Cenozoic sedimentary rocks in Socorro valley, New Mexico

Bruce DeBrine, Z. Spiegel, and D. Williams

1963, pp. 123-131. https://doi.org/10.56577/FFC-14.123

in:

Socorro Region, Kuellmer, F. J.; [ed.], New Mexico Geological Society 14 th Annual Fall Field Conference Guidebook, 204 p. https://doi.org/10.56577/FFC-14

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

CENOZOIC SEDIMENTARY ROCKS IN SOCORRO VALLEY, NEW MEXICO

B. DeBrine,[1] Z. Spiegel,[2] and D. William[1]

INTRODUCTION

The Cenozoic rocks in parts of Socorro Valley and adjacent areas have been mapped in varying degrees of detail by the writers in connection with a hydrogeologic study of the Socorro area being conducted by the Research and Development Division of the New Mexico Institute of Mining and Technology. Emphasis was given to establishing the stratigraphic sequence of the Cenozoic formations and to correlation of these rocks with sediments that have been mapped in adjacent areas. Specific correlations are made with the early Cenozoic sediments mapped by Denny (1940) in the San Acacia area north of the present field area and to units mapped by Winchester (1920), Wilpolt et al. (1946), and Tonking (1957) in areas to the west and northwest. Correlation of early Tertiary units mapped by Wilpot et al. (1946, 1951) on the eastern side of the Socorro Valley with equivalent units in the western regions is also presented (see fig. 1).

Field work consisted of reconnaissance traverses in four-wheel-drive vehicles in the major arroyos of the area followed up by foot-traverses in the more inaccessible intervening areas. Data were recorded on 7½-minute and 15-minute series topographic maps (scales 1:24,000 and 1:62,500, respectively).

Mapping of the Cenozoic sediments in the Socorro Valley is readily divided into two areas separated by alluvium of the Rio Grande flood plain. These areas are the western Socorro–Lemitar mountains region and the eastern region of the broad, heavily dissected piedmont slopes between a series of hills along the eastern edge of the valley and the river's flood plain. See figure 2 (in pocket).

WESTERN LEMITAR–SOCORRO MOUNTAINS

The Lemitar Mountains are a north-south trending range covering approximately 40 square miles, and are located approximately five miles northwest of the town of Socorro. They are bordered on the north by San Lorenzo arroyo, on the west by the Snake Ranch Flats, on the east by the Rio Grande Valley, and on the south by Nogal Canyon. The Socorro Mountains start at the southern boundary of the Lemitar Mountains. They cover approximately 30 square miles; the east and west borders are extensions of the boundaries of the Lemitar range but bordered on the south by U.S. Highway 60. The area is shown on three topographic quadrangle maps, the Socorro 7½-minute, Lemitar 7½-minute, and Magdalena 15-minute.

The maximum relief in the mapped area is approximately 2000 feet, from a low of 5000 feet on the eastern edge to a high of 7000 feet on top of Strawberry Peak, located in the southern Lemitar Mountains.

The Lemitar Mountains for the most part are tilted fault blocks dipping westward; in several places they could be defined as true cuestas, for example, Red Mountain and in the vicinity of Lemitar Canyon. The average dip of these tilted fault blocks is about 30 degrees. Accompanying the fault blocks are numerous land slide blocks, which can be seen in considerable detail in the vicinity of Strawberry Peak and in the southeastern part of Socorro Mountain.

Numerous linear and nobby topographic features can be explained by intrusive dikes and plugs, particularly in the southern Lemitar Mountains.

The over-all drainage for the area is eastward from the Magdalena Mountains across the Snake Ranch Flats through and around the Socorro–Lemitar mountains into the Rio Grande Valley. A prominent drainage divide exists in the central Lemitar Mountains on the north side of Lemitar Canyon. North of Lemitar Canyon, the drainage is north into San Lorenzo arroyo. South of Lemitar Canyon, the drainage is south into Water and Nogal canyons.

Pre-Tertiary Rocks

The Lemitar Mountains dip westward affording the observer a chance to go down section by going eastward. The Tertiary rocks are bounded on the east by limestones of Pennsylvanian age. This contact runs approximately down the middle of the Lemitar Mountains. Small patches of the Abo formation of Permian age have been exposed along the Pennsylvanian and Tertiary contact (fig. 2, NW¼-SE¼, sec. 11, T. 1 S., R. 2 W.).

Tertiary Strata

Baca formation (middle Eocene?): The Baca formation as described by Winchester (1920) and renamed by Wilpolt et al. (1946) is not evident in the Socorro–Lemitar mountains.

