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STRUCTURAL PROBLEMS ALONG THE EAST SIDE OF THE SOCORRO CONSTRICTION, RIO GRANDE RIFT

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INTRODUCTION

The Socorro constriction was defined by Kelley (1952) in his discussion of the tectonics of the Rio Grande depression. The constriction represented a narrow link between the wider expressions of the rift, the Albuquerque-Belen Basin to the north and the San Marcial Basin to the south. More recent work (Chapin and Seager, 1975; Kelley, 1979; Woodward, 1977) has emphasized the extensional nature of the Rio Grande rift and has recognized that the rift is much more complex to the south where it merges with the Basin and Range province of southern New Mexico. Kelley (1982) states that the Socorro constriction, while included in the Rio Grande rift, may be a part of a much older and broader structural belt which includes the Jornada del Muerto Basin, the San Andres Mountains, Tularosa Basin, and northern end of the Sacramento Mountains. Some of the relations exposed along the eastern edge of the Socorro constriction are older than the Rio Grande rift and certainly do not represent crustal extension.

Detailed mapping, although not continuous, has been completed in a patchwork pattern from latitude 33° 50' N to 34° 15' N and between longitude 106° 40' W and 106° 46' W. This rectangular area covers the majority of the eastern side of the Socorro constriction where Pennsylvanian and Permian rocks are exposed (see Kelley, 1982, fig. 1). Theses by Rejas (1965), Maulsby (1981), Bauch (1982), and Fagrelius (1982) have documented a pattern of overturned folds, steep reverse faults, and decollement-like structures previously not emphasized along this part of the rift (see fig.1-15.2a, first day road log, this guidebook). Recent mapping by Rosen (oral commun., 1983) has demonstrated that the Tones Member of the Yeso Formation (Permian) rests at a very low angle upon Mancos Shale (upper Cretaceous) near the northeast corner of the rectangular area described above. These exposures suggest a possible Laramide age for some of the decollement structures, but do not date the overturned folds.

GEOLOGIC SUMMARY

The rock units consist of isolated Precambrian blocks; 500-600 m of Pennsylvanian clastic rocks and limestones; more than 600 m of Permian limestones, shales, sandstones, and evaporites (most units incomplete due to faulting or erosion); nearly 250 m of Triassic sandstone, siltstone, and mudstone; about 350 m of marine and non-marine upper Cretaceous sediments; variable thicknesses of Tertiary volcaniclastic and volcanic rocks (intrusive as well as extrusive); and irregular masses of Tertiary and Quaternary valley fill and pediment gravel. These are confined to elongate blocks bounded by steeply dipping normal or reverse faults, predominantly striking north-south. A second group of faults strikes northeast and is probably somewhat earlier than the north- south faults. A third set of faults, often with large stratigraphic throws, strikes northwest; these are better developed toward the southern end of the Socorro constriction, but have been recognized throughout the area in which detailed mapping has been done. Decollement structures, often closely paralleling bedding, are found within the blocks, usually between units of the Permian section. Narrow (less than 1000 m wide) zones of overturned folds and beds in Pennsylvanian and Permian rocks alternate with relatively undeformed blocks where dips do not exceed 30°, except as a result of drag on the high-angle faults. Such abrupt variations in attitude, combined with local absence of parts of the stratigraphic section, exemplify the structural problems associated with the east side of the Socorro constriction.

STRATIGRAPHY

Precambrian Rocks

Precambrian gneiss, amphibolite, quartz-potassium-feldspar schist, epidosite, pegmatite, and aplite are found in the core of the Joyita Hills at the north end of the Socorro constriction. Small (250 m by 1500 m, or less) blocks of Precambrian quartz monzonite have been juxtaposed along north-trending faults against Tertiary sediments or Pennsylvanian units in the region immediately east of Socorro. These small blocks are often tilted gently to the east with a vertical or steep reverse fault on the west and Pennsylvanian sedimentary rocks in depositional contact to the east. Locally, a sheeted or imbricate structure is indicated. The southernmost block, at Arroyo del Tajo, was cored for a disseminated uranium test and quartz monzonite extends to a depth of at least 200 m. None of the metamorphic units present in the Joyita Hills were encountered and xenoliths or inclusions of similar rocks in the outcrops are very sparse.

Pennsylvanian Rocks

Pennsylvanian rocks in central New Mexico have been classified in a variety of ways. Thompson (1942) developed a detailed stratigraphy based primarily on fusulinid zonation which is not everywhere applicable because of rapid facies changes. Wilpolt and Wanek (1951) in their reconnaissance of the area east of Socorro grouped the rocks into two formations and four members; such generalization does not adapt readily to the detailed mapping required to delineate structure. Thus, most investigators have applied Thompson's (1942) divisions with appropriate modifications where required.

The oldest Pennsylvanian rocks in the Socorro constriction are assigned to the upper clastic member of the Sandia Formation (Wilpolt and Wanek, 1951). A basal conglomerate with boulders and cobbles of chert in a coarse-grained, quartz-arenite matrix is overlain by interbedded greenish-gray siltstones, coarse-grained to pebbly quartz arenites, thin-bedded carbonate mudstones, and thin limestone layers. The limestones contain a robust fauna of brachiopods, crinoids, and bryozoans with sparse, large, solitary, horn corals, and gastropods. Precambrian clasts in the basal conglomerate are rare, although the basal contact, with Sandia Formation resting nonconformably upon a surface of low relief, is exposed on each of the Precambrian blocks.

The Desmoinesian, Missourian, and Virgillian parts of the Pennsylvanian sequence overlie the Sandia Formation conformably with thin-bedded to massive gray limestone interbedded with calcareous gray silty and micaceous shale. Clastic units alternate with limestone and carbonate mudstone and most are fossiliferous (see fig. 1-36.8, first day road log, this guidebook) with varying amounts of chert present. The majority of the formational boundaries are placed at lithologic changes from predominant limestone to shale, siltstone, or sandstone, or where abrupt changes in the amount of chert are recognized. The lower part of the section contains more limestone and carbonate mudstone with the central part of the column predominantly clastic, while the upper part of the Virgillian section is composed of massive, thick-bedded limestone and carbonate mudstone (Moya Formation of Thompson, 1942). Strike valleys are often cut in the finer grained elastics which often appear to be shaly; however, the rocks are usually silt-sized and true shale is not common. Thus, the Pennsylvanian rocks are considerably more competent under stress than the ledge and slope topography might suggest.

