Pennsylvanian rocks in north-central New Mexico

Frank E. Kottlowski
1961, pp. 97-104. https://doi.org/10.56577/FFC-12.97

in:

Albuquerque Country, Northrop, S. A.; [ed.], New Mexico Geological Society 12 th Annual Fall Field Conference Guidebook, 199 p. https://doi.org/10.56577/FFC-12

This page is intentionally left blank to maintain order of facing pages.

PENNSYLVANIAN ROCKS IN NORTH-CENTRAL NEW MEXICO

FRANK E. KOTTLOWSKI
State Bureau of Mines and Mineral Resources Division of New Mexico
Institute of Mining and Technology

For untold centuries the Mississippian limestones had lain exposed to the sun. Then tongues of the early Pennsylvanian seas invaded the karsted lowlands. Chert, limestone pebbles, and reddish clay from the Mississippian beds and quartz, feldspar, and mica from the Precambrian-rock hills where the Mississippian had been completely removed—these mingled to form the clastic member of the early Pennsylvanian Sandia formation in what is now north-central New Mexico. Local coal swamps developed on lowlands bordering debris-choked bays. By middle Pennsylvanian, Desmoinesian time, much of the region was covered by shallow seas teeming with invertebrate life and only high parts of the positive areas were exposed to local erosion—the Zuni dome to the southwest, the Pedernal mountain range to the southeast, and the Penasco-Santa Fe (Uncompahgre-San Luis) mountainous islands and shoals to the north. To the northeast, thick argillaceous sediments filled the Mora basin, contrasting with the "normal" marine bioclastic (recrystallized drewite?) limestones of the Desmoinesian seas and the local biohermal masses near atolls and islands.

Late Pennsylvanian time, Missourian and Virgilian, was marked by increasing tectonism. Parts of the Zuni dome may have been awash, but the Pedernal mountains and Penasco-Santa Fe-Uncompahgre ranges towered above the arkose-encumbered seas; thickest, coarse-grained sediments were deposited in the Mora, Estancia, Lucero, and San Juan basin areas. The results are shown in the arkosic limestone member of the Madera limestone and the lower beds of the arkosic red-bed Sangre de Cristo formation. This pulsating active orogeny extended at least into Wolfcampian time as recorded by the middle Sangre de Cristo formation, Bursum formation, and lower and middle Abo and Cutler formation red beds. In most places, the end of the Pennsylvanian period is now registered only by an obscure bedding plane within red beds or within intercalated marine limestones and terrestrial deposits.

PREVIOUS GEOLOGIC STUDIES

The type localities of the Sandia and Madera formations of the Magdalena group are in the Sandia Mountains east of Albuquerque and they have been mapped in some detail within most of the mountain ranges of north-central New Mexico. Herrick (1900) proposed the term Sandia series for the lower part of the "Coal Measures" of the Sandia Mountains. Keyes (1903) named the upper limestones of the Upper Carboniferous the Madera limestone, for the village of La Madera in the eastern foothills of the Sandia Mountains. Gordon (1907) labeled the strata between the Mississippian Kelly limestone below and the Abo red-bed formation above as the Magdalena group in the Magdalena Mountains and other areas of central New Mexico, and used the Sandia and Madera formations as the two main divisions of the group. Darton (1928) described the gross characteristics of the Magdalena group, noting its thinness or absence in the Zuni, Pedernal, and Nacimiento Mountains. He commented that the plane of division between the Sandia and Madera formations appears not to be constant, and that the transitions from one formation to the other differ in different localities. Renick (1931) described the Magdalena group in the western Nacimiento Mountains and western San Pedro Mountain, showing that locally the Abo red beds rest directly on Precambrian rocks, and suggesting that the absence and thinness of the Pennsylvanian strata at the northwest corner of the Nacimiento uplift was due to post-Pennsylvanian uplift and erosion prior to deposition of the Abo formation.

Melton (1925) and Ver Wiebe (1930) outlined the southern parts of the Uncompahgre-San Luis uplift which they considered as extensions of the late Paleozoic Ancestral Rockies from Colorado into north-central New Mexico. Needham (1937) described scattered collections of Pennsylvanian fusulinids from the region, and gave (Needham, 1940) generalized correlations based on the faunas.

Thompson (1942) believed the typical Sandia formation to be confined to the general region in and near the Sandia Mountains, and listed faunal correlations of Pennsylvanian units in north-central New Mexico with his faunal-stratigraphic sequence for the south-central part of the State. He described overlapping relationships of Pennsylvanian and Permian beds onto Precambrian rocks in the Pedernal Hills, Zuni Mountains, and Nacimiento Mountains. The Sandia formation of the Sandia Mountains area was correlated, by fusulinid studies, with the early Desmoinesian Elephant Butte formation. The thick argillaceous Desmoinesian of the eastern Sangre de Cristo Mountains, east of Figure 1, in the area of the Rowe-Mora basin (Read and Wood, 1947) was noted.

During the middle 1940's geologic maps compiled by members of the U. S. Geological Survey and the University of New Mexico, covering much of the Pennsylvanian outcrop area of north-central New Mexico, were published (Read and others, 1944; Henbest and Read, 1944; Northrop and Wood, 1946; Kelley and Wood, 1946; Wilpolt and others, 1946) and the Pennsylvanian stratigraphy synthesized by Read and Wood (1947). Read and others (1944) mapped the area of Figure 1 east of Albuquerque and south of Santa Fe, and measured many sections in the Manzano, Manzanita, Sandia, and Sangre de Cristo Mountains. They compiled an isopach map showing the combined thickness of the Pennsylvanian strata and Abo-Sangre de Cristo formations; some Mississippian (Armstrong, 1955) and possible Devonian(?) (Baltz and Read, 1960) rocks were included in the basal Sandia formation. The Madera limestone was shown grading upward into the red-bed Sangre de Cristo formation in the southern Sangre de Cristo Mountains, but locally the red beds rest on Precambrian rocks.