1 New Mexico Institute of Mining and Technology.
2 New Mexico State Engineer's Office.

Popotosa formation (post-Eocene?): The Popotosa formation was originally described by Denny (1940) in the area between San Lorenzo arroyo and the Ladron Mountains. Numerous outcrops of a gypsum-rich red clay (see Tc, fig. 2), in the Lemitar–Socorro mountains are believed to be equivalent, at least in part, to Denny's Popotosa formation. The Popotosa formation in this area is considered by Spiegel (1962) to be equivalent to Tonking's (1957) Spears member of the Datil formation. Outcrops of this red gypsum-rich clay occur in the northern Socorro Mountains in the vicinity of the Snake Ranch and in the eastern edge of the Socorro Mountains (fig. 2). Scattered patches of this clay are also exposed on slopes throughout most of the western Lemitar Mountains. The Popotosa formation is believed to be a favored host rock for pre-Santa Fe intrusions. Slope wash from the igneous knobs covers most of the Popotosa formation, but it is commonly found in areas of deep erosion and hillside weathering. Sedimentary layers of gypsum several inches thick can be found in several places.

Resting on clays of the Popotosa in several locations is a red sedimentary breccia (see Tvb, fig. 2), Socorro Spring issues from fractures in this breccia. The breccia is believed to be conformable on the clay of the Popotosa formation which forms a lower impermeable boundary for the aquifer.

Datil formation: The Datil formation was originally described by Winchester (1920) in the Bear(?) Mountains as a sequence of sandstones, tuffs, and flows. Wilpolt et al. (1946) renamed the bottom 684 feet of Winchester's section the *Baca formation*. Tonking (1957) redescribed the type section of the Datil formation in the vicinity of the Bear Mountains and subdivided it into three distinct members. The lower Spears member consists of tuffs and volcanic-rich detrital rocks; the middle Hells Mesa member consists of welded rhyolite tuffs and rhyolite flows; and the upper La Jara Peak member consists of basalt and basaltic andesite flows. In the map area, possible equivalents of all three members of the Datil formation were mapped. The term "equivalent" here means that the units appear to be stratigraphically of Datil age, but in the various locales in the area, the flows and associated detrital rocks are from different vent areas. Thus, the source of the Datil in the Bear Mountains is from vents in that area; in the Socorro Valley area, the Datil sources are in the Socorro–Lemitar region on the west side, and equivalent flows and detrital material east of the Rio Grande are from vents in that vicinity.

The Spears member or its equivalent occurs as a purplish gray conglomerate exposed in the northern Lemitar Mountains in the vicinity of Red Mountain. The purplish gray sediment is between the Pennsylvanian limestone on the east and the welded tuffs and rhyolite ridges on the west. Aside from this isolated patch no other exposures of this conglomerate have been found.

The predominant units of the Datil formation, or its equivalent, in the Lemitar Mountains are welded tuffs and rhyolite flows. The main western ridges of the Lemitar Mountains are composed of a massive rhyolite (Tmr) with phenocrysts of glassy sanidine. Underlying this rhyolite and intruded in part by it is a thick sequence of orange-pink to gray, welded and semiwelded tuffs (Twt). The tuffs crop out south of Red Mountain and in Lemitar Canyon (see fig. 2). The red breccia of Socorro Spring is upfaulted against a weathered tuff and volcanic-derived clay unit on the east.

The La Jara Peak member (?) of the Datil formation is believed to be represented in the southern Socorro Mountains by basaltic andesite intrusives and flows.

Between the equivalents of Tonking's Datil and the Santa Fe formation lies a sedimentary volcanic-derived breccia, conglomerate and agglomerate. This sedimentary unit comprises much of the Lemitar Mountains. Red Mountain to the north is composed entirely of this Datil-derived unit. North of Nogal Canyon near Snake Ranch and north of Strawberry Peak, the conglomerate is the principal ridge-former. The characteristic feature of the conglomerate is the inclusion of boulders and fragments of the massive rhyolite identified by sanidine phenocrysts as Hells Mesa(?) age.

Santa Fe group: Poorly sorted volcanic-rich siltstone, sandstone, and conglomerate overlie or are interbedded with the La Jara Peak member (?) of the Datil formation.

The Santa Fe group is not evident in the Lemitar Mountains except in the northern San Lorenzo area where massive sandstones, siltstones, and conglomerates comprise much of the section there. The Santa Fe group bordering the Lemitar–Socorro mountains to the west and southwest of the Socorro Mountains tentatively includes the alluvial fan deposits of the Snake Ranch Flats.

QUATERNARY PERIOD

The Santa Fe group is overlain in the southern Socorro Mountains by high level Quaternary basalts. Equivalents of these basalt flows are not evident in the Lemitar Mountains.

Gravel deposits of Quaternary age are unconsolidated and for the most part are volcanic-derived. These pediment-capping gravels occur locally throughout both the Lemitar and Socorro mountains.

Alluvial fill, cover, and slope wash that are present in varying degrees in the area were mapped as Qs in Figure 2.