Permian Rocks

Permian rocks in the Socorro constriction are correlated with four or five formations depending upon the mapping treatment of the Glorieta Sandstone. The lowermost unit, the Bursum Formation (Wilpolt and others, 1946), is transitional between the uppermost Pennsylvanian rocks and the overlying Permian beds of the Abo Formation. Rejas (1965) mapped intertonguing relationships between the Moya limestones and shales (Thompson, 1942) and the dark purplish-red and green shales and gray limestones of the Bursum Formation. The upper part of the Bursum contains arkose and arkosic conglomerate little different from the overlying coarse-grained sandstones and arkoses of the basal Abo beds; the contact is often covered but may be placed at the base of the lowest coarse sandstone above the highest nodular limestone in the Bursum.

The Abo Formation is uniformly very dark reddish brown, fine-grained sandstones with interbedded mudstones and siltstones; a few coarser-grained channel sandstones are present in the lower part of the section. The Abo conformably overlies the Bursum Formation and grades upward into the overlying Yeso Formation. Sedimentary structures are noteworthy for their variety and abundance in the Abo, as well as fossil plant impressions and vertebrate and insect fossil tracks. Mud cracks (see fig. 1-35.4a, first day road log, this guidebook) raindrop impressions, ripple marks of several types, small scale crossbedding, and spheroidal or ellipsoidal white volumes where the reddish colors are bleached are prominent throughout the section.

The Yeso Formation is divided into four members which are, in ascending order, the Meseta Blanca Sandstone Member, Torres Limestone Member, Canas Gypsum Member, and Joyita Sandstone Member. A clear understanding of the structure is only possible with detailed knowledge of the Yeso section. The Meseta Blanca Sandstone is uniformly fine-grained sandstone at the base grading upward to medium-grained sandstone, interbedded with siltstone and shale. Sorting of the grains is variable, although it is better than the underlying Abo Formation. Salt casts are common in the finer-grained portions and their appearance has been used as a guide to the conformable contact between the Abo and Yeso Formations (see fig. 1-48.2c, first day road log, this guidebook). Variation in the selection of the contact, combined with faulting and structural complexity, has created thickness variations from 40 to nearly 100 m; the higher figures appear to be near the true values.

The upper contact of the Meseta Blanca Sandstone Member is generally placed where thin-bedded, medium-grained, moderately sorted sandstone is overlain by calcareous, crossbedded, coarse-grained, poorly sorted sandstone. Between 15 and 30 m of calcareous sandstone underlie the lowermost limestone unit in the Tones Limestone Member and the limestone is often used to approximate the contact. Above the lowest limestone in the Tones Member, alternating layers of sandstone, mudstone, thick-bedded limestone, breccia, and gypsum occur. The sandstone beds are thickest and dominate the section with a lithology similar to the basal Tones units. The mudstones are silty, less than 2 m thick, and are usually interbedded with fine-grained, well-sorted siltstone layers less than 0.1 m thick. Fagrelius (1982) states: "The limestones are gray to black, sandy, medium-bedded and contain vuggy porosity. Few fossils were found in the Tones limestone layers; the lowermost limestone bed contains a few braciopods and gastropods and the uppermost limestone contains abundant fossil material (brachiopods, gastropods, pelecypods, crinoid columnals, algae and oolites)." Breccia is varicolored and laterally discontinuous with randomly oriented, angular fragments of limestone up to boulder size floating in a silt- to medium-sand matrix. Silicification of breccia is common; they often stand out as resistant ledges extending a few meters along strike. Gypsum layers are massive and extremely irregular. Variations in thickness are common, in part due to nondeposition locally, in part due to post-depositional solution, and in part due to removal by low-angle faulting.

The contact between the Tones Limestone Member and the overlying Canas Gypsum Member is usually obscured by faulting but is conformably where undistorted. Because of local gypsum layers in the Torres and the removal of the entire Canas Gypsum Member by low-angle faulting in many localities, extreme variations in the thicknesses assigned to the two units have been reported (Bauch, 1982, p. 48-49). Wilpolt and others (1946) measured 181.8 m of Tones Limestone Member at the type locality and Bauch (1982) found an incomplete thickness of Canas Gypsum Member of 99.1 m. Fangrelius (1982) reports Canas Gypsum Member as "thin-bedded breccia, limestone, mudstone, siltstone, sandstone, and gypsum"; the entire section is less than 11 m thick with all units poorly sorted, soft and crumbly, and commonly calcareous or gypsiferous. When present, the Canas Gypsum Member is dominated by thin limestone and impure gypsum beds with the gypsum becoming thicker, purer, and more massive toward the top of the member.

The contact between the Canas Gypsum Member and the overlying Joyita Sandstone Member is marked by a thick (2 m) white gypsum bed overlain conformably by a red to tan, poorly sorted, fine- to medium-grained, calcareous sandstone; commonly the contact is a low-angle fault with Joyita resting on the upper units of the Tones and the Canas completely missing. Where the section is complete the Joyita is more than 90 percent sandstone, although siltstone, mudstone, and shale are interbedded and often cemented with gypsum or calcite. The Joyita Sandstone Member is nearly 50 m thick in complete sections and the sorting improves upward toward a well-sorted, well-rounded, fine-grained sandstone at the top. The Joyita Sandstone Member grades upward into the overlying Glorieta Sandstone and again the contact is difficult to pick. The contact is usually placed at a change from friable, fine-grained, sub-arkose below to light-gray to white, calcareous quartz arenite with low-angle crossbedding and medium grain size above.

The Glorieta Sandstone is interpreted by some (Read and Andrews, 1944; King, 1945) as a basal clastic member of the San Andres Formation and by others (Needham and Bates, 1943) as a separate formation. It will be treated herein as a separate formation. Fagrelius (1982) reports nearly 45 m of Glorieta Sandstone in the southern part of the Socorro constriction and Bauch (1982) measured over 70 m in the central part of the area; Rejas (1965) and Maulsby (1981) described only incomplete sections. All agree that the Glorieta is medium- to fine-grained, sub- to well-rounded, well-sorted, calcareous, quartz sandstone, usually crossbedded and thick- to very thick-bedded. The rock is both texturally and mineralogically mature. Scattered hematite concretions and irregular hematite and limonite staining are found sporadically in some layers but they are not stratabound. With gradational contacts above and below, variations in thickness are common, depending upon facies differences.

The San Andres Formation is best exposed in the southern part of the Socorro constriction where an incomplete section of nearly 70 m was measured (Fagrelius, 1982). At the type locality (Rhodes Canyon in the San Andres Mountains) about 80 km to the south, nearly 181 m is reported (Needham and Bates, 1943). Nearly 90 percent of the section in the Socorro constriction is limestone and limestone breccia with minor interbedded mudstone and sandstone. Chert nodules and silicified zones are common in the lower limestone beds; sandstone layers are more prominent in the middle part of the section, interbedded with limestone and irregular zones of breccia; the upper limestone strata are interbedded with mudstone and siltstone. The limestone beds are thick-bedded to massive and the formation is characterized by ledgy and cliff-like topography; the interbedded mudstones, sandstones, and siltstones are too thin to provide prominent slopes. An incomplete upper gypsum member is reported by Fagrelius (1982) and the presence of gypsum is noted in the Oscura Mountains—Chupadera Mesa area by Kottlowski and others (1956). Because in many areas in central New Mexico a karst surface was developed on the San Andres Formation in late Permian time, very few complete sections of the formation are known.

