Origin of the Popotosa Formation
North-central Socorro County
New Mexico

James Earl Bruning

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ORIGIN OF THE POPOTOSA FORMATION, NORTH-CENTRAL SOCORRO COUNTY, NEW MEXICO

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James Earl Bruning

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ABSTRACT

The Popotosa Formation of Miocene age represents the basal Santa Fe Group and crops out in discontinuous exposures along the east edge of the Mogollon-Datil volcanic field in north-central Socorro County, New Mexico. The formation is composed of fanglomerate and playa sediments deposited during Basin and Range deformation and consists of conglomerate, sandstone, siltstone, mudstone, and volcanic rocks. Deposition of the Popotosa Formation began about 24 m.y. B.P. during the emplacement of the upper third of La Jara Peak Andesite and continued at least to late Miocene time when rhyolitic flows and domes were emplaced from the Socorro and Magdalena Peak volcanic centers. The upper limit of Popotosa deposition has not been established but it is believed not to have continued much beyond 11 m.y. B.P.

The Popotosa Formation usually overlies volcanic rocks of Oligocene or Miocene age; locally, it overlies older prevolcanic rocks. In general, it is the youngest well-indurated sedimentary unit present and is commonly overlain with angular unconformity by poorly indurated sedimentary deposits of the upper Santa Fe Group which contain higher proportions of prevolcanic detritus.

The rock units of the Popotosa Formation can be subdivided into two basic lithofacies--the fanglomerate facies and the playa facies. These lithofacies are made up predominantly of clasts from

silicic welded tuffs and andesites, but clasts from granite, schist, quartzite, chert, limestone, and sandstone are present locally. Local fanglomerates, identifiable by unique lithologic characteristics, are the fanglomerate of Dry Lake Canyon (predominantly andesitic detritus) and the fanglomerate of Ladron Peak (predominantly Precambrian and late Paleozoic detritus). Maximum exposed thickness of the fanglomerate facies, the fanglomerate of Ladron Peak, and the playa facies is about 5,500 feet; however, numerous faults make it difficult to determine the true thickness.

Flow directions, as determined from sedimentary structures and pebble counts, were utilized to reconstruct dispersal patterns. The source areas were the Colorado Plateau to the northwest; the Gallinas, San Mateo, and Magdalena Mountains to the west, southwest, and south; the Ladron Mountains to the north; and Polvadera Mountain in the center of the basin. Only the western half of the basin has been studied; the eastern half of the Popotosa basin probably has been destroyed by uplift and erosion along the east side of the Rio Grande rift.

The Popotosa Formation represents alluvial-fan/playa deposition in an arid to semi-arid climate. Deposition of the Popotosa began about 24 m.y. B.P. during the emplacement of La Jara Peak Andesite. The Colorado Plateau began to rise shortly thereafter and shed detritus from the northwest into the Popotosa basin. The original basin was modified by uplift of the ancestral Magdalena Mountains which were eroded until they were buried beneath their own debris. During this period of degradation the Ladron Mountains were rapidly uplifted and the fanglomerate of Ladron Peak developed. Volcanism was sporadically active throughout the deposition of the Popotosa. Following the deposition of the Popotosa Formation came a long period of block faulting, erosion, and deposition which formed the present topography. The Popotosa basin was greatly modified during this period by uplift of several intrabasin horsts, such as the Bear, Magdalena, and Socorro-Lemitar Mountains.

INTRODUCTION

Purpose and Method of Study

The purpose of this study is to determine the origin and areal extent of the Popotosa Formation in the north-central portion of Socorro County. The Popotosa Formation is a suite of conglomerates, sandstones, siltstones, and volcanic rocks of Miocene age whose distribution, thickness, and stratigraphic variations were previously poorly defined or unknown.

The investigation started with the determination of the external and internal geological framework of the Popotosa Formation. This was achieved by detailed mapping (scale 1:24,000) in the type area between San Lorenzo Arroyo and the Ladron Mountains and by reconnaissance mapping on the same scale of other areas in which the Popotosa Formation was thought to exist. The areal extent of the Popotosa Formation and its subdivision into facies was delineated by this mapping as was the stratigraphic relationships between the Popotosa and younger and older rocks. The mapping also provided information regarding regional structures, thickness variations, and age relationships of the Popotosa Formation. The probable source areas of the clasts in the Popotosa Formation were determined by examining the lithologies represented in pebble and cobble counts of the Popotosa conglomerates and by determining flow directions from a study of pebble imbrications and of channeling and parting lineation.

The second part of the investigation determined the internal geological framework within the Popotosa Formation, i.e.; the interrelationships of the sub-units. Sedimentary structures such as crossbedding, channeling, and parting lineation indicated more precisely the mode and environment of deposition. Examination of the fabric of the deposit, the sorting, roundness, and size of the clasts, aided in interpreting the manner of deposition. The type of cementation and the diagenetic and authigenetic changes of the minerals were determined from thin-section analysis of samples at various stratigraphic intervals.

Interpretation of the origin of the Popotosa Formation utilized all the above analyses and descriptions. The time scale used for interpreting the chronological order of events for the deposition of the Popotosa was that of Harland and others (1964).

Location and Accessibility

The Popotosa Formation crops out discontinuously in the north-central portion of Socorro County. It occurs primarily in an area approximately 35 miles long, from south of Socorro to north of Bernardo, and 32 miles wide, from Socorro to about 12 miles west of Magdalena (fig. 1).

A nearly continuous north-south belt of the Popotosa Formation is exposed on the eastern side of the study area. Other exposures, varying from a few hundred square feet to several square miles, can be seen in Water Canyon, on South Baldy, on the southeast side of Magdalena Peak, and west of the Bear Mountains (pl. 1).

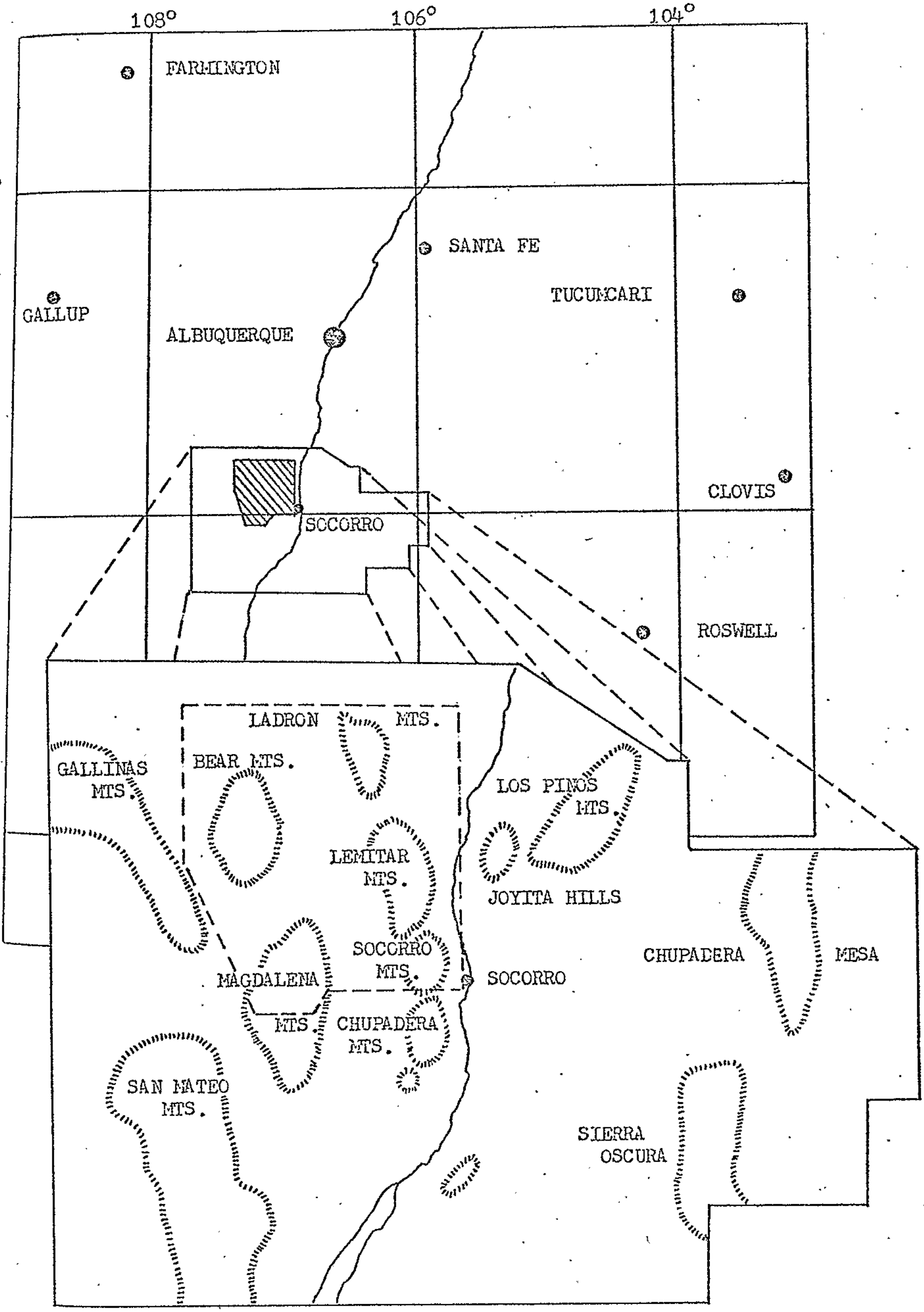

Figure 1. Index map of New Mexico, showing location of Socorro County and map area.

The region is accessible by the paved roads Interstate 25, U. S. Highway 60, and State Road 52. Graded dirt roads such as the Magdalena-Riley-Bernardo road, the road to Abbe Spring off N. M. 52, and numerous other unnamed county and ranch roads enhance the accessibility to the area. There are many arroyos which provide easy access to almost any point by four-wheel-drive vehicles.

Previous Investigations

There have been numerous investigations within the studied area. Prior to 1940 most of the work was primarily of a reconnaissance nature (Herrick, 1900; Winchester, 1920; and Darton, 1928). Denny (1940) named the Popotosa Formation for the arroyo by that name in T. 2 N., R. 2W., and states that it is well exposed in the valley of Silver Creek, T. 1 N., R. 2 W. According to Denny the Popotosa Formation may represent the transition between the Miocene epoch of volcanic activity, now dated as largely Oligocene, and the period of basin deposition dominantly of Pliocene age, now dated as Miocene and Pliocene. Spiegel (1955, p. 40) states that "the Popotosa Formation is inferred to be equivalent in age and origin to the Abiquiu Tuff of Smith (1938), the Picuris Tuff of Cabot (1938), and the Abiquiu Formation of Stearns (1953)." The Abiquiu Formation of Stearns is thought to be lower Santa Fe Group which is early or middle Miocene. Later, Spiegel (1962) erroneously considered the Popotosa to be equivalent to Tonking's (1957) Spears Member of the Datil Formation. Debrine, Spiegel and

Williams (1963), Weber (1963), and Black (1964) have noted that the Popotosa overlies the Baca Formation in the Bear Mountains, east of the Rio Grande and northeast of the Ladron Mountains.

T. M. Woodward (oral communication, 1972) has mapped the Popotosa in the area west of Polvadera Mountain and has observed it overlying older Tertiary volcanics. Outcrops of the Popotosa Formation on Socorro Mountain to the south have been mapped in part by Laskey (1932), Smith (1963), Lowell (1967) and Burton (1971). Burton believes that the entire section of the Popotosa is present and that it lies upon Precambrian argillite and lower Pennsylvanian limestones and shales and is capped by a Pliocene (?) tuff. Outcrops of the Popotosa Formation in Water Canyon and on South Baldy have been mapped by Kalish (1953), Stacy (1968) and D. A. Krewedl (oral communication, 1972). The Popotosa in this area has been observed to overlie older Tertiary volcanics. In the area west of the Bear Mountains, both Tonking (1957) and Brown (1972) have mapped fanglomerates which they suggest may be similar in age and origin to the Popotosa Formation.

