Echinoderms				A			C		
Foraminifera							R		
Mollusks									?
Sponges									
Ostracods							R		R

Age: Mississippian Thickness: 64' Location: North Fork Canyon

Formation: Kelly Fm. Code: MNFk

Sample Number:	1	2	2'	3	4	6
% Matrix:	47	100	95	35	30	70
Carbonate	47	100	95	35	30	70
Silica						
Clay						
% Terrigenous Grains:			3			15
Quartz			3			15
Feldspar						
Other:						
Other:						
% Allochems:						
Pellets						
Oolites						
Intraclasts						
Lithoclasts						
Composites						
% Fossils:	53		2	65	70	15
Brachiopods				C	R	R
Bryozoans				R	R	C
Algae						
Corals						
Echinoderms	A		R	A	A	C
Foraminifera						
Mollusks						
Sponges						
Ostracods						

Age: Pennsylvanian	Thickness: 562'						Location: North Fork Canyon					
Formation:	Sandia Fm.											
Sample Number:	1	2	3	4	5	6	7	8	8"	9	11	12
% Matrix & Cement:	30	75	30	20	30	30	25	25	97	75	25	80
Carbonate	20	5		10	5	5	20	20	97	10	15	
Silica	10	60	25	10	20	20	5	5		35	10	50
Clay		10	5		5	5				25		30
% Terrigenous Grains:	70	25	70	80	70	70	75	75		25	75	20
Quartz	65	15	69	80	69	69	65	65		15	75	19
Feldspar	2											
Other: Mica		10	1		1	1				10		1
Other: Chert	3						10	10				
% Allochems:												
Pellets												
Oolites												
Intraclasts												
Lithoclasts												
Composites												
% Fossils:									3			
Brachiopods									R			
Bryozoans												
Algae												
Corals												
Echinoderms									R			
Foraminifera												
Mollusks												
Sponges												
Ostracods												

Age: Pennsylvanian	Thickness: 763	Location: North Fork Canyon					
Formation:	Madera Ls.							
Sample Number:	1	2	3	5	6	7	9	10
% Matrix:	95	95	40	85	20	85	85	95
Carbonate	95	95	25	85	20	85	85	95
Silica			13					
Clay			2					
% Terrigenous Grains:			60		60	5		
Quartz			55		59	5		
Feldspar					1			
Other: Mica			3					
Other: Chert			2					
% Allochems:					15			
Pellets								
Oolites								
Intraclasts								
Lithoclasts								
Composites								
% Fossils:	5	5		15	5	10	15	5
Brachiopods		R		A		?	A	C
Bryozoans	R	R		C	R			R
Algae								
Corals								
Echinoderms	R	R		C	R		R	R
Foraminifera	?			R	R			
Mollusks				A	R	?	A	
Sponges								
Ostracods							R	

