BULLETIN 66

# Summary of Pennsylvanian Sections in Southwestern New Mexico and Southeastern Arizona

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# *Abstract*

Pennsylvanian strata in southwestern New Mexico and southeastern Arizona range from Morrowan(?) to Virgilian in age, are disconformable to angularly unconformable above Precambrian to Upper Mississippian rocks, and are as much as 4,000 feet thick, although in most localities they range from 1,000 to 2,000 feet in thickness. The Pennsylvanian-Permian contact in many areas appears to be gradational, and the boundary is drawn within a zone of indeterminate age between Virgilian and Wolfcampian fossil-bearing beds. Permian rocks at some localities, as well as Cretaceous and Tertiary rocks in other places, are erosionally unconformable on the Pennsylvanian strata. In the southern Hueco Mountains and the Florida Mountains areas, all the Pennsylvanian beds apparently were removed by erosion during early Permian time.

Pennsylvanian rocks in southeastern Arizona are mapped as the Horquilla formation and lower part of the Earp formation of the Naco group, and in south-central Arizona as the Naco formation and lower part of the Supai red beds. In southwesternmost New Mexico, the upper part of the Horquilla formation is younger than in Arizona and includes Wolfcampian beds. Pennsylvanian strata in central and southwestern New Mexico generally have been referred to the Sandia and Madera formations of the Magdalena group by the U. S. Geological Survey, or to the faunal equivalents of the Morrow, Derry (Atoka), Des Moines, Missouri, and Virgil series, which were subdivided by Thompson (1942) into groups and formations.

Lithic units have been named from outcrops in isolated mountain ranges, such as the Gobbler, Beeman, and Holder formations in the Sacramento Mountains, the Red House, Nakayc, and Bar B formations in the Caballo Mountains, and the Panther Seep formation in the San Andres Mountains.

Clastic sediments were derived chiefly from the Pennsylvanian-age Pedernal Mountains to the east, and locally from the Florida, Joyita, Zuni-Defiance, and Kaibab positive-tending areas, which at times during the Pennsylvanian were emergent and during other epochs were covered by shallow seas. Five troughs or basinal downwarps, where thick sections were deposited, stand out on the isopach map: (I) the Estancia trough, in which Pennsylvanian sediments approach 4,000 feet in thickness; (2) the Orogrande basin, containing as much as 3,000 feet of Pennsylvanian rocks, of which more than two-thirds was deposited in Upper Pennsylvanian time; (3) the Pedregosa basin, in which Pennsylvanian strata are almost 2,500 feet thick; (4) the Lucero basin, with as much as 2,700 feet; and (5) the San Mateo basin, with almost 2,700(?) feet of Pennsylvanian strata. The Orogrande, San Mateo, and Lucero basins are alined along a north-south trend that probably marks a channelway northward across the Cabezon sag to the Paradox basin; the Pedregosa

and Orogrande basins probably connected eastward, in northern Chihuahua and westernmost Texas, with the Marfa and Delaware basins. Over a large area from Clifton, Arizona, southeastward to the Florida Mountains in New Mexico, Pennsylvanian rocks are absent, and Permian or Cretaceous strata rest on pre-Pennsylvanian rocks.

The Pennsylvanian sequence is a limestone lithofacies (clastic ratio less than 0.25) throughout most of the southern part of the area. Northward it grades into lime-shale and then into shale-lime lithofacies of interbedded red beds and nodular limestone on the Mogollon Rim, but of interbedded grayish calcareous shale and fossiliferous limestone west of the Pedernal landmass. Deposits in the Pedregosa basin are chiefly of limestone and lime-shale; those in the Orogrande basin are shale-lime at the south and sand-lime lithofacies on the north, whereas the Pennsylvanian beds in the Estancia trough are of shale-lime lithofacies that intertongue eastward, toward the Pedernal Mountains, with a sand-shale lithofacies. In small areas near the Joyita Hills and Florida Mountains, lime-sand and sand-lime lithofacies dominate; the Joyita Hills are on the east side of the Lucero basin, which shows a westward gradation from sand-lime to lime-sand to lime-shale, and toward the Zuni positive area, to shale-lime. The thick San Mateo sections are of lime-shale lithofacies.

Pennsylvanian strata are potential sources of oil and gas at least in the northern and eastern parts of the region, on the southern edge of the Colorado Plateau, and in the Estancia Valley, Acoma embayment, Chupadera Mesa, Jornada del Muerto, and the Tularosa Valley. Even the basin-and-range country and Datil-Mogollon volcanic plateau are underlain by possibly productive Pennsylvanian (and Permian) beds. Large-scale use of the various Pennsylvanian rocks as industrial minerals and rocks is hampered by the long distances to populous areas, the limestones, shale, and gypsum having been used only locally for building stone and crushed rock, in agriculture, and to make bricks, tile, cement, and lime products.

# *Introduction*

Southwestern New Mexico and southeastern Arizona are a geologic frontier for the study of Paleozoic rocks, especially of the thick and seemingly monotonous Pennsylvanian sequence. Geologic work on Pennsylvanian rocks to date has been chiefly of a reconnaissance nature. Field geologists mapping these beds have tended to overemphasize mapping on topographic expression of the sequences and the use of photogeology. The work has produced a reasonable picture of Pennsylvanian stratigraphy, considering the vast areas to be covered, the long stretches between outcrops of Pennsylvanian sedimentary rocks, and the abrupt and complex relationships of sedimentation, erosion, and nondeposition.

This account of the Pennsylvanian rocks in southwestern New Mexico and southeastern Arizona can be only a resume of published and available unpublished material, along with personal observations that range from gross reconnaissance to relatively detailed mapping. This report thus can be considered a starting point for the study of the Pennsylvanian in the area, not a fully documented summary. More work needs to be done in almost every locality, but a full treatment of the Pennsylvanian, both from field work and laboratory studies, would require a decade. The writer hopes that this compilation will point out areas of immediate interest for detailed study, whether the Pennsylvanian strata are of academic or economic interest.

The region considered (fig. 1, pl. 1) has as its northeasternmost point the Pedernal massif of Precambrian rocks, which is almost exactly at the geographic center of New Mexico. The eastern boundary extends southward from the Pedernal Hills to Carrizozo (New Mexico) and along the west-facing escarpment of the Sacramento Mountains to the Hueco Mountains in westernmost Texas, thence westward along the international boundary to about 85 miles west of Nogales (Arizona), and then north to near the geographic center of Arizona (about halfway between Prescott and Jerome), the northern boundary extending eastward back to the Pedernal Hills. The region is about 360 miles east to west, and 230 miles north to south, a total of about 83,000 square miles, larger than the State of Oklahoma and about the same size as Utah. Less than 5 percent (estimated) of the region has outcrops of Pennsylvanian rocks, but most of the region is, or once was, underlain by Pennsylvanian strata.

New Mexico and Arizona are a long distance from the type sections of the Morrow, Des Moines, Missouri, and Virgil series. Correlation, therefore, is based chiefly on fusulinid zoning; Des Moines series, for example, is used in the sense of a time-stratigraphic unit and not as a rock-stratigraphic unit directly traceable into the type Des Moines series. Series is not capitalized; some paleontologists have suggested that "series" be capitalized when referring to a time-stratigraphic unit and

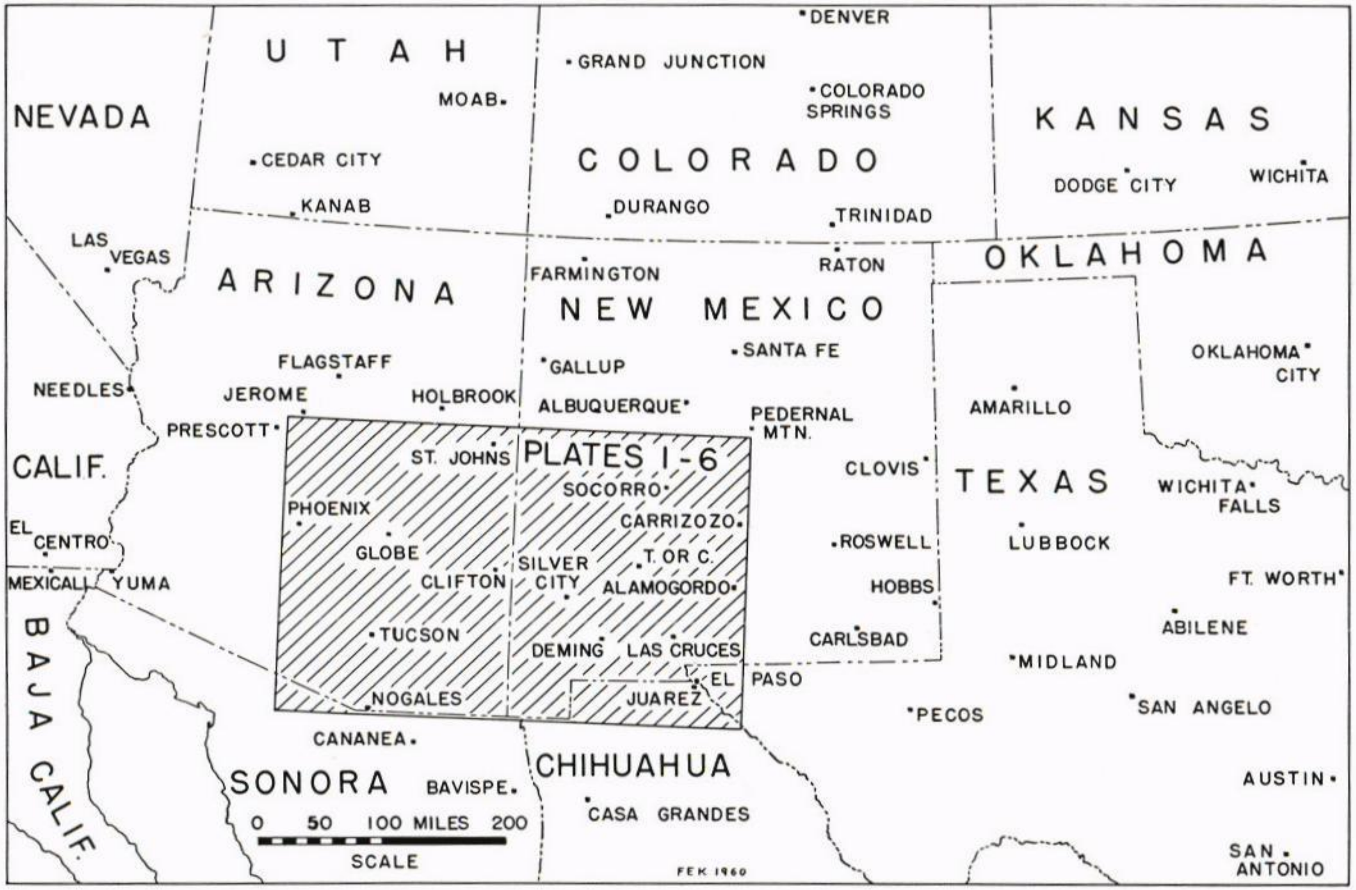


Figure 1

LOCATION OF AREA STUDIED AS SHOWN ON PLATES 1-6 lowercased when used as a rock-stratigraphic unit. Recently other stratigraphers, perhaps stinging from the slight to rocks as compared to fossils, have suggested that all rock terms (formation, limestone, series, et al.) be capitalized when used formally with a distinctive rock-unit label. Thus, "The Madera Limestone is thin to thick bedded. The limestone is underlain by the Sandia Formation," but "The Madera Limestone is thin to thick bedded. The Madera Limestone is underlain by the Sandia Formation." Why not *Triticites Meeki?* Soon the petrographers will be envious and use "Monte Largo Biotite Hornblende Granite," and technical geologic writing will resemble German *in* the capitalization of all nouns.

## *Acknowledgments*

At the suggestion of Dr. Lloyd C. Pray, Ohio Oil Co., and by the request of Dr. Carl C. Branson, University of Oklahoma, this compilation was undertaken to be a chapter in the American Association of Petroleum Geologists Symposium Volume (1960) on the Pennsylvanian of North America. The large amount of detail available on the local Pennsylvanian sections, and the verbosity of the writer, resulted in this report, of which the chapter for the Symposium Volume is essentially a brief summary.

Sources include much unpublished material generously given by geologists familiar with individual areas. Dr. Donald L. Bryant, Arizona University, and Dr. Eldred D. Wilson, Arizona Bureau of Mines, were major contributors of information on southeastern Arizona, along with Mr. H. Wesley Peirce, Arizona Bureau of Mines, and Mr. K. C. Havenor, Pure Oil Co. Mr. G. H. Sturgeon, Shell Oil Co., released sections measured by company geologists in southeastern Arizona. Dr. Harold R. Wanless, Illinois University, contributed copies of the 27 sections measured by him in Arizona. Dr. Willis W. Tyrrell, Jr., Pan American Petroleum Corp., described the Pennsylvanian section in the northern Whetstone Mountains; Dr. Rudy C. Epis, Colorado School of Mines, the Pedregosa Mountains section; and Dr. Floyd F. Sabins, California Research Corp., the sections in the Chiricahua Mountains.

Unpublished measured sections and fusulinid identifications by Dr. M. L. Thompson, Illinois Geological Survey, are the basis for much of the material on the Pennsylvanian of southwestern New Mexico. Messrs. 0. Ben Bourn and William J. Witt, Standard Oil Co. of Texas; Dr. Sherman A. Wengerd, Univ. of New Mexico; Garner L. Wilde, Robert E. Best, Frank A. Packard, and Richard D. Holt, Humble Oil & Refining Co.; Norman D. Raman, James A. Smith, Wendell J. Stewart, and William J. Braden, Texaco, Inc.; and Drs. Eugene Callaghan, Frederick J. Kuellmer, Christina Lochman-Balk, Rousseau H. Flower, Robert H.

Weber, and Robert A. Bieberman, New Mexico Bureau of Mines and Mineral Resources, contributed valuable suggestions and information on New Mexico sections. Roy W. Foster, New Mexico Bureau of Mines, aided in subsurface studies and described the Pennsylvanian sequence in the Lemitar Mountains. Dr. Richard H. Jahns, California Institute of Technology, described the Sierra Cuchillo and northern Black Range sections; Dr. Eugene G. Cserna, Idaho State College, the Fra Cristobal Mountains section; Dr. Robert A. Zeller, Jr., consulting geologist, the Big Hatchet Mountains sections; Dr. Clay T. Smith, New Mexico Institute of Mining and Technology, the Zuni Mountains Pennsylvanian section; and Mr. Charles H. Hardie, the northern Hueco Mountains section. Dr. Lloyd C. Pray described sections of the Sacramento Mountains area and provided related subsurface data. Most of the drafting was done by William E. Arnold, New Mexico Bureau of Mines, and the typing of various stages of the manuscript was performed by Bessie Vigil, Shirlee Stahmann, Nadine Richards, and Fidelia Razaghnia, also of the Bureau staff. Florence J. Kottlowski was of considerable assistance in field work and in proofreading and editing. At many points the text has profited by the criticisms and suggestions of M. L. Thompson, Sherman A. Wengerd, Donald L. Bryant, Roy W. Foster, and Edmund H. Kase.

Glenda K. Niccum assisted in preparing the index.

# *Physiography*

The region (pl. 1) is chiefly in the Mexican Highland section of the Basin and Range province, extending onto the west edge of the Sacramento section on the east, and the Sonoran section on the west, with the northern part of the region in the Datil section of the Colorado Plateau province (that is, the Mogollon Rim region of Arizona). Outcrops of the Pennsylvanian rocks in the basin-and-range country occur in isolated ranges, largely dissected fault-block mountains, which are separated by wide aggraded desert plains, the bolsons of the Spanish who first set eyes on the region more than four centuries ago. The areas that are drained to the sea and not to interior playas—that is, those areas which receive enough rainfall to be drained—contribute chiefly to the waters of the Rio Grande in New Mexico and the Gila River in western New Mexico and southern Arizona, although the south edge of the Colorado Plateau in the Springerville and St. Johns area is tributary to the Little Colorado River. The Datil volcanic plateau is on the backbone of the continent, the Continental Divide, where the Pennsylvanian strata crop out along the edges of the Colorado Plateau, being hidden beneath Permian, Mesozoic, and Tertiary rocks to the north, where mesas and sharp canyons dominate the topography.

# *General Characteristics of the Pennsylvanian*

Most geologists think of the Pennsylvanian rocks in southwestern New Mexico and southeastern Arizona as a monotonous sequence of limestones, which include minor amounts of shale and sandstone chiefly near the base and near the top. Actually, the limestone lithofacies (clastic ratio less than 0.25) is concentrated in the southern part of the area (pl. 5), from the Gunnison Hills (sec. 20, pl. 1, 8) east-southeastward to the Big Hatchet (sec. 96, p1. 1, 7) and Robledo (sec. 83) Mountains, with a small area predominantly of carbonate rocks in the Sierro Cuchillo (sec. 65) and the Hermosa (sec. 68) area. Shale, siltstone, and sandstone make up more than half of the Pennsylvanian beds in almost a third of the region herein discussed. These areas of clastic rocks are along the north and east edges of the region, reflecting sediments derived from the Zuni-Defiance and Kaibab landmasses (pl. 10) on the north and the Pedernal landmass to the east (pl. 12). Shales and silt-stones, for the most party limy and with numerous limestone nodules, compose the bulk of the clastic rocks, although quartzose and feldspathic sandstones are abundant in basal beds in places, and reddish feldspathic sandstones in some localities are common interbeds near the top of the Pennsylvanian.

Southwest and west of the Zuni Mountains in the Mogollon Rim area, red-bed clastic rocks are the dominant Pennsylvanian beds, and the Pennsylvanian—Permian contact is within the lower or middle part of red beds attributed to the Supai formation (pl. 11). In the Estancia trough, just west of the present-day Pedernal Hills, the Pennsylvanian sequence thickens from a knife edge to over 4,000 feet in less than 8 miles (westward). Greenish to blackish shales and green to pinkish feldspathic sandstones form almost 75 percent of the deposits. The Orogrande basin, which occupies an area nearly contiguous with the present-day Tularosa Valley (pl. 1, 3), contains in places more than 3,000 feet of Pennsylvanian sediments, of which as much as 2,400 feet was probably deposited in Virgilian time. The Upper Pennsylvanian rocks are deltaic-to brackish-water clastics and precipitates, consisting of silty brownish shales, dark carbonaceous shales, dark-gray argillaceous limestones, laminated calcilutites, silty calcarenites, silty calcareous sandstones, thick lenses of massive biostromal limestone, and several lenticular gypsum beds.

Deposits in the Lucero basin reach 2,700 feet in thickness in the southwestern Ladron Mountains and consist of a lower sandy phase, a medial cherty limestone, and upper interbeds of limestone and shale that appear to grade upward into red beds of the Abo formation. The

TABLE 1. SECTIONS OF PENNSYLVANIAN ROCKS SHOWN ON PLATES 1-6

| Map No. | Name of Section | Thickness (feet) | Clastic Ratio | Sand-Shale Ratio | Location | Source |
|---|---|---|---|---|---|---|
| | ARIZONA SECTIONS | | | | | |
| 1 | South of Jerome | 325+ | 8.0+ | 0.40 | NE cor-15N-2E | McNair (1951) |
| 2 | Aztec Land & Cattle Co. well | 1,080 | 2.6 | 0.07 | Sec 19-15N-18E | Huddle and Dobrovolny (1945) |
| 3 | New Mexico-Arizona Land Co. well | 1,075 | 3.2 | 0.07 | Sec 34-15N-19E | Idem |
| 4 | Franco-Ariz. well | 150 | 1.7 | 0 | Sec 14-14N-26E | Idem |
| 5 | Argo State No. 2 well | 0 | — | — | Sec 22-15N-29E | Idem |
| 6 | Fossil Creek | 675 | 5 | 0.2 | Sec 12-12N-7E | Idem |
| 7 | Spring Canyon | 890+ | 3.3 | 0.24 | Sec 31-9N-16E | Idem |
| 8 | Carrizo Creek | 1,045 | 3.6 | 0.13 | Sec 6-6N-20E | Idem |
| 9 | Escudilla Mtn. | 100+ | — | — | N½-7N-30E | D. L. Bryant, oral communication |
| 10 | Salt River Canyon | 1,184 | 2.0 | 0.08 | 4-11 miles N of highway bridge | H. R. Wanless, unpub. sec. |
| 11 | Black & White Rivers | 1,170 | 1.2 | 0.12 | Near junction | Huddle and Dobrovolny (1945) |
| 12 | Queen Creek Canyon | 1,160+ | 0.99 | 0.17 | Sec 36-1S-12E | Idem and H. R. Wanless, unpub. sec. |
| 13 | San Carlos Reservoir | 1,400 | 0.71 | 0.06 | Sec 3-3S-18E | H. R. Wanless, unpub. sec. |
| 14 | Granville | 235+ | 0.52 | 0.24 | SW¼-2S-29E | Idem |
| 15 | Saddle Mtn. | 950+ | 0.34 | 0.21 | E½-5S-16E | Webber (1925) |
| 16 | Vekol Mts. | 795+ | 0.25 | 0.04 | Sec 34-9S-2E | H. R. Wanless, unpub. sec. |
| 17 | Waterman Mts. | 1,000+ | 0.3 | 0.1 | SW cor-12S-9E | D. L. Bryant, oral communication |
| 18 | Tucson Mts. | 1,000+ | 0.37 | 0.02 | Sec 26-12S-11E | Idem |
| 19 | NE. Chiricahua Mts. | 1,880 | 0.21 | 0.97 | Sec 23-15S-30E | Sabins (1957) |
| 20 | Gunnison Hills | 2,100 | 0.19 | 0.45 | Sec 4-16S-23E | Gilluly et al. (1954) |
| 21 | Portal | 1,900 | 0.22 | 0.05 | Sec 21-17S-31E | Sabins (1957) and H. R. Wanless, unpub. sec. |
| 22 | N. Santa Rita Mts. | 1,250? | 0.8 | 0.1 | E½-18S-15E | Johnson (1941) |
| 23 | Empire Mts. | 1,040? | 0.8 | 0.05 | Sec 4-18S-17E | H. R. Wanless, unpub. sec. |
| 24 | N. Whetstone Mts. | 1,350 | 0.47 | 0.14 | S½-18S-19E | W. W. Tyrrell (1957) |
| 25 | S. Whetstone Mts. | 1,710 | 0.78 | 0.04 | Sec 22-19S-19E | S. M. Jones and W. D. Bacheller, unpub. sec. |
| 26 | Swisshelm Mts. | 2,040 | 0.48 | 0.1 | Sec 35-19S-27E | Loring (1947) and Thompson (1954) |

TABLE 1. SECTIONS OF PENNSYLVANIAN ROCKS SHOWN ON PLATES 1-6 (continued)

| Map No. | Name of Section | Thickness (feet) | Clastic Ratio | Sand-Shale Ratio | Location | Source |
|---|---|---|---|---|---|---|
| 27 | Central Santa Rita Mts. | 1,200? | 0.31 | 0.14 | Sec 29-20S-14E | Anthony (1951) |
| 28 | Tombstone Hills | 1,795 | 0.30 | 0.79 | Sec 36-20S-22E | Gilluly et al. (1954) |
| 29 | Pedregosa Mts. | 2,485 | 0.33 | 0.59 | Sec 22-20S-29E | R. C. Epis (1956) |
| 30 | Patagonia Mts. | 1,330? | 0.2 | 0.4 | N½-23S-16E | Kartchner (1944) |
| 31 | Naco Hills | 1,390 | 0.41 | 0.01 | Sec 26-23S-23E | Williams (1951) |
| | NEW MEXICO SECTIONS | | | | | |
| 32 | Skelly No. 1 Goesling | 0? | — | — | Sec 27-3N-21W | R. H. Weber, oral communication |
| 33 | Mitchel-Red Lake well | 570 | 3.9 | 0.35 | Sec 2-3N-8W | Darton (1928) |
| 34 | Mesa Aparejo | 1,950 | 1.07 | 0.26 | Sec 13-5N-3W | Kelley and Wood, (1946) |
| 35 | Mesa Sarca | 2,490 | 0.68 | 0.35 | Sec 30-4N-3W | Idem |
| 36 | N. Ladron Mts. | 2,260 | 0.37 | 0.36 | Sec 14-3N-3W | Idem |
| 37 | S. Ladron Mts. | 2,700 | 0.76 | 1.07 | Secs 30-2N-2W, 25 & 26-2N-3W | Cheetham (1950) |
| 38 | Manzano Mts. | 1,620 | 0.57 | 0.84 | Sec 1-5N-5E | Read et al. (1944), composite section |
| 39 | Witt-Meadows well | 1,690 | 2.20 | 0.45 | Sec 23-6N-7E | Interpretation by R. L. Bates |
| 40 | Murphree-Berkshire well | 1,510? | 4? | 0.5? | Sec 19-6N-9E | Well samples, elect. log |
| 41 | Gardner-Kidwell well | 3,955 | 3 | 0.55 | Sec 21-6N-10E | Idem |
| 42 | Superior-Blackwell well | 410? | 19 | 3.3 | Sec 31-6N-11E | Idem |
| 43 | Rattlesnake Hill | 0 | — | — | Sec 21-4N-10E | Outcrops |
| 44 | Eidal-Mitchel well | 1,603 | 2.59 | 0.31 | Sec 33-4N-8E | Interpretation by R. C. Northup |
| 45 | Abo Pass | 1,290 | 0.77 | 0.54 | Sec 31-3N-5E | Wilpolt et al. (1946) |
| 46 | Sierra Montosa | 1,380 | 0.56 | 0.82 | Sec 8-1N-4E | Idem |
| 47 | Joyita Hills | 180+ | 1.12 | 0.46 | Sec 23-1N-1E | Idem |
| 48 | Turret Mesa | 1,370 | 2.20 | 0.98 | Sec 28-1N-3E | Idem |
| 49 | Gallinas Mts. | 0 | — | — | Sec 23-1S-11E | Kelley et al. (1946) |
| 50 | Polvadera Mtn. | 715+ | 0.82 | 0.12 | Sec 2-2S-2W | R. W. Foster, unpub. sec. |
| 51 | Skelly-Goddard well | 1,480 | 0.73 | 0.20 | Sec 22-2S-4E | Well samples |
| 52 | Magdalena Mts. | 1,185+ | 1.04 | 0.45 | Sec 31-2S-3W | Loughlin and Koschmann (1942) |
| 53 | Cerros de Amado | 2,130 | 1.29 | 0.49 | Sec 35-2S-1E | Wilpolt and Wanek (1952) |
| 54 | Socorro Peak | 1,000+ | 1.5 | 0.2 | Sec 9-3S-1W | Outcrops |

TABLE 1. SECTIONS OF PENNSYLVANIAN ROCKS SHOWN ON PLATES 1-6 (continued)

| Map No. | Name of Section | Thickness (feet) | Clastic Ratio | Sand-Shale Ratio | Location | Source |
|---|---|---|---|---|---|---|
| 55 | Lockhart No. 1 well | 1,375 | 0.45? | 0.3? | Sec 28-4S-6E | Well samples, elect. log |
| 56 | Coyote Hills | 200+ | — | — | Sec 28-5S-1W | Outcrops |
| 57 | N. Oscura Mts. | 920 | 0.23 | 0.46 | Sec 36-5S-5E | Thompson (1942) |
| 58 | Standard-Heard well | 1,745 | 1.0 | 0.76 | Sec 33-6S-9E | Well samples, elect. log |
| 59 | Little San Pasqual Mtn. | 1,100? | 0.4 | 0.2 | Sec 5-7S-1E | Outcrops |
| 60 | Eaton Ranch | 2,650± | 0.4 | 0.1 | Sec 17-8S-4W | Outcrops |
| 61 | Mockingbird Gap | 1,931 | 0.78 | 2.68 | Sec 34-8S-5E | Thompson in Kottlowski et al. (1956) |
| 62 | N. Fra Cristobal Mts. | 1,620 | 0.77 | 0 | Sec 12-10S-3W | Cserna (1956) |
| 63 | Sun-Victorio No. 1 well | 1,815 | 0.56 | 0.25 | Sec 25-10S-1W | Foster in Kottlowski et al. (1956) |
| 64 | Monticello | 1,950? | 0.5 | 0.4 | Sec 25-10S-6W | Outcrops |
| 65 | Sierra Cuchillo | 1,400 | 0.14 | 0.75 | Sec 18-11S-7W | Jahns (1944) |
| 66 | Mud Springs Mts. | 1,705 | 0.51 | 0.07 | Sec 12-13S-5W | M. L. Thompson, unpub. sec. |
| 67 | Rhodes Canyon | 2,506 | 1.12 | 0.25 | Sec 13-13S-3E | Kottlowski et al. (1956) |
| 68 | Hermosa, Black Range | 1,500? | 0.2 | 0.7 | Sec 19-13S-8W | R. H. Jahns, oral communication |
| 69 | Tularosa Basin well | + | — | — | Sec 34-13S-7E | Kottlowski et al. (1956) |
| 70 | N. Caballo Mts. | 1,120 | 0.45 | 0.05 | Sec 11-15S-4W | Kelley and Silver (1952) |
| 71 | Hembrillo Canyon | 3,034 | 1.36 | 0.16 | Sec 9-16S-3E | Kottlowski et al. (1956) |
| 72 | Indian Wells-La Luz | 2,980 | 1.43 | 0.83 | Sec 3-16S-10E | Pray (1952) |
| 73 | Kingston, Black Range | 680+ | 0.51 | 0.15 | Sec 18-16S-8W | Kuellmer (1954) |
| 74 | Santa Rita | 820+ | 0.59 | 0.02 | Sec 22-17S-12W | Spencer and Paige (1935) |
| 75 | Mimbres Valley | 991 | 0.56 | 0.02 | Sec 20-17S-11W | H. R. Wanless, unpub. sec. |
| 76 | Silver City | 89+ | 0.35 | 0 | Sec 4-18S-14W | Entwistle (1944) |
| 77 | Mule Canyon & Peak | 2,010 | 1.10 | 0.52 | Sec 14-17S-10E | Pray (1952) |
| 78 | Nigger Ed Canyon | 1,995 | 0.36 | 0.13 | Sec 18-19S-11E | Pray (1952) |
| 79 | Ash Canyon | 2,825 | 1.36 | 0.22 | Sec 28-19S-4E | Kottlowski et al. (1956) |
| 80 | Cooks Peak | 200+ | 0.81 | 0.35 | Sec 25-20S-9W | Jicha (1954) |

TABLE 1. SECTIONS OF PENNSYLVANIAN ROCKS SHOWN ON PLATES 1-6 (continued)

| Map no. | Name of section | Thickness (feet) | Clastic ratio | Sand-shale ratio | Location | Source |
|---|---|---|---|---|---|---|
| 81 | Plymouth-Evans well | 3,050? | 1.1 | 0.4 | Sec 15-20S-9E | Interpretation by L. C. Pray |
| 82 | Sun-Pearson well | 2,230 | 1.2 | 0.3 | Sec. 35-20S-10E | Well samples, elect. log, fossils |
| 83 | Robledo Mts. | 670+ | 0.21 | 0.06 | Sec 35-21S-1W | Outcrops |
| 84 | Otero-McGregor well | 915+ | 0.69 | 0.05 | Sec 5-22S-10E | Well samples |
| 85 | Kinney-State well | 1,168± | 0.16 | 0 | Sec 14-23S-10E | Idem |
| 86 | Victorio Mts. | 0+ | — | — | Sec 30-24S-12W | Outcrops |
| 87 | Bishop Cap | 1,400+ | 0.25? | 0.3? | Sec 26-24S-3E | M. L. Thompson, unpub. section |
| 88 | Peloncillo Mts. | 1,900? | 0.14 | 0 | SE¼-25S-21W | Quaide (1953), Gillerman (1958) |
| 89 | Ernest-Located Land well | 1,556+ | 0.82 | 0.2 | Sec 20-25S-7E | Kottlowski et al. (1956) |
| 90 | Florida Mts. | 0 | — | — | Sec 7-26S-7W | Outcrops, Bogart (1953) |
| 91 | Seaboard-Trigg well | 1660-2150 | 0.4? | 0.4? | Sec 18-26S-11E | Well samples, elec. log |
| 92 | Tres Hermanas Mts. | 636? | 0.28? | 2.7? | Sec 25-27S-9W | Bogart (1953) |
| 93 | Vinton Canyon | 2,700± | 0.25 | 0.41 | 5 miles E of Vinton | Nelson (1940), Thompson (1948), Harbour (1958) |
| 94 | Hueco Mts. | 1,700+ | 0.36 | 0.38 | N of Powwow Canyon | King, King, and Knight (1945) |
| 95 | Rancheria Peak | 400+ | 0.10 | 2.5 | 9 miles SE of Hueco Inn | Idem |
| 96 | Big Hatchet Mts. | 2,450 | 0.04 | 0 | SE¼-31S-15W | Zeller (1958) |
| 97 | Huckleberry-Federal well | 70? | — | — | Sec 11-2N-16W | Well samples, elec. log |
| 98 | Trout Creek | 365+ | ? | ? | Sec 3-5S-21W | Outcrops (faulted) |
| 99 | Humble-State well | 2,190 | — | — | Sec 25-32S-16W | Scout report |
| 100 | N. Hueco Mts. | 1,200+ | — | — | Sec 23-26S-9E | Hardie (1958) |

San Mateo basin deposits may be as much as 2,700 feet thick and include some dark silty calcilutites and many interbeds of dark shales.

In most of the region, the Pennsylvanian sequence is 1,000 to 2,000 feet thick and consists chiefly of cherty or noncherty continental-shelf limestones that range from aphanitic lime muds (calcilutites) to coarse-grained bioclastic beds and pebbly calcarenites. The Pennsylvanian rocks in the Big Hatchet Mountains area (sec. 96) include more than 2,400 feet of limestone, clastic rocks comprising less than 4 percent of the sequence. In southern Arizona, southwesternmost New Mexico, and westernmost Texas, the lower 70-95 percent of the Pennsylvanian is chiefly massive- to thin-bedded limestone, the upper rocks being interbedded limy shales, silty limestones, and some feldspathic sandstones. Northward the basal beds are more clastic and include numerous inter-beds of blackish carbonaceous shales, quartzose sandstones, arenaceous calcarenites, and chert-limestone pebble-conglomerates.

Pennsylvanian rocks are absent in the southern Hueco Mountains of Texas, in the Pedernal Hills east of Estancia Valley, on the south flank of the Zuni Mountains (secs. 5, 32, pl. 1, 3), and over a large northwest-trending area from the Florida Mountains (sec. 90, pl. 4) to the Clifton—Morenci area (sec. 14). Whereas the absence of Pennsylvanian rocks in the Clifton—Florida area is due chiefly to erosion during early Wolfcampian and early Mesozoic times, there is evidence of a late-Pennsylvanian landmass in the Florida Mountains area. There are few outcrops of Pennsylvanian rocks on the Datil—Mogollon volcanic plateau, and only a few wells have been drilled in the area, so that the thickness and lithology, and indeed the existence, of the Pennsylvanian is partly a matter of speculation. Outcrops (secs. 9, 98) of Pennsylvanian rocks as far north as latitude 34° N., near the New Mexico—Arizona Stateline, suggest that much of this large volcanic area is underlain by appreciable thicknesses of Pennsylvanian strata.

Basal Pennsylvanian beds are unconformable on thick-bedded coral-line crinoidal Mississippian limestones throughout much of the area (pl. 2) but overlie Precambrian rocks and pre-Mississippian strata in the north-central and northeastern parts of the region. In most of the northern and central parts of the region, the Pennsylvanian limestones are overlain conformably, disconformably, or unconformably by the Supai or Abo red beds (pl. 6). In southeastern Arizona and south-central New Mexico, the upper contact is within, at the base of, or at the top of a sequence of interbedded pale-red beds and clastic limestones variously referred to the Andrada formation (see pl. 9, Nomenclature Chart), Earp formation, Bursum formation, or Powwow clastic member of the Hueco formation. In southern New Mexico and westernmost Texas, the overlying strata arc limestones of the Hueco formation or equivalent beds, such as the upper part of the Horquilla limestone in the Big Hatchet Mountains and locally the Powwow conglomerate.

In places the Pennsylvanian beds are shattered by many faults and silicified, and in areas near coarse-grained intrusive igneous bodies, the limestones have been metamorphosed to marbles, the shales to hornfels, and the sandstones to metaquartzites. The Basin and Range province contains many mining districts wherein the Pennsylvanian rocks are favored host rocks for lead, copper, zinc, fluorite, and barite ores. Although many of the limestones are dense and cherty, there are numerous biohermal and biostromal beds, many of the sandstones arc relatively coarse grained and porous, and in places there are thick sections of brackish marine shales and fetid petroliferous limestones.

Basal beds of the Pennsylvanian in this region appear to be chiefly of Derryan (Atokan) age except in the Sacramento (sec. 77, pl. 7), Hueco, and Big Hatchet Mountains of New Mexico and in the southeastern corner of Arizona, where the lowest beds may be of Morrowan age. Early species of *Millerella,* with an almost complete exclusion of other Pennsylvanian fusulinid genera (in some localities due perhaps to happenstance in collecting small fusulinids), provide the basis of the Morrowan age designation. Beds of Derryan age (Bend—Atoka), the Zones of *Profusulinella* and *Fusulinella,* occur in all sections except at Cooks Peak[1] (sec. 80) and Joyita Hills (sec. 47), although basal beds in many of the central and northern sections are principally clastic unfossiliferous rocks that have not been zoned. Beds of Desmoinesian (Strawn) age, the Zone of *Fusulina,* are thick cherty limestones that form the prominent ledgy cliffs considered typical of the Pennsylvanian strata throughout much of the region. The zone appears to be present and of considerable thickness in all sections, but some of the few relatively detailed faunal studies indicate an absence of the upper part of the zone in the northeastern Chiricahua Mountains (secs. 19, 21, pl. 8; Sabine, 1957) and the southern San Andres Mountains (sec. 79). In the Sacramento Mountains, along the east edge of the region, there are deltaic clastic sediments within the Desmoinesian (Pray and Graves, 1954), and at the northwest corner of the region, near Fossil Creek (sec. 6), the Desmoinesian rocks are a few marine limestones within a red-bed sequence.

Beds of Upper Pennsylvanian age, the Missourian (Canyon) and Virgilian (Cisco) series (the Zone of *Triticites),* appear to have been deposited in most of the area but in places have been removed by post-Pennsylvanian or late-Pennsylvanian erosion. Early *Triticites* of the Missourian series are sparsely distributed in the shaly limestones typical of the zone. Beds equivalent to the Virgil series are the most variable of the Pennsylvanian zones and range from red beds of the lower Supai formation, on the Mogollon Rim, to the massive limestones that occur in the Oscura Mountains (sec. 57) and in contiguous areas. The Virgilian series is more than 2,000 feet thick in the Estancia Valley and southern San Andres Mountains but in many areas has been partly or entirely removed by erosion.

1. Although named for Lt. Col. Philip St. George Cooke, most maps (e. g.. Darton. 1917) label the mountain "Cooks Peak."

# *Previous Geologic Work*

## SOUTHEASTERN ARIZONA

Studies of the Pennsylvanian rocks in Arizona can be grouped into two periods. The earlier period ranged from the dawn of geological investigation in the Southwest to about 1935; during this time, the Pennsylvanian was regarded chiefly as a rock type associated with some of the ore deposits, was in places lumped as Carboniferous along with the Mississippian, Devonian, and lower Permian, and was generally described as a thousand or more feet of limestone. Darton's (1925, p. 6689) summary of stratigraphic studies up to 1923 and Stoyanow's (1926, p. 311, 313, 320-322) notes on stratigraphic work are the notable publications during this earlier period.

Since 1935, much of the available information on Pennsylvanian strata has been compiled by Drs. Stoyanow and McKee, and in theses by their students at the University of Arizona. There has been a recent acceleration of stratigraphic work at the University under the direction of J. F. Lance and W. D. Pye, and at the Arizona Bureau of Mines by H. W. Peirce. Relationships of the upper Pennsylvanian and lower Supai red beds have been studied in some detail along the Mogollon Rim by Stoyanow (1936, 1942), Winters (1948, 1951), Jackson (1951, 1952), McKee (1945, 1947, 1951), and Hughes (1949, 1952); upper Paleozoic rocks in the rim area and as far south as Superior were measured by Huddle and Dobrovolny (1945). Much unpublished stratigraphic work has been done by various oil companies, by geologists of the Arizona Bureau of Mines, and Dr. Harold R. Wanless, Illinois University.

The most recent notable contributions, other than theses, have been those of Gilluly, Cooper, and Williams (1954), who described stratigraphic and mappable units in the southeastern part of the State, and Dr. Donald L. Bryant (1952, 1955), in his study of the Permian and upper Pennsylvanian of southeastern Arizona; also Floyd L. Sabins's (1957) Chiricahua and Dos Cabezas Mountains inquiry, and Havenor and Pye's (1958) and Havenor's (1959) summaries of the Pennsylvanian in Arizona.

Gilbert (1875, p. 177) and Marvine (1875, p. 198-230) in their reconnaissance of northern and central Arizona noted and named the Aubrey group and Redwall limestone, which form prominent outcrops along the Mogollon Rim from Fort Apache westward. The lower beds of the Aubrey group were called the Aubrey sandstones, but this term was later replaced by the Coconino sandstone and Supai red beds; basal beds of the Supai contain Pennsylvanian fossils in places. Reagan (1903, p. 265-308) measured many sections and described the geology of the area near Fort Apache. Ransome (1903, p. 39-46; 1904, p. 4) named and mapped the Globe limestone in the Globe copper mining district, and from this limestone collected fossils identified as Devonian, Mississippian, and Pennsylvanian in age by H. S. Williams and G. H. Girty. Ransome noted that the Globe limestone is overlain with pronounced erosional unconformity by the Whitetail conglomerate, a prevolcanic Tertiary (Eocene?) gravel, and by Tertiary dacite pyroclastic rocks. In the Bisbee quadrangle, Mule Mountains, and Naco Hills, Ransome (1904, p. 44-55) named and mapped the Naco limestone, a light-gray ledgy limestone with some beds of silty pinkish limestone, having an estimated thickness of about 3,000 feet, overlain with erosional unconformity by the Lower Cretaceous Glance conglomerate, and underlain by the Mississippian Escabrosa limestone. Fossils collected from the Naco limestone were divided by G. H. Girty into two groups, a lower one of Pennsylvanian aspect, and an upper fauna similar to that from the Hueco limestone, now considered of Lower Permian age.

Campbell (1904, p. 243-244), in his reconnaissance of the Deer Creek coal field on the southwest flank of the Mescal Mountains, reported about 1,300 feet of Carboniferous(?) limestone cropping out above Cambrian quartzites and shales, and overlain unconformably by the greenish-gray sandstones and shales of the Upper Cretaceous coal-bearing sequence, whose basal bed is ferruginous-chert conglomerate. Andesitic volcanic rocks were reported to overlie and interfinger with the Cretaceous sediments. Campbell's tentative Carboniferous limestone includes rocks of Devonian, Mississippian, and Pennsylvanian age. Lindgren (1905a, p. 72) found the Mississippian Modoc limestone overlain with erosional unconformity by the Upper Cretaceous Pinkard formation southwest of Morenci in the Clifton—Morenci copper mining area, but in the northern part of the Clifton quadrangle (Lindgren, 1905b, p. 5), about 8 miles north of Clifton, the Tule Spring limestone was mapped, consisting of a lower 200 feet of Mississippian beds and an upper 300 feet of Pennsylvanian strata, unconformably overlain by Tertiary volcanic rocks.

Ransome (1919, p. 133-166) summarized the Paleozoic sections found in the Arizona mining districts during the early geologic investigations. He illustrated generalized sections of the Naco limestone (Pennsylvanian and Permian) at Bisbee and Tombstone, Tule Springs limestone (Mississippian and Pennsylvanian) north of Clifton, Tornado limestone (Mississippian and Pennsylvanian) at Ray, Globe, and near Roosevelt Dam, and sections of the Redwall limestone and Supai formation along the Mogollon Rim. The Globe limestone (Ransome, 1903, p. 39-46) was replaced by the Martin limestone (Devonian) and the Tornado limestone (Mississippian and Pennsylvanian) for the Ray and Globe—Miami districts (1919, p. 45-48). In the Ray district, the Tornado limestone was estimated to be more than 1,000 feet thick and is overlain unconformably by andesitic tuffs and breccias, which to the east, along Deer Creek, overlie and interfinger with coal-bearing Upper Cretaceous beds.

Darton (1925, p. 66-89) noted that the Tornado limestone was equivalent to the Mississippian Escabrosa limestone and the Pennsylvanian part of the Naco limestone. The faunas of the original Naco were considered to indicate Pennsylvanian and Lower Permian divisions within the formation, but Darton found no lithologic basis for separating the divisions. Faunas similar to those from the lower Naco were listed from the lower Supai red beds or upper Redwall limestone of the Mogollon Rim area. Outcrops of Naco limestone were noted in the Empire, Santa Rita, Patagonia, Tucson, Silver Bell, Vekol, Waterman, and Slate Mountains, and Sierra Blanca, as well as in the ranges east of Bisbee. Upward gradation from Naco limestone into Supai red beds is illustrated by a section measured by Darton along Carrizo Creek south of the Mogollon Rim, about 20 miles northwest of Fort Apache.

Ross (1925a, p. 22-24; 1925b, p. 7-11) mapped the Tornado limestone in the Aravaipa, Stanley, Saddle Mountain, and Banner mining districts east of Winkelman, and measured a generalized section of about 1,200 feet of the limestone, with Mississippian fossils in the lower beds and Pennsylvanian faunas in the bulk of the section. The Pennsylvanian strata were seen to be unconformably overlain by Upper Cretaceous sandstones, shales, conglomerates, and andesites of the same sequence that occurs in the Deer Creek coal field. Webber (1925) measured and described a section of Pennsylvanian rocks in the northern Galiuro Mountains southeast of Winkelman. This section was discussed by Stoyanow (1926, p. 321-322), who noted its abundant faunas. Stoyanow also noted the Pennsylvanian rocks exposed south of the Mogollon Rim between Pine and Payson, which consist of a basal conglomerate, up to 50 feet thick, overlain by (estimated) hundreds of feet of interbedded limestone, conglomerate, sandstone, and shale, a much more clastic Pennsylvanian fades than the Naco limestone of southern Arizona and the Pennsylvanian limestones in the Galiuro Mountains.

Darton (1926, p. 819-852) in his résumé of Permian strata in Arizona and New Mexico listed a generalized section south of the Mogollon Rim along Canyon Creek, and noted that limestones containing Pennsylvanian fossils are in places interbedded with the lower part of the Supai red beds.

Stoyanow (1936, p. 507, 514-523, 535-536) correlated the known sections of Paleozoic rocks in Arizona; rejected the term Tornado limestone; discussed the relationships of the predominantly marine Pennsylvanian of southern Arizona with more clastic beds to the north, and the influence of Mazatzal land during Pennsylvanian time; and named the Galiuro limestone to include the Pennsylvanian section on Saddle Mountain near Winkelman, discussing its relationship to the Naco limestone of southern Arizona. Later, Stoyanow (1942, p. 1273-1276) described the Pennsylvanian paleogeography (fig. 2) in Arizona, which shows a predominantly marine section in the southeastern part of the

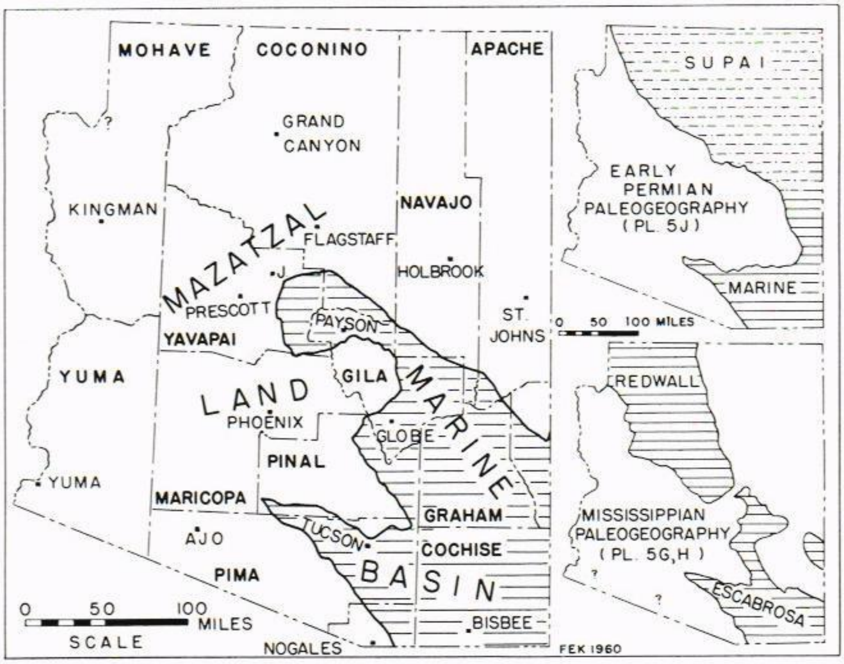


Figure 2

STOYANOW'S PENNSYLVANIAN PALEOGEOGRAPHIC MAP OF ARIZONA

After Stoyanow (1942, pl. 5i).

State that became more elastic near the Mogollon Rim, where Pennsylvanian rocks grade upward into the Supai red beds. McKee (1945, p. 25-32) measured and described a section of Supai red beds in Oak Creek Canyon, indicating that the basal Supai is of possible Pennsylvanian age. Huddle and Dobrovolny (1945) listed sections of upper Paleozoic rocks measured in central Arizona, and were the first to study systematically in some detail the Mississippian, Pennsylvanian, and lower Permian rocks in the important Mogollon Rim area. McKee (1947, p. 282-292) noted boulders in Cretaceous(?) conglomerates in the New Water Mountains of southwestern Arizona and suggested that they indicate the deposition of Pennsylvanian rocks in that area, where outcrops of Pennsylvanian rocks are almost unknown.

Hughes (1949, p. 32-36; 1952, p. 635-657) described the Supai formation in the Black Mesa (of northwestern Arizona) and Chino Valley area, just northwest of the northwest corner of Plate 1, and collected fossils from his lower member of the Supai red beds, which he considered of early Pennsylvanian age. Winters (1951, p. 10-16) studied the Pennsylvanian—Permian rocks near Fort Apache, found a clear separation between the Naco limestone and overlying Supai red beds, and collected Virgilian fusulinids in the uppermost Naco strata. Jackson (1951, p. 84-91; 1952, p. 143-146) studied the Pennsylvanian—Permian fades of the Supai formation along the Mogollon Rim between Fort Apache and Oak Creek Canyon and concluded that the basal third of the Supai red beds is of Pennsylvanian age. McNair (1951, p. 503-541) measured sections of Paleozoic strata in northwestern Arizona, his southeasternmost section being south of Jerome. McKee (1951, p. 491-493) discussed the location of sedimentary basins in Arizona and adjoining areas as based on isopach maps of the thicknesses of systems. His thicknesses of Pennsylvanian rocks for southeastern Arizona are chiefly from Huddle and Dobrovolny (1945) and unpublished sections by Dr. Harold R. Wanless. Wanless and Merrill (1951, p. 1487) briefly discussed cyclic sedimentation of Pennsylvanian deposits in southern Arizona, as shown by the 27 unpublished sections studied by Wanless and his students, and Wanless (1955, p. 1631) briefly discussed the fades of Pennsylvanian and Wolfcampian rocks in Arizona and adjoining regions.

The guidebook compiled by the Arizona Geological Society for the Cordilleran Section meeting of the Geological Society of America in Tucson, April 1952, contained several articles mentioning Pennsylvanian rocks in southern Arizona, such as Bryant's (1952, p. 27-42) on the Tucson Mountains, Wilson's (1952, p. 96-105) on the area between Ray and Superior, and Jackson's (1952, p. 143-146) on the Supai red beds in central Arizona. Huddle and Dobrovolny (1952, p. 88-90) discussed the Devonian and Mississippian rocks in central Arizona and described the karst topography and residual soils at the base of the Naco formation, which were developed on the Redwall limestone.

Gilluly, Cooper, and Williams (1954) raised the Naco to group status and subdivided the group into six formations recognizable and mapped in central Cochise County. The Pennsylvanian formations named are the Horquilla limestone (Derryan to mid-Virgilian?) and Earp formation (Virgilian and basal Wolfcampian). Detailed sections measured in the Mule, Dragoon, and Little Dragoon Mountains, and in the Tombstone and Gunnison Hills, along with a comprehensive faunal study and correlations, make this the most significant published contribution to the study of Pennsylvanian strata in southern Arizona.