Henbest and Read (1944) listed the stratigraphic distribution of Pennsylvanian fusulinids from measured sections in the Nacimiento Mountains, concurring with and proving Thompson's (1942) suggestion that the northwestern part of the range was a granite ridge early in Pennsylvanian time and subsequently was progressively overlapped northward by younger and younger Pennsylvanian and Permian sediments. They noted the local presence of possible Mississippian beds between the basal Pennsylvanian strata and the Precambrian rocks, as veri-

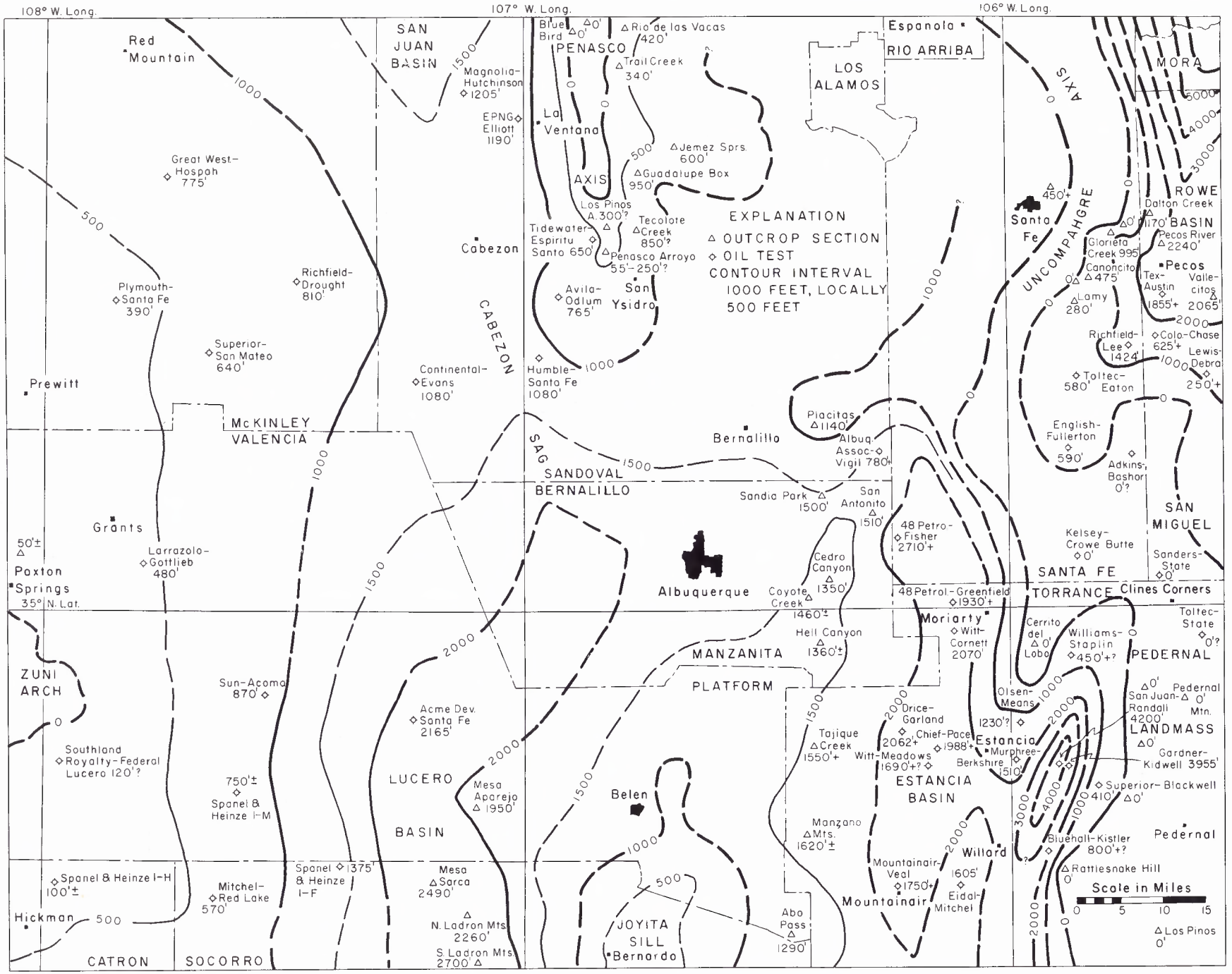

FIGURE 1 — ISOPACH MAP OF PENNSYLVANIAN ROCKS IN NORTH-CENTRAL NEW MEXICO

fied by faunal studies (Armstrong, 1955, 1958; Fitzsimmons, Armstrong, and Gordon, 1956). Mapping of the Nacimiento Mountains and San Pedro Mountain by Northrop and Wood (1946) outlined a narrow north-south positive area (as shown by an isopach map) that was exposed to erosion during most of Pennsylvanian time, and was bordered on the west and east by Pennsylvanian-Permian-age sedimentary basins. Five faunal zones, based on both megafossils and fusulinids, were recognized in the Pennsylvanian sequence. The San Pedro-Nacimiento landmass was termed the Penasco axis by Read and Wood (1947).

The thick, dominantly marine Pennsylvanian section of the Lucero uplift area was mapped by Kelley and Wood (1946), and key sections were measured to describe the rocks of the Pennsylvanian-age Lucero-area sedimentary basin. Wilpolt and others (1946) mapped the Abo Pass area near the junction of Socorro, Valencia, and Torrance Counties; their stratigraphic studies indicated a Pennsylvanian positive area, called the Joyita axis, that was suggested as a southern continuation of the Penasco axis.