EAST SIDE OF SOCORRO VALLEY

Mapping on the east side of the valley was limited to the broad, heavily dissected slopes west of the series of low hills of pre-Tertiary rocks extending from the Cerrillos de Coyote to Loma de las Cañas. The western edge of the area is the Rio Grande. The mapped areas are almost entirely in the western halves of the Mesa del Yeso and Loma de las Cañas 7½-minute quadrangle sheets. Small adjacent areas of the Lemitar and Socorro 7½-minute sheets were also mapped.

Maximum relief in the area is 700 feet, from 4600 feet elevation along the Rio Grande at Socorro to 5300 feet elevation near the base of Loma de las Cañas. The area is drained by several west-flowing arroyos, tributaries of the Rio Grande. Most of them originate on the west slopes of the pre-Tertiary hills, but the larger ones head farther east. Downcutting by these streams has heavily dissected the gentle piedmont slope between the hills and the Rio Grande. Arroyo cuts are the locales where the exposures are best developed as the intervening ridges are covered to varying degrees by slope wash and drift sand.

The Cenozoic rocks in this area have been mentioned in several previous investigations in the Socorro Valley. Geological reconnaissance has been made by Herrick (1904), W. T. Lee (1907), Bryan (1926, 1932, 1938), Darton (1928), Denny (1940, 1941), and Wilpolt et al. (1946, 1951). Most of these investigators were mapping the older rocks to the east and gave the Tertiary beds only a passing glance. Denny mapped the Tertiary sediments in the area to the north. Bryan's surveys were never formally published in detail and his work in the Socorro Valley was described only briefly in the works cited above.

The pre-Santa Fe rocks on the east side of the valley have only been mapped to the degree necessary to determine the nature of the contact with the Santa Fe beds and to establish source beds relationships for the various units of the Santa Fe.

PRE-SANTA FE CENOZOIC ROCKS

Baca(?) formation: The oldest Cenozoic beds exposed in the mapped area are a series of predominant red conglomerates and silty sandstones. These beds were mapped by Wilpolt as the Baca formation, based on their stratigraphic position below the Datil and could represent an eastern facies of a vast undefined Baca basin of Eocene age (Spiegel, 1962).

The Baca (?) formation lies unconformably below the Datil in sec. 14, T. 2 S., R. 1 E. and is in fault contact with the Datil in secs. 13 and 24, T. 3 S., R. 1 E. In sec. 34, T. 2 S., R. 1 E. south of Arroyo de los Pinos is a section of conglomerates and sandstone lying beneath Santa Fe beds and intruded by a red breccia that is similar to that found west of the Rio Grande near U.S. Highway 60 and at Socorro Spring (see Spiegel, 1962). These exposures are what Darton (1928) referred to as *Tertiary agglomerate*. The outcrops in Arroyo de la Parida (sec. 14, T. 2 S., R. 1 E.) unconformably overlie Triassic beds (see Darton, 1928, pl. 14C). North of Ojo del Coyote, sec. 4, T. 2 S., R. 1 E., is a small exposure of conglomerate not mapped by Darton.

In secs. 11 and 14, T. 2 S., R. 1 E., along the gas pipeline just north of Arroyo de la Parida, is a sequence of red volcanic-derived sediments and red breccia lying between the Baca (?) and the Santa Fe. These beds may be the equivalent of Tonking's Spears member of the Datil and the Popotosa of Denny (Spiegel, 1962).

Datil (?) formation: A series of agglomerates, tuffaceous sandstone, and rhyolitic and andesitic flows that were mapped as Datil (?) formation unconformably underlies the Santa Fe formation in this area. The flows are present in continuous exposures along the low ridges from Arroyo de la Parida north to the Joyita Hills, just outside the map area. The scattered outcrops of Datil (?) in the Loma de las Cañas quadrangle are mostly volcanic-derived sediments. In Arroyo de los Pinos is an excellent exposure of the contact between this sedimentary facies of the Datil (?) and the Santa Fe. Darton (1928) noted this outcrop as well as one to the south in secs. 27 and 34, T. 2 S., R. 1 E., which he considered to be similar. Wilpolt and Wanek (1951), however, designated the southern outcrop as Baca (?) with two Tertiary intrusions. The writer's investigation of these outcrops bears out Wilpolt's interpretation. The outcrop in Arroyo de la Parida is Datil (?), while the outcrop to the south is Baca (?). Wilpolt's "Tertiary intrusion" is red breccia similar to the outcrop north of Arroyo de la Parida. The sedimentary facies of the Datil (?) here could probably be correlated as an equivalent of Tonking's Spears member in the Bear Mountains.

If this correlation is correct, the red volcanic sediments in sec. 11, T. 2 S., R. 1 E., could possibly be included in the Spears member.

THE SANTA FE GROUP

The Santa Fe beds which were mapped in this area are probably correlative with the upper buff member of the Santa Fe formation of Bryan and McCann (see Baldwin, 1956) in the Rio Puerco area and with Spiegel's upper unnamed formation of the Lower Jemez River area (Spiegel, 1961). The beds are referred to simply as the Santa Fe formation because the lower members of the group have not been recognized. The Santa Fe formation has been divided into several members in the mapped area, based on the pebble composition of the conglomerate beds.