Recent work includes mapping of previously unreported outcrops of the Naco limestone on the San Carlos Indian Reservation by Bromfield and Shride (1956); studies of the thick Pennsylvanian sections in the Pedregosa Mountains by Epis (1956), the Chiricahua Mountains by Sabins (1957), and the northern Whetstone Mountains by Tyrrell (1957); description of the Supai red beds in the Jerome area by Anderson and Creasey (1958); and a discussion of Pennsylvanian sedimentation in Arizona by Mr. Kay C. Havenor (1958), a thesis summarized by Havenor and Pye (1958). The guidebook for the 1959 meeting of the Cordilleran Section of the Geological Society of America in Tucson included a summary article by Havenor (1959) on the Pennsylvanian of southeastern Arizona, and articles describing Pennsylvanian rocks in the Waterman Mountains (McClymonds, 1959) and Empire Mountains (Galbraith, 1959), as well as comments on outcrops of Pennsylvanian strata along the various field-trip routes.

## SOUTHWESTERN NEW MEXICO

The most valuable regional report on the Pennsylvanian strata in southwestern New Mexico is that of Thompson (1942), which offers a detailed classification based on measurements of more than 50 sections and study of the fusulinid zones. This report summarized previous studies of the Pennsylvanian, all of which, in common with most later reports, are of relatively small areas (mining districts or quadrangles) or are restricted to reconnaissance mapping for petroleum structures. Later papers (Thompson, 1948, 1954, 1956) emphasized the fusulinid zones.

In one of the early articles on the Pennsylvanian, Gordon (1907) proposed the term Magdalena group (fig. 3) for all sedimentary rocks in central New Mexico between the Kelly limestone (Mississippian) below and the Abo red beds (Permian) above, a unit that in places is synonymous with Pennsylvanian, but in other areas has been used to include Mississippian and perhaps Devonian rocks at the base, and Wolfcampian rocks at the top. Gordon divided the Magdalena group

Figure 3

**TYPICAL EXPOSURES OF TYPE SECTION, MAGDALENA GROUP, NEAR KELLY MINE, MAGDALENA MOUNTAINS**

into a lower clastic phase, the Sandia formation, and an upper carbonate phase, the Madera limestone. This nomenclature is the one used at present by the U. S. Geological Survey and others. The chief reason for using "Magdalena group" rather than "Pennsylvanian" is perhaps to indicate inclusion of more than only Pennsylvanian strata within the group.

In the Silver City mining district, Paige (1916) originally proposed the term Fierro limestone to include rocks of Mississippian and Pennsylvanian age. Spencer and Paige (1935) later dropped this term, adopted the Magdalena group, and subdivided the latter into a lower Oswaldo formation and an upper Syrena formation. Darton (1928), in his classic description of the stratigraphy of New Mexico, referred the Pennsylvanian and associated rocks to the Magdalena group and described the general lithology, location, and estimates of thicknesses of the Pennsylvanian strata throughout the State. Nelson (1940) subdivided the lower part of the Magdalena formation in the Franklin Mountains, from base upward, into the La Tuna member, Berino member, and Bishops Cap member. Needham (1937) studied scattered fusulinid collections from Pennsylvanian and Permian rocks in the State and (1940) listed general correlations of some sections in southwestern New Mexico.

Thompson (1942, 1948, 1954) divided the Pennsylvanian strata into correlatives of the Des Moines, Missouri, and Virgil series and introduced a new series name, Derry, for the pre-Desmoinesian strata in the State. He subdivided each series into two groups, the Derry series into the Green Canyon group below and Mud Springs group above, the Des Moines series into the Armendaris group below and Bolander group above, the Missouri series into the Veredas group below and Hansonburg group above, and the Virgil series into the Keller group below and Fresnal group above. Thompson also designated 16 formations and 1 member. He noted that the lithology of the Pennsylvanian in New Mexico varies markedly from place to place and did not suggest that his fusulinid faunal zones could be recognized within similar lithic sequences throughout the State. The formations proposed are recognizable by lithology alone in areas near their type localities, and some of the formations retain their distinctive lithic characteristics for long distances; the Coane formation and Council Springs limestone, for example, are distinctive units more than 100 miles north and northwest of the Oscura Mountains. One difficulty, however, is that the Pennsylvanian strata in most places crop out on steep slopes (fig. 4) and as cliffs, so that any thin units form very narrow or overlapping bands when projected onto a map. To date, most field geologists have not had the time nor the paleontologic data to map such detailed units as Thompson's formations. Also, whereas some of the formations can be recognized in much of south-central New Mexico, others change markedly in lithology away from the type localities, so that their equivalents can be correlated only by detailed fusulinid studies.

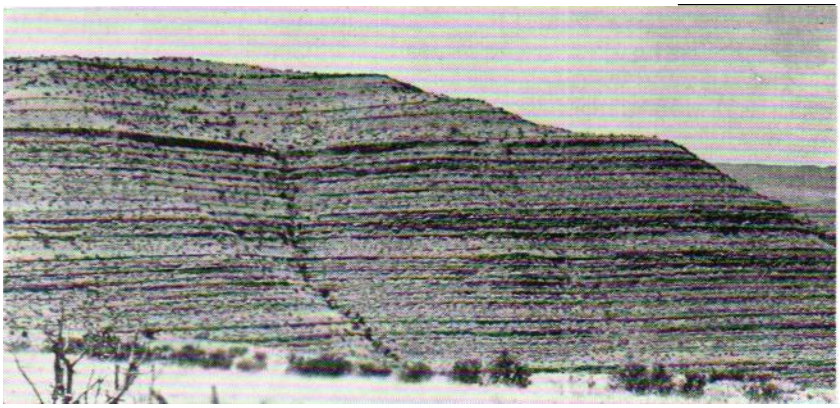

Figure 4

**TYPICAL LEDGY OUTCROPS OF DESMOINESIAN LIMESTONES ON MESA SARCA**

Loughlin and Koschmann (1942) described the Magdalena group at its type locality in the Magdalena mining district. Read et al. (1944) compiled a preliminary map and several stratigraphic sections of Pennsylvanian rocks exposed in parts of Torrance and Valencia Counties. King, King, and Knight (1945) mapped and measured sections in the Hueco Mountains, dividing the Magdalena limestone into three lithic divisions. Wilpolt et al. (1946) mapped and measured sections of Pennsylvanian strata in the Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa. Kelley and Wood (1946) studied the Carboniferous rocks in the Lucero uplift area. Stark and Dapples (1946) mapped and described the Pennsylvanian strata in the Los Pinos Mountains, using the series as mapping subdivisions. Bates et al. (1947) reported on the geology of the Gran Quivira quadrangle.

Read and Wood (1947) summarized studies by the U. S. Geological Survey in northern New Mexico and set forth the philosophy of that Federal agency in relationship to Pennsylvanian stratigraphy. The Pennsylvanian and part of the Lower Permian are considered a single sedimentary cycle, called the Magdalena group, which is divided into: (1) a suite of transgressive sediments, the upper clastic member of the Sandia formation; (2) an evenly and widely distributed facies of marine sediments deposited during a period of maximum marine transgression, the lower limestone member of the Madera limestone; and (3) unevenly distributed and restricted, alternating marine and continental sediments that represent a period of offlap or marine regression (the arkosic limestone member of the Madera limestone, and in places including the Bursum formation). Furthermore, these three lithic phases form three distinct topographic expressions: a basal ledgy slope, a dominating medial series of ledgy cliffs, and an upper sequence of alternating ledges and slopes that become reddish toward the top before grading into the Abo red beds. No time or faunal limitations are placed on any of the units, nor implied, as they are essentially facies determined only by the predominant lithology; they serve, therefore, as admirable formations for rapid reconnaissance mapping, an advantage for some purposes of petroleum exploration.

Lloyd (1949) discussed the Pennsylvanian rocks in southeastern New Mexico and their relationships to some outcrops in southwestern New Mexico, including a columnar section measured by Dr. M. L. Thompson in the Sacramento Mountains. Wilpolt and Wanek (1952) mapped the area from east of Socorro to the western part of Chupadera Mesa and the northern end of the Oscura Mountains. Kelley and Silver (1952), measuring a section of Pennsylvanian rocks in the north-central part of the Caballo Mountains, assigned the Pennsylvanian to the Magdalena group but set up three new formational units (in ascending order, the Red House, Nakaye, and Bar B formations) that are approximately equivalent to the three broad units used in northern New Mexico. Kottlowski (1952) mapped a small area in the Hansonburg mining district (Oscura Mountains), using Thompson's formations, which are useful mappable units on the scale 1:6,000 (500 feet to 1 inch).

Bogart (1953) examined outcrops of the Pennsylvanian—Permian rocks in Luna County and listed several measured sections. Kuellmer (1954) mapped a belt across the Black Range and measured several Pennsylvanian sections. Jicha (1954) mapped the Lake Valley quadrangle and described the Pennsylvanian rocks. Otte (1959) made a very detailed field study of the late-Pennsylvanian and early-Permian rocks in the northern Sacramento Mountains, traced the outcrop gradation from marine sediments into nonmarine rocks, and found that deposition was essentially continuous from late Pennsylvanian into early Permian, although only 4 miles to the southeast of his area a major angular unconformity separates Pennsylvanian and Permian strata. Pray (1952, 1954, 1959) mapped most of the western escarpment of the Sacramento Mountains, measured sections of Pennsylvanian rocks, and set up three formations that are mappable units in the area (in ascending order, the Gobbler, Beeman, and Holder formations). Thompson and Kottlowski (1955) briefly summarized the Pennsylvanian and marine Lower Permian sequences in south-central New Mexico. Kottlowski, Flower, Thompson, and Foster (1956) measured, and described in some detail, stratigraphic sections in the San Andres Mountains, and made megascopic, binocular, and petrographic studies of the Pennsylvanian rocks. Fusulinid zonation was based on identifications by Thompson.

Foster (1956) summarized the subsurface and outcrops data on Pennsylvanian rocks of west-central New Mexico. Gillerman (1958) mapped the Paleozoic strata in the central Peloncillo Mountains, Zeller (1958) the strata in the Big Hatchet Mountains, and Hardie (1958) the Pennsylvanian—Permian units in the northern Hueco Mountains. Harbour

(1958) noted the upper Paleozoic rocks present in the northern Franklin Mountains. Kottlowski (1958) described the Pennsylvanian—Permian relationships near Deming, Oppel (1959) the Pennsylvanian—Permian contact of the type Fresnal-group section, Wengerd (1958, 1959b) the Pennsylvanian of the Lucero Basin area, and Kottlowski (1959) the Pennsylvanian of west-central New Mexico.

In addition to the published reports, many areas of Pennsylvanian rocks in southwestern New Mexico have been mapped, and the sequence described. Dr. M. L. Thompson, Illinois Geological Survey, has measured many sections in this region and has been working on the fusulinid data. Pennsylvanian sections have been mapped and studied in the northeastern Black Range and Sierra Cuchillo by Dr. R. H. Jahns, in the Fra Cristobal Mountains by Dr. E. G. Cserna, and in the Robledo (fig. 16) and Dona Ana Mountains by the writer. Many petroleum geologists have measured sections, and collected and identified the fusulinid faunas. Most of their information however, is unavailable to the general public, although all have been extremely cooperative, as far as possible, in sharing such data.

# *Areal Summary of Southwestern New Mexico*

The southwestern quarter of New Mexico (pl. 1) is divisible into four physiographic units: (1) the Datil section of the Colorado Plateau, comprising southwestern Valencia County, Catron County, western Socorro and western Sierra Counties, and northern Grant County; (2) the Rio Grande depression and bordering uplifts, including central Socorro and central Sierra Counties; (3) the Mexican Highland section of the Basin and Range province, covering Hidalgo, Luna, and Dona Ana Counties, southern Grant County, eastern Sierra County, and western Otero County; and (4) the Sacramento section of the Basin and Range province, including central Otero County, western Lincoln County, eastern Socorro County, and western Torrance County.

## DATIL SECTION

The Datil volcanic plateau is a region of rugged forested mountains and interspersed grassy plains, mostly over a mile in elevation, an area where the Continental Divide traces its sinuous course between lofty peaks. Volcanic rocks and associated sediments blanket underlying pre-Tertiary strata except near the borders of the plateau or in a few places where basal lavas have been dissected deeply enough, or have been structurally elevated enough, to allow limited exposure of Paleozoic limestones. Pennsylvanian rocks crop out near Silver City and Santa Rita on the south edge of the plateau; on the east edge of the Black Range near Kingston, Hillsboro, Lake Valley, Hermosa, and Winston; on the south and east sides of the San Mateo Mountains near Monticello and Eaton Ranch; and in the Magdalena Mountains. Amid the lavas, Pennsylvanian beds crop out along Trout Creek northwest of Luna, and Permian and Triassic strata occur on the south flank of Horse Mountain, about halfway between Datil and Reserve. To the north, in northern Catron and northern Socorro Counties, Cretaceous sedimentary rocks underlie the northward thinning edge of the Cenozoic volcanic rocks, and too few test holes have been drilled to obtain a clear picture of the Pennsylvanian beds.

### SKELLY No. 1 GOESLING

Near the Arizona border, a stratigraphic test by Skelly Oil Co., drilled in sec. 27, T. 3 N., R. 21 W. (No. 32, pl. 1), penetrated Abo-like red beds on red Precambrian granite. There is no indication of the age of the basal Abo red beds in this test hole; they may be of Pennsylvanian or Permian age.

## HUCKLEBERRY No. 1 FEDERAL

The Huckleberry oil test, drilled about 7 miles north of Quemado (No. 97, pl. 1), also found Abo red beds resting on red Precambrian granite. Comparison of the electric log with that of the Tidewater No. 1 Mariano test (about 50 miles north of the northern boundary of pl. 1) suggests that from 70 to 200 feet of the basal Abo may be of Pennsylvanian age in the Huckleberry test. However, the Pennsylvanian in the Tidewater No. 1 Mariano well is interbedded red beds and thin fossiliferous limestones, whereas the basal Abo of the Huckleberry No. 1 Federal is entirely unfossiliferous red-bed clastic rocks.

## TROUT CREEK

On the ridge southwest of Trout Creek (sec. 3, T. 5 S., R. 21 W.), Robert H. Weber, New Mexico Bureau of Mines, mapped a small patch of Pennsylvanian strata in fault(?) contact with andesitic-latitic rocks near the base of the volcanic sequence. This Pennsylvanian outcrop may be a float block in the volcanic rocks, or a small upthrown fault block. Although the beds dip at high angles, they are relatively unbroken and are not baked or intruded by the igneous rocks, and no fragments of the Pennsylvanian limestones were found within the nearby surrounding volcanic beds. The partial section exposed is 350 to 400 feet thick (fig. 5) and contains fusulinids of probable Desmoinesian age.

Near the top of the exposed section are interbeds(?) of pink calcareous shale and brown lenticular arkosic sandstone. Fossil-fragment calcarenite and algal micro-oolitic limestones appear to be the most common carbonate rocks. Some of the clastic limestones contain scattered grains of red siltstone and local lenses of limestone conglomerate. If one postulates 200 to 400 feet of early Pennsylvanian below the measured section, and at least 300 feet (plus?) of late Desmoinesian, Missourian, and Virgilian strata above, the Pennsylvanian section may have a thickness of 1,100 feet or more.

Just across the boundary in Arizona, on the northeast edge of Escudilla Mountain, in secs. 28 and 29, T. 7 N., R. 31 E., 61/2 miles northwest of the Trout Creek outcrops, Professor Donald Bryant, Arizona University, reported Virgilian fusulinids collected by Chester T. Wrucke, U. S. Geological Survey, from 50 to 100(?) feet of much-faulted Pennsylvanian strata underlying basal Tertiary volcanic rocks (sec. 9). The strata are poorly exposed and cut by many faults, but there appear to be interbeds of reddish-brown shales amid the massive to nodular, fossiliferous limestones. Identification of fusulinids (in rock specimens collected by James A. Smith and Wayne Bock, Texaco, Inc.) by Wendell J. Stewart, of Texaco, Inc., suggests that the various fault slices are mostly of Missourian and tipper Desmoinesian age.

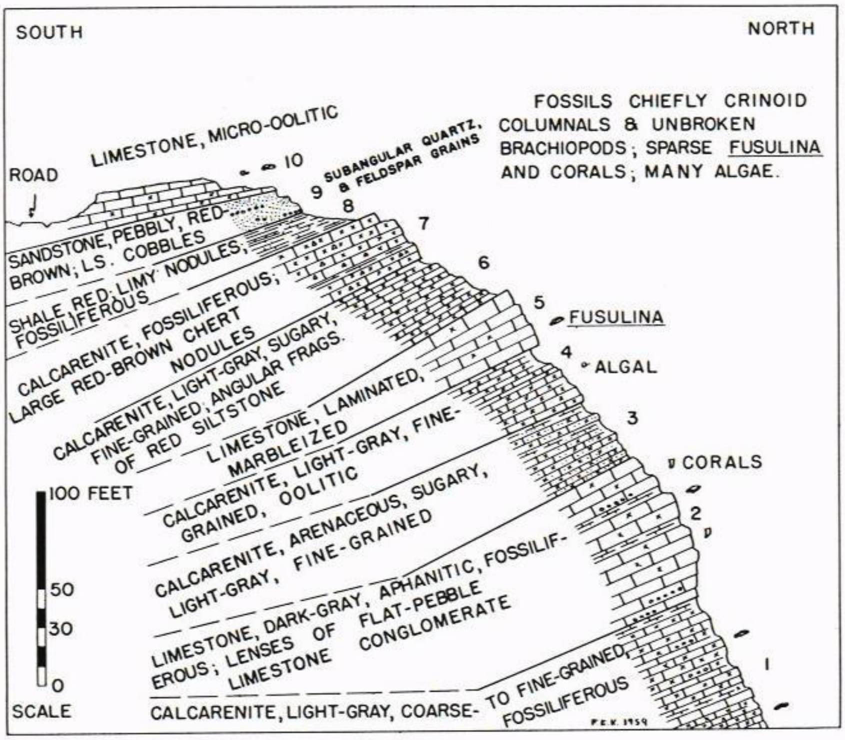


Figure 5

TROUT CREEK COLUMNAR SECTION

ZUNI MOUNTAINS

North of the north boundary of the index map (pl. 1) and about 70 miles north and slightly west of Datil, red beds overlie the Precambrian rocks of the Zuni Mountains. Perhaps as much as 125 feet of the basal conglomerates, arkose, and siltstone contains lenses of limestone that yielded bryozoa and brachiopods of Desmoinesian and Missourian aspect, as identified by Cheetham (1950) and Arthur L. Bowsher (then of the U. S. Geological Survey, now with Sinclair Oil & Gas Co.). These limestone lenses crop out in N1/2 sec. 2, NW cor. and SW¼ sec. 18, and NW cor. sec. 19, T. 11 N., R. 13 W., and in S1/2 sec. 12, sec. 13, and along the north line of sec. 24, T. 11 N., R. 14 W. A generalized section as listed by Cheetham, in ascending order above the Precambrian rocks (granite, granite-gneiss, sericite and chlorite schists, and metarhyolite), is: (1) 0 to 10 feet of grayish-orange arkosic conglomerate, (2) 0 to 30 feet of massive, grayish red-purple, pebbly arkose containing thin (1 to 3 inches) lenses of light-gray, gastropod-bearing limestone, (3) 0 to 10 feet of fossiliferous, light-gray to brownish-purple, silty shale, (4) 0 to 12 feet of fossiliferous, greenish-gray to purplish-gray limestone in beds 1 to 3 feet thick separated by thin (2 to 4 inches), purple shale interbeds, (5) 0 to 5 feet of light-gray, thin-bedded, dense limestone, (6) red arkosic sandstones, mudstones, and siltstones, typical of the Abo red beds in the Zuni Mountains.

Darton (1928, p. 139-141) reported as much as 40 feet of limestone in the basal red beds at two localities in the Zuni Mountains but noted that noncalcareous Abo red beds overlie the Precambrian granite at many other places. The Pennsylvanian—Permian boundary probably varies within short lateral distances, from hillock to valley on the prered-bed surface, and possibly only some of the basal beds are of Pennsylvanian age. Oral reports from various petroleum geologists record collection of fusulinids from the limestone lenses in the lower Abo that have been identified as late-Pennsylvanian—early-Permian *Triticites* types. Based on the limestones present in the basal part of the red-bed sequence, and on the assumption that the sections of only nonmarine clastics are chiefly lower Permian, Thompson (1942, p. 14-15) suggested overlap of Virgilian beds onto the Precambrian on the east and northeast sides of the Zuni Mountains, and overlap of Permian red beds onto Precambrian granites on the southwest and west sides. Location of the Zuni landmass (the southeastern part of the Zuni-Defiance positive area) during Pennsylvanian time appears to be chiefly to the south-southwest of the present Precambrian core of the Zuni Mountains, and it joined northward with the Defiance upland west and northwest of the Zuni Mountains area. Relationships to the south are poorly known, as the Paleozoic strata are concealed beneath southward dipping Mesozoic beds and extensive sheets of Cenozoic lavas.

The Pennsylvanian isopach map compiled by McKee (1951, pl. 2A) showed two test holes drilled southeast and southwest of the Zuni Mountains in approximately T. 6 N., R. 14 W., and T. 4 N., R. 9 W. Pennsylvanian beds were reported to be 1,570 and 1,428 feet thick, respectively, in these two wells; the source was given as an oral communication from C. D. Johnson and G. A. Hemenway, Sinclair Oil & Gas Co. Mr. Hemenway stated (letter of September 24, 1956) that these test holes appear to have been misplotted, and that he does not know of any wells drilled at those localities. The sparse data in surrounding areas suggest that marine Pennsylvanian is thin or absent for a considerable distance south-southwest of the Zuni Mountains (e.g., Spanel-Heinze No. 1H Santa Fe Pacific oil test in sec. 27, T. 4 N., R. 11 W.).

### MITCHELL & SONS No. 1 RED LAKE

About 30 miles northeast of Datil and 35 miles southeast of the Zuni Mountains, the Mitchell & Sons No. 1 Red Lake (sec. 33, pl. 1-6) drilled in sec. 2, T. 3 N., R. 8 W., on the Red Lake anticline, encountered (Darton, 1928, p. 133) 574-542 feet of Pennsylvanian beds below the Abo red beds and above Precambrian "granite." The clastic ratio of the

Pennsylvanian section is almost 4, and the sand-shale ratio 0.35. The Abo red beds are predominantly reddish shale and siltstone, with "lime" and "lime shells" scattered throughout. There are no sandstones reported from the lower 587 feet of the red beds; the presence of fine-grained clastics and of "lime" suggests gradation from the "Magdalena" group into Abo red beds, and allows the possibility that some of the basal reddish rocks may be of upper Pennsylvanian age, as well as probably ruling out truncation of the Pennsylvanian strata by erosion during late-Pennsylvanian or early-Permian time.

### SOUTH SUWANEE DOME

About 30 miles northeast of the Red Lake anticline (3 miles north of the north border of pl. 1), the Acme Oil Co. No. 1 New Mexico—Arizona Land Co. test drilled on the South Suwanee dome penetrated at least 1,700 feet, and probably 2,165 feet, of Pennsylvanian rocks. Between depths of 4,145 and 4,610 feet is 465 feet of micaceous arkosic sandstone with minor limestone lenses(?), that may be a thick coarse-grained granite-wash type of deposit (Pennsylvanian?), or weathered (Precambrian?) arkosic sandstone and granite. The Williams and Gore No. 1 New Mexico Land & Cattle Co. test drilled in the same section (sec. 27, T. 7 N., R. 4 W.) in 1957 stopped in Pennsylvanian limestone after penetrating about 1,017 feet of Pennsylvanian rocks beneath the Abo red beds. These tests are on the east side of the structural Acoma basin, a southeastward embayment of the San Juan basin (Bates, 1942, p. 134), and are probably on the northwest margin of the Pennsylvanian-age Lucero basin or sag (Wengerd, 1958, p. 215). The clastic ratio for the upper 1,700 feet (depths 2,445 to 4,145 feet) of the Pennsylvanian in the Acme test is about 0.64, and the sand-shale ratio 0.22, pointing out the dominance of fine-grained clastic rocks above the basal 465-foot sandstone of uncertain age.

### LUCERO MESA-LADRON MOUNTAINS

On the east edge of the Lucero uplift, west of Belen on the west margin of the Rio Grande trough, Kelley and Wood (1946) measured three sections of the Magdalena group, which they subdivided into the Sandia formation and Madera limestone. Total rocks considered as Pennsylvanian in age range from about 1,950 feet on Gray Mesa (sec. 34, pl. 1-6; Mesa Aparejo on the 1956 U. S. Geol. Survey Mesa Aparejo topographic quadrangle map) southward, to about 2,130 feet on Mesa Sarca (sec. 35; Cadronito Hill of Thompson, 1942, and Monte de Belen of Kelley and Wood, 1946), and to 2,260 to 2,490 feet in the western Ladron Mountains (sec. 36). Units mapped by Kelley and Wood (1946) are the lower limestone member of the Sandia formation, the upper clastic member of the Sandia formation, and three members of the Madera limestone, which are, in ascending order, the Gray Mesa member, Atrasado member, and the Red Tanks member. The lower limestone member of the Sandia formation is the unit described by Armstrong (1955, p. 34) as the Caloso formation of Mississippian age, which occurs only as small erosional remnants in the northern Ladron Mountains but thickens and is persistent southward.

The clastic member of the Sandia formation is about 410 feet thick in the northern Ladron Mountains but is not completely exposed on Mesa Sarca and *Mesa* Aparejo, *where,* however, the upper part appears similar to that of the northern Ladron section and retains its thickness. More than half of the member is poorly exposed, but the clastic ratio is probably about 2, and the sand-shale ratio about 0.9. Rocks attributed to the basal sandy phase of the Pennsylvanian, the Sandia formation, near Red Lake (sec. 30) are about 190 feet thick, and have a clastic ratio of 18 and a sand-shale ratio of 1.4; this compares with a thickness of 230 feet, and a clastic ratio of 1.3 and sand-shale ratio of 0.95 for the Sandia formation in the Acme Oil Co. No. 1 New Mexico—Arizona Land Co. If the 465 feet of sandstone below the 4,145-foot depth of the Acme test is included in the upper clastic member of the Sandia, the clastic ratio is 5.9, and the sand-shale ratio 5.6; definitely a facies suggesting near-shore deposition or a flood of sand from nearby uplands.

The Gray Mesa member of the Madera limestone is correlative with the lower limestone member of the Madera as used by the U. S. Geological Survey, and is predominantly of gray, ledgy, cherty limestone, with several biostromal beds that form persistent thick cliffs (fig. 6). The member ranges from about 800 to 890 feet thick, as measured by Kelley and Wood (1946). The Atrasado member is about 760 feet thick in the northern Ladron Mountains but thins to the north to about 555 feet on Mesa Sarca and Mesa Aparejo, and becomes more shaly in the northern sections. The Atrasado member is the approximate equivalent of the upper arkosic limestone member of the Madera limestone anti differs from the Gray Mesa member in containing more clastic beds, as well as including some arkosic sandstone lenses.

The Red Tanks member ranges from 200 to 320 feet in thickness in the three sections and consists of interbedded reddish and buff sandstone, siltstone, and shale, limestone pebble-conglomerate, thin-bedded gray limestone, gray shale, and gray arkosic sandstone. The member is formed by an interbedding of the marine sediments of the upper Pennsylvanian and the continental beds of the overlying Abo red *beds,* and is essentially conformable with these underlying and overlying facies. The Red Tanks member has been correlated by some geologists with the Bursum formation (Early Wolfcampian) but appears more likely to be a lithologic equivalent of upper Virgilian strata to the south and east, which were placed in the Bruton formation by Thompson (1942). Differentiation of the Bruton and Bursum formations in south-central New Mexico, from Abo Pass southward, will require detailed mapping and extensive faunal studies, as in places they appear conformable, whereas in other localities the two units are not coextensive.

Figure 6

**CLIFF OF BIOSTROMAL LIMESTONE NEAR TOP OF MESA SARCA**

The Madera limestone in the northern Ladron Mountains, Mesa Sarca, and Mesa Aparejo thins northward from 1,850 to 1,540 feet, thins to 1,470 feet in the Acme Oil Company's well, and westward thins to only 380 feet near Red Lake (sec. 30). The lower Gray Mesa member is mostly limestone in the two southern sections, but these sections do contain a few beds of brown arkosic sandstone; the upper part of the Gray Mesa member on Mesa Sarca includes some thick shale beds, whereas the entire member on Mesa Aparejo is almost 50 percent limy shales. A similar northward increase in amount of shales and shaly beds occurs in the Atrasado member. The northward increase in fine-grained clastics is reflected in the clastic ratio for the Madera limestone, which increases from 0.28 for the northern Ladron Mountains to 0.52 at Mesa Sarca and 0.90 at Mesa Aparejo, whereas the sand-shale ratio decreases from 0.43 for the northern Ladron Mountains section to 0.12 for the Mesa Aparejo section of the Madera limestone. The clastic ratio for the entire Pennsylvanian section ranges from 0.37 in the northern Ladron Mountains to 1.07 on Mesa Aparejo; paralleled again by a decrease in percentage of sandstone as compared to shale.

SOUTHERN LADRON MOUNTAINS

On the southwest edge of the Ladron Mountains, the basal blackish shales and sandstones of the upper clastic member of the Sandia formation unconformably overlie about 90 feet of Lower Mississippian sedimentary rocks that rest on Precambrian granite gneiss. Northward the Mississippian sequence thins or is locally absent, owing to erosion during late-Mississippian or early-Pennsylvanian time, so that there are only remnants near Navajo Gap at the north end of the Ladron Mountains. The Pennsylvanian rocks form an eastward facing scarp and cap the westward dipping backslope of the southern Ladron Mountains, but dip beneath Cenozoic sediments, so that uppermost Pennsylvanian beds are exposed in scattered windows. The lower part of the Pennsylvanian was mapped by Noble (1950), who measured 643 feet of the Sandia formation (upper clastic member) unconformable on the Lower Mississippian Caloso formation (lower limestone member of the Sandia) at the south edge of the Ladron Mountains, about 2 miles north of the Rio Salado (sec. 37). Only 3 miles to the north, the basal sandy facies of the Pennsylvanian has thinned to 402 feet.

Maps and reports submitted to Prof. Clay 1'. Smith, New Mexico Institute of Mining and Technology, by Alan H. Cheetham, R. E. Slingerland, and D. H. Richter, as a part of the 1950 geologic field course, show (Cheetham, 1950) a complete section of the Pennsylvanian, about 2,700 feet thick, measured in sec. 30, T. 2 N., R. 2 W., and secs. 25 and 26, T. 2 N., R. 3 W. This section was checked by the writer (fig. 7) and appears reasonable, although it is broken by many faults (of small stratigraphic displacement). The Desmoinesian beds include an unusual number of sandstones and shales (total 33 and 350? feet thick, respectively) and are 850 to 860 feet in thickness. The sandstones are clean, light gray, and quartzose, cemented by calcite, and with some conglomeratic lenses of limestone cobbles. The shales are chiefly dark gray and range from carbonaceous and silty to limy, with limestone nodules and lenses. The Desmoinesian strata are suggestive of marine deposition at some distance from a low landmass (Zuni arch). Missourian and Virgilian beds include much shale and considerable arenaceous calcarenite, but only a few lenticular sandstone beds. Typical of these coarser grained clastic rocks is unit 165 (and other lenses near this horizon), which is locally a brown, limy, arkosic, pebbly sandstone, with grains and pebbles of granite, orange-tinted calcite, weathered feldspar, quartz, whitish plagioclase, and limestone.

The upper part of the Pennsylvanian section, as well as overlying red beds, is poorly exposed and broken by faults but has some aspects of both the Red Tanks member of the Madera limestone and the Bur-sum formation. Purplish limy shale grading upward into argillaceous, nodular, fossiliferous limestone, then into reddish-brown limy conglomerate, with clasts of limestone, fossils, quartz, and pinkish siltstone, is typical. The fossils collected are not diagnostic. The purple-and-red beds may be Virgilian in age or may be basal Wolfcampian.

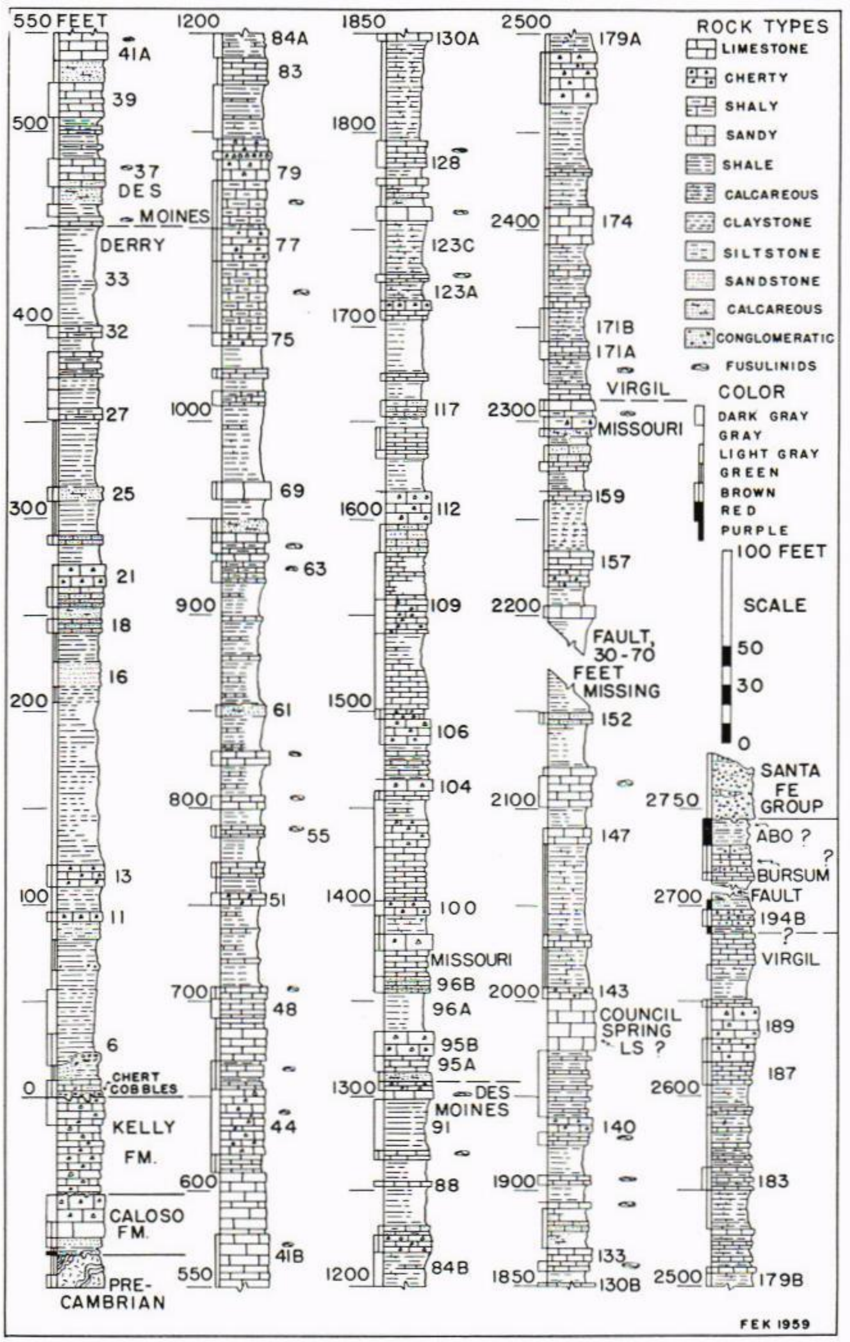


Figure 7

COLUMNAR SECTION IN SOUTHERN LADRON MOUNTAINS

Revised from Cheetham (1950).

**MAGDALENA MOUNTAINS**

The type section of the Magdalena group is in the northern Magdalena Mountains (sec. 52, pl. 1-6), where the Pennsylvanian strata rest on the early Middle Mississippian Kelly limestone. The group was subdivided by Loughlin and Koschmann (1942, p. 16-20) into the Sandia formation below and the Madera limestone above. The sequence is cut by numerous faults, many being strike faults with dip-slip, and locally has been metamorphosed to whitish marble, argillite, and quartzite, or has been silicified and mineralized. Thicknesses reported for the formation vary considerably from place to place owing to the lenticular nature of the beds and the numerous concealed faults.

The Sandia formation appears to be 580 to 600 feet thick and has been divided into 6 mappable members: (1) lower quartzite member, 90 to 130 feet thick, of greenish to brown quartzite with some interbedded shale and thin limestone (some of the quartzite beds are coarse grained to pebbly); (2) lower limestone member, 65 to 80 feet thick, of argillaceous thin-bedded limestone with subordinate amounts of blackish shale, quartzite, and sandy limestone; (3) middle quartzite member of brownish medium- to coarse-grained quartzite, occurring as lenticular beds more than 1,000 feet long and up to 18 feet thick; (4) shale member, about 320 feet thick, of blackish carbonaceous shale, with many interbeds of thin black limestones and fine-grained to pebbly quartzites; (5) upper limestone member, 25-35 feet thick, of algal medium-grained lenticular limestones; (6) upper quartzite member, as much as 65 feet thick, of light-gray lenticular quartzite with interbedded shale and limestone. On Granite Mountain, in the hills north of the main part of the Magdalena Mountains, a poorly exposed section of the Sandia formation was estimated to be about 2,300 feet thick; however, as pointed out by Loughlin and Koschmann (1942, p. 17), this apparent thickness appears to be considerably exaggerated by strike faults.

Near Kelly, the Madera limestone consists of two members, a lower 300 feet of thin-bedded bluish-black limestones, and an upper 300 feet or more of massive bluish-gray limestones. The lower member includes interbeds of bluish-gray fissile shale, gray medium-grained quartzite, and limestone-pebble conglomerate. Limestones in the upper member contain patches and veinlets of dolomite, some laminae and thin beds of yellowish argillaceous limestone, and gray to black chert nodules (fig. 8). Subordinate interbeds are of thin-bedded shaly mottled limestone, gray calcareous shale, and grayish-brown quartzite. The lenses of limestone conglomerate form prominent outcrops as much as 500 feet in length and 15 feet thick in the upper part of the lower member, containing pebbles of quartzite, quartz, and limestones in a matrix of quartzose calcarenite. The limestone clasts are flat platy fragments deposited more or less parallel to the bedding; these limestone-peb-

Figure 8
CROSSLAMINATED CRINOIDAL CALCARENITE CONTAINING CHERT LENSES,
MADERA LIMESTONE, MAGDALENA MOUNTAINS

ble/cobble conglomerates grade laterally and upward into limy quartz granule sandstones containing scattered clasts of limestone.

Loughlin and Koschmann (1942, pl. 2, p. 19-21) noted no angular discordance with the overlying Abo red beds except near the southern end of the district (headwaters of south fork of Patterson Canyon), where they implied that arkose and limestone-pebble conglomerates of the Abo truncate the upper beds of the Madera limestone.

Compared with sections of Pennsylvanian rocks to the north (Ladron Mountains), south (San Mateo Mountains), and east (Cerros de Amado), the Magdalena section is anomalous, resembling only the section on Socorro Mountain, which has "its head chopped off"; i.e., upper Pennsylvanian beds are absent, owing to faulting or to erosion during early Tertiary time. All outcrops of the upper Madera and lower Abo strata as shown on Loughlin, Koschmann, and Stringfield's geologic map (ibid., pl. 2) were examined, and all contacts between the limestone and red beds appear to be fault contacts (e.g., southeast of Kelly, south of Chihuahua Gulch, and headwater gulches of Patterson Canyon). The shaly Abo beds were a favorable horizon for intrusion of dikes and sills, and were an incompetent sequence that acted as a lubricant for many of the faults; as a result numerous small disconnected slices (horses) were left along fault planes.

The youngest Pennsylvanian beds (uppermost beds near Kelly) previously reported (Needham, 1937, p. 13) contain *Triticites kellyensis,* an upper Missourian form. Younger beds near Kelly were removed by erosion during Recent time, so that only about 600 feet of the Madera limestone remains. On Tip Top Mountain and its west slope, a mile northeast of Kelly, perhaps a 1,000 feet of the Madera limestone is present on the steep wooded mountain sides, but probable faults are concealed, so that the thickness is uncertain. A relatively unbroken section of the upper part of the Madera crops out on the ridge (center of north line of sec. 18, T. 3 S., R. 3 W.) west of the West Virginia tunnel; it is faulted against Tertiary andesite on the west, and probably against the Abo on the southwest. The Sandia formation is not exposed below the Madera where lowest beds are cut by the north fork of Patterson Canyon, and 400 to 600 feet of the upper Madera is exposed on the ridge. Upper beds partly exposed along the south-bounding gulch of the ridge are chiefly (80 percent) of shale; they are limy and concretionary, with many limestone nodules and lenses, and are pink, olive, gray, and pale purple. The limestone lenses in the shale are very fossiliferous, being essentially coquinas of crinoid columnals, bryozoa, and algae. I nterbeds are: algal limestone; limestone-pebble conglomerates with pebbles angular to subrounded; dense light-gray to olive limestone with irregular laminae of purple shale; arenaceous calcarenite interlaminated with limy sandstone; and 5- to 10-foot ledges of gray finely crystalline limestone bearing fusulinids and brachiopods. Virgilian *Triticites* were collected from near the top; younger beds were removed by Recent erosion.

These shaly beds have been exposed by recent gullying and were not previously reported; they resemble lithic units of the upper Virgilian Bruton formation. A contact with the Abo was not found amid the wooded slopes. As not even the lower part of the Madera is exposed below this 400- to 600-foot section, the writer suggests that 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. The Abo red beds, thinned by erosion (and by faulting) during Tertiary time, are reportedly only 100 to 175 feet thick and are overlain by purplish andesite and latite. In places the red beds were removed by erosion during the early Tertiary, so that volcanic rocks now rest on eroded parts of the Madera or locally even on the Sandia formation.

From the 1,185 feet of Pennsylvanian estimated by Loughlin and Koschmann (1942), it appears that the clastic ratio is 1.04, about the average of such ratios to the north and east, which are 0.76 to 1.29; the sand-shale ratio is also about average, being 0.45. This section, whatever its thickness, contains a high percentage of "grit" (quartzose sandstone composed of coarse-grained angular fragments and small pebbles), suggesting relative nearness to a source, presumably the southeastern end of the Zuni arch. If the Madera limestone is about 1,200 feet thick and is about 80 percent limestone, the clastic ratio would be lowered to only 0.67, suggesting adjacency to a central New Mexico accessway joining the Lucero and San Mateo basins—with coarse clastics flushed in from the Zuni arch during early Pennsylvanian time, and clays during late Pennsylvanian time. Periodically, as shown by the flat-pebble limestone conglomerates, shoal areas developed, and eventually, in late Pennsylvanian time, the sea retreated to the south and deposition of nearshore and continental red beds dominated.

### COUNCIL ROCK FAULT ZONE

The Council Rock mining claims occur along a N. 15° W.-trending fault zone that appears to extend from Cat Mountain near the headwaters of Mulligan Gulch (T. 3 S., W. edge of R. 5 W.) northward past Council Rock (northeast of Tres Montosas) and Gallinas Spring and to connect with the faults mapped by Tonking (1957, pl. I) just west of Hook ranch (SE¼ T. 1 N., R. 6 W.). In the SEIA sec. 25, T. 2 S., R. 6 W., 50 to 100 feet of interbedded limestone-pebble to limestone-boulder conglomerate and limy sandstone crops out on the west, upthrown side of the fault zone, is overlain by eolian sand, and is faulted against the basal Tertiary andesitic rocks. No fossils were found, but the beds are similar to parts of the Pennsylvanian in the Magdalena Mountains. Detailed mapping of this fault zone, which lies amid rolling forested hills, might uncover a thicker pre-Tertiary sequence. Near Hook ranch, Cretaceous strata are faulted against the early Tertiary(?) Baca formation sediments, but close to Council Rock some outcrops of Precambrian rocks are reported.

### SOUTHEASTERN SAN MATEO MOUNTAINS

On the east side of the San Mateo Mountains, a previously unreported section of Pennsylvanian rocks (fig. 9) is exposed in a complex fault block (fig. 34) near Eaton's (Foster's) ranch (sec. 30, p1. 1-6). The beds crop out as low east-west ridged hills, the bedding planes dipping 30 to 85 degrees to the south-southeast, and are cut by numerous faults (many not shown on fig. 34), including some dip-slip breaks.

The lower 500 feet of the Eaton ranch section (units 1-28, fig. 9) is poorly exposed but appears divisible into 2 sequences: (1) a lower series (units 1-13) of interbedded light-gray, green, and brown sandstones, gray to dark-gray arenaceous fossiliferous calcarenites, and blackish shale, and (2) an upper sequence (units 14-28) of interbedded dark-gray limy shale and dark-gray limestones, the latter including some arenaceous algal pebbly calcarenites, as well as scattered chain corals and cup corals. The lower sequence may be cut by a strike dip-slip fault where measured (middle fault block, fig. 34), as it appears to be several hundred feet thicker in the northeastern and northwestern parts of the outcrop.

Basal beds of the Pennsylvanian are tan to light-gray crosslaminated pebbly sandstones lying unconformably upon, and locally filling chan-

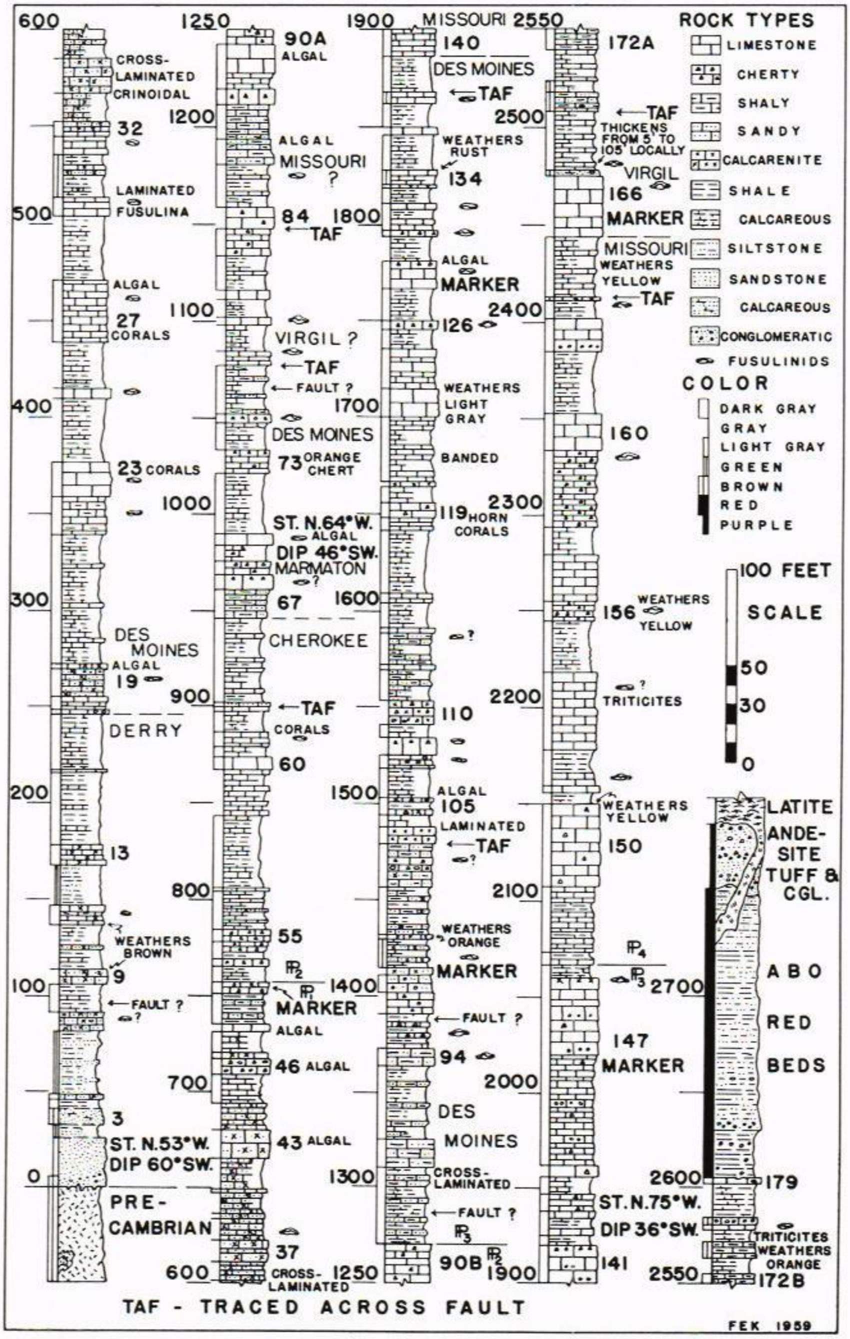


Figure 9
Eaton Ranch columnar section

nels cut into, the underlying brown coarse-grained Precambrian muscovite granite. Basal pebbly lenses contain subrounded to angular fragments, chiefly of quartz but including some chert and silicified limestone (dolomite?). Near the base (unit 3) is a persistent brownish-black arkosic hematitic limy sandstone, resembling in some aspects the Cambrian-Ordovician Bliss sandstone of southwestern New Mexico. Chonetid brachiopods, chiefly from interbeds of greenish-black shale and shaly olive limestone, date these beds as lower Pennsylvanian in age.

The Derryan-Desmoinesian time line is somewhere within units 14-18; if 200 feet of Derryan is faulted out in the measured section, this allows a maximum of 450 feet for the Derryan strata.

Desmoinesian fusulinids have been identified by Garner L. Wilde, Humble Oil & Refining Co., from units 19-137; the possible Desmoinesian-Missourian contact being near the base of unit 140, an apparent thickness of about 1,640 feet is indicated for the Desmoinesian. There is, however, a strong suggestion of a "joker" in the section somewhere within measured units 77-95; Missourian fusulinids (not seen by the writer) have been reported from about unit 86, and Virigilian fusulinids from ER77?, Desmoinesian fusulinids having been identified from underlying and overlying beds. Fusulinids identified by Wilde suggest a Lower Desmoinesian-Upper Desmoinesian (Cherokee-Marmaton) faunal boundary near the top of unit 67, with Upper Desmoinesian forms in units 71 and 74; then possible Lower Desmoinesian fusulinids from units 95, 98, and 107, and Upper Desmoinesian fusulinids up to unit 137. The faunal evidence suggests several faults, or indropped fault slivers, in the unit 77-95 interval, and a repetition of 500 to 900 feet of the Desmoinesian sequence, leaving 1,300 to 900 feet as a possible thickness of the Desmoinesian strata.

This fault, fault sliver, or fault zone is not apparent in the outcrop. Each bed of units 75-98 was walked out the length of the major middle fault block (fig. 34), and the beds appear to be parallel; any fault must be an almost perfect strike dip-slip fault. A sequence similar to that of the measured section occurs in the other fault blocks of the Eaton ranch outcrops; however, as shown on the geologic map (fig. 34), there are strike dip-slip faults outside of the middle block that barely cut across the beds.

Mapping of the Precambrian, Pennsylvanian, Permian, and Cenozoic rocks near Eaton ranch was done in an effort to spot this repeated section and to see if the total Pennsylvanian anywhere, across an unfaulted(?) section, is less than 2,500 to 2,600 feet thick. Cross-sections of any of the apparently unfaulted sequences (outcrop width and dips from fig. 34), however, give thicknesses within the 2,400 to 2,700-foot range. The mapped units are arbitrary lithic sequences chosen because they appear to be easily differentiable.

The sequence of units 32-90 (fig. 9) has many beds similar to units 97-147, owing either to a repeat of similar lithologies or, as suggested by the fusulinid faunas, owing to a fault in about unit 76 and unit 91. These same two sequences occur throughout the Pennsylvanian outcrops, however, and if due to faulting, date the strike dip-slip movement as prior to any displacement on the other numerous faults.

Units 32-44 (150 feet thick) are of distinctive arenaceous calcarenites marked by brown silty crosslaminae and with many lenses of crinoidcolumnal calcarenite. Units 97-103 (90 feet thick) are similar but contain many conglomeratic lenses made up of granules and small pebbles of angular to subrounded quartz, and flat-pebble limestone fragments. Marine(?) current directions, suggested by the directions of crosslaminae, were from the southeast quadrant, as observed in units 97-103, but from the southwest in units 32-44. Bed 46 is of dark-gray cherty algal conglomeratic limestone dissimilar to the algal calcarenite of unit 105. The black, argillaceous to silty, fossiliferous cherty limestones of units 51, 53, and 55 resemble somewhat the dark-gray laminated fossiliferous cherty limestones of units 107-108 but lack the limestone-flat-pebble conglomerate lenses of the latter. The dark-gray finely crystalline thick-bedded limestone of units 60-62 is not very similar to the black buff-weathering aphanitic cherty limestone of unit 119 and contains large chain corals, in contrast to the large irregular horn corals of unit 119. The top of unit 62 is 195 feet above the top of unit 44; unit 119's top is 165 feet above the top of unit 103.