APPENDIX III

CLASSIFICATION SYSTEMS

Volumetric Allochem Composition	Limestones, Partly Dolomitized Limestones, and Primary Dolomites (see Notes 1 to 6) — >10% Allochems, Allochemical Rocks (I and II): Sparry Calcite Cement > Microcrystalline Ooze Matrix — Sparry Allochemical Rocks (I)	>10% Allochems, Allochemical Rocks (I and II): Microcrystalline Ooze Matrix > Sparry Calcite Cement — Microcrystalline Allochemical Rocks (II)	<10% Allochems, Microcrystalline Rocks (III): 1–10% Allochems — Most Abundant Allochem	<10% Allochems, Microcrystalline Rocks (III): <1% Allochems	Undisturbed Bioherm Rocks (IV)	Replacement Dolomites[7] (V): Allochem Ghosts — Evident Allochem	Replacement Dolomites[7] (V): No Allochem Ghosts
>25% Intraclasts (i)	Intrasparrudite (Ii:Lr) Intrasparite (Ii:La)	Intramicrudite* (IIi:Lr) Intramicrite* (IIi:La)	Intraclasts: Intraclast-bearing Micrite* (IIIi:Lr or La)	Micrite (IIIm:L); if disturbed, Dismicrite (IIImX:L); if primary dolomite, Dolomicrite (IIIm:D)	Biolithite (IV:L)	Finely Crystalline Intraclastic Dolomite (Vi:D3) etc.	Medium Crystalline Dolomite (V:D4)
<25% Intraclasts: >25% Oölites (o)	Oösparrudite (Io:Lr) Oösparite (Io:La)	Oömicrudite* (IIo:Lr) Oömicrite* (IIo:La)	Oölites: Oölite-bearing Micrite* (IIIo:Lr or La)			Coarsely Crystalline Oölitic Dolomite (Vo:D5) etc.	Finely Crystalline Dolomite (V:D3)
<25% Intraclasts: <25% Oölites: Volume Ratio of Fossils to Pellets >3:1 (b)	Biosparrudite (Ib:Lr) Biosparite (Ib:La)	Biomicrudite (IIb:Lr) Biomicrite (IIb:La)	Fossils: Fossiliferous Micrite (IIIb: Lr, La, or Ll)			Aphanocrystalline Biogenic Dolomite (Vb:D1) etc.	
<25% Intraclasts: <25% Oölites: Volume Ratio of Fossils to Pellets 3:1–1:3 (bp)	Biopelsparite (Ibp:La)	Biopelmicrite (IIbp:La)	Pellets: Pelletiferous Micrite (IIIp:La)			Very Finely Crystalline Pellet Dolomite (Vp:D2) etc.	etc.
<25% Intraclasts: <25% Oölites: Volume Ratio of Fossils to Pellets <1:3 (p)	Pelsparite (Ip:La)	Pelmicrite (IIp:La)					

* Designates rare rock types.

1 Names and symbols in the body of the table refer to limestones. If the rock contains more than 10 per cent replacement dolomite, prefix the term "dolomitized" to the rock name, and use DLr or DLa for the symbol (e.g., dolomitized intrasparite, Li:DLa). If the rock contains more than 10 per cent dolomite of uncertain origin, prefix the term "dolomitic" to the rock name, and use dLr or dLa for the symbol (e.g., dolomitic pelsparite, Ip:dLa). If the rock consists of primary (directly deposited) dolomite, prefix the term "primary dolomite" to the rock name, and use Dr or Da for the symbol (e.g., primary dolomite intramicrite, IIi:Da). Instead of "primary dolomite micrite" (IIIm:D) the term "dolomicrite" may be used.

2 Upper name in each box refers to calcirudites (median allochem size larger than 1.0 mm.); and lower name refers to all rocks with median allochem size smaller than 1.0 mm. Grain size and quantity of ooze matrix, cements or terrigenous grains are ignored.

3 If the rock contains more than 10 per cent terrigenous material, prefix "sandy," "silty," or "clayey" to the rock name, and "Ts," "Tz," or "Tc" to the symbol depending on which is dominant (e.g., sandy biosparite, TsIb:La, or silty dolomitized pelmicrite, TzIIp:DLa). Glauconite, collophane, chert, pyrite, or other modifiers may also be prefixed.

4 If the rock contains other allochems in significant quantities that are not mentioned in the main rock name, these should be prefixed as qualifiers preceding the main rock name (e.g., fossiliferous intrasparite, oölitic pelmicrite, pelletiferous oösparite, or intraclastic biomicrudite). This can be shown symbolically as Ii(b), Io(p), IIb(i), respectively.

5 If the fossils are of rather uniform type or one type is dominant, this fact should be shown in the rock name (e.g., pelecypod biosparrudite, crinoid biomicrite).