Datil-derived member: The oldest member in the area is an alluvial fan deposit that is composed mainly of material derived from the Datil formation. The beds are a light gray conglomerate containing pebbles in the coarser-grained sections that are predominantly volcanic material of the Datil formation; some pebbles are of Paleozoic sedimentary rocks. This member rests unconformably on the Datil formation and is overlain either by the Yeso-derived member or the mixed-source member. Extensive exposures are found in the Mesa del Yeso quadrangle where the source area, the Datil beds, are prevalent to the east. Farther south in the Loma de las Cañas quadrangle, this member either is not exposed or is missing because of a paucity of Datil in that area.

The outcrop pattern of the older rocks east of the Santa Fe beds suggest that the Datil (?) formation was either removed more rapidly here than farther north or was not so thick in this area.

Yeso-derived member: In the Mesa del Yeso quadrangle, the member overlying the Datil-derived member is composed primarily of beds of a light gray conglomerate and sandstone which contains pebbles predominantly of sandstone and limestone of the Yeso, Glorieta, and San Andres formations with lesser amounts of Pennsylvanian limestone and Abo sandstone.

The member interfingers with a tan, silty-clay member in the area from San Acacia south to the vicinity of the Sabino ranch, sec. 8, T. 2 S., R. 1 E., suggesting the mixing of the alluvial fan deposits bordering the eastern edge of the Socorro Valley with flood plain deposits of an axial river or possibly with a central playa in a local structural depression.

Farther south in the Loma de las Cañas quadrangle, this member is included in the mixed-source member because of poorer exposures in that area and uncertain correlation. The Yeso-derived member in this quadrangle probably grades upward into the mixed-source member which here contains little of the red material that distinguishes the upper member to the north.

Mixed-source member: The youngest alluvial fan deposit in the mapped area is the most extensive. It is a deposit of red conglomerate, sandstone, and siltstone in the Mesa del Yeso quadrangle and the northern part of the Loma de las Cañas quadrangle, composed chiefly of pebbles from the Abo, Yeso, and Triassic "red beds" with lesser amounts of material from Pennsylvanian and Datil (?) beds. In the southern half of the Loma de las Cañas quadrangle, this unit is predominantly light gray and tan in color due to the predominance of Pennsylvanian and Yeso material in the beds. This color change reflects the change of the composition of the beds in the source area of this member from north to south. It also suggests a generally westward drainage pattern for the tributaries of the master stream in this region.

In the northern part of the mapped area, notably in the vicinity of Arroyo de la Parida, the stream or streams depositing the mixed-source member were eroding an area which at that time was covered by Permian and Triassic red beds (the Valle de la Parida region). Farther south, possibly because of greater uplift in the eastern highlands, the tributary streams were eroding an area covered primarily by Pennsylvanian beds; the Triassic and Permian here were removed earlier and may have been deposited in an unexposed member correlative to the Yeso-derived and Datil-derived members to the north, or were eroded in pre-Santa Fe time.

Axial River Deposit member: Interfingering with the above fan deposits in the western part of the mapped area is a tan, fine-grained flood plain deposit or playa type. This member is exposed in the lower reaches of most of the arroyos in the area and probably represents the eastern limit of the axial river flood plain or, prior to the establishment of a through-going drainage stream, the eastern edge of a playa in the Socorro basin.

Interfingering with this member is a gray, relatively well-sorted sand and gravel unit composed of material derived from sources outside the mapped area. The pebbles are well rounded and composed chiefly of igneous and metamorphic rocks (notably quartzite), probably from a source area to the north. This unit represents the channel of an axial river which flowed through the Socorro depression. The member probably transgresses the time interval rep-

resented by all the eastern fan deposits, because it is interfingered with or in a stratigraphic portion correlative with all the previously described members.

QUATERNARY(?) ANDESITIC FLOWS

Capping the isolated mesa and rimming the terrace east of the Rio Grande at San Acacia is an andesitic flow that extends along the Rio Grande almost to the mouth of Arroyo Alamillo (south boundary of Sevilleta Grant, T. 1 W., R. 1 E.). This outcrop (TQb) has been mapped by Wilpolt and Yanek (1951) as a Quaternary flow, but it is actually interbedded in the river deposit member of the Santa Fe and is therefore assigned early Quaternary(?) age.