The distribution and correlation of the Pennsylvanian rocks in northern New Mexico was summarized by Read and Wood (1947) based upon the above-mentioned mapping and stratigraphic investigations. They presented an isopach and facies map of the Pennsylvanian rocks showing the location of the basins and positive features, as well as the ratio of clastic to calcareous sediments—one of the earlier maps of this type. The Pennsylvanian-early Permian sedimentary cycle was noted as consisting of two phases, an older marine one, and a younger continental phase. The marine phase was listed as (1) a suite of transgressive sediments, the upper clastic member of the Sandia formation, (2) evenly and widely distributed marine sediments that were deposited during maximum transgression, the lower gray limestone member of the Madera limestone and part of the upper arkosic member, and (3) unevenly distributed and restricted alternating marine and continental sediments that represent a period of offlap or marine regression, part of the upper arkosic member and Red Tanks member of the Madera limestone, and the Bursum formation. This marine phase is encompassed within the Magdalena group. The overlying continental phase is the Abo red beds and arkoses of central New Mexico, the Sangre de Cristo formation of the Sangre de Cristo Mountains, and the lower part of the Cutler formation of the San Pedro Mountain area.

Bradish and Mills (1950) suggested correlations between the Magdalena group and the Pennsylvanian units of the Paradox basin region. Cheetham (1950) collected and identified (as collaborated by Arthur L. Bowsher) bryozoans and brachiopods of Desmoinesian and Missourian aspect from limestone lenses within basal red beds of the Zuni Mountains. These rocks appear to have been shoreline deposits on the edge of the Zuni arch. McKee (1951) drew an isopach map of the Pennsylvanian of New Mexico and Arizona with the New Mexico part based chiefly on above-listed studies. Brill (1952) made lithologic and isopach studies in the Sangre de Cristo Mountains region.

Foster (1957) reviewed the occurrence of the Pennsylvanian in west-central New Mexico and included interpretations of the subsurface data. Smith and others (1958, 1959) mapped and briefly described lenses of Pennsylvanian limestones lying on the Precambrian rocks of the northwestern and southeastern Zuni Mountains. Wengerd (1959) and Kottlowski (1959) discussed the Pennsylvanian of the region from the Zuni Mountains eastward to the Manzano Mountains, each drawing isopach maps that show some differences in interpretation. Wengerd's paper, along with a previous one (Wengerd, 1958b), was directed at the petroleum possibilities of the Lucero basin region. He (1958a) summarized the habitat of oil in the Pennsylvanian of the San Juan Basin, and with Matheny (Wengerd and Matheny, 1958) made a detailed analysis of the Pennsylvanian outcrop and subsurface data for the Four Corners region, including the northwestern part of Figure 1. Fetzner (1960) described the Pennsylvanian in about the same region and his interpretations of paleotectonics, thickness, and sand-shale ratios for north-central New Mexico differ but slightly from earlier published studies. Kottlowski's (1960) summary of Pennsylvanian sections in southwestern New Mexico barely reaches the south edge of Figure 1 but most of New Mexico is covered by a regional paleogeographic sketch map (ibid., pl. 10). Several quadrangles in the southwestern Sangre de Cristo Mountains near Santa Fe were mapped by the writer (Kottlowski, in Spiegel and Baldwin, 1956) and the Pennsylvanian rocks examined in an area that was near the southern termination of the Uncompahgre-San Luis axis.

AREAL DESCRIPTIONS OF THE PENNSYLVANIAN ROCKS

The Pennsylvanian outcrops and the Pennsylvanian beds reached in oil tests throughout north-central New Mexico fall naturally into seven geographic areas: the Zuni Mountains, Ladron Mountains-Lucero Mesa, Manzano-Manzanita-Sandia Mountains, Estancia Basin-Pedernal Hills, southwestern Sangre de Cristo Mountains, San Pedro-Nacimiento Mountains, and the southeastern San Juan Basin.

Zuni Mountains

Local limestone lenses occur sporadically in the lower part of the Abo red beds of the Zuni Mountains. Most of the fossils reported (Cheetham, 1950) from these scattered marine deposits are of Pennsylvanian age. As much as 125 feet of the basal red beds may be various parts of the Pennsylvanian and Desmoinesian, Missourian, and Virgilian probably present locally. The Pennsylvanian-Permian boundary must vary within short distances from hillock to valley on the pre-red bed surface, and probably only some of the basal noncalcareous beds are of Pennsylvanian age. Whereas the present area of the Zuni Mountains appears to have been near the shoreline during most of Pennsylvanian time, the higher part of the Pennsylvanian-age Zuni uplift was probably to the southwest.

On the eastern flanks of the Zuni Mountains, in the southern San Juan Basin, Acoma area, and North Plains-Mesa del Oro area, a few scattered oil tests have been drilled through the Pennsylvanian and into the underlying Precambrian rocks. These wells record a gradual thickening toward the northeast (Plymouth-Santa Fe, Superior-San Mateo, Richfield-Drought, Continental-Evans, Great Western-Hospah) into the southeastern San Juan Basin, and a somewhat more abrupt thickening toward the southeast (Larrazolo-Gottlieb, Sun-Acoma, Spanel Heinze 1-M, Mitchel-Red Lake) into the Lucero basin (Wengerd, 1958b). Southward, as shown (Southland Royalty-Federal Lucero, Spanel Heinze 1-H) along the southwest border of Figure 1, the Pennsylvanian is thin, and is dominantly a shoreline facies. A large region between Grants and Albuquerque is untested, so that a possible northern extension

of the Lucero basin to the 3-corners area at the junction of Bernalillo, Sandoval, and Valencia Counties is hypothetical.