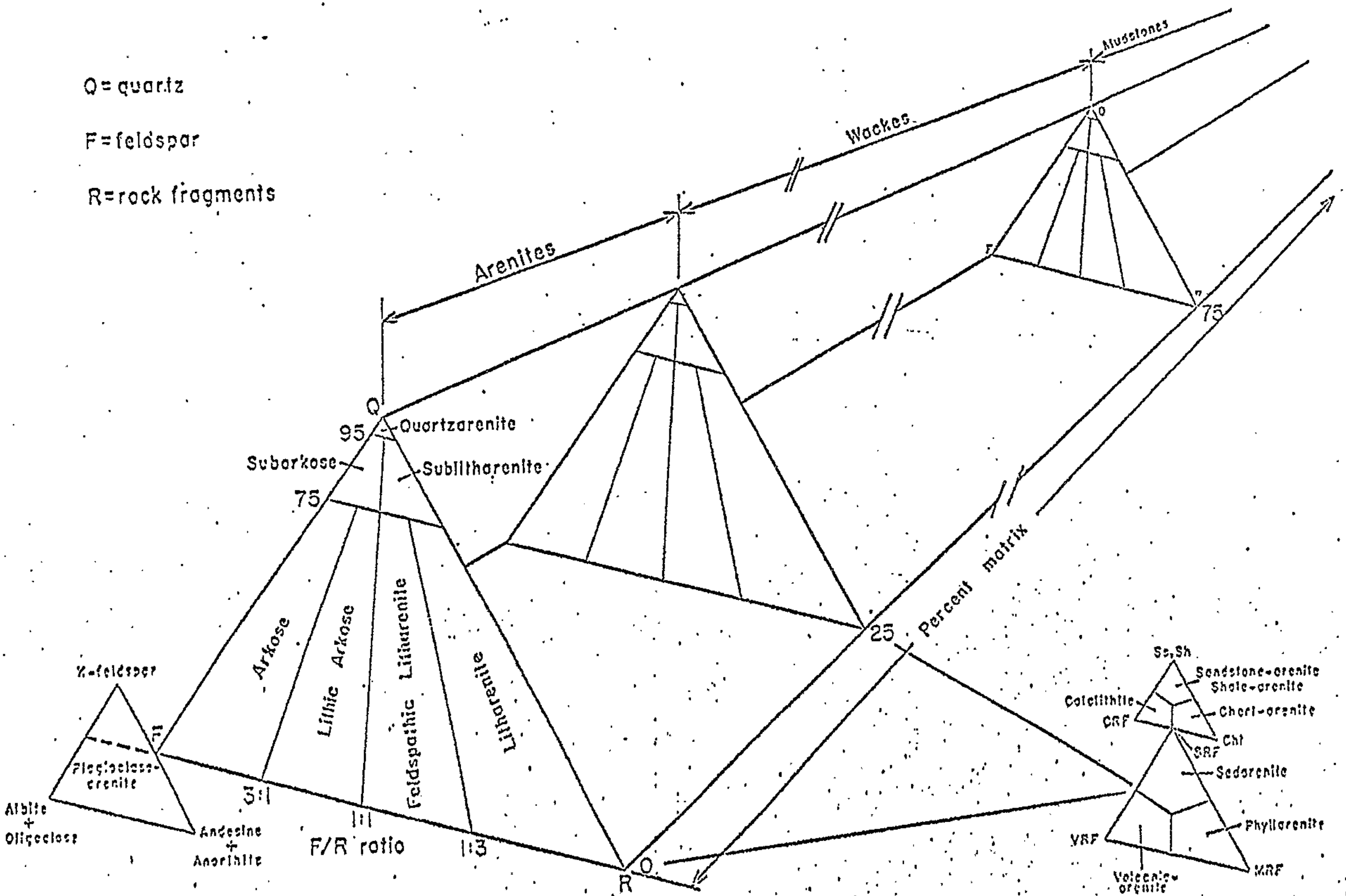
6 If the rock was originally microcrystalline and can be shown to have recrystallized to microspar (5–15 micron, clear calcite) the terms "microsparite," "biomicrosparite," etc. can be used instead of "micrite" or "biomicrite."