The previous investigators have only observed isolated areas of the Popotosa and, to date, a regional stratigraphic study of the Popotosa Formation has been lacking.

Acknowledgments

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REGIONAL SETTING

The area in which the Popotosa Formation crops out is a transitional zone between the Colorado Plateau province and the Sonoran-Chihuahua system, a subdivision of the Basin and Range province (Eardley, 1962). The region is characterized by extensive volcanic accumulation and moderately-dipping sedimentary strata which have undergone late Cenozoic faulting. The faulting has resulted in topographic features which are characteristic of the Basin and Range province. Most of the region averages between 6,000 and 8,000 feet in elevation. The lowest elevation is about 4,500 feet in the drainage system of the Rio Grande near Socorro. The highest elevation is South Baldy, 10,783 feet, in the Magdalena Mountains.

The major structural provinces within the study area (fig. 2) are the Colorado Plateau and the Rio Grande rift. Subdivisions within these provinces are:

<u>Colorado Plateau</u>

1. Lucero Uplift
2. Acoma Embayment
3. Mogollon Slope

<u>Rio Grande rift</u>

1. Bear Mountains
2. Magdalena Mountains
3. Socorro-Lemitar Mountains
4. Ladron Mountains
5. La Jencia Basin
6. Mulligan Gulch Graben

Colorado Plateau

The Colorado Plateau is a rectangular crustal block which includes between 130,000 and 150,000 square miles of northwestern New Mexico, northeastern Arizona, southeastern Utah, and western

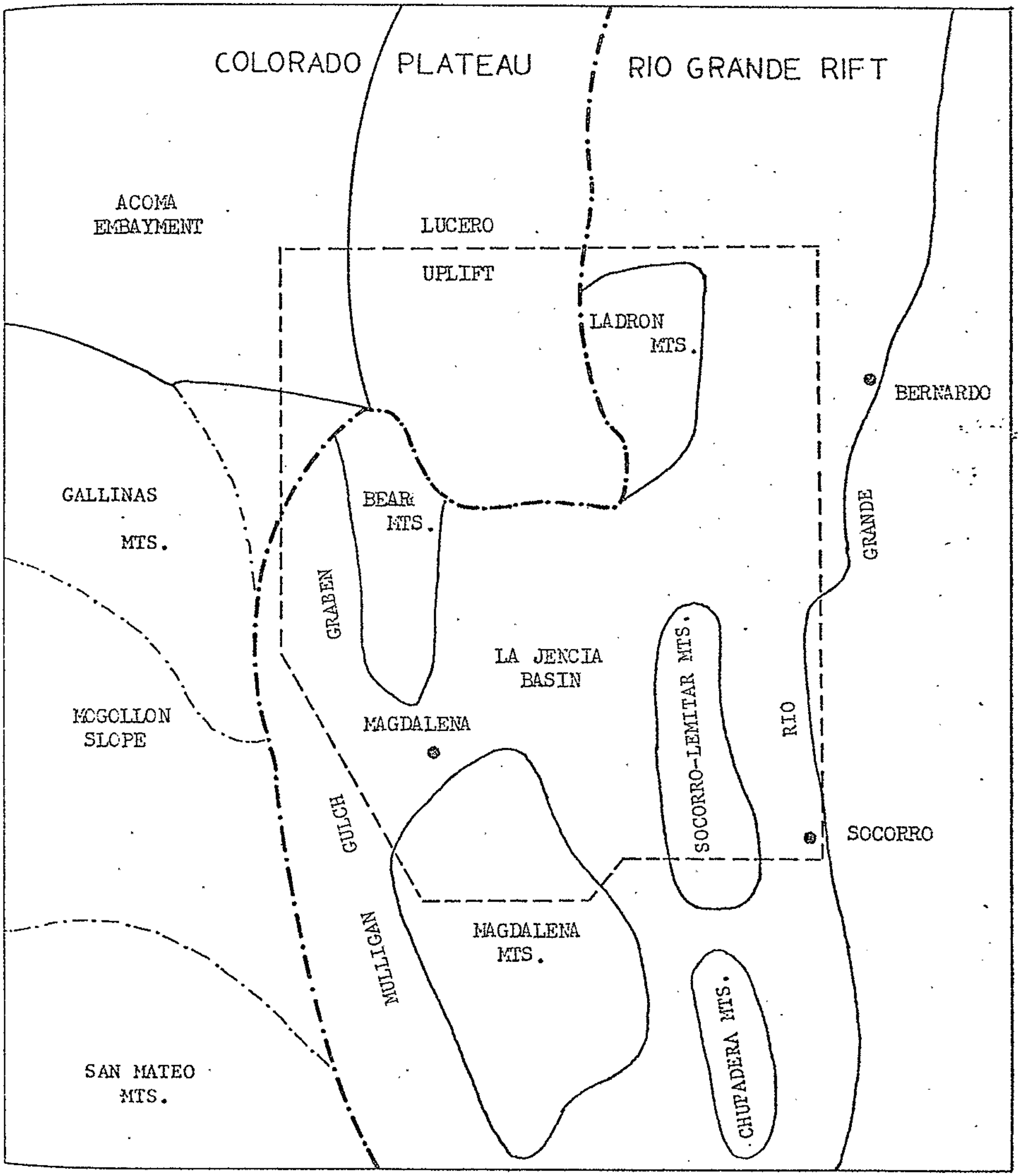


Figure 2. Major structure provinces and subdivisions within the map area. Modified from Fitzsimmons (1959). Scale 1 : 500,000.

Colorado (Smith, 1970). It is the lesser deformed part of the crust within the broad zone of Laramide orogeny. Most of the Plateau consists of flat-lying sedimentary strata 6,000 to 10,000 feet thick overlying a Precambrian basement complex (Eardley, 1962). The nearly flat-lying strata are locally disturbed by large monoclinal flexures of Laramide age. Intrusive and extrusive igneous rocks of Tertiary age also occur within the Colorado Plateau especially around the margins. Fitzsimmons (1959) differentiated the Lucero uplift, the Acoma embayment and the Mogollon slope within the Colorado Plateau in the study area.

The eastern edge of the Colorado Plateau in the study area is a north-trending belt of west dipping late Paleozoic and Mesozoic rocks known as the Lucero uplift. Dimensions of this structure are about 40 miles north-south and 10 miles east-west (Fitzsimmons, 1959, p. 114). The topographic relief on the eastern flank of the uplift averages only about 1,000 feet but the overall structural relief may be as much as 20,000 feet because of downfaulting of the Rio Grande rift. Stratigraphic displacement of 3,000 feet is common throughout the uplift (Kelly and Wood, 1946). The present elevation of the Lucero upland above the surrounding area is primarily a result of uplift and erosion in latest Tertiary and Quaternary time. The Lucero uplift separates the southern part of the Acoma embayment from the Rio Grande rift.

Cretaceous and older folded and faulted strata lie to the west of the Lucero uplift in the Acoma embayment (Jicha, 1958). The southern part of the Acoma embayment is modified by a number of north-trending anticlines and synclines which exhibit faulting of varying intensities. Fitzsimmons (1959) reports that strata in the upper drainage of Alamosa Creek and the Rio Salado dip about 20 degrees to the southwest; and Tonking (1957) observed a dip averaging due south in the area north and east of the Bear Mountains.

The Acoma embayment passes into the Mogollon slope, considered by some to be the southern part of the Colorado Plateau. The Mogollon slope is not a single geomorphic surface but is rather an area of individual ranges and associated depositional slopes and flats (Fitzsimmons, 1959). The northern part of the Mogollon slope consists mainly of Mesozoic and Tertiary strata which dip to the south (Tonking, 1957).

Rio Grande Rift

The dominant feature of the Basin and Range province in New Mexico is the Rio Grande rift. It extends for about 600 miles from the Mexican border to near Leadville, Colorado. The greatest topographic relief is about 8,000 feet with an average of about 5,000 feet along the main basins (Chapin, 1971a). The Rio Grande rift is characterized by Basin-and-Range-type faulting which has produced a series of basins and mountain ranges arranged en echelon with a general north trend. The time of initiation of rifting is difficult to determine with precision, but the presence of Middle and Late Miocene fossils in basal alluvial fill together with K-Ar dates on interbedded volcanic rocks suggests that rifting began at least 18 million years ago (Chapin, 1971a, p. 191).

The Bear Mountains are a 13 mile long by 4 mile wide, north-northwest-trending, westward-tilted uplift bordered on the north by the Lucero uplift, on the east by a downfaulted basin known as Snake Ranch Flats or La Jencia Basin (Brown, 1972), and on the west by the north-trending Mulligan Gulch graben. Tertiary volcanic rocks of the Spears, Hells Mesa, and La Jara Peak formations comprise the major portion of the Bear Mountains. Numerous mafic dikes are also present.

The Magdalena Mountains, like the Bear Mountains, are a north-northwest-trending, westward-tilted uplift formed by late Cenozoic block faulting (D. A. Krewedl, oral communication, 1972). The structural horst, 13 miles long and 7 miles wide, produces about 4,500 feet of topographic relief, the greatest in the study area. The Magdalena Mountains are bounded on the northeast by La Jencia Basin, on the north-northwest by the Bear Mountains, and on the west by the Mulligan Gulch graben. The Magdalena Mountains consist primarily of Precambrian granites, argillites, and quartzites; late Paleozoic limestones, quartzites, and shales; and Tertiary ash-flow tuffs, andesites, monzonites and granites (Loughlin and Koschmann, 1942).

The Socorro-Lemitar Mountains are a 13 mile long by 3 mile wide, north-trending uplift which is tilted on the west into La Jencia Basin. Polvadera Mountain at 7,292 feet and Socorro Peak at 7,243 feet are the highest elevations. The rock units are Precambrian granites, argillites, and quartzites; late Paleozoic limestones, shales, and quartzites; and Tertiary volcanic, intrusive, and sedimentary rocks. Socorro

Peak is a late Miocene volcanic center consisting of volcanic domes and domal flows (Burton, 1971). Precambrian and late Paleozoic rocks crop out almost continuously along the eastern flank of Polvadera Mountain but are exposed on the west flank only in a small uplifted fault block (T. M. Woodward, oral communication, 1973). These rocks are also exposed in a small area on the northeast side of Socorro Peak.

The Ladron Mountains are located at the southeast corner of the Lucero uplift and the Colorado Plateau and north of the Socorro-Lemitar uplift (Fitzsimmons, 1959). They are a westward-tilted, north-trending, fault block mountain range. The Ladron uplift occupies an area about four by five miles with a maximum elevation of 9,176 feet. Schists, gneisses, quartzites, and granites of Precambrian age form the core of the range. Rocks of late Paleozoic and Mesozoic age form a westward-dipping hogback along the west flank of the Precambrian core (Black, 1964; Haederle, 1966).

La Jencia Basin, or Snake Ranch Flat, is about 14 miles long and 9 miles wide. It has been downfaulted against the uplifts of the Bear and Magdalena Mountains on the west and the Socorro-Lemitar Mountains on the east. The basin is composed of late Tertiary and Quaternary sediments derived from the erosion of the surrounding uplifts (Debrine, Speigel and Williams, 1963). The major drainage from the basin is La Jencia Creek flowing northeast to the Rio Salado; minor drainage to the southeast is via Socorro Canyon and Nogal Canyon, but the south-central portion of the basin has internal drainage to a playa near Water Canyon Lodge.