Ladron Mountains-Lucero Mesa

One of the thicker sections is at the southern edge of the Ladron Mountains where the Pennsylvanian is probably about 2,700 feet thick. Derryan and Desmoinesian strata are well exposed along the western backslope of the range, but Missourian and Virgilian beds are scattered on the western dip slope in low ridges amid blanketing sheets of Cenozoic gravels and travertine. A section measured by Cheetham (1950), as checked and modified by the writer, shows many fine-grained clastic rocks in the Derryan, unusually numerous sandstone and shale beds in the Desmoinesian, and a large percentage of shale and much arenaceous calcarenite in the upper Pennsylvanian. Northward in the Ladron Mountains, Mesa Sarca, Mesa Aparejo, and the Acme Development Co.-Santa Fe oil test, the Pennsylvanian thins to about 2,000 feet and contains a larger amount of argillaceous detritus. Some of the variation in thickness is in the lower sandy beds (probably mainly of Derryan age) which are 695 to 450 feet thick in the southern Ladron Mountains and in the Acme-Santa Fe oil test, but only about 400 feet thick in the intervening sections.

Wengerd (1959) noted that during Pennsylvanian time this Ladron Mountains-Lucero Mesa area was a broad, westward-projecting sag-like shelf off the basinal axis of the Cabezon-Lucero-San Mateo-Orogrande marine accessway which joined the Paradox basin on the north to the Sonoran geosyncline on the south. He suggested that the Pennsylvanian sediments vary from gray limy shale and shaly limestone near the axis of the accessway to massive carbonate rocks, possibly of reef origin, westward across the break-in-slope toward the Zuni positive area.

As mapped by Kelley and Wood (1946), the Pennsylvanian from Lucero Mesa southward into the northern Ladron Mountains was divided into the Sandia formation and Madera limestone of the Magdalena group. The lower limestone member of the Sandia is of Mississippian age (Noble, 1950; Armstrong, 1958). The upper clastic member of the Sandia formation was reported to thin toward the north, west, and northeast. The Madera limestone was divided into the lower Gray Mesa member, the middle Atrasado member, and the upper Red Tanks member. The Gray Mesa member is dominantly gray to dark-gray cherty limestone with several biostromal beds (Fig. 2) that form persistent thick cliffs; the member is about 800 to 890 feet thick. The Atrasado member thins northward from 760 feet in the northern Ladron Mountains to about 555 feet on Mesa Sarca (Monte de Belen) and Mesa Aparejo (Gray Mesa), and becomes more shaly in the northern sections. This member contains more clastic beds than the Gray Mesa member, and some of the clastic rocks are red shales and arkosic sandstones. The Red Tanks member is 200-230 feet thick 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 appears to be essentially conformable with the underlying Pennsylvanian strata and the overlying Abo red-beds formation. The Pennsylvanian-Permian boundary may occur somewhere within the Red Tanks member.

Figure 2. Cliff of biostromal limestone near top of Mesa Sarca.

Manzano-Manzanita-Sandia Mountains

No oil tests have penetrated as deep as the Pennsylvanian rocks in the Albuquerque-Belen basin (Kelley, 1954) or graben of the Rio Grande structural depression. The Cenozoic sediments alone may be 1 to 3 miles thick in this complex graben, suggesting that the top of the Pennsylvanian may be 2 to 5 miles below the surface. To the east, however, the Magdalena group crops out over much of the crest and eastern dip slopes of the Los Pinos, Manzano, Manzanita, and Sandia Mountains. As mapped by Read and others (1944) and Wilpolt and others (1946), the group was divided into the clastic member of the Sandia formation, the lower limestone member of the Madera limestone, and the upper arkosic limestone member of the Madera limestone. Near Abo Pass the early Permian Bursum formation is relatively conformable on the Madera limestone, whereas northward the Abo formation rests on the Madera. Thin local erosional remnants of Mississippian limestones occur between the Pennsylvanian strata and Precambrian rocks in the Sandia and Manzano Mountains. These Mississippian rocks are essentially continuous in the northern Sandia Mountains from the Tecolote Peak area northward.

In the Manzano Mountains, Read and others (1944) measured about 160-250 feet of the upper clastic member of the Sandia formation, 430-705 feet of the lower limestone member of the Madera, and more than 950 feet of the upper arkosic limestone member. Whereas the clastic ratio (0.6) is slightly lower than that for the Mesa Sarca outcrops to the west, the sand-shale ratio (0.8) is much higher than that for sections to the west, west of the Rio Grande, indicating relative nearness to the Pedernal landmass to the east. The clastic member of the Sandia formation consists mainly of greenish to blackish shaly siltstones and sandstones, with thin beds of shale and limestone as well as several ledge-forming beds of limestone-chert-quartz pebble-conglomerate. The lower member of the Madera is dominantly cherty limestone, with some nodular shaly beds and scattered thin lenses of white sandstone. 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. Some gypsiferous shales were described by Stark

and Dapples (1946) near Abo Pass in the upper Pennsylvanian beds.

The Magdalena group is somewhat thinner (1,350 -1,450 feet) in the northern Manzano and in the Manzanita Mountains owing chiefly to thinning of the lower limestone member of the Madera limestone. In the Sandia Mountains (Fig. 3), the Magdalena group, exclusive of the local remnant Mississippian strata, is about 1,500 feet thick and thins northward to the Placitas area—apparently owing to loss of upper beds of the upper arkosic limestone member of the Madera limestone. A 50-foot-thick buff sandstone at the base of the arkosic limestone member appears to be a prominent unit near San Antonito. Thin coal seams occur in the Sandia formation and locally in the arkosic limestone member.