7 Specify crystal size as shown in the examples.

Classification of Carbonate Rocks (after Folk, 1959).

<table>
<tr><td colspan="5">Recognizable Depositional Texture</td><td rowspan="5">Depositional Texture is not Recognizable</td></tr>
<tr><td colspan="4">Original Components Not Bound During Deposition</td><td rowspan="4">Orginal Components Bound</td></tr>
<tr><td colspan="3">Contains Mud</td><td rowspan="3">Lacks Mud</td></tr>
<tr><td colspan="2">Mud Supported</td><td rowspan="2">Grain Supported</td></tr>
<tr><td>Less than 10% Grains</td><td>More than 10% Grains</td></tr>
<tr><td>MUDSTONE</td><td>WACKESTONE</td><td>PACKSTONE</td><td>GRAINSTONE</td><td>BOUNDSTONE</td><td>CRYSTALLINE CARBONATE</td></tr>
</table>

Classification of Carbonate Rocks (after Dunham, 1962).



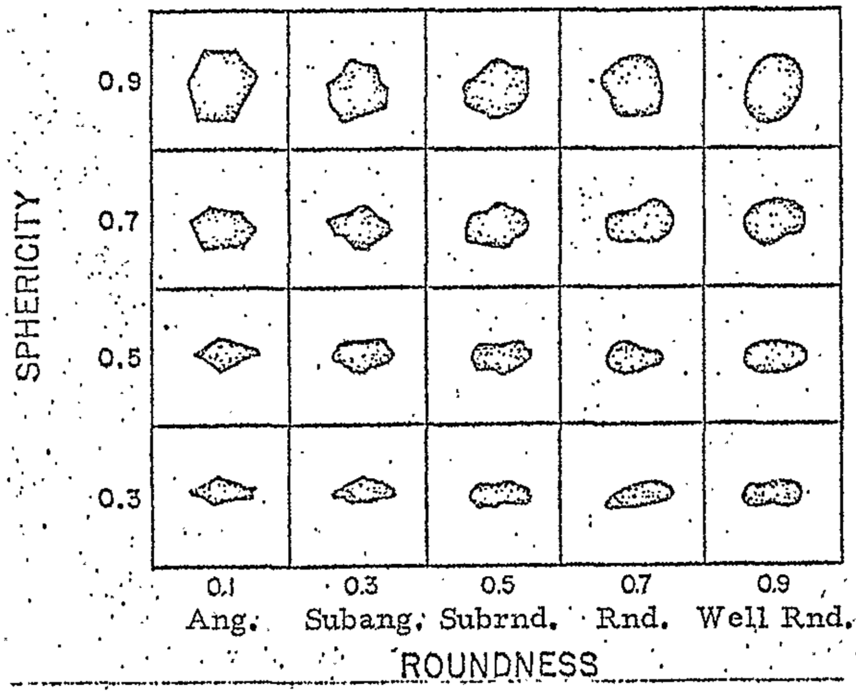
Classification of Terrigenous Rocks (modified after Dott, 1964, and Folk, 1968).

	U.S. Standard sieve mesh	Millimeters		Phi (ϕ) units	Wentworth size class
GRAVEL	Use wire squares	4096		−12	
		1024		−10	Boulder
		256	256	− 8	
		64	64	− 6	Cobble
		16		− 4	Pebble
	5	4	4	− 2	
	6	3.36		− 1.75	
	7	2.83		− 1.5	Granule
	8	2.38		− 1.25	
	10	2.00	2	− 1.0	
SAND	12	1.68		− 0.75	
	14	1.41		− 0.5	Very coarse sand
	16	1.19		− 0.25	
	18	1.00	1	0.0	
	20	0.84		0.25	
	25	0.71		0.5	Coarse sand
	30	0.59		0.75	
	35	0.50	1/2	1.0	
	40	0.42		1.25	
	45	0.35		1.5	Medium sand
	50	0.30		1.75	
	60	0.25	1/4	2.0	
	70	0.210		2.25	
	80	0.177		2.5	Fine sand
	100	0.149		2.75	
	120	0.125	1/8	3.0	
	140	0.105		3.25	
	170	0.088		3.5	Very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
SILT	270	0.053		4.25	
	325	0.044		4.5	Coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	Medium silt
	Use	0.0078	1/128	7.0	Fine silt
	pipette	0.0039	1/256	8.0	Very fine silt
MUD	or	0.0020		9.0	
	hydro-	0.00098		10.0	Clay
	meter	0.00049		11.0	
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