Disconformably overlying the San Andres Formation in the southern part of the Socorro constriction is the Bernal Formation (Bachman, 1953). Less than 30 m of section is present (Fagrelius, 1982) and it is predominantly interbedded, buff to gray to maroon mudstone and red-brown to maroon siltstone; lesser amounts of sandstone and shale usually occur in the upper part of the formation. Soft-sediment deformation, channel-fill structures, and collapse features occur sporadically in the layers. The contact with the overlying Dockum Group is disconformable.

Triassic Rocks

Red beds referred to the Dockum Group by Fagrelius (1982) were subdivided by him into a lower sandstone unit correlated with the Santa Rosa Sandstone (Darton, 1922) and an upper mudstone-siltstone unit correlated with the Chinle Formation (Gregory, 1916). A similar subdivision was made 80 km to the east in the Little Black Peak quadrangle by Smith and Budding (1959).

The Santa Rosa Sandstone is composed of 70 to 75 m of multicolored, red- to reddish-brown to tan to gray, crossbedded, fine- to coarse-grained, poorly to moderately sorted, micaceous sandstone interbedded with conglomerate and shale; thin, red to maroon siltstone and mudstone layers impart an overall reddish-brown to reddish-orange color to the unit. In contrast to many of the earlier elastic rocks of the Permian section, the Triassic sandstones are markedly micaceous. The Santa Rosa Sandstone grades upward into the overlying Chinle Formation, although the lithology along the contact is not constant and as the sandstones and mudstones intertongue, the contact may rise or fall stratigraphically. The contact is usually placed at the base of the lowermost mudstone layer, above which there is little or no sandstone for several meters stratigraphically.

The Chinle Formation is dominantly mudstone, rarely fissile, with thin sandstone and siltstone interbeds. Local conglomerate lenses with pebble-sized clasts of limestone and calcareous sandstone are scattered throughout the section. No single unit is traceable along strike for more than a few tens of meters and outcrops are often weathered and discontinuous. Individual laminae weather maroon to purple in color with speckled light-gray to white bleached areas. In the southern part of the Socorro constriction, Fagrelius (1982) measured 165 m of Chinle Formation. To the north, most of the exposures are faulted and incomplete sections are present. The upper contact of the Chinle Formation is an unconformity and the formation has been beveled from north to south so that the Chinle is thicker to the north and thinner to the south. The predominance of mudstone makes the formation relatively incompetent and structures are difficult to identify within it or trace through it.

Cretaceous Rocks

The Dakota Sandstone overlies the Chinle Formation unconformably with a few feet of relief locally. The Dakota Sandstone was originally described by Meek and Hayden (1962) but its usage has been extended throughout much of the Rocky Mountain region and rarely are rocks called Dakota the same age or lithology in adjacent regions. The Dakota Sandstone is used herein to describe the upper Cretaceous sandstones at the base of the widespread marine Mancos Shale. No specific age nor correlation with other units called Dakota is implied nor intended. The Dakota Sandstone is well-exposed in the Carthage area of the Socorro constriction and in scattered outcrops to the north and east. Limited exposures are found between the Joyita Hills and the Los Pinos Mounatins where the Albuquerque-Belen Basin narrows into the north end of the constriction. The Dakota Sandstone is medium- to coarse-grained, thick-bedded to massive, crossbedded, tan to white, locally pebbly sandstone with interbedded mudstone, siltstone, and shale. A thin (1-3 m) varicolored shaly mudstone with discontinuous lenses of chert, shale, and siltstone-pebble conglomerate occurs at the base of the Dakota Sandstone. Although these beds may be weathered Chinle, or possibly the remnant of a younger Jurassic(?) unit, they are here included with the Dakota Sandstone. Good exposures are confined to fresh cuts and the beds may not be everywhere present. The Dakota Sandstone is well-jointed, with slickensided surfaces common along the joint surfaces; bedding planes preserve evidence of burrowing. Ripple marks, hematite staining and small hematite and limonite concretions are common. The weathered surfaces are often coated with desert varnish, yielding an overall tan to brown appearance. A tripartite pattern is sometimes well-developed with a lower massive sandstone unit; a middle unit of interbedded sandstone, mudstone, siltstone, and shale which occasionally contains carbonaceous debris; and upper sandstone layers which become thinner-bedded near the top and grade into the overlying Mancos Shale. Calcareous cement is prominent along the upper contact.

The Cretaceous section above the Dakota Sandstone has been studied recently in considerable detail by Hook, 1981; Cobban and Hook, 1979; and Hook, this guidebook. They divide the beds from bottom to top into the Mancos Shale (lower part), the Tres Hermanos Formation, the D-Cross Tongue of the Mancos Shale, the Gallup Sandstone, and the Crevasse Canyon Formation. Several of these units contain abundant fossils, many of which are guide species or genera allowing detailed correlations with upper Cretaceous sections to the north and west. The reader is referred to the paper by Hook in this guidebook for details.

A total of 301 m of upper Cretaceous rocks (Dakota through D-Cross Tongue) was measured by Fagrelius (1982) in the Carthage area; he assigned 135 m to the lower part of the Mancos Shale, 75 m to the Tres Hermanos Formation, and 91 m to the D-Cross Shale Tongue. The shales are very similar: thickly laminated, calcareous, dark-gray to black, and locally fissile. Sandy and silty concretions, often cemented with hematite or limonite, are irregularly distributed; some contain ammonites. Much of the shale in the lower part of the Mancos Shale and in the lower portion of the D-Cross Shale Tongue is gypsiferous and the D-Cross Tongue becomes sandy and silty near the top with a zone of large concretions (1-2 m in diameter) a few meters below the top; a few of the concretions have well-developed cone-in-cone structures preserved. The Tres Hermanos Formation consists of alternating sandstone and shale with interbedded fossilerous limy sandstone layers near the base and silty shale zones containing logs of petrified wood about 30 m below the top; a rapidly oscillating marine to non-marine environment is indicated. A massive, tan sandstone bed a few meters below the top of the member has been informally termed the "oyster bed" because of the abundant *Lopha bellaplicata novamexicanus* it contains (see fig. 1-60.9, first day road log, this guidebook). The D-Cross Tongue grades upward into the overlying Gallup Sandstone which marks the last marine deposition in central New Mexico. The contact is usually placed where sandstone becomes dominant over shale or siltstone and abundant marine fossils disappear.