The distinctive beds of units 122-124, black laminated limestone weathering light gray banded by light brown, do not occur in the unit 63-67 interval. Units 68-71, of dark-gray finely crystalline massive cherty limestone with upper algal lenses, are similar to units 126-128 but contain different species of *Fusulina*. The former are 295 feet above unit 44, and the latter 290 feet above unit 103. Units 73-75 and 130, which contain the same fusulinid species according to Garner Wilde, are similar dark-gray silty aphanitic cherty thin-bedded limestones.

Units 86-90 (top is 575 feet above unit 44) are of mottled, dark-gray to black aphanitic limestones with scattered chert flakes and nodules, and with algal lenses like the distinctive unit 147 (top is 575 feet above unit 103), which, however, contains many lenses of limestone-flat-pebble conglomerate and "pods" of sedimentary limestone breccia (fig. 10).

Rocks of Missourian age (units 140-165) may be about 560 feet thick, depending on where contacts are drawn between fusulinid-bearing beds (fig. 11). They are lithologically similar to the blackish Desmoinesian limestones, although tending to include more massive beds, and probably are richer in clay impurities as compared to the large amount of quartz silt in the underlying strata. Virgilian beds (units 166-179) are about 160 to 260 feet thick if none of the lower Abo red beds are of Virgilian age. The massive light-gray, crinoidal, finely to coarsely crystalline limestone of unit 166 gives way upward to lenticular interbedded limy shales and argillaceous limestones. Unit 167 is the first noncarbonate-rock clastic bed above the Derryan strata and is a distinctive lenticu-

Figure 10

LIMESTONE SEDIMENTARY-BRECCIA BED, DESMOINESIAN, EATON RANCH SECTION

Figure 11

FUSULINID COQUINA, EATON RANCH SECTION

far gray to greenish-gray brown-weathering calcareous pebbly sandstone; grains are chiefly of quartz, with some of chert and limestone; lenses of limestone conglomerate, pebbles flat to rounded, occur locally. Upper clastic beds, units 177 and 179 plus lenses within units 173-179, are of brown to dark-gray limestone conglomerate and coarse-grained calcarenite; pebbles are rounded to subangular and chiefly of limestone, with minor quartz, chert, and silicified limestone.

The Abo red beds appear relatively conformable on units 177-179 and grade upward from reddish and pale-olive shales and siltstones into dark reddish-brown crosslaminated siltstones and shales. Local lenses of limestone-siltstone-cobble conglomerate occur 25 to 50 feet above the base, and 1- to 3-foot blocks of silicified limestone are scattered through the basal red-bed shales and siltstones. The Abo is unconformably overlain by andesitic tuff and volcanic conglomerate on the east ridges of Buck Mountain, but the main peaks of the mountain are of latite (quartz latite?) intrusives and tuff-breccia unconformable with upper Pennsylvanian beds.

The relatively recent fault scrap bounding the west edge of the Pennsylvanian outcrops (fig. 34) continues south-southeastward for 3 miles from Buck Mountain to cross Nogal Canyon where Yeso strata are faulted against downthrown latites and rhyolites. Along the north edge of the arroyo draining San Juan Canyon, 3 miles east-northeast of Eaton ranch (in secs. 2, 11, and 12, T. 8 S., R. 4 W.), are a low hill and several mounds exposing part of the Eaton ranch Pennsylvanian section, probably about units 46-91. The limestone beds strike N. 20° W., and dip 15°-25° E. These scattered outcrops suggest that the bedrock, beneath the pediment gravels, of a large area east and southeast of Eaton ranch is of Pennsylvanian and Permian strata.

About 2 miles northeast of Monticello (sec. 64), on the south side of the San Mateo Mountains and about 15 miles southwest of Eaton ranch, is a similar section of Pennsylvanian strata, although much more metamorphosed. Many of the beds are silicified and broken by strike dip-slip faults, so that accurate measurement is difficult. An almost complete section from Derryan to Virgilian is present, based on identification of fusulin ids; both the upper and lower contacts, however, are along faults, although adjacent volcanic rocks are the andesitic tuffs, breccias, and volcanic sediments typical of the basal Tertiary in the region. There appear to be more sandstones in the lower part of the Monticello section than near Eaton ranch, but the total exposed section is thinner, the belt of outcrops being more than a mile wide, with the average dip of the beds for the most part more than 35 degrees to the east-northeast. Probably not less than 1,950 feet of Pennsylvanian beds crops out, but even detailed mapping and faunal studies may not determine the sequence satisfactorily.

Whether the Pennsylvanian near Eaton ranch is 2,700 or 1,800 to 2,200 feet thick, the lithology and thickness of the Desmoinesian sequence are unusual. Throughout most of New Mexico, the Desmoinesian is 600 to 900 feet thick; so the possible 900 to 1,800 feet in the eastern San Mateo Mountains is noteworthy, especially as it is on the east edge of the volcanic sheets that blanket the Datil—Mogollon region westward into Arizona.

Only a few of the limestones from the Eaton ranch Desmoinesian are the typical cherty gray, medium- to thick-bidded, crystalline fossiliferous (corals, brachiopods, bryozoa, crinoids) "shelf" limestones. The arenaceous calcarenites are not normal in the Desmoinesian except for a few clastic beds in the Magdalena Mountains, and the dark-gray to black aphanitic limestones and dark shales are equally foreign. The calcarenites have fine-grained or silt-size quartz along with the limestonecalcite-fossil grains, and are crosslaminated, the marine currents having been from the southeast or southwest—but the source of the quartz, it is likely, was to the northwest and probably a long distance away.

The black silty limestones, some thinly laminated and cherty, with local lenses of breccia conglomerate and intraformational limestone-flat-pebble conglomerate, local algal lenses, and calcilutite texture, contain only a few whole fossils, although lenses of brachiopod coquina, bryozoa, scattered to abundant crinoid columnals, or sparse fusulinids occur. These are some of the features of the Bone Spring type of "hasinal" deposits, but the Eaton ranch beds suggest deposition in shallower seas. Along with the blackish limestones are considerable thicknesses of shale ranging from gray limy nodular beds, with much intercalated argillaceous to silty limestone, to black noncalcareous shale. Are these deposits from a slightly deeper, partly stagnant "basin" amid a shallow shelf sea, or sediments laid down in wide, partly restricted lagoons bordering a detritus-supplying positive area that was some distance to the northwest? The sparseness of "fresh" debris, such as feldspars, and the large amount of clay and silt-size material suggest a location at considerable distance from any actively eroded landmass.

**SIERRA CUCHILLO '**

The Pennsylvanian strata in the Sierra Cuchillo (sec. 65) just east of the Black Range near Winston have been considerably contact metamorphosed near intrusive rocks, so that coarse-grained marble and dense hornfels, as well as granulite and tactite, occur in some areas. The beds have been referred to the 'Magdalena group by Jahns (1944) and mapped as the Sandia formation and Madera limestone. The Sandia formation is about 150 feet thick and consists of interbedded shale, greenish to reddish-brown sandstone, light-gray to brown orthoquartzite, and cherty limestone. A basal chert-pebble conglomerate overlies lower Mississippian limestones with a pronounced unconformity that involves an erosional surface with several tens of feet of relief. The Madera limestone is about 1,250 feet thick and is of the typical fine- to medium-grained gray cherty limestones, with local lenses of limestone-pebble conglomerate and, near the top, reddish-brown to greenish-gray sandstone interbeds.

A limestone-red beds transition zone, 60 to 110 feet thick, occurs between the dominantly carbonate Magdalena group and the overlying Abo red beds, and has yielded fossils of Virgilian age. The lower part of the Abo red beds includes a few thin lenticular beds of limestone-pebble conglomerate and silty greenish limestone. The Pennsylvanian—Permian contact, as in the Mogollon Rim area, appears to be an indecipherable horizon somewhere within the lower part of the red-bed sequence. The Pennsylvanian rocks in the Sierra Cuchillo are broken by many faults and metamorphosed; Dr. Richard H. Jahns (personal communication) has noted the possibility that part of the section may have been faulted out, as thicker sections occur to the northeast, east, southeast, and south.

### BLACK RANGE

Several fault-bounded blocks of Pennsylvanian carbonate rocks are reported by Jahns along the eastern margin of the Black Range from Winston northward to about 5 miles north of the Sierra-Socorro county line; in all cases, the exposed strata are nodular silty limestones and interbedded reddish siltstones of upper Pennsylvanian age overlain by Abo red beds, which are beneath the Tertiary volcanic rocks.

Southward in the Black Range, near Hermosa, a thicker Pennsylvanian section (sec. 68) is exposed on the eastward edge of the Tertiary-Quaternary lava that covers much of the Datil—Mogollon plateau to the west. The Hermosa section is similar both to the Sierra Cuchillo section and to the thicker section of the Pennsylvanian in the Mud Springs Mountains to the east. Basal clastic beds unconformably overlie lower Mississippian limestones, and the Madera limestone grades up into the Abo red beds, the basal beds of which, however, have yielded lower Permian fossils Uahns, personal communication).

In the Black Range, near Kingston, the Pennsylvanian rocks are involved in much faulting and are intruded by quartz monzonite bodies. Kuellmer (1954, p. 17, 22-24) measured a section more than 650 feet thick just west of Kingston, a considerable thinning of the Pennsylvanian when compared with sections to the north and east. The section (sec. 73) is notable for the large percentage of limy shales, blackish and greenish shales, and silty shaly limestones, which, in part at least, may be lagoonal deposits. The clastic ratio of 031 contrasts with that of the Sierra Cuchillo Pennsylvanian, which is only 0.14; however, most of the elastic beds are fine grained, as shown by the sand-shale ratio of 0.15, which contrasts with the 0.75 sand-shale ratio of the Sierra Cuchillo section. The Pennsylvanian beds near Kingston are in places disconformable on the lower Mississippian Lake Valley formation and in other localities overlie a monzonite sill; they appear to grade up into the Abo red beds through a transition sequence of interbedded nodular limestones and reddish siltstones. Furthermore, most of the Pennsylvanian fusulinid zones appear to be present, although thin or partly missing, Virgilian fusulinids having been identified from the upper transition zone. Tertiary erosion has in places removed the overlying Abo red beds, so that the basal Tertiary andesitic volcanic rocks locally rest on upper Pennsylvanian strata. In some places light-gray brown-weathering sandstone and black shales, resembling Cretaceous rocks, overlie the Abo red beds.

The possibility remains that parts of the Pennsylvanian section near Kingston have been thinned by faulting, and that a complete section may exceed 1,000 feet.

### COOKS PEAK

Southeast of the main part of the Datil—Mogollon volcanic plateau in the Cooks Peak area, the Pennsylvanian (sec. 80) is even thinner, Jicha (1954, p. 21-24) having measured only 200 feet of Pennsylvanian on the northwest side of Cooks Peak; 3 miles to the south, on the south side of Cooks Peak, the Pennsylvanian sequence is only 40 to 80 feet thick. Fusulinids found near the top of the section are of early Missourian age, whereas those near the base are of lower Desmoinesian age; with the megafossils identified from beds near the base of the section, the faunal content suggests that only Desmoinesian and lower Missourian strata are present. The sequence is marked by numerous lenses of limestone-chert-pebble conglomerate, by laminated blackish calcilutites, and by fossiliferous calcarenites; south of Cooks Peak, the Pennsylvanian beds are almost entirely calcarenites, with many lenses of limestone and chert pebbles.

This elastic section must have been deposited at no great distance from the Florida landmass (pl. 10), which is postulated as occurring to the south, and suggests that this positive area was active in part during Pennsylvanian time, as well as in early Permian time. The Pennsylvanian rocks are overlain unconformably by beds attributed to the Lobo/ Abo red beds, which are sparsely fossiliferous, and resemble the Pennsylvanian strata except for the abundance of red beds. The basal Abo beds are somewhat similar to the Powwow conglomerate, consisting of limestone-chert conglomerates with calcarcnite matrix and reddish silty shales. Sparse fossil evidence suggests that these Abo/Lobo red beds near Cooks Peak are of Wolfcampian age; they are lithologically dissimilar to the type Lobo formation of the Florida Mountains, which more nearly resembles the basal early Cretaceous red beds of the Big Hatchet Mountains area (Zeller, 1958). To the northwest, Elston (1953, p. 22) reported similar conglomerates and red beds, mapped as the Abo formation, that overlie about 1,000 feet of Pennsylvanian strata southwest of the NI imbres River Valley and east of Santa Rita.

### MIMBRES VALLEY

Wanless (McKee, 1951, pl. 2A) measured 991 feet (sec. 75) of Pennsylvanian strata south of New Mexico Highway 180 and west of the Mimbres River. Near the Delk ranch, in and near sec. 33, T. 17 S., R. 11 W., and secs. 3 and 4, T. 18 S., R. 11 W., the Pennsylvanian rocks appear to approach 1,200 feet in thickness and are similar to the sequence north and west of Santa Rita, except that some individual units arc thicker.

### SANTA RITA-SILVER CITY

North of Santa Rita (sec. 74), the Pennsylvanian strata are about 820 feet thick and have been mapped as the Oswaldo formation below and Syrena formation above. According to Spencer and Paige (1935, p. 22-26), the Oswaldo formation is about 425 feet thick and is almost entirely limestone, with a basal 20 to 30 feet of shale, a bed of white chert at the base, and some shale interbeds in the upper thin-bedded part of the formation. The Syrena formation is a maximum of 395 feet thick, consisting of a basal 100 to 130 feet of shale and an upper part of interbedded limestone and shale. Thompson (1942, p. 18) noted that beds of tipper Virgilian age are absent in this Santa Rita section; however, Spencer and Paige (1935) reported that the Syrena formation is overlain by irregular, thin sequences of the Abo red beds above a transitional zone, about 110 feet thick, of interbedded marine limestones and shales and continental red beds. Diagnostic fossils have not been reported from this transitional sequence, which may be of late Virgilian age (as in the Sierra Cuchillo) or early Wolfcampian in age (Bursum equivalent). To the southwest of Santa Rita and to the west toward Silver City, the Abo red beds were removed by erosion during early and middle Mesozoic time, and the basal Cretaceous Beartooth quartzite rests with erosional unconformity on various parts of the Pennsylvanian sequence. Just west of Silver City, Entwistle (1944, p. 23) reported only 89 feet (sec. 76) of Pennsylvanian beds left beneath the Beartooth quartzite; on Bear Mountain, about 6 miles northwest of Silver City, the Beartooth quartzite overlies a thin Mississippian sequence, and on Treasure Mountain, 6 miles west of Silver City, the Beartooth quartzite overlies the Silurian Fusselman dolomite. In the Little Burro Mountains, southwest of Silver City, the Beartooth quartzite or Tertiary volcanic rocks were deposited on eroded Precambrian granites and metamorphic rocks.

The Beartooth quartzite is considered to be of Upper(?) Cretaceous age by the U. S. Geological Survey; similar sedimentary rocks at the same stratigraphic position in the Cooks Peak area are called the Sarten sandstone and contain Lower Cretaceous fossils. The absence of Pennsylvanian strata west of Silver City is therefore considered to be due to erosion during post-mid-Wolfcampian—pre-early Cretaceous time. Possibly sections of Pennsylvanian rocks exceeding 900 feet in thickness may have been left beneath this post-Pennsylvanian erosional surface in the area now blanketed by Tertiary rocks west and northwest of Silver City. The clastic ratio of the Santa Rita section is only 0.56, with a sand-shale ratio of 0.02, a lithofacies not normally associated with nearshore deposits.

Geologic conditions near Silver City and near the Clifton—Morenci mining district (fig. 29) in Arizona (80 miles west-northwest of Silver City) are similar. Both areas are windows of pre-Tertiary rocks, which crop out through and beneath a blanket of Tertiary volcanic rocks near the south edge of the Datil—Mogollon volcanic plateau, where the sheets of extrusive rocks are broken into basin-and-range structure and topography. In both areas, the Pennsylvanian sequence has been partly or wholly removed by erosion during either (I) the interval from early Permian to early Cretaceous time, or (2) late Cretaceous to early Tertiary time. Anywhere in the region between Silver City and Clifton there may be relatively thick sections of Pennsylvanian rocks, preserved from erosion during these Mesozoic—Tertiary intervals and now concealed by the Tertiary rocks.

## RIO GRANDE DEPRESSION AND BORDERING UPLIFTS

The Rio Grande structural depression in southwestern New Mexico occupies central Socorro and central Sierra Counties, as well as the northwest tip of Dona Ana County. The depression appears to be a complex graben, bounded in many places by horsts with inward facing scarps and outward dipping monoclines. The Rio Grande depression, or trough, extends northward beyond the area herein considered and consists of numerous northward alined basins connected en echelon by narrow constrictions to form an overall north-northeasterly structural and topographic trough. The structural trend of this depression dies out south of Hatch in the Sierra de las Uvas, where typical basin-and-range structure and physiography become dominant.

The Rio Grande depression is filled for the most part by varying but thick amounts of Cenozoic sediments. Northwest of Belen, for example, the Humble Oil & Refining Co. No. 1 Santa Fe Pacific oil test (sec. 18, T. 6 N., R. I W.) went through 9,925 feet of Cenozoic deposits before encountering Cretaceous rocks, and there may be as much as 5,000 feet of Tertiary sediments above the horizon in which the well was started. West of the Fra Cristobal Mountains, the Gartland No. 1 Garner Federal test was abandoned after drilling through 6,524 feet of Tertiary rocks; the Gartland No. 1 Brister oil test, drilled about 3 miles to the east through the Tertiary section, went into Cretaceous rocks at a depth of only 1,450 feet.

### OIL TESTS NEAR BELEN

There have been about 11 wells drilled more than 1,900 feet deep in the Rio Grande trough near Belen. None of the tests are reported to have penetrated Pennsylvanian strata, as most of the wells bottomed in Tertiary bolson deposits. On the west side of the trough, west of Belen, Pennsylvanian strata thicken southward from 1,540 to 1,850 feet from Mesa Aparejo to the northern Ladron Mountains, as noted previously. East of Belen, on the east side of the trough, in the Manzano Mountains, the Pennsylvanian rocks are exposed on the crest of the range and cap the dip slope to the east. Armstrong (1955, p. 30) reported local lenses of Mississippian limestones as much as 22 feet thick between the Precambrian and basal Pennsylvanian rocks, but in most places in the Manzano Mountains pebbly sandstones of the Sandia formation unconformably overlie the Precambrian granites and metamorphic rocks. Reiche (1949, p. 1198) noted numerous lenses of chert-pebble conglomerate at the base of the Pennsylvanian sequence and pointed out that the chert must have come from rocks younger than Precambrian and older than the Sandia formation.

### MANZANO MOUNTAINS

Sections measured by Read et al. (1944) in the Manzano Mountains and on the eastern slopes from west of Manzano northward to Bosque Peak show 160 to 250 feet of the upper clastic member of the Sandia formation, 430 to 705 feet of the lower limestone member of the Madera limestone, and more than 950 feet of the upper arkosic limestone member of the Madera limestone, with about 1,620 feet (sec. 38) as an average of the total aggregate thickness of the Pennsylvanian (fig. 12). The clastic ratio of 0.57 is slightly lower than that for the Mesa Sarca section to the west, but the sand-shale ratio of 0.84 is much higher than that for sections to the west, indicating relative nearness to the Pedernal landmass to the east. The sand-shale ratio for the Sandia formation is not abnormally large, most of the additional percentage of sandstone being in the upper arkosic member of the Madera limestone.

The clastic member of the Sandia formation consists chiefly of greenish to blackish shaly siltstones and sandstones, with thin beds of clayey shale and limestone and several ledge-forming beds of limestonechert-quartz-pebble conglomerate. The lower member of the Madera limestone is dominantly cherty limestone, with some nodular shaly beds and scattered thin lenses of white sandstones. The upper member of the Madera limestone is composed of cherty limestone, gray shale, feldspathic calcarenite, and arkosic sandstone; reddish siltstone and reddish arkosic sandstone occur as interbeds near the top, a gradational facies from the marine Pennsylvanian into the Abo red beds, which appears partly equivalent to the Virgilian Bruton formation and partly to the Wolfcampian Bursum formation.

### ABO PASS

To the south, in the Abo Pass area (sec. 45) between the Manzano and Los Pinos Mountains, Pennsylvanian strata are about 1,290 feet

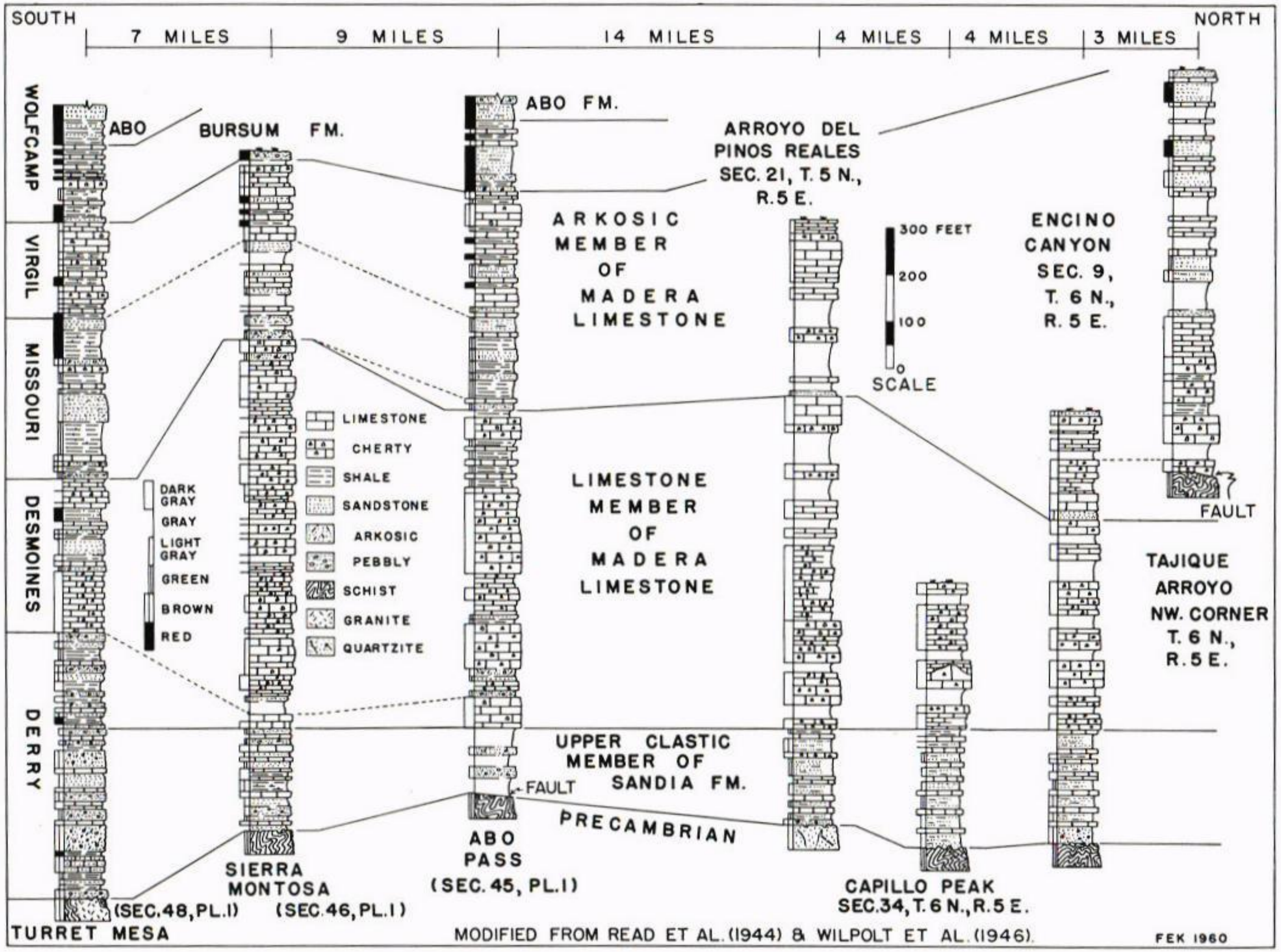


Figure 12

SECTIONS OF PENNSYLVANIAN ROCKS IN MANZANO AND LOS PINOS MOUNTAINS thick, the upper clastic member of the Sandia formation being about 190 feet in thickness, the lower limestone member of the Madera limestone 670 feet, and the upper arkosic member of the Madera 430 feet. The Madera is overlain by the Bursum formation of Early Wolfcampian age, which at this locality is of typical purplish shale, reddish arkose, nodular shaly limestone, and dense massive gray limestone. Stark and Dapples (1946) have also measured sections in the Abo Pass area and southward in the Los Pinos Mountains, subdividing the Pennsylvanian into zones based on fusulinids. These zones, which contain fusulinid faunas that correspond to those of the standard midcontinent terminology, were mapped on a scale of 1:63,360. The above writers quoted Needham's comment (1937, p. 14) concerning the Sandia and Madera formations:

> The plane of division between the two is so inconsistent and the litho-logic character of the Pennsylvanian rocks varies to such an extent from place to place that divisions corresponding to the Sandia and Madera formations cannot be recognized in many parts of the state.

The Pennsylvanian sequence in the Los Pinos Mountains and adjoining areas (fig. 12), and its differentiation into the Sandia and Madera formations, are proof of Needham's statement. The essential definition of the upper clastic member of the Sandia formation (the lower limestone member in all cases apparently being of pre-Pennsylvanian age) is given by Read and Wood (1947, p. 224) as follows:

> a dominantly clastic deposit of early Pennsylvanian age . . . a transgressive suite of sediments . . . that must, in a regional sense, vary slightly in age limits.

The Sandia formation, restricting it to the upper clastic member of Pennsylvanian age, should then include all basal Pennsylvanian sediments up to the point where clastic beds become less than 50 percent of the sequence. The Madera limestone is essentially (Read and Wood, 1947, p. 223-225):

> dominantly marine sediments . . . consisting of . . . (lower) evenly and widely distributed marine sediments deposited during a period of maximum marine transgression, and (upper) unevenly distributed and restricted alternating marine and continental sediments that represent a period of offlap or marine regression.

As has been noted, the upper part of this latter suite of sediments includes in places the Bursum formation of Lower Wolfcampian age. To the south, in parts of southern New Mexico, the "lower Madera" maximum marine transgression continued from Derryan through Wolfcampian time in some localities.

### Los PINOS MOUNTAINS

Three well-exposed sections of the Pennsylvanian beds occur in the Los Pinos Mountains: (1) at the north end, in and east of Abo Pass;

(2) 9 miles to the south-southwest, on the south side of Sierra Montosa;
(3) 6 miles to the southwest, at the south end of the Los Pinos Mountains, on Turret Mesa. Sections (fig. 12) measured by Wilpolt et al. (1946) and Stark and Dapples (1946) at these three localities are reasonably similar, and the units can be recognized easily in the outcrop.

The base of the Sandia formation near Abo Pass (sec. 45) is a fault plane, but nearby sections expose 180 to 195 feet of beds attributed to the formation. The lower 130 feet of the limestone member of the Madera as mapped includes 40 feet of pebbly arkosic sandstone, with the lowest sandstone about 65 feet above the base, and apparently at the base of the Desmoinesian series (contact of Zone of *Fusulinella* below and of *Fusulina* above). At Sierra Montosa (sec. 46), the Sandia formation is 195 feet thick, but the upper 100 feet is almost 50 percent limestone; 70 feet above the top, arkosic pebbly sandstones occur in the limestone member of the Madera formation.

On Turret Mesa (sec. 48), the Sandia formation as designated by Wilpolt et al. (1946) is 350 feet thick, but the basal 180 feet of the overlying limestone member of the Madera limestone is predominantly sandstone and shale, with a clastic ratio of 8 as compared with a elastic ratio of only 4.7 for the unit mapped as the Sandia formation on Turret Mesa. The entire 530 feet appears to be in the Zone of *Fusulinella,* the Derry series. Several miles to the northeast, on Tongue Ridge (sec. 12, T. 1 N., R. 3 E., projected onto Sevilleta Grant), Derryan strata are about 325 (possibly 390) feet thick, whereas beds attributed to the Sandia formation are 310 feet thick, although the basal 90 feet of the overlying limestone member of the Madera limestone is at least 50 percent clastic.

Mapping by Wilpolt et al. (1946) suggested that the clastic basal 180 feet of the Madera limestone on Turret Mesa grades laterally into massive limestones 6 miles to the northeast on Sierra Montosa; mapping by Stark and Dapples (1946), however, suggested that the 530 feet of Derryan beds on Turret Mesa thin to the northeast to only 250 feet on Sierra Montosa (fig. 12). Unfortunately, outcrops between the sections are in places poorly exposed and interrupted by thrust faults, so that very detailed field mapping is needed to clarify the relationships. Based on the given definitions of the Sandia and Madera formations, however, the basal elastic phase attributed to the Madera limestone on Turret Mesa should be considered as part of the Sandia formation even if it does grade laterally into a limestone sequence. If facies are to be mapped, as is the stated intention when the Sandia and Madera formations are used, the contacts must be expected to cross time surfaces. Conversely, a statement referring to "Sandia and early Madera time" is inexact, as the period when the fades were deposited varies considerably from place to place.

The Virgilian ranges from 200 to 230 feet in thickness in the Los Pinos Mountains area, with uppermost Virgilian fusulinids not reported; the Missourian is 230 to 340 feet thick, the Desmoinesian 500 to

770 feet thick, and the Derryan (and perhaps older Pennsylvanian beds) ranges from 260 to 530 feet in thickness. Rocks of Derryan age thicken toward the southwest and become slightly coarser and more arkosic in that direction. Desmoinesian strata thin abruptly from Sierra Montosa to the southwest and become more clastic (fig. 13). Missourian beds thicken toward the southwest, and although their clastic ratio in all three sections is greater than 1.0, there is a change from fine-grained sandstone, siltstone, and shale to arkosic pebbly sandstones in a southwestern direction. Strata of Virgilian age are relatively constant in thickness and lithology, consisting of cliff-forming noncherty limestone with interbeds of reddish to greenish shale and sandstone; in places rubbly limestone conglomerates of the basal Bursum formation appear unconformable on the Virgilian strata.

Stark and Dapples (1946, p. 1145-1153) studied, in some detail, the lithologies of the Pennsylvanian rocks and recognized several sequences of cyclic sedimentation. The rocks vary so greatly laterally as well as horizontally that a considerably more complex history is suggested than that of simple cycles. For the total Pennsylvanian sequence, a marked southwestward increase in clastic rocks is shown by the clastic ratios of 0.77 at Abo Pass, 0.56 at Sierra Montosa, and 2.2 on Turret Mesa. Sand-shale ratios for the same three areas are 0.54, 0.82, and 0.98 respectively, indicating an increase in amount of sandstone toward the southwest (fig. 13).

### JOYITA HILLS

Ten miles west of Turret Mesa (at the southern end of the Los Pinos Mountains) are the joyita Hills (sec. 47), a low north-northeast-trending series of ridges that rise a few hundred feet above Cenozoic sediments on the east bank of the Rio Grande. Structurally, the joyita Hills are a complex horst bounded on all sides by faults and cut by numerous transverse, oblique, and strike faults. The highest ridge is about 4 miles long, trends north-northeast, and is of Precambrian granite and granite gneiss, which are faulted against Tertiary volcanic rocks on the southeast and overlain by steeply dipping Pennsylvanian strata on the northwest.

There are dip-slip faults along the Precambrian—Pennsylvanian contact, but the upper clastic member of the Sandia formation appears to be about 100 to 150 feet thick, although there are sheared and crumpled zones in the shaly beds of the formation. Much of the unit consists of blackish carbonaceous marine shales; greenish and brownish shales, bone coal laminae, pebbly to fine-grained sandstones, and dark arenaceous limestones also occur. No fusulinids were found, although calcareous lenses and nodules in the shales contain numerous brachiopods and other marine fossils. There appears to be little evidence of Derryan age for this basal clastic unit, as the first fusulinids found in limestones at the base of the limestone member of the Madera limestone are

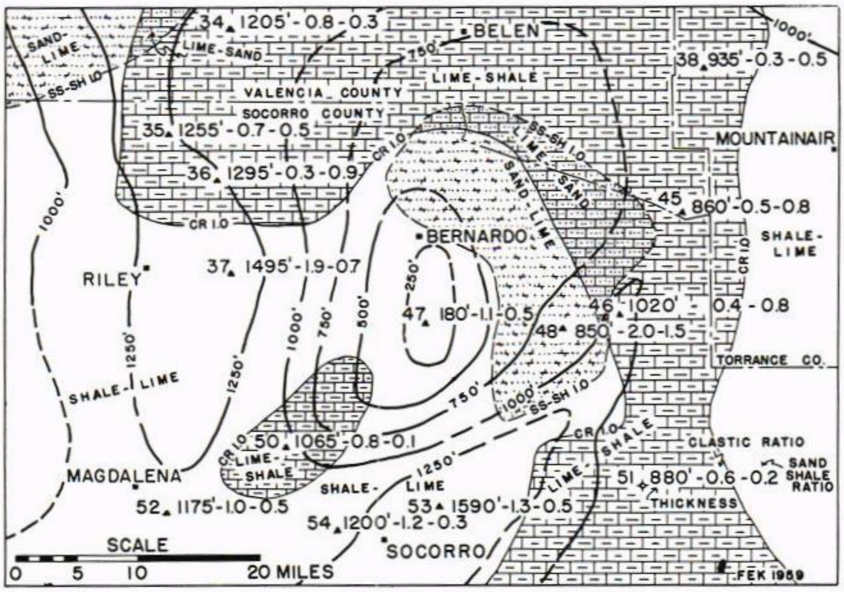


Figure 13

DERRYAN AND DESMOINESIAN ISOPACH AND LITHOFACIES MAP OF JOYITA HILLS AREA

Contour interval 250 feet. Section numbers from Table 1. Thickness mostly estimated.

*Fusulina similar* to the species that are common well above the base of the Desmoinesian. These basal elastic beds in the Joyita Hills, therefore, may have been deposited at almost the same time that marine limestones and minor interbedded elastics of lower Desmoinesian age were being deposited in the areas to the east and west.

The lower limestone member of the Madera limestone appears to be only 80 to 120 feet thick; the upper arkosic member may be entirely absent, although there are some thin beds of feldspathic calcarenite locally present. The cherty ledge-forming Madera limestones cap a cuesta overlooking a strike valley eroded in the Sandia shales and dip west-northwest into a broad strike valley cut in the Bursum formation and lower beds of the Abo red beds. The westernmost persistent limestones of the limestone member are silicified and, where they are exposed in the cross-cutting canyons, are brecciated and crumpled.

At the southern edge of the Los Pinos Mountains, Stark, Norton, and Staatz (1943) mapped silicified breccia zones in the Pennsylvanian limestones and noted that these zones marked strike dip-slip faults which cut out much of the Pennsylvanian sequence. The silicified zones in the Joyita Hills may mark such a fault zone along which most of the Pennsylvanian has been downdropped, so that uppermost Virgilian and

Bursum strata appear to overlie cherty limestones of the lower part of the limestone member of the Madera limestone.

This hypothesis of faulting probably was considered by Wilpolt et al. (1946) and rejected; unfortunately, the rocks are too poorly exposed, too broken by other faults, and in places too silicified for one to be sure of the relationships. Wilpolt et al. (1946) suggested that the Joyita Hills area was a positive element elevated in middle Pennsylvanian time. They pointed out the thinness of the exposed Pennsylvanian in the Joyita Hills and suggested that a resistant monadnock, termed the Joytta positive area, was a stable feature during Sandia and early Madera time (which, one supposes, may mean Derryan and early Desmoinesian time). The abundant fresh pink feldspars in the Sandia formation and lower part of the Madera limestone at Turret Mesa (lower 530 feet of the Pennsylvanian, which appears to be Derryan in age) are believed by Wilpolt et al. (1946) to be derived from the Joyita positive area.

The upper part of the limestone member of the Madera limestone is believed to have been deposited over the Joyita area. Wilpolt et al. (1946), however, suggested uplifting of that area at the end of the deposition of the limestone member (perhaps late Desmoinesian time), removal of all but 80 to 120 feet of the Madera limestone from the Joyita area, and deposition to the east and west of the lower part of the arkosic member, the feldspars of the arkosic member apparently being derived from some part of the Joyita positive area (not now exposed) where all of the Pennsylvanian was stripped off and the Precambrian bared to erosion. The upper part of the arkosic member is chiefly massive limestone, representing, it is suggested, a time of relative quiescence. During this time, however, although hundreds of feet of limestones and some clastic rocks were deposited to the east and west, no correlative sediments were deposited in the Joyita Hills area.

If the thinness of the Madera limestone is not due to faulting but to late Pennsylvanian erosion, one should expect considerable channeling of the upper surface beneath the Bursum formation, but the Bursum and Madera beds are essentially conformable. A typical sequence of the Madera and overlying rocks is, in ascending order: (1) cherty limestones bearing *Fusulina;* (2) silicified and brecciated limestones; (3) thin-bedded nodular shaly limestones; (4) feldspathic calcarenites, fine- to coarse-grained; (5) interbedded fossiliferous marly purplish shales and dense silty gray limestones; (6) reddish, brownish, and purplish arkoses, in part pebbly; (7) irregular thin dense gray limestone; and (8) arkoses, siltstones, and shales, dark reddish-brown, typical of the Abo red beds. Units 4-7 are probably referable to the Bursum formation, although fusulinids were not found, and the feldspathic calcarenites are similar to those in the arkosic member of the Madera limestone. There is the possibility, of course, that the silicified brecciated zone (unit 2) is the expression of a late Pennsylvanian erosion surface and not a fault breccia.

The large amount of feldspathic sandstone in the Sandia formation on Turret Mesa (fig. 12, 13) does suggest a nearby source, and the Joyita Hills, as well as an area to the south, may have been entirely exposed to erosion during Derryan time, as the basal deposits in the Joyita Hills are perhaps early Desmoinesian in age. The feldspars in the arkosic member of the Madera limestone, however, may just as well have come from the Zuni and/or Pedernal landmasses to the west and east; indeed, the large amount of arkosic material suggests source areas of considerable size.

Wengerd (1959) suggested that the Joyita Hills area was a "sill" (probably in the form of low islands and shallow shoals) separating the Estancia basin to the northeast from the Lucero basin to the west. Detrital sediments probably were not often swept across this shallow shelf, so that the clastic rocks to the west were derived chiefly from the Zuni landmass, and those of the Estancia basin were washed from the Pedernal landmass (pl. 10).

### CERROS DE AMADO

In the Cerros de Amado, a group of hills on the east side of the Rio Grande, 5 miles northeast of Socorro and 10 miles south of the Joyita Hills, Wilpolt and Wanek (1951) measured about 2,130 feet (sec. 53) of Pennsylvanian rocks unconformable on Precambrian granite and grading up into red beds and limestones, which they mapped as the Bursum formation. No diagnostic fossils have been found in the almost 100 feet of interbedded reddish clastic rocks and gray limestones attributed to the Bursum formation, and that unit in the Cerros de Amado may be of Virgilian age. However, near Ojo de la Parida, 3 miles to the northeast, Professor Clay T. Smith, of New Mexico Institute of Mining and Technology, reported (personal communication) Wolfcampian fusulinids from a lithologically similar sequence.

The upper clastic member of the Sandia formation is 635 feet thick, although the lower 170 feet of the limestone member of the Madera is predominantly of clastic rocks. The limestone member is 955 feet thick, and the upper arkosic member of the Madera limestone is at least 540 feet thick. The basal 805 feet appears to be in the Derryan series, the overlying 785 feet of the sequence in the Desmoinesian, and the upper 540 or 630 feet in the Missourian and Virgilian. There are too few fusulinid-bearing beds reported to determine the exact limits of these latter two zones, although only the upper 130 feet appears to be of Virgilian age. Derryan beds consist of brownish, reddish, and greenish pebbly sandstones, greenish to blackish limy to carbonaceous shales, and dark-gray silty limestones. Desmoinesian strata are typical gray cherty and noncherty ledge- and cliff-forming limestones, but with considerable interbedded gray calcareous shale and some lenses of gray sandstone, pebbly to arkosic. Upper Pennsylvanian rocks include a lower third chiefly of shale, with interbeds of pebbly sandstone; a medial part of interbedded shale, limestone, and sandstone; and upper beds of massive cherty limestone, a cherty phase of Thompson's (1942, p. 70-72) Moya formation. Not including the Bursum(?) beds, the clastic ratio is about 1.3, and the sand-shale ratio 0.5, for the entire Pennsylvanian section.

Recent work by Hambleton (1959) on the Missourian sections in the Cerros de Amado, Mesa Sarca, and the northern Oscura Mountains showed that Thompson's (1942) Missourian formations of the Oscura Mountains can be recognized northwestward into the Cerros de Amado and Mesa Sarca areas. Hambleton's petrographic analyses of the Missourian limestones suggested confirmation of the joyita "sill," and included descriptions of small algal reefs, as well as back-reef and reef-flank deposits, in the Cerros de Amado. An unexpected major constituent of the limestone insoluble residues was montmorillonite• clay (not illite) mixed with some kaolinite.

SOCORRO-LEM ITAR MOUNTAINS

West and northwest of Socorro, on the west side of the Rio Grande trough, in the Socorro and Lemitar Mountains, scattered fault slices of Pennsylvanian beds occur from Socorro Peak north to Polvadera Mountain. In places, massive crinoidal Mississippian limestones are present between basal Pennsylvanian beds and the Precambrian rocks, whereas in other localities only the clastic member of the Sandia formation occurs, resting unconformably on Precambrian argillite, schist, and granite gneiss. Pennsylvanian strata were partly removed by Tertiary erosion in many parts of these mountains, and in all localities appear to be unconformably overlain by Tertiary sediments or Tertiary volcanic rocks. In most places the sedimentary rocks are broken by numerous faults, intruded by sills and dikes of Tertiary age, and are silicified near fractures. Although in a zone of extensive volcanism, cut by many intrusive igneous masses and overlain by thick piles of extrusive rocks, the Pennsylvanian strata are not appreciably metamorphosed except close (1 inch to several feet) to contacts with the igneous rocks.

On the northeast side of Socorro Peak, about 3 miles west-northwest of the city of Socorro, more than 1,000 feet (sec. 54) of Pennsylvanian strata crop out. The beds are cut by numerous faults, many of the thinner shaly beds are folded, and the entire outcrop area is strewn with much talus from the rhyolite breccia-tuff that forms the bold cliffs capping the peak. Uppermost exposed beds of the Pennsylvanian, which contain species of *Fusulina* (Needham, 1937, p. 12), are faulted against the rhyolitic rocks, but in a small fault block to the north, Lasky (1932, p. 120) reported lavas resting on an eroded surface of the Pennsylvanian rocks.

Basal beds apparently unconformable (in a faulted zone) on greenish Precambrian schist and argillite are brownish pebbly quartzites containing lenses of arenaceous fossiliferous calcarenites. The lower 550 to 600 feet of the Pennsylvanian consists of slope-forming shales, thin-bedded nodular to lenticular limestones, and sandstones, with shales predominating. Lenticular 1-inch seams of bone coal occur in the shales, in places only a few inches away from fossiliferous limestone laminae. The shales are gray, greenish, and blackish; some are carbonaceous, others are limy and contain numerous nodules and lenses of argillaceous limestone. The limestones vary from those that are argillaceous, aphanitic, dense, and blackish to beds that are fossiliferous brownish calcarenites. Sandstones occur chiefly near the base of the section, where they are greenish to brownish, coarse grained and pebbly to silty, quartzitic to limy, and consist of very lenticular beds.

The upper 400 to 450 feet is of ledge- and cliff-forming cherty limestones, with numerous interbeds of limy shale in the lower part, and shaly nodular limestone near the top of the exposed section. Coquina and fossiliferous calcarenite beds are common, fusulinids being the most abundant of the fossils. In the lower part of the upper limestone sequence, assigned by Lasky to the Madera limestone, are striking greenish to brownish feldspathic quartzitic pebbly sandstones that grade laterally into brownish arenaceous fossiliferous calcarenites. Needham (1937, p. 12, 14-15) found *Fusulina* and *Wedekindellina* in the upper 400 feet of the section, referred to the Desmoinesian, the lower 500 to 600 feet being of Derryan age. The section appears somewhat thinner than correlative parts of the Pennsylvanian to the east in the Cerros de Amado, where the sequence to the top of the Desmoinesian is about 1,590 feet thick; upper Desmoinesian strata, however, do not appear to be exposed on Socorro Peak, so that the original thickness of the Pennsylvanian before Tertiary erosion may have been almost 1,900 feet.

North of Socorro Peak in the Lemitar Mountains, and south and west of Polvadera Mountain, several faulted slices of Pennsylvanian strata crop out. On the east side of the range, the Precambrian metamorphic rocks and granites are overlain by massive crinoidal Mississippian limestones (lower Sandia formation?), which are in fault contact with the lower, shaly (upper Sandia formation) part of the Pennsylvanian. On the west side of the range, deeply weathered Precambrian rocks appear to be depositionally overlain by basal Pennsylvanian sandstones and shales. The lower, shaly part of the Pennsylvanian is thin, but this is due, in part at least, to faults within the shaly sequence. The overlying Madera limestone is more than 565 feet thick (sec. 50) as measured by Roy W. Foster, New Mexico Bureau of Mines and Mineral Resources, who mapped the area for the 1959 geologic map of northwestern New Mexico, and is unconformably overlain by Tertiary conglomerates and volcanic rocks. At least 715 feet, and perhaps as much as 1,100 feet, of Pennsylvanian strata remains beneath the Tertiary erosion surface. The highest fusulinids found appear to be Desmoinesian *Fusulina,* suggesting that Missourian and Virgilian beds were removed by erosion during early Tertiary time.

The section in the Lemitar Mountains is only 11 miles southwest of the Joyita Hills, about the same distance from the Joyita area (sec. 47) as the sandy section of lower Pennsylvanian on Turret Mesa (sec. 48) at the south end of the Los Pinos Mountains. Although the Lemitar Mountains section contains much clastic material in its lower beds, the clastics are chiefly fine-grained and dominantly clay-sized particles, suggesting that most of the sand-sized materials from both the Zuni landmass and postulated Joyita land area were deposited before reaching the Lemitar-Socorro area. The larger amount of arenaceous sand and feldspathic material of the Pennsylvanian sections in the Los Pinos Mountains and east of Socorro in the Cerros de Amado, as compared with the slight amount of similar materials in the Lemitar Mountains section, also suggests that much of this coarser clastic sediment came southward from the Joyita positive area, whereas the large portion of the clay-sized sediments may have been derived from the east from the Pedernal landmass. The Socorro-Lemitar Mountains locality was probably near the southwest flank of the Lucero basin during most of Pennsylvanian time.

## COYOTE HILLS

The southern extension of the Socorro Mountains is called the Chupadera Mountains, although south of Nogal Canyon locally known as the Coyote Hills (sec. 56). It is a tilted horst, like the Socorro Mountains, with Neogene volcanic and sedimentary rocks uplifted above the Rio Grande graben and generally dipping to the west away from the complex graben. Near the south end of the range, Precambrian metamorphic and granitic rocks are exposed (fig. 14), overlain by limy reddish-brown arkose and massive crinoidal limestones of the Mississippian Caloso formation (correlative with the lower Lake Valley formation; Armstrong, 1958, p. 15). The Mississippian rocks cap several hills and are in fault contact with Tertiary volcanic rocks. To the south, whitish tuffs overlie Precambrian granite and granodiorite, and about a quarter of a mile farther south Pennsylvanian strata occur intruded by rhyolite.

The Pennsylvanian includes about 200 feet of thin-bedded fossiliferous limestones and much brown to black shale; the base of the section is below the valley floor, whereas the upper contact against banded and brecciated rhyolite is marked by silicified and mildly altered limestone. Poorly preserved fusulinids appear to be *Profusulinella* of early Derryan age. Erosion during early Tertiary time has differentially removed parts of the Carbonaceous sequence in the Coyote Hills area, so that possibly the entire Pennsylvanian section is preserved a few miles away in the Rio Grande graben or to the west beneath the Neogene volcanic rocks.

The pre-Tertiary rocks of the Coyote Hills were "found," geologically speaking, by Kenneth Rheim, examined by Roy W. Foster and the writer, and mapped on aerial photographs to determine the geologic relationships (fig. 14).

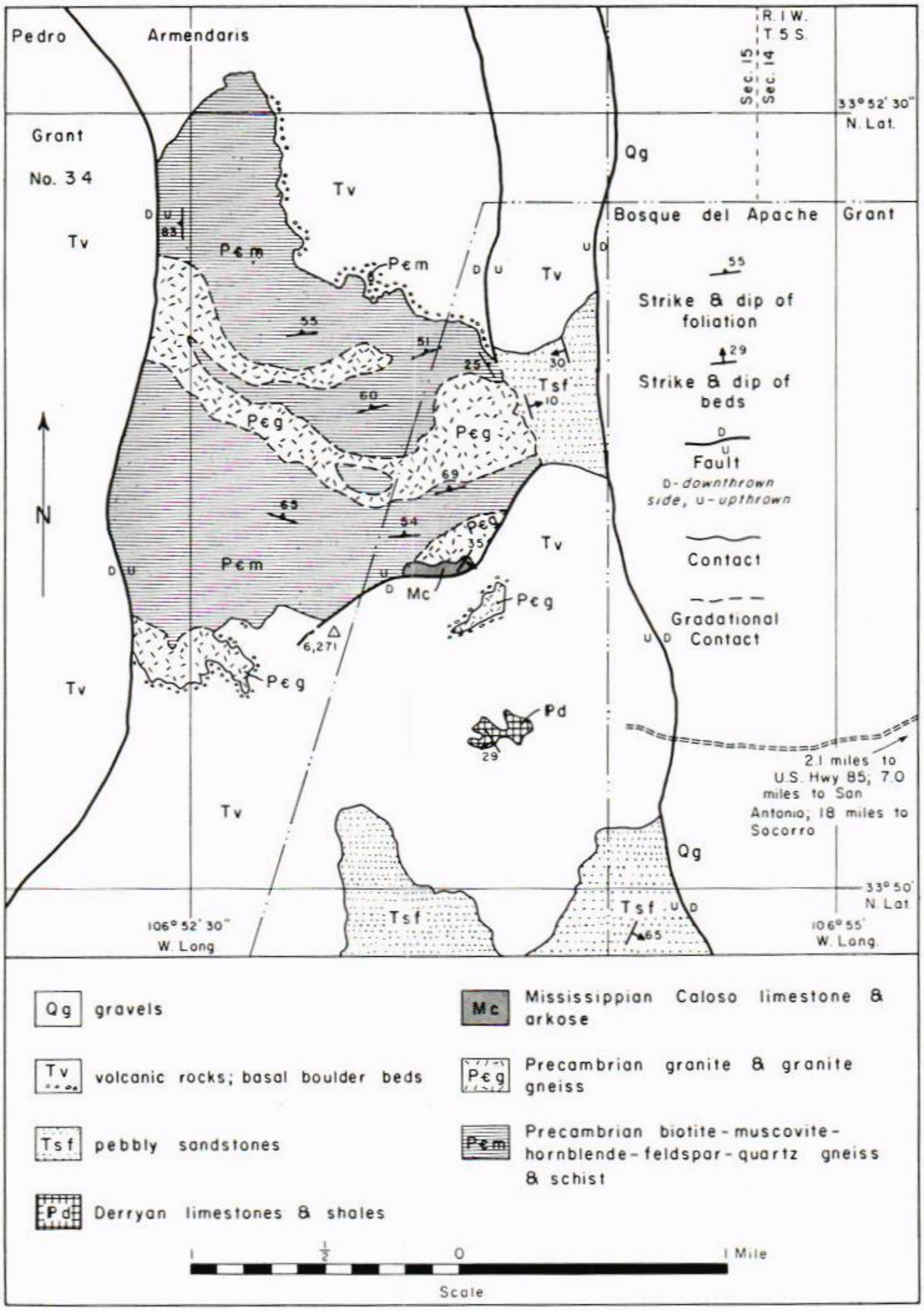


Figure 14

GEOLOGIC MAP OF COYOTE HILLS, SHOWING OUTCROPS OF PRECAMBRIAN, MISSISSIPPIAN, AND PENNSYLVANIAN ROCKS

On the northeast side of this Coyote Hills inlier of Precambrian rocks, the basal Tertiary is locally a tuffaceous cobble to boulder conglomerate. Blocks up to 2 feet in diameter, subrounded to angular, consist of Pennsylvanian limestone, coarsely crystalline crinoidal Mississippian limestone, and various types of Precambrian rocks. The limestone clasts typically have a 1-mm skin of ferruginous powdery chert; fossiliferous Pennsylvanian fragments contain numerous brachiopods *(Marginifera, Dictyocloslus, Composita, Neospirifer, Chonetes,* et al.), horn corals, and fusulinids. *Fusulinella, Fusulina,* and *Triticites* were identified from various limestone clasts, suggesting that the source rocks range from Derryan to tipper Pennsylvanian in age.