PEDIMENT AND TERRACE DEPOSITS

Most of the interstream divides in the mapped area are capped by a cover of pediment gravels, which, near the eastern contact with the older formations, consists of material derived from the adjacent areas. Near the present course of the Rio Grande, on several terrace levels, there are deposits of well-rounded gravel and sand which represent different levels of Quaternary stream erosion. The lowermost of these surfaces is underlain by a cut-and-fill channel and flood plain deposit that the river and its major tributaries have developed in recent time. Fill of the inner valley is composed of deposits of sand and gravel very similar to the older axial river deposit member of the Santa Fe formation and, in part, may be reworked material of this unit. This type of deposition and erosion persisted throughout Pleistocene time, but changing climatic and base level conditions caused degradation in cycles that produced a sequence of cut-and-fill terraces of material in part reworked from the thicker axial river deposit member of the Santa Fe. Slope wash from the terrace deposits masks the underlying axial river deposit member, but good outcrops of the latter in several places provide a basis for the inferred presence of the older river deposits below the late terrace deposits throughout Socorro Valley.

ALLUVIUM

Several of the high mesas and some of the lower terrace slopes are covered by loose, drifting sand that to a large extent represents material lifted from a broad stream bottom to the adjoining banks, principally by strong southwest winds.

The stream bottoms are covered by recent sands and gravels as is the bed of the Rio Grande. These two deposits have been mapped as recent alluvium.

STRUCTURE IN THE SANTA FE GROUP

The Santa Fe beds generally dip a few degrees to the west-southwest. Numerous faults, mostly of small displacement, were noted. The faulting appears to be concentrated in a zone trending south-southeast from the San Acacia–Joyita hills area. Little evidence of this zone was found south of Arroyo de la Parida. The displacement is generally down to the west. Little evidence of the postulated southward extension of the west Joyita fault of Wilpolt and Wanek (1951) was found. Faults noted were west of the postulated fault zone but could be related to the zone of weakness associated with the west Joyita fault.

Faulting and folding in the older rocks were not found to extend into the Santa Fe. Evidently the post-Santa Fe faulting observed is related to faulting reported by Denny (1940) to the northwest. Movement on the eastern edge of the Rio Grande depression is practically nil, and the area of active post-Santa Fe subsidence apparently is concentrated on the west side of Socorro Valley.

EXPOSURES IN ARROYO DE LA PARIDA

The largest tributary of the Rio Grande in this area is the Arroyo de la Parida which enters the river in the northeast corner of the Socorro 7½-minute quadrangle. It drains a fairly long but narrow area east of its mouth. This intermittent stream has carved a deep canyon through the Datil formation and the Santa Fe beds. As it is the only stream in the Socorro region which has such spectacular exposures, it has been visited by several previous investigators. Before the present alignment of U.S. Highway 85 (west of the Rio Grande) was established, the main road north from Socorro crossed the arroyo near its mouth and ascended a ridge to the north, affording easy access to and good views of the outcrops at the lower end of the arroyo. Lindgren et al. (1910, pl. 16B) shows a view of the middle reach of the arroyo taken from the old highway. Darton (1928, pl. 14C) published a photograph of Santa Fe conglomerates in Arroyo de la Parida. In the same work (pl. 9B) he shows a bone-bearing conglomerate unconformably overlying red sandstone and shale just below Ojo de la Parida.

Several of the units of the Santa Fe group as used in this report are exposed in this arroyo. The lowermost unit (Tsfd, Datil-derived material) is found in several places in the stretch of the stream from the Datil–Santa Fe contact to its last bend in sec. 16, T. 2 S., R. 1 E. Most of the material overlying this unit is the mixed-source unit Tsfu, characterized

here by many Abo pebbles. In secs. 20 and 21, T. 2 S., R. 1 E., in the lowermost mile of the arroyo, is the cliff exposure mentioned previously by Darton. Speaking of this outcrop, Darton (1928, p. 57) says,

> It is probable that this formation [the Santa Fe Group] extends southward along the Rio Grande valley under Albuquerque, for in that region there are exposed two separate formations of valley fill lying nearly horizontal and a *third older one of conglomerate* [author's italics] is well exhibited east of Socorro. . . .

Actually this "third older one" is the youngest, as it overlies a bed of river gravel that has been dated upper Pliocene (Needham, 1936) which is younger than the beds exposed farther north in the Albuquerque area. Darton (1928) evidently did not note the river beds, since they are mostly covered by slope wash and slump from the upper beds, masking the distinctive gray sand of the river deposit member. The deposit member was apparently recognized by Herrick (1904).

Also in the lower reaches of the arroyo and the surrounding ridges, particularly to the north, interfingering of the river deposits and the alluvial fan material from the east can be observed.

This bed of river deposits was dated as upper Pliocene by fossils uncovered by Needham (1936). He found the lower jaw of a four-tusked mastodon from valley fill about six and one-half miles northeast of Socorro along the south bluff of Arroyo de la Parida (the above-mentioned outcrop), in material described as

> . . . unconsolidated sand and gravel light in color, poorly sorted and highly cross-bedded. The pebbles are much waterworn and are made up of a wide variety of igneous and metamorphic rocks with a few fragments of sedimentary rocks. Unquestionably, the material was laid down by a river flowing in the basin near Socorro.