Terminology and class intervals for grade scales.

Basic Criterion	Subordinate Criteria					
Character of lower boundary surface of set of cross-strata	Shape of sets of cross-strata	Attitude of axis of set of cross-strata	Symmetry of set of cross-strata	Arching of cross-strata	Dip of cross-strata	Length of cross-strata
Nonerosional surfaces (simple cross-stratification)	Lenticular	Plunging	Symmetric	Concave	High angle (> 20 degrees)	Small scale (< 1 foot)
Planar surfaces of erosion (planar cross-stratification)	Tabular	*Nonplunging*	*Asymmetric*	Straight		Medium scale (1 to 20 feet)
Curved surfaces of erosion (trough cross-stratification)	Wedge-shaped			Convex	Low angle (< 20 degrees)	Large scale (> 20 feet)

Classification of cross bedding (after McKee and Weir, 1953).



Classification of sphericity and roundness (after Krumbein and Sloss, 1963).

Thickness of Unit		Terms for Thickness of Stratification Units
Metric System	English System	
-0.3 cm.	-1/10 in.	Thinly laminated
0.3–1.0	1/10–2/5	Thickly laminated
1–3	2/5–1	Very thinly bedded
3–10	1–4	Thinly bedded
10–30	4–12	Mediumly bedded
30–100	1–3 ft.	Thickly bedded
100–	3–	Very thickly bedded

Classification of bedding (after Ingram, 1954).

I. Mode of Formation
- P: Passive Precipitation
  - P: Normal pore filling
  - Ps: Solution-fill
- D: Displacive Precipitation
- N: Neomorphism
  - N: as a general term, or where exact process unknown.
  - N_i: Inversion from known aragonite.
  - N_r: Recrystallization from known calcite.
  - N_d: Degrading (also N_{id}, N_{rd}).
  - N_s: Original fabric strained significantly.
  - N_e: Coalescive (as opposed to porphyroid).
    - (the above may be combined as N_{rds}).
- R: Replacement

II. Shape
- E: Equant, axial ratio $< 1\frac{1}{2}:1$
- B: Bladed, axial ratio $1\frac{1}{2}:1$ to $6:1$
- F: Fibrous, axial ratio $> 6:1$

III. Crystal Size
- Class 1, 2, 3, 4, 5, 6, or 7

IV. Foundation
- O: Overgrowth, in optical continuity with nucleus.
  - O: Ordinary
  - O_m: Monocrystal
  - O_w: Widens outward from nucleus
- C: Crust, physically oriented by nucleant surface.
  - C: Ordinary
  - C_w: Widens outward from nucleus
- S: Spherulitic with no obvious nucleus (fibrous or bladed calcite only)
- No Symbol: randomly oriented, no obvious control by foundation

Summary of code for authigenic calcite (after Folk, 1965).