Mulligan Gulch graben is a narrow trough, three to five miles wide, extending from Mulligan Gulch on the south to Abbe Spring on the north and separating the San Mateo and Gallinas mountains from the Bear and Magdalena mountains (Chapin and others, in preparation). The graben appears to be rather shallow and probably contains 1,000 to 2,000 feet of detritus shed from the neighboring uplifts of the Gallinas, San Mateo, Bear, and Magdalena mountains. This fill consists of an andesitic facies of the Popotosa Formation, the fanglomerate of Dry Lake Canyon (Brown, 1972), capped by pediment gravels and remnants of the basalt of Council Rock.

PRE-POPOTOSA GEOLOGIC HISTORY

Central New Mexico was part of a broad shelf during Precambrian time on which accumulated a large quantity of clastic sediments and a lesser amount of volcanic rocks which were later intruded and metamorphosed (Smith, 1963).

Geologic events during early Paleozoic time are uncertain as no sedimentary record now exists in the study area. The earliest Paleozoic depositional episode recorded in northern Socorro County occurred during Mississippian time when the sea transgressed from the south and sediments were laid down at least as far north as the southern end of the Ladron Mountains (Kelly and Wood, 1946). Rocks of Mississippian age are exposed also in the Magdalena Mountains and on Polvadera Mountain. The strata vary from 0 to 150 feet thick as a result of early Pennsylvanian and later erosion. These strata are principally carbonate deposits of the Kelly and Calosa formations of Osage age (Armstrong, 1963).

During Pennsylvanian time, the sea transgressed over most of central New Mexico with the deepest part of the sedimentary basin located in the southern part of the Lucero region (Kelly and Wood, 1946). Marine limestones, quartzose sandstones, and shales were deposited. The Pennsylvanian strata lie unconformably on either Precambrian granitic and metamorphic rocks or on Mississippian rocks. The Pennsylvanian rocks in the Magdalena Mountains belong to the Magdalena Group and consist of the Sandia Formation, 600 feet, and the overlying

Madera Limestone, 1,000 feet (Kottlowski, 1963). In the Socorro-Lemitar Range, only the lower part of the Pennsylvanian section remains beneath the early Tertiary erosion surface (Kottlowski, 1963). Smith (1963) believes that of the 1,200 feet of strata present on Socorro Mountain, the lower 500 feet might be assigned to the Sandia Formation and the remaining 700 feet to the Madera Formation. The Sandia Formation is also recognized in the southern part of the Ladron Mountains.

In early Permian time red-brown shales, siltstones, and sandstones of the Abo Formation were deposited in littoral and fluvial environments. These sediments lie conformably and unconformably on the older Pennsylvanian strata. Then the marine strata of the Yeso and San Andres Formations were deposited in a transgressing sea (Kelly and Wood, 1946). Limestones, sandstones, gypsum, and shales accumulated in a basin characterized by sporadically restricted marine conditions. At the close of Paleozoic time, the region was broadly uplifted but little deformation occurred during this period of emergence (Kelly and Wood, 1946).

The area was relatively stable during the beginning of the Mesozoic Era. Throughout lower Triassic time central New Mexico was exposed to erosion and no sedimentary record exists. Sedimentation began with the Chinle Formation during upper Triassic time. Tonking (1957) has interpreted these red beds as having a similar mode of deposition to that of the Abo Formation. The finer-grained strata represent floodplain sedimentation, and the lenticular conglomerates and crossbedded sandstones indicate channel or alluvial-fan deposition.

Outcrops of the Chinle Formation are found in the Ladron Mountains and in the region north of the Bear Mountains (Tonking, 1957; Black, 1964). The Chinle disconformably overlies the San Andres Formation. Evidence of Jurassic deposition is lacking in the study area, but to the north in the Lucero uplift, deposition of the Morrison Formation took place in an arid climate (Jicha, 1958). The area was relatively stable with little erosion or deposition during early Cretaceous time. Deposition began again in late Cretaceous time with the spreading of broad epicontinental seas in which was deposited the transgressive Dakota (?) Sandstone, the overlying Mancos Shale and the regressive Mesaverde Group (Kelly and Wood, 1946). These Cretaceous rocks have been mapped to the north and west of the study area.

The close of the Mesozoic Era and the early Cenozoic Era were characterized by the widespread uplift and deformation of the Laramide Orogeny. A major uplift involved an area extending from the southern Gallinas Range on the west to Socorro Peak on the east and as far north as Polvadera Mountain and the Joyita Hills, but the southern extent is as yet undefined (C. E. Chapin, oral communication, 1973). This uplift and others to the north and east were eroded during the Eocene with concurrent deposition of as much as 2,500 feet of arkosic sediments in adjacent basins to form the Baca Formation (Snyder, 1971). Erosion continued to the close of Eocene time when the highlands had been beveled and the basins filled. Cenozoic volcanism started in early Oligocene time in the center of the Mogollon

Plateau in Catron County; a volcaniclastic alluvial apron of andesitic and latitic detritus formed around the volcanic centers and extending north and east buried the Magdalena area to a depth greater than 1,000 feet. Volcanism in the study area began shortly thereafter and culminated in middle Oligocene time, 32-30 m.y., with the building of a 2,000 foot thick ash-flow plateau across the Magdalena area (Brown, 1972). The ash-flow tuffs thinned northward and eastward but covered most of the study area. In late Oligocene time, the ash-flow plateau was broken by north trending extensional fault zones into which numerous stocks and dikes of monzonitic to granitic composition were intruded. The Nitt and Anchor Canyon stocks have been dated at 28 m.y. (Weber and Bassett, 1963, p. 220). Then a long period of erosion ensued during which many of the stocks were breached and hogback ridges formed where faulting had previously tilted the strata. In early Miocene time volcanism resumed with the extrusion of La Jara Peak Andesite (23.8 ± 1.2 m.y., Chapin, 1971b) in the area north and west of Magdalena. As much as 2,000 feet of basaltic andesitic flows accumulated with only minor sedimentary interbeds. Near the end of the eruptions, coarse gravels of the Popotosa Formation were shed into the basin from the south, probably from the Magdalena Mountains.

NOMENCLATURE APPLIED TO THE MAPPABLE UNITS

Rock units deposited prior to the Popotosa Formation have been grouped on the basis of lithology and age to simplify the map. Only a brief discussion is given. For further information the reader is referred to papers by Loughlin and Koschmann (1942); Kelly and Wood (1946); Tonking (1957); Brown (1972); Krewedl (in preparation); and Chapin and others (in preparation).

The oldest rocks mapped in the study area are Precambrian in age and consist of granite, gneiss, and ancient sediments now represented by schist, quartzite, and argillite. The late Paleozoic rocks include the Kelly and Calosa formations (carbonate rocks) of Mississippian age; the Magdalena Group (carbonates, shales, and quartzites) of Pennsylvanian age; and the Abo, Yeso, and San Andres Formations (shales, siltstones, sandstones, and limestones) of Permain age. Shales, siltstones, and sandstones of the Chinle Formation, Dakota (?) Sandstone, Mancos Shale, and the Mesaverde Group have been collectively mapped as Mesozoic rocks. The Tertiary rocks have been mapped as the Baca Formation, Tertiary intrusives, Tertiary felsic volcanic rocks, and Tertiary andesitic rocks. The Baca Formation of Eocene age consists of conglomerate, sandstone and shale. The rock units mapped as Tertiary intrusives are mostly granites and monzonites. Tertiary felsic volcanic rocks consist of the Spears Formation, Hells Mesa Rhyolite, A. L. Peak Formation, and the Potato Canyon Rhyolite; most are latitic and rhyolitic in composition, but local interbedded andesite flows have been included in this category. The Tertiary andesitic rocks include La Jara Peak Andesite, the andesite of South Baldy, the andesite of Landavaso Reservoir, and numerous other andesites. Descriptions of recently named formations of Tertiary age may be found in Deal and Rhodes (in press), Chapin and others (in preparation), and Krewedl (in preparation).

The rock units of the Popotosa Formation can be subdivided into two basic lithofacies, the fanglomerate facies and the playa facies. The relationships of these two facies are shown in Figure 3 where coalescing fanglomerates of the highlands grade down slope into the playas of the basin. The change from fanglomerate facies to playa facies is gradual and occurs where subequal quantities of sandstones and conglomerates are interbedded. The thickness and lateral extent of these facies are dependent upon several factors: rate of subsidence of the basin, rate of uplift of the surrounding mountains, tilt of the basin floor, climate, resistance of rocks in the source areas, and internal deformation of the basin. Consequently, the facies shift back and forth as the basin fills. More than one playa deposit may develop if the internal drainage of the basin is interrupted by large alluvial fans built into the basin or by uplift of intrabasin horsts.

Distinguishing between the different playa facies is extremely difficult, if not impossible, in areas of discontinuous exposures. Playa facies, although similar in lithology and stratigraphic position, may not have developed within the same basin. Playa deposits at different stratigraphic levels in the same basin may be indistinguishable.

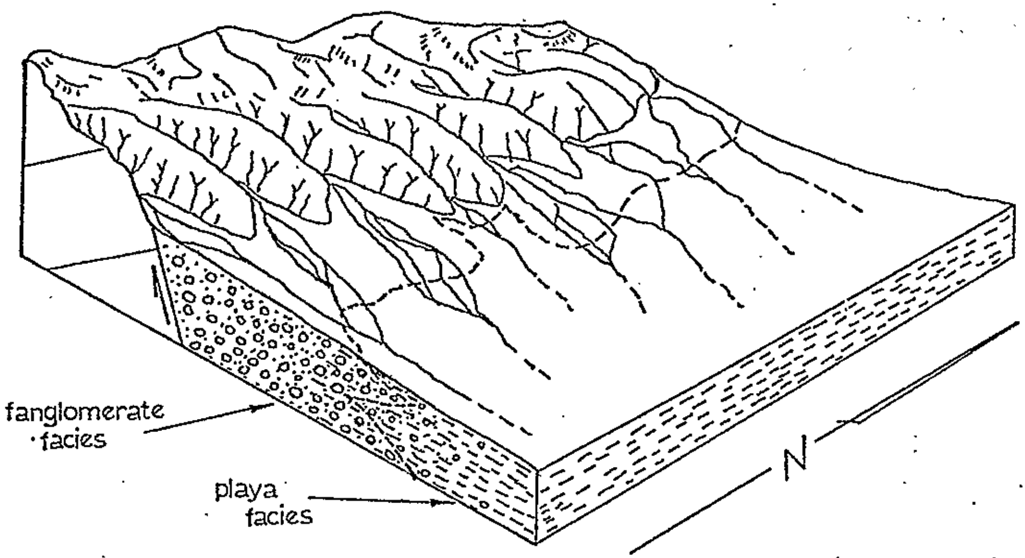


Figure 3. Spacial relationship of the fanglomerate and playa facies of the Popotosa Formation.

Mountains composed of the same rock units give rise to similar fanglomerates which grade into similar playa deposits. Only when the mountains are composed of different rock units can the basin deposits be distinguished on the basis of lithology. In the Popotosa Formation, the different playa facies are considered equivalent only in areas where they are continuously exposed.