On the south side of the Precambrian inlier, Mississippian rocks in places overlie the Precambrian, and lower Pennsylvanian strata crop out (fig. 14). The basal Tertiary unit is locally a boulder conglomerate containing huge blocks of Precambrian, Mississippian, and Pennsylvanian rocks, some of which are remnants of broken beds measuring 10 by 4 by 2 to 5 feet. Such large relatively unbroken fragments could not have traveled far. Together with the existence of Mississippian and Pennsylvanian outcrops, this suggests that a thick Pennsylvanian sequence remains beneath the Tertiary rocks a short distance to the south and southwest.

### LITTLE SAN PASQUAL MOUNTAIN

About 23 miles south of Socorro (and 11 miles south-southeast of the Coyote Hills), on the east side of the Rio Grande Valley, is Little San Pasqual Mountain, a small horst about 4 miles long, tilted to the east-southeast and with a steep scarp overlooking the Rio Grande Valley to the west. Darton (1928, fig. 79B) considered the mountain to be an anticline composed of Permian rocks. Most of the outcrops, however, are of Pennsylvanian strata, which dip to the east and are lithologically similar to the Pennsylvanian in the Oscura Mountains. On the west side of the horst, the lower Pennsylvanian beds are drag folded along the west-bounding fault zone, so that they dip westward steeply to almost vertically, and are faulted against purplish Tertiary andesitic breccias. Upper Derryan, Desmoinesian, Missourian, and Virgilian beds are well exposed, but older strata are concealed beneath the drag folds. Scattered ledges of Abo red beds and of the Yeso and San Andres formations occur on the edge of the Jornada del Muerto to the east, overlying the Pennsylvanian; the Bursum formation appears to be covered by purplish soil between the highest Virgilian beds exposed and the Abo red beds. Probably more than 1,100 feet (sec. 59) of Pennsylvanian strata occurs in this area, although the lower part of the section is concealed and upper beds are poorly exposed on the eastward dip slope. The section differs from those to the north near Socorro in containing a larger percentage of limestone in the Desmoinesian and Missourian rocks but differs from the northern Oscura Mountains Pennsylvanian sequence in the thicker clastic facies at the base. Thickness, clastic ratio, and sand-shale ratio are, of course, only estimates based on incomplete data.

### FRA CRISTOBAL MOUNTAINS

For almost 20 miles south-southwest from Little San Pasqual Mountain to the Fra Cristobal Mountains, the east side of the Rio Grande Valley is a sand-covered slope with outcrops only of Cenozoic sediments and Recent basalt flows. The Fra Cristobal Mountains are another tilted horst on the east side of the complex Rio Grande graben. In the northern part of the range there is about 1,620 feet (sec. 62) of the Pennsylvanian strata. Above the Pennsylvanian is a transition zone of interbedded purplish limestones and shales, 15 to 20 feet thick, an upward gradation into typical Abo red beds. In the northern part of the Fra Cristobal Mountains, the basal Pennsylvanian beds are unconformable on Precambrian granites and gneisses but southward truncate successively younger formations, from the Cainbrian-Ordovician Bliss sandstone to the lower part of the Lower Ordovician El Paso group.

The Pennsylvanian rocks in the range have been subdivided by Dr. Eugene Cserna (1956) into three mapping units: (1) a basal shaly member, about 266 feet thick; (2) a medial cherty limestone member, about 1,087 feet thick; and (3) an upper shaly member, about 266 feet thick. The basal member is primarily greenish to brownish slightly calcareous shale with some interbeds of blackish shale and thin-bedded limestones. The medial member is of ledge- and cliff-forming cherty limestones, medium- to dark-gray, aphanitic to fossiliferous, with interbeds of greenish to black limy shale and nodular shaly limestone. The upper member consists of alternating gray to black shales, shaly limestone, thin to massive cherty limestones, and some thin-bedded crinoidal coquinas. The clastic ratio is about 0.77, although the lateral gradation from limy shale to shaly argillaceous limestone makes any estimate of the clastic ratio inaccurate. Almost no sandstones are reported from the Pennsylvanian of the northern Fra Cristobal Mountains; in the central part of the range, however, the lower part contains a few lenses of pebbly quartz sandstone, hematitic sandstone, and limy arenites, that grade laterally into arenaceous calcarenites.

### CABALLO MOUNTAINS

In the northern Caballo Mountains, 2 miles south of Palomas Gap, Kelley and Silver (1952, p. 253-256) measured 1,120 feet (sec. 70) of Pennsylvanian rocks, which they credited to the Magdalena group and subdivided into three stratigraphic formations that were not used in mapping. The basal unit was called the Red House formation, which is 362 feet thick on South Ridge and consists dominantly of thin-bedded limestone and shale containing limestone nodules and lenses. Thin sandstone beds occur locally near the base of the Red House formation, as well as limestone-pebble conglomerate and arenaceous calcarenite.

The formation varies in thickness because of deposition on an erosional surface of considerable regional relief, the basal beds resting on strata ranging from Lower Mississippian to Middle Ordovician in age.

The medial unit in the Caballo Mountains was called the Nakaye formation, which is 419 feet thick on South Ridge. The formation consists dominantly of thick to massive ledges of cherty limestone. The upper unit is the Bar B formation, 339 feet thick at its type section, which consists of thin-bedded limestone and shale. Uppermost beds are of intercalated reddish-brown siltstone, limestone-pebble conglomerate, medium-bedded limestone, and calcareous sandstone, transitional beds grading upward into the Abo red beds. No fossils are reported from these upper beds; so the location of the Pennsylvanian-Permian boundary is not recorded.

The type localities of Thompson's formations (1942, p. 26-55) of Derryan and Desmoinesian age (Middle Pennsylvanian) are in the Derry Hills, a southwestern detached block of the Caballo Mountains, and in the Mud Springs Mountains, which are a few miles northwest of the Caballo Mountains. The formations of the Derry series can be recognized by lithology in the Caballo Mountains, but the Desmoinesian units thin and become less clastic from the Mud Springs Mountains southeastward to the Palomas Gap area. The section in the northern Caballo Mountains is made up of rocks similar to those in the Fra Cristobal Mountains, although the recorded measured section is thinner and there is a smaller amount of shale. Only a few sandstone and conglomeratic beds occur, and these are in the lower part of the Pennsylvanian. The clastic ratio is about 0.45, and the sand-shale ratio is 0.05. The amount of argillaceous material in the Pennsylvanian strata of the Caballo Mountains has been considerably overestimated. The Nakaye formation, for example, has a clastic ratio of 0.11, not 0.25, and the Bar B formation has a clastic ratio of 0.48 instead of 4.

The Pennsylvanian sequence is reported to thicken to about 1,700 feet (Kelley and Silver, 1952, p. 91) in the Caballo Mountains southward from Palomas Gap but in the southern area is involved in overturned folding, thrust faulting, and normal faulting, so that a complete section is difficult to piece together. About 20 miles south-southeast of the southern Caballo Mountains, in the Robledo Mountains, the Upper Pennsylvanian carbonate sequence appears to grade upward into a thick Lower Permian carbonate sequence, mapped as the Bursum and Hueco formations by the writer, and it may be that the reported thick section of the Magdalena group in the southern Caballo Mountains includes in its upper part some non-red-bed strata of Lower Permian age.

### DERRY HILLS

The type section of the Derry series is in the Derry Hills, about a mile east of the small village of Derry. At the type locality, the series is about 130 feet thick (Thompson, 1942, p. 28) but thickens to the north to 225 feet in the Mud Springs Mountains. Basal beds of the Derry series were named the Arrey formation by Thompson (1942, p. 35-36). Although the fusulinid fauna of the formation consists principally of *Millerella,* it is considered to be in the lower part of the Zone of *Profusulinella* (Thompson and Kottlowski, 1955, p. 75). The lower group of the Derry series, the Green Canyon group, consists of rocks containing fusulinids of the Zone of *Prof usulinella.* The upper part of the Derry series is referred to the Mud Springs group, which includes the Zone of *Fusulinella.* As thus defined, the Derry series is almost the exact equivalent of the Atoka series (Thompson, 1948, p. 68). The Lampasas series, however, includes in addition strata equivalent in fusulinid faunas to the lower half of the type section of the Des Moines series.

In most of southwestern New Mexico and southeastern Arizona, the basal Pennsylvanian strata are of Derryan age. Beds containing only species of *Millerella* are not per se of pre-Derryan-Morrowan age, but if overlain by strata that contain primitive *Prof usulinella,* such as *P. copiosa,* they are of probable Morrowan age. Basal Pennsylvanian beds in the central Franklin Mountains, Sacramento Mountains, and the Hueco Mountains in El Paso County, Texas, appear to be of Morrowan age and are beneath faunal equivalents of the Arrey formation.

**MUD SPRINGS MOUNTAINS**

The Mud Springs Mountains are a small fault-block range on the west side of the Rio Grande Valley northwest of Truth or Consequences (formerly Hot Springs). They contain about 1,705 feet of Pennsylvanian rocks as measured (sec. 66) by Dr. M. L. Thompson (Gehrig, 1958) along Whiskey Canyon. Derryan beds are about 225 feet thick and are chiefly marine limestones, cherty in part, with interbeds of shale and conglomeratic sandstone. Strata of the Desmoinesian series are about 700 feet thick and consist of highly cherty limestones with thin beds of nodular shaly limestone, gray and red shales, and some arkosic sandstones. Rocks of Missourian age are about 320 feet thick and are chiefly cherty algal limestones below and interbedded limestones and shales above. The Virgilian beds are about 460 feet thick and are of massive to nodular limestones with interbeds of reddish, greenish, and gray shales and arkosic sandstone.

Between the upper Pennsylvanian strata and Abo red beds, there is about 62 feet of alternating and intercalated nodular, purplish to gray, fossiliferous limestone and purplish-red shale, which may be equivalent to the early Wolfcampian Bursum formation. The elastic ratio for the Whiskey Canyon section in the northern Mud Springs Mountains is 0.51, very close to that of the thinner section in the northern Caballo Mountains. Clastic ratios for the series are: Derryan, 0.42; Desmoinesian, 0.27; Missourian, 0.39; and Virgilian, 1.41. The sand-shale ratio for the entire section is only 0.07.

### OIL TESTS NEAR TRUTH OR CONSEQUENCES

Two oil tests drilled in the Rio Grande trough north of Truth or Consequences encountered Pennsylvanian rocks, and an oil test drilled on a transverse anticline on the east *edge* of the Caballo Mountains went through considerable thicknesses of the Pennsylvanian beds. As interpreted by Foster (Kottlowski et al., 1956, p. 79-81), the Gartland No. 1 Brister oil test (sec. 8, T. 12 S., R. 4 W.), drilled near the west edge of the Rio Grande Valley, penetrated Pennsylvanian rocks below the Abo red beds at a depth of 6,605 feet and went through 1,980 feet of faulted Pennsylvanian limestones and blackish shales, Precambrian granite, and fault gouge. The Summit No. IA Mims well (sec. 2, T. 13 S., R. 4 W.), drilled in the Rio Grande graben north of Truth or Consequences, encountered Pennsylvanian rocks beneath Abo red beds at a depth of 5,645 feet and bottomed after penetrating 550 feet of upper Pennsylvanian strata. The Carr No. 1 Gentry State test well (sec. 32, T. 15 S., R. 3 W.), drilled on the Putnam anticline on the east edge of the Caballo Mountains, penetrated numerous sections of Pennsylvanian rocks and pre-Pennsylvanian strata, apparently being drilled into a faulted overturned block such as those exposed in the Caballo Mountains.

## MEXICAN HIGH LAND SECTION OF BASIN AND RANGE PROVINCE

The southwestern corner of of New Mexico, south of the Mogollon volcanic plateau and west of the Sacramento Mountains, is typical basin-and-range country, with northward or northwestward elongated mountain ranges rising above the surrounding bolson plains. The physiographic section extends westward into southeastern Arizona and grades eastward into the Sacramento section in the Tularosa Valley. Many of the ranges are composed almost entirely of Neogene volcanic rocks, and the intervening graben bolsons contain thick sequences of relatively unconsolidated Cenozoic sediments, as well as volcanic rocks. In places, a fairly complete section from Cambrian to Permian occurs; in other areas, Cretaceous rocks rest on Precambrian granites.

### FLORIDA MOUNTAINS

Southwest of the Caballo Mountains and south of Cooks Peak in the Florida Mountains (sec. 90), the Wolfcampian Hueco formation is reported by Bogart (1953, p. 27) to overlie Mississippian beds, with no Pennsylvanian strata present. The contact between the Mississippian (Lake Valley formation?) and the Hueco limestone is poorly exposed. Locally, it is a silicified, brecciated thrust-fault zone with the thin-bedded cherty Mississippian limestones crumpled into folds of the small sled-runner type; in other places, the contact is in a narrow covered zone, on either side of which the Mississippian and Permian beds have discordant dips. Outcrops scattered throughout this 20-foot-thick partly covered slope are: (1) basal black bioclastic limestone with some fragments and small lenses of chert-limestone-granule conglomerate, clasts angular to subrounded; (2) black fossiliferous limestone beds, 6 to 12 inches thick, separated by purplish fossiliferous shale laminae; and (3) upper lenses of light-brown limy crosslaminated silty sandstone and pinkish-purple limy fossiliferous sandstone. Above are the thick-bedded Clark-gray fossiliferous limestones typical of the Hueco. The contact between the lower clastic Hueco beds and the Mississippian is relatively conformable, but locally 10 to 20 feet of relief occurs on top of the Mississippian.

These relationships could have been obtained by uplift and slight erosion during late Pennsylvanian-early Permian time, with the deposition and removal of a considerable thickness of early and middle Pennsylvanian sediments, or by the existence during most of Pennsylvanian time of a low landmass in the general vicinity of the Florida Mountains. In the Cooks Peak area to the north, Pennsylvanian strata are dominantly clastic limestones, are thin, and apparently represent deposits of only Desmoinesian and lower Missourian age. In the Santa Rita area to the northwest, in the Robledo Mountains to the northeast, and in the Tres Hermanas Mountains to the southwest, the Pennsylvanian sequence is relatively thin (635 to 820 feet), but is chiefly marine limestone and shale, except for sandstones in the Tres Hermanas Mountains. This suggests either a low landmass in the Florida Mountains area, or scattered islands amid shallow seas over the entire triangular area from the Tres Hermanas Mountains northwest to Santa Rita and northeast to the Robledo Mountains (Kottlowski, 1958).

## TRES HERMANAS MOUNTAINS

In the Tres Hermanas Mountains, Bogart (1953, p. 63) measured 636 feet (sec. 92) of beds believed to be of Pennsylvanian age; locally they apparently grade upward into the Hueco formation and appear disconformable on cherty Mississippian marble. Brachiopods typical of the Missourian series in the midcontinent area were found. The lower half of the Pennsylvanian sequence is thick-bedded siliceous limestone, dolomitic in part, with some beds metamorphosed to marble; there are also thick interbeds of fine-grained greenish to brownish crosslaminated quartzite (or silicified siliceous limestone), and much bedded and nodular chert. The upper beds are of thin-bedded limestone intercalated with thin chert beds, both medium- to dark-gray in color, and with shale lenses and partings throughout the sequence. The clastic ratio is 0.28, and the sand-shale ratio is 2.7(?). As the only fossils reported are perhaps of Missourian age, the section may contain only beds of Upper Pennsylvanian age, although the sedimentary rocks are in places much metamorphosed.

In the area where Bogart (1953) measured his section, the basal Hueco rocks are algal limestones with lenses of limestone-pebble conglomerate. Traced laterally, these algal beds grade into lenticular units of brown, reddish-brown, and greenish chert-pebble conglomerates, with the pebbles chiefly angular. Above are brownish-gray sandstones and siltstones with interbeds of dark-gray limestone; these strata grade up into the blackish, blue-gray-weathering fossiliferous limestones typical of the Hueco. The basal clastic unit of the Hueco is unconformable on the underlying Pennsylvanian strata.

The Pennsylvanian includes much more shale-hornfels and interbedded sandstone than the Permian Hueco, and the faunas of the two sequences are different. The Hueco contains mainly gastropods, ranging from large *Euomphalus* to tiny high-spired ones, large fusulinids, a few scattered pelecypods and brachiopods, and minor lenses of crinoidal calcarenite. The Pennsylvanian, in contrast, has many beds of crinoidal columnal "sand," and a fauna of horn corals, long irregular corals, small fusulinids (recrystallized), and brachiopods *(Derbyia, Co7nposita, Marginif era, Crurithyris, Dictyoclostus, Linoproductus, et al.).*

**VICTORIO MOUNTAINS**

In the Vittorio Mountains, northwest of the Tres Hermanas Mountains, Lower Cretaceous clastic rocks and fossiliferous limestones unconformably overlie the Ordovician Montoya dolomite (pl. 13), and in the subsurface of the surrounding area probably rest northwestward on the El Paso limestone and Bliss sandstone, and southwestward on the Silurian Fussclman dolomite. This is an extension of relationships west of Silver City, where erosion during early Mesozoic time removed the Pennsylvanian and part of the pre-Pennsylvanian strata.

Basal conglomerates of the Lower Cretaceous beds contain clasts chiefly of silicified Silurian and Ordovician dolomites and limestones, as well as much quartz and chert, but some fragments of Mississippian and Pennsylvanian limestones, altered andesite, and Precambrian black quartz-mica schist and pegmatite are also present. Local lenses of volcanic conglomerate and sandstone, and of green lithic andesite tuff, occur near the base of the Cretaceous strata, suggesting nearby eruption of volcanic rocks in early Cretaceous time. These Cretaceous beds were referred to the Gym limestone by Darton (1928, p. 340); as pointed out, however, by Bogart (1953, p. 2), they are merely part of the many units locally erroneously placed in the Gym by Darton. The Permian fauna collected by Darton from this Cretaceous sequence, and identified by H. Girty, probably came from boulders in the basal conglomerates; poorly preserved molluscs from fossiliferous limestones near the center of the sequence are of early Cretaceous age, according to Dr. Rousseau
A. Flower, New Mexico Bureau of Mines paleontologist (personal communication).

Erosionally unconformable on the Lower Cretaceous beds, which are 600 to 800 feet thick, is about 2,000 feet of Tertiary andesitic volcanic and sedimentary rocks (pl. 13). Amid the agglomerates, conglomerates, and red to purplish sandstones of the lower one-third of the Tertiary sequence are rounded to angular pebbles and boulders of silicified Paleozoic, Cretaceous, and Precambrian rocks, which appear to be either reworked from the Cretaceous conglomerates or eroded from upper parts of the Cretaceous strata. Deep erosion and truncation of Paleozoic beds appear to have been mainly in early and middle Mesozoic time, the Tertiary rocks in most places having been deposited on the Cretaceous strata.

In the Klondike Hills, only 10 miles south of the Victorio Mountains, a thick Mississippian unit and remnants of the Pennsylvanian (and Permian?) sequence crop out on the low hills. The Victorio Mountains and Klondike Hills appear to be near the southeastern limit of the area exposed to erosion during early Mesozoic time, shown on Plate 4 as the large sole-shaped mass projecting northwestward from Luna County.

## BIG HATCHET MOUNTAINS

In the extreme southwest corner of New Mexico, Pennsylvanian beds crop out in the Big Hatchet Mountains, Sierra Rica, eastern and northern Animas Mountains, and in the central Peloncillo Mountains. These exposures are all in areas of complicated structure, where there has been much thrust faulting, normal block faulting, and intrusion by Cretaceous and Tertiary igneous rocks. The Pennsylvanian section (sec. 96) in the Big Hatchet Mountains has been mapped and studied in detail by Zeller (1958), whose fusulinid collections have been identified by John W. Skinner and Garner L. Wilde, Humble Oil & Refining Co.

The Pennsylvanian rocks disconformably overlie Upper Mississippian strata, the Paradise formation, and grade without notable break tip into Wolfcampian limestones. Zeller (pl. 7) listed four generalized lithic units, in ascending order: (1) 360 feet of dark-gray oolitic medium-to thin-bedded limestone, with some basal siltstone interbeds; (2) 190 feet of aphanitic limestone alternating with crinoidal limestone; (3) 780 feet of cherty medium-to thin-bedded crinoidal limestones, with a few beds of shale; and (4) 1,120 feet of partly dolomitized light-gray aphanitic to finely crystalline massive limestone, with some thin-bedded limestone. The uppermost lithic unit continues for another 100 feet but contains Wolfcampian fusulinids. Somewhat similar massive limestones occur for yet another 700 feet before the lower Permian beds become more clastic. Biohermallike structures occur in the upper beds (fig. 15). The entire carbonate-rock sequence is called the Horquilla limestone by Zeller and is similar, although much thicker and less clastic, to that of the Pennsylvanian and lower Permian in the Robledo Mountains, where the lower carbonate facies is about 1,765 feet thick below a tongue of Abo-like red beds that occur in the upper part of the Hueco formation.

The clastic ratio is reported by Zeller to be about 0.04, and the sand-shale ratio almost 0, the only noncarbonate clastic beds being siltstones

Figure 15

REEFLIKE VIRGILIAN AND WOLFCAMPIAN LIMESTONES CAPPING BIG HATCHET PEAK

near the base of the Pennsylvanian and some shale beds near the middle of the Desmoinesian. Thinsection and polished-section studies of the limestones by Zeller suggest that most of the carbonate rocks are of clastic origin, being composed of oolites, crinoidal fragments, and other broken fossil shells. The massive upper beds appear to be biohermal to biostromal reefs, which are replaced irregularly by masses of dolomite.

Zonation of the section, as based on the fusulinid studies of Skinner and Wilde, indicates the following maximum thicknesses of series, in ascending order: (1) Morrowan or Derryan, 250 feet; (2) Derryan, 435 feet; (3) Desmoinesian, 960 feet; (4) Missourian, 455 feet; and (5) VII- gilian, 350 feet.

The uniqueness of the upper Pennsylvanian and lower Permian sections in the Big Hatchet Mountains on the west side of the Florida landmass or islands, and in the Robledo Mountains on the east side of that postulated positive area, should be emphasized (pl. 10, 12). Whereas in many localities in southeastern Arizona and southwestern New Mexico there appears to be no significant break in sedimentation from late Pennsylvanian to early Permian time, the contact between rocks of the two periods is found within a relatively clastic sequence. As has often been stated, the clastic sediments are the result of erosion of widespread, if erratic, uplift at the end of the Pennsylvanian period. In the Big Hatchet and Robledo Mountains, however, this time surface between the two periods is an as yet indistinguishable plane within a monotonous limestone sequence.

This raises the problem of nomenclature: What should one call the Pennsylvanian—Permian carbonate rock sequence? The limestones can be referred, of course, to the Magdalena group, which in places has been used to include strata from Mississippian into lower Permian; or to the Naco group, which, as defined by Gilluly et al. (1954), encompasses strata of the entire Pennsylvanian and Permian age. No previously defined formational terms, however, fit the unit. The Madera limestone is much more restricted, even by its users, and the Horquilla formation of southeastern Arizona is limited, at its type locality, to Pennsylvanian strata and does not include uppermost beds of the Pennsylvanian. Gillerman (1958) and Zeller (1958), however, included this Pennsylvanian—lower Permian limestone sequence in the Horquilla limestone/formation for southwesternmost New Mexico (pl. 9). The upper limestones of the Horquilla in New Mexico are therefore correlative with the interbedded red beds and limestone of the Earp formation of southeastern Arizona, as well as with the Bursum and lower part of the Hueco of south-central New Mexico.

Pennsylvanian rocks in the northwestern Sierra Rica and northern and eastern Animas Mountains occur as parts of thrust plates, so that no complete section is exposed, although the rocks appear similar to those of the Big Hatchet Mountains and Peloncillo Mountains sections.

### PELONCILLO MOUNTAINS

Pre-Tertiary strata crop out in the central Peloncillo Mountains in scattered fault-block slices for distances of 6 miles north and 3 miles south of Granite Gap, which is traversed by U. S. Highway 80 (Gillerman, 1958, pl. 1). The beds are cut by numerous faults and intruded by many dikes and sills; the many breccia "beds," in most places wedged-shaped lenses, hint of the multiplicity of obscure faults. The geology has been mapped by Gillerman (1958) and Quaide (1953), Quaide's sections having been checked by Professor Donald L. Bryant, University of Arizona; the result is several versions of the Pennsylvanian and Permian stratigraphy. A complete Pennsylvanian section is probably not exposed, because of the extensive faulting.

Quaide's sections were measured across East Ridge (Blue Mountain of Gillerman, 1958, pl. 1) and included equivalents of formations assigned by Gilluly et al. (1954) to the lower part of the Naco group, the Horquilla formation, Earp formation, and Colina limestone. The measured thickness of the Horquilla formation, compensating for several faults and a sill, is about 1,580 feet; Derryan, Desmoinesian, and Missourian fusulinids were identified from limestone beds. The basal fetid cherty limestones of the Horquilla formation rest with apparent conformity on the Upper Mississippian Paradise formation. The Earp formation is conformable on the Horquilla and is about 1,025 feet thick, containing Virgilian fusulinids in the lower 300 feet and poorly preserved Wolfcampian *Triticites?* in the upper 35 feet.

Although the Pennsylvanian strata may be as much as 2,550 feet thick, comparison with the Portal and Dunn Spring Mountain sections of the Pennsylvanian in the Chiricahua Mountains of Arizona (Sabins, 1957), to the west, suggests that about 1,900 feet of the Peloncillo Mountains section is correlative to the Pennsylvanian beds to the west. The beds are chiefly cherty limestones, with a sequence of interbedded greenish shales and thin-bedded limestones near the top of the Derryan, and with much interbedded limy shale at the top (basal Earp formation) in the Virgilian. The clastic ratio is about 0.14, almost an average of the 0.21 from the Dunn Spring Mountain section to the west and of the 0.04 from the Big Hatchet Mountains section to the southeast.

Gillerman (1958, p. 31-35) noted that nowhere in the area was a complete section of the Horquilla limestone observed, although his map and cross-sections show an almost complete section, about 1,400 to 1,800 feet thick, on Blue Mountain. Based on scattered measured sections, he estimated the thickness of the Horquilla limestone as 1,350 to 1,500 feet. Fusulinids collected from the Horquilla limestone (or limestones of the Earp formation) suggest an age range from Derryan to early Wolfcampian, but occur in partial sections broken by faults and interrupted by many sills. For example: Near the Silver Hill mine (Gillerman, 1958, p. 119-121, section MS 8), the basal 400 to 500(?) feet of the Horquilla limestone is concealed by faulting, Desinoinesian fusulinids were found 85 to 163 feet above the base of the measured section, and then no fusulinids were reported in 490 feet of limestone, above which is a 300foot-thick quartz monzonite sill; near the sill the limestones are marbleized and silicified; above the sill (which actually cuts across the limestone beds), in beds similar to some limestones of the Earp formation, early Wolfcampian fusulinids were collected. The 831 feet of Gillerman's measured section of the Earp formation (MS 9) conformably overlies the Horquilla limestone of this section (MS 8), and scattered throughout are the same (or similar) species of fusulinids as occur in the limestones above the sill. As Gillerman noted (1958, p. 32), "an unknown thickness of strata may have been faulted out within the upper part [of section MS 8] along a quartz monzonite porphyry sill."

About 17 miles to the west, in the Chiricahua Mountains, Sabins (1957) measured 2,710 feet of the Earp formation; more than 50 miles to the southeast, in the Big Hatchet Mountains, Zeller (1958) found about 1,000 feet of interbedded limy and clastic rocks that he referred to the Earp formation. Gillerman's map and cross-sections indicated a thickness of 800 to 1,400 feet for the Earp; the limestones above the Silver Hill mine sill, containing Wolfcampian fusulinids, might have been placed in the Earp formation if a complete, unfaulted, and unmetamorphosed section of the Horquilla and Earp formations were exposed.

North of Cienega Peak, Gillerman (1958, section MS 7, p. 118-118, and p. 34) collected Virgilian fusulinids from the upper beds of the Horquilla formation, and 80 feet above (across a poorly exposed sequence), early Wolfcampian *Schwagerina*. He noted that the Permian forms occur in beds that may belong to the Earp formation.

The Pennsylvanian—Permian boundary in this area is amid the interbedded elastic rocks and limestones of the Earp formation to the west (where the lower Earp is of Virgilian age), and within the massive limestones of the upper Horquilla formation to the southeast (where the upper Horquilla is of Wolfcampian age). The central Peloncillo Mountains appear to be near, if somewhat to the west of, the district where the Virgilian—Wolfcampian boundary occurs near the gradational contact of the Horquilla limestone and overlying Earp formation.

### HUMBLE No. 1BA STATE

About a score of oil tests have been drilled more than a 1,000 feet deep in southwestern New Mexico west of the Rio Grande and south of Silver City. Only 6 of these tests have gone more than 3,000 feet, the deepest well, prior to 1958, bottoming at 6,171 feet. The Humble Oil & Refining Co. No. 1AB State, drilled in 1958 (sec. 99), bottomed at 14,585 feet in the Ordovician El Paso limestone. Almost all of the wells were drilled into areas underlain by thick Cenozoic bolson deposits, where geologic control from outcrops is poor. Some of the wildcat tests are reported to have penetrated as deep as Permian beds, but only the Hachita Dome Inc. No. 1 Federal test (northeast of the Big Hatchet Mountains) and the Humble test encountered pre-Permian strata.

The Humble No. I BA State oil test was drilled on a surface anticline (outcrops of Cretaceous rocks) and was reported to have reached the top of the Horquilla limestone at about a 7,000-foot depth. In the upper Wolfcampian part of the Horquilla are considerable thicknesses of black silty shales and fine-grained sandstones. The top of the Pennsylvanian, based on fusulinids, was picked at 9,330 feet deep; the base, at the top of the Mississippian Escabrosa limestone, was at a depth of 11,430 to 11,520 feet. The Paradise formation, of late Mississippian age, is about 300 feet thick in the nearby Big Hatchet Mountains but appears to be absent in samples from the test. This absence of the Paradise formation, in addition to anomalous thicknesses of some of the Pennsylvanian fusulinid zones (as compared to nearby outcrops), suggests that some faults were crossed. Without compensating for dips, the Pennsylvanian encountered is about 2,190 feet thick and is chiefly gray to dark-gray, disappointingly dense limestone. The only shows of oil and gas were reported from the Permian.

### ROBLEDO MOUNTAINS

East of the Florida Mountains, volcanic rocks and some patches of Cretaceous strata make tip the pre-Quaternary outcrops eastward to the Rio Grande Valley. On the west side of the river, northwest of Las Cruces, a well-exposed section (sec. 83) of Pennsylvanian beds occurs in the Robledo Mountains, a wedge-shaped southward dipping fault block. The Pennsylvanian section (fig. 16) is thin compared to sections to the north, east, and south, being only about 670 feet thick. Derryan beds at the base are only 12 to 17 feet thick, consisting of blackish silty limestones and greenish-gray shales, but they overlie a thick Tertiary rhyolite sill that has assimilated part of the Paleozoic section, so that these basal beds may be only remnants of a thicker Derryan sequence. The sill, which averages 450 feet in thickness, has assimilated part of the underlying beds and rests on variable thicknesses of Devonian shales or shaly Lower Mississippian marls.

Beds containing Desmoinesian fusulinids are about 235 feet thick and consist chiefly of massive cherty limestones interbedded with nodular shaly limestones. Interbeds of limy shale and greenish-black calcareous sandstone occur in the basal 60 feet. Strata in the Zone of Missourian fusulinids are about 215 feet thick and arc dominantly nodular slope-forming limestones, and gray to purplish limy shales with several intercalated thick-bedded ledge-forming limestones. The basal 25 feet of shaly limestone and limy shale is reddish brown and purplish to gray; it thickens and thins along the outcrop, although never more than a few degrees disconformable on the eroded surface of underlying massive cherty limestones.

Virgilian beds are about 215 feet thick and consist of medial massive noncherty limestone cliffs underlain by limy shale and nodular limestone and overlain by intercalated massive noncherty limestone and nodular thin-bedded limestone. Overlying early Wolfcampian beds attributed to the Bursum formation by Thompson (1948, p. 23) are similar to upper Virgilian rocks but include some lenses of reddish-brown shale. Fusulinids from the uppermost part of the Virgilian on Robledo Mountain are believed by Thompson (1942, p. 74) to represent a zone that is in the very youngest stratigraphic part of the Virgilian in North America. The apparent gradation from these uppermost Virgilian strata into the overlying early Wolfcampian limestones and shales is, therefore, no surprise. The clastic ratio is 0.21, and the sand-shale ratio about 0.06, for the composite Pennsylvanian section. The Derryan series is very thin, and parts must be absent; a more or less complete faunal range appears to be present, however, in the three younger series, although the entire section is thinner than most Pennsylvanian sections in southwestern New Mexico.

### BISHOP CAP

East of the Robledo Mountains, Pennsylvanian strata crop out in the Organ Mountains but in most places are poorly exposed, broken by faults, and locally metamorphosed by the Organ Mountains Tertiary monzonite batholith. Just south of the Organ Mountains, the Penn-

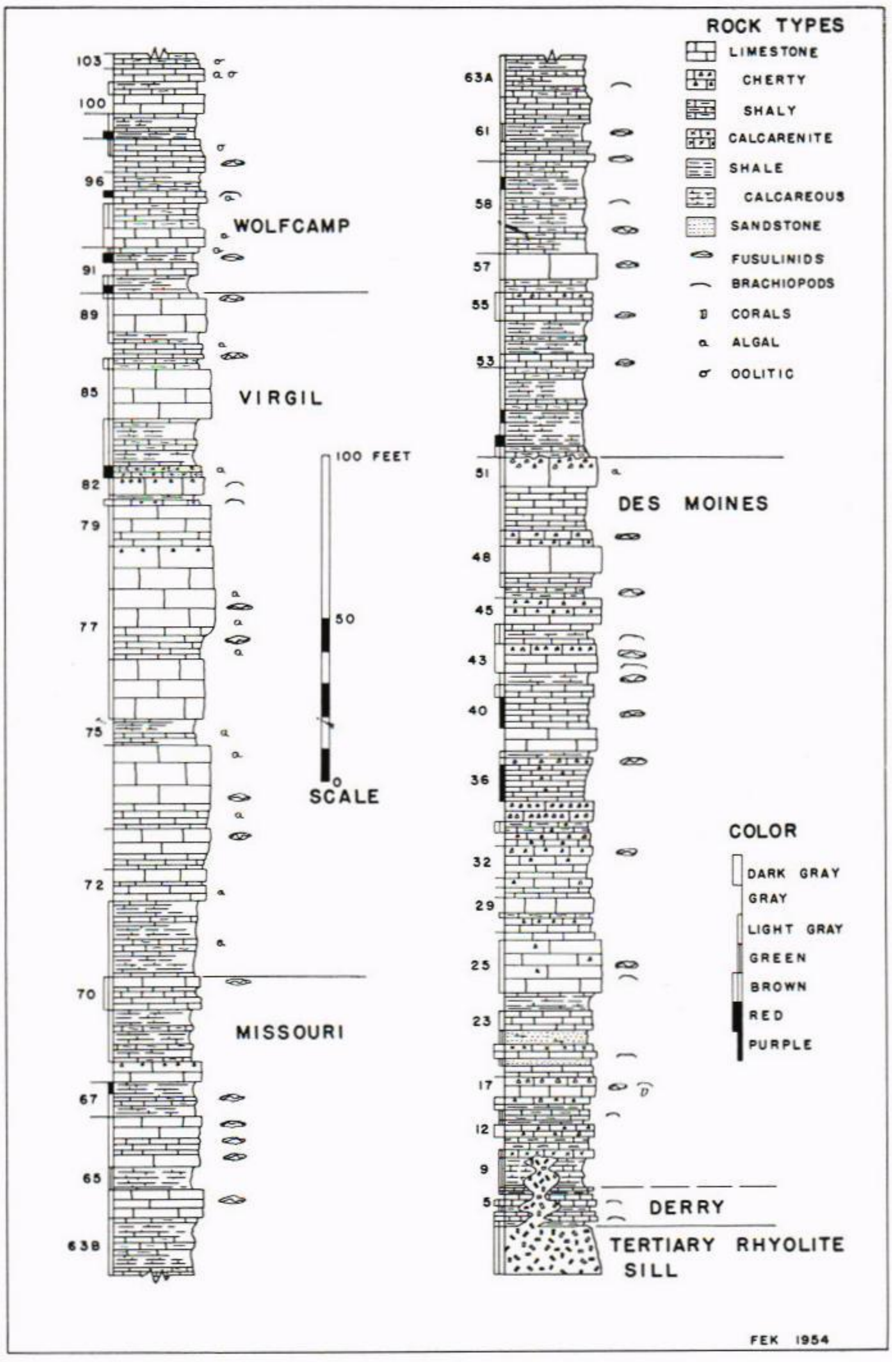


Figure 16
COLUMNAR SECTION OF PENNSYLVANIAN ROCKS IN ROBLEDO MOUNTAINS

sylvanian rocks occur on Bishop Cap, a broken fault-block range. Only the lower part of the Pennsylvanian section (sec. 87) is present, upper beds having been removed by Recent erosion, but in the southern Organ Mountains, in scattered blocks, the thick shaly Virgilian sequence is overlain by the massive limestones of the Wolfcampian Hueco formation.

FRANKLIN MOUNTAINS

South of Bishop Cap, in the northern and west-central Franklin Mountains, Pennsylvanian rocks form the steeply dipping westernmost strata of the westward tilted fault-block range, and Permian Hueco limestones crop out in low western foothills. Near Vinton Canyon (sec. 93), only the lower 1,535 feet of the Pennsylvanian is exposed, the upper beds being concealed by alluvium. In a small synclinal U-shaped ridge west of the range, just north of the New Mexico—Texas Stateline and west of Anthony Gap, uppermost Virgilian beds occur overlain apparently conformably by the Hueco formation. These upper Pennsylvanian strata (fig. 17) are lithically similar to the Panther Seep formation as mapped in the San Andres Mountains to the north. A gypsum bed, at apparently the horizon of the upper gypsum bed of the Panther Seep formation near the Love ranch (sec. 79), has been quarried by the Southwest Portland Cement Co. near Anthony Gap. Gypsum at apparently the same stratigraphic horizon was encountered in the Ernest No.

Figure 17

SILTY, CARBONACEOUS, THINLY LAMINATED CALCILUT1TES OF PANTHER SEEP FORMATION, NORTHERN FRANKLIN MOUNTAINS

I Located Land Co. oil test (sec. 89) near Newman, in the Hueco Basin, 17 miles to the east-southeast.

Thompson (Thompson and Kottlowski, 1955, p. 72) identified Morrowan(?) and Derryan fusulinids from the basal 800 feet of the northern Franklin Mountains Pennsylvanian section, near and south of Vinton Canyon, and Desmoinesian fusulinids from the upper part (600-735 feet) of Nelson's (1940) Vinton Canyon section. Stewart (1958) described upper Strawn (Desmoinesian) fusulinids from Nelson's units 98 and 118 (upper Berino and lower Bishop Cap members). Harbour (1958, p. 1728) pieced together the beds concealed by alluvium above the Vinton Canyon section, and reported about 1,200 feet of possible upper Pennsylvanian consisting of siltstone and lesser amounts of shale, limestone, gypsum, and conglomerate. Harbour did not report any diagnostic fossils from this clastic-rock *sequence* but noted that it is overlain conformably by 2,200 feet of limestones lithically similar to the Hueco formation.

The lower 1,500 to 1,600 feet of the Pennsylvanian was divided by Nelson (1940) into, in ascending order, the La Tuna, Berino, and Bishop Cap members of the Magdalena formation. The La Tuna member is about 360 feet thick, consists of massive cherty limestone with some thin-bedded fossiliferous shaly limestone near the top, and rests unconformably on the Upper Mississippian Helms formation; it grades up into the Berino member. The latter member is 545 feet thick and consists of thin-bedded finely crystalline gray to blackish limestone, cherty in lower beds and capped by fossiliferous limy shale and argillaceous limestone. The upper exposed part of the Pennsylvanian at Vinton Canyon is called the Bishop Cap member, 630 feet thick, and is composed of coarsely to finely crystalline limestone with some interbeds of limy shale, fine-grained sandstone, limestone-pebble conglomerate, and near the top, chert-pebble conglomerate. These conglomerates may be the beds Harbour (1958) reported as persistent markers at the base of his upper Pennsylvanian silty unit.

## SAN ANDRES MOUNTAINS

North of the Organ Mountains, the San Andres Mountains, a westward tilted fault-block range, provide a continuous exposure of Pennsylvanian rocks for a distance of 85 miles to the southern end of the Oscura Mountains at Mockingbird Gap. Four of the best exposed sections in the range (fig. 23), in Ash Canyon, Hembrillo Canyon, Rhodes Canyon, and near Mockingbird Gap, south to north, have been studied in some detail by Kottlowski, Flower, Thompson, and Foster (1956). The Pennsylvanian beds thicken southward from 1,930 feet near Mockingbird Gap (sec. 61) and 2,500 feet in Rhodes Canyon (sec. 67) to 3,035 feet at Hembrillo Canyon (sec. 71), and then thin to 2,825 feet near Ash Canyon (sec. 79).

Virgilian beds, assigned to the Panther Seep formation, thicken southward in the range, being 825 feet thick at Mockingbird Gap, 1,460 feet thick in Rhodes Canyon, 1,825 feet thick at Hembrillo Canyon, and 2,390 feet near Ash Canyon. Strata bearing Derryan to Missourian fusulinids range from 1,050 to 1,210 feet in thickness at the three northern sections but are only 435 feet thick near Ash Canyon, comparable with a correlative thickness of 465 feet on Robledo Mountain and contrasted to more than 1,700 feet of pre-Virgilian strata to the south.

Basal Derryan beds in the San Andres Mountains unconformably overlie the Lower Mississippian Lake Valley limestone, except at the south end of the range, where the underlying beds are the Middle Mississippian Rancheria formation, and at the extreme north end in Mockingbird Gap, where basal sandstones were deposited on Devonian strata (fig. 23). The Pennsylvanian beds were deposited on a pronounced erosional surface, which in places cuts almost through the entire Mississippian section, the channel fills being chiefly of chert-pebble conglomerates.

Derryan beds (fig. 18) near Mockingbird Gap are about 215 feet thick. The lower beds consist of conglomeratic limy sandstone and arenaceous calcarenite, the upper beds being composed of cherty dark-gray limestone with interbeds of siliceous siltstone, limestone-pebble conglomerate, calcarenite, and blackish shale. In and near Rhodes Canyon, the Derryan sequence is about 230 feet thick, but as shown by mapping in the area, the thickness varies greatly from place to place, sandy beds being almost entirely absent above low pre-Derryan hills. Basal beds are conglomerates, with lenses of dark-gray carbonaceous shale, and grade up into limy quartzitic sandstone, all overlain by a sequence of silty calcarenite. The upper beds are calcareous sandstone, dark-gray limy siltstone, and carbonaceous shale.

Beds containing Derryan fusulinids in Hembrillo Canyon are about 345 feet thick. The lower beds consist of chert conglomerate, calcareous sandstone, arenaceous limestone, and carbonaceous shale, overlain by silty limestone with some shale interbeds. The Derryan interval in Ash Canyon is only 105 feet thick and consists of argillaceous limestone, arenaceous calcarenite, limy shale, cherty limestone, and upper carbonaceous shales that are unconformably overlain by arenaceous Desmoinesian limestone.

Strata containing Desmoinesian fusulinids in the San Andres Mountains are chiefly massive- to medium-bedded cherty or coquinoid limestones, with arenaceous calcarenites near the base and argillaceous limestones near the top. The lithology is typical of rocks of this zone, which form the prominent ledgy Pennsylvanian cliffs and contain abundant fusulinids throughout southern New Mexico. In Rhodes (sec. 67) and Hembrillo (sec. 71) Canyons, the Desmoinesian series is about 600 feet thick, and a relatively complete range of Desmoinesian fusulinids was identified by M. L. Thompson. In Ash Canyon (sec. 79), however,

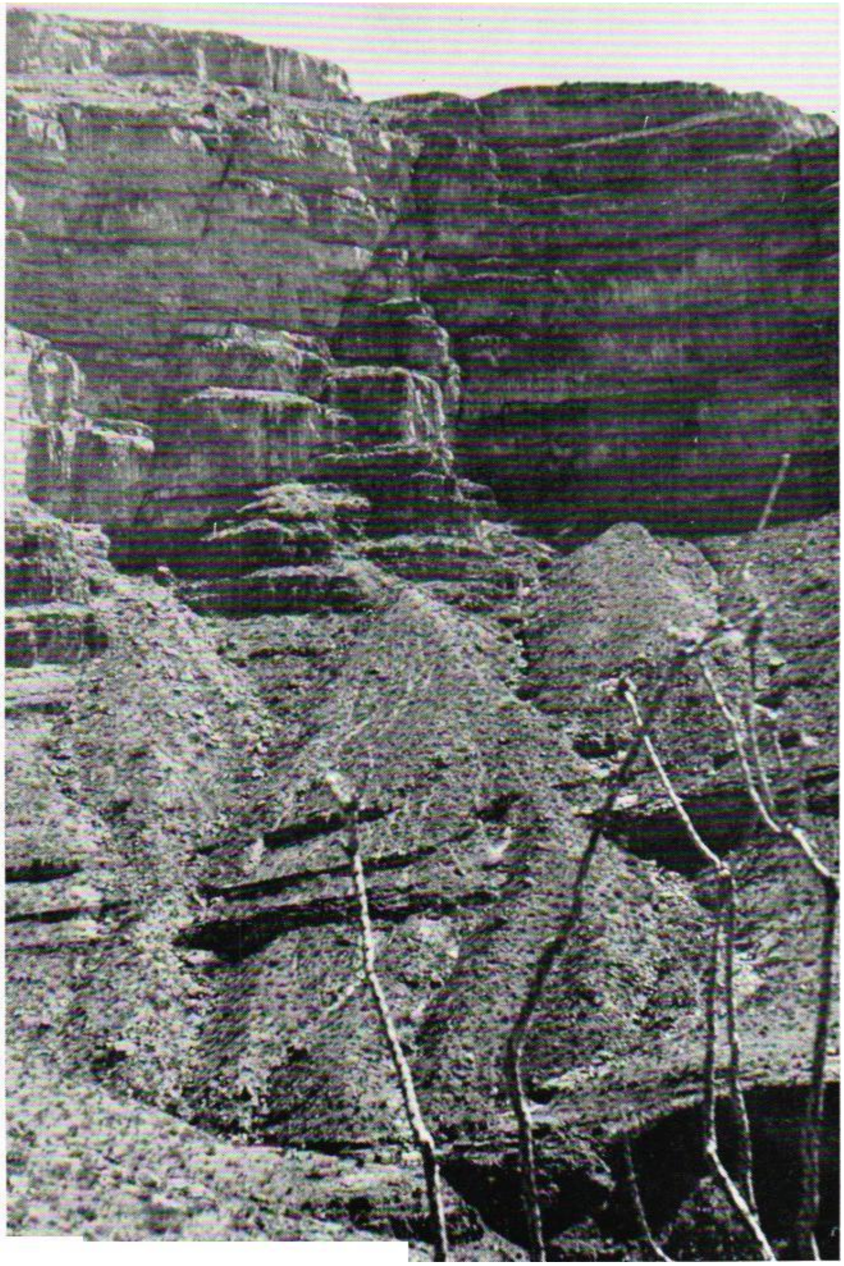

Figure 18

**TYPICAL LOWER PENNSYLVANIAN AND PRE-PENNSYLVANIAN OUTCROPS, SHEEP MOUNTAIN, NORTHERN SAN ANDRES MOUNTAINS**

Upper massive cliffs, Desmoinesian strata; upper slope, Derryan rocks; middle ledges, Mississippian beds; lower slope, Devonian; basal cliff, Montoya dolomite.

only 185 feet of strata is attributed to the series, and beds of upper Desmoinesian age appear to be absent. Near Mockingbird Gap (sec. 61), Desmoinesian rocks are about 540 feet thick and are chiefly typical cherty limestones. They include, however, several interbeds of greenish and reddish sandstones and, near the top, a lens of quartz-pebble conglomerate.

Rocks of Missourian age (fig. 19) are interbedded argillaceous limestone and calcareous shale, with medial massive cherty limestone and, at Mockingbird Gap, numerous beds of greenish micaceous sandstone. In Ash Canyon, the Missourian beds are predominantly massive cherty limestone somewhat similar to the underlying Desmoinesian strata. The thickness of the Missourian series varies considerably, ranging from 145 feet in Ash Canyon to 345 feet near Mockingbird Gap, more than 50 percent of the northern section being clastic rocks.

Sedimentary rocks containing Virgilian fusulinids in the San Andres Mountains are lithologically distinct from beds typical of the series in the surrounding parts of New Mexico. In the range they consist of deltaic- to brackish-water clastic rocks and precipitates, including silty brownish shales, dark carbonaceous shales, dark-gray argillaceous limestones, laminated calcilutites, silty calcarenites, silty calcareous sandstone, and thick lenses of massive biostromal limestones. Two thick gypsum beds (as previously reported by Thompson, 1942, p. 17-18)

Figure 19

UPPER MISSOURIAN AND LOWER VIRGILIAN STRATA, RHODES CANYON, NORTH-CENTRAL SAN ANDRES MOUNTAINS

Ledges in left foreground are upper Missourian limestones; slopes and cliffs above are of Virgilian strata.

Figure 20

PENNSYLVANIAN OUTCROPS FROM HEMBRILLO PASS, CENTRAL SAN ANDRES MOUNTAINS, LOOKING EASTWARD

Kaylor Mountain capped by cliffs of Missourian and Desmoinesian limestones; along Hembrillo Canyon in center, lower Pennsylvanian and pre-Pennsylvanian rocks crop out. In right center, hills capped by bioherms amid the shaly Virgilian sequence.

occur near the top of the Virgilian in and near Ash Canyon, and there are numerous biohermal reefs in the sequence near Hembrillo Canyon (fig. 20, 21, 22).

These distinct deposits have been mapped as the Panther Seep formation in the north-central part of the San Andres Mountains (Kottlowski et al., 1956, p. 42-47) and appear to have been deposited in a narrow north-south basin (pl. 3, 10) extending from the Rhodes Canyon area (fig. 19) southward to the Texas—New Mexico Stateline near Newman. The sediments suggest deposition in relatively shallow marine waters close to near-shore reefs, as well as some continental deposition, but with an overall constant subsidence. To the east (Sacramento Mountains), north, and west, Virgilian beds are thinner (pl. 12) and contain significant amounts of interbedded red beds, arkosic sandstones, and gray calcareous siltstones. The sediments were derived from the Pedernal landmass to the east and are chiefly fine-grained materials, indicating transportation over considerable distances.

In Rhodes Canyon, the Panther Seep formation is overlain unconformably by conglomerates attributed to the early Wolfcampian Bur-sum formation, and whereas there are somewhat similar elastic beds as far south as Ash Canyon, the Pennsylvanian—Permian contact has been drawn in the southern part of the range at the base of massive cliff-

Figure 21

VIEW TO NORTHEAST FROM HEMBRILLO PASS

Kaylor Mountain in center; bioherms of Virgilian age in left center.

Figure 22

CLOSER VIEW OF BIOHERMALLIKE MASSES, VIRGILIAN, HEMBRILLO CANYON

Note the occurrence at two levels.

forming limestones bearing Wolfcampian fusulinids. Virgilian fusulinids appear to be present (although sparse) throughout the formation in the Rhodes Canyon area, but upper beds attributed to the Panther Seep formation to the south are relatively unfossiliferous and may in part be of lower Permian age. The formation thickens progressively southward, being 825 feet thick near Mockingbird Gap, 1,460 feet at Rhodes Canyon, 1,825 feet near Hembrillo Canyon, and 2,390 feet near Ash Canyon. Similar rocks have been drilled in oil tests to the southwest in the Tularosa Valley, but Virgilian strata were removed almost entirely by erosion during early Wolfcampian time in the Hueco Mountains and southeastern Sacramento Mountains.

To summarize the clastic ratios and sand-shale ratios for the total Pennsylvanian in the San Andres Mountains is somewhat inconsistent, inasmuch as there is much variance within and between individual zones and lithic trends in lower beds may be reversed by opposing trends in upper beds. The total average ratios can be used, however, for comparison with other sections in the region. The clastic ratio increases southward from 0.78 at Mockingbird Gap and 1.12 in Rhodes Canyon to 1.36 in Hembrillo and Ash Canyons. The sand-shale ratio is about 2.7 near Mockingbird Gap but only 0.25 at Rhodes Canyon, 0.16 in Hembrillo Canyon, and 0.22 near Ash Canyon.