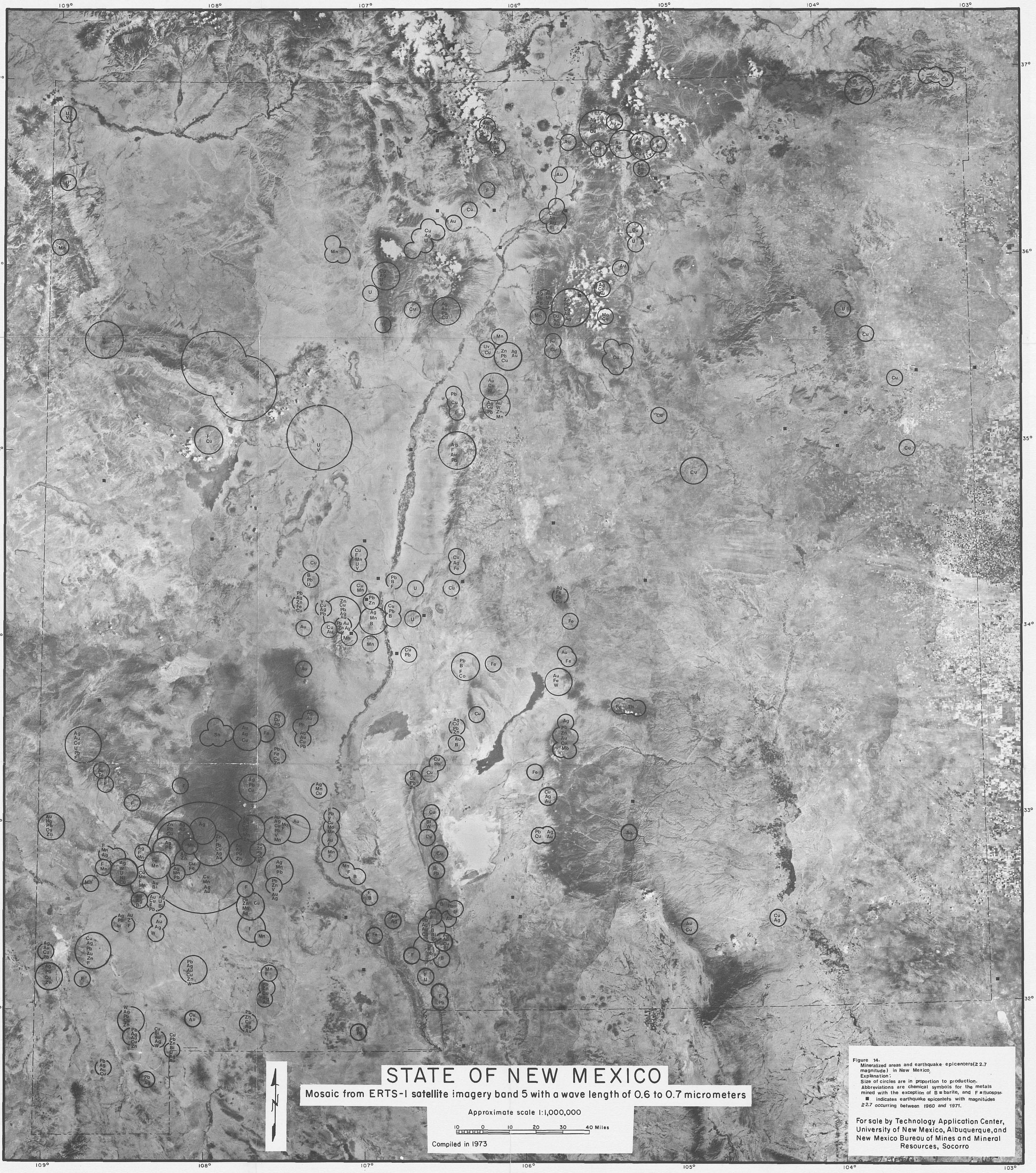


Figure 14.
Mineralized areas and earthquake epicenters (≥ 2.7 magnitude) in New Mexico.
Explanation:
Size of circles are in proportion to production.
Abbreviations are chemical symbols for the metals mined with the exception of B = barite, and F = fluospar.
■ indicates earthquake epicenters with magnitudes ≥ 2.7 occurring between 1960 and 1971.