Fanglomerate facies also are not necessarily equivalent in source and time of deposition. Most of the fanglomerate facies are similar in that the detritus was derived mainly from felsic and basic volcanic rocks of Tertiary age. Local fanglomerates, identifiable by unique lithologic characteristics, are present along the west side of the Bear Mountains and the south and east sides of the Ladron Mountains. The fanglomerate of Dry Lake Canyon is made up predominantly of andesitic detritus derived from La Jara Peak Andesite which comprised the dip slope of the westward-tilted north end of the Magdalena Mountains. The fanglomerate of Ladron Peak has an unusually large component of Precambrian and late Paleozoic detritus derived from rapid uplift of the Ladron Mountains. The lighter colored clasts give the facies a silver-gray appearance which contrasts with the reddish to buff colors of fanglomerates derived principally from volcanic rocks. The stratigraphic position of these facies with older rocks can be seen in Figures 4a and 4b.

The nomenclature of the rock units overlying the Popotosa has also been simplified. The sediments mapped as the upper Santa Fe

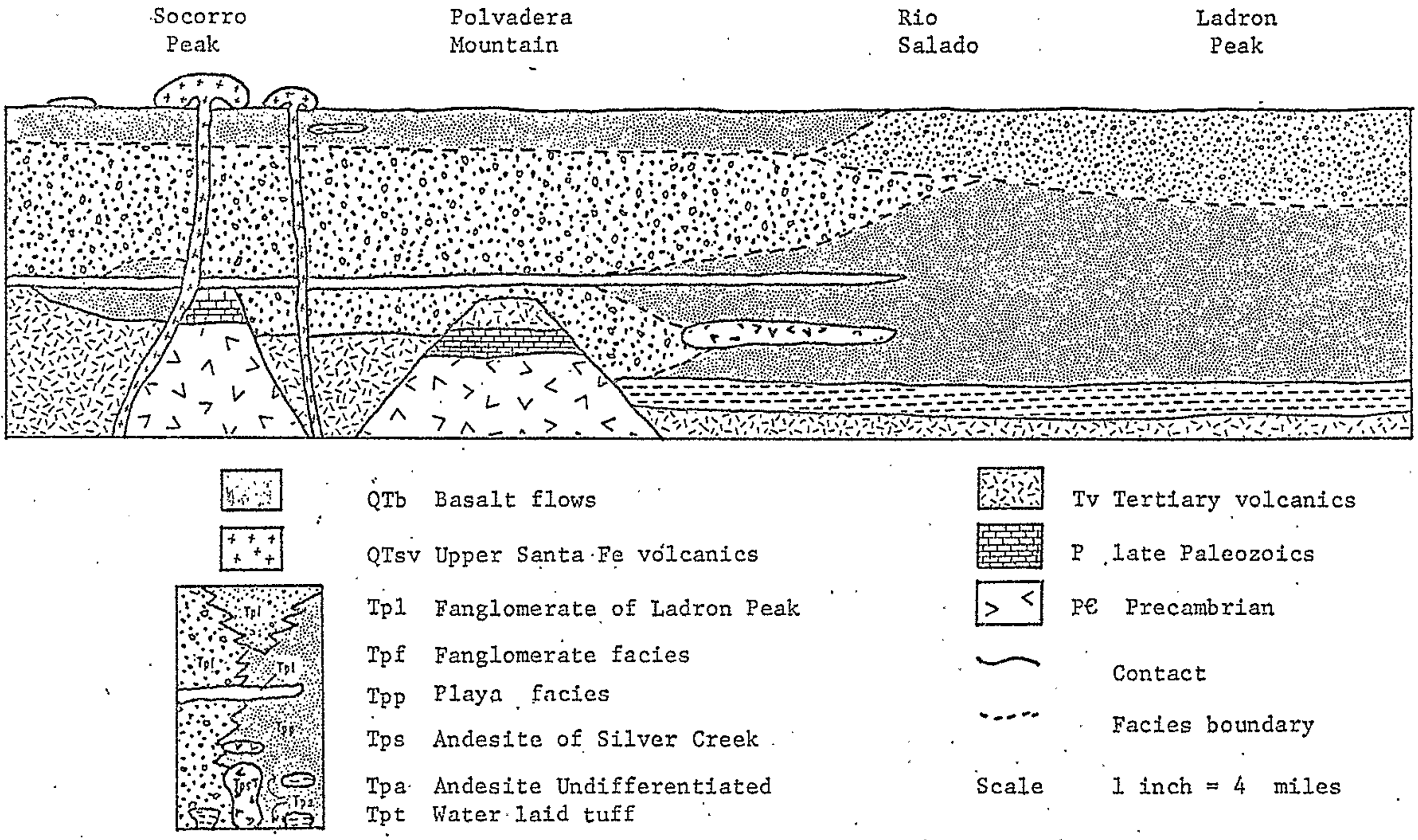


Figure 4a. Stratigraphic relationship of the Popotosa Formation with older rocks in the Socorro-Lemitar Mountains and the type area. The Popotosa is shown prior to extensive deformation and erosion.

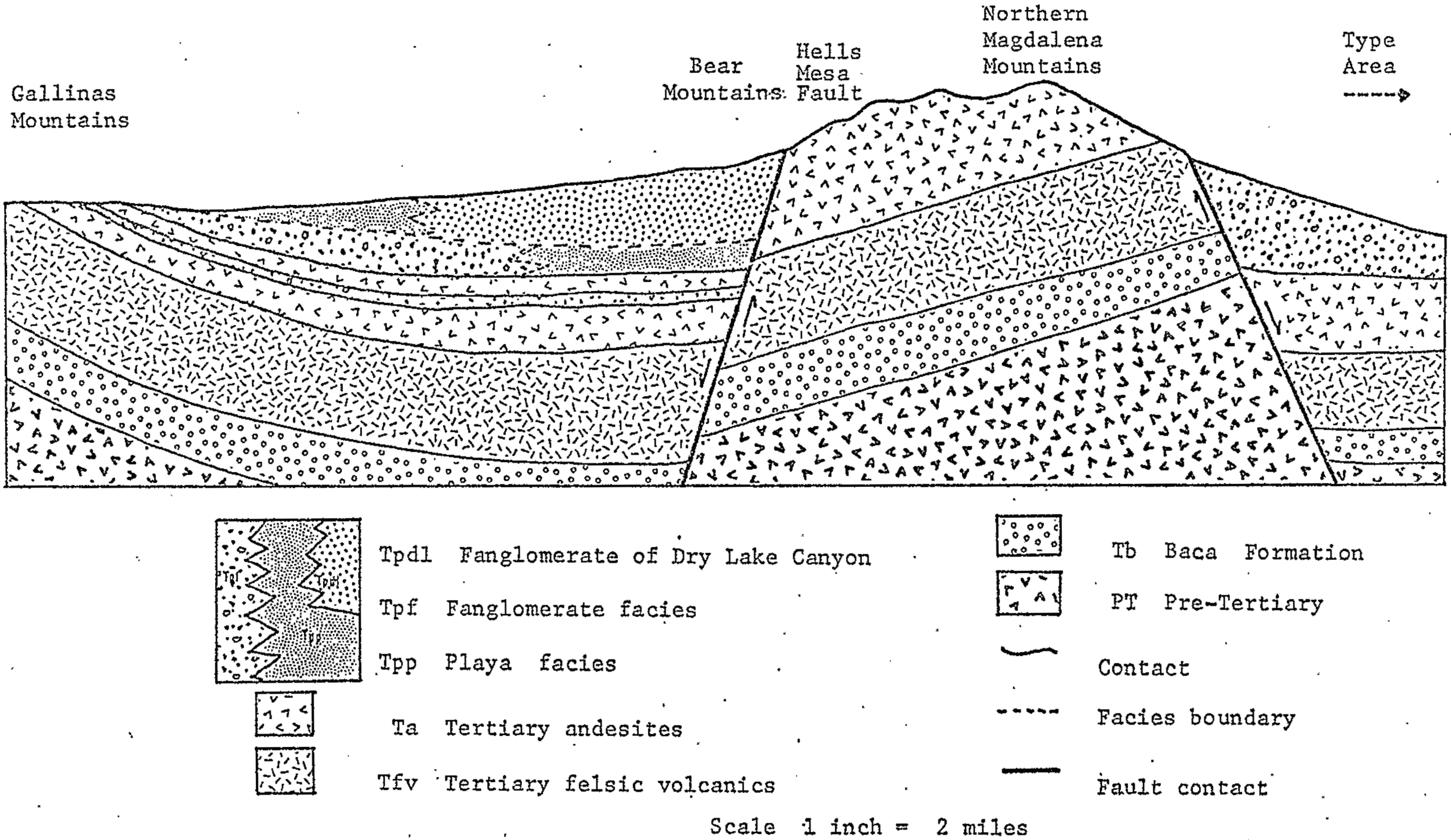


Figure 4b. Stratigraphic relationship of the Popotosa Formation with older rocks in the Bear Mountains. The Popotosa is shown prior to extensive deformation and erosion.

Group include pediment gravels and younger alluvium. The intrusive rocks of the upper Santa Fe Group have been mapped as a separate unit. Talus, Quaternary-Tertiary basalt flows, and stream gravels have been mapped as individual units.

DESCRIPTION OF THE POPOTOSA FORMATION

Type Area

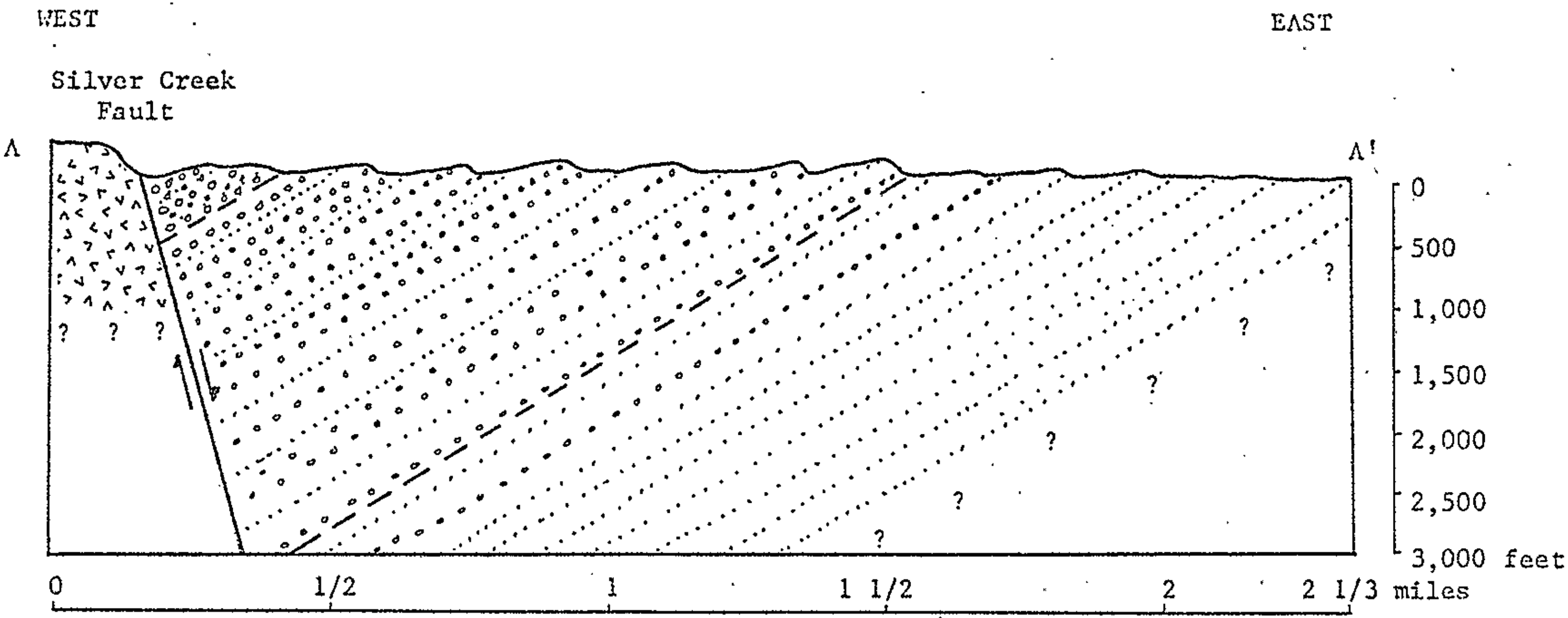
Lithology

The Popotosa Formation was originally described by Denny (1940) in the area between San Lorenzo Arroyo and the Ladron Mountains. This area was designated as the type area and the formation was named for Arroyo Popotosa, a south-draining tributary of the Rio Salado. Denny (1940, p. 77), subdivided the Popotosa Formation in the valley of Silver Creek into two parts. The lower part consists of red tuffaceous sandstones and lenses of gravel containing angular pebbles of volcanic rocks not more than a few inches in diameter. The upper part rests conformably on the lower part and is primarily cross-bedded sandstones and conglomerates. The detritus is predominantly volcanic in origin with angular to subrounded clasts as much as six inches in diameter. The formation rests both conformably and unconformably on the andesite of Silver Creek (15.8 $\pm$ 1.5 m.y.; Weber, 1971, p. 34). Along Popotosa Arroyo, the Popotosa Formation consists of fine-grained sand and red and gray silty clay conformably overlain to the west by coarser gravels. These gravels are composed predominantly of clasts of granite, schist, quartzite, and sandstone.