The upper two units, the Gallup Sandstone and the Crevasse Canyon Formation are usually considered parts of the Mesaverde Group. The Mesaverde Group was originally described by Holmes (1877) from exposures at Mesa Verde, Montezuma County, Colorado. Because of the complexities of upper Cretaceous stratigraphy, the term Mesaverde has been used both as a formation and as a group term, and has been extended to uppermost upper Cretaceous rocks over much of Colorado, Wyoming, Utah, Arizona, and New Mexico. The Gallup Sandstone has medium- to thick-bedded, buff, crossbedded, medium- to coarse-grained quartz sandstone at the base grading upward into interbedded light-gray shale and brown-buff, silty sandstone with irregular carbonaceous partings similar to the overlying Crevasse Canyon Formation. In the Socorro constriction the Crevasse Canyon Formation attains importance as the host for the coal beds of the Carthage field and other outlying prospects. A 1.5-m coal bed, which grades laterally into carbonaceous shale, occurs 7 to 15 m above the Gallup Sandstone. Locally, one or two thinner (less than 1 m) coal beds are found above the lowest unit, but they are thin and discontinuous and of no importance. The lower 30 to 50 m of the Crevasse Canyon Formation contains a monotonous alteration of concretionary sandstone, siltstone, carbonaceous mudstone, and shale with few units traceable more than a few tens of meters along strike or down dip. The Crevasse Canyon Formation is overlain by the Baca Formation (Eocene) with angular unconformity and its total thickness in this area is not known. Some repetition of section by faulting is evident and drilling in the southern part of the Carthage coal field suggests a potential thickness of a few hundred meters.

Tertiary Rocks

The eastern side of the Socorro constriction contains bouldery to finer-grained clastics of the Baca Formation (Eocene), isolated exposures of andesitic volcanic rocks and volcaniclastic debris tentatively assigned to the Spears Formation (Oligocene), and a thick prism of Santa Fe Group sediments that intertongue with Pleistocene to Recent gravelly alluvium and Holocene eolian sand. Most of the Santa Fe beds are assigned to the Sierra Ladrones Formation (Machette, 1978) which contains a piedmont-fan facies associated with an older basin-fill facies and a basin-floor facies of axial-river deposits of the ancestral Rio Grande.

The Baca Formation is characterized by very coarse bouldery conglomerate (clasts as much as 2 m in diameter) and coarse arkosic sandstone interbedded with mudstone and siltstone (see fig. 1-59.95, first day road log, this guidebook). Clasts of Precambrian granite, Pennsylvanian limestone, and Permian limestone and sandstone are common and the formation is alternately red to white in color depending upon the abundance of each particular clast source. The Baca is noteworthy for its lack of volcanic clasts and volcaniclastic debris except in the uppermost units where it grades into the overlying Spears Formation (see Cather, this guidebook). The Baca was deposited as a fanglomerate facies in a high energy environment across an irregular surface. It overlies with sharp angular unconformity Cretaceous, Permian, and Pennsylvanian rocks and is indicative of major tectonism in early Tertiary (Laramide?) time. Because of younger faulting and lack of exposures, complete thicknesses of Baca are not available; a few hundred meters is certainly present.

Andesitic volcanic rocks and volcaniclastic rocks, tentatively correlated with the Spears Formation, rest with gradational contact on the Baca Formation in one of the southerly forks of Arroyo del Tajo. A few small basaltic-andesite dikes cut the Spears in this area and may represent a small volcanic center. Scattered outcrops of Spears along the western margin of the eastern outcrops of the Socorro constriction show unconformable relationships on the older rocks similar to the Baca Formation. Where more extensive exposures of volcanic and volcaniclastic rocks occur on the southeast side of the Joyita Hills at the northern end of the Socorro constriction, and in the northwest corner of the Jornada del Muerto, younger ash-flow tuffs of the normal volcanic succession overlie the Spears. In the Socorro constriction, the Spears Formation is unconformably overlain by the Sierra Ladrones Formation of the Santa Fe Group.

The Santa Fe Group, represented almost entirely by the Sierra Ladrones Formation in the Socorro constriction, is a complex mixture of intertonguing piedmont-fan alluvium, older basin-fill sands and gravels, and basin-floor fluvial deposits of the ancestral Rio Grande. It is difficult to separate the Quaternary valley fill from the older sediments since it too represents complex intertonguing between tributary (side arroyo) alluvium and axial-river deposits. Most of the Sierra Ladrones Formation along the east side of the Socorro constriction reflects the lithology of the source beds from which it was derived. A wide variety of sandstone, mudstone, siltstone, and conglomerate, with varying degrees of calcareous cementation, is exposed in every arroyo. Some layers are well-indurated and resistant providing prominent ledges, whereas others are poorly cemented and friable and weather to incoherent debris piles. Boundaries between Sierra Ladrones Formation and Quaternary alluvium are often arbitrary and approximate. Geophysical data (Sanford, 1968) suggests that at least 600 m of Santa Fe Group beds may fill the deepest parts of the rift in the Socorro constriction.

Quaternary Rocks

Valley fill, eolian sand, alluvial-fan debris, and lag gravels cap some of the higher erosion surfaces and fill the bottoms of most large arroyos. Talus debris, particularly below resistant sandstone and limestone ledges conceals outcrops on steeper slopes. However, it is only on surfaces of low relief that Quaternary deposits cause difficulty in the interpretation of the geology.

STRUCTURE

The east side of the Socorro constriction contains intensely folded and faulted rocks that have undergone several periods of tectonism. Because of a number of gaps in the stratigraphic record it is difficult to establish precise ages for many of the structural elements. Early tight compression, post-Permian and perhaps pre-late Triassic, was followed by broader, gentler folding (Laramide?) which involves the youngest Cretaceous rocks. Extensive movement along high-angle faults, with at least three principal strike directions, has offset a complex flat-lying detachment surface, or surfaces (decollement?), that mainly involves Permian rocks. However, a decollement(?) places beds of the Tones Member of the Yeso Formation on Mancos Shale near the northeastern corner of the Socono constriction, and in other areas the same or similar decollements eliminate all or parts of the Torres, Canas, and Joyita Members of the Yeso Formation as well as the Glorieta and San Andres Formations.