### JORNADA DEL MUERTO

Only 7 oil tests have been drilled more than 2,000 feet deep in the Jornada del Muerto south of the Jornada basalt flows (pl. 1), and only three of these tests penetrated rocks as old as Pennsylvanian. The Sun Oil Co. No. 1 Vittorio Land & Cattle Co. (sec. 63) was located near the middle of the Jornada del Muerto, about 22 miles northwest of Rhodes Pass, and drilled into Precambrian granite at a depth of about 6,000 feet. Pennsylvanian sedimentary rocks encountered are about 1,815 feet thick; about 1 1/2 miles to the northwest, however, the No. 2 test well went through only 1,740 feet of Pennsylvanian strata. In both wells, Abo red beds overlie the Pennsylvanian section, and basal chert-pebble conglomerates rest on the lower part of the Ordovician Montoya group. Probable thicknesses of the Pennsylvanian series are: Virgilian, 1,005 feet; Missourian, 170 feet; Desmoinesian, 370 feet; and Derryan, 270 feet. Lithologies are similar to those of the sections in the northern San Andres and northern Fra Cristobal Mountains. There is much more sandstone than in the sections to the west but less than in the Pennsylvanian of the northern San Andres Mountains, the clastic ratio being about 0.56 and the sand-shale ratio about 0.25.

The Sunray Mid-Continent Oil Co. No. 1-M Federal oil test (sec. 23, T. 15 S., R. 2 W.), completed as a dry hole in April 1959, was spudded in the lower part of the Tertiary sediments, about 4 miles west of the topographic center of the Jornada del Muerto, and about one-half mile west of the Aleman ranch. Pennsylvanian rocks were reported encoun-

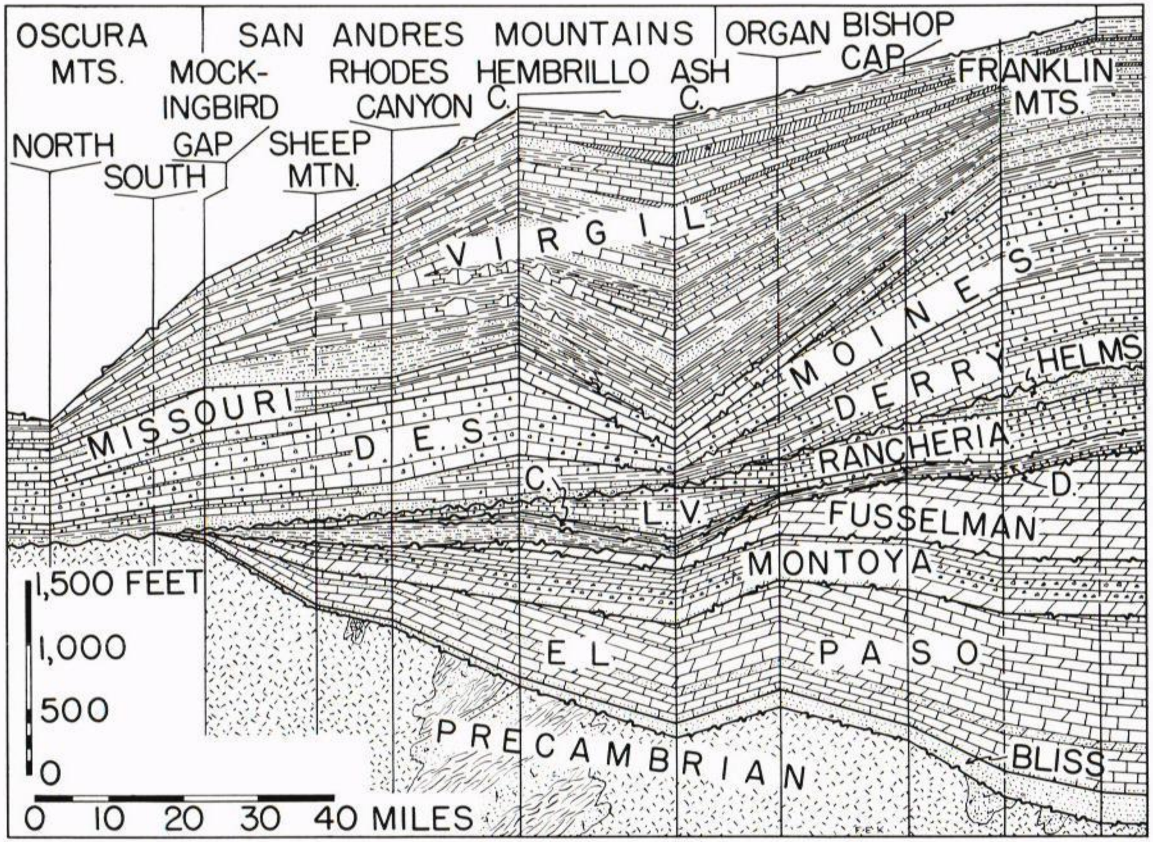


Figure 23

NORTH-SOUTH DIAGRAMMATIC SECTION OF PRE-PERMIAN STRATA FROM OSCURA MOUNTAINS TO EL PASO

L. V., Lake Valley; C., Caballero; D., Devonian.

tered between depths of 6,065 and 8,692 feet, a thickness (not corrected for dip) of 2,627 feet. The cuttings and the electric log suggest a section much more like that of the Hembrillo Canyon area (sec. 71), 22 miles to the east-southeast, than the Palomas Gap Pennsylvanian section in the Caballo Mountains, 12 miles to the west-northwest.

## SACRAMENTO SECTION OF BASIN AND RANGE PROVINCE

A relatively narrow strip of south-central New Mexico between the Great Plains to the east and the typical basin-and-range country to the west is contained in the Sacramento section of mature block mountains and plateaus, which are gently tilted to the east and dip into and under the Great Plains. The Hueco Mountains in New Mexico and Texas, and the Sacramento and Oscura Mountains, Sierra Blanca, and Chupadera Mesa in southern and central New Mexico, are the uplifts in this physiographic section; parts of the Tularosa Valley, northern Jornada del Muerto, and Estancia Valley are bolsons in the Sacramento section. Surface outcrops are predominantly of Permian strata except near Sierra Blanca, where Cretaceous strata and Tertiary igneous rocks are dominant, and in the bolsons, where Quaternary sediments blanket the underlying, more consolidated older beds.

### OSCURA MOUNTAINS

The type localities (fig. 24) for most of the Upper Pennsylvanian formations of Thompson (1942, p. 55-82) are in the northern Oscura Mountains (sec. 57). In the northern part of the range the Pennsylvanian sequence is only 920 feet thick; basal Derryan beds unconformably overlie Precambrian granites, and the uppermost Virgilian strata arc in places apparently conformable, and in other localities unconformable, beneath the overlying early Wolfcampian Bursum formation. Derryan beds are from 100 to 150 feet thick, the lower beds consisting of conglomerates, sandstones, and black shales of variable thickness, and the upper beds being composed of dark-gray cherty nodular limestones (Kottlowski, 1952). The Desmoinesian, about 325 feet thick, is of the typical cherty thick- to massive-bedded limestones. The Missouri series, about 235 feet thick, consists of thin- to massive-bedded limestones with interbeds of arkosic sandstones and red shale. The Virgil series is about 210 feet thick and consists of lower interbedded light-gray limestones, arkosic sandstones, and red shale; medial massive limestone; and upper red shales with interbeds of nodular limestone. The clastic ratio is about 0.23, and the sand-shale ratio 0.46, for the composite Pennsylvanian section.

The Missouri series in this area was divided into two groups and five formations by Thompson (1942, p. 55-66). The lower, Veredas group encompasses, in ascending order, the Coane formation, Adobe forma-

Figure 24

DESMOINESIAN AND M ISSOURIAN OUTCROPS, OSCURA MOUNTAINS, NEAR TYPE SECTIONS OF M. L. THOMPSON'S MISSOURIAN FORMATIONS

Coane limestone is the middle cliff, and the Council Spring limestone the upper persistent cliff.

don, and Council Springs limestone. The Coane formation is 60 to 80 feet thick and consists of thin- to massive-bedded limestones that contain distinctive yellow-brown-weathering nodules, lenses, and stringers of chert. The fauna is characterized by *Wedekindellina ultimata,* which marks the basal zone of the Missourian series over wide areas of the Central and Western United States (Thompson, 1956; Thompson and Kottlowski, 1955, p. 76). The Adobe formation includes nodular to thick-bedded cherty to noncherty limestones, gray to reddish shales, and greenish feldspathic sandstone; the basal beds are arkosic sandstone with pebbly lenses and numerous fresh angular feldspar grains and are considered the base of the upper arkosic member of the Madera formation by Wilpolt and Wanek (1951). The formation is 45 to 55 feet thick and forms a ledgy slope beneath the overlying Council Springs limestone, a massive cliff-forming bed, 15 to 25 feet thick, of very light-gray coarsely to finely crystalline fossiliferous limestone.

The upper, Hansonburg group of the Missouri series is divided into the lower, Burrego formation and upper, Story formation. The Burrego formation is about 50 feet thick and consists of massive- to thin-bedded and nodular gray limestones with some thin arenaceous to arkosic crinoidal calcarenite beds distinctively colored brown, orange, green, and purple from place to place. Lenses of dark-gray, reddish-brown, and olive shale, and brown limy sandstone occur in the lower part of the formation. The Story formation ranges from 55 to 80 feet in thickness and consists of lower reddish and gray shale and greenish, reddish, and brown arkosic micaceous sandstone; and upper light-gray massive-bedded fossiliferous limestone.

The Keller group below and the Fresnal group above are assigned to the Virgil series. The Del Cuerto formation below and Moya formation above are assigned to the Keller group, and the Bruton formation to the Fresnal group in the northern Oscura Mountains. The Del Cuerto formation is 75 to 90 feet thick and consists of nodular gray limestone, reddish, greenish, and brown feldspathic sandstone, limestone-pebble conglomerate, and reddish to gray limy shale. The Moya formation is 50 to 60 feet thick and is of massive, irregularly bedded cliff-forming limestone that caps many of the dip slopes in the Oscura Mountains. The Bruton formation, as restricted by Thompson (1954, p. 18), is 75 to 85 feet thick and is composed chiefly of reddish shales with interbeds of gray and brown limy shales and nodular shaly limestones.

In the central Oscura Mountains, about 9 miles southeast of Thompson's section, Wilpolt and Wanek (1951) measured more than 700 feet of Upper Pennsylvanian beds (Missourian and Virgilian), compared with the 445 feet in the northern part of the range and the 1,170 feet found near Mockingbird Gap to the south. These upper Pennsylvanian strata are more clastic southward and eastward (sec. 58) and suggest that one of the higher parts of the Pedernal landmass in late Pennsylvanian time was in the vicinity of the present site of Sierra Blanca (pl. 1, south of Carrizozo).

## OIL TESTS NEAR THE OSCURA MOUNTAINS

East of the Oscura Mountains, the Standard of Texas Oil Co. No. 1 Heard Federal oil test (sec. 58) penetrated at least 1,350 feet (perhaps 1,745 feet) of Pennsylvanian before encountering Precambrian diorite and gneiss. Numerous red beds and arkosic sandstones occur in the sequence, especially in the upper part; these feldspathic clastic rocks indicate the nearness of the deposits to the Pedernal landmass. The clastic ratio is essentially 1, and the sand-shale ratio about 0.76; more expressive are the large amounts of angular feldspars and the numerous pebbly sandstone beds.

The Sun Oil Co. No. 1 Bingham State oil test was drilled on the northwest flank of the Oscura Mountains about a mile west of the fault zone that is on the west border of the main fault block of the range. About 1,100 feet of Pennsylvanian rocks was penetrated beneath the Bursum formation and overlying Precambrian rocks. To the north, on the northern extension of the Oscura Mountains, the Oscura anticline, three oil tests have been drilled through the Pennsylvanian by J. R.

Lockhart within a distance of a mile along the axis of the anticline. Pennsylvanian strata (sec. 55) thicken northward from 1,260 to 1,375 feet in the three wells, are beneath interbedded red beds and limestones assigned to the Bursum formation, and overlie Precambrian granite and quartzite. Lower rocks are predominantly blackish shale and dark-gray silty limestone, with lenses of whitish quartzose sandstone also reported.

To the northeast, on the northwest flank of the northern part of the Jornada del Muerto, the Skelly Oil Co. No. 1 Goddard oil test (sec. 51) penetrated about 1,480 feet of Pennsylvanian beds overlain by the Bursum formation, and underlain by Precambrian quartzite. This test was drilled on the east flank of the Prairie Springs anticline. The upper contact of the Pennsylvanian with early Wolfcampian strata is not known from the available data, being somewhere within interbedded red beds and limestones typical of the Bursum and Bruton formations. Much red shale, siltstone, and arkosic sandstone occurs in upper Pennsylvanian beds, and the lower 250 feet of the sequence is predominantly blackish shales. Although the cuttings are contaminated by caved Abo red beds, the clastic ratio appears to be about 0.73, and the sand-shale ratio about 0.20.

### ESTANCIA VALLEY

Many oil and gas tests have been drilled in the southern part of the Estancia Valley in southern Torrance County, and a carbon dioxide gas field was developed on the small Wilcox dome northwest of Estancia. The valley is a closed basin, with surface and ground water draining into Laguna del Perro, a string of salt pans alined north-south in the central and southern parts of the valley. Structurally the Estancia Valley is an elongated (north-south) basin; Pennsylvanian and Permian strata dip eastward toward the central axis from the Manzano Mountains on the west and rise slightly on the east side, where upper Paleozoic beds abut against the Precambrian rocks of the low Pedernal Hills. Southward the valley is bordered by the high Mesa Jumanes, the northern part of Chupadera Mesa, a topographic feature developed on resistant Permian sandstones and limestones.

On the west side of the Estancia Valley, in the Manzano and Los Pinos Mountains, Pennsylvanian strata are 1,300 to 1,600 feet thick (secs. 38, 45, 46, 48), but on the east side of the valley, the Pennsylvanian beds pinch out against the Precambrian core of the Pedernal Hills and are overlapped by Permian strata (fig. 25). The westernmost outcrop of Precambrian rocks is on Rattlesnake Hill (sec. 43), where, on the west edge, Yeso(?) sandstones appear to overlie the Precambrian metamorphic and granitic rocks. To the south, in the Gallinas Mountains (sec. 49), Kelley et al. (1946) noted arkosic sandstone and conglomerate of the Abo red beds on Precambrian granite and gneiss. About 4 miles west of the Precambrian outcrops on the west edge of Rattlesnake Hill, the Bluehall Oil Co. No. 1 Kistler oil test was drilled through the Yeso and

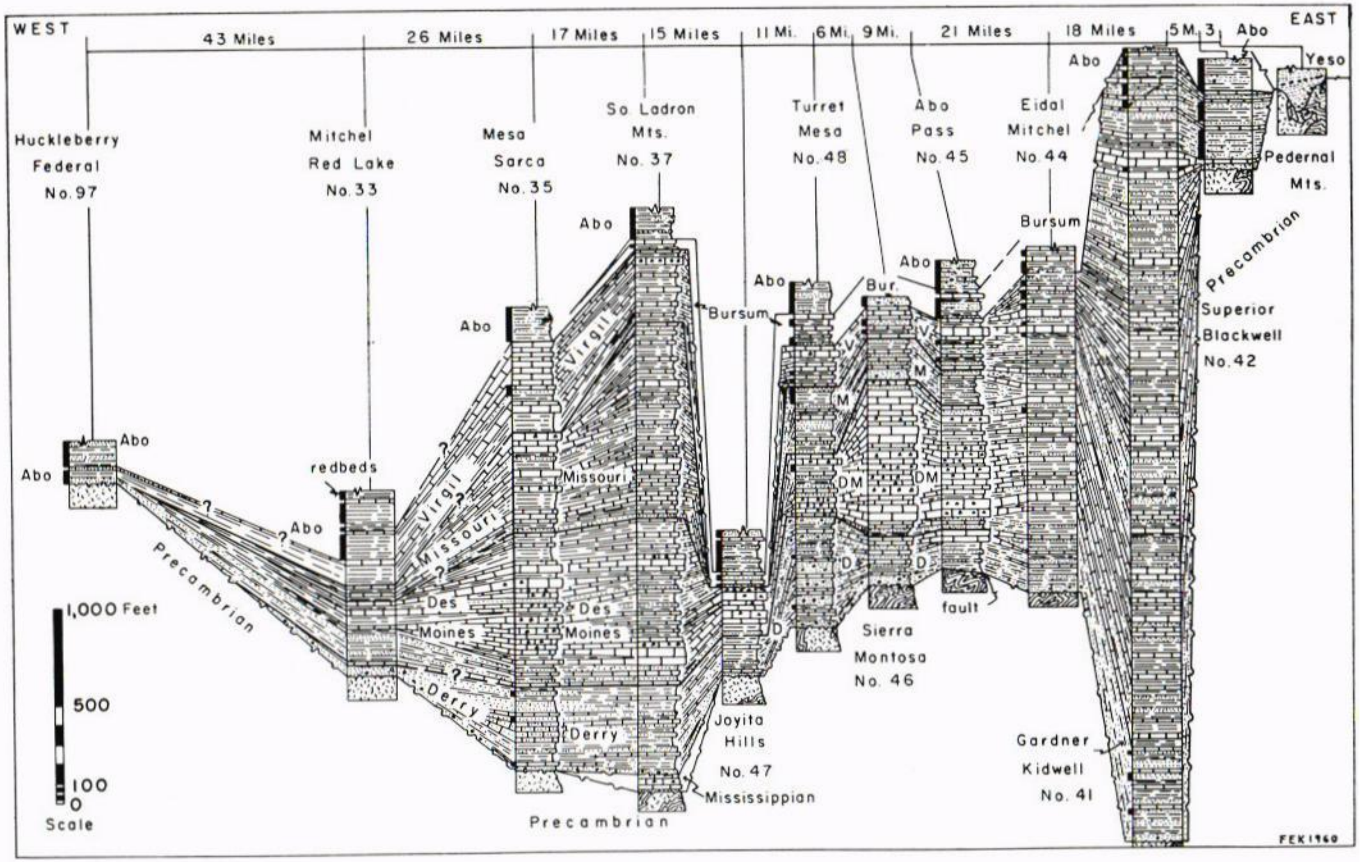


Figure 25

DIAGRAMMATIC SECTION FROM ZUNI ARCH EASTWARD TO PEDERNAL MOUNTAINS

Abo formations into the Pennsylvanian and appears to have bottomed (total depth 1,780 feet) in the upper part of the Madera limestone (Read et al., 1944); the thickness of the pre-Permian beds is not known.

To the north, about 11 miles north-northeast of Willard, the San Juan Coal & Oil Co. No. 2 Randall well was drilled to a depth of 5,321 feet. The well site is about 9 miles west of the Precambrian outcrops on the west side of the Pedernal Hills, where the Yeso formation (Leonardian) overlies the Precambrian rocks, filling channels and surrounding hills carved from quartzite. According to Bates (1942, p. 289), the test went through the Yeso and Abo formations, and drilled in Pennsylvanian rocks from a depth of 1,040 to 5,321 feet, suggesting that 4,281 feet of Pennsylvanian strata was penetrated. The lower 1,000 feet is predominantly of sandstone and shale, whereas the upper 3,280 feet is chiefly limestone, shaly limestones, and shale. The basal several hundred feet includes much angular pink feldspar and may be "granite wash" or broken granite.

Beds in this area may be dipping steeply, so that an exaggerated thickness would be recorded by well data; however, the sedimentary section does appear to be very thick above the Precambrian rocks. About 3 miles to the northeast, Read et al. (1944) mapped Permian beds that dip 35 degrees to the east, but these beds are drag folded along a fault zone, one of several along the west edge of the Pedernal Hills, suggesting that the east side of the Estancia Valley may be a graben instead of a simple syncline.

The Gardner Petroleum Corp. No. 1 Kidwell oil test (sec. 41) was drilled about a mile east of the San Juan No. 2 Randall well to a depth of 5,918 feet, the top of the Pennsylvanian strata being reported at 1,865 feet and Precambrian rocks at 5,900 feet. The Madera limestone was recorded as being 3,505 feet thick, and the sandy Sandia formation as 530 feet thick. If the top of the Pennsylvanian and the base of the Abo red beds were picked at about the same horizon in these two oil tests, which are only a mile apart, the beds have an apparent dip of about 10 degrees to the east. With this amount of dip, the true thickness of the Pennsylvanian in the Gardner No. I Kidwell well is about 3,954 feet (Madera, 3,432 feet; Sandia, 522 feet). The upper beds are almost 50 percent black to greenish shale, which is interbedded with black and tan to gray limestone, and with much green, gray, and pink sandstone, quartzose to arkosic. Samples are contaminated by caved red shale and red arkose from the Abo red beds, but there appear to be many beds of pink to reddish arkosic sandstone within the Pennsylvanian sequence. The elastic ratio is estimated at about 3; the sand-shale ratio is about 0.55.

The sediments appear to have been deposited in a rapidly sinking, local basin that was very near the Pedernal landmass. The coarseness of the lower arkoses of the Abo red beds suggests that the basal Permian beds may be erosionally unconformable on the Pennsylvanian strata;

fossil data, however, are not available for dating any of the rocks encountered. Although the Pedernal landmass just to the east may have been subject to much erosion during early Middle Pennsylvanian time (Derryan), the area seems to have been at or near sea level during at least part of Middle and Upper Pennsylvanian time, even though quartzose and feldspathic sandstones in the upper Pennylvanian strata record considerable intermittent uplift and erosion.

About 4 miles southeast of the Gardner No. 1 Kidwell well, the Superior Oil Co. No. 28-31 Blackwell (sec. 42) oil test was drilled to a depth of 2,646 feet. Precambrian granite and black mica schist were reported at a depth of 2,590 feet. The test began in the Yeso formation and was still in Abo-like red beds on top of the Precambrian; perhaps as much as 2,000 feet of "Abo" was penetrated. The red-bed sequence is very arkosic; fragments of fresh granite and of angular pink feldspars are common. Interbeds of gray limestone and grayish to greenish calcareous sandstone occur in the lower 400 feet. Fossil evidence to date this thick red-bed series is lacking. Inasmuch, however, as the Abo red beds 4 miles to the west are only 550 feet thick, the writer suggests that the lower rocks may be of Pennsylvanian age, being near-shore and terrestrial deposits that grade laterally into the sandstones, shales, and limestones penetrated in the Gardner No. I Kidwell well.

About a mile southeast of Estancia and 7 miles east of the San Juan No. 2 Randall well, the Murphree & Bond No. 1 Berkshire oil test (sec. 40) was drilled into Precambrian mica schist at a depth of 3,100 feet. The top of the Abo red beds appears to be at a depth of 590 feet, and the cuttings are almost entirely reddish shales and siltstones to a depth of 2,110 feet. The lower 990 feet above the Precambrian consists of interbedded blackish to greenish shales, finely crystalline limestones, and many pinkish to greenish arkosic to quartzose sandstones. This lower sequence is typical of the Pennsylvanian in the Estancia basin but is much thinner than Pennsylvanian beds to the east or west. In contrast, the overlying Abo red beds are about 1,520 feet thick as compared with 550 feet in the Gardner No. 1 Kidwell well to the east. To the west, the nearest (8 miles) outcrops are of the upper arkosic member of the Madera limestone; probably only basal beds of the Abo formation were penetrated in wells to the west. Traces of limestone occur below depths of about 1,590 feet; and the electric log shows numerous thin beds of either argillaceous limestone or hard siltstone from 1,590 to 2,110 feet.

The Gilbreath No. 1 Berkshire oil test, located one-fourth mile to the east, had shows of dense limestone from depths of 1,420 feet to 1,980 feet, where a dominantly limestone sequence begins. Upper beds of the Pennsylvanian as exposed in outcrops and in wells to the west contain many interbeds of reddish arkosic sandstone and reddish shale, indicating that the lower part of the red-bed sequence penetrated in the Murphree & Bond well may be of Pennsylvanian age. About 10 miles to the north-northeast is a large area of outcrop of Precambrian rocks called the Cerrito del Lobo, which appears to be an expression of a Pennsylvanian and early Permian ridge west of the main Pedernal landmass, and which is responsible for the thin marine Pennsylvanian sequence and thick Pennsylvanian—lower Permian red-bed series penetrated in the Berkshire wells.

Eight miles west of the Berkshire oil tests, the Witt Ice & Gas Co. No. 1 Meadows gas test (sec. 39) was drilled to a depth of 2,123 feet and encountered Precambrian micaceous quartzite at 1,900 feet. The upper arkosic member of the Madera limestone crops out about 3 miles to the west, the Pennsylvanian strata on the east side of the Manzano Mountains directly to the west being about 1,600 feet thick. Much red sandy shale and reddish arkose occurs throughout the well but chiefly in the upper 850 feet; however, limestone containing *Triticites?* occurs at a depth of only 280 feet, and the entire 1,690 feet below the valley fill is assigned to the Pennsylvanian, although uppermost beds may be of the Bursum formation.

The upper 640 feet is a sand-lime facies with a clastic ratio of 2.3 and a sand-shale ratio of 1.1; these ratios are similar to those of sand-lime facies composing the upper arkosic beds of the Pennsylvanian in Abo Pass and in the Los Pinos Mountains to the southwest, but differ from the lime-shale facies to the west in the Manzano Mountains. The medial sequence wherein thick limestone beds occur, the approximate lithic equivalent of the limestone member of the Madera limestone, is about 690 feet thick; it has a clastic ratio of 1.7 and sand-shale ratio of 0.3, a shale-lime facies. This contrasts with the limestone facies of the member in the Manzano Mountains (clastic ratio, 0.1), and the lime-shale facies near Abo Pass (clastic ratio, 0.26), but is about the same as the shale-lime facies in the southern Los Pinos Mountains (clastic ratio, 1.3). The basal 360 feet includes much shale; it has a clastic ratio of 3.6 and sand-shale ratio of 0.1, being a shale-lime facies similar to the upper clastic member of the Sandia formation in the Manzano Mountains. From Abo Pass southward in the Los Pinos Mountains, however, the basal sequence is a sand-lime facies, as it is in most of the Estancia basin.

About 15 miles to the south-southeast, between Mountainair and Willard, the Eidal Manufacturing Co. No. 1 Mitchel oil test (sec. 44), was drilled into Precambrian mica schist at a depth of 3,518 feet. Sandstones, limestones, and anhydrite of the Yeso formation were penetrated from the base of the valley fill (118 feet) to 850 feet, then Abo-like red beds to a depth of 2,090 feet, and Pennsylvanian strata for 1,428 feet to the top of the Precambrian schist. The Abo-like red-bed sequence is 1,240 feet thick, compared with 811 feet measured by Needham and Bates (1943, p. 1654-1657) near Abo State Monument, about 14 miles to the west-southwest. From a depth of 1,373 feet to 2,090 feet, there are a few limestone beds in the sequence and numerous reddish arkoses and greenish sandstones among the predominant reddish sandy silty shales.

The Bursum formation is about 200 feet thick east of Abo Pass (Wilpolt et al., 1946) and consists of similar interbedded red beds and nodular to massive limestones; however, there are also many reddish shales and arkoses in the Virgilian beds in the area.

The Pennsylvanian—Permian contact is probably somewhere in the lower part of the red bed-limestone sequence above the depth of 2,090 feet. An arbitrary contact drawn at 1,916 feet is above greenish to blackish nonred shales, greenish to gray sandstones, and finely crystalline limestones; also, the feldspars in the arkosic sandstones are not heavily stained by hematite coatings. There are some purplish limy shales above the 1,916-foot depth that appear similar to those typical of the Lower Wolfcampian Bursum formation. The Madera limestone unit is a shale-lime facies; the basal 273 feet, which could be attributed to the upper clastic member of the Sandia formation, is a sand-shale facies with clastic ratio of over 13 and sand-shale ratio of 1.02. Although some of the sandstones in the basal Pennsylvanian sequence are limy and shaly, many are porous, medium to coarse grained, and arkosic. The lower shale beds are mainly blackish and carbonaceous, and in part at least contain marine fossils.

The Mountainair Oil & Gas Co. No. 1 Veal oil test was drilled on the north edge of Mountainair, about 7 miles west of the Eidal No. I Mitchell well. The top of the Abo red beds beneath the Yeso formation is probably at about 730 feet, the top of the Bursum formation at either 1,290 or 1,510 feet. From 1,600 feet to the bottom of the test at 3,104 feet, marine limestones make up more than 50 percent of many of the intervals, and the sandy beds of the Sandia formation do not appear to have been reached. The Pennsylvanian beds, therefore, are probably more than 1,750 feet thick in this area and include a greater percentage of limestone than in the Eidal No. 1 Mitchell well.

## CHUPADERA MESA

No petroleum tests have been drilled on Chupadera Mesa, owing in part to the difficulty of mapping the surface structures, as the dips of the outcropping San Andres limestones may be due either to folds or to solution of the limestone and of the gypsum-anhydrite in the underlying Yeso formation. The Pennsylvanian strata are probably of similar thickness and lithology as those encountered in the southern Estancia basin, in the Standard of Texas No. 1 Heard well on the Carrizozo anticline (sec. 58), and in the Lockhart (sec. 55) wells on the Oscura anticline. The west edge of the Pedernal landmass appears to have extended southeast from the Gallinas Mountains (sec. 49, pl. 1), suggesting a pinching out of the Pennsylvanian beds to the northeast and an increase in the amount of coarse-grained arkosic sandstones; similar relationships occur on the east side of the Estancia basin, as described above.

Pennsylvanian beds cap much of the Oscura Mountains but do not crop out on Chupadera Mesa nor on the northeast side of the Tularosa Valley in Sierra Blanca. The northernmost Pennsylvanian outcrops along the east side of the Tularosa Valley are just east of Tularosa. Only one deep oil test has been drilled in the central and northern parts of the Tularosa Valley; this well, the Tularosa Basin Oil Co. No. 2 Belmont (sec. 69), probably bottomed in upper Pennsylvanian or lower Permian strata at a depth of 3,965 feet.

#### SACRAMENTO MOUNTAINS

In the northwestern Sacramento Mountains, the upper Pennsylvanian and lower Permian rocks have been studied and mapped by Otte (1959) in the area from Fresnal Canyon northward to just east of Tularosa, where the northward dipping Virgilian beds dip beneath overlying Wolfcampian strata. Otte's field studies and paleontologic evidence indicated that deposition was essentially continuous from late Pennsylvanian into early Permian time in the Tularosa and La Luz area (sec. 72), a contrast with the High Rolls area 4 miles to the southeast (of La Luz Canyon), where a major angular unconformity separates the Pennsylvanian and Permian strata. Although Virgilian beds are dominantly marine, there are numerous clastic beds of near-shore origin. Interbedded marine and continental sediments span the time interval from late Virgilian into early Wolfcampian, the fusulinids suggesting that some of the youngest Virgilian faunas in North America occur within the sequence.

As shown by the lithologic and faunal characteristics of the sedimentary deposits, abrupt lateral transition toward the east and southeast, toward the Pedernal landmass, from open-marine conditions to terrestrial flood-plain environments must have occurred repeatedly within a distance of a few miles. A typical lateral succession of contemporaneous deposits was determined by Otte (1959) to be, from west to east: (1) massive marine limestone, (2) nodular argillaceous fusulinidbearing limestone, (3) silty limestone containing shallow marine fossils such as molluscs and brachiopods, (4) dolomitic limestone, (5) green calcareous shale, and (6) marine to nonmarine red shale and other terrigenous clastic rocks.

Studies of the faunas indicate that ammonoids believed to be characteristic of late Pennsylvanian age occur stratigraphically above brachiopods and fusulinids *(Schwagerina* and *Dunbarinella)* of early Wolfcampian age.

Virgilian beds were mapped by Otte and by Pray (1952) as the Holder formation (Pray, 1954), which includes equivalents of the Fresnal group (above) and Keller group (below) of Thompson's (1942, p. 67-79) Virgil series. The Holder formation is thickest near Fresnal and La Luz Canyons (sec. 72), where it totals about 855 feet; the formation thins to the south and southeast toward the central part of the Sacramento Mountains. The clastic ratio for the formation near La Luz is about 1.6 and the sand-shale ratio 0.27. The clastic material in the Holder formation was derived from the Pedernal landmass, which was probably 15 to 25 miles to the east. As the percentage of red beds and limestone-pebble conglomerates increases toward the top of the formation, the landmass must have supplied more clastic material toward the end of Virgilian time.

The base of the Holder formation is marked by local masses of thick reef limestones, which have been described in detail by Plumley and Graves (1953). The reefs (fig. 26) are about 100 feet thick; although recrystallization has destroyed much of the internal structure, they appear to be chiefly of algal origin. Numerous similar reefs occur in the Virgilian Panther Seep formation in the central San Andres Mountains west of the Tularosa Valley, and are reported in basal Virgilian beds in the northern Hueco Mountains to the south (King et al., 1945).

The Sacramento Mountains are essentially a tilted warped fault-block, uplifted on the west several miles along a north-northwest-trending fault zone, and with sedimentary beds generally dipping gently to the east. The structurally highest point is about 15 miles southeast of Alamogordo, where Precambrian rocks crop out at the foot of the range along the west-bounding fault zone. The Paleozoic rocks dip away from this point both to the north and south, so that upper Pennsylvanian beds disappear beneath the Wolfcampian beds at the north near Tularosa and to the south near Culp Canyon. The bold western escarpment of the range is capped by Permian limestones about 6 miles east of the west edge of the mountains, and these limestones form the surface outcrops on the long dip slope to the east into the Pecos Valley.

Pray (1952) has mapped the geology of the western escarpment of the Sacramento Mountains and studied the Pennsylvanian rocks in detail. The beds of Pennsylvanian age range from almost 3,000 to about 2,000 feet in thickness and record a period of structural unrest, as indicated by the numerous coarse-grained clastic strata derived from nearby areas of uplift and erosion, and by the notable lateral variation of the beds. Pray (1954) divided the Pennsylvanian rocks into three formations (pl. 9) and one member, and mapped these units from the northern limit of their outcrop east of Tularosa to their southernmost exposures near Culp Canyon.

The basal Gobbler formation, of Morrowan(?) to middle Missourian age, is 1,200 to 1,630 feet thick and consists of coarse-grained quartz sandstone, argillaceous limestone, and shale. In the southwest and northeast parts of the escarpment, the Bug Scuffle limestone member, as much as 800 feet thick, forms cliffs of gray cherty limestone and grades abruptly into shallow-marine and deltaic clastic rocks that trend northwest through the area (Pray and Graves, 1954, p. 1295-6). This deltaic facies is about 1,000 feet thick and 4 miles wide, is of Desmoinesian age, and

Figure 26

DRY CANYON BIOHERM, VIRGILIAN, SACRAMENTO MOUNTAINS

Photograph by L. C. Pray.

is believed to be an elongate delta that was fed by a major river draining westward from the Pedernal landmass to the east.

The overlying Beeman formation, of upper Missourian age, is 350 to 500 feet thick and consists of feldspathic sandstone, limestones, and shale. The numerous sandstones of the Gobbler and Beeman formations are rich in first-generation clastic minerals apparently derived from Precambrian rocks, from which it appears that such rocks were exposed to erosion in the Pedernal Mountains during most of Pennsylvanian time. The upper unit, the Holder formation of Virgilian age, is as much as 855 feet thick; as noted by Otte (1959), it includes discontinuous algal reefs at the base, whereas the upper beds are characterized by reddish marls, nodular limestone, and whitish massive limestones.

Near Tularosa, sedimentation was essentially continuous from Pennsylvanian into Permian time. Elsewhere in the Sacramento Mountains, however, the Abo red beds overlie older strata with marked erosional unconformity and in places rest on truncated beds as old as the Lower Mississippian Lake Valley formation. Basal sandy and conglomeratic beds of the Pennsylvanian are regionally unconformable on Mississippian strata in the range. At the south, near Table Top and Negro Ed Canyon (sec. 78), the underlying beds are the Helms formation of Chester age; in Mule Canyon (sec. 77), the Pennsylvanian strata rest on the Rancheria formation of Meramec age; and at the north end of the pre-Pennsylvanian outcrops near Indian Wells (sec. 72), the underlying rocks are the Lake Valley formation of Osage age.

The section (sec. 72) measured by Thompson (1942, p. 75-79; Lloyd, 1949, pl. 4) and Pray (1952, pl. 14) near Indian Wells and La Luz Canyon includes about 2,980 feet of Pennsylvanian rocks, which are assigned to the following series by Thompson: (1) Morrowan(?), 110 feet; (2) Derryan, 325 feet; (3) Desmoinesian, 760 feet; (4) Missourian, 930 feet; and (5) Virgilian, 855 feet. Pray mapped the lower 1,630 feet in his Gobbler formation, the next 495 feet in the Beeman formation, and the upper 855 feet in the Holder formation. East of Alamogordo, in Alamo Canyon, Pray measured 1,975 feet of Pennsylvanian rocks, the Gobbler formation being about 1,445 feet thick and the Holder formation only 90 feet thick beneath Abo red beds and conglomerates. In Mule Canyon and near Mule Peak (sec. 77), the Pennsylvanian totals 1,960 feet, but the top is an erosion surface; the Gobbler formation is about 1,305 feet thick and the Holder formation is at least 255 feet thick.

To the south, in Deadman Canyon (sec. 14, T. 18 S., R. 10 E.), the Pennsylvanian is about 2,050 feet thick, the Gobbler formation being 1,340 feet thick, the Beeman formation about 415 feet thick, and the Holder formation 300 feet thick, overlain unconformably by Abo conglomerates. In the Table Top—Negro Ed Canyon section (sec. 78), only 1,840 feet of Pennsylvanian remains, but the upper beds are eroded; the Gobbler formation is about 1,195 feet thick, the Beeman formation almost 450 feet thick, and the Holder formation more than 195 feet thick. To the east and southeast, the lower conglomeratic tongue of the Abo red beds is unconformable on the Beeman or Gobbler formation, whereas to the south-southeast, near Culp Canyon, this basal clastic unit overlies Virgilian beds and has been mapped by Carl C. Branson (personal communication to Lloyd C. Pray) as the basal Powwow conglomerate member of the Hueco formation.

The thicker sections in the northwestern part of the range reflect an overall northward thickening of the three formations mapped by Pray but are especially due to the thickening of the Holder formation (Virgilian), which in the southern sections was thinned by erosion during early Wolfcampian time. The total Pennsylvanian section contains many additional clastic beds to the north, the clastic ratios being 0.36 for the Table Top—Negro Ed Canyon section, 1.10 for the Mule Canyon section, and 1.43 for the Indian Wells section, although reduced to about 0.9 for the Fresnal Canyon—Tularosa area. This northward increase is in part a lithic reflection of the clastic delta of Desmoinesian age that occurs northeast of Alamogordo. Sand-shale ratios also increase northward from 0.13 at Table Top and 0.15 in Deadman Canyon (sec. 14, T. 18 S., R. 10 E.) to 0.52 in Mule Canyon and 0.83 in the Indian Wells—La Luz section. These relationships, as well as the numerous feldspathic clastic beds penetrated in the Standard of Texas No. 1 Heard well (sec. 58), suggest that one of the higher parts of the Pennsylvanian Pedernal Mountains was north-northeast of Alamogordo, perhaps in the general vicinity of Ruidoso, east of Sierra Blanca.

## TULAROSA VALLEY

South-southwest of Culp Canyon there are no outcrops of Pennsylvanian rocks along the east side of the Tularosa Valley or Hueco Basin for 40 miles until the northern Hueco Mountains are reached near the New Mexico—Texas Stateline, where basal beds of the Hueco formation unconformably overlie the upper part of the Pennsylvanian (King et al., 1945; Hardie, 1958). Pennsylvanian beds have been encountered in many of the oil tests drilled along the southeast side of the Tularosa Valley, in the northern foothills of the Hueco Mountains, and on the back slope of Otero Mesa (Horse Mesa), a relatively low upland connection between the Sacramento and Hueco Mountains.

The Plymouth Oil Co. No. 1 Evans Federal oil test (sec. 81) was drilled on the east side of the Tularosa Valley northeast of the jarilla Mountains and about 8 miles west of the southern Sacramento Mountains. At a depth of about 3,060 feet, below intertongued limestones and red beds of the Abo, Hueco, and Bursum(?) formations, Pennsylvanian rocks were encountered (Pray, 1959) that appear to be about 3,570 feet thick and that overlie the Upper Mississippian Helms formation. Dips of up to 30 degrees are reported from upper beds in the test hole, suggesting that the thickness of the Pennsylvanian is exaggerated by penetration of steeply dipping beds.

About 470 feet of the Mississippian Helms and Rancheria formations was drilled through below the Pennsylvanian beds, whereas in Grapevine Canyon, at the southern end of the Sacramento Mountains to the east, these two formations total only 360 feet. The Helms and Rancheria formations thicken rapidly in a southward direction in this area, but the oil test is almost due west of the outcrop measured section; i.e., normal (perpendicular) to the direction of thickness variation. If the actual thickness of the Helms and Rancheria formations in the well is nearly that of the Grapevine Canyon section, an exaggeration ratio of 36 to 47 is indicated; if applicable to the Pennsylvanian, this suggests a true thickness of 2,735 feet for the Pennsylvanian sequence.

Desmoinesian and older Pennsylvanian beds would be about 695 feet thick (reduced from 910 feet), and Missourian and Virgilian strata about 2,040 feet thick (reduced from 2,660 feet). However, in the southern Sacramento Mountains, the Missourian and older Pennsylvanian rocks, the Gobbler and Beeman formations, are about 1,640 feet thick (sec. 78); as the Missourian is about 500 feet thick, the pre-Missourian Pennsylvanian is about 1,140 feet thick. This is almost twice the 695 feet calculated from thicknesses of the Mississippian units and is even less than the 910 feet of Desmoinesian and Derryan beds penetrated. The thickening of the section encountered in the well, as compared with the Sacramento Mountains outcrops, is almost entirely at the top of the Pennsylvanian in beds attributed to the Virgilian, although Pray (1959, fig. 16) suggested that the upper 500 feet may be a Bursum equivalent. In the San Andres Mountains, 30 miles to the west, the Virgilian Panther Seep formation is about 2,400 feet thick (sec. 79), which is similar to the thickness of the Virgilian in the oil test.

About 7 1/2 miles east-southeast of the Plymouth test, the Sun Oil Co. No. 1 Pearson well (sec. 82) was drilled on the edge of the Sacramento Mountains, south of Culp Canyon. Outcrops near the well site are of the lower tongue of the Abo red beds (Powwow conglomerate correlative?) and the lower part of the Hueco limestone (Pendejo tongue). The rocks drilled are anomalous, at least down to the top of the Bug Scuffle limestone member of Pray's (1959) Gobbler formation at a depth of 3,030 feet. Only 5 miles to the northeast, along Culp Canyon, Bachman and Hayes (1958) measured about 600 feet of Hueco limestone below the upper tongue of the Abo red beds, and about 175 feet of Abo below the Hueco, although the lower 180 feet of the Hueco is of interbedded limestone and clastic rocks. Whereas the well apparently spudded in lower Hueco beds, Wolfcampian fusulinids are reported as low as a depth of 1,940 feet (fig. 27). A possible base of the Bursum faunal zone is at 1,990 feet, at the base of intercalated green fossiliferous feldspathic limy sandstone and arenaceous calcarenite that contain pebbles of limestone. The massive brown limestone above this clastic unit is oolitic and algal, and has yielded lower Bursum fusulinids.

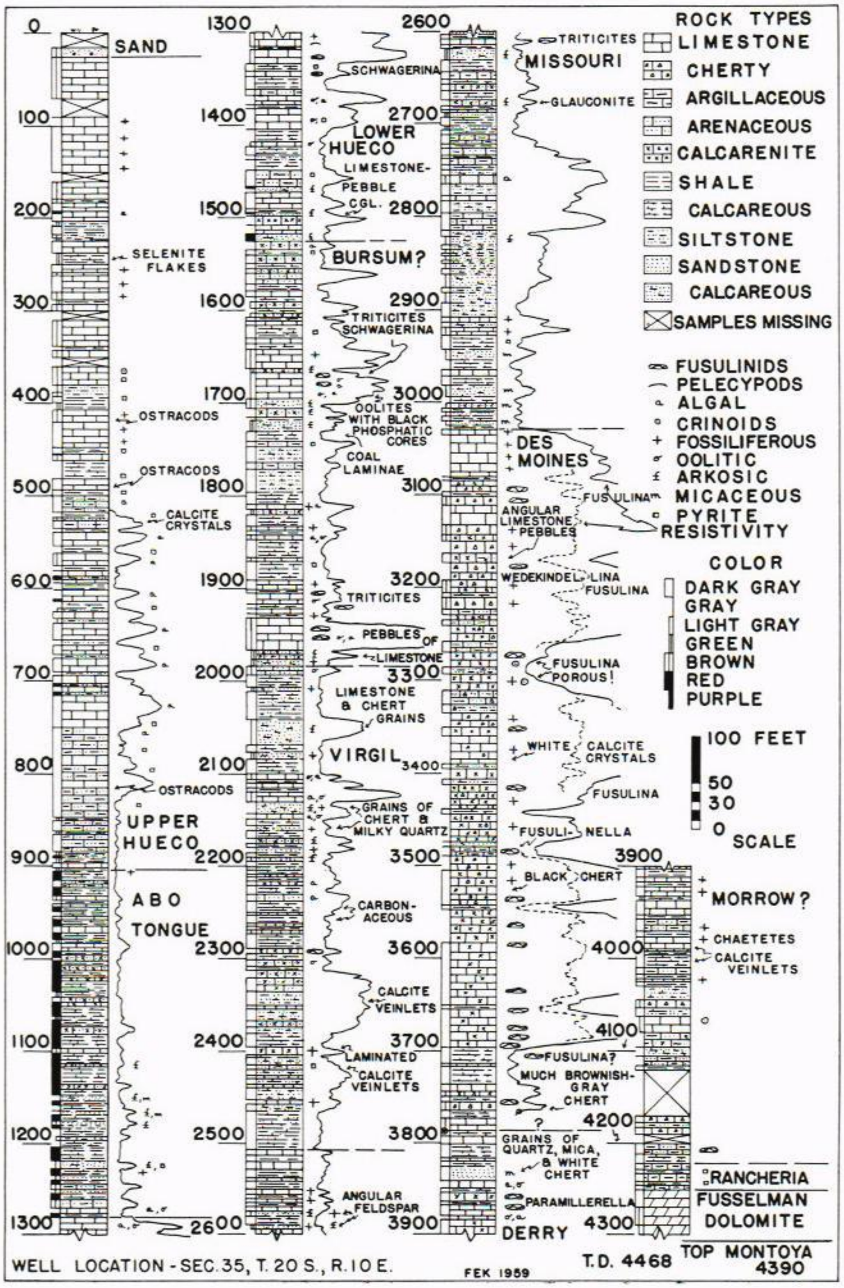


Figure 27

PERMIAN AND PENNSYLVANIAN ROCKS DRILLED IN SUN NO. 1 PEARSON OIL TEST

Possible equivalents of the Bursum formation, and of the Laborcita formation of Otte (1959), are, in the 1,520- to 1,990-foot depth interval, a sequence of dark-gray to black, greenish, and brownish limestone, arenaceous calcarenite, calcareous shale, and limy feldspathic sandstone. Oolitic and algal beds, as well as some laminae of bone coal, are notable. From the base of the thin alluvium to the 1,520-foot depth are 3 units, apparently all of Wolfcampian age, as dated by fusulinids and ostracods, and correlative with the Hueco limestone and Abo red beds. The upper 900 feet is of dark-gray to black or brown limestones with some interbedded green, gray, and black pyritic shale, and dark-gray to red calcareous siltstone. Algal limestone is prominent in the 500- to 900-foot interval. From depths of 900 to 1,280 feet there is a red-bed Abo-like sequence, with some brown, green, and dark-gray strata, dominantly of shale and silty to arenaceous calcarenite in the upper part, but of feldspathic micaceous sandstone and limy shale near the base. The lower Hueco, at depths of 1,280 to 1,520 feet, is chiefly an upper sequence of dark-gray to light-gray, algal, oolitic, fusulinid-bearing limestone, whereas the basal beds are mainly red to gray arkosic sandstone, gray shale, black silty limestone, and gray calcarenite. Fragments of limestone pebbles occur in the lower, coarser grained clastic units.

This Permian sequence contrasts with that of the outcrop in the southern Sacramento Mountains, 5 to 10 miles to the east, where there does not appear to be any Bursum equivalent, and where the postBursum Wolfcampian strata consist of lower and upper red-bed sequences with a medial limestone tongue, the reverse of the middle red-bed tongue, between limestone sequences, that was encountered in the Sun No. 1 Pearson oil test.

Most of the intertonguing of the Abo red beds, which thicken to the north, and the Hueco limestones, which thicken to the south, occurs within a distance of 10 to 15 miles near and north of Ash Canyon, in the San Andres Mountains (about 35 miles west of the Sun No. 1 Pearson well); directly to the east (of Ash Canyon), in the southern Sacramento Mountains, the bulk of this red bed-limestone intertonguing takes place between Dog Canyon and Culp Canyon, a distance of about 12 miles. Farther to the west, along the Rio Grande, a similar intertonguing takes place at the same latitudes from the southern Caballo Mountains southward to the Robledo Mountains. The rocks encountered in the Sun No. 1 Pearson test emphasize that the well was drilled near the northern marine margin of the hinge line between dominant Abo red-bed deposition and Hueco marine limestone sedimentation.

The thick section of Bursum(?) and lower Hueco strata in this oil test, and their lithologies, suggest that some upper unfossiliferous part of the Panther Seep formation (Kottlowski et al., 1956) of the southern San Andres Mountains, tentatively believed to be of upper Virgilian age, is probably of early Wolfcampian age; discussion of these lower

Permian strata is therefore germane in this synopsis of the Pennsylvanian beds.

There are other pertinent problems, if somewhat oblique to that of the Pennsylvanian, in this oil test. To the east in the outcrop, and to the west in the Plymouth No. 1 Evans well, the pre-Pennsylvanian rocks consist of 360 to 470 feet of Mississippian strata, 5 to 25 feet of the Devonian, and 65 to 120 feet of the Fusselman dolomite. In the Sun No. 1 Pearson test, the base of the Pennsylvanian appears to be near the depth of 4,220 feet below relatively fine-grained clastic beds bearing (caved?) fusulinids. The rocks at a depth of from 4,220 to 4,250 feet are dark argillaceous limestone and dark calcareous pyritic shale apparently of the Mississippian Rancheria formation. The dark-gray to brownish crystalline dolomite at the 4,250- to 4,290-foot depth seems to be an atypical Fusselman unit. Only 30 feet of Mississippian strata appears to be present!

Beds in the nearby outcrops are cut by several faults, and the out-cropping strata (as well as some of the beds in the oil test) have dips of 10 to 20 (in some places 35) degrees. Calcite veinlets, in chips and cores, and scattered crystals of calcite suggest some fracturing and possible faulting of the strata encountered. The abnormally thin Mississippian section may, however, record local erosion of upper Mississippian beds in early Pennsylvanian (and late Mississippian?) time.

Even if the beds drilled in the oil test have an average dip of 15 degrees, the thicknesses penetrated are only exaggerated 3 to 4 percent. The Wolfcampian section (top eroded) would be 1,930 feet thick instead of 1,990 feet, and the Pennsylvanian beds would total 2,160 feet instead of 2,230 feet in thickness.

Virgilian strata are probably about 515 feet thick (1,990-2,505) and are dark silty to calcarenitic limestone, dark limy siltstone and fine-grained feldspathic sandstone, and blackish limy to silty shale—lithologies similar to those of the Panther Seep formation in the San Andres Mountains, as well as resembling some of the Wolfcampian beds. Algal and oolitic limestones, arkosic arenaceous calcarenite, and arkosic limy sandstones containing grains of limestone, chert, and milky quartz stand out amid the upper Virgilian beds. Much of this clastic material apparently was derived from the Pedernal uplands to the east and, as should be expected nearer the source, is coarser grained than similar rocks in the southern San Andres Mountains.

Missourian beds, poorly dated by sparse fusulinids, are about 525 feet thick (2,505-3,030) and grade downward from upper interbedded blackish limestone and shale into medial interbedded dark-gray silty limestone, greenish feldspathic calcareous sandstone, feldspathic arenaceous calcarenite, and blackish limy siltstone, and into lower interbedded dark-gray limy siltstone, light-gray micaceous calcareous sandstone, and blackish limestone and shale. This sequence is thicker and contains more coarser grained clastic beds than the roughly correlative Beeman formation of the southern Sacramento Mountains outcrops to the northeast.

Desmoinesian beds, more or less correlative to Pray's Bug Scuffle limestone member of the Gobbler formation, may be as much as 760 feet thick (3,030-3,790), although identification of the fusulinids in the lower beds varies with the individual paleontologist. Derryan *Fusulinella* were identified below depths of 3,650 feet by some specialists, but Desmoinesian *Fusulina* were believed present (cave?) in lower beds by other specialists. Gray to brown cherty limestone and fossiliferous cherty calcarenite are typical of this zone; a few dark-gray siltstone inter-beds occur in the upper part of the section, whereas blackish calcareous shales are interbedded in the lower part. Some of the crinoidal calcarenites are surprisingly porous.