A type locality for the Popotosa Formation is herein designated along the drainage system of Cañada de la Tortola, T. 1 N., R. 1 W., in the type area. This locality has been chosen because it constitutes the only region where all three facies, the playa facies, the fanglomerate facies, and the fanglomerate of Ladron Peak are well exposed (fig. 5). The areas previously described by Denny, in the valley of Silver Creek and along Popotosa Arroyo, contain only two of these facies.

Stratigraphic studies of the surrounding areas show that the Popotosa is a bolson deposit of laterally gradational facies. In the type area, the playa facies, the fanglomerate facies, and the unique fanglomerate of Ladron Peak are recognized.

The playa facies crops out in the valley of Silver Creek and in the area west of the Loma Pelada fault. The outcrop morphology of this facies varies greatly from one exposure to another. In the valley of Silver Creek, it usually forms greyish-buff, steeply dipping hogbacks with the more indurated sandstones exposed on the dip slope (fig. 6). The more easily eroded siltstones and sandstones are weathered out causing an uneven surface on the front slope. Partial masking of stratification in the playa facies by oozing of mud over more indurated strata occurs on the front slope (fig. 7). Spherical sandstone balls, such as those in Figure 8, are common erosional characteristics of the dip slope. This same hogback topography can be seen to the north in the area west of the Loma Pelada fault. The color varies in this area from reddish brown near the base of the section to greyish brown and buff higher in the section. Locally, the playa facies is poorly-indurated which results in an undulating surface covered with alluvium derived from the sandstones.



Andesite of Silver Creek--a series of aphanitic, gray to black basaltic andesite flows and flow breccias.

Fanglomerate of Ladron Peak--silver gray, pebble and cobble conglomerates, about 500 feet thick.

Fanglomerate facies--reddish-brown to buff, conglomerates and sandstones, about 2,700 feet thick.

Playa facies--reddish-brown, sandstones, siltstones, and mudstones, about 2,300 feet thick.

Figure 5. Type section along drainage of Canada de la Tortola.

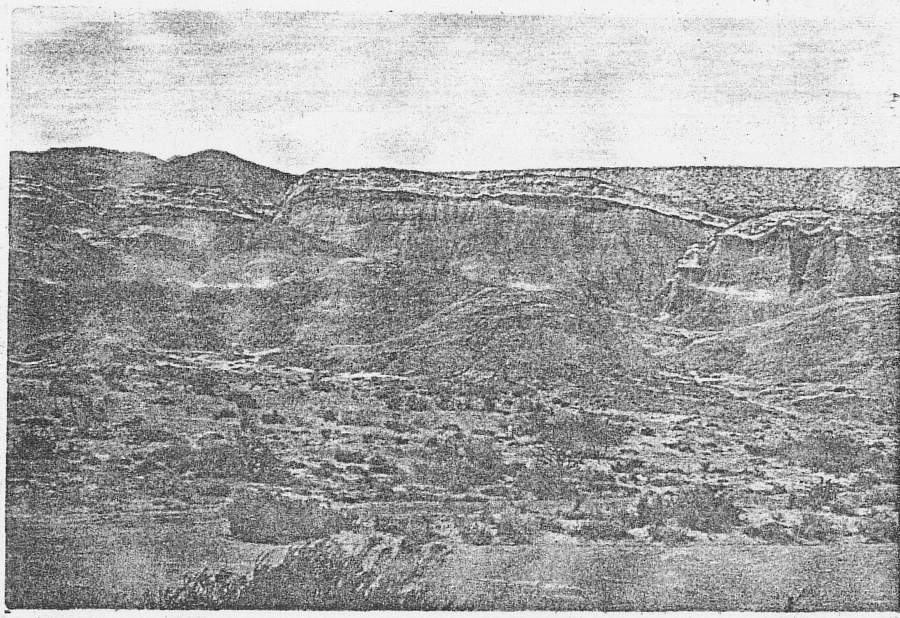


Figure 6. Steeply-dipping, greyish-buff colored hogbacks of the playa facies in the valley of Silver Creek. Whitish water-laid tuffs cap hogback in middle distance; mesa in background is upper Santa Fe capped by caliche.

Figure 7. Partial masking of stratification in playa facies by oozing of mud over more-indurated strata.

Figure 8. Lag gravel of concretion-like sandstone balls formed on dip slope of playa facies by differential erosion.

The playa facies has well-developed bedding which varies in thickness from one-fourth inch in the finer-grained sandstones to as much as four inches in the coarser-grained sandstones. These moderately to well sorted beds have about equal amounts of sandstone and siltstone lenses which are locally cross-bedded. Gravel lenses may comprise as much as ten percent of the playa facies in the valley of Silver Creek. These lenses are usually one to two inches thick, but occasionally they are as much as one foot in thickness. They may be as much as ten feet wide but commonly are only three to six feet wide. Gravel lenses are absent in the area west of the Loma Pelada fault except near the boundary between the playa and the fanglomerate facies.

Massive, three-to-five-foot-thick grayish-white ash-fall and water-laid tuffs, extending from north of the Rio Salado to south of San Lorenzo Arroyo, occur within the playa facies. They contain broken crystals of plagioclase, sanidine, quartz, and some biotite; lithic fragments are abundant. These tuffs occur in other areas of the playa facies but not as extensively. They commonly were altered to montmorillonite. Other montmorillonite deposits apparently not directly associated with the tuffs also occur in the playa facies. One of the deposits located about two and one-fourth miles north of the mouth of Popotosa Arroyo was mined in the 1950's but is now used only by ranchers for lining water tanks. Secondary gypsum in the form of selenite crystals is abundant west of the Loma Pelada fault.

Field evidence suggests that the playa facies is interbedded with a series of aphanitic, gray-to-black, basaltic andesite flows and flow breccias which are known as the andesite of Silver Creek (Weber, 1971). These flows vary from 5 to 15 feet thick with autobrecciated tops and bottoms (fig. 9). Many of the rubble zones contain manganese mineralization. The flows are vesicular, with some of the vesicles filled with calcite. An exhumed volcanic cone containing a thick sequence of lapilli tuffs is present at the northern end of these flows.

The sediments in all Popotosa facies have been named according to the classification of Williams, Turner and Gilbert (1954). Rocks in the playa facies are predominantly volcanic wackes and to a lesser extent volcanic arenites. These sandstones contain between 20 and 30 percent feldspar, which is primarily plagioclase but minor amounts of sanidine are also present. Quartz varies from 10 to 30 percent but seldom is greater than 15 percent. Volcanic lithic fragments are abundant and vary from 15 to 40 percent. Biotite, hornblende, clinopyroxene, chlorite, sphene, and magnetite are the common heavy minerals and usually constitute less than 15 percent of the rock. The sand grains are moderately sorted and average about .2 mm in diameter; the abundance of lithic fragments, about .4 mm in diameter, imparts a poorly sorted appearance to the facies. The cement varies from about 10 to 30 percent; the common cementing agents are calcite or silica and clay. Secondary overgrowths on sand grains are generally lacking but calcite overgrowths on quartz grains are present in one thin section.

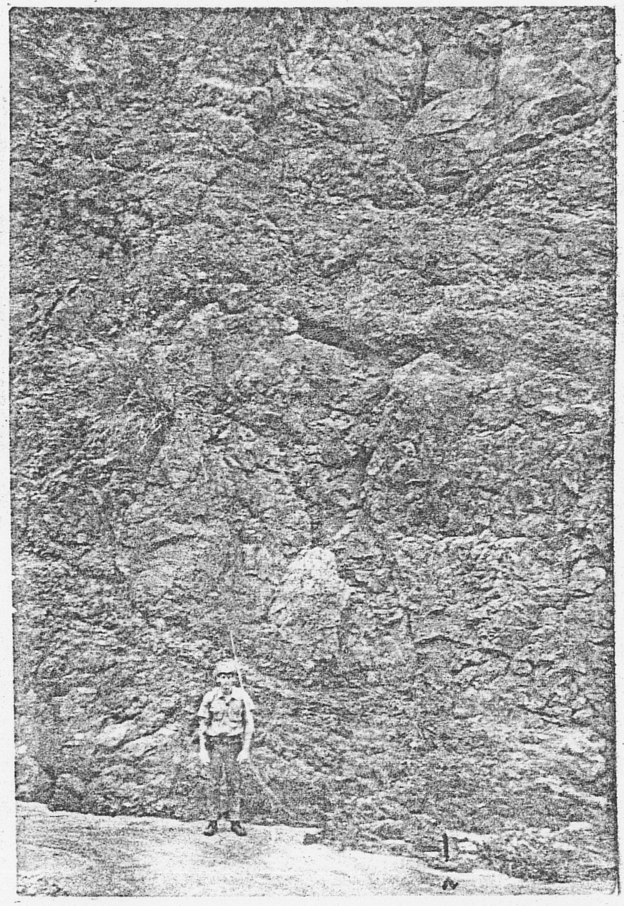


Figure 9. Thin 5 to 15 foot lava flows with auto-brecciated tops and bottoms in the andesite of Silver Creek.

The lithology of the clasts in the type area is given numerically in Tables 1 to 4 and diagrammatically on Plates 2 to 2D. The clasts in the playa facies west of the Silver Creek fault (plate 2B) are made up entirely of igneous rocks of Tertiary age. In the four pebble counts from this area, felsic volcanic fragments show a slight increase to the north at the expense of andesitic clasts. Monzonite clasts from Tertiary plutons also increase in number to the north. In the playa facies east of the Silver Creek fault (plate 2D) the clasts from Tertiary igneous rocks are the major constituent in the south, but become a minor component in the north. Andesitic detritus is not as abundant in this area as it is to the west. A noticeable influx of late Paleozoic clasts starts near Cañada de la Tortola and remains relatively constant to the north. Precambrian granitic clasts were found only north of the Rio Salado; quartzitic material increases slightly to the north. Clasts of felsic volcanic rocks and late Paleozoic rocks increase slightly upward through the section at the expense of andesitic material.