Folding

At least two periods of folding are shown by the rocks on the east side of the Socono constriction and additional later warping may be related to drag on the younger faults. An early period of folding involves Pennsylvanian and Permian rocks (Meseta Blanca and Tones Members) with the beds forming anticlinal folds overturned to the east. The best exposures are in Arroyo del Tajo in section 18, T3S, R2E (see fig. 1-42.05, first day road log, this guidebook). Similar overturning to the east in the form of a Z-shaped fold is exposed in Pennsylvanian rocks in section 35, T2S, R1E. Less tightly folded Moya limestones show some overturning south of Ojo de Amado in Arroyo de los Pinos (sec. 27, T2S, R1E). Very tightly contorted thin limestone layers are found in the upper part of the Sandia Formation in section 35, T2S, R1E, and similar crumpled limestones occur in the lower Torres Member of the Yeso Formation in section 18, T3S, R2E, south of Arroyo del Tajo. Another area of crumpled lower Torres limestone occurs in sections 20 and 29, T4S, R2E, beneath a decollement(?) surface. In the eastern part of section 34, T2S, R1E, Baca Formation dipping 30°SW lies with angular unconformity on Pennsylvanian limestone dipping 14°NE. Returning the Baca to a flat initial dip would increase the dip on the Pennsylvanian beds to 52°NE; some steeply folded pattern was certainly eroded to provide the surface on which the Baca was deposited. Tight folding in the Torres and Meseta Blanca Members is also present west of the BLM road in sections 5 and 8, T4S, R2E (see figs. 1-48.2a, d; first day road log, this guidebook). Similar crumpling in other parts of the region is suggested by bedding patterns but the structures have not been documented by detailed mapping. The tight folding, overturning, and crumpling is confined to Pennsylvanian and Permian rocks. Similar folded patterns have not been found in Triassic, Cretaceous, or Tertiary rocks.

In the Carthage area Permian, Triassic, and Cretaceous rocks and perhaps the Baca Formation are folded into a broad, open antiform plunging south with the western limb downfaulted into the rift. It is difficult to assign an age or trend to this structure since it encompasses nearly the entire east-west dimension of the area. A similar broad anticline, the Prairie Springs anticline, is shown by Wilpolt and Wanek (1951) several kilometers to the east; the two structures may be related, along with other flexures (Oscura anticline, Torres syncline, Wilpolt and Wanek, 1951) to the east. Tertiary rocks other than the Baca Formation are not involved in this broad open folding.

Minor steepening of gently dipping beds is common near high-angle faults of moderate displacement (a few tens of meters of stratigraphic throw). Such drag almost always agrees with the sense of the fault displacement but a few cases of reverse drag are known. Fault displacements often change rapidly along strike, so drag in the beds is often subject to unusual stresses. Rotation of blocks between faults with different sense of displacement also results in altered bedding attitudes. Such changes in dip and strike are usually very local and have no bearing on the regional stress field.

Faulting

Rejas (1965) recognized three sets of high-angle faults (dips greater than 60°) in the Socorro constriction. Fagrelius (1982) suggested the presence of a fourth set of high-angle faults and the occurrence of low-angle faults (often nearly parallel to bedding) as well. Bauch (1982) and Maulsby (1981) confirmed the occurrence of the low-angle faults (called "decollement" by Bauch, 1982, p. 55) and noted that they were offset by Rejas' (1965) sets two and three.

The earliest faults (excluding the decollement) strike about N 40° E and offset Pennsylvanian and Permian rocks in the central and northern parts of the area; they are much less common to the south, although Fagrelius (1982) shows one prominent fault associated with a small graben structure in section 10, T5S, R2E, which appears to be offset by a decollement. Rejas (1965) felt the northeast faults were the earliest structures sincethey were affected by almost all other structural patterns. Some of the northeast faults are reverse faults and thus may be associated with the decollements, especially where they have a westerly dip. Dis placements (stratigraphic throw is practically the only measurement available) are variable but zones with several hundred meters of stratigraphic throw can be identified (see fault zone extending northeastward from Minas de Chupadera); most displacements are considerably less, usually with only a few tens of meters of stratigraphic throw.

The north-trending faults were divided by Rejas (1965) into two groups depending upon their relationship to the Sierra Ladrones Formation. Rejas' (1965) group two faults do not offset the Sierra Ladrones Formation, whereas his group three faults do. Group two faults affect all units up to Spears Formation (Oligocene). If Sierra Ladrones Formation is absent, there is not way to distinguish between group two and group three faults; they probably represent a continuum of activity in which some have had more recent movement than others but all are related to the same stress field. The north-south faults include the eastern boundary faults of the Rio Grande rift (see fig. 1-63.0, first day road log, this guidebook) which may have large displacements (a few hundred meters of stratigraphic throw); however, these faults may show only a few meters of stratigraphic throw for several hundred meters along strike; reversals (scissors faults) of displacement along strike are also known. Many of the north-south faults branch and coalesce along strike, sometimes disappearing completely when displacements are opposite in sense but nearly equal.

Northwest-trending faults are among the youngest fractures mapped. They offset most other structures but are covered by Quaternary alluvium. The major northwest-trending fault zone in the northern part of Fagrelius' (1982) area is offset by some north-trending faults but truncates others. It is probably at least partially contemporaneous with the north-trending, rift-boundary faults and thus its relations are not clear-cut. The northwest-trending faults are far less common than either north- or northeast-trending fractures, but their stratigraphic throws are among the larger displacements (100-300 m).

A major zone of decollements (dips generally less than 15°) has been identified from section 33, T4S, R2E, to section 21, T1S, R2E. Such decollements commonly occur at the contact between the Tones and Canas Members of the Yeso Formation, but large parts of the section may be eliminated so that the decollement surface, or surfaces, may occur as low as middle or lower Tones Member and as high as upper San Andres Limestone. In section 21, T1S, R2E, Tones Member rests on Mancos Shale (see fig. 1-15.2a, b; first day road log, this guidebook); at the southeast corner of the Joyita Hills, Oligocene volcanic rocks appear to rest on Eocene and Cretaceous rocks above a low-angle fault that has cut out most of the Spears Formation (see figs. 1-22.4a, b; first day road log, this guidebook). The relation between this low-angle fault and the Permian decollement surfaces is not clear. To the south, the decollement surfaces are gently warped and thus appear to be earlier than the broad folding involving the pre-Tertiary rocks; however, the overthrust relationships in section 2, T1S, R2E suggest at least some continued movement in post-Mancos time. In sections 9, 10, and 15, T4S, R2E, several decollement surfaces are exposed; Glorieta sandstone rests on Tones Member in section 15, whereas San Andres Limestone rests on Tones Member in section 9, and in section 10 San Andres Limestone dipping 60°SW rests on Glorieta Sandstone dipping 15°SE (fig. 1). In almost all cases, the Canas Member of the Yeso is missing; in other areas all or parts of the Tones and Joyita Members and part or all of the Glorieta Sandstone may also be absent. Dating the decollement surfaces is difficult since they are confined to such a narrow stratigraphic zone. At the north end of Loma de las Canas in section 8, T3S, R2E, a decollement surface truncates a southward-plunging syncline developed in the underlying Canas and Torres Members; the decollement surface is, in turn, faulted down to the east nearly 60 m by a north-trending fault at the south end of Lomas de las Canas. Decollement surfaces have not been recognized where overturned fold-