The lower Pennsylvanian beds are about 430 feet thick (3,790-4,220), including upper strata of Derryan age and probable Morrowan rocks in the lower part. Upper beds of these zones are blackish limestone and shale, microalgal and micro-oolitic, with a prominent bed of dark-gray, noncalcareous, fine- to medium-grained sandstone (subgraywacke?) containing angular grains of quartz, white chert, and mica. Medial beds are interbedded blackish limestone and calcareous to carbonaceous shale; the lower rocks include light-gray to blackish, cherty to silty limestones, gray to black limy siltstone and cherty sandstone, and black carbonaceous shale. These basal Pennsylvanian strata do not include much coarse-grained clastic rock, a trait typical of the basal Pennsylvanian in the southern Sacramento Mountains but contrasting with the basal beds in the northern Sacramento Mountains and the central and northern San Andres Mountains. To the south, in the Franklin and Hueco Mountains, lower Pennsylvanian strata are chiefly massive limestones.

About 8 miles south-southwest of the Sun No. 1 Pearson well, the Otero Oil Co. No. 1 McGregor oil test (sec. 84) was drilled on the west edge of the foothills of Horse Mesa (Otero Mesa). The base of the Hueco red beds and limestones was encountered at a depth of 815 feet, and the well bottomed in upper(?) Pennsylvanian strata at 1,730 feet. About 9 miles to the south-southeast, the Kinney Oil and Gas Co. No. 1 State oil test (sec. 85) was reported by Carl C. Branson (personal communication to Robert L. Bates) to have spudded in the upper Hueco formation and to have bottomed at 2,168 feet at the top of Mississippian rocks after penetrating about 1,170 feet of Pennsylvanian strata.

Near the indefinite boundary between the Tularosa Valley and the Hueco Basin, about 9 miles north of the New Mexico-Texas line, the Ernest No. 1 Located Land Co. oil test (sec. 89) bottomed in about 1,555 feet of Pennsylvanian rocks whose top is at a depth of 2,385 feet beneath the Powwow conglomerate. The Pennsylvanian strata appear lithologitally similar to those of the Panther Seep formation and include several beds of gypsum (as do the upper Pennsylvanian outcrops in the northern Franklin Mountains to the southwest).

About 25 miles east of the Ernest oil test, on the northeast side of the Hueco Mountains, the Seaboard Oil Co. No. 1 Trigg Federal oil test (sec. 91) bottomed in lower Pennsylvanian or upper Mississippian rocks at a depth of 5,600 feet. The top of red beds apparently equivalent to the basal Powwow member of the Hueco formation was hit at a depth of 3,040 feet, the top of the Canyon-Missouri series being reported (scout report) at 3,785 feet, and the top of the Strawn-Des Moines series at 3,990 feet. The 745 feet between the top of the Powwow and the Missourian is made up of interbedded red beds, greenish limy shales, and reddish to greenish limestones. Arkosic sandstones occur in the upper 100 feet, and buff, dark-gray, and light-gray silty limestones are numerous in the lower 450 feet, suggesting that the Pennsylvanian-Hueco contact is near the depth of 3,350 feet. About 10 miles to the southwest, in the north-central Hueco Mountains, erosion during pre-Hueco time almost entirely removed the Virgilian strata, and in oil tests to the northeast, Missourian beds also are absent. The pre-Missourian beds total almost a thousand feet in the Hueco Mountains but appear considerably thicker in the Seaboard oil test, suggesting that the beds dip at relatively high angles or are repeated by faulting. Lithologies are similar to the section in the Hueco Mountains, shaly silty limestones and limy shales being dominant.

### SOUTHERN PEDERNAL MOUNTAINS

East of the area shown on Plate 1 (index map), Pennsylvanian rocks are thin or absent, indicating the location and existence of the Pennsylvanian-age Pedernal Mountains or Pedernal landmass. Most geologists suggest that the main bulk of this landmass in Pennsylvanian time was north of T. 18 S. (about the latitude of sec. 78, p1. 1). To the south, on the eastern slope of Otero Mesa, south of the Sacramento Mountains, and southward to the New Mexico-Texas Stateline, the few scattered oil tests suggest either a continuous, though sinuous range, or a group of partly isolated islands in the late Pennsylvanian seas stretching southward to join the Diablo Platform of King (1942).

About 12 miles east-southeast of Alamogordo, the Southern Production Co. No. 1 Cloudcroft oil test encountered only 800 feet of Pennsylvanian strata, mostly of pre-Missourian age, unconformably overlain by Abo red beds and conglomerates. About 17 miles east-northeast of the Kinney No. 1 State well (sec. 85), the Turner No. 1 Everett oil test found thin (200 feet?) or no Pennsylvanian rocks beneath the Powwow member of the Hueco formation and above Devonian beds. The Union Oil Co. No. I McMillan oil test, drilled 20 miles southeast of the Kinney No. 1 State well, penetrated 1,030 feet of Pennsylvanian beneath the Powwow red beds and conglomerates and above Mississippian rocks.

Lloyd (1949, fig. 4) noted that only Derryan and Desmoinesian strata are present in this well. In a north-south line about 30 miles east of the east border of Plate I, a series of oil tests[2] encountered Precambrian or thin Lower Paleozoic rocks beneath lower Permian strata.

Several oil tests drilled in the 1953-1958 period, however, suggest either an eastern offshoot of the Orogrande basin near and south of the village of Pinon (T. 19 S., R. 15 E.), or thick local remnants of Pennsylvanian strata (not removed by erosion in early Permian time). The Stanolind No. 1 Thorn Unit (sec. 15, T. 21 S., R. 14 E.) bottomed at 4,646 feet in probable lower Pennsylvanian rocks and may have cut through more than 2,000 feet of Pennsylvanian strata. The Zapata Petroleum Corp. No. 1 Federal (sec. 14, T. 20 S., R. 14 E.) may have penetrated almost 2,000 feet of Pennsylvanian beds.

South of the New Mexico-Texas Stateline, in northeastern Hudspeth County (about 39 miles east-southeast of the Seaboard No. 1 Trigg Federal well, sec. 91), the General Crude Oil Co. No. I Merrill & Voyles oil test (sec. 8, Block 69, T. 2 S.) went into a thin section of the Upper Mississippian Helms formation beneath the Powwow member of the Hueco formation, with no Pennsylvanian rocks reported (Haigh, 1953, p. 78-81). The nearby Jones No. 1 Mowry oil test (sec. 36, Block 70, T. 2 S.) is reported (ibid.) to have encountered about 140 feet of Pennsylvanian limestone beneath the Powwow conglomerate and above a thick section of the Helms formation. In the Pump Station Hills, about 10 miles southwest of the Jones No. 1 Mowry well, Precambrian granite porphyry and rhyolite (Masson, 1956) apparently are overlain by YesoBone Spring limestones (Leonardian).

The Magnolia No. 1-39881 University oil test (sec. 19, Block C, Univ. Lands) was drilled about 31/2 miles south of the New Mexico-Texas Stateline and 19 miles east of the El Paso and Hudspeth Counties boundary. Haigh (ibid.) identified about 1,495 feet of Pennsylvanian strata in the oil test beneath the Hueco formation and above the Helms formation, but almost 685 feet of the Pennsylvanian interval is occupied by igneous sills. The Seaboard & Shamrock No. 1 C University oil test, drilled 41/2 miles southeast of the Magnolia well, encountered (West Texas Geol. Soc. Guidebook, 1949, p. 86) Desmoinesian limestones below the Hueco formation and penetrated 1,145 feet of Pennsylvanian beds before topping the Helms formation.

On the east edge of the Diablo Plateau, 13 miles east of the boundary between El Paso and Hudspeth Counties and 12 miles south of New Mexico, the California Co. No. 1 University Theisen oil test (sec. 19, Block E, Univ. Lands) bottomed in Precambrian schist at a depth of 4,725 feet. Some geologists (West Texas Geol. Soc. Guidebook, 1949, p. 86-87) consider that the base of the Hueco formation and the top of

2. The Hunt No. 1 McMillan-Turner (sec. 6, T. 26 S., R. 16 E.), Sun No. 1 Pinon (sec. 19, T. 19 S., R. 17 E.), Gulf No. 1 U Chavez (sec. 10, T. 18 S., R. 16 E.), Humble No. 1 N State (sec. 35, T. 14 S., R. 17 E.), and the Stanolind No. 1 Picacho (sec. 10. T. 12 S., R. 18 E.).

the Mississippian were encountered at a depth of 1,642 feet and that no Pennsylvanian rocks were penetrated. Haigh (1953, p. 82-83) reported Pennsylvanian strata from a depth of 600 to 1,780 feet beneath the Hueco formation and above the Helms formation.

The Hueco formation is unconformable (fig. 28) on Missourian beds at the east end of Powwow Canyon, about 12 miles west of the well site, and the upper Pennsylvanian rocks exposed appear to thicken to the northeast. The basal Pennsylvanian in Powwow Canyon is massive cherty coralline limestone, but to the south, on Rancheria Mountain, the basal beds are greenish limy sandstones, blackish fossiliferous silty shales, and dark-gray sandy fossiliferous limestones. If compared with the Powwow Canyon section, one might place the top of the Mississippian at the first clastic beds encountered below the Permian-Pennsylvanian limestones. Cuttings indicate that typical Helms formation strata probably occur only below a depth of 1,780 feet, the sandstones, sandy limestones, and shales from 1,642 to 1,780 feet being similar to basal Pennsylvanian clastic rocks near Rancheria Mountain, especially resembling some of the micaceous glauconitic sandstones.

The upper 1,642 feet of rocks penetrated in the oil test is predominantly limestone; it has either all been referred to the Hueco formation, or the upper part to the Hueco formation and the lower 1,180 feet to the Pennsylvanian. Conglomerates and reddish clastic rocks typical of the basal Powwow conglomerate member of the Hueco formation are not present, although in the Hueco Basin Oil Co. well about 6 miles to the north-northwest the conglomerate is more than 270 feet thick. Similarly, the Deer Mountain red shale member of the Hueco formation does not appear to be present in the well, although 7 miles to the west outcrops of the member are about 175 feet thick and 775 to 1,050 feet above the base of the Hueco formation.

Some thin reddish shales and sandstones, along with pinkish dolomitic limestones, occur at a depth of 315 feet, which appears to be near the Hueco formation-Pennsylvanian contact. Limestones below are somewhat sandy, similar to the lowermost Virgilian beds in the northern Hueco Mountains, and the main mass of the limestones from a depth of 320 to 1,640 feet is cherty and includes interbedded shales and argillaceous marls. Chert makes up as much as 70 percent of some of the beds. Although some of the limestones in the Hueco formation are cherty, they rarely contain more than scattered chert nodules. Chert in some of the upper beds is whitish to orange, and some of the limestones are crowded with black phosphatic fossil fragments; both features are characteristic of Missourian beds in the Hueco Mountains.

### HUECO MOUNTAINS

In the Hueco Mountains north of Powwow Canyon (which is traversed by U. S. Highway 62-180), the Pennsylvanian sequence (sec. 94) appears to be more than 1,700 feet thick where upper beds were not removed by erosion during early Wolfcampian time. The Morrowan(?) series has a maximum thickness of 410 feet (Thompson, 1948, p. 69-72) and includes chiefly massive coralline limestones, with several cherty marker beds. In places the basal 25 to 50 feet is of coarse-grained to conglomeratic reddish-brown sandstone, with lenses of chert pebbles and some beds of dark sandy shale; limestone, however, is dominant, in contrast with many of the basal Pennsylvanian sections to the north. The Derryan is 375 to 425 feet thick, consisting of a lower two-thirds of massive- to thin-bedded cherty limestones and an upper third of argillaceous nodular limestone and limy shale.

The Desmoinesian is 310 to 400 feet thick, is marked by a basal thick massive-bedded light-gray cherty limestone, a medial limy shale and shaly limestone sequence, and upper massive light-gray cherty limestones overlain by interbedded cherty limestones and limy shales. The Missourian may be as much as 315 feet thick and consists of interbedded cherty limestones and limy shales, with some beds of limestone-pebble conglomerate. Most of the chert weathers orange, and many of the limestones are speckled by black phosphatic flecks (King et al., 1945). Massive coralline and algal reefs as much as 175 feet thick occur in places and appear laterally equivalent to upper Missourian or lower Virgilian limestones. Virgilian strata occur only in the northern part of the range and are at least 200 feet thick beneath the early Wolfcampian erosion surface. They are interbedded fusulinid-bearing limestones, limestone-pebble conglomerates, and sandy pebbly marls.

Near the head of Powwow Canyon, the basal beds of the Hueco formation overlie the Pennsylvanian strata with pronounced erosional and angular unconformity, resting in turn on Missourian, Desmoinesian, and Derryan strata in a distance of about a mile along the canyon wall (fig. 28). About 10 miles to the southeast, on Rancheria Mountain (sec. 95), only the basal 400 feet of the Pennsylvanian remains. A few miles farther south, the Hueco formation is unconformable on Mississippian and older strata. About 30 miles south-southeast of Rancheria Mountain, on the north side of the Finlay Mountains, an oil test penetrated a thin section of the Hueco formation overlying Silurian strata (West Texas Geol. Soc. Guidebook, 1949, p. 86).

Hardie (1958, p. 43-45) mapped the geologic units of the northern Hueco Mountains, north of the New Mexico-Texas Stateline and north of the area of King and King's (1945) geologic map. Only the upper 1,200 feet of the Pennsylvanian strata is exposed. These strata have a slightly greater northward dip than the overlying basal massive limestones of the Hueco formation, so that progressively younger Pennsylvanian beds are exposed beneath the Permian in a northward direction. Probably most of the pre-Hueco strata exposed are of Virgilian age.

The lower 900 feet of the outcropping Pennsylvanian is of alternating shales, limestones, and limestone-chert-pebble conglomerates, whereas the upper 300 feet is chiefly massive limestone with a few inter-

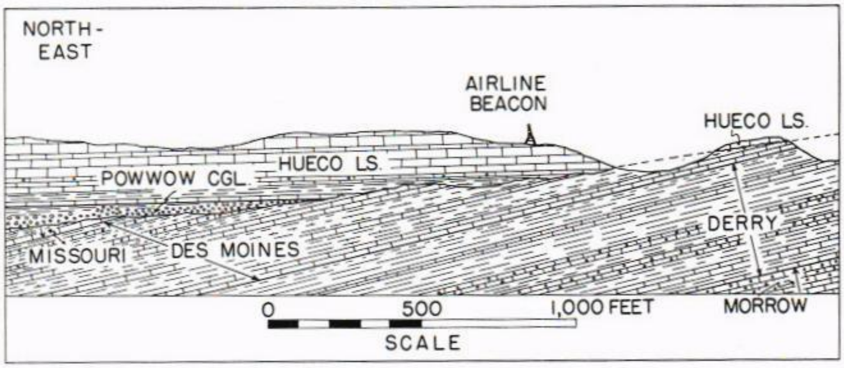


Figure 28

SKETCH OF UNCONFORMITY AT BASE OF PERMIAN STRATA IN POWWOW CANYON

Modified from King, King, and Knight (1945).

beds of shale and conglomerate. Calcareous shale, pale grayish-red to olive and light-gray, makes up about half of the section. The limestonechert-pebble conglomerates and associated calcarenites, dark-gray to gray, compose almost 15 percent of the section; they appear to be in continuous tabular beds, although locally filling channels cut in underlying rocks. Most of the limestone clasts, granule to cobble size, are rounded; chert grains are mainly red jasper; the sparse quartz grains are angular and range from fine sand to silt size. Locally the conglomeratic beds contain petrified logs, Hardie (1958, p. 44) reporting one piece 12 feet long and another 3 feet in diameter.

Along the northwest edge of the northern Hueco Mountains, a gypsum bed from 25 to 75 feet thick crops out in the upper 200 feet of the Pennsylvanian below the lower Hueco limestones, but Hardie (1958, p. 45) did not find any gypsum beds on the northeast side of the range within the Pennsylvanian outcrops encircling laccolithic Red Mountain.

These northern Hueco Mountains Pennsylvanian outcrops are informative. They establish the northward thickening of the upper Pennsylvanian (and earliest Wolfcampian?) beneath the erosion surface at the base of the Hueco formation, and they are of the "Panther Seep formation" type of sediments, which are now known to occur from the Rhodes Canyon area of the San Andres Mountains (sec. 67, pl. 1) southward 90 miles to the west-central Franklin Mountains, and from the Sunray Mid-Continent No. 1M Federal oil test (on the west slope of the Jornada del Muerto) southeastward 70 miles to the Sun No. 1 Pearson well, and southward to the northern Hueco Mountains. These rocks are chiefly elastic materials laid down in shallow marine waters, often in a shallow euxinic basin, as suggested by the black silty calcilutites, and at times under hypersaline conditions, resulting in deposition of gypsum. Then again, local and probably extensive shoaling areas led to the development of algal bioherms and, at the outset, fossiliferous calcarenite lenses and limestone conglomerates. Cyclic sedimentation was usual; irregular cycles in the southern San Andres Mountains consist of basal limy olive arkosic crosslaminated sandstones. These sandstones, in part filling channels cut into underlying rocks, were probably blanketlike stream or near-shore deposits; they grade upward into greenish sandy shale, and then into blackish silty carbonaceous calcilutites interbedded with dark limy to carbonaceous shales (Kottlowski et al., 1956, p. 44).

The cyclic sediments of the type Fresnal group, the upper Virgilian in the northern Sacramento Mountains, as described by Cline (1959), are more typical of near-shore deposits laid down close to their Pedernal upland source; rapid lateral changes are as prominent as the vertical cyclic arrangement. The Virgilian of the northern Hueco Mountains appears to be a mixture of the blackish fine-grained Panther Seep sediments and of the Fresnal group's alternating gray fossiliferous marine limestone and red bed-limestone conglomerate cycles.

Pennsylvanian rocks do not crop out in the Hueco Basin between the Hueco Mountains and the Franklin Mountains; the few oil tests drilled in the Hueco Basin south of the New Mexico-Texas Stateline have encountered from 3,000 to 4,920 feet of Cenozoic bolson deposits without striking any consolidated bedrock. The mountain ranges on the southwest side of the Rio Grande in Mexico are composed only of Cretaceous and Cenozoic rocks, as far as is known. The only relatively complete Pennsylvanian section in the Franklin Mountains is at the northwest and west-central part of the range (sec. 93), as has been described.

## NORTHERN MEXICO

In northern Mexico, south of southeastern Arizona and southwestern New Mexico, Pennsylvanian rocks crop out (King, 1942, p. 109-119) in only a few of the isolated ranges in the basin-and-range country and northern Sierra Madre Occidental. Taliaferro (1933, p. 16-19) measured about 2,450 feet of the Naco limestone above the Mississippian Escabrosa limestone in the mountain ranges around the Cabullona Basin, about 20 miles south of the Arizona border south of Bisbee. Both Pennsylvanian and Permian beds were probably grouped in the Naco limestone. Southeast of Cabullona and about 55 miles south of Arizona, near El Tigre and near Bavispe, Imlay (1939, p. 1729-1733) measured about 5,500 feet of Carboniferous and Permian limestones, of which less than 2,250 feet may be of Pennsylvanian age. Mulcahy and Velasco (1954) correlated the Puertocitos limestone of the Cananea mining district (50 miles south of Bisbee), which is about 2,000 feet thick, with the Naco limestone. The Puertecitos overlies the Chivatera mineral zone, which is developed in a limestone said to be similar to the Mississippian Escabrosa limestone, and is overlain by a thick series of volcanic rocks.

About 20 to 25 miles east and southeast of the Big Hatchet Mountains (sec. 96) in northernmost Mexico, Permian and Pennsylvanian strata crop out in Sierra de los Moscos, Sierra Boca Grande, and Sierra de Enmedio. The Permian and Pennsylvanian rocks appear to be similar to those exposed in the Big Hatchet Mountains, according to Robert A. Zeller, Jr. (personal communication, 1956).

# *Areal Summary of Southeastern Arizona*

In a discussion of Pennsylvanian rocks, the southeastern quarter of Arizona is divisible into three geomorphic regions. The southeast corner and southern area along the Mexican border (pl. 1) constitute one region, encompassing most of Cochise, Pima, and Santa Cruz Counties; the 50-mile-wide strip along the Gila River, including most of Greenlee, Graham, Pinal, and southern Gila Counties, is the second region; and the Mogollon Rim and southern edge of the Colorado Plateau, embracing parts of Apache, Navajo, Coconino, Yavapai, and northern Gila Counties, is the third natural subdivision.

## SOUTHEASTERN ARIZONA

Southeastern Arizona exhibits the topography that is typical of the Mexican Highlands section of the Basin and Range province, in which north- and northwest-alined fault-block mountain ranges alternate with similarly alined valleys and bolsons. Complex thrust faulting, intrusion, and mineralization obscure some of the stratigraphic relationships in the fault-block mountains. Pennsylvanian strata are known to crop out in the Dos Cabezas, Chiricahua, Pedregosa, Swisshelm, Mule, Dragoon, Little Dragoon, Huachuca, Whetstone, and Guadalupe Mountains, and in the Naco, Gunnison, and Tombstone Hills, in Cochise County; in the Patagonia, Santa Rita, Empire, Sierrita, Tucson, Rincon, Santa Catalina, Waterman, and Silver Bell Mountains in Santa Cruz and Pima Counties; and in the Vekol Mountains in southwestern Pinal County (pl. 7).

### CENTRAL COCHISE COUNTY

The Pennsylvanian rocks in the Dragoon, Little Dragoon, and northern Mule Mountains, and Tombstone and Gunnison Hills have been mapped and studied in detail by Gilluly et al. (1954). In the Little Dragoon Mountains and Gunnison Hills, Pennsylvanian rocks overlie the Black Prince limestone of middle to late Mississippian age; to the south, in the Dragoon and northern Mule Mountains and Tombstone Hills, Pennsylvanian strata overlie the early or middle Mississippian Escabrosa limestone with little or no evidence of either erosional or angular discordance, despite the apparent lack of beds equivalent to the Black Prince limestone.

Gilluly et al. (1954, p. 15-16) raised the Naco limestone to Naco group and subdivided the group into six formations, the basal subdivision being the Horquilla limestone, of Derryan, Des Moinesian, Missourian, and early(?) Virgilian age, but the second oldest subdivision being the Earp formation, of early(?) Virgilian to early Wolfcampian age. The overlying Colina limestone contains a fauna similar to that of the Hueco formation, of middle and Late Wolfcampian and perhaps early Leonardian age. The upper three formations, the Epitaph, Scherrer, and Concha formations, are of Leonardian age. The Horquilla limestone and Earp formation are the approximate equivalents of the post-Mississippian part of the Magdalena group of New Mexico as the group is used by the U. S. Geological Survey and are equivalent to the upper Sandia formation, Madera limestone, and Bursum formation.

The Horquilla limestone is the most widely exposed formation of the Naco group, forming gently sloping hills and ledgy dip slopes above the cliffs of Mississippian limestones. Most of the Horquilla limestone is dense, aphanitic, thin to medium bedded, and pinkish gray on fresh fracture, with some scattered thick- to massive-bedded, medium-gray, medium to coarsely crystalline beds. The basal limestones are thin bedded, shaly, and mottled, with thin interbeds of reddish-brown shale. A few lenses of reddish-weathering shaly limestone occur in the upper part of the formation. Chert nodules and small fusulinids are characteristic features.

The Horquilla limestone is about 1,200 feet thick in the northern Mule Mountains and Tombstone Hills (sec. 28) but thickens northward to 1,600 to 1,750 feet in the Gunnison Hills (sec. 20) and Little Dragoon Mountains. The clastic ratio increases from essentially zero in the Tombstone Hills to about 0.08 in the Gunnison Hills. The clastic beds are entirely shale or siltstone, except for some coquina calcite "sands." The contact between the Horquilla limestone and overlying Earp formation is arbitrarily chosen at the point where shales that occur in the upper part of the Horquilla limestone become dominant over limestone interbeds. The lithology is similar to that of Derryan to early Virgilian beds in southern New Mexico.

The Earp formation consists of interbedded thin-bedded shaly limestone, medium- to massive-bedded limestone, orange laminated dolomite, reddish shale, and sandstone. The formation ranges from about 600 feet in thickness in the Tombstone Hills to more than 1,100 feet thick northward in the Gunnison Hills. The characteristic outcrop is a gentle ledgy slope at the base, steepening upward to a fairly persistent ledge beneath the ledgy cliff of the overlying Colina limestone. Clastic ratios range from 0.99 at Earp Hill in the southern Tombstone Hills, and 1.01 in the Dragoon Mountains, to 0.71 in the Gunnison Hills. Sand-shale ratios are 0.79 at Earp Hill, 0.23 in the Dragoon Mountains, and 0.97 in the Gunnison Hills.

The thicker and more sandy section of the Earp formation in the Gunnison Hills has been mapped by John R. Cooper, U. S. Geological Survey, as two members, a lower member of light-colored limestones, bearing abundant fusulinids, and an upper member of dark limestones with gastropod-cephalopod faunas and a conspicuous basal conglomerate.

Concerning the faunas collected from the type Earp formation, Williams noted (Gilluly et al., 1954, p. 36) that "probably no beds in this stratigraphic section are younger than early Virgil, if so young as that." Fusulinids, however, were not found in the upper part of the Earp formation at Earp Hill, although Upper Pennsylvanian brachiopods were found within 115 feet of the top. In the section of the Earp formation in the Gunnison Hills, not much more than 350 feet of the lower part of the formation can be attributed to the Pennsylvanian on fusulinid evidence. Above, except for a basal Permian(?) sandstone unit of Cooper (No. 66), the lower member of the Earp formation contains almost no sandstone and is similar faunally and lithologically to the Bursum formation of southern New Mexico.

Although the lithic units of the Naco group of Gilluly et al. (1954) were proposed for the Pennsylvanian and lower Permian strata only in central Cochise County, the formations can be recognized as far east as the Big Hatchet Mountains in New Mexico, and westward to the Cochise-Pima county line in the Whetstone Mountains. At the original section of the Naco in the Naco Hills, however, only the lower three formations of the Naco group of Gilluly et al. are exposed, the Horquilla, Earp, and Colina formations. Inclusion of upper Permian units in the Naco group greatly exceeds the beds placed in the original Naco and equates the Naco group with the Pennsylvanian and Permian systems. Stoyanow's (1936, p. 1276) restriction of the Naco limestone, his Naco sensu stricto, to the basal, predominantly limestone unit having Pennsylvanian faunas equivalent to the Horquilla formation of Gilluly et al. is more in keeping with the use of Naco by most Arizona geologists for the past twenty years (Bryant, 1955).

### NACO HILLS AREA

The section of Pennsylvanian rocks at the south end of the Naco Hills (sec. 31) has been measured by Harold R. Wanless (personal communication), of Illinois University, and the fusulinids studied by F. E. Williams (1951). The Horquilla formation, or Naco limestone sensu stricto, is about 1,050 feet thick, although the basal beds are involved in faulting, so that the base of the unit is not certain. The Derryan series is probably about 300 feet thick and consists mostly of light-gray fossil-fragment limestone, with shaly interbeds and, near the base, red shales containing limestone nodules and pebbles. The Desmoinesian is about 360 feet thick, chiefly of the typical cherty limestones, with upper Desmoinesian fusulinid faunas not found in upper relatively barren rocks.

No Missourian or lower Virgilian fusulinids are reported, but a sequence of limestones, siltstones, and upper dolomites, about 385 feet thick, is referred to the Missourian and is possibly the uppermost unit of the Horquilla formation. Wanless, however, suggests that 190 feet of overlying beds be included in the Horquilla formation. The Earp formation is probably about 735 feet thick, below the massive Colina limestone, and includes a basal 340 feet of possible Virgilian age, although the highest Virgilian fusulinids were found 275 feet above the base and the lowest Wolfcampian fusulinids near the top of the beds assigned to the Earp formation, leaving a 375-foot zone without fusulinids, an interval that appears to be transitional from Virgil into Wolfcamp.

The clastic ratio of beds assumed to be of Pennsylvanian age in the Naco Hills is about 0.41, although the many covered intervals arc difficult to interpret. Only a few feet of sandstone was seen and reported; the sand-shale ratio, therefore, is only 0.01. Shale and siltstone far exceed the amount reported by Ransome (1904), occurring for the most part as calcareous shale interbedded with nodular marly limestone. Much of the siltstone is clayey and is various tints of pink and light red. The limestones are typically light colored; many are pinkish gray, cherty, dense, and aphanitic, apparently being calcilutites, although calcarenites and coquinoid and coquina limestones are numerous in the Desmoinesian series. Some of the finely crystalline to aphanitic limestones are dolomitic, and most of them contain much quartz silt.

In the Huachuca Mountains, west of the Naco Hills, only about 300 to 400 feet of the lower part of the Naco formation is exposed in the thrust plates examined by Alexis (1949) and Weber (1950). In the Patagonia Mountains (sec. 30), west of the Huachuca Mountains, Smith (1956) noted the limestones of the Horquilla formation overlain by the red shales and thin shaly limestones of the Earp formation but gave no further description. Kartchner (1944) listed a description of Naco limestone (sensu stricto of Stoyanow) section that is the probable equivalent of the Horquilla formation, but only compared overlying beds with the Earp formation (Stoyanow's lower Manzano fauna beds) as described by Stoyanow. Many of the Pennsylvanian limestones of this district are sandy, silty, or argillaceous and are pinkish to greenish. Their thickness, in part estimated from somewhat incomplete data and examination, is about 1,130 feet, this total including both the Horquilla formation and perhaps 200 feet of Pennsylvanian beds in the basal part of the Earp formation. The clastic ratio is about 0.19, and the sand-shale ratio about 0.37, the shales, siltstones, and fine-grained sandstones occurring in the upper Pennsylvanian Earp sequence or as interbeds with sandy and silty calcarenites in the Horquilla formation. Basal beds overlying the Escabrosa limestone are of conglomerate and limy reddish sandstone containing pebbles of chert, jasper, and Mississippian limestone.

**WHETSTONE MOUNTAINS**

In the Whetstone Mountains, west of the Tombstone Hills and northeast of the Patagonia Mountains, the Horquilla formation is 825 to 1,300 feet thick, depending in part on where the upper contact is drawn, the thicker sections being to the south. Rocks below the Horquilla are reported to be the Escabrosa limestone or a thin representative of the upper Mississippian Black Prince formation. The Earp formation is from 600 to 900 feet thick and appears divisible into two distinct members separated by a conspicuous jasper-pebble conglomerate. Beds below the conglomerate appear to thicken in the southern part of the range. Fusulinids collected by S. M. Jones and W. D. Bacheller, Shell Oil Co., from strata below the conglomerate marker bed have been identified by J. H. Todd as very young Virgilian *Triticites,* suggesting that all of the beds below the conglomerate are of Pennsylvanian age. Tyrrell (1957), however, reported Wolfcampian *Triticites* from a limestone directly beneath the jasper-conglomerate marker bed. Identification of some species of *Triticites* as Virgilian or Wolfcampian may depend in part on the worker, but these beds must be near the Pennsylvanian-Permian boundary.

As no diagnostic fossils were found in the upper part of the Earp formation, the Wolfcampian age of the upper Earp can be corroborated by correlation with the Gunnison Hills section, where Henbest has identified *Schwagerina* from beds about 100 feet below a similar conglomerate. This suggests a somewhat risky, long-range correlation of the conglomerate with the Powwow conglomerate (of probable middle Wolfcampian age) at the base of the Hueco formation in New Mexico and Texas, which is unconformable on beds ranging from oldest Wolfcampian to Virgilian and older.

As Bryant (1955) has pointed out, the upper Pennsylvanian—lower Permian units of the Naco group as defined by Gilluly et al. (1954) (i.e., the Earp, Colina, and Epitaph formations) become indistinguishable westward from the Whetstone Mountains and are mapped as the Andrada formation, a term published by Eldred D. Wilson (1951, p. 50) for a sequence of interbedded limestones, dolomites, reddish siltstones, and gypsum. The Andrada formation, as thus defined, ranges from late Pennsylvanian to Leonardian in age.

Rocks of Pennsylvanian age are about 1,350 feet thick in the Middle Canyon area (sec. 24) in the center of the range, as reported by Willis W. Tyrrell, Jr. (1957), and by Jones and Bacheller, Shell Oil Co. In this canyon, the Horquilla formation ranges from 835 to 1,000 feet in thickness, and the Virgilian(?) part of the Earp formation is 350 to 440 feet thick. To the south, in Dry Canyon (sec. 25) and near Sands ranch, the Pennsylvanian beds are probably as much as 1,700 feet thick, the Horquilla formation being about 1,250 to 1,300 feet thick, as recorded by Wanless and by Jones and Bacheller, and the lower Earp formation, below the conglomerate marker beds, being about 400 to 475 feet thick. In this area, the upper 300 to 350 feet assigned to the Horquilla formation is almost 50 percent elastic rocks and 50 percent carbonate rocks;

therefore, the contact between the Horquilla and Earp formations could be drawn within the interbedded sequence.

This abrupt southward thickening of the Horquilla formation, 450-250 feet in a distance of about 5 miles, suggests that the relatively monotonous limestone sequence is not as simple as it may seem, and that valuable information could be gained by close examination and detailed mapping of the faunal zones and lithic units. Fusulinids identified by J. H. Todd, Shell Oil Co., show that the Horquilla formation in Dry Canyon ranges in age from Derryan to Missourian, the lower Earp formation containing only Virgilian fusulinids. The collection of Missourian fusulinids from the upper part of the Horquilla formation is from cherty limestones interbedded with shales and siltstones, a sequence and zone that is barren in much of southeastern Arizona.

As described by Tyrrell (1957), the Horquilla formation consists of three lithic units: (1) a lower 100 feet of gray limestone, in nodular thin lenticular beds, cherty in part, fossiliferous, cropping out as thin ledges or ledgy slopes, with thin interbeds of reddish shale and siltstone and containing Derryan *Prof usulinella* and primitive *Fusulinella;* (2) a medial 300 feet of gray thin- to thick-bedded fossiliferous limestones, containing numerous gray to black nodules and lenses of chert, masses of *Chaetetes* and late Derryan and early Desmoinesian fusulinids; the thicker bedded limestones form ledges or low cliffs, whereas silty or coquina limestones crop out as rubbly slopes; and (3) an upper 600 feet of ledge-forming gray limestones alternating with slope-forming shaly silty limestones, silty limy shales, and sandy calcareous siltstones. Late Desmoinesian, Missourian, and early Virgilian fusulinids were collected from the upper unit by Tyrrell.

The Earp formation can be divided into two lithic divisions: (1) a lower 450 to 540 feet of interbedded pebbly sandstone, siltstone, and shale, reddish to buff, with a few scattered nodular limestone interbeds; (2) an upper unit of black aphanitic dolomites and limestones interbedded with clastic beds. About 350 to 440 feet above the base of the Earp formation, 100 feet more or less from the top of the lower predominantly clastic sequence, is the marker conglomerate bed, 5 to 10 feet thick, lenticular, crossbedded, and composed of limestone and red chert pebbles in a tan limy sandstone matrix. The clastic rocks of the Earp formation are limy to marly, and the conglomerate lenses and pebbly sandstones contain chiefly limestone pebbles.

The clastic ratio for the Pennsylvanian beds (Horquilla formation and lower Earp formation) in and near Middle Canyon is 0.47 as compared with 0.78 for the Dry Canyon area; the sand-shale ratio is about 0.14, in comparison with 0.04 for the southern part of the Whetstone Mountains. About three-fourths of the increase in thickness from north to south is due to the increase in shale and siltstone beds.

The southern section in Dry Canyon and near Sands ranch can be divided roughly into eight lithic and faunal units: (1) a basal 35 feet of reddish conglomerate sandy siltstone and shale, with pebbles of chert and limestone; (2) about 115 feet of medium- to thick-bedded limestone capped by limy sandy siltstone; (3) 100 feet of thin- to medium-bedded limestone, with interbeds of nodular shaly limestone, containing an early Derryan fusulinid fauna; (4) about 370 feet of typical Desmoinesian limestones, partly cherty, ledge-forming, with shaly silty interbeds and early Desmoinesian fusulinids; (5) 170 feet of limy siltstone and shale with limestone interbeds; (6) 180 feet of interbedded shales, silt-stones, and limestones, bearing Missourian fusulinids; (7) 330 feet of interbedded silty limestones and reddish siltstones, containing Virgilian fusulinids; (8) about 400 feet of brown to grayish limy siltstones and silty sandstones with some limestone interbeds, containing late Virgilian fusulinids in beds below the red-chert-conglomerate marker bed. The top of the Horquilla formation is placed at the top of either unit 6 or 7. Specimens of *Triticites* from the limestones below the conglomerate marker bed of the Earp formation are of species referred to the uppermost Virgilian by many fusulinid specialists but to the lower Wolfcampian by others.

EMPIRE MOUNTAINS

Pennsylvanian rocks in the Empire Mountains (sec. 23), the next range west of the Whetstone Mountains, are involved in much faulting, and are metamorphosed and mineralized. Many of the limestones have been changed to marbles, the shales and siltstones to hornfels. Fossils have been destroyed, and the sequence is probably cut by many dip-slip faults, especially where weaker beds predominate. The ratio of shales and siltstones to carbonate rocks is well shown by these outcrops in the Empire Mountains, as the finer grained clastic rocks have been metamorphosed to hard hornfels and now crop out as resistant ledges, whereas in most other areas it is difficult (without excavating) to tell whether covered slopes are underlain by shales, siltstones, marls, shaly limestones, or friable calcarenites.

Jones and Bacheller, Shell Oil Co., suggested that the basal 1,040 feet of the post-Escabrosa beds are of Pennsylvanian age, a conjecture based almost entirely on lithologic features, as most of the fossils have been obliterated by silicification and recrystallization. The part of the sequence that correlates with the Horquilla formation is described by them as about 600 feet of limestone with interbeds of siltstone, the limestones being coarsely recrystallized and in part epidotized and tremolitized, many beds being replaced by silica, and the siltstones being altered to hornfels. Basal beds are quartzite and silicified shale. The upper 440 feet is interbedded and intercalated limestone, marble, quartzite, and hornfels, typical of a metamorphosed equivalent of the lower Earp formation, clastic rocks predominating in the upper part and carbonate rocks in the lower part. Bryant (1955) also included 470 feet of overlying alternating siltstones, fine-grained sandstones, and thin limestones in the Earp formation, giving a total thickness of 910 feet for the equivalent of the Earp formation.

About 865 feet above the base of the Pennsylvanian strata is a prominent silicified conglomerate that may be equivalent to the marker conglomerate found in the Earp formation to the east, in the Whetstone Mountains and Gunnison Hills. Bryant (1955) noted the intertonguing of lithologies above the Horquilla formation and classified the equivalents of the Earp, Colina, and Epitaph formations as the Andrada formation, which as thus defined includes upper Pennsylvanian beds in its basal portion. How much of the Andrada formation in the Empire Mountains is Pennsylvanian and how much is Permian cannot be determined because of the destruction of the fossils. The clastic ratio derived from Wanless's relatively detailed section, if an arbitrary top is chosen 1,010 feet above the base of his Pennsylvanian (which is beneath the predominantly elastic upper part of the Earp formation equivalent), is 0.78, with a clastic ratio of 0.61 for the Horquilla formation and one of 1.18 for the lower part of the Earp formation. The sand-shale ratio is only 0.05 although the amount of fine-grained sand present in some of the hornfels is difficult to estimate.

#### SANTA RITA MOUNTAINS AREA

Pennsylvanian and Permian rocks in the Santa Rita Mountains, west of the Empire and Patagonia Mountains, are also much metamorphosed and altered to marbles, hornfels, and quartzites. Along Cottonwood Canyon, in the central part of the range, Wanless (personal communication) measured about 632 feet of beds that appear to be of Pennsylvanian aspect. These beds are notable for the high percentage of limestone, marbleized and epidotized, with only about 10 percent hornfels, suggesting that the upper clastic beds of the Pennsylvanian, the lower Andrada formation, are faulted out of the section. Anthony (1951) estimated the Naco formation (sensu stricto of Stoyanow) to be about 1,200 feet thick (sec. 27) in Montosa Canyon, just north of Cottonwood Canyon, but pointed out that bedding-plane faulting makes any measurements doubtful. Probably the basal 700 feet is equivalent to at least part of the Horquilla formation, the upper 500 feet being a basal sequence of the Andrada formation. A rough estimate of the clastic ratio is 0.31; of the sand-shale ratio, 0.14.

In the northern part of the Santa Rita Mountains, in the Helvetia mining district (sec. 22), Johnson (1941) reported about 1,500 feet of the Naco formation, the lower 700 feet being chiefly light-gray limestones with shale interbeds, a probable Horquilla formation equivalent, and the upper 800 feet being predominantly shales and siltstones altered to hornfels, with some limestone interbeds, a lithology typical of the lower part of the Andrada formation but with no suggestion as to where the Pennsylvanian-Permian boundary might be. Basal Pennsylvanian beds are of greenish shales containing pebbles and boulders of quartzite, chert, quartz, and limestone. This clastic bed is not reported from the southern part of the range; there, the base of the Naco formation is either a fault or an intrusive contact.

In the Sierrita Mountains, west of the Santa Rita Mountains, the Pennsylvanian rocks are too metamorphosed and broken by too many faults to indicate anything except that the Naco formation is present (Eckel, 1930) and is composed chiefly of marbles, quartzites, and hornfels. Pennsylvanian rocks in the Rincon Mountains and northeastern Santa Catalina Mountains are similarly metamorphosed and difficult to interpret.

In the foothills of the Tucson Mountains, west of Tucson, Bryant (1952, p. 39) reported over 1,000 feet of Pennsylvanian rocks (sec. 18) overlying the Escabrosa limestone with apparent conformity and composed of thin- to thick-bedded limestones and interbedded siltstones; the top is concealed by alluvium. Intraformational conglomerate lenses of limestone pebbles and cobbles occur throughout the upper part of the exposed Pennsylvanian sequence, and an undetermined part of these upper beds is probably equivalent to the lower part of the Earp and Andrada formations. *Chaetetes,* typical of beds bearing Desmoinesian fusulinids, is reported (Britt, 1955) only as high as 460 feet above the base of the Pennsylvanian; so the 900 to 1,000 feet measured may be nearly the entire thickness of the Pennsylvanian in this area. The clastic ratio is estimated to be 0.37, and the sand-shale ratio 0.02, but overlying concealed strata are probably more clastic and probably more arenaceous. Some of the limestone beds are quarried to make cement, not a common practice, as many of the Pennsylvanian limestones in southern Arizona contain too high a percentage of silica.

#### WATERMAN MOUNTAINS

Northwest of the Tucson Mountains, in the Waterman and Silver Bell Mountains, Ruff (1952) reported 670 feet of the Naco limestone, higher beds being concealed and cut out by dip-slip faults. He found *Chaetetes in* the uppermost exposed beds, which suggests that only middle Pennsylvanian strata are represented in the outcrops. McClymonds (1959) reported a thinner section of the Horquilla limestone but noted that the variation in thickness is probably due to faulting. Bryant (personal communication) estimated over 1,000 feet of the Horquilla formation below the section of the Andrada formation that he measured in the Waterman Mountains (sec. 17) and pointed out that upper Pennsylvanian and lower Permian rocks in this part of Arizona are in many places the focus of a zone of thrust faulting because they are relatively nonresistant siltstones, shales, and interbedded thin limestones.

Ruff (1952) listed his measured section in some detail; the basal Pennsylvanian is disconformable on the lower Mississippian Escabrosa limestone and consists of conglomerates of red chert and limestone pebbles and cobbles in a sandy red shale and siltstone matrix. Above 455 feet of thin-bedded to thick-bedded limestone is about 210 feet of arenaceous pale-red thin-bedded limestone with siltstone and shale in terbeds.

Locally McClymonds (1959) found a fossil karst topography at the top of the Escabrosa limestone, overlain by the basal Pennsylvanian quartzite-jasper pebbles and red mudstone.

### VEKOL MOUNTAINS

Northwest of the Silver Bell Mountains, in the Vekol Mountains, which extend from the southwest corner of Pinal County southward into Pima County, the Pennsylvanian is more than 795 feet thick as measured (sec. 16) by Wanless (personal communication), with higher beds concealed by alluvium and pediment gravels. Carpenter (1947) reported that Cretaceous(?) quartzites and siliceous red beds rest with angular unconformity on the Naco limestone in the Vekol Mountains, the Naco limestone in places being less than 100 feet thick. The upper 20 to 100 feet of the underlying Escabrosa limestone is stained pinkish to tan and is cut by pre-Naco joints and clastic dikes, the contact with the Naco (Horquilla) being an irregular surface overlain by 5 to 20 feet of basal Pennsylvanian red shales, tan quartzites, and reddish-brown and greenish sandstones containing lenses of chert-limestone-sandstonepebble conglomerates and breccias.

The bulk of the exposed Pennsylvanian is of thin- to medium-bedded limestone, ranging from lithographic to coarsely crystalline, with numerous chert nodules, laminae, and stringers. Pink to reddish-brown shale beds and partings occur throughout the section, associated with nodular shaly slope-forming limestones. Many of the limestones are composed chiefly of fossil fragments and vary from coquinas and calcarenites to coquinoid limestones. The clastic ratio is about 0.25, the sand-shale ratio less than 0.04.

This is one of the westernmost sections of Pennsylvanian rocks known in southern Arizona. It shows little lithologic variance, however, from the correlative beds to the east and offers no indication of a western shoreward facies. The lack, or thinness, of Pennsylvanian deposits to the west appears mostly due to erosion during early and middle Mesozoic time. Suggestion of a Pennsylvanian landmass in southwestern Arizona is based on the lack of known Pennsylvanian sections or the thinness of incomplete sections and of faulted and metamorphosed sections.

### SOUTHWESTERN ARIZONA

One of the most important sections of Pennsylvanian rocks, for determination of the existence or nonexistence of a southwestern Arizona landmass during Pennsylvanian time, is that measured by Eldred D. Wilson (personal communication) in the Growler Mountains (west of west border of pl. 1), which are about halfway between Tucson and the western border of Arizona, and about 50 miles southwest of the Vekol Mountains. Here Wilson measured 95 feet of possible Pennsylvanian rocks above the Escabrosa limestone and overlain by quartzites and marbles of possible Permian age. The rocks are too metamorphosed to determine whether the thinness of the Pennsylvanian section is due to nondeposition or to late Pennsylvanian or early Permian erosion.

Outcrops of Pennsylvanian or Carboniferous limestones are reported by Darton (1925) in southwestern Arizona in the Growler Mountains, Sierra Blanca, and Puerto Blanca, Slate, Plomosa, Harquahala, and Dome Rock Mountains. These rocks in most places are metamorphosed and broken by many faults, so that thicknesses, original lithology, and fossils are uncertain. In the Providence Mountains of southern California, however, Thompson and Hazzard (1946, p. 39) measured sections of Pennsylvanian rocks above the Mississippian Monte Cristo formation and below beds containing Wolfcampian fusulinids. Strike dip-slip faults cut the lower part of the Pennsylvanian, but 825 to 915 feet of Pennsylvanian beds is believed to be present, rocks similar to those of the Horquilla formation or the Naco limestone (sensu stricto); namely, thin- to thick-bedded cherty limestones, with some thin interbeds of fine-grained sandstone in the lower part. This is a thinner section of Pennsylvanian than that exposed in southern Nevada but is not much thinner than the correlative strata in southeastern Arizona; except for the thin sandstone beds, it is not a shoreline facies, as might be expected if a landmass existed in southwestern Arizona during all or part of Pennsylvanian time.

### SWISSHELM MOUNTAINS

In eastern Cochise County, east of the Tombstone and Gunnison Hills, Pennsylvanian rocks occur in the Swisshelm, Pedregosa, Guadalupe, Chiricahua, and Dos Cabezas Mountains, and in these areas are referable to the Horquilla and lower Earp formations. Although the Pennsylvanian beds are not, for the most part, as metamorphosed as they are west of the Whetstone Mountains, they are cut by numerous faults that cut out or repeat parts of the section and lead to variances in measurements and interpretations.

The Swisshelm Mountains of south-central Cochise County are broken by many faults, which complicate determinations of the Pennsylvanian stratigraphy. Shell Oil Co. geologists (S. S. Day, W. D. Bacheller, C. M. Gilbert, R. Epis, R. Waite, and S. M. Jones) measured a section at the north end of the range that included 1,265 feet of Pennsylvanian beds terminated by a fault. Fusulinids from the upper beds of the section are of Upper Missourian age. Isolated outcrops in the area yielded Virgilian fusulinids but could not be tied into the measured section.

Loring (1947) mapped the area and measured a composite section (sec. 26) in which he attributed about 2,300 feet to the Naco formation of Permian—Pennsylvanian age. Identifications of fusulinids by Thompson (1954, p. 26) established the upper 260 feet of Loring's measured Naco to be of Wolfcampian age, leaving a possible 2,040 feet of Pennsylvanian strata, a thickness that does not appear excessive in view of the thick sections in the Gunnison Hills, Pedregosa Mountains, and Big Hatchet Mountains. The Pennsylvanian—Permian boundary is within a sequence of alternating limestones, marls, and reddish shales of the Earp formation equivalent.

Basal beds disconformable on the Escabrosa limestone are conglomerates and shales. Many interbeds of fine-grained clastic rocks and intraformational limestone-pebble conglomerates occur throughout the lower, normally carbonate-rock Pennsylvanian sequence. The clastic ratio is about 0.48, whereas the sand-shale ratio varies considerably because of gradation, thickening, and thinning of sandy siltstones into silty sandstones, the ratio ranging from 0.02 to 0.18. Fusulinids collected from the Pennsylvanian represent an almost complete range of the fusulinid zones from Derryan through Virgilian, the abundance of Missourian fusulinids being in sharp contrast with the lack of fusulinids from probable Missourian sequences in other sections of southeastern Arizona.

PEDREGOSA MOUNTAINS

In the Pedregosa Mountains, just east of the Swisshehn Mountains, Rudy C. Epis (1956) measured and mapped 2,115 feet of the Horquilla formation overlain conformably by 1,050 feet of the Earp formation (sec. 29). The Horquilla formation is conformable on the Paradise formation of Upper Mississippian age, which is nearly identical in fauna and lithology with the type Paradise. The lower 370 feet of the Earp formation is of Virgilian age, so that the total thickness of the Pennsylvanian is about 2,485 feet, although there is a 250-foot transition zone of Virgilian or Wolfcampian age above the definite Virgilian beds. As in the Swisshelm Mountains, the Horquilla formation contains thick persistent lenses of interbedded calcareous shale, siltstone, sandstone, and thin-bedded limestone. The clastic ratio for rocks of Pennsylvanian age is about 0.33, and the sand-shale ratio about 0.6.

On the basis of fusulinid determinations by M. L. Thompson, Epis reported the following thicknesses of series: (1) Derryan, 570 feet; (la) Derryan or Desmoinesian, 140 feet; (2) Desmoinesian, 530 feet; (2a) Desmoinesian or Missourian, 345 feet; (3) Missourian, 190 feet; (3a) Missourian or Virgilian, 125 feet; (4) Virgilian, 550 feet; and (4a) Virgilian or Wolfcampian, 250 feet. Beds of Pennsylvanian age may be, therefore, as much as 2,700 feet thick. Even without the Virgilian-Wolfcampian transitional beds, the Pennsylvanian section is the thickest reported from Arizona.

This thick sequence can be generalized into 17 lithologic units, from base upward: (1) limestone, medium- to massive-bedded, oolitic to cherty, 75 feet; (2) interbedded thin-bedded limestone and calcareous clastic sediments, 50 feet; (3) limestone, medium- to thick-bedded, oolitic to cherty, with *Chaetetes* biostromes near top, 220 *feet;* (4) partly covered limestone with interbeds of sandstone, siltstone, and shale, 40 feet; (5) limestone, thick-bedded, cherty, 90 feet; (6) partly covered thin-bedded limestone, sandstone, shale, and siltstone, 155 feet; (7) limestone, thick-bedded, lower part cherty, 170 feet; (8) medium-bedded limestone interbedded with buff calcareous fine-grained clastic rocks, 95 feet; (9) limestone, medium- to thick-bedded, lower cherty, upper cliff-forming, 70 feet; (10) buff thin-bedded siltstone and sandstone with limestone interbeds, 25 feet; (11) limestone, medium-bedded, lower 40 feet cherty, 115 feet; (12) interbedded nodular fusulinid limestone, calcareous shale, sandstone, and siltstone, with medial 25-foot cliff of massive *Chaetetes*bearing limestone, 165 feet; (13) limestone, fetid, medium-bedded, with medial crinoidal calcarenite, 115 feet; (14) limestone, thick- to medium-bedded, cliff-forming, cherty, aphanitic, blackish, with abundant fusulinids, 520 feet; (15) limestone, medium- to thick-bedded, with numerous fusulinids and subordinate buff silty shale, siltstone, and sandstone, 210 feet; the uppermost beds of the Horquilla formation; (16) partly covered buff silty marl, siltstone, and sandstone, with subordinate medium-bedded fusulinid-bearing limestone; basal beds of the Earp formation, 145 feet; (17) limestone, medium-bedded, fusulinid-bearing, fetid, with interbeds of calcareous shale, siltstone, and sandstone, 225 feet.