The fanglomerate facies occurs in the valley of Silver Creek and also on a tributary north of the Rio Salado. To the east of the Silver Creek fault, this facies is found only south of the Rio Salado. The steep westward dip and the high degree of induration of the fanglomerate facies results in hogbacks similar to those of the playa facies. These hogbacks are more resistant, have greater relief, and lack the weathered "drip stone" appearance on the front slope. In San Lorenzo Canyon, where the dip is low, differential erosion has sculptured steepsided bluffs of conglomerates and sandstones (fig. 10). This facies is reddish-buff in color except north of the Rio Salado where a large influx of andesitic material gives a purplish cast.

The fanglomerate facies consists of interbedded conglomerate and sandstone lenses. Conglomeratic lenses make up 10 to 20 percent of the unit near the base and increase to as much as 80 percent towards the top of the section. The gravel lenses are only three to five inches thick and 20 to 30 feet wide near the base but increase to as much as 80 percent towards the top of the section. The gravel lenses are only three to five inches thick and 20 to 30 feet wide near the base but in-crease to as much as three feet thick and 200 feet wide near the top. Stratification in the sandstone is well developed and varies from a few inches to a few feet in thickness, but cross-stratification is rare. Poorly sorted subangular to subrounded clasts in the gravel lenses vary in diameter from less than an inch to more than one foot. Boulders greater than a foot in diameter are most abundant near the top of the section. A thin bed of limestone, three to four inches thick, is interbedded with the sandstone in the area west of Silver Creek.

The sandstones within the fanglomerate facies are medium to coarse-grained lithic wackes. Lithic fragments vary from 20 to 65 percent and commonly comprise about 40 percent of the rock. Feldspar varies from 10 to 35 percent and averages about 20 percent; quartz also varies from 10 to 35 percent but is seldom greater than 20 percent. Other minerals present are biotite, hornblende, clinopyroxene, chlorite

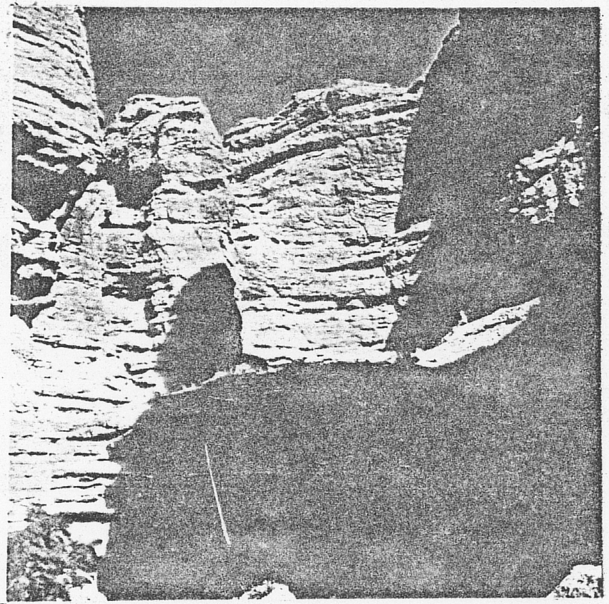


Figure 10. Steepsided sandstone buffs sculptured by differential erosion in San Lorenzo Canyon.

and magnetite; they comprise less than 15 percent of the rock. Poorly sorted angular to subangular grains average .25 mm but range upward to 1.30 mm. Calcite and/or silica and clay are the common cements and generally make up 20 to 30 percent of the rock. Overgrowths of calcite and silica are rare.

Pebble counts reveal several trends in the fanglomerate facies in the area west of the Silver Creek fault (plate 2A). Andesitic material is the major constituent throughout most of this area and comprises more than 90 percent of the clasts where this facies overlies Tertiary andesites. Clasts of felsic volcanic rocks increase higher in the section. In the area of the Rio Salado, an influx of late Paleozoic and Precambrian detritus is present. Monzonitic and quartzitic material are sporadically dispersed or locally concentrated.

Andesitic clasts are not as abundant in the area east of the Silver Creek fault (plate 2C), but Tertiary volcanic rocks still comprise the major portion of detritus in this area. A large influx of late Paleozoic and Precambrian detritus and a smaller amount of quartzitic material occur in the area between the Cañada de la Tortola and the Rio Salado. Clasts from Tertiary plutons are minimal and were noted in only one pebble count.

The fanglomerate of Ladron Peak is exposed only to the east of the Silver Creek fault. A rolling hilly topography is typical of this facies and as a result vegetation is more abundant and good exposures are less common. The fanglomerate of Ladron Peak along the Popotosa Arroyo consists of reddish-buff sandstones and conglomerates which have developed hogback topography. In this area, the facies appears similar to the other fanglomerate facies but the clasts were derived primarily from late Paleozoic and Precambrian rocks.

Silver-gray conglomeratic lenses of subangular to subrounded pebbles, cobbles, and boulders comprise the major portion of the fanglomerate of Ladron Peak. Sandstone lenses are present in the lower part of the section. About 60 percent of the conglomerates are pebble conglomerates in which isolated pebbles "float" in a coarser sand matrix. The cobbles in the cobble-boulder conglomerates are between two and six inches in diameter, some boulders as much as two and one-half feet across. These coarse lenses vary from three inches to two feet in thickness but commonly are only six inches thick. They usually have widths of 20 to 30 feet but some are greater than 100 feet. The unit is poorly to moderately sorted with some local large-scale, 20-foot, cross-bedding.

Pebble counts in the fanglomerate of Ladron Peak (plate 2B) show a sharp decrease in Tertiary igneous detritus and a marked increase of late Paleozoic and/or Precambrian rocks. Tertiary volcanic detritus is most abundant at the northern and southern outcrops. Late Paleozoic clasts increase rapidly in number from the south until the count is diluted by a flood of Precambrian granitic detritus north of the Rio Salado, after which they decrease in abundance northward. Quartzitic material follows the trend of the Precambrian detritus.

Monzonitic material is absent. Both late Paleozoic and Precambrian clasts increase upward through the section at the expense of Tertiary volcanic detritus.

Thickness and Areal Extent

The Popotosa Formation is well exposed in the type area except where it is locally obscured by pediment gravels and alluvium. Stratigraphic studies suggest that the combined facies of the Popotosa Formation have a maximum estimated thickness at the type locality of about 5,500 feet. However, numerous faults make it difficult to determine the true thickness.

The playa facies has an estimated minimum thickness of at least 800 feet and a possible maximum thickness of 3,500 feet. This facies is exposed west of the Silver Creek fault in an area about eight miles north-south by one mile east-west. Dips in this area are 25 to 50 degrees to the west. The playa facies and the andesite of Silver Creek are terminated to the north and to the east by the Silver Creek fault; to the south the playa facies grades into the fanglomerate facies and to the west it is conformably overlain by the fanglomerate facies. East of the Silver Creek fault, the playa facies is more extensive and forms an outcrop belt as much as three miles in width extending from south of San Lorenzo Arroyo to the Ladron Mountains. To the east, the playa facies has been faulted against sediments of the upper Santa Fe Group along the Loma Pelada fault. To the west, and in the area north of the Rio Salado, the playa facies appears to be conformably overlain by the fanglomerate of Ladron Peak.

The fanglomerate facies has an estimated minimum thickness of at least 2,700 feet and a possible maximum thickness of 6,200 feet. West of the Silver Creek fault and south of the Rio Salado, this unit conformably overlies the playa facies and older Tertiary rocks. In this area, the fanglomerate facies is overlain by younger Santa Fe sediments with a slight angular unconformity. North of the Rio Salado, the fanglomerate facies is faulted on the east against the fanglomerate of Ladron Peak along the Silver Creek fault, faulted on the west against pre-Tertiary rocks along the Cerro Colorado fault,and on the north apparently overlies Tertiary andesite. South of the Rio Salado, the fanglomerate facies is exposed on the east side of Silver Creek fault. North of the San Lorenzo fault, this facies conformably overlies the playa facies and is either conformably overlain by the fanglomerate of Ladron Peak or is faulted against the andesite of Silver Creek. South of the San Lorenzo fault, the fanglomerate facies interfingers with the playa facies and apparently overlies older Tertiary and Precambrian rocks.

The fanglomerate of Ladron Peak, exposed only east of the Silver Creek fault, has an estimated minimum thickness of at least 500 feet and a possible maximum thickness of about 3,000 feet. South of the Rio Salado this facies conformably overlies the fanglomerate facies while north of the Rio Salado, it conformably overlies the playa facies.

Age and Stratigraphic Position

The upper and lower contacts of the Popotosa Formation in the type area are for the most part obscured by major faulting. The relationship of the Popotosa Formation and younger sediments can be observed in the valley of Silver Creek where the fanglomerate facies is overlain with slight angular unconformity by younger Santa Fe Group sediments (fig. 11) and along San Lorenzo Arroyo where the playa facies is overlain with sharp angular unconformity by younger Santa Fe Group sediments (fig. 12). No exposures were found of the depositional contact of the fanglomerate of Ladron Peak with younger Santa Fe Group sediments.

Contacts of the Popotosa Formation with older rocks are numerous in the area south of San Lorenzo Canyon where the fanglomerate facies unconformably overlies Tertiary andesites and rhyolitic ash-flow tuffs of Oligocene age. To the east, the fanglomerate facies appears to overlie Precambrian rocks. In the valley of Silver Creek, the playa facies lies conformably on the andesite of Silver Creek dated by Weber (1971, p. 34) at 15.8 m.y. Locally the two appear unconformable where penecontemporaneous slumping of the playa facies has occurred. The andesite interfingers with both the playa and fanglomerate facies of the Popotosa Formation in the valley of Silver Creek and in San Lorenzo Canyon. The andesite of Silver Creek is interbedded with the playa facies both in San Lorenzo Canyon and in the drainage system of Cañada de la Tortola suggesting that deposition of the Popotosa Formation in

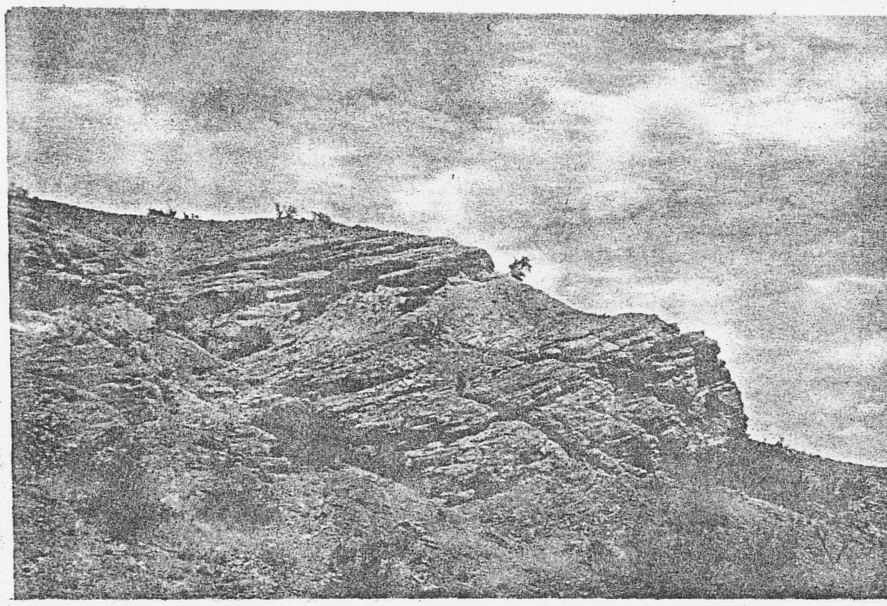


Figure 11. Slight angular unconformity west of Silver Creek between the fanglomerate facies of the Popotosa Formation and less-indurated, lighter-colored gravels of the upper Santa Fe Group