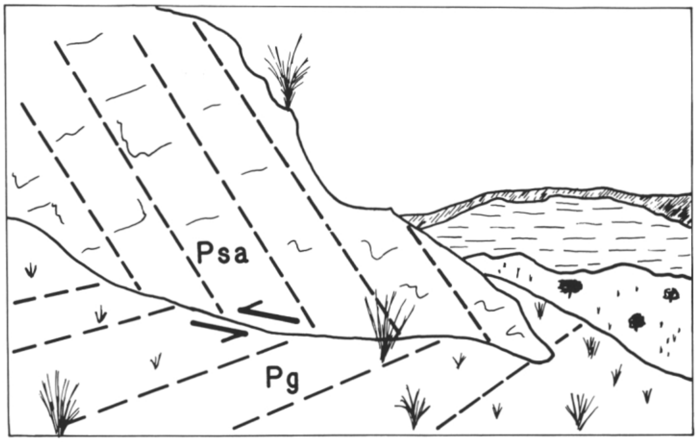


Figure 1. Sketch of a photograph (Fagrelius, 1982, fig. 18) of the decollement(?) surface between Glorieta (Pg) and San Andres (Psa) Formations.

ing has occurred, although steep reverse faulting is present along the overturned eastern flanks of the folds. Additional detailed mapping will be required to solve the age relationships.

CONCLUSIONS

The east side of the Socorro constriction exposes incomplete sections of Precambrian, Pennsylvanian, Permian, Triassic, Cretaceous, Tertiary, and Quaternary rocks whose variability is the result of both rapid facies changes and tectonic complexity. Detailed studies of the Pennsylvanian sedimentary rocks (Hambleton, 1959; Siemers, 1978, and this guidebook) indicate a shallow marine environment with numerous islands of Precambrian rocks shedding arkosic materials into adjacent lagoons. Some of the currently exposed Precambrian blocks have sheared and sheeted zones suggesting considerable compressive stress during or after Pennsylvanian time. Since little hiatus occurs between Pennsylvanian and Permian rocks, it is not surprising that both upper Pennsylvanian and lower Permian rocks are involved in strongly compressed overturned folds with the compressive stress applied from the west. These narrow en-echelon zones may be the result of strong right-lateral shear along the Rio Grande rift prior to the major extensional events (C. E. Chapin, 1983, oral commun.); the evidence is insufficient to determine which interpretation might be most likely.

The decollements are an additional problem since their lateral extent is unknown and their displacement is therefore not estimated. They may be thrusts associated with the overturned folds, which is supported by their nearly universal confinement to the single Callas surface of movement. Or they may be gravity glide sheets related to a late Cretaceous or early Tertiary uplift in the longitude of the present rift or slightly to the west. Socorro Peak documents such an uplift, since sediments later than Pennsylvanian are eroded and the Tertiary volcanic sequence rests on lower Pennsylvanian rocks. Farther north some Permian rocks are found beneath the volcanic rocks but to the south the volcanics rest on Precambrian. Little distortion of either the upper or lower plates of the decollement surfaces is evident, although in some cases more than 200 m of section may be missing between the plates. A similar effect is noted in section 21, T1S, R2E, where Torres beds rest upon a member of the Mancos Shale, a particularly incompetent unit, with no folding in either member apparent. Gentle folding of the decollement surfaces at some localities suggests either a pre-Cretaceous origin or formation during the post-Cretaceous warping.

Faulting on the east side of the Socorro constriction is complex and can be divided into several groupings. Aside from a few faults most displacements are less than 30 m of stratigraphic throw, although the aggregate shift across several faults of the same type may amount to several hundred meters. The continuity of individual fault surfaces is limited to a few hundred meters, but some groups of obviously closely related fractures may extend for a few kilometers. The earliest faults, the N 40° E set, are roughly parallel to a Precambrian grain and may represent renewal of activity along those directions. The most abundant faults, the north-trending features, are the result of formation of the Rio Grande rift and they show activity up to the very recent times. The north-south faults displace all structures although some individual faults may have been dormant since middle Tertiary time. The sense of displacement is commonly down to the west but some fractures, particularly to the east, are down to the east and uniformity is not achieved. The northwest-trending faults are the least common, although they may have displacements that are among the largest measured. They appear to be contemporaneous with the north-south faults since their interactions are not consistent. It is not clear why they formed unless the stress field was not pure tension but a more complex relation.

Extensional tectonics has been proposed as the principal mechanism for the development of the Rio Grande rift. Certainly the most recent activity would support this view. However, Mesozoic and Paleozoic rocks record tectonic mechanisms which appear to be far removed from extensional phenomena and which require a different model for their elucidation.

ACKNOWLEDGMENTS

The author is indebted to Angel Rejas who did the first detailed work in the area and demonstrated that Thompson's (1942) subdivisions of the Pennsylvanian rocks could be adapted to geologic mapping. John Bauch and Joe Maulsby confirmed the presence of the decollement surfaces and Kurt Fagrelius demonstrated that they were earlier than the majority of other faults. Fagrelius also showed that the surfaces were warped or folded and provided evidence for the existence of more than a single surface. Bob Osburn of the New Mexico Bureau of Mines and Mineral Resources took most of the pictures referred to in the text. Numerous classes of students from New Mexico Institute of Mining and Technology have mapped small patches of the area and aided in the understanding of the problem. John MacMillan reviewed the manuscript and the author is grateful for his suggestions.

REFERENCES

Bachman, G. 0., 1953, Geology of a part of northwestern Mora County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM-137.

Bauch, J. H. A, 1982, Geology of the central area of the Loma de Las Callas quadrangle, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 115 p.

Chapin, C. E. and Seager, W. R., 1975, Evolution of the Rio Grande rift in the Socorro and Las Cruces areas: New Mexico Geological Society Guidebook 26, p. 297-321.

Cobban, W. A. and Hook, S. C., 1979, *Collignoniceras woolgari woolgari* (Mantell) ammonite fauna from Upper Cretaceous of Westem Interior: New Mexico Bureau of Mines and Mineral Resources Memoir 37, 51 p.

Darton, N. H, 1922, Geologic structure of parts of New Mexico: U.S. Geological Survey Bulletin 726, p. 173-275.

Fagrelius, K. H., 1982, Geology of the Cerro del Viboro area, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 138 p.