Figure 3. — Cliffs and ledges of Madera limestone at Sandia Crest.

Wengerd (1959) noted thinning of the Pennsylvanian marine section in the Manzano and Manzanita Mountains as compared with the Lucero-area sections to the west, and suggested the existence of a north-south-trending platform separating the Lucero basin from the Estancia basin to the east; he called this postulated submarine platform the "Manzanita platform." Small bioherms of **Chaetetes** corals were found by Wengerd (1959) in the Madera limestone of the Manzano and Sandia Mountains and were believed to indicate shallow-water break-in-slope areas favorable to organic reef development.

Estancia Basin-Pedernal Hills

Many oil and gas tests have been drilled in the southern part of the Estancia Basin in southern Torrance County, and a small carbon dioxide gas field was developed on the Wilcox dome northwest of Estancia. Pennsylvanian and Permian rocks dip gently eastward from the Manzano and Manzanita Mountains into the Estancia Basin but pinch out against the Precambrian-rock core of the Pedernal Hills to the east where the Pennsylvanian strata are overlapped by the Permian beds. Numerous shows of oil and gas have been reported, mainly from the bituminous black shales and porous sandstones of the lower Pennsylvanian. Comparison of the Pennsylvanian rocks penetrated in the various oil tests suggests that they were deposited on the west flank of a landmass that was supplying eroded detritus more or less continuously throughout the period. Except for brief localized floods of clastic sediments, however, a relatively small amount of debris accumulated in the Estancia depositional basin until near the end of Pennsylvanian time; then thick red beds and arkoses were derived from abrupt uplift of the Pedernal "Mountains" in a tectonic interval that was concluded by deposition of the lower Permian continental Abo red beds.

The Pennsylvanian-age Estancia basin appears to have contained two troughs, (Fig. 1), both bordering the west side of islands or peninsulas. The southeastern trough lay just east of the present location of Laguna de Perro, apparently terminating northward in a bay between Cerrito del Lobo and the northwestern part of the Pedernal Hills. Any northeastward connection to the Rowe-Mora trough (Read and Wood, 1947) must have been a shallow narrow strait as the marine Pennsylvanian section is absent or thin in the Toltec-State, Kelsey-Crowe Butte, and Sanders-State oil tests of the southeastern Santa Fe- southwestern San Miguel Counties area. In the "Perro" trough there is abrupt thickening of the Pennsylvanian westward from the Pedernal landmass. The Yeso formation is unconformable on Precambrian rocks (Fig. 4) 4 miles east of the Superior-Blackwell oil test; in this well red beds and coarse-grained arkoses dominate but the lower 400 feet, above Precambrian granite and schist, include interbeds of gray limestone, black shale, and gray to greenish calcareous shale of probable Pennsylvanian age.

Figure 4. — Basal Yeso conglomerate unconformable on Precambrian quartzite (beneath hammer head) in Pedernal Hills.

Just 4-5 miles to the northwest, two oil tests, the Gardner-Kidwell and the San Juan-Randall No. 2, encountered about 4,000 feet of probable Pennsylvanian strata. The lower Sandia formation unit is 530-1,000 feet thick and consists of arkose, sandstone, and shale, whereas the Madera unit (3,432-3,280 feet thick ?) is of dark-gray to tan limestone, shaly limestone, and black to greenish shale. In the Gardner-Kidwell test, there are many interbeds of green to pale-red sandstone, quartzose to arkosic. About 5 miles farther to the west in the Murphree-Berkshire oil test the possible Pennsylvanian strata, including many upper interbeds of red shales and siltstones, is only about 1,510 feet thick. To the south, however, in the Bluehall-Kistler oil test, at least 800 feet of Pennsylvanian rocks were encountered, with the well bottoming in the upper part of the Madera limestone. This latter well is only 4 miles northwest of the Precambrian outcrops on Rattlesnake Hill, and suggests a southern continuation of the thick Pennsylvanian section in the Gardner-Kidwell oil test, a thick section deposited on an abrupt

edge of the Pedernal landmass. As this paper was written, however, the Abernathy and Jones-Dean oil test, being drilled (sec. 28, T. 3 N., R. 9 E.) about 9 miles south and 1 mile east of Willard, was yielding cuttings, at depths below 4,150 feet, of sericite-garnet schist (from bedrock, or from pebbles?) after penetrating less than a thousand feet of marine Pennsylvanian rocks.

The western "trough" may extend from south of Mountainair (southward under Chupadera Mesa?) northward to north of Edgewood and Moriarty as outlined by a series of oil tests which drilled incomplete Pennsylvanian sections ranging from 2,000 to 2,700 feet in thickness. Near Mountainair, the Mountainair-Veal oil test penetrated at least 1,750 of the Pennsylvanian and apparently had not reached the Sandia formation. The Drice-Garland and Chief-Pace wells, drilled west of Estancia, went through 1,988-2,062 feet of Pennsylvanian rocks but were abandoned in the Sandia formation. West of Moriarty, the Witt-Cornett and Forty-Eight Petrol.-Greenfield oil tests spudded in upper Madera limestones and encountered 1,930-2,069 feet of Pennsylvanian beds. Farther north and west, in southwestern Santa Fe County, the Forty-Eight Petrol.-Fisher well began in the arkosic member of the Madera and went through 2,710 feet of Pennsylvanian before encountering Precambrian schist and granite. About 5 miles northwest of this latter oil test, Read and others (1944) measured only 1,510 feet of a complete Pennsylvanian section on the back slope of the Sandia Mountains.