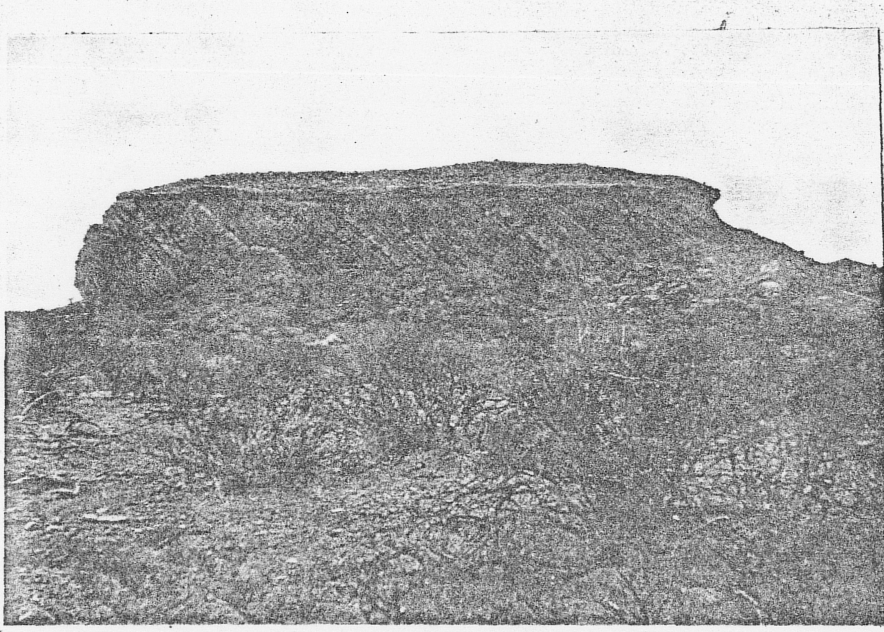


Figure 12. Sharp angular unconformity between the playa facies of the Popotosa Formation and the light-colored gravels of the upper Santa Fe Group along San Lorenzo Arroyo.

the type area began at least as early as 15.8 m.y. B.P. and may have begun earlier since the lower contacts of the Silver Creek andesite are not exposed. The upper limit of Popotosa deposition is indeterminate in this area.

Relationship to Major Structures

Structures within the type area consist of three major north-trending faults and numerous other faults with apparent small displacements. According to Denny (1940, p. 102), the Cerro Colorado normal fault (plates 1 and 2) probably has a throw of several thousand feet along which the Ladron uplift took place. This fault zone can be traced north of the Rio Salado for about 8 miles until it is lost beneath upper Santa Fe Group sediments. The fault zone is a series of subparallel normal faults which have locally downfaulted small slivers of late Paleozoic and Mesozoic sedimentary rocks. A fault-line scarp is visible locally where pre-Tertiary rocks abut against the younger Popotosa Formation

The Silver Creek fault, a normal fault with about 6,000 feet of displacement, is similarly related to the Ladron uplift (Denny, 1940). This fault can be traced from San Lorenzo Arroyo north to the Rio Salado, a distance of eight miles. At San Lorenzo Arroyo, the Silver Creek fault is offset about one mile to the west by a major northeast-trending fault zone. The Silver Creek fault can be traced three miles farther south; then it apparently bends toward the west. At the Rio

Salado, the Silver Creek fault is offset to the west about one mile by a northwest-trending fault which may be an extension of the Ladron fault. The Silver Creek fault can be traced northward, locally covered by pediment gravels, until at the Cosby ranch it disappears under younger Santa Fe Group sediments.

The Popotosa Formation is terminated to the east by the Loma Pelada fault zone. Denny (1940, p. 103) has estimated a possible throw of 5,000 feet for this early Quaternary fault and Evans (1963, p. 212) has estimated a possible displacement of at least 1,000 feet. Along the steeply dipping fault zone, the Loma Blanca facies of the upper Santa Fe Group is downdropped against the playa facies of the Popotosa for about 13 miles from Canada Vivoroso north to Canada Colorada. To the east of Arroyo Rendija, the Loma Pelada fault has downfaulted a sliver of the fanglomerate of Ladron Peak. Another fault sliver occurs in the Sierra Ladrones where the upper portion of the playa facies has been uplifted between the Popotosa Arroyo and the upper drainage system of the Arroyo Tio Lino.

Within the type area a horst of andesitic rocks is exposed in the area between Canada Vivorosa and Arroyo Rendija. This horst is bounded by a series of north-trending faults. In the area of pebble count 29 (plates 1 and 2D), the transitional phase between the playa facies and the fanglomerate facies, has been uplifted with the horst. This uplift has also caused anticlinal warping within the surrounding playa facies.

Sedimentary Structures

Within the type area several types of sedimentary structures were observed throughout the Popotosa Formation. Trough-shaped discordant contacts of cross-bedding formed by the scour-and-fill action of strong currents occur in all three facies. Small-scale cross-bedding is present in the fanglomerate facies. Cross-bedding is not abundant, as most of the scour-and-fill action produced laterally-extensive shallow channels of gravel without much cross-bedding. Axes of these channels, and of deeper channels, generally trend east-west. Pebble imbrication is prominent in both deep and shallow channels. Parting lineation (fig. 13), although not common was also used in determining flow direction, primarily within the playa facies where gravel lenses are absent. Both clay balls and clay clasts have been observed in the playa facies but are not common. Graded bedding occurs locally within the playa facies. Most of the siltstones and mud-stones in the playa facies have planar bedding (fig. 14). Clastic dikes filling fractures in the andesite are relatively common in areas where the Popotosa has been deposited on the andesite of Silver Creek.

Socorro-Lemitar Mountains

Lithology

The type area of the Popotosa Formation is bordered on the south by the Socorro-Lemitar Mountains. Denny (1940) described the

Figure 13. Parting lineation in the light-brown siltstone of the playa facies.

Figure 14. Planar bedding in siltstones and mudstones of the playa facies east of Popotosa Arroyo. Note gypsum seams parallel to strata and also along fault planes.

Popotosa only within the type area and did not follow the formation farther south. South of San Lorenzo Arroyo, the Popotosa Formation consists of the fanglomerate facies and the playa facies; the fanglomerate of Ladron Peak, composed largely of pre-Tertiary detritus, is absent in this area.

The fanglomerate facies represents basal Popotosa in most of the area south of San Lorenzo Arroyo and overlies the Precambrian and Tertiary rocks of the Socorro-Lemitar uplift. Outcrops of the fanglomerate facies are exposed discontinuously southward through these mountains; large, moderately dipping (35 to 40 degrees) hogbacks are especially conspicuous as Red Mountain and the hogback west of Strawberry Peak. In the valley west of Polvadera Mountain, the fanglomerate facies forms inconspicuous outcrops along the arroyos. Farther south, within the Socorro Mountains, this facies crops out both on ridges and in the arroyos. Andesite flows are interbedded with the facies on the east flank of Socorro Peak (Smith, 1963; Burton, 1971).

In the area of the Socorro-Lemitar uplift, the fanglomerate facies varies from an extremely well-indurated conglomerate with a deep, reddish-brown color to a less well-indurated conglomerate with a reddish-buff to buff color. Most of the conglomerate in the uplifted area is the well-indurated, reddish-brown conglomerate. However, in the areas northwest of Red Mountain and northeast of Polvadera Mountain, the well-indurated, reddish-brown conglomerates grade into the less-indurated, reddish-buff to buff conglomerate, which is characteristic of the type area.

The fanglomerate facies in the Socorro-Lemitar Mountains consists of fluvial conglomerates and sandstones in which the conglomerates comprise 50 to 100 percent of the unit. Conglomeratic mudflows are most prevalent near the base of the Popotosa and become increasingly coarser to the south. These mudflows locally comprise as much as 70 percent of the conglomerates present. Sandstone lenses may comprise as much as 50 percent of the fanglomerate facies in areas where it grades into the playa facies. Sandstone beds as much as 60 feet thick are interbedded with conglomerates in the Arroyo del Puertecito.

The sandstones lenses are mostly four to ten inches thick and 10 to 20 feet wide; lenses two to three feet thick are rare. The fanglomerate facies is conspicuously stratified but sorting within individual conglomerate units is crude; the poorly-sorted clasts of pebble to boulder size usually are "floating" in a fine-grained matrix. The clasts vary from less than an inch to three and one half feet in diameter, but average three to six inches. In addition to the wide range in size, the clasts vary greatly in degree of rounding; they are commonly subangular to subrounded but range from angular to well-rounded. Sedimentary structures, such as cross-bedding and pebble imbrication, are not abundant in this facies except where it grades into the playa facies. The grayish-white ash-fall and water-laid tuff which is prevalent within the playa facies in the valley of Silver Creek, and elsewhere in the type area, also occurs in the fanglomerate facies in the valley west of Polvadera Peak.

The major portion of the fanglomerate facies is composed of volcanic conglomerates in which the volcanic clasts vary from 60 to 80 percent and are embedded in a well-indurated, reddish-brown matrix. The matrix is composed of small lithic fragments (40 to 70 percent), crystal fragments (15 to 25 percent), and red well-indurated clay. Sanidine and quartz are the most abundant crystal fragments; biotite, hornblende, clinopyroxene, chlorite, and magnetite make up the rest of the detrital minerals and total less than five percent of the rock. The detrital mineral grains are generally 0.4 mm to as much as 1.8 mm in length. The common cements of the matrix are hematite and silica with smaller amounts of calcite; about 15 to 30 percent of the matrix is cement. Trace amounts of zeolites are also present. Hematite ordinarily rims both the lithic fragments and the mineral grains.

The interbedded sandstones are petrographically similar to those of the type area. They are volcanic wackes and contain about 35 percent feldspar, 15 to 20 percent quartz and about 35 to 45 percent volcanic lithic fragments. Biotite, hornblende, clinopyroxene, chlorite, epidote, and magnetite comprise about 10 to 15 percent. The sandstones are poorly sorted with angular to subangular grains averaging .2 mm in length. The grains are cemented by calcite and silica; the amount of cement varies from 15 to 30 percent of the rock.

The lithology of the clasts in the Socorro-Lemitar Mountains is given numerically in Tables 3 and 4 and shown diagrammatically on Plates 2C and 2D. The lithic fragments found in this area have been derived from Tertiary volcanic rocks; they range from pink, gray, and white crystal-poor to crystal-rich tuffs and flow-banded rhyolites to red or bluish-black andesites and basalts. Felsic volcanic clasts are more abundant than andesitic clasts except in exposures near U. S. Highway 60 and in the valley west of Polvadera Mountain. Andesitic material is the primary constituent in areas where the fanglomerate facies overlies Tertiary andesites. Clasts from Tertiary plutons or from late Paleozoic and Precambrian rocks have not been noted in this area by the writer; however, Lowell (1967) observed clasts of Precambrian granite sparsely dispersed in this facies in the southern part of Socorro Mountain.

The playa facies is not as well exposed as the fanglomerate facies. It can be traced south from the type area to where it grades into the fanglomerate facies west of the Silver Creek fault and to where it conformably overlies the fanglomerate facies east of the fault. Farther south the playa facies is found in two outcrop areas, one to the east of Strawberry Peak and the other immediately north of U. S. Highway 60. Still smaller exposures occur on Socorro Peak. Hogbacks, similar to those of this facies in the type area, appear to the east of Strawberry Peak and farther south. North of U. S. Highway 60, the playa facies is covered in part by younger basalt flows, talus and alluvium.