Gregory, H. E., 1916, The Navajo country, a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico and Utah: U.S. Geological Survey Water Supply Paper 380, 219 p.

Hambleton, A., 1959, Interpretation of the paleoenvironment of several Missourian carbonate sections in Socorro County, New Mexico, by carbonate fabrics [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 87 p.

Holmes, W. H., 1877, Geological report on the San Juan district: U.S. Geological and Geographical Survey of the Territories, Ninth Annual Report for 1875, p. 237-276.

Hook, S. C., 1981, Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 180, 35 p.

Kelley, V. C., 1952, Tectonics of the Rio Grande depression of central New Mexico: New Mexico Geological Society Guidebook 3, p. 92-105.

, 1979, Tectonics of the Colorado Plateau and new interpretation of its eastern boundary: Tectonophysics, v. 61, p. 97-102.

, 1982, The right-relayed Rio Grande rift, Taos to Hatch, New Mexico: New Mexico Geological Society Guidebook 33, p. 147-151.

King, R. E., 1945, Stratigraphy and oil producing zones of the pre—San Andres formations of southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 23, 31 p.

Kottlowski, F. E., Flower, R. H., Thompson, M. L., and Foster, R. W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir I, 132 p.

Machette, M. N., 1978, Geologic map of the San Acacia quadrangle, Socorro County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1415, scale 1:24,000.

Maulsby, J., 1981, Geology of the Rancho de Lopez area east of Socorro, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 85 p.

Meek, F. B. and Hayden, F. V., 1862, Descriptions of new Silurian (Primordial) Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska by the exploring expedition under the command of Capt. Wm. F. Raynolds, U.S. Topographical Engineers, with some remarks on the rocks from which they were obtained: Philadelphia Academy of Sciences Proceedings, v. 13, p. 415-447.

Needham, C. E. and Bates, R. L., 1943, Permian type sections in central New Mexico: Geological Society of America Bulletin, v. 54, p. 1653-1668.

Read, C. B. and Andrews, D. A., 1944, Geology of a part of the upper Pecos River and Rio Galisteo region, New Mexico: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 8.

Rejas, A., 1965, Geology of the Cerros de Amado area, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 128 p.

Sanford, A. R., 1968, Gravity survey in central Socorro County: New Mexico Bureau of Mines and Mineral Resources Circular 91, 14 p.

Siemers, W. T., 1978, The stratigraphy, petrology and paleoenvironments of the Pennsylvanian system of the Socorro region, west-central New Mexico [Ph.D. thesis]: New Mexico Institute of Mining and Technology, Socorro, 259 p.

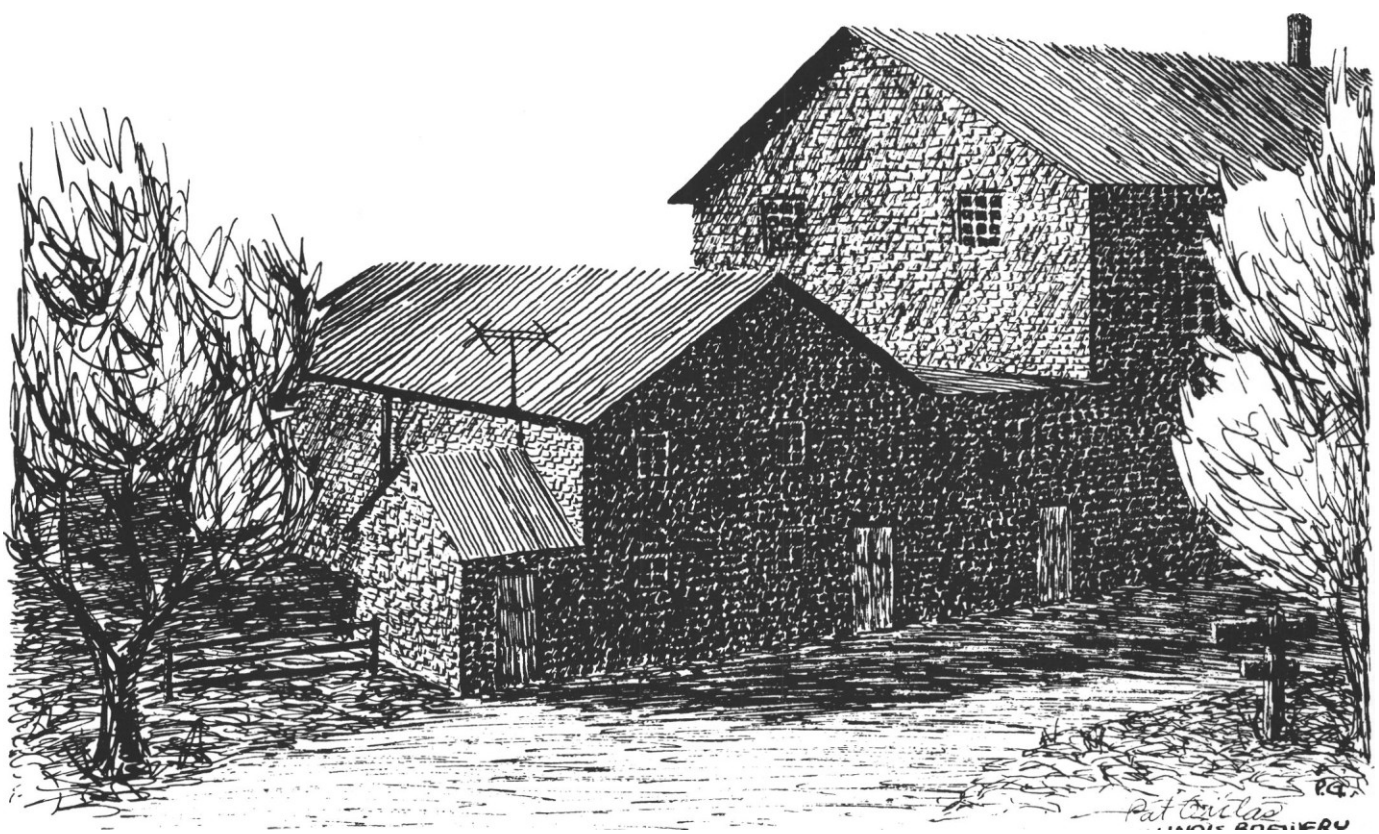
Smith, C. T. and Budding, A. J., 1959, Reconnaissance geologic map of Little Black Peak fifteen-minute quadrangle, east half, New Mexico: New Mexico Bureau of Mines and Mineral Resources Geologic Map 11.