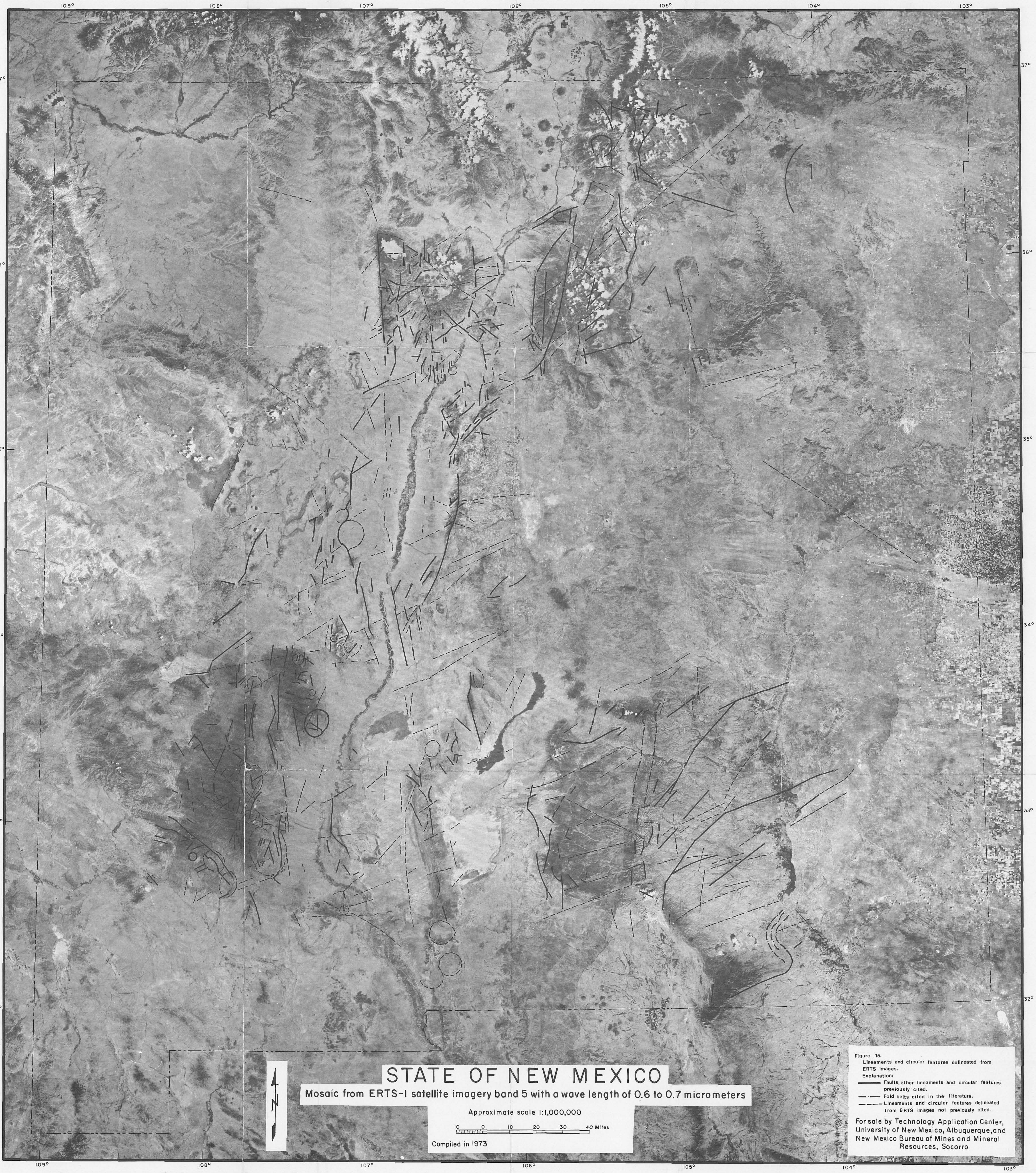


Figure 15. Lineaments and circular features delineated from ERTS images.