This jaw and a horse tooth found later in the same deposit were dated upper Tertiary, probably upper Pliocene, by Dr. C. L. Glasin of the United States National Museum.

Several students at the New Mexico Institute of Mining and Technology have uncovered fossils in the same exposure (LeMone, 1955).

Upstream, at the south end of Valle del Ojo de la Parida and east of the Datil outcrops, the arroyo cuts through several exposures of a conglomerate bed which has been placed by Wilpolt and Wanek (1951) in the Baca. These exposures are more nearly like the deposits that Gardner described in the Carthage region to the south rather than the Baca from Winchester's Datil in the Bear Mountains to the west. Darton (1928) mentions this conglomerate (*see above*) as probably Triassic overlying Permian. However, the underlying beds are entirely Triassic, which would most likely place the conglomerate in the Tertiary (Eocene?), according to Wilpolt and Wanek (1951).

PALEOGEOLOGY

EARLY TERTIARY EVENTS

At or near the end of the Mesozoic, the Laramide revolution formed the highlands to the east and northeast of the Socorro area. There followed a period of erosion in the highlands and deposition of the Baca equivalents in broad, as yet incompletely defined basins of Eocene time. In this area, the Baca basin extended at least from the region of the eastern highlands (the hills extending from the Los Pinos Mountains to the Carthage area) to the region of the Bear Mountains north of Magdalena. This period was followed by mid-Tertiary volcanic activity which, according to Kelley (1952), occurred in three periods, and by the uplift, and high-angle faulting which produced the Santa Fe formation. Early in this period, according to Spiegel (1962), the Popotosa formation was deposited in the eastern part of a relic of the Baca basin, the Spears member of the Datil formation interfingered with the Popotosa formation from the west. The early Tertiary red volcanic sediments (Tc(?)) near the south end of Valle del Ojo de la Parida were probably laid down during this time. These deposits and later flows filled the Socorro basin and other depressions to the south and east. The eastern highlands probably were not completely covered, according to Bates (1947):

> At the end of Cretaceous time compression from the west thrust up sediments on west dipping strata along the Montosa and Paloma thrust faults. The partly worn-down upthrust masses are now seen as the Los Pinos and Manzano Mountains. . . .

He also postulated that mid- or late Tertiary relaxation resulted in normal faulting along the previous fault zones or faults with the directions reversed; that the Los Pinos fault extended to the vicinity of the Gonzales Prospect (sec. 3, T. 3 S., R. 1 E.) and formed the eastern limit of the Rio Grande depression; that Datil flows occurred during this period; and that the Los Pinos, Manzano, and Socorro–Lemitar mountains were formed.

This belt of faulting may have extended south and southwest of the Gonzales Prospect forming a basis for a drainage divide in the eastern part of the Socorro area. The Laramide thrusting may have left a highland extending from the Cerrillos del Coyote area an indeterminate distance to the south and southwest. This positive mass withstood Eocene ero-

sion and formed a divide between a Baca basin to the west (Spiegel, 1962) and a Baca (?) basin to the east, as well as a source area for deposition. The basin to the southeast was located at the site of the northern part of the present Jornado del Muerto. The Datil sediments and flows did not completely cover this divide, as evidenced by the thinning of Datil-type beds between Arroyo de los Pinos and Carthage. At the end of these early Tertiary events, the Socorro area was left a closed basin with the beginnings of uplift in its interior.

SANTA FE EVENTS

In Pliocene (?) time, a north-south trending highland mass of Mesozoic, Permian, and Pennsylvanian rocks, and a few scattered deposits of Baca (?) and Datil existed along the eastern edge of the map area. To the west, the beginnings of the Socorro Mountains were present in the form of deposits of fine-grained sediments, playa beds, intrusive rocks, flows, and tuffs comprising the Popotosa (?)–Datil volcanic sequence. The principal sediment sources to the west were the volcanic rocks of the Mogollon Plateau (Kottlowski, 1959). The eastern highlands were relatively higher than the Socorro Mountains and were composed of more resistant material. Consequently, initially, the alluvial fans that developed along the eastern edge of the basin were shorter and coarser-grained than those that developed along the western edge. The ancestral Rio Grande flowed into the site of Socorro Valley basin from the north and flowed along the eastern edge of the area from San Acacia to San Antonio. No major tributaries seem to have existed during this period along the eastern slopes of the depression. In the Mesa del Yeso quadrangle, two small fan axes are suggested by outcrop patterns. One is an outlet from the south end of Valle del Ojo de la Parida in sec. 27, T. 1 S., R. 1 E., with the fan spreading west-southwest from that point. The other is in the vicinity of Arroyo de la Parida from sec. 11, T. 2 S., R. 1 E., west-southwest.