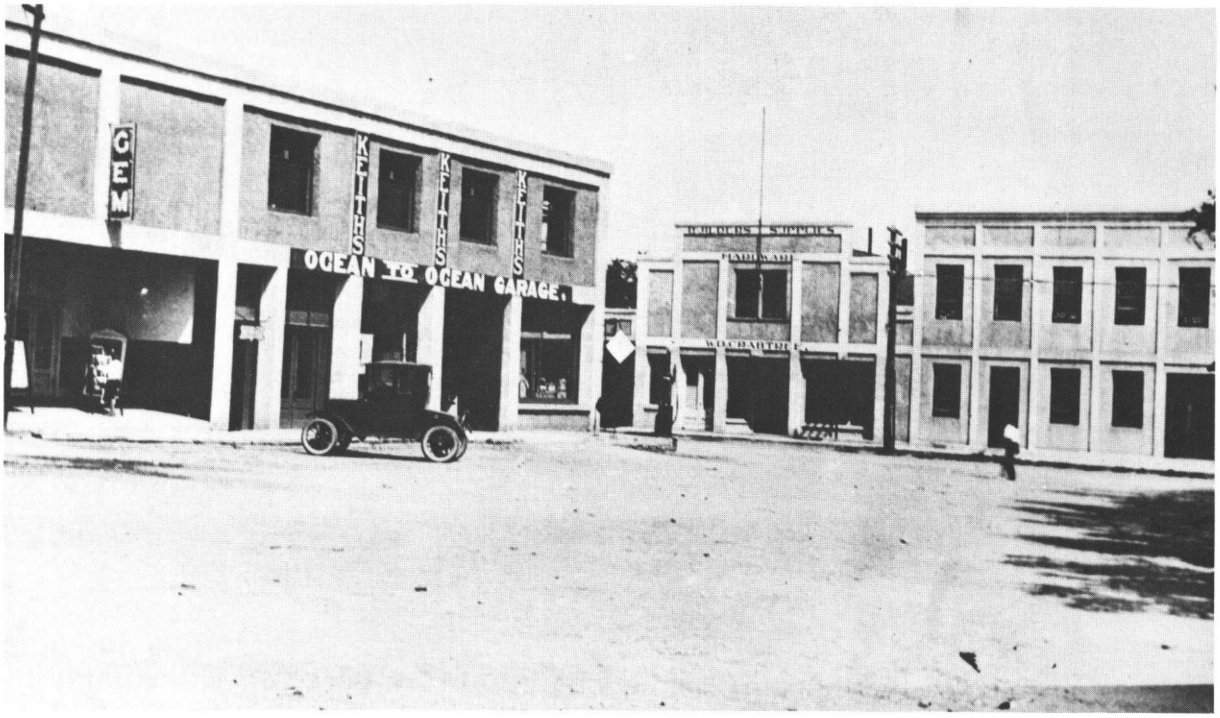
Thompson, M. L., 1942, Pennsylvanian system in New Mexico: New Mexico School of Mines, State Bureau of Mines and Mineral Resources Bulletin 17, 92 P.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, G., 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. Geological Survey Oil and Gas Investigations Preliminary Map 61.

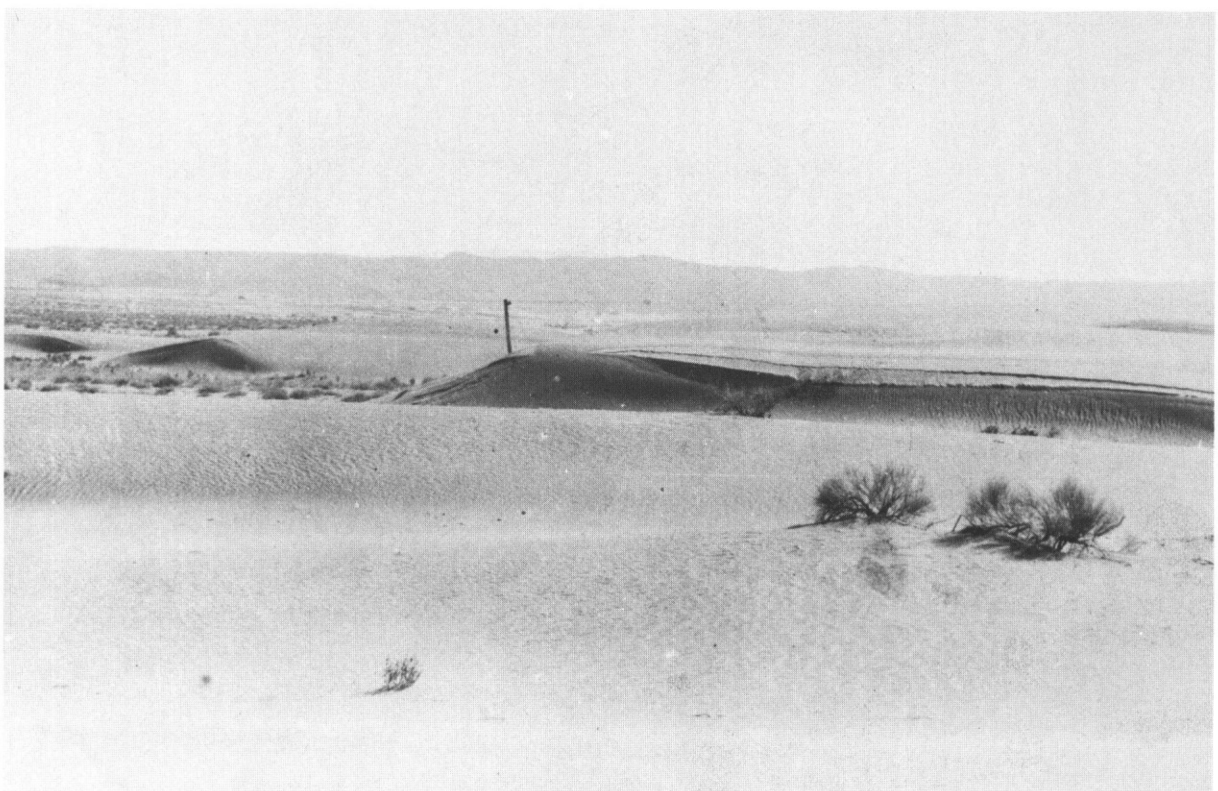
Wilpolt, R. H. and Wanek, A. A., 1951, Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM 121.

Woodward, L. A., 1977, Rate of extension across Rio Grande rift near Albuquerque, New Mexico: Geology, v. 5, p. 269-272.





Keith's Ocean-to-Ocean Garage on the northwest corner of the Socorro Plaza in the early 1920's (photo courtesy of Socorro County Historical Society).



THERE MUST BE A ROAD HERE SOMEWHERE. The log says to follow the telephone lines across the sand dunes north of Socorro (photo courtesy Socorro County Historical Society).