Along the east side of the northern part of this "Moriarty" trough is Cerrito del Lobo, a gently domed knob of Precambrian rocks overlapped by upper Permian and Triassic strata. This positive area extends northward into southeastern Santa Fe County to tie onto the northern end of the Pedernal Hills uplift; it probably extends northward to join the Uncompahgre axis of Read and Wood (1947) although there is no oil test nor outcrop data in west-central and northern Santa Fe County to verify or disprove its existence.

Southwestern Sangre de Cristo Mountains

Read and others (1944) and Read and Andrews (1944) mapped the southwestern Sangre de Cristo Mountains from T. 16 N. southward. Brill (1952) measured some sections in the upper Pecos River area and described the relationships of late Paleozoic lands and seas extending from north-central New Mexico northward into Colorado. Baltz and Bachman (1956) described the Pennsylvanian rocks of the southeastern Sangre de Cristo Mountains, providing control for the northeast border of the region shown on Figure 1.

The Pennsylvanian is more than 2,240 feet thick (Read and others, 1944) near Pecos, as part of the Sangre de Cristo formation red beds that overlie the Madera limestone is probably of late Pennsylvanian age. The Sandia formation, about 375 feet thick, rests unconformably on karsted cherty Mississippian limestone (Baltz and Read, 1960; Armstrong, 1958), and consists of gray to brown sandstone, shale, and thin limestone with local conglomerate beds. The lower gray member of the Madera limestone is about 635 feet thick, and is chiefly dark-gray cherty limestone with considerable dark-gray shale in the upper part, and pebbly sandstone in the lower beds. The arkosic member of the Madera limestone is about 1,230 feet thick and consists of gray to light-gray arkose and arkosic limestone with some interbedded shale. Arkoses near the top of the member are reddish, the gradational contact with the overlying Sangre de Cristo formation being picked at the top of the highest limestone.

Southeastward toward Vallecitos, the Pennsylvanian rocks are similar in lithology and thickness to those of the Pecos area. The southwestern end of the Rowe-Mora Basin appears to be in east-central Santa Fe County, southwest of Pecos, as shown by the absence(?) of marine Pennsylvanian rocks in the Adkins-Bashor oil test, the thin (580-590 feet, sections of the English-Fullerton and Toltec-Eaton wells, and the relatively thick (1,425 feet) marine Pennsylvanian beds of the Richfield-Lee oil test. To the northeast—north and east of the northeast corner of Figure 1—the thick clastic deposits of the Mora basin total 7,000-8,500 feet in thickness (Baltz and Bachman, 1956).

West of Pecos, the marine Pennsylvanian strata thin to about 995 feet near Glorieta and to only 475 feet of intercalated red siltstones, gray argoses, and thin gray limestones near Canoncito. Part of this thinning is due to intertonguing with and equivalent replacement of the upper part of the Pennsylvanian by the Sangre de Cristo formation, but along Apache Canyon near Lamy the Magdalena group (restricted) is only 280 feet thick. A few miles west of Canoncito, and in the area north of Glorieta, Read and others (1944) found the Sangre de Cristo formation unconformable on Precambrian rocks, marking a southeast edge of the Uncompahgre-San Luis landmass.

Except for a few isolated fault blocks of Pennsylvanian rocks near Santa Fe, there is no outcrop nor well-data control for the large area of northwestern and northern Santa Fe County, Los Alamos County, southern Rio Arriba County, and northeastern Sandoval County. The thick clastic Pennsylvanian of the upper Pecos River valley and the Rowe-Mora basin must have been derived at least in part from a Precambrian landmass rock source in northeastern Santa Fe County, to judge from the amount and angularity of the fresh feldspar grains in the arkoses and arkosic limestones. One wonders if there was a deep sedimentational trough west of this southern Uncompahgre prong, a thick buried Pennsylvanian section in western Santa Fe County, saved from erosion during post-Pennsylvanian time, and downdropped in the Rio Grande structural depression.

East of Santa Fe in the foothills of the southwesternmost Sangre de Cristo Mountains a few square miles of Pennsylvanian rocks have been mapped by the writer (in Spiegel and Baldwin, 1956) in the Santa Fe and Seton Village quadrangles. Locally as much as 50 feet of the Mississippian cherty limestone and underlying Mississippian or Devonian limestone, sandstone, and shale occur beneath the Sandia formation but in most places the basal Pennsylvanian rests on deeply and thoroughly weathered Precambrian rocks. Irregularities are common along the basal contact with as much as 150 feet of local relief noted; in places depressions in the pre-Pennsylvanian surface were filled by carbonaceous shales and shaly coal beds. In most of the mapped area, the Pennsylvanian is overlain unconformably by the Tertiary Santa Fe formation but locally a thin remnant of the red-bed Sangre de Cristo formation gradationally overlies the arkosic member of the Madera. The complete marine Pennsylvanian does not exceed 500 feet in thickness and resembles the Magdalena group section near Lamy except in having a considerable thickness of cliff-forming cherty limestone in the limestone member of the Madera, and in showing nonred-bed arkose and limestone of the arkosic member.

The lithologies and thicknesses suggest that these outcrops were on the west side of the southern Uncompahgre-San Luis prong.

Nacimiento Mountains and San Pedro Mountain

As noted by Henbest and Read (1944) and Northrop and Wood (1946), the lower limestone member of the Sandia formation, of Mississippian age, is extremely discontinuous, the Pennsylvanian in most places in these mountain ranges resting on Precambrian rocks. Armstrong (1955) and Fitzsimmons, Armstrong, and Gordon (1956) collected Mississippian fossils from these lower discontinuous limestones and placed them in the Arroyo Penasco formation of Meramec age. The clastic member of the Sandia, or actually the restricted Sandia formation, consists of dark-brown, grayish-brown, and brownish-green sandstone and impure arenaceous limestone, with minor coal lenses, underclays, and siltstones. Thickness is reported (Northrop and Wood, 1946) to vary considerably because of the unevenness of the surface on which the unit was deposited. The formation is absent in the central and northern part of the Nacimiento Mountains, where the Madera limestone or Abo-Cutler red beds overlie the Precambrian rocks.