The thick Pennsylvanian section in the Pedregosa Mountains of southeastern Arizona should be compared with the thick section in the Big Hatchet Mountains of southwestern New Mexico, about 55 miles to the east. The latter section is of a similar thickness but is composed almost entirely of carbonate rocks, the clastic ratio being about 0.04, as reported by Robert A. Zeller, Jr. (personal communication).

Southeast of the Pedregosa Mountains, in the southeasternmost corner of Arizona, are the Guadalupe Mountains, a southern extension of the Peloncillo Mountains. Pennsylvanian and Permian rocks crop out in the western foothills, are cut by numerous faults, and are folded. C. M. Gilbert and L. F. Daugherty, Shell Oil Co., measured the exposed sections and reported less than 100 feet of Pennsylvanian strata in fault contact with Permian beds; no accurate estimate of thickness, lithology, and depositional relationships can be gained from the exposed Pennsylvanian rocks.

**CHIRICAHUA MOUNTAINS**

Pennsylvanian rocks crop out along the northeast side of the Chiricahua Mountains, northeast of the Pedregosa and Swisshelm Mountains, complete sections being exposed near Portal and Hilltop, and a composite section from Blue Mountain to Dunn Springs Mountain. The

Portal section (sec. 21) is one of the most studied in the State, being easily accessible, not metamorphosed, and relatively unbroken by faults. Amazingly, however, although there are four relatively detailed studies of the section, the thicknesses, lithologies, and faunas separately arrived at are not in much agreement. Estimates of the thickness of the Horquilla formation, based on lithologic descriptions of Raydon (1952), Sabins (1957), Wanless (in Zirkle, 1952), and the Shell Oil Co. field party (S. M. Jones, W. D. Bacheller, L. F. Daugherty, and C. M. Gilbert), range from a possible 1,045 feet to as much as 1,840 feet, depending on where the contact is drawn with the Earp formation, and the amount of clastic beds recorded. Reconnaissance checks of the section suggest 1,600 feet as a reasonable thickness for the Horquilla formation. Even greater variance in thickness is recorded for beds lithologically equivalent to the Earp formation.

Dependent in part upon identification of advanced species of *Triticites* as upper Virgilian types or lower Wolfcampian species, the thickness of total Pennsylvanian rocks is somewhere in the range of 1,585 to 2,450 feet, although a composite check of the various measured sections with the outcrops indicates about 1,900 feet of possible Pennsylvanian beds below limestones bearing *Schwagerina*. The Pennsylvanian—Permian contact appears indistinguishable amid a sequence of alternating nodular limestones and limy shales and siltstones. The thickness of the fusulinid zones of the Pennsylvanian varies among the individual reports chiefly because of happenstance in collecting such small fossils as fusulinids. The Derryan and perhaps older Pennsylvanian is 330 to perhaps 550 feet thick, the Desmoinesian about 600 feet thick, the Missourian perhaps 370 feet thick, and the Virgilian about 600 feet thick. Missourian fusulinids were reported only by Sabins (1957), who noted them directly above limestones bearing lower Desmoinesian fusulinids.

The Horquilla formation is of the usual thin- to thick-bedded limestones, cherty and fossiliferous, with shaly silty beds in the lower part, as well as irregular lenses and partings of tan shale and siltstone. The lower part of the Earp formation, the part believed to be of Virgilian age, is made up of interbedded carbonate and clastic rocks; the finer grained clastic beds, such as shale, siltstone, and fine-grained silty sandstone, predominate over medium-grained and coarser grained sandstones, in contrast to the section on Dunn Springs Mountain to the northwest, where the coarser grained clastics are dominant. The clastic ratio is about 0.22, the sand-shale ratio about 0.05. Wanless (Zirkle, 1952) found no fusulinids in the basal 190 feet, and the lowest fauna he described is of Upper Derryan age. Probable lower Derryan and perhaps Morrowan rocks occur at the base of the Pennsylvanian, disconformable on the Chesterian Paradise formation.

Papke (1952) and Brittain (1954) have described the Naco formation in the Hilltop mining area, northwest of Portal, west of Blue Mountain, and south of Dunn Springs Mountain. The Pennsylvanian is metamorphosed in part and broken by faults. Shales and siltstones are altered to yellowish and greenish hornfels; many of the limestones are silicified and recrystallized to marble. The section appears similar to those near Portal and Blue Mountain.

Sabins (1957) mapped the northeastern part of the Chiricahua Mountains and measured a detailed section (sec. 19) of the sedimentary rocks exposed therein. His composite section of the Horquilla formation, the lower half measured on Blue Mountain and the upper half on Dunn Springs Mountain, is about 1,600 feet thick, of which at least 550 feet is Derryan and perhaps Morrowan, about 730 feet is lower Desmoinesian, and 320 feet is assigned to the Missourian. Pre-Desmoinesian Pennsylvanian rocks may total 750 feet, there being a barren sequence of 200 feet between beds definitely in the Zones of *Fusulinella* and *Fusulina*. Of considerable note is the lack of fusulinids of upper Desmoinesian age, *Triticites* of the Missourian series occurring just above *Wedekindellina euthysepta* of the lower Desmoinesian. Although many of the thin-bedded limestones are shaly and silty, this is one of the most calcareous sections of the Horquilla formation reported. The clastic ratio is only 0.11, and this estimate of the clastic ratio includes covered intervals as part of the clastic fraction, even though they may be nodular limestones.

Sabins (1955) placed the Pennsylvanian—Permian contact within a 40-foot sandstone sequence above beds containing Virgilian fusulinids, and below strata in which *Schwagerina* typical of lower Wolfcampian age were found. The basal 250 to 280 feet of the Earp formation is, therefore, of Virgilian age. The clastic beds of the basal Earp formation in the Portal section differ strikingly from those in the Dunn Springs Mountain section, clastic beds from the latter area being predominantly sandstones and a few siltstones, whereas the beds near Portal are shales with minor siltstones. The clastic ratio for the total Pennsylvanian is about 0.21, similar to that of the Portal and Gunnison Hills Pennsylvanian; the sand-shale ratio, however, is about 0.97, the largest reported for southern Arizona.

A complete section of Pennsylvanian rocks is not exposed in the Dos Cabezas Mountains, which are northwest of the Dunn Springs Mountain section and northeast of the Gunnison Hills. About 1,225 feet of the Horquilla formation was measured by S. M. Jones and W. D. Bacheller (1953, p. 149) on the south side of the range, where higher beds are covered by alluvium. The highest beds exposed contain Desmoinesian fusulinids, suggesting that the thickness and faunal zones are similar to those of the Dunn Springs Mountain section. The Pennsylvanian beds exposed near Dos Cabezas, however, are somewhat more clastic, shale interbeds being more numerous than to the southeast.

## GILA RIVER REGION

The 50-mile-wide strip centered roughly on the Gila River, occupying most of Greenlee, Graham, Pinal, and southern Gila Counties, is a transition from the basin-and-range topography and structure of southern Arizona to the topography of the Colorado Plateau, whose southern edges are near the Mogollon Rim and Datil volcanic area. Topography and structure trend northwest and are transected by the Gila River, which has cut narrow canyons through the ranges and in places follows the broad intermontane valleys for some distance.

Pennsylvanian rocks crop out near the New Mexico—Arizona State-line north of Clifton, in the northern part of the Galiuro Mountains, in the Dripping Springs Mountains north of Winkelman and east of Ray, in the Tortilla Mountains west of Ray, in the Mescal Mountains, in the peaks and ridges south and west of the San Carlos Reservoir, on the northeast side of Bonita Creek valley northeast of the Gila Mountains, along the escarpment east of Superior, and in the mountains around Globe. Many of the areas are active mining districts, the Pennsylvanian limestones being favorable host rocks, which are altered and intricately faulted. Erosion during Mesozoic, Tertiary, and Recent times has reduced the original thickness of the Pennsylvanian strata; reasonably complete sections occur only east of Superior and southwest of the San Carlos Reservoir.

Pennsylvanian rocks in the Globe—Miami district were originally included in the Globe limestone by Ransome (1903, p. 39-46), a unit which also included rocks of Devonian and Mississippian age. Lindgren (1905b) named a thin Mississippian-Pennsylvanian limestone sequence the Tule Spring limestone from outcrops north of Clifton. Ransome (1919, p. 45-48) replaced the Mississippian-Pennsylvanian part of the Globe limestone with the Tornado limestone for the Ray, Superior, and Globe areas. Stoyanow (1936) named the Pennsylvanian rocks on Saddle Mountain, west of Winkelman, the Galiuro limestone. More recently Huddle and Dobrovolny (1945), Winters (1951), Jackson (1951), Wan-less (1955), and Wilson (1952) have applied the term Naco limestone or formation to the Pennsylvanian rocks in the Gila River region.

### SADDLE MOUNTAIN AREA

One of the most fossiliferous sections, the fossils in many beds being pinkish and silicified, is that on Saddle Mountain (sec. 15) east of Winkelman, where Webber (1925) and Stoyanow (1926) listed 865 to 950 feet of the Galiuro limestone, resting disconformably on the Escabrosa limestone and overlain by thin Cretaceous(?) sandstones, which are unconformable beneath Tertiary(?) lavas. The megafossils have been listed and zoned in some detail, but no comparisons have been published as to the fusulinid zonation. Except for basal shales and interbeds of shale and siltstone, with the expected limestones in the lower part of the formation, the Galiuro limestone is similar to the lower part of the original Naco limestone. The clastic ratio of 0.34 and the sand-shale ratio of 0.21 represent only the lower part of the Pennsylvanian and for that part are more clastic than the Naco or Horquilla limestone to the south.

In the section on Tornado Peak, at the south end of the Dripping Springs Mountains north of Winkelman, only 375 feet of the basal part of the Pennsylvanian is exposed, higher beds having been eroded away. To the east, in the Deer Creek drainage area and near Stanley, the Pennsylvanian beds are 500 to 800 feet thick and are unconformably overlain by Lower Cretaceous coal-bearing sequences that intertongue with andesitic volcanic rocks.

### QUEEN CREEK CANYON

Along Queen Creek Canyon, east of Superior, the Naco limestone disconformably overlies the lower Mississippian Escabrosa limestone (Harshman, 1939) or Redwall limestone (Huddle and Dobrovolny, 1945), the name applied to the Mississippian unit depending on whether the problem is approached from the south (Escabrosa) or from the north (Redwall). From 1,100 to as much as 1,390 feet of Pennsylvanian has been reported from this area, but the Pennsylvanian strata are overlain with deep erosional unconformity either by the Tertiary Whitetail conglomerate or by Tertiary dacite flows and tuffs. Northward from Queen Creek, the Naco limestone is thinned by erosion and is absent at King's Crown Peak, where dacite flows overlie the Escabrosa limestone (Harshman, 1939); southward the Naco limestone is in places only 200 feet thick beneath the Tertiary volcanic rocks and volcanic sediments.

Harshman (1939) and Short et al. (1943) have noted a conglomerate bed at the base of the Naco limestone in the area. The rounded pebbles are of jasper, quartzite, limestone, and schist, the percentage of schist pebbles increasing northward; this suggests a source from the north, where probable Precambrian rocks were exposed to erosion. The conglomerate bed, however, appears from outcrops along Queen Creek Canyon to be above the base of the Pennsylvanian as that base was chosen by Huddle and Dobrovolny (1945) and Wanless (measured section, May 1949, personal communication to Eldred D. Wilson). Both HuddleDobrovolny and Wanless include in the basal part of the Naco limestone some 40 to 45 feet of thin-bedded cherty light-gray to pink limestone underlain by 30 to 45 feet of dark-red to purplish sandy shales and chert conglomerate and breccia, which appears to have been derived under karst conditions from the underlying cliff-forming Escabrosa/Redwall limestone. These thin-bedded limestones and reworked residual red soils were mapped by Short et al. (1943) as upper beds of the Escabrosa limestone.

Without faunal evidence, it may be presumptuous to conclude other than that the karst topography was developed on the Redwall/Escabrosa limestone (which has yielded early Mississippian faunas in this area) sometime during the upper Mississippian and/or lower Pennsylvanian time. Most geologists, however, would group the residual materials with the overlying Pennsylvanian rocks; indeed, they are similar in origin and lithology to the Molas formation of southeastern Colorado, in which Derryan fusulinids have been found.

This section (sec. 12) contrasts with those to the south because of the large amount of clastic rocks. The lower 780 feet of the Pennsylvanian barely includes more limestones than shale, siltstones, and sandstones, and could, therefore, be termed a lithic equivalent of the Horquilla formation. The upper almost 390 feet of the section resembles the unit mapped as the Earp formation to the south, with shales and siltstones more numerous than limestones, and with a relatively high percentage of sandstones. Sandstones in the lower two-thirds of the Pennsylvanian strata are thin conglomeratic beds or are included in a massive 20- to 27-foot ledge, brownish and quartzitic, that is a marker bed about 210 feet above the base of the Naco formation. The clastic ratio, as calculated from the section measured by Wanless, is about 0.99, and the sand-shale ratio is 0.17. The amount of shaly nodular limestone and limy shale varies considerably along the strike, many of the beds being a hard to soft marl cementing lenses of fossil coquinas; the amount of shale or of limestone recorded is thus somewhat a matter of interpretation. Although many of the beds have a reddish to pinkish tint, coloring is more pastel than to the north along the Mogollon Rim, where many of the beds are dark red, a coloring more typical of the Pennsylvanian Supai red beds.

### COOLIDGE DAM

The most complete section of Pennsylvanian rocks reported from the Gila River area was measured by Wanless (sec. 13) east of Coolidge Dam (San Carlos Reservoir). The upper 154 feet of the measured section is of red shale and light-gray to brown sandstone; the highest fusulinids were found 251 feet below the top, the lowest fusulinids 1,308 feet from the top. Wanless noted beds lithologically similar to the Black Prince limestone of Gilluly et al. (1954) near the base of his section, and there appears to be no distinctive break in the 160 feet between the limestones similar to the Black Prince limestone and the lowest limestones containing fusiform fusulinids. The base of the Pennsylvanian may be about 1,400 feet below the top of the measured section, although Wan-less measured 1,475 feet down to the top of the Escabrosa limestone.

The beds dip about 30 degrees and crop out as alternating ledges and slopes, the concealed intervals being deeply covered by slope wash and talus, preventing a complete picture of the lithology; thus it is not known whether the numerous concealed beds are nonresistant limestone, shale, siltstone, or sandstone. Trenching several of the thick concealed intervals with a shovel revealed marly limestones and shales;

namely, an intimate intercalation of pinkish limy shale and of nodular gray argillaceous limestone. On the assumption that the concealed intervals are about half shaly limestone and half limy shale, the clastic ratio is about 0.71 for the 1,400 feet suggested as of possible Pennsylvanian age; the sand-shale ratio is about 0.06. If the upper 154 feet, which is almost entirely clastic beds, is not of Pennsylvanian age, the clastic ratio for the lower 1,246 feet is about 0.53; in both cases considerably lower than that for the Queen Creek section to the northwest and higher than the Gunnison Hills section to the south.

## BONITA CREEK VALLEY

Previously unreported outcrops of upper Paleozoic rocks were mapped by Bromfield and Shride (1956) along the south front of the Gila Mountains and to the northeast across Bonita Creek valley, below the Natanes Plateau rim that borders the northeast side of the valley. Apart from reference to the existence of the Naco limestone, as much as 1,200 feet thick in the Mescal and Hayes Mountains of the San Carlos Indian Reservation, the Naco is mentioned merely as a sequence of medium-bedded gray limestone with some intercalated shales.

The largest areal outcrop of Precambrian and Paleozoic rocks is along Park Creek, a tributary joining Bonita Creek from the northeast, where the geologic map (Bromfield and Shride, 1956, pl. 52) shows Tertiary volcanic rocks unconformable on strata ranging in age from Carboniferous to Precambrian. On the west side of the Gila Mountains and on the north rim of the Natanes Palteau (the south rim of Salt River Canyon), Tertiary volcanic rocks or older Tertiary(?) gravels overlie the Naco limestone, although locally resting on pre-Pennsylvanian strata. Similar relationships occur in the Clifton area to the southeast, and far to the east, near Socorro, on the east edge of the Datil-Mogollon volcanic plateau.

In the Clifton area (fig. 29), as well as to the west of the Gila Mountains southwest of Coolidge Dam and in the Deer Creek basin, Cretaceous or Cretaceous(?) rocks, sedimentary and/or volcanic, unconformably overlie the Paleozoic beds on a pronounced erosional surface developed in early and middle Mesozoic time. During this erosional period much of the pre-Mesozoic strata was stripped also from the Silver City, Burro Mountains, Victorio Mountains, and Steeple Rock areas of northern Hidalgo, northwestern Luna, and southwestern Grant Counties, New Mexico; locally the erosion began in late Permian time, and in places lasted into late Cretaceous time.

## GRANVILLE

To the east, along the southern edge of the Datil-Mogollon volcanic plateau, and near the village of Granville (sec. 14) north of Clifton, the Pennsylvanian is probably more than 235 feet thick (McKee, 1951) and is unconformably overlain by Tertiary volcanic rocks. This is the

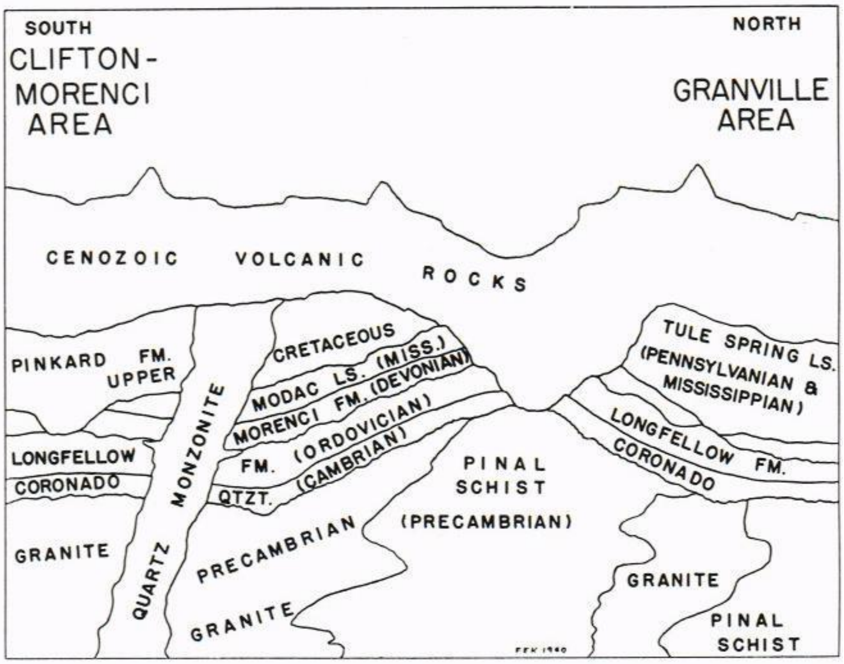


Figure 29

DIAGRAMMATIC SKETCH OF STRATIGRAPHIC RELATIONSHIPS IN CLIFTON-MORENCI AREA

Tule Springs limestone section of Lindgren (1905b). Near Morenci and Clifton, 5 to 8 miles to the south, a thin sequence of fossiliferous Upper Cretaceous beds overlie, with erosional unconformity, the Mississippian Modoc (Escabrosa?) limestone (fig. 29). The Pennsylvanian rocks are poorly exposed near Granville, which is in the high forested country typical of the Datil-Mogollon plateau, but appear similar to the lower Pennsylvanian rocks exposed to the south in the Dos Cabezas and Chiricahua Mountains.

Possibly erosion during Tertiary and/or Mesozoic times may not have cut so deeply into Pennsylvanian rocks in some parts of the present volcanic plateau, so that there may be considerable areas northeast of Clifton wherein thick sections of Paleozoic strata are concealed beneath the volcanic rocks.

## MOGOLLON RIM REGION

North of a line drawn from Globe to Granville, Pennsylvanian rocks crop out only along the Mogollon Rim and the eastern reaches of the Salt River, erosion apparently having stripped off most of the Paleozoic rocks in the intervening region. The Mogollon Rim area is one of the most rugged and wildest in Arizona, the outcrops of Pennsylvanian rocks are in many places difficult to reach, and the relationships are complex because of facies changes from the predominant limestone typical to the south and the Supai-type red beds to the north.

In many places in southern Arizona the contact between the Pennsylvanian and Mississippian is difficult to find; along the Mogollon Rim and Salt River, deposits of reworked residual soil mark the Mississippian-Pennsylvanian contact. To the south the Pennsylvanian-Permian contact is gradational within a sequence of intercalated limestones and fine-grained clastic rocks in the lower part of the Earp formation or equivalent sequences, and can be found within 100 feet or so on the basis of fusulinids; in the Mogollon Rim area the boundary between the Pennsylvanian and Permian is in most places within an unfossiliferous red-bed sequence usually referred to the Supai red beds, and there is no faunal basis for determining the approximate location of the gradational time-line contact. The lower Pennsylvanian is contained in a unit, referred to as the Naco formation, consisting of nodular fossiliferous limestones interbedded with red beds; the upper Pennsylvanian is within the lower part of the red-bed sequence called the Supai formation.

The Mississippian limestones that underlie the Pennsylvanian rocks in this area are referred usually to the Redwall limestone. In Spring Canyon (sec. 7) along the upper reaches of Canyon Creek, northwest of Grasshopper, the Redwall limestone is only about 30 feet thick but thickens eastward to 210 feet in Salt River Canyon, thickens westward to 280 feet south of Jerome (McNair, 1951, p. 515), and thickens southward to 420 feet near Superior (Harshman, 1939). The top is a pronounced erosion surface, Huddle and Dobrovolny (1945) reporting relief of 30 to 50 feet in many places, with cavern breccia and fillings of reddish sandy silts locally extending through the entire Redwall limestone.

Basal Pennsylvanian beds are reworked residual materials, red clays, silts, and cherts, typical of karst conditions that occurred in late Mississippian and early Pennsylvanian time. This karst residuum is probably more common than has been reported, Wanless (personal communication) having seen it in situ as far southeast as the Granville (north of Clifton) section. Among the numerous other geologists who have observed local red shales and chert pebble-conglomerates/breccias at or near the base of Pennsylvanian sections in southern Arizona are Williams (1951), Kartchner (1944), Johnson (1941), Ruff **(1952),** Carpenter (1952), and Harshman (1939).

Huddle and Dobrovolny (1945) measured numerous sections in a regional study of the Paleozoic rocks exposed in central Arizona; their material is the only relatively detailed published account of Paleozoic stratigraphy in the Mogollon Rim area. McNair (1951) reported on the Paleozoic rocks of the region to the west, Jackson (1951, 1952) studied the Supai formation along the Mogollon Rim, and Winters (1948) measured sections of the Supai red beds near Fort Apache. Wanless (personal communication to Eldred Wilson) has measured many sections along the Mogollon Rim and near Salt River Canyon, and has collected fusulinids from significant horizons.

### JEROME AREA

The northwesternmost section that can be considered to be in the southeastern quarter of Arizona is that south of Jerome, where McNair (1951, p. 515) measured more than 300 feet (the top an erosion surface) of lower Supai red beds unconformable on the Redwall limestone (sec. 1). Similarly, Anderson and Creasey (1958, p. 53-55) reported a maximum of 370 feet of the lower Supai near Jerome and noted considerable limestone and limestone breccia-conglomerate amid the red beds. To the northwest the lower part of the Supai red-bed facies inter-tongues with the upper part of the Callville limestone, which has yielded Virgilian fusulinids; near Peach Springs the Pennsylvanian part of the Supai formation is at least 325 feet thick.

Of considerable note is McNair's (1951, p. 531) observation that the dip of crossbedding in the Supai is in most places south or southeast, indicating that the currents bringing the sediments came from the north and northwest, directions in which the existing record indicates no known landmass. The lithic depositional features of the Supai red beds are considered by McNair to indicate deposition in a shallow-water marine environment and not in a continental mud-flat or delta environment. Many of the beds labeled sandstone are either silty very fine-grained sandstones or sandy siltstones; conglomeratic beds are in most places made up of relatively angular fragments of underlying rock and are not the well-rounded stream-deposited type of cemented gravels.

### NACO—SUPAI CHARACTERISTICS

In their study of sections in central Arizona, Huddle and Dobrovolny (1945) divided the Pennsylvanian-lower Permian sequence into a lower, predominantly carbonate unit, the Naco formation, and an upper, red-bed unit, the Supai formation. The contact between the two formations was drawn by them at the horizon where the gradational sequence changed from one dominated by limestones and limy beds to a dominance of red-bed clastic rocks. They noted the northward and westward gradation of the upper limestones of the Naco formation into the lower clastic beds of the Supai formation, but the Pennsylvanian-Permian boundary appears in all cases to be within relatively unfossiliferous sequences of red beds.

The Naco formation as designated by Huddle and Dobrovolny (1945) is 475 to 785 feet thick along the Mogollon Rim, thickening eastward from Fossil Creek (sec. 6, pl. 1) to Salt River Canyon (sec. 10, pl. 1). Where the Naco formation is thick, as in Salt River Canyon, fusulinids ranging from Derryan to Virgilian in age were collected; at the thin section along Fossil Creek, the upper beds assigned to the Naco formation yielded Desmoinesian fusulinids, the field relationships suggesting that westward the carbonate Missourian and Virgilian beds intertongue with unfossiliferous Supai red beds.

The limestones of the Naco are for the most part aphanitic, dense, and light gray to tan, but in the upper part of the formation tend to be reddish, purplish, and greenish. The carbonate beds vary greatly in thickness within a few score feet along the strike; many are nodular, shaly, and silty, grading laterally in one direction into limy shale containing numerous limestone nodules, and into massive coquinoid limestone in the opposite direction. As in the Pennsylvanian limestones near the Gila River, numerous nodules, lenses, beds, and stringers of chert, weathering pinkish to reddish brown, occur in the limestones.

Many beds of light-colored argillaceous nodular marls and limy shales are present and contain many fossiliferous lenses. The shales included in the Naco formation are varicolored, ranging from almost white, through shades of gray and green, to pink, red, and purple; most of the shales are limy or calcareous, and silty, grading laterally into siltstone. Conglomeratic lenses are common, although not very persistent laterally, and consist of angular to subrounded pebbles and cobbles of limestone and siltstone in a shaly limy matrix, which in many places is of fossil-fragment hash.

Huddle and Dobrovolny (1945) reported a sequence of gray limestone beds that weather tan and contain fossils of late Desmoinesian age. The limestones of this zone are silty and sandy, laminated to cross-laminated, thin bedded to nodular, and marked by nodular masses of brown limestone in which the centers are replaced by pinkish to reddish translucent chert. The thickness of the Pennsylvanian strata below this marker zone is almost constant in the area, ranging from 225 to 300 feet, the thicker sequence being to the west, not to the east, as would be suggested by the westward thinning of the Naco formation facies.

The Supai formation was divided by Huddle and Dobrovolny (1945) into three members, which are in part contemporaneous and grade laterally into each other, being more easily recognized by their topographic expression and color from a distance than by close examination of the outcrop. The lower member is 200 to 540 feet thick and is composed of siltstone, fine-grained sandstone, and shale, with some limestone interbeds; it crops out typically as a gentle slope broken by a few resistant ledges. The member ranges in age from Desmoinesian to perhaps as young as Wolfcampian and interfingers with the underlying Naco formation and overlying middle member. Contact with the middle member was drawn arbitrarily at the top of the highest bed of gray limestone or at the base of the first massive bed of crossbedded sandstone.

Individual beds are highly irregular in thickness, varying as much as 12 feet within a lateral distance of several hundred feet. The limestones are for the most part silty and reddish, and nodular, containing reddish and reddish-brown chert nodules and lenses, as well as scattered coquina lenses. The shales are intercalated with siltstones, are calcareous to limy, contain many limestone nodules, and vary in color from red and purple to green and gray.

Sandstones of the lower member are lenticular, commonly laminated, crosslaminated, and, on a small scale, crossbedded. They are mainly fine grained and silty; sieve analyses would probably classify many of the beds labeled sandstones as siltstones. The clastic beds are calcareous and contain nodules and lenses of dense limestone and reddish chert. Although the weathering color is predominantly reddish, many of the sandstones and hard siltstones are gray, olive, and greenish gray on fresh fractures. As below in the Naco formation, lenses of limestone-siltstonepebble conglomerate and pellet conglomerate occur. Some of the beds are gypsiferous and contain numerous veinlets and laminae of recrystallized gypsum.

The middle member of the Supai red beds is 250 to 400 feet thick and consists of dark reddish-brown siltstone, sandstone, and shale, which crop out as cliffs and steep slopes. The lithology is very similar to that of the Abo red beds of New Mexico. On the basis apparently of plant fossils, the middle member is believed by Huddle and Dobrovolny (1945) to be of "Leonardian age but may include Wolfcampian beds." The highest limestones of the lower member of the Supai red beds have yielded Virgilian fusulinids near Fort Apache, suggesting that the middle member of the Supai more likely is predominantly of Wolfcampian age.

Precise thicknesses of the Pennsylvanian cannot, of course, be calculated from available data. Winters (1951) in his study of sections and fossils in the Fort Apache area concluded that the lower member of the Supai formation as measured by Huddle and Dobrovolny (1945) near Fort Apache should be included in the Naco formation, and raised the contact between the Naco and Supai formations to above the highest fossiliferous limestone in which he identified Virgilian fusulinids (Jackson, 1952, p. 145).

Jackson (1951) measured sections along the Mogollon Rim northwestward from Promontory Butte and called the lower member of the Supai red beds the Packard Ranch member, and the middle member of the Supai the Oak Creek member. He correlated both the Packard Ranch member and the Oak Creek member as measured along Fossil Creek with the upper part of the Naco formation of Winters in the Fort Apache area, which was called the lower member of the Supai formation by Huddle and Dobrovolny. The only way to solve the relationships of the interfingering red beds and carbonate rocks and to determine the approximate location of zones is by detailed mapping and tracing of outcrops. Although the units of Huddle and Dobrovolny cross time lines, the best approximation to be gained from the available data is to consider the lower member of the Supai as uppermost Pennsylvanian, as it is near Fort Apache, and calculate thicknesses, clastic ratios, and sand-shale ratios on this basis.

### FOSSIL CREEK

Three sections measured along Fossil Creek (sec. 6) are available. Huddle and Dobrovolny (1945) assigned 475 feet to the Naco formation and 200 feet of strata to the lower member of the Supai red beds. Jackson (1951) measured 414 feet of the Naco formation and 211 feet of the lower Packard Ranch member of the Supai red beds. Wanless's section (personal communication to Eldred Wilson) included only the lower 365 feet of the Naco formation. Clastic ratios for the three different measured sections vary considerably but average about 5; sand-shale ratios also vary but average about 0.2, depending upon how many beds are called sandstone and how many are labeled siltstone. Even beds assigned to the Naco formation are predominantly clastic rocks, being lithologically somewhat similar to the Earp formation of southeastern Arizona.

### SALT RIVER CANYON AREA

The unit called the Naco formation in the Mogollon Rim-Salt River Canyon area by Huddle and Dobrovolny (1945) thickens to the southeast, being 475 feet thick along Fossil Creek, 530 feet thick along Spring Canyon (sec. 7), 745 feet thick along Carrizo Creek (sec. 8), 770 feet thick in Salt River Canyon (sec. 10), and 785 feet thick near the junction of the Black and White Rivers (sec. 11). Desmoinesian and older Pennsylvanian rocks, however, appear to thin only slightly in a southeastward direction, being about 375 feet thick along Fossil Creek, 390 feet along Spring Canyon, and 440 feet along Salt River and Black and White Rivers. Thinning of beds in the Naco formation is almost entirely in the post-upper Desmoinesian beds, and this thinning is mostly due to interfingering with Supai red beds. The lower member of the Supai formation is 300 to 385 feet thick from Spring Canyon to Black River, but only 200 feet thick along Fossil Creek. Clastic ratios of the Naco formation decrease from almost 5, at Fossil Creek, to about 0.96, at Black River; sand-shale ratios range irregularly from 0.07 to 0.13, for the northwestern sections, down to 0.04, at Black River.

Along Spring Canyon (sec. 7), beds assumed to be of Pennsylvanian age are more than 890 feet thick, have a clastic ratio of nearly 3.3, and have a sand-shale ratio of 0.24. To the southeast, along Carrizo Creek (sec. 8), possible Pennsylvanian strata are about 1,045 feet thick, and have a clastic ratio of 3.6 and a sand-shale ratio of 0.13. On the north edge of Salt River Canyon, the Pennsylvanian rocks, as interpreted from reports by Huddle and Dobrovolny (1945) and by Wanless (personal communication), are 1,115 to 1,184 feet thick; the sand-shale ratio is 0.08, and the clastic ratio is about 2. Near the junction of the White and Black Rivers, the Naco formation and lower member of the Supai formation total 1,170 feet thick; they have a clastic ratio of 1.2 and a sand-shale ratio estimated as 0.12.

Northeast of the Mogollon Rim and Salt River Canyon areas, Pennsylvanian rocks are known only in the subsurface of the south edge of the Colorado Plateau. Evidence of age is even more obscure in data from drill cuttings. Where red beds overlie Precambrian rocks, it does not mean necessarily that the basal red beds, whether called Supai or Abo, are of Permian age. Much of the lower part of the Supai red beds to the west is of Pennsylvanian age; why not, then, part of the red-bed clastic rocks to the east, near the Zuni landmass, the probable source of some of the clastic material, especially as a basal sedimentary sequence of red beds and limestones reported from some parts of the Zuni Mountains contains Pennsylvanian fossils?

### OIL TESTS NEAR HOLBROOK

Three test holes drilled southwest of Holbrook are interpreted by Huddle and Dobrovolny (1945) to have encountered 385 to 545 feet of the Naco formation with thinning to the northeast, and 495 to 590 feet of the lower Supai member, also thinning to the northeast. The Naco and lower Supai are 1,080 feet thick in the Union Oil Co. and Continental Oil Co. Aztec Land and Cattle Co. No. 1 (sec. 2); they have a combined clastic ratio of 2.6 and sand-shale ratio of 0.07. Some gypsum beds occur in the lower member of the Supai red beds, as they do in the Union Oil Co. and Continental Oil Co. New Mexico—Arizona Land Co. No. 1 (sec. 3), which penetrated a combined thickness of 1,075 feet of Naco and lower Supai, with a clastic ratio of 3.2 and sand-shale ratio also of 0.07. About 12 miles to the north, just off Plate 1, the Great Basin Oil Co. Taylor-Fuller No. 1 went through 880 feet of the Naco formation and lower member of the Supai red beds, which had a clastic ratio of almost 2 and a sand-shale ratio of almost 0.5; the changes from sections 2 and 3 reflect a decrease of shale to the north and increase of sand.

East of these test wells and north of St. Johns, two oil tests reportedly encountered no Naco-like rocks. In the Franco-Arizona Oil Co. Government No. 1 test, the lower member of the Supai red beds is reported as resting on granite and to be 150 feet thick, with a clastic ratio of about 1.7; sandstone is not reported. About 18 miles to the east, the Argo Oil Corp. State No. 2 went into Precambrian(?) quartzite below beds attributed to the middle member of the Supai formation or, if one comes from the east, the Abo red beds. These relationships suggest that the Pennsylvanian and Permian strata lap onto the Zuni positive area from the west. It is rather unusual, however, for shoreline clastic rocks abutting against the sourceland, as in this case, to be predominantly shales and limestones.

The recent series of oil tests near Holbrook and northwest of St. Johns has shown similar thicknesses, rock types, and areal relationships of the Naco-Supai intertonguing, emphasizing the northeastward approach from a "Holbrook" marine basin or gulf onto the Zuni-Defiance landmass.

The mystery as to how many, if any, Pennsylvanian strata remain beneath the lavas of the Datil volcanic plateau is one of considerable interest for further exploration for buried mineral resources. To the south, near Granville, at least 235 feet of Pennsylvanian rocks is exposed unconformably overlain by Tertiary volcanic rocks. Near Fort Apache the Pennsylvanian is probably at least 1,100 feet thick. North of St. Johns, and directly to the east just inside of New Mexico, lower Permian(?) Abo-Supai red beds overlie Precambrian rocks. Red beds, containing perhaps a few intercalated dark-gray marine shales (Pennsylvanian? caved?), overlie the Precambrian, according to cuttings from the Huckleberry No. 1 Federal (No. 97, pl. 1) and Mae Belcher No. 1 State (east of Springerville, just west of the Arizona—New Mexico Stateline) oil tests. On the northwest(?) and northeast sides of Escudilla Mountain, however, Prof. Donald Bryant, University of Arizona, reported (personal communication) Virgilian fusulinids collected from Pennsylvanian limestones overlain by Tertiary volcanic rocks.

## ESCUDILLA MOUNTAIN

The Pennsylvanian outcrops on the edges of Escudilla Mountain were noted first by Chester T. Wrucke, U. S. Geological Survey. About 50 to 100 feet of much-faulted sedimentary rocks underlies the basal Tertiary volcanic unit (sec. 9); the strata are poorly exposed in heavily wooded country, but there appear to be interbeds of reddish-brown shales amid the massive to nodular fossiliferous limestones. Identification of fusulinids (in rock specimens collected by James A. Smith and Wayne Bock, Texaco, Inc.) by Wendell J. Stewart, of Texaco, Inc., suggests that the various fault slices are mostly of Missourian and upper Desmoinesian ages. These probably are merely upper remnants of pre-Tertiary strata; with the fault block of Desmoinesian rocks, near Trout Creek (sec. 98) about 10 miles to the southeast, they suggest a considerable thickness of Pennsylvanian rocks in the area.

The Pennsylvanian rocks on Escudilla Mountain and along Trout Creek, when compared with the thicknesses, lithologies, and ages of the Pennsylvanian sections to the east, southeast, and west, indicate a southward thickening and a southward change from nearshore to marine shelf deposits, strengthening the postulate that a considerable thickness of marine Pennsylvanian has been laid down throughout the DatilMogollon plateau area.

## *Nomenclature*

Two approaches have been made to the delineation of Pennsylvanian sedimentary units in southwestern New Mexico and southeastern Arizona; both have advantages and disadvantages in correlating between areas where it is not possible to walk out marker beds, or selected sequences, from one locality to the next. One approach, used chiefly by the U. S. Geological Survey, is to lump the Pennsylvanian strata, and in places the underlying Mississippian beds and overlying Permian rocks, in the Magdalena group in New Mexico or the Naco group in Arizona. If pre-Pennsylvanian and post-Pennsylvanian rocks are eliminated from the Magdalena group (although this has not always been possible), the remainder is the equivalent of the Pennsylvanian system, of which the term Magdalena then is a somewhat unnecessary duplication. As used by Gilluly et al. (1954), the Naco group in southeastern Arizona (pl. 9) is equivalent to all the Pennsylvanian-Permian rocks. For strictly reconnaissance mapping, use of these groups outlines areas of Pennsylvanian or of Pennsylvanian-Permian rocks, which is sufficient for the purposes of such mapping. In many areas, the Pennsylvanian-Permian contact cannot be determined, even with detailed faunal studies, within a few hundred feet; so there is perhaps need for inclusive stratigraphic terms.

The Magdalena group has been subdivided into a lower Sandia formation, an upper Madera limestone, and in places an uppermost Bursum formation. As redefined by Thompson (1948, p. 17-19), the Bursum formation is restricted to red beds interbedded with Early Wolfcampian limestones, but as usually employed (Wilpolt and Wanek, 1952), the formation in some localities also includes Virgilian or possible Virgilian red beds and limestones. The Sandia formation has been divided into two members, a lower limestone member, which is now considered to be of Mississippian and perhaps in part of Devonian age, and an upper clastic member, which appears to be mostly of Derryan age. The Madera limestone has also been subdivided into two members, a lower limestone member, typified by the cherty Desmoinesian limestones, and an upper arkosic member, whose base is picked at the base of the lowest feldspathic sandstone occurring in the Madera limestone.

Locally the Magdalena has been used as a group term and subdivided into formations of different names from the Sandia and Madera, but of the same magnitude and of similar lithology; or Magdalena has been used as a formation name more or less equivalent to Pennsylvanian.

The Naco group in southeastern Arizona has been divided into the basal Horquilla formation, the Earp formation, and other younger formations (in ascending order, Colina limestone, Epitaph dolomite, Scherrer formation, and Concha limestone, all of Permian age). The Horquilla formation is chiefly limestone, although not always a "limestone lithofacies" (clastic ratio less than 0.25), and in most of Arizona appears to range in age from Morrowan(?) to Virgilian. In southwesternmost New Mexico, in Hidalgo County, the Horquilla limestone (Gillerman, 1958; Zeller, 1958) extends up into the Wolfcamp and varies from a reefy marginal-shelf limestone facies to a basinal black silty shale and dolomite facies. The Earp formation, of interbedded limestones and pinkish clastic strata, in most areas is of Virgilian and Wolfcampian age, although entirely of Wolfcampian age in Hidalgo County, where it appears to be a western phase of the Abo-tongue lithology of the Hueco formation.

West of the Cochise County type sections of the Naco group, the Earp, Colina, and Epitaph formations grade into the Andrada formation of interbedded gypsum, pinkish clastic beds, limestone, and dolomite, the Pennsylvanian-Permian contact being a bedding plane somewhere in the lower part of the Andrada formation. North and northwest of Cochise County, the Pennsylvanian is mapped as the Naco limestone; with a northwestward increase in clastic rocks, the Pennsylvanian becomes contained within the Naco formation and lower Supai red beds along the Mogollon Rim.

The other approach to establishment of Pennsylvanian units is to set up divisions based on lithology and zonation of the fusulinids into the series and parts of series as generally recognized in Pennsylvanian strata throughout North America except for the Eastern United States area. This method has been chiefly the tool of the stratigrapher-paleontologists, and in only a few areas have the Pennsylvanian strata been mapped in enough detail to determine whether the fusulinid zones have formational significance (Stark and Dapples, 1946; Kottlowski, 1952; Hambleton, 1959). One would indeed be naive to expect erosional or depositional breaks in all places cognate on the one hand with boundaries of all faunal zones or, on the other hand, with photogeologic contacts. Many field geologists (Pray, 1952; King, King, and Knight, 1945; and others) have mapped formations, divisions, or members of the Pennsylvanian based on local lithologic characteristics and have tied their units into fusulinid zones to determine intra-Pennsylvanian depositional history and paleogeography rather than merely gross Pennsylvanian geologic history.

Thompson (1942, 1948, 1954) divided the Pennsylvanian strata of south-central New Mexico into series, groups, and formations based on fusulinid zones and local lithology. His series designations were those of the midcontinent area, except for the use of Derry for the Zone of *Prof usulinella* and *Fusulinella* (Atoka or Bend). The formations are difficult to use in small-scale areal mapping (1:48,000, 1:62,500, and smaller) because of cartographic limitations in depicting thin units, as the Pennsylvanian outcrops in most places form steep slopes or ledgy cliffs. The lithology of some of the formations also changes greatly away from the type localities. Mapping of the Pennsylvanian in the region

TABLE 2. OIL TESTS, PENNSYLVANIAN SECTIONS, AND PERTINENT LOCALITIES IN WEST-CENTRAL NEW MEXICO (see fig. 30)

| PENNSYLVANIAN SECTIONS | OTHER LOCALITIES |
|---|---|
| I. Marshall-Miller oil test, 3-15N-19W | 6. Fort Wingate |
| 2. Tidewater-Mariano oil test, 8.15N-13W | 10. Pinehaven 1 |
| 3. Plymouth-Santa Fe oil test, 13-15N-10W | 11. McGaffey |
| 4. Richfield-Drought oil test, 4-15N-6W | 13. Page |
| 5. Avila-Odlum oil test, 15-15N-1W | 16. l'rewitt |
| 7. Superior-San Mateo oil test. 14-14N-8W | 17. Bluewater |
| 8. Continental-Evans oil test, 2-13N-4W | 18. Mt. Taylor 21. |
| 9. Humble-Santa Fe oil test, 20.14N-1W | Mt. Sedgewick |
| 12. Section NW. of Page | 24. Laguna |
| 14. Section SW. of Page | 25. Ojo Caliente |
| 15. Section along Cottonwood Creek | 27. Brown Mountain |
| 19. Section along Bluewater Creek | 28. Red Lake Ranch |
| 20. Outcrops in Sawyer area | 31. Omega (a village) |
| 22. Section near La Jara Spring | 32. Pie Town |
| 23. Larrazolo-Gottlieb oil test. 21-10N-9W | 39. Miller Ranch |
| 26. Acme Development Co.-Santa Fe oil test, 27-7N-4W | 40. Alamo Day School |
| 29. Skelly-Goesling strat test, 27-3N-21W | 41. Puertecito |
| 30. Huckleberry-Federal oil test, 11-2N-16W | 42. North Lake (playa) |
| 33. Mitchel-Red Lake oil test, 2-3N-8W | 43. Bear Mountains |
| 34. Mesa Aparejo section | 44. La Joya 49. |
| 35. Mesa Sarca section | Tres Montosas |
| 36. Northern Ladron Mountains section | 56. Horse Mountain |
| 37. Southern Ladron Mountains section | 57. Coyote Hills |
| 38. Manzano Mountains composite section | |
| 45. Abo Pass section | |
| 46. Section on Sierra Montosa | |
| 47. Joyita Hills section | |
| 48. Section on Turret Mesa | |
| 50. Polvadera Mountain section | |
| 51. Skelly-Goddard oil test, 22-2S-4E | |
| 52. Magdalena Mountains section | |
| 53 Cerros de Amado section | |
| 54. Socorro Peak section | |
| 55. Section along Trout Creek | |
| 58. Sun-Bingham State oil test, 23-5S-5E | |
| 59. Section in northern Oscura Mountains | |
| 60. Spanel & Heinze-Santa Fe I -H oil test, 27-4N-I 1W | |
| 61. Spanel & Heinze-Santa Fe 1-NI oil test, 5-5N-7W | |
| 62. Spanel & Heinze-Santa Fe I -F oil test, 17-4N-5W | |

has not reached the state of detail where even Thompson's groups have been generally used as mapping units, an indication of the level of knowledge of the Pennsylvanian system in New Mexico and Arizona.

Thompson subdivided (p1. 9) each post-Moi-rowan series into two groups: the Derry series into the Green Canyon group below and Mud Springs group above, the Des Moines series into the Armendaris group below and Bolander group above, the Missouri series into the Veredas group below and Hansonburg group above, and the Virgil series into the Keller group below and Fresnal group above. He also designated

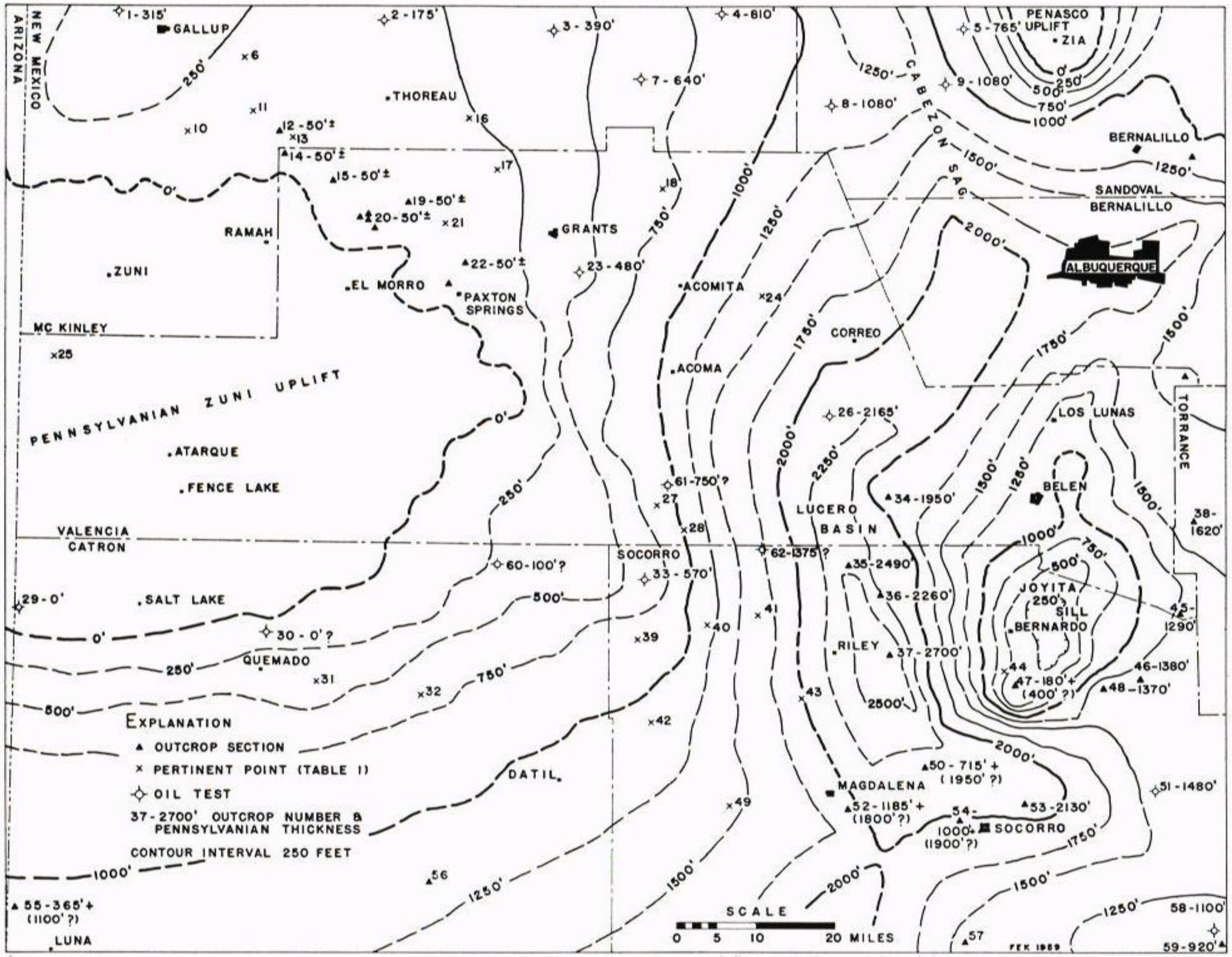


Figure 30

ISOPACH MAP OF PENNSYLVANIAN ROCKS IN WEST-CENTRAL NEW MEXICO

16 formations and one member that are recognizable by lithology alone in areas near the type localities. Some of the formations retain their distinctive lithic characteristics for long distances; the Coane formation and Council Springs limestone, for example, are distinctive units more than 100 miles north and northwest of the Oscura Mountains.

Numerous local names have been used by various geologists in separated areas for formations and members of the Pennsylvanian system (pl. 9). In the Franklin Mountains, Nelson (1940) and Harbour (1958) have subdivided the Magdalena group into, in ascending order, the La Tuna formation, Berino formation, Bishop Cap formation, and an unnamed, chiefly siltstone, unit. In the Sacramento Mountains (pl. 7, sec. 77), Pray (1952, 1954) and Otte (1959) have mapped the Pennsylvanian beds as, in ascending order, the Gobbler formation and its local Bug Scuffle limestone member, the Beeman formation, and the Holder formation. In the northwestern part of the range, the uppermost Pennsylvanian beds are in the lower part of Otte's (1959) Laborcita formation. Kelley and Silver (1952) separated the Magdalena group in the Caballo Mountains into, in ascending order, the Red House, Nakaye, and Bar B formations. Kottlowski et al. (1956), in the San Andres Mountains (sec. 67, fig. 7), split off the upper Pennsylvanian (Virgilian age, probably including some early Wolfcampian beds) as the Panther Seep formation, a distinctive lithic unit from Mockingbird Gap southward for at least 110 miles to the northern Franklin Mountains. In the Silver City mining district, the Pennsylvanian has been mapped (Spencer and Paige, 1935) as the Oswaldo formation below and Syrena formation above.

# *Basal Relationships and Paleogeology*

Positive-tending areas that contributed sediments to the Pennsylvanian streams and seas in southwestern New Mexico and southeastern Arizona were the Pedernal Mountains on the east, the Zuni-Defiance landmass on the north (fig. 30), the Florida landmass north of the present Florida Mountains, possibly the postulated Joyita uplift north of the present Joyita Hills, and from far north of the region, along the Utah-Arizona border, the Kaibab uplift as outlined by Heylmun (1958) and shown on the paleogeographic map (pl. 10). The Joyita and Florida positive-tending areas appear to have been of relatively local consequence, and the Zuni-Defiance landmass seems to have been of low relief, occasionally awash beneath the shallow Pennsylvanian seas, with only parts of the Pennsylvanian Pedernal Mountains contributing large amounts of clastic materials. The Kaibab uplift was probably at times a local source for the Supai delta, and at times part of the delta.