South of this area, in the Loma de las Cañas quadrangle, no large tributaries were developed as the axis of the basin was relatively near the source area and most of the fans were short and small; however, there is a slight suggestion of a relatively large fan in the vicinity of Arroyo de las Cañas. A large embayment of the river flood plain was present in this quadrangle in the vicinity of Arroyo del Tajo north to the divide south of Arroyo del Coyote, as evidenced by the generally finer-grained character of the beds and by the eastward swing of the axial river deposit member. This could mean that no drainage of any consequence from the east existed in this vicinity.

This over-all lack of drainage from the east into the depression in the Socorro region may indicate that much of the material from the eastern highlands was carried to the southeast into another basin or the head of a major eastern tributary to the ancestral Rio Grande.

COURSE OF AN ANCESTRAL UPPER PLIOCENE–PLEISTOCENE RIO GRANDE IN SOCORRO VALLEY

Bryan (1938) and Denny (1940, 1941) postulated that the Socorro basin was a playa region in Popotosa and Santa Fe time. However, no evidence has been found to indicate that a playa existed continuously. According to Bryan and Denny, the Rio Grande of that time flowed to the east over the south end of the Los Pinos Mountains (northeast of the Socorro region). This postulation was based on two outcrops of river gravels found by Denny in the San Acacia area and on Bryan's observations that the Santa Fe deposits in the Socorro region were finer-grained to the west and appeared to be due to alluvial fans debauching into a central playa in a closed basin. Bryan evidently overlooked the river deposits in which Needham found the Pliocene fossils, and another river-type deposit near San Antonio, which Bryan himself dated Pliocene (*see* Needham, 1936). Denny noted that Needham had found the fossils in the Socorro area, but still directed the Pliocene Rio Grande over the Los Pinos. He did this on the basis of inferred direction of stream flow based on pebble orientation in his two river deposit sites. Denny also found two fossil sites in the Santa Fe beds in the San Acacia area. One, yielding bones dated upper middle to upper Pliocene, was in the high bluffs about two miles southwest of La Joya, north of the Socorro area, and the other was on the east side of the present Rio Grande about two miles north of Contreras in silt beds interbedded with river deposits. These were plant remains which were not definitely dated but were post-Miocene.

Stark and Dapples (1946, p. 1127) discount the idea of a Pliocene Rio Grande flowing over the Los Pinos Mountains. They presented three factors:

1. An ancient (not recent) dissected fan in the area in question indicated that the drainage at that time was eastward from the Precambrian rocks of the mountains (not south).
2. The present radial drainage pattern from the Precambrian rocks must have been established following the initial uplift of the range, which was pre-middle Pliocene.
3. In the western flank of the granite and rhyolite areas are two westward-draining valleys containing flats greater than one quarter mile wide. These are mature stage valleys unique among the youthful valleys that are characteristic of this area of the mountains.

The present mapping has outlined what is probably the eastern edge of a through-flowing stream in Pliocene (?) and Pleistocene time. River sands and gravels that are apparently correlative with the fossil locale in Arroyo de la Parida extend through the Socorro area (see fig. 2). These deposits interfinger both with playa or flood plain deposits and fan deposits. These beds together with Stark's evidence (summarized above) would indicate that a late Pliocene–Pleistocene Rio Grande did flow through the Socorro basin and not over the Los Pinos Mountains. Bryan's and Denny's playa appears to be only a locally depressed area in the valley of the ancestral Rio Grande.

There is a possibility that an older playa preceded the through-flowing stream in this basin. Wright (1946) postulated two axes of deposition to the north in the Rio Grande depression. A closed or playa-type basin was separated by a low, south-trending, drainage divide from an open basin to the east containing a through-flowing stream. Wright postulates that the playa may have slightly preceded the complex of fan and river deposits. An analogous situation could have existed in the San Acacia area in early or middle Santa Fe time, but all evidence is now deeply buried. A gravity survey made by Anderson (1955) offers some support for the hypothesis of two depositional axes. His profile shows a ridge in the bedrock on the east side of the Socorro Valley that could have been a drainage divide in late Tertiary time.

Evidence is not known for conjecturing a through-flowing master stream in the Socorro "basin" prior to late Pliocene time. The river gravels in Socorro Valley area that are definitely dated as upper Pliocene appear to be the oldest Santa Fe beds exposed. The alluvial fans to the east, which interfinger with the river deposits in the area immediately north of Arroyo de la Parida, sec. 17, T. 2 S., R. 1 E., are younger than, contemporaneous with, or slightly older than the stream gravels. All are equivalent to the upper buff member of Bryan and McCann (Baldwin, 1956). Some are probably of early Pleistocene age.

North of the above locale, the river gravels interfinger with flood plain or playa-type beds, which in turn, interfinger with fan deposits to the east. This suggests that a meandering channel existed at that time, much like that of the present Rio Grande. The fans of the larger tributaries may have caused some of the meanders which subsequently were incised by another meander and then dissected by their own channels cutting down to the grade of the river. As evidenced by recent action of the Rio Grande and its larger tributaries, the sand and gravel deposits are (and were) laid down by both the axial stream and the tributaries reworking previously deposited channel sands in the flood plain of the master stream.