The lower gray limestone member of the Madera limestone consists of dark-gray limestone interbedded with gray shale and a few sandstones. In the center of the Nacimiento Mountains, this member rests on the Precambrian rocks but northward it too is absent, either by nondeposition or by a facies change into the upper Madera. The upper arkosic member of the Madera limestone is made up of gray limestone, arkosic limestone, gray and red shale, and arkose, and rests on the lower Madera member in the south but on the Precambrian rocks to the north. Northrop and Wood (1946) noted that its thickness and age vary considerably as a result of overlap relations. Gradationally above the Madera are terrestrial clastic beds assigned to the Abo in the south and to the Cutler formation in the north; in the northwestern Nacimiento Mountains and southwestern San Pedro Mountain the Abo-Cutler strata unconformably overlie Precambrian rocks—this is the real core of the Penasco axis. The relations near Los Pinos and Penasco Arroyos in the southwestern Nacimiento Mountains are complex. Locally, as mapped by Northrop and Wood (146), the arkosic member of the Madera is on the Precambrian, whereas in nearby areas Armstrong (1955) found early Pennsylvanian beds between the Madera limestone and the Mississippian Arroyo Penasco formation. He called these ferruginous red shales, sandstones, and conglomerates the Log Springs formation and found evidence of post-Log Springs, pre-Madera faulting. Such tectonic activity is what one would expect near the south end of an active positive area.

There is no well-data control to the east of these ranges. Was the Penasco axis an isolated island lying amid deeps west of the Uncompahgre-San Luis axis? Certainly there is no abrupt eastward thickening shown in the outcrops; a deep trough may have existed between the Penasco axis and the Uncompahgre axis but more likely the area was covered by a shallow "shelf" sea, a wide southward-facing bay, in which less than 2,000 feet of Pennsylvanian beds were deposited.

Southeastern San Juan Basin

To the west and southwest of the Nacimiento Mountains is the area of the Cabezon sag of Wengerd and Matheny (1958), a shallow marine accessway between the Pennsylvanian-age San Juan basin to the northwest and the Lucero-San Mateo-Orogrande chain of basin-like features to the south. Directly westward from the Nacimiento Mountains, the Pennsylvanian thickens in 6 miles from a knife-edge on the margin of the Penasco axis to about 1,190 feet in the El Paso Nat. Gas Co.-Elliott oil test near La Ventana. The Magnolia-Jicarilla 1-A and Skelly-Crittenden wells, 25-30 miles to the north, penetrated about 1,860-1,990 feet of marine Pennsylvanian strata, suggesting that a Pennsylvanian-age sedimentation basin bordered the west margin of the San Pedro-Nacimiento Mountains region. To the south-southwest of the Penasco axis, the Pennsylvanian rocks increase gradually in thickness from 650-765 feet in the Tidewater-Espiritu Santo and Avila-Odlum wells to about 1,080 feet in the Humble-Santa Fe and Continental-Evans oil tests of southwestern Sandoval County. These latter two oil tests lie athwart Wengerd and Matheny's (1958) Cabezon sag or strait, a saddlelike paleogeographic feature also shown on Read and Wood's (1947) isopach and facies map of northern New Mexico.

Near Bernardo, close to the center of the southern border of Figure 1, was the site of the Joyita axis of Read and Wood (1947) and Wilpolt and others (1946), postulated as a small north-south-trending positive area. As this local axis is directly south (about 85 miles) of the southern end (as far as is known) of the Penasco axis, there has been much speculation that the two are part of a discontinuous north-south positive area (Read and Wood, 1947), perhaps the west flank of Wengerd's (1959) submarine "Manzanita platform." The hypothetical axis is now deeply buried in the Rio Grande depression, but clues may be found in the sediments to the east in the Manzano-Sandia Mountains, or to the west in the Ladron-Lucero area.

CONCLUSIONS

As pointed out previously by many geologists, the Pennsylvanian rocks of north-central New Mexico reflect complex paleogeographic relationships. Source areas were the Zuni landmass to the southwest, the Pedernal mountains to the southeast, the Uncompahgre-San Luis-Cerrito del Lobo axis on the east and northeast, and the Penasco axis or island in northern Sandoval and southern Rio Arriba Counties. Thick sections, rich in clastic rocks, were deposited in the Rowe-Mora basin, Estancia basin, Lucero basin, and southeastern San Juan basin. The rest of the area, from the ancient shorelines to the edges of the stagnant deeps, spawned the prolific invertebrate life recorded in the Sandia and Madera formations, and may have been the natural habitat of oil.

REFERENCES CITED

Armstrong, A. K., 1955, Preliminary observations on the Mississippian system of northern New Mexico: New Mexico Bur. Mines and Mineral Res. Circ. 39, 42 p.

....., 1958, The Mississippian of west-central New Mexico: New Mexico Bur. Mines and Mineral Res. Mem. 5, 34 p.

Baltz, E. H., Jr., and Bachman, G. O., 1956, Notes on the geology of the southeastern Sangre de Cristo Mountains, New Mexico, in New Mexico Geol. Soc. Guidebook of southeastern Sangre de Cristo Mountains, New Mexico, 7th Field Conf.: p. 96-108.

Baltz, E. H., Jr., and Read, C. B., 1960, Rocks of Mississippian and probable Devonian age in Sangre de Cristo Mountains, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 1749-1774.