Throughout the region *herein* considered, the basal Morrowan(?) and Derryan deposits are sandy and shaly except to the south, where Pennsylvanian limestones overlie Mississippian carbonate rocks with only local disconformity. Desmoinesian beds are dominantly marine limestones except along the northwestern edge (the Mogollon Rim area) and in such areas as the north-central Sacramento Mountains, where deltaic clastic beds were derived from the Pedernal Mountains and are interbedded with limestones, and except for the black shaly deposits of the Eaton Ranch area. Upper Pennsylvanian strata range from massive marine limestones to interbedded marine limestone and red-bed clastic rocks, and to entirely terrestrial clastic beds.

Early Pennsylvanian rocks apparently rest conformably on Upper Mississippian beds (chiefly Chesterian) in the southern part of the region (pl. 2)—on the Helms formation in the Hueco, Franklin, and southern Sacramento Mountains, and on the Paradise or Black Prince formation in the Big Hatchet, Peloncillo, Chiricahua, and Pedregosa Mountains and in the Gunnison and Tombstone Hills. Basal beds are chiefly thin- to thick-bedded limestones, although in places they include glauconitic sandstones, reddish silty shales, and limestone-chert-pebble conglomerates. In almost all areas where Pennsylvanian strata overlie Upper Mississippian beds, the basal Pennsylvanian may be referable to the Morrowan series. These seas of Morrowan age appear to have been present in the region discussed only near the southern border of New Mexico and in extreme southeastern Arizona, occupying about the same position as late-Mississippian seas. During this time, the Mississippian rocks in south-central Arizona and parts of south-central New Mexico were subjected to karst conditions, with red clay soils and residual cherts locally developed, as well as sink holes and small caverns; this central area, however, was not high above the Morrowan seas and supplied very little clastic sediment.

Derryan rocks were deposited with erosional unconformity on Lower Mississippian beds (Osagian, locally Meramecian) in most of the central and western parts of the region; northeastward they lapped onto older rocks down to the Precambrian. South and southeast of the Zuni-Defiance landmass, Derryan strata in places overlie Precambrian rocks, and the absence of pre-Mississippian Lower Paleozoic beds appears due to erosion during Devonian and early Mississippian times. Isolated erosional remnants of Mississippian strata, unconformable on Precambrian rocks, are scattered beneath the basal Pennsylvanian in this area. In the central part of southwestern New Mexico, Derryan rocks northward successively overlap Lower Mississippian, Devonian, Silurian, Ordovician, and Cambrian strata before resting on Precambrian rocks.

Basal Pennsylvanian beds in much of southeastern Arizona appear to be derived chiefly from residual karst soils, but in southwestern New Mexico north of the New Mexico—Texas line the basal Pennsylvanian beds range from limestone-chert conglomerates and coarse-grained limy sandstones to carbonaceous and coaly shales. Most of the chert and limestone pebbles were derived from the underlying Mississippian rocks; feldspar and mica are sparse sand grains except in the northern sections, where the Pennsylvanian rests on Precambrian granites and metamorphic rocks. Derryan beds in the southern sections are predominantly of marine limestone and shale, whereas those to the north and northeast are of interbedded shallow-marine limestone and shoreline clastic rocks.

Lower Middle Pennsylvanian beds (Derryan) are apparently absent in the Joyita Hills (sec. 47) and Cooks Range (sec. 80), and in places along the Mogollon Rim in central Arizona. The Pedernal Mountains and Zuni-Defiance, Florida, and Joyita uplifts were probably all emergent during this time, but only locally (such as the northern San Andres Mountains area) were they the source of any considerable amount of sediments.

Rocks of Desmoinesian age are typical cherty, marine continental-shelf limestones of rather uniform overall thickness, 500 to 700 feet, in most parts of southwestern New Mexico and southeastern Arizona. In the Cooks Peak area (sec. 80), the Desmoinesian series is thin and is composed mainly of calcarenites and limestone-chert-pebble conglomerates, shallow marine sediments that appear to have been deposited at no great distance north of a low landmass, or group of islands, somewhere north of the present Florida Mountains. In the Joyita Hills (sec. 47), the Desmoinesian sequence is thin, and if parts of the Pennsylvanian strata are not concealed by faulting, the Desmoinesian beds appear overlain unconformably by basal Wolfcampian strata, suggesting that somewhere near the present Joyita Hills there was a low emergent landmass during late Desmoinesian to Virgilian time.

West of the Pedernal Mountains, there are scattered sections wherein the Desmoinesian series contains an abnormal amount of interbedded clastic rocks; these deposits suggest local but relatively high relief of parts of the Pedernal positive area in Upper Middle Pennsylvanian time. The thick sequence of black limestone and shale in the Eaton Ranch area (sec. 60) reflects a relatively rapidly sinking basin of anaerobic waters located either as lagoonal seas marginal to the Zuni positive-tending area or as restricted basins amid the vast continental-shelf sea. Southeast of the Jerome area of Arizona, as shown by the Fossil Creek section (sec. 6), Desmoinesian beds are a few limestones interbedded with red beds, indicating development of the Supai delta (pl. 10) during Middle Pennsylvanian time in that area. To the southeast, near Salt River Canyon (sec. 10), the red beds appear to be dominant only in Upper Pennsylvanian strata.

The Missourian series includes mainly shaly limestone interbedded with some massive reefy limestone (pl. 7, 8, 12), as well as with red beds and other clastic rocks throughout much of the region. Desmoinesian to Virgilian carbonate strata intertongue into the lower Supai red beds in a northwestward and northward direction in the Mogollon Rim area, and Missourian fusulinids have not been reported from unfossiliferous rocks between the Desmoinesian and Virgilian strata. On Cooks Peak only early Missourian beds occur unconformably overlain by Permian red beds. In the eastern and northeastern parts of the region, the first appearance of numerous feldspathic sandstones is in Missourian strata.

Beds of Virgilian age have been entirely or partly removed by later erosion, or were never deposited, in some sections of southwestern New Mexico and south-central Arizona, but in other areas appear to record continuous deposition up into early Wolfcampian time. In the entire region, the Virgilian strata are interbedded marine limestones and nearshore clastic rocks; along the Mogollon Rim in south-central Arizona, the series is dominated by red beds, and west of the Pedernal Mountains arkosic material is prominent in the numerous sandstones of the upper Pennsylvanian beds.

## JOYITA HILLS

The postulated landmass in the vicinity of the Joyita Hills (Wilpolt et al., 1946) is based on the thin section exposed there (sec. 47), as well as on the many arkosic sandstones in the Upper Pennsylvanian beds and the thick sandy basal Pennsylvanian sequence of sections to the east, south, and west. About 5 miles northeast of the Joyita Hills, there is an outcrop of Precambrian rocks overlain by late Cenozoic bolson deposits, but the removal of Pennsylvanian rocks at this outcrop may have taken place in Tertiary time rather than during some part of the Pennsylvanian period. The Pennsylvanian sequence in the vicinity is a lime-sand or sand-lime lithofacies (p1. 5; fig. 13), but this is principally due to the amount of sandstone in basal beds. The evidence suggests a low monadnock near (to the north?) the Joyita Hills in Derryan time, which, along with the Pedernal Mountains to the east and the Zuni arch to the west-northwest, may have been the source of the sands in the surrounding sections; then deposition of a relatively normal but thin Desmoinesian and younger Pennsylvanian sequence, which was considerably reduced by erosion during early Wolfcampian time. The Pennsylvanian rocks in the Joyita Hills are broken by many faults, so that there is the possibility that the post-Desmoinesian beds are concealed along strike dip-slip (bedding plane) faults.

Wengerd (1959) suggested that the Joyita landmass was a shoals or sea-bottom-sill area awash between the Lucero and Estancia basins, preventing sediments from the Pedernal landmass from reaching the Lucero basin and providing conditions favorable for the growth of biohermal reefs.

## FLORIDA ISLANDS

In the Florida Mountains (sec. 90), lower Permian (Hueco) limestones appear to rest with relative conformity on Mississippian limestones (Bogart, 1953, p. 27). Nowhere in the Florida Mountains, however, does the fossiliferous Permian overlie any rocks older than Mississippian. To the north, on Cooks Peak (sec. 80), the Pennsylvanian beds are mainly clastic limestones, calcarenites, and limestone-chert-pebble conglomerates; the section is thin and appears to represent only late Desmoinesian and early Missourian strata. The Pennsylvanian is thin to the northwest near Santa Rita, to the northeast in the Robledo Mountains, and to the southwest in the Tres Hermanas Mountains (pl. 12). There was a low landmass at and south of Cooks Peak during Derryan time, and probably near the Florida Mountains throughout Pennsylvanian time, although early Permian erosion occurred in the Santa Rita and Cooks Peak areas and may be responsible for the relationships in the Florida Mountains. The Pennsylvanian Florida "Mountains" were probably a group of islands amid shallow seas.

## ZUNI—DEFIANCE ARCH

Fossiliferous Pennsylvanian beds appear to be absent in a small area on the north-central edge of the region (pl. 3), which is the southernmost extension of the Zuni-Defiance positive-tending area (pl. **10;** fig. 30). North of the region discussed herein, this upland, during parts of Pennsylvanian time, may have extended as far north as the southwest corner of San Juan County (New Mexico), and during brief periods was linked with the Kaibab positive-tending area near Kanab, Utah. At times the entire area may have been awash beneath shallow seas. The basal red beds that overlie Precambrian rocks throughout most of the Zuni arch may in places be of Pennsylvanian age, as are some of the interbedded red beds and limestones south of the Zuni Mountains, and indeed at the crest of the present Zuni Mountains (Cheetham, 1950). The sediments are chiefly fine grained and appear to have been deposited in shallow seas or on shoreline coastal plains, suggesting a low, periodically emergent area, surrounded and occasionally penetrated by shallow seas. The scattered lenses of fossiliferous limestone in the basal red beds of the Zuni Mountains reportedly contain Desmoinesian to Virgilian fossils.

## PEDERN AL LANDMASS

The Pedernal landmass, named by Thompson (1942, p. 12-14) in one of the earlier descriptions of this feature, appears to have been a mountainous area throughout most of Pennsylvanian time. As plotted by Lloyd (1949, fig. 4), in part from gravity surveys, the Pedernal Mountains of Pennsylvanian and early Permian time occupied what is now the eastern part of Torrance County and the western and central parts of Lincoln County, and extended southward into eastern Otero County and westernmost Chaves County. The mountainous area was bordered on the west by at least two troughlike basins of deposition, the northern, called the Estancia trough, on the east side of the present Estancia Valley, and the southern, called the Orogrande basin, occupying an area similar to that of the present Tularosa Valley. Pennsylvanian sediments deposited in these troughs may approach 4,000 feet in thickness, the thickest part being of Virgilian age. To the east (and east of pl. 1-6), in central and southern Otero county, thin sections of Pennsylvanian rocks are chiefly of lower Pennsylvanian age, the Virgilian and in places older Pennsylvanian sequences having been removed by erosion during early Wolfcampian time. Coarse-grained clastic beds are numerous in almost all the Pennsylvanian series in localities close to and west of the Pedernal Mountains, so that this eastern upland area may have been the source for most of the clastic rocks deposited in the greater part of southwestern New Mexico and in parts of southeastern Arizona.

The east-west relationships across the Orogrande basin up onto the Pedernal upland are shown diagrammatically in Figure 31 and Plate 12. The marine continental-shelf carbonate-rock sequence in the Robledo Mountains grades abruptly eastward into the complex thick basinal deposits exposed in the southern San Andres Mountains, which range from basinal black silty calcilutites, biostromal limestones, and gypsum beds, to cyclic deltaic deposits consisting of basal calcareous arkosic crosslaminated sandstone, grading upward into sandy shale and then up into silty carbonaceous calcilutites interbedded with dark-gray calcareous to carbonaceous shales. The gypsum beds are in the upper part of the Pennsylvanian section (or in the basal Wolfcampian), suggesting isolation and stagnation of the Orogrande basin in late Pennsylvanian-early Permian time.

Eastward to the south-central Sacramento Mountains (pl. 12), the section is somewhat similar, except that the Missourian beds are a near-

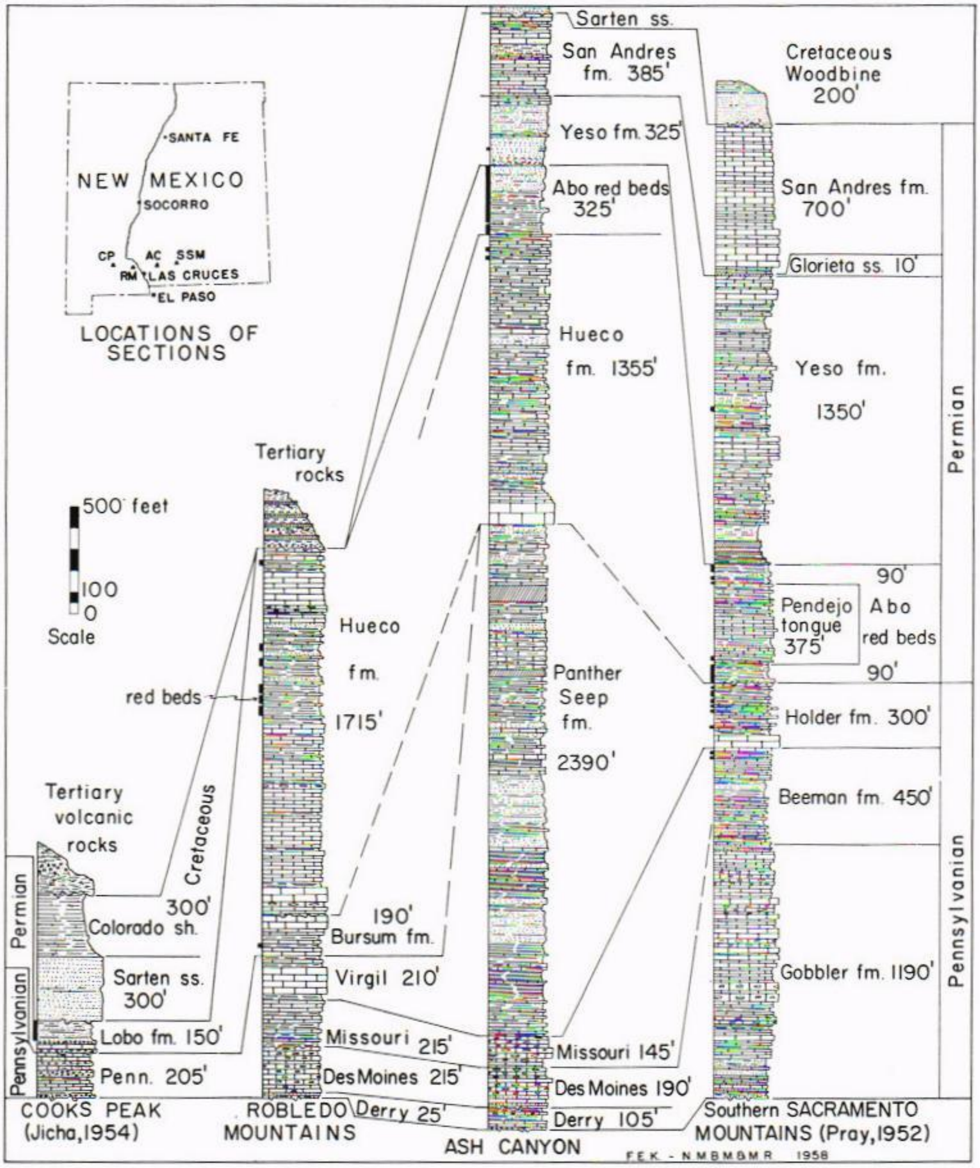


Figure 31

UPPER PALEOZOIC ROCKS WEST AND EAST OF MESILLA VALLEY shore facies not present in the San Andres Mountains, and most of the Virgilian strata have been removed by erosion during late Pennsylvanian-early Permian time. Farther east, near the present crest of the Sacramento Mountains, the Southern Production Co. No. 1 Cloudcroft well (sec. 5, T. 17 S., R. 12 E.) showed truncation and removal of the upper Pennsylvanian down to the middle of the Des Moines series; still farther east and near the top of the Pennsylvanian Pedernal upland, the Lubbock Machine & Supply Co. No. 1 Randle-Anderson well (sec. 3, T. 16 S., R. 16 E.) went into Precambrian granite beneath basal Permian red beds.

The large amount of sediments derived from the Pedernal upland and deposited westward in the Orogrande basin and adjoining areas contrasts with the relatively small amount of detritus washed eastward toward the Delaware basin and its northwestern shelf. The Pedernal Mountains may have been higher on the west and may have drained chiefly to the west during Pennsylvanian time.

Southward, near the New Mexico—Texas line, the north-south trend of the Pedernal Mountains appears to extend to and join the Diablo platform (King, 1940, p. 718, figs. 11, 19). This westernmost Texas uplift, however, occurred almost entirely in early Wolfcampian time and was not an emergent land during the Pennsylvanian period, at least not in the area that now comprises northern Hudspeth County, Texas.

The age of the uplift (or exposure to erosion) of the Pedernal landmass has been discussed by many writers in recent years. The uplift has been projected back into geologic time to be labeled as a positive area during pre-Pennsylvanian time. The pre-Pennsylvanian strata in the San Andres and Sacramento Mountains are chiefly carbonate rocks and do show, between lithic and faunal units, intermittent uplift northward, expressed as erosional truncation and slight depositional thinning northward. The resultant time-rock units are southward thickening wedges. However, there is no noticeable eastward thinning, and no nearshore facies of these lower Paleozoic strata, suggesting that they were deposited across the site of the Pedernal landmass but were removed by erosion during Pennsylvanian or early Permian time.

The culminating and maximum uplift of the Pedernals was in late Pennsylvanian and early Permian time, as shown both by the truncation of older rocks beneath Wolfcampian strata on the margins and over the Pedernal landmass, and by the thick deposits of clastic strata of late Pennsylvanian and early Permian age in the Orogrande and Estancia basins west of the landmass. During most of early and middle Pennsylvanian time, the Pedernal positive area was perhaps a scattered group of hilly islands, the source of detritus shifting throughout the period. The amount of Derryan clastic rocks in the northern San Andres Mountains and in the area east of Socorro, for example, suggests local uplands in the vicinity of Sierra Blanca and the Gallinas Mountains area (sec. 47), respectively. The deltaic facies of the Desmoinesian described by

Pray and Graves (1954) from the Alamo Canyon area of the Sacramento Mountains was derived from erosion of Precambrian rocks to the east, probably southeast of Cloudcroft. Arkosic sandstones in the Missourian strata of the Sacramento Mountains and other areas require sources along the Pedernal trend from east of Cloudcroft to north of the present-day Pedernal Mountain.

Most of the shoreline facies were removed later by erosion or are buried in the subsurface, but similar strata are exposed today around Pedernal Mountain, where the Permian Yeso formation, of tan sandstones and some thin fossiliferous limestones, fills valleys between hills of Precambrian rocks. Talus breccias and slump blocks cemented by tan limy sandstone occur on the edges of the resistant quartzite hills, and lenses of breccia-conglomerate extend away from the ancient hillsides into the valley fill of tan crossbedded to evenly bedded sandstone. The outcrops show a vivid picture of the sedimentation, and one can almost hear the ancient waves rolling up against the quartzite ridges, and see the dying struggle of the brachiopod that left his shell in the beach sand.

## KAIBAB UPLIFT

Heylmun (1958, p. 1801-2) suggested that the Kaibab uplift, with its highest points near Kanab, Utah, was a northwestward extension of the Zuni-Defiance arch across northeastern Arizona, initiated in late Derry-an or early Desmoinesian time. Intermittent uplifts during middle and late Pennsylvanian time are believed to have caused the cyclic deposits of the Hermosa formation to the northeast along the southwest border of the Paradox Basin. This postulated Kaibab arch may have been the source of the lower Pennsylvanian-age Supai red beds in the Jerome (sec. 1) and western Mogollon Rim areas (pl. 10). These Pennsylvanian red beds include a minor amount of limestone lenses and are composed principally of quartz silt and calcite, stained by hematite, sediments suggestive of derivation from pre-existing sedimentary rocks. McNair (1951) believed the Supai in the area west of Jerome to be shallow-water marine deposits; at least locally along the Mogollon Rim, the Supai red beds resemble some present-day delta deposits. The original sediments, rich in hematite, were either dumped so rapidly that the red pigment was not reduced, or the shifting of environments from shallow marine to delta and back did not permit significant reduction of the iron oxides.

Southward from the Mogollon Rim (pl. 11), the Pennsylvanian rocks, especially the upper strata, become less clastic, the red beds decrease in number and thickness, the amount of limestone increases, and the total thickness of the section increases to the almost 2,500 feet present in the Pedregosa basin (sec. 29, pl. 8). The source of the clastic sediments appears to have been chiefly from the north.

## UPPER CONTACT

Upper Pennsylvanian beds appear conformable beneath lower Permian sediments in most of southeastern Arizona (pl. 6), the contact being within interbedded marine limestones and clastic rocks of the Earp formation or lower Andrada formation. Locally a prominent conglomerate appears to mark the base of Wolfcampian beds in the Earp formation. Along the Mogollon Rim, the uppermost Pennsylvanian beds are mainly red beds, with some interbeds of nodular limestones. In central Pima County, Lower(?) Cretaceous rocks are unconformable on various parts of the Pennsylvanian system. The mountain ranges of western Gila County, western Pinal County, Maricopa County, and southeastern Yavapai County show (pl. 4) only Tertiary(?) rocks unconformable on Precambrian rocks. A narrow east-west belt from the Santa Catalina Mountains, near Tucson, to the Vittorio Mountains (sec. 86), west of Deming, exhibits Lower(?) Cretaceous beds unconformable on Pennsylvanian and older rocks. North of this belt is a wider one extending from Winkelman eastward to Silver City, where Upper(?) Cretaceous beds overlie Pennsylvanian and older strata. Dating of the Cretaceous beds on the basis of fossil plants is not in complete agreement with the dating of similar lithic units by marine fossils; thus the uncertainty as to Lower or Upper Cretaceous age.

Tertiary volcanic and sedimentary rocks overlie Pennsylvanian beds, or locally Permian and Mesozoic rocks, throughout most of the Mogollon-Datil volcanic plateau area from Superior (sec. 12), on the west, to the northernmost part of the Black Range, on the east. Tertiary erosion may have removed the entire Pennsylvanian sequence in some areas concealed beneath this hardened sea of lava and pyroclastic rocks. Along the west side of the Rio Grande graben in the Lemitar (sec. 50) and Socorro (sec. 54) Mountains, Tertiary rocks (fig. 32) rest with pronounced erosional unconformity on Pennsylvanian beds, although a few miles to the east, on the east side of the graben (sec. 53), the Pennsylvanian sequence is more than 2,100 feet thick.

In a V-shaped area from Cooks Peak northward to the Zuni Mountains, and in much of the Estancia Valley, Abo red beds rest on Pennsylvanian strata, in places unconformably on early Virgilian or older rocks, but in other localities apparently with conformity on late Virgilian strata. The interbedded red beds and marine Wolfcampian limestones of the Bursum formation overlie upper Pennsylvanian beds in an A-shaped area from Abo Pass (sec. 45) southward to the northern San Andres Mountains and northern Sacramento Mountains. To the south (see pl. 6), the Hueco limestone rests on the Pennsylvanian sequence, although there are lenses of early Wolfcampian limestones and clastic rocks referable to the Bursum formation in some places. Along the east border of the region, the Powwow conglomerate member of the Hueco, or coarse-grained clastic beds attributed to the Abo red beds,

Figure 32

BRECCIA-CONGLOMERATE, BASAL TERTIARY, COYOTE HILLS

Large angular fragments of schist, gneiss, and Pennsylvanian limestone in siliceous tuffaceous siltstone matrix.

are erosionally unconformable on various parts of the Pennsylvanian; to the east, among the remnants of the Pedernal Mountains, the red beds overlie Precambrian rocks. In southwesternmost New Mexico, the Pennsylvanian-Permian boundary is within a zone in the upper part of the Horquilla limestone.

No karst topography was developed on upper Pennsylvanian limestones (as there was, for example, on the upper Permian San Andres limestone beneath the Triassic erosion surface), suggesting that basal Permian beds, whether the Abo red beds or the Hueco-Bursum carbonate rocks, were deposited directly on the Pennsylvanian with very little time lag; therefore, the basal Permian must be Wolfcampian, early Permian, in most areas.

## *Thickness of the Pennsylvanian*

Thicknesses attributed to the Pennsylvanian sequence depend in part on several intangible variables. In some areas the top of the Pennsylvanian is an indefinite bedding plane within unfossiliferous clastic beds or unfossiliferous limestones; this is particularly true along the Mogollon Rim and northward, where some geologists have drawn the top of the Pennsylvanian at the base of the red beds and others have estimated it to be at the top of the highest limestone lens. The thin sections near Granville (sec. 14) and Silver City (sec. 76) are due supposedly to erosion during Triassic-early Cretaceous and/or Tertiary time, but there is some proof that at least part of the area (see pl. 3, 10) was emergent during Pennsylvanian time and that Pennsylvanian beds were not deposited near Deming. North of Phoenix, Tertiary rocks overlie Precambrian rocks in many of the mountain ranges, but there is the possibility that some Pennsylvanian sections are preserved in the graben valleys between the mountain ranges or in remote canyons in the mountains.

Pennsylvanian rocks are absent on the southern tip of the Zuni arch shown on the north-central edge of Plate 3, on the Pedernal upland along the northeast edge, in the southern Hueco Mountains in the southeast corner (pl. 4), and on the large shoe-shaped area extending northwest from the Florida Mountains to Clifton. The thinness or absence of Pennsylvanian rocks in the Florida-Clifton area and southern Hueco Mountains is mostly the result of post-Pennsylvanian erosion, although near the Florida Mountains intra-Pennsylvanian deformation is indicated.

The incomplete data suggest thinning westward from Superior (sec. 12), Arizona, but in most of southwestern New Mexico and southeastern Arizona, except near the positive-tending areas, the Pennsylvanian sequence is between 1,000 and 2,000 feet thick. The thickness of the system beneath the Mogollon-Datil volcanic plateau is not actually known, as there are only a few pre-volcanic-rock outcrops for the 145 miles between the Black River section (sec. 11) and Sierra Cuchillo (sec. 65). Thicknesses and the lithologies of the sections on the edge of the volcanic plateau, however, indicate that a normal Pennsylvanian sequence was deposited in the plateau area. Several widely scattered outcrops of Pennsylvanian and Permian strata near the middle of the volcanic plateau suggest that Cretaceous or Cenozoic erosion has not removed much of the hidden Pennsylvanian.

Five basins are outlined on the isopach map (pl. 3): (1) the small narrow Estancia trough (sec. 41) west of the Pedernal Mountains, which contained as much as 4,000 feet of Pennsylvanian deposits, mostly of upper Pennsylvanian age and with greenish to blackish shales and green to red feldspathic sandstones common; (2) the Orogrande basin (named by Lloyd C. Pray), which extended from Rhodes Canyon in the San Andres Mountains (sec. 67) southward to the northern Franklin Mountains (sec. 93) and eastward to the Sacramento Mountains (sec. 72), and which contained in places more than 3,000 feet of sediments, of which more than two-thirds is of Virgilian (and possible early Wolfcampian) age; (3) the Pedregosa basin, which extended from the Gunnison Hills (sec. 20) southeastward to the Pedregosa Mountains (sec. 29) and the Big Hatchet Mountains area (sec. 96), containing as much as 2,500 feet of Pennsylvanian deposits, chiefly of dense limestone (pl. 12), and ranging southward into northern Sonora; (4) the Lucero basin (Wengerd and Matheny, 1958), a narrow north-south elongated feature centered on the 2,700-foot section in the southern Ladron Mountains (sec. 37); and (5) the San Mateo basin, which contained about 2,050 to 2,650 feet of interbedded limestone and shale, the limestones varying from coarse-grained calcarenites to black calcilutites.

Use of the term basin may be misleading, as one tends to think of a deep-sea basin such as the Midland and Delaware basins of Permian time in southeastern New Mexico and western Texas. At times these southwestern New Mexico basins may have been stagnant, starved "holes" of deep water amid broad continental-shelf seas, but during most of the period they were either (1) merely slightly deeper than surrounding areas, or (2) their bottoms sank more rapidly, owing to structural weakness or because of the weight of sediments poured in from nearby landmasses. The carbonaceous strata (black petroliferous shales of the Estancia trough, black calcilutites and shales of the Orogrande and Pedregosa basins of Virgilian and early Wolfcampian age, and the black Desmoinesian-age limestones of the San Mateo basin) suggest an anaerobic environment; they are interbedded, moreover, with cyclic sequences and deltaic deposits, and contain limestone-cobble breccia-conglomerate lenses, algal beds, small-scale crosslaminations, and other features of shallow-water deposits. The sediments and their sparse fauna indicate broad lagoons of fetid water bordering the landmasses or archipelagoes, or large local depressions amid the shallow continental-shelf seas, with occasionally restricted circulation due to fringing shoals, arcs of reeflike masses, or chains of low islands.

The Orogrande basin may have extended much farther south than the present Pennsylvanian outcrops in the Franklin and Hueco Mountains, but the record of its southern margin was wiped out by erosion during early Wolfcampian time. The basinal deposits vary from black fetid silty shales and dark calcilutites, through such different deposits as bioclastic limestones and evaporites, to cyclic deltaic beds. Relatively persistent sea connections appear to have existed from the Pedregosa basin eastward to the southern Orogrande basin, and thence eastward (pl. 10) around the southern tip of the Pedernal Mountains to the Delaware basin and southeastward to the Marfa basin. The Paradox basin of the Four Corners and San Juan Basin area probably was connected, during maximum marine inundation, with the coalesced PedregosaOrogrande-Delaware-Marfa sea via a southward channel over the Cabezon sag (between the Zuni arch and the Penasco axis) and through the Lucero and San Mateo basins into the Orogrande basin. The Rowe-Mora basin may have connected via the Estancia trough south-southwestward with the Lucero-San Mateo-Orogrande chain of basins.

These Pennsylvanian basins and uplands show a striking alinement with present-day structural trends that originated chiefly in middle-Tertiary time. On the east side of the region, where present structures trend north-south, the Pedernal upland and the Orogrande and other basins also trend north-south. In southwesternmost New Mexico and southeastern Arizona, present structures parallel the northwest-southeast trend of the Pedregosa basin and Florida-Clifton eroded upland (pl. 4).

# *Lithofacies Studies*

The lithology of the Pennsylvanian rocks has not been examined in much detail in southwestern New Mexico and southeastern Arizona, although Read and Wood (1947, fig. 2) compiled a facies map of northern New Mexico, Thompson (1942, 1948, 1954) described the general lithologies of the series in south-central New Mexico, and Stoyanow (1942) the general characteristics of the system in southeastern Arizona. The lithofacies map (pl. 5) compiled for this report unfortunately is based in places on fragmentary information but is probably generally representative of the rocks occurring in the region.

The largest area of limestone lithofacies (clastic ratio less than 0.23: i. e., conglomerates, sandstones, siltstones, and shales make up less than 20 percent of the total Pennsylvanian section) is in the southern part of the area, from the Gunnison Hills (sec. 20) eastward to the Franklin Mountains (sec. 93); the western part includes the thick sections deposited in the Pedregosa basin. Sparse data indicate a limestone lithofacies for the southwestern corner of the southeastern quarter of Arizona, and for a small area near Sierra Cuchillo (sec. 65) and Hermosa (sec. 68) in northwestern Sierra County, New Mexico.

Most of the region is occupied by lime-shale (clastic ratio from 0.25 to 1, and sand-shale ratio under 1) and shale-lime (clastic ratio from I to 8, and sand-shale ratio under 1) lithofacies, which in addition filled most of the southern part of the Orogrande basin. The shale-lime lithofacies in central Arizona and south of the Zuni arch is a red-bed facies that contrasts with the drab to blackish shale-lime facies of the Orogrande basin. West of and near the Pedernal upland, red beds are numerous, especially in upper Pennsylvanian strata.

Sand-lime (clastic ratio from I to 8, and sand-shale ratio more than 1) and lime-sand (clastic ratio from 0.25 to I, and sand-shale ratio more than 1) lithofacies occur near the Florida and Tres Hermanas (sec. 92) Mountains, in the area from the southern Ladron Mountains (sec. 37) eastward to the southern Los Pinos Mountains near the Joyita Hills and on the east flank of the Lucero basin, and in a broad area eastward from Mockingbird Gap (sec. 61) covering the northern edge of the Orogrande basin. In the extreme northwestern corner near Jerome (sec. 1), the lower Supai red beds of probable Pennsylvanian age are a red-bed shale-sand lithofacies (siltstone is calculated with shale, and conglomerate calculated with sandstone) that grades southeastward into the red-bed shale-lime facies of the Mogollon Rim area. The easternmost flank of the Estancia trough, a few miles west of Precambrian outcrops, contains a Pennsylvanian sand-shale lithofacies. Although this includes many red beds (reddish shales, siltstones, and arkoses), there are notable amounts of greenish-gray micaceous quartzose sandstones derived from the quartzites and schists of the Pedernal Hills, as well as greenish arenaceous shale and black petroliferous shale. These sandy facies occur near postulated Pennsylvanian positive-tending areas. North of the map area (pl. 1, 5), in the Zuni Mountains, the thin section of Pennsylvanian rocks is of reddish arkose and some fossiliferous limestones (Cheetham, 1950; Smith, 1958), a sand-lime lithofacies.

The clastic ratios and sand-shale ratios calculated for the measured sections in the region include all the Pennsylvanian strata in each section. The result gives only a gross idea of the lithology and not necessarily of rocks of the same age; for example, the Powwow Canyon section (sec. 94) in the Hueco Mountains ranges from Morrowan(?) to early Virgilian in age, the Cooks Peak section (sec. 80) is only late Desmoinesian to early Missourian, and the Mud Springs Mountains section (sec. 66) is Derryan to Virgilian in age. Lithofacies maps have not been made for each series, because not enough fusulinid studies (nor those of other fossils) have been made.

Most of the Pennsylvanian rocks in the region appear to have been deposited in shallow-marine waters on the continental shelf east of the Cordilleran geosyncline. Deposits in the five "basins" (pl. 3, 10) range from black fetid silty limestone and black silty shale, probably typical of deeper anaerobic water sediments, through cyclic sequences of marine and nonmarine deltaic beds, to gypsum/anhydrite beds. Near some of the basins are numerous biohermallike reefs, such as those around the Orogrande basin, as now exposed in the northwestern Sacramento Mountains, central San Andres Mountains, and northern Hueco Mountains; near the Lucero basin outcropping on Mesa Sarca; and on the northeast flank of the Pedregosa basin in the Big Hatchet and east-central Animas Mountains and Sierra Rica. Black carbonaceous and coaly shales, with local coal laminae, occur within the shelf facies near Pennsylvanian uplands, suggesting coastal lagoonal swamps. Some of the limestones of the shelf sequence appear to be thick massive biostromal beds; these occur between basins and within some of the thicker sections, but not between basins and nearby uplands.

Pennsylvanian strata of the Supai delta, as shown on the paleogeographic map (pl. 10), are chiefly red beds that grade southward into interbedded red beds and limestones, and farther southward into a predominantly limestone sequence (pl. 11). The rocks appear to vary from shallow-water marine to deltaic deposits, intertongue westward with the Callville limestone (McNair, 1951) and southward into the Naco formation, but pinch out eastward onto the Defiance-Zuni arch. Studies of the average direction of crosslaminations have been made in Coconino and Yavapai Counties, Arizona; McKee (1940) found south and south-southeast trends in the lower Supai of the Grand Canyon area (shown by arrows on pl. 10), Hughes (1952) measured south and south-southwest trends near Ashfork (west of Flagstaff), and Jackson (1952) noted south-southeast trends along the Mogollon Rim (south of Flagstaff). These suggest that much of the lower Supai, of probable

Pennsylvanian age, originated from the north, from the vicinity of the Kaibab arch. Supai red beds near Holbrook, and similar beds to the southeast, probably derived much of their clastic materials from the Zuni-Defiance positive-tending area.

Lithofacies of the Pennsylvanian in southwestern New Mexico and southeastern Arizona are a reflection of the paleogeography of the period, as shown in Plate 10 and as compared with Plate 5. Relationships outside the region herein discussed were derived from the following sources: Four Corners area, Wengerd and Strickland (1954), Herman and Barkell (1957), and Wengerd and Matheny (1958); west-central New Mexico, Foster (1957); north-central New Mexico, Read and Wood (1947) and, with south-central Colorado, Brill (1952); southeastern Colorado, Maher and Collins (1953); northeastern New Mexico, Roy W. Foster (personal communication); northwestern Texas, Roth (1955); southeastern New Mexico, Adams et al. (1951), Lloyd (1949), and Galley 1958); and south-central Utah, Heylmun (1958).

## *Petrographic Studies*

Sidwell and Warn (1951) described the mineral content and some petrographic features of the upper Pennsylvanian rocks exposed in Abo Canyon (sec. 45), and Kottlowski and Foster (Kottlowski et al., 1956, p. 36-47, pl. 4, 5) made binocular and thinsection studies of the Pennsylvanian rocks in the San Andres Mountains. Stark and Dapples (1946, p. 1145-1153) described the various types of rocks that make up the Pennsylvanian in the Los Pinos Mountains and attempted to relate the lithic types to ideal cycles of sedimentation. Their work was entirely with megascopic features. Plumley and Graves (1953) described petrographic characteristics of the Virgilian reefs in the Sacramento Mountains (fig. 26). Hamleton (1959) studied the carbonate-rock fabrics of the Missourian beds in central Socorro County and attempted deduction of the environments as based on the megascopic and microscopic features of the limestones.

Several unpublished reports have been compiled by oil company geologists on reef rocks and other strata, but only a few of the Pennsylvanian rocks of this region have been studied petrographically. The several studies published have been relatively cursory, leaving a very fertile field for future geologic work. Much of the depositional history could be worked out by detailed studies of the numerous rock types; the various sandstones, arkoses, and graywackes; the range of shales from silty reddish beds to black carbonaceous shales, the limy to arkosic silt-stones; the thin coal beds and underclays; the almost infinite varieties of limestones, such as various calcarenites, calcilutites, coquinas, and marls, as well as coquinoid and biohermal limestones; the chert beds; and the gypsum.

One of the interesting features noted by Sidwell and Warn (1951, p. 4) is that the flaggy coquinoid limestones of Missourian and Virgilian age near Abo Pass in most places grade up into thin to thick beds of gray calcareous to gypsiferous micaceous shales. The gypsum occurs as a finely crystalline binding material, as laminae, veinlets, and nodules. Although the gypsum was also noted by Stark and Dapples (1946, p. 1148), it has not been mentioned by other geologists who have mapped the area, and is an important indication as to the conditions of sedimentation.

As described from cursory petrographic examination of the Pennsylvanian sections in the San Andres Mountains, almost all the limestones are of fossiliferous clastic types, being composed of sorted to unsorted fossil-fragment debris cemented by crystalline to cloudy cryptocrystalline calcite and minor ferruginous clay. Even the dense aphanitic limestones appear to be derived from clastic lime mud and are often marked by small crosslaminations and small-scale contemporaneous deformation features, such as tiny slump blocks (1 mm thick), lenses of breccia, and small crumpled folds and imbricate thrust slices between parallel undeformed laminae.

# *Mineral Resources of the Pennsylvanian*

Pennsylvanian rocks are the host and gangue of metallic ores in many of the mining districts in southwestern New Mexico and southeastern Arizona, especially in limestone contact metamorphic zones. Nonmetallic economic minerals and rocks occur in great abundance in the Pennsylvanian sequence but are too far from populous regions to have been of more than local use. Although there are thick, possibly petroliferous, marine sedimentary sections in the region, only a few authentic shows of oil and gas have been reported from the widely scattered oil tests drilled. The complications of basin-and-range structure and Cenozoic sedimentation have discouraged exploration.

## COAL

Only thin coal lenses have been found in the Pennsylvanian strata of New Mexico, and these occur in the north-central part of the State, near Pecos and Santa Fe. These coal beds, in the lower part of the Pennsylvanian, have been mined sporadically for local use, such as in small lime kilns, but are of too limited and erratic extent to be considered economic. In south-central New Mexico, the lower Pennsylvanian (Derryan) rocks include blackish carbonaceous shales, with coaly laminae, that have been prospected in many places in the search for minable coal, but without success. Carbonaceous shales also occur in upper Pennsylvanian strata in some localities, such as the San Andres Mountains, but contain coaly laminae and lenses, as far as has been reported, only on the east slope of the Sandia-Manzano Mountains.

No coal beds or even coaly laminae are reported from the Pennsylvanian of southeastern Arizona, and most of the shales in the lower and upper parts of the sequence appear more ferruginous than carbonaceous.

## GYPSUM

Two thick gypsum beds occur in the upper part of the Panther Seep formation in the southern San Andres Mountains, where they crop out a few hundred feet beneath the basal cliff-forming limestone of the Wolfcampian Hueco formation. The lower gypsum bed is 25 to 40 feet thick near Ash Canyon (sec. 79), and the upper gypsum bed about 80 to 105 feet thick. In the northern Franklin Mountains, just north of the New Mexico—Texas Stateline, the upper(?) gypsum (fig. 33) was quarried at several places by the El Paso Cement Co., now the Southwestern Portland Cement Co. A thick gypsum bed at apparently the same general stratigraphic horizon was reported by Hardie (1958, p. 45)

Figure 33
LAMINATED GYPSUM, UPPER PANTHER SEEP FORMATION, IN QUARRY NEAR ANTHONY GAP, NORTHERN FRANKLIN MOUNTAINS

in the northern Hueco Mountains. These gypsum beds may be of early Wolfcampian age.

Some of the shales in upper Pennsylvanian beds are gypsiferous and may be of considerable use in the making of cement, as they would supply the gypsum, silica, and alumina that are added to limestone to produce some common types of cement.

## OIL AND GAS

There has been one producing carbon dioxide gas field on the northeast border of the region, northwest of Estancia. Shows of oil and natural gas are reported from the Holbrook anticline west-northwest of St. Johns, Arizona, from the numerous small structures in the Estancia basin, and from many of the wells drilled in the graben valleys of the Basin and Range structural province. Shows of hydrocarbons in the latter area appear chiefly to have been in the Cenozoic rocks, and the legitimate shows are probably due to migration from older pre-Cenozoic strata, in part from the Pennsylvanian. Areas in which the Pennsylvanian rocks may contain oil and gas and that have not been adequately tested are: (I) the southern edge of the Black Mesa Basin west of St. Johns, (2) the Acoma embayment northwest of the Ladron Mountains and Mesa Sarca, (3) Estancia Valley, (4) Chupadera Mesa, (5) Jornada del Muerto, and (6) Tularosa Valley. In all these areas the Pennsylvanian rocks include possible reservoir rocks and source beds.

The basin-and-range country west of the Rio Grande and south and west of the Mogollon-Datil volcanic plateau has been considered as an unlikely area for the accumulation of commercial amounts of petroleum (Brown, 1952, p. 60-67). Many parts of the area have undergone intense structural deformation (fig. 34), and Pennsylvanian rocks have been metamorphosed and mineralized in some localities near large, relatively coarse-grained, intrusive masses, but in view of the widespread deformation, there are, surprisingly, many areas where the sedimentary rocks have not been altered and are undisturbed. Thrust faults, intrusive rocks, and volcanic rocks have been emphasized as deterrents to the trapping and retention of petroleum in this area; however, much oil has been found amid thrust sheets in the Turner Valley fields of southwestern Alberta and in some of the California fields, and the northeastern oil fields in Mexico produce from massive brittle cherty limestones interbedded with volcanic tuff beds and cut by numerous basaltic dikes and plugs. The difficulties of exploration for petroleum in the basin-and-range country are the greatest drawbacks to finding any oil and gas that might be present. No authentic oil seeps are reported from the region, an unfavorable sign, and the Pennsylvanian and other pre-Tertiary strata in most bolsons are buried beneath thousands of feet of Cenozoic sediments and some volcanic rocks. Possible structural traps in petroliferous rocks are almost impossible to locate by present-day geophysical methods because of this thick and lithologically variable valley fill.

Pennsylvanian limestones, the Naco and Magdalena groups as generalized, have been condemned as dense finely crystalline beds of low porosity, with too few interbedded porous sandstones to form commercial reservoirs. Although there are many Pennsylvanian sections in which dense limestones and interbedded argillaceous limestones predominate, there are enough fetid porous permeable beds in most sections to constitute reservoirs under suitable structural conditions. Many coarse-grained arkosic sandstones occur in the lower Earp and lower Andrada formation, in the Sandia formation, in the upper part of the Madera limestone, and throughout the system in sections near the Pennsylvanian positive-tending areas. Lenticular fossil-fragment calcarenites, and reef-like masses, both biohermal and biostromal, appear to have the best possibilities for production, other than fracture-controlled secondary porosity or cavernous porosity developed by leaching of limestone. Detailed studies of the outcrop and subsurface Pennsylvanian rocks could indicate the belts of reeflike limestones and suggest general locations for drilling.

Pre-Cenozoic structure and strata of the Mogollon-Datil volcanic plateau can only be estimated from the pre-Cenozoic outcrops on the edges of the plateau and amid the volcanic rocks; again, the difficulties of exploration for structures beneath the thin to thick blanket of vol-

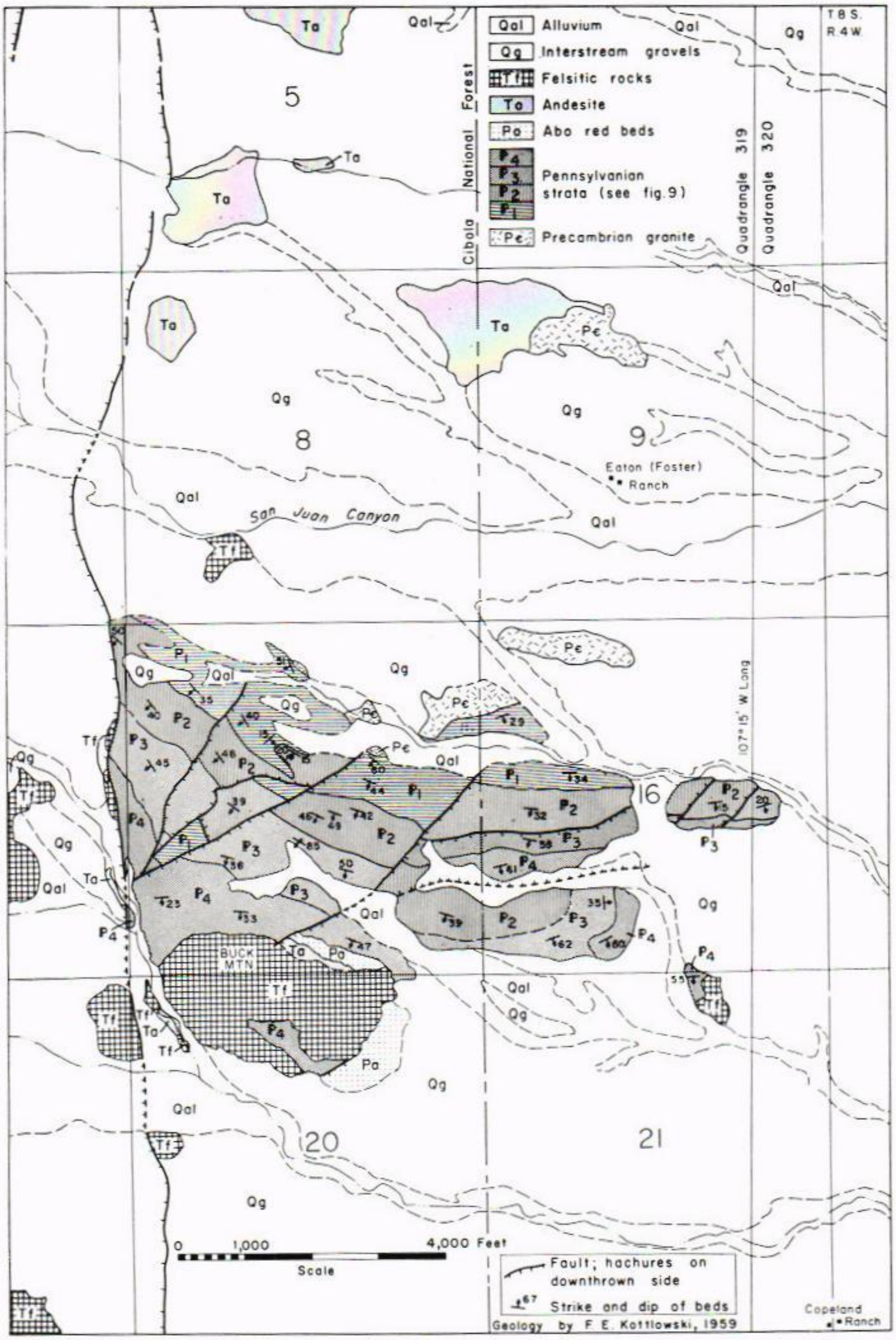


Figure 34
GEOLOGIC MAP OF EATON RANCH FAULT BLOCK

canic rocks are a considerable deterrent to the finding of oil and gas. The 1,000- to 2,650-foot sections of Pennsylvanian rocks on the edges of the volcanic plateau (sec. 60, Eaton Ranch; sec. 65, Monticello; sec. 74, Santa Rita; sec. 11, White and Black Rivers) suggest a substantial thickness of the Pennsylvanian below the volcanic rocks. The limestone lithofacies of the Sierra Cuchillo section (sec. 65) and the lime-shale of the San Mateo basin section are of marine beds probably deposited far from any Pennsylvanian upland, and indicate that marine strata were deposited over much of the present volcanic-rock area.

## OIL SHALE

Dark-gray shales from upper Pennsylvanian rocks east of Abo Pass have yielded oil at the rate of 41 gallons per ton on distillation (Bates, 1942, p. 288). The blackish shales occur as thick beds in some Pennsylvanian sections but have not been tested, except near Abo Pass, to determine whether they are carbonaceous (coaly) or bituminous (sapropelic). Many of the dark shales have carbonaceous plant films and marine fossils in the same laminae and probably contain a mixture of humic and sapropelic material.

## SHALE AND CLAY

Pennsylvanian shales and claystones have been used locally to produce tile and brick, and in places are the source of alluvial clays that have been used for centuries to make adobe brick. The gypsiferous shale interbeds of the upper Pennsylvanian sequence are of potential use in the manufacture of cement.

## LIMESTONE

Pennsylvanian limestones have been used locally for building stone and flagstone, and to make crushed rock, lime, and cement. Crushed limestone, used for concrete, road metal, railroad ballast, and smelter flux, is quarried as near as possible to localities where it is consumed, generally from small roadside quarries.

The Arizona Portland Cement Co. quarries Pennsylvanian limestones from the Picacho de Calera Hills at the northwest tip of the Tucson Mountains, northwest of Tucson. The Ideal Cement Co. has completed a plant near Tijeras, about 15 miles east of Albuquerque, on the back slope of the Sandia Mountains, where it will quarry the upper Pennsylvanian limestones and shales. The Permanence Cement Co. has sampled and drilled the upper Pennsylvanian rocks east of Abo Pass (sec. 45) preparatory to construction of a cement plant at Scholle, a small railroad station on the Atchison, Topeka and Santa Fe Ry. and U. S. Highway 60, 27 miles southeast of Belen.

Only a few chemical analyses of Pennsylvanian limestones from the region have been published. Some of the high-lime beds from the Oscura Mountains contain (Kottlowski, 1957, p. 37) 98.4 percent calcium carbonate, 1.3 percent magnesium carbonate, and 0.3 percent insoluble residues. Other impure limestones include as much as 10 to 30 percent quartz silt and clay, and some of the beds, especially of the Desmoinesian units, contain from 5 to 35 percent chert. Chemical requirements for limestones vary, of course, with the use, but for most purposes for which the chemical impurities are possible detriments, calcium carbonate should exceed 97 to 98 percent, magnesium oxide should be less than 2 percent, silica less than 1 percent, alumina less than 1 to 2 percent, phosphorus pentoxide less than 0.005 percent, and iron oxide less than 0.25 to 1 percent.

The explosive expansion of road building, due in part to the Federal Interstate Highway program, has emphasized the need for resistant, dependable aggregate for concrete and asphaltic binding material. Relatively pure limestone is monomineral; it thus does not suffer from differential expansion of component minerals as does granite as used in the Zuni Mountains and Santa Fe areas, or andesite, as used in the Lordsburg area. Outcrops of suitable Pennsylvanian limestones occur in almost all parts of southwestern New Mexico and arc easily and inexpensively available for the making of crushed-rock products.

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