As traced by the outcrops of the river sands and gravels, the Pliocene Rio Grande entered the Socorro area west of the Joyita Hills through the San Acacia channel, flowed south essentially along the present course of the river.

South of the Socorro region, Kelley and Silver (1952, p. 184) refute the theory that an ancient Rio Grande flowed through the Jornado del Muerto. According to several investigators, the Rio Grande did not become a through-flowing stream until late Pliocene or early Pleistocene time. Additional detailed mapping southward from Socorro Valley would probably settle the controversy.

REFERENCES

Anderson, R. C. (1955) *A gravity survey of the Rio Grande trough near Socorro, New Mexico*, Trans. AGU, v. 36, n. 1, pp. 144-148.

Baldwin, B. (1956) *The Santa Fe Group of North-Central New Mexico, in* Guidebook of Southeastern Sangre de Cristo Mountains, New Mexico, Seventh Field Conference, New Mex. Geol. Soc., pp. 115-121.

Bates, R. L. (1942) *The oil and gas resources of New Mexico*, N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Bull. 18, p. 46.

Bryan, Kirk (1926) *Ground-water reconnaissance in Socorro County, New Mexico*, N. Mex. State Eng., Bienn. Rpt. VII, p. 81-86.

——— (1932) *Pediments developed in basins with through drainage as illustrated by the Socorro area, New Mexico* (abs.), Geol. Soc. Am. Bull., v. 43, p. 128-129.

——— (1938) *Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico*, Regional Planning, Part VI-Upper Rio Grande, National Resources Committee, v. 1, pp. 197-225.

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

Denny, C. S. (1940) *Tertiary geology of the San Acacia area, New Mexico*, Jour. Geol., v. 48, p. 73-106.

——— (1941) *Quaternary geology of the San Acacia area, New Mexico*, Jour. Geol., v. 49, p. 225-260.

Herrick, C. L. (1904) *Laws of formation of New Mexico mountain ranges*, Am. Geologist, v. 33, p. 301-312, 393.

Kelley, V. C. (1952) *Tectonics of the Rio Grande Depression of Central New Mexico*, Guidebook of Central New Mexico, N. Mex. Geol. Soc., Third Annual Field Conf., pp. 93-105.

Kelley, V. C., and Silver, C. (1952) *Geology of the Caballo Mountains*, Univ. N. Mex. Publ. Geol., no. 4.

Kottlowski, F. E. (1959) *Pennsylvanian rocks on the northeast edge of the Datil Plateau*, Guidebook of West-Central New Mexico, N. Mex. Geol. Soc., Tenth Annual Field Conf., pp. 57-62.

Lee, W. T. (1907) *Water resources of the Rio Grande valley in New Mexico and their development*, U.S. Geol. Surv., Water-Supply Paper 188, 59 p.

LeMone, D. V. (1955) *Geological investigation of the Santa Fe formation near Socorro, New Mexico*, Paper presented at the ninth annual meeting, N. Mex. Geol. Soc.

Lindgren, W., Graton, L. C., and Gordon C. H. (1910) *The ore deposits of New Mexico*, U.S. Geol. Surv., Prof. Paper 68, 361 pp.

Needham, C. E. (1936) *Vertebrate remains from Cenozoic rocks*, Science, v. 84, p. 537.

Spiegel, Zane (1955) *Geology and ground-water resources of northeastern Socorro County, New Mexico*, N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Ground-Water Rpt. 4, 99 pp.

——— (1961) *Late Cenozoic sediments of the lower Jemez River region*, Guidebook of the Albuquerque Country, N. Mex. Geol. Soc., Twelfth Annual Field Conf., pp. 132-138.

——— (1962) *Preliminary report on the geology and water resources of the Socorro region*, unpublished manuscript in files of Ground-Water Department, RD&D, N. Mex. Inst. Min. and Tech.

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

Tonking, W. H. (1957) *Geology of Puertecito Quadrangle, Socorro County, New Mexico*, N. Mex. Inst. Min. and Tech., State Bur. Mines and Mineral Res., Bull. 41.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, Georges (1946) *Geologic map and stratigraphic sections of Paleozoic rocks in Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro counties, New Mexico*, U.S. Geol. Surv., Oil and Gas Inv. Prelim. Map 61.

———, and Wanek, A. A. (1951) *Geology of the region from Socorro and San Antonio east to Chupadera Mesa, Socorro County, New Mexico*, U.S. Geol. Surv., Oil and Gas Inv. Map OM 121.

Winchester, D. E. (1920) *Geology of Alamosa Creek Valley, Socorro County, New Mexico*, U.S. Geol. Surv., Bull. 716-A, 15 p.

Wright, H. E., Jr. (1946) *Tertiary and Quaternary geology of the lower Rio Puerco area, New Mexico*, Geol. Soc. Am. Bull., v. 57, pp. 303-456.