Bradish, B. B., and Mills, N. K., 1950, Pennsylvanian rocks of the San Juan Basin, in New Mexico Geol. Soc. Guidebook of the San Juan Basin, New Mexico and Colorado, 1st Field Conf.: p. 58-61.

Brill, K. G.,Jr., 1952, Stratigraphy in the Permo-Pennsylvanian zeugogeosyncline of Colorado and northern New Mexico: Geol. Soc. America Bull., v. 63, p. 809-880.

Cheetham, A. H., 1950, Preliminary survey of some New Mexico Bryozoa: New Mexico School of Mines unpub. senior thesis, 107 p.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, 356 p. (1929).

Fetzner, R. W., 1960, Pennsylvanian paleotectonics of Colorado Plateau: Am. Assoc. Petroleum Geologists Bull., v. 44, p. 1371-1413.

Fitzsimmons, J. P., Armstrong, A. K., and Gordon, M., Jr., 1956, Arroyo Penasco formation, Mississippian, north-central New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 1935-1944.

Foster, R. W., 1957, Stratigraphy of west-central New Mexico, in Four Corners Geol. Soc. (Guidebook) Geology of southwestern San Juan Basin, 2d Field Conf.: p. 62-72.

Gordon, C. H., 1907, Notes on the Pennsylvanian formations in the Rio Grande valley, New Mexico: Jour. Geology, v. 15, p. 805-816.

Henbest, L. G., and Read, C. B., 1944, Stratigraphic distribution of the Pennsylvanian Fusulinidae in a part of the Sierra Nacimiento of Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Chart 2.

Herrick, C. L., 1900, The geology of the White Sands of New Mexico: Jour. Geology, v. 8, p. 112-128; Univ. New Mexico Bull., v. 2, fascicle 3, 17 p.

Kelley, V. C., 1954, Tectonic map of a part of the upper Rio Grande area, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Map OM-157.

Kelley, V. C., and Wood, G. H., Jr., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 47.

Keyes, C. R., 1903, Geological sketches of New Mexico: Ores and Metals, v. 12, p. 48.

Kottlowski, F. E., 1959, Pennsylvanian rocks on the northeast edge of the Datil plateau, in New Mexico Geol. Soc. Guidebook of west-central New Mexico, 10th Field Conf.: p. 57-62.

....., 1960, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico Bur. Mines and Mineral Res. Bull. 66, 187 p.

McKee, E. D., 1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., v. 62, p. 481-506.

Melton, F. A., 1925, The ancestral Rocky Mountains of Colorado and New Mexico: Jour. Geology, v. 33, p. 84-89.

Needham, C. E., 1937, Some New Mexico Fusulinidae: New Mexico Bur. Mines and Mineral Res. Bull. 14, 88 p.

....., 1940, Correlation of Pennsylvanian rocks of New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 173-179.

Noble, E. A. 1950, Geology of the southern Ladron Mountains, Socorro County, New Mexico: Univ. New Mexico unpub. master's thesis, 81 p.

Northrop, S. A., and Wood, G. H., Jr., 1946, Geology of Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 57.

Read, C. B., and Andrews, D. A., 1944, Upper Pecos River and Rio Galisteo region, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 8.

Read, C. B., and Wood, G. H., Jr., 1947, Distribution and correlation of Pennsylvanian rocks in late Paleozoic sedimentary basins of northern New Mexico: Jour. Geology, v. 55, p. 220-236.

Read, C. B., and others, 1944, Geologic map and stratigraphic sections of Permian and Pennsylvanian rocks of parts of San Miguel, Santa Fe, Sandoval, Bernalillo, Torrance, and Valencia Counties, north-central New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 21.

Renick, B. C., 1931, Geology and ground-water resources of western Sandoval County, New Mexico: U. S. Geol. Survey Water-Supply Paper 620, 117 p.

Smith, C. T., 1958, Geologic map of Inscription Rock fifteen-minute quadrangle: New Mexico Bur. Mines and Mineral Res. Geol. Map 4.

Smith, C. T., and others, 1959, Geologic map of Foster Canyon quadrangle, Valencia and McKinley Counties, New Mexico: New Mexico Bur. Mines and Mineral Res. Geol. Map 9.

Spiegel, Z. E., and Baldwin, W. B., 1956, Geology and water resources of the Santa Fe area, New Mexico, with contributions by F. E. Kottlowski and E. L. Barrows, and a part on geophysics by H. A. Winkler: U. S. Geol. Survey Water-Supply Paper (in manuscript).

Stark, J. T., and Dapples, E. C., 1946, Geology of the Los Pinos Mountains, New Mexico: Geol. Soc. America Bull., v. 57, p. 1121-1172.

Thompson, M. L., 1942, Pennsylvanian system in New Mexico: New Mexico Bur. Mines and Mineral Res. Bull. 17, 92 p.

Ver Wiebe, W. A., 1930, Ancestral Rocky Mountains: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 765-788.

Wengerd, S. A., 1958a, Origin and habitat of oil in the San Juan Basin of New Mexico and Colorado, in Weeks, L. G., ed., Habitat of oil—a symposium: Am. Assoc. Petroleum Geologists, p. 366-394.

....., 1958b, Lucero basin attracts wildcatters—New Mexico's newest prospect: Oil and Gas Jour., v. 56, p. 207-215.

....., 1959, Regional geology as related to the petroleum potential of the Lucero region, west-central New Mexico, in New Mexico Geol. Soc. Guidebook of west-central New Mexico, 10th Field Conf.: p. 121-134.

Wengerd, S. A., and Matheny, M. L., 1958, Pennsylvanian system of Four Corners region: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2048-2106.

Wilpolt, R. H., and others, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 61.