The playa facies is not as well indurated as the fanglomerate facies. The color varies from brown and reddish-brown to buff and, locally, to shades of bluish-green, green or yellow (fig. 15). Bedding within the playa facies is well developed and varies from less than an inch to as much as one foot in thickness. Much of the bedding in outcrops of the playa facies has been destroyed by weathering which has formed a crumbly "cauliflower"-like surface. Cross-bedding is abundant locally. Generally the sandstones and siltstones are present in about equal amounts, but locally one or the other may be as much as 90 percent. Gravel lenses are lacking in the playa facies except in areas where it grades into the fanglomerate facies. In these areas, reddish-buff to buff conglomeratic lenses comprise as much as 50 percent of the outcrop.

Gravel lenses are usually three to six inches thick and six to ten feet wide, but some are as much as one foot thick and 40 feet wide. The subrounded clasts are two to three inches in diameter with a few as great as ten inches. A basalt flow, 25 to 30 feet thick, is interbedded in the playa facies east of Strawberry Peak. Gypsum, in the form of selenite crystals is locally abundant; some gypsum veins are as much as two inches thick.

Thickness and Areal Extent

The upper and lower contacts of the Popotosa Formation are not exposed in the Socorro-Lemitar Mountains. Most of the exposures in

Figure 15. Light-green mudstones and siltstones interbedded with typical reddish-brown strata in the playa facies east of Strawberry Peak. Note white veins and lenses of selenite.

this area are either of the fanglomerate facies or of the playa facies. Exposures of the two facies in contact occur in the Socorro Mountain region where a total thickness of 1,000 feet has been estimated for the Popotosa Formation. The thickness is difficult to estimate because of faulting.

The fanglomerate facies extends south from the type area until truncated by the Socorro-Lemitar uplift. It crops out discontinuously in the area west of Polvadera Mountain and south to Strawberry Peak. In this area, the thickness varies from 20 to 30 feet to as much as 1,200 feet. Smaller exposures occur farther south in the areas of Socorro Peak, Blue Canyon, Socorro Spring, Sedillo Spring and U. S. Highway 60. Thickness at these exposures varies from 30 feet to 250 feet and possibly to 500 feet.

The playa facies, located in a two by three mile area east of Strawberry Peak, may be as much as 1,000 to 1,500 feet thick. Farther south, in the Socorro Mountains, exposures vary in thickness from 30 to 350 feet and possibly to 500 feet. North of U. S. Highway 60, this facies is obscured by younger basalt flows and talus but may be at least 300 feet thick where it makes up the slopes of Black Mesa.

Age and Stratigraphic Position

Throughout the Socorro-Lemitar Mountains the Popotosa Formation is faulted against younger and older rock units. In the areas north and west of Polvadera Mountain, the fanglomerate facies overlies a basaltic andesite which is very similar in appearance to both La Jara Peak Andesite and the andesite of Silver Creek. A short distance to the north, in San Lorenzo Arroyo, the Popotosa Formation is interbedded with the andesite of Silver Creek. Whether the andesite beneath the Popotosa Formation in the north and west flanks of Polvadera Mountain is the andesite of Silver Creek or La Jara Peak Andesite is uncertain. This andesite rests directly on ash-flow tuffs of the Potato Canyon Rhyolite and the A. L. Peak Formation, suggesting that it may be La Jara Peak Andesite. Farther south this andesite is missing and the fanglomerate facies lies depositionally on crystal-rich to crystal-poor rhyolitic tuffs of the Potato Canyon Rhyolite dated at 30 m.y. by Deal and Rhodes (in press). Clastic dikes composed of the finer grained matrix of the fanglomerate facies are abundant wherever the facies overlies the Potato Canyon Rhyolite (fig. 16). To the east of Strawberry Peak where the section is faulted against pre-Popotosa rocks, the fanglomerate facies is conformably overlain by the playa facies.

Socorro Mountain is a volcanic center which was active during late Tertiary time. In this area the Popotosa Formation has been intruded by, and interbedded with, volcanic domes and flows of andesitic to rhyolitic composition. A grayish-white air-fall and water-laid tuff, similar in appearance to the one interbedded with the Popotosa farther north, but considerably thicker, is interbedded with and overlies the playa facies and locally appears to underlie the

Figure 16. Contact of the Popotosa Formation with the underlying Potato Canyon Rhyolite. Note small clastic dikes and typical reddish-brown, well-indurated fanglomerates of the Popotosa.

fanglomerate facies. It also unconformably overlies late Paleozoic sediments. This tuff is well exposed near Socorro Spring and crops out discontinuously northward along the east face of the mountain block. Elsewhere, the fanglomerate facies overlies rhyolite flows. East of the Socorro Peak, Smith (1963) and Burton (1971) reported that the Popotosa Formation is interbedded with a series of porphyritic andesite flows as much as 125 feet thick.

The fanglomerate facies is usually exposed as ridges where the overlying playa facies is absent. However, the playa facies does conformably overlie the fanglomerate facies in some localities. The playa facies crops out extensively south of Blue Canyon but is exposed only locally on Socorro Mountain; it is overlain by either the Tertiary-Quaternary basalts of Black Mountain or by the trachyandesite flows and associated tuffs of Socorro Peak. The trachyandesites have been dated by the K/Ar method at 11.5 million years (C. T. Smith, oral communication, 1971) and 10.7 million years (Burke and others, 1963). Deposition of the Popotosa Formation in the Socorro-Lemitar Mountains probably began concurrently with deposition in the type area which was at least 16 m.y. B.P. as dated by the andesite of Silver Creek. Deposition may have been initiated considerably earlier since the Popotosa is interbedded with La Jara Peak Andesite (24 m.y., Chapin, 1971b) in the northern Bear Mountains west of the Socorro-Lemitar Mountains.

Relationship to Major Structures

North-trending faults of major discplacement which uplifted the Socorro-Lemitar Mountains probably exist both to the east and to the west of the mountains but are buried beneath younger Santa Fe sediments. However, faulting of lesser magnitude is abundant throughout the uplift. Numerous north-trending longitudinal faults and east-trending transverse faults have abutted Precambrian and late Paleozoic rocks against younger Tertiary rocks. A series of east-northeast-trending transverse faults are present in the area of Polvadera Mountain (T. M. Woodward, oral communication, 1972) where the northeast-trending San Augustin lineament of the Rio Grande rift has truncated the uplift (Chapin, 1971a). These faults have dropped the fanglomerate facies against Precambrian rocks northeast of Polvadera Mountain and against late Paleozoic strata northwest of Polvadera Mountain. East of Strawberry Peak, both the playa and fanglomerate facies have been faulted against Tertiary volcanic rocks and late Paleozoic and Precambrian rocks by longitudinal faults bounding the east side of the uplift. To the south, in Socorro Mountain, the playa facies is locally faulted against the younger trachyandesite.

Faulting within the Popotosa is common in the northern portion of the uplift in which the displacement appears to be small except for the southern extension of the Silver Creek fault. Near San Lorenzo Canyon, the Silver Creek fault has exposed the contact between the fanglomerate facies and the andesite of Silver Creek along the western margin of the fault and the contact between the fanglomerate and playa facies along the eastern margin of the fault. Faulting has taken place within the Popotosa Formation to the east of Strawberry Peak. However, most of the faults appear to have little displacement except for the north-trending fault along the western portion of this area which has uplifted the fanglomerate facies against the playa facies to the east.

Sedimentary Structures

The fanglomerate facies in the Socorro-Lemitar Mountains is moderately well stratified but individual conglomerate beds are relatively structureless. Conglomeratic mud flows have random fabrics and even the fluvial conglomerates are poorly sorted. Pebble imbrications (fig. 17) are present in the better sorted units; channeling and cross-bedding occur locally in areas where fluvial conglomerates are predominant. Laterally extensive, shallow channels of gravel are abundant in the northern portion of the uplift and are similar to those in the type area. Clastic dikes penetrate the underlying volcanic units.

The playa facies contains sedimentary structures which are similar to those found in the type area. Trough-shaped discordant contacts of cross-bedding are abundant locally (fig. 18); but most of the bedding in this facies consists of parallel laminae.

Figure 17. Pebble and cobble imbrication in the fanglomerate facies of the Popotosa Formation near Strawberry Peak.

Mud clasts such as those in Figure 18 are seldom observed and parting lineation is uncommon.

Bear Mountain - Mulligan Gulch Graben

Lithology

The Popotosa Formation in the Bear Mountain-Mulligan Gulch graben region crops out extensively in two areas. One area is to the west of the Bear Mountains in T. 2 S., R. 5 W. and was mapped by Tonking (1957). He described the sedimentary strata as a fanglomerate deposited during Santa Fe time. The Popotosa Formation in this area is a bedded sequence of conglomerates, sandstones, siltstones, and mudstones. The sandstones, siltstones, and mudstones comprise the playa facies which is located in the southeast portion of the area. This facies is well exposed in sec. 23, T. 1 N., R. 5 W., where a landslide has exposed about 300 feet of section (fig. 19). The remaining portion of this area consists of the fanglomerate facies which is a sequence of interbedded conglomerates and sandstones with abundant clasts of felsic volcanic rocks.

The second area in which the Popotosa forms extensive outcrops is located directly to the south in Dry Lake Canyon. The Popotosa Formation in this area has been mapped by Brown (1972) and D. B. Simmons (oral communication, 1973). Brown named this facies of conglomerates, mudflow-deposits, and sandstones of domi-

Figure 18. Cross-bedding in fine sandstones and mudstones of the playa facies east of Strawberry Peak. Note mud clast to left of pencil.

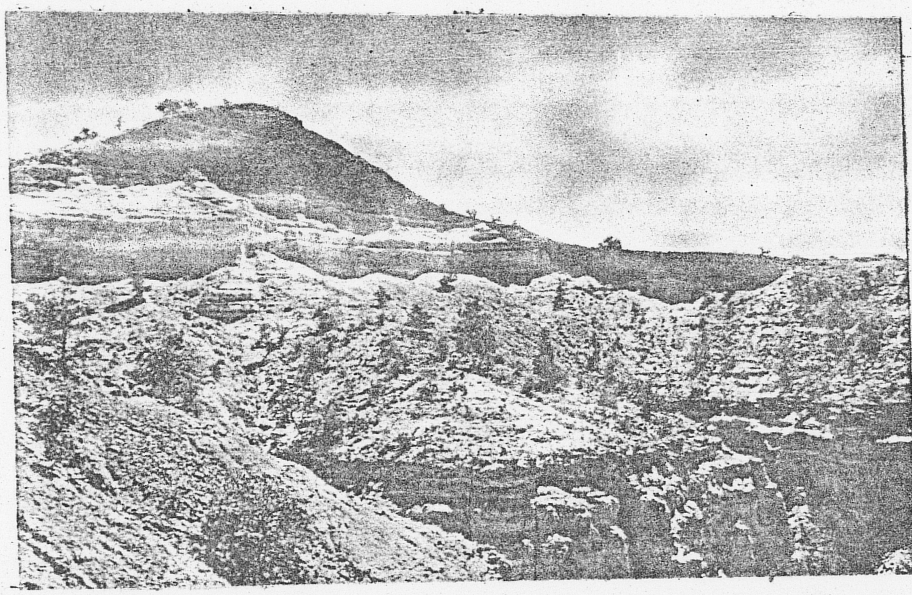


Figure 19. About 300 feet of the playa facies exposed in a landslide scar west of the Bear Mountains. Note interbedding of thin andesitic gravel lenses of the fanglomerate of Dry Lake Canyon at lower right; the fanglomerate of Dry Lake Canyon also caps the hill.

nantly andesitic detritus the fanglomerate of Dry Lake Canyon. Still farther south, along U. S. Highway 60, additional exposures of the fanglomerate of Dry Lake Canyon occur.

The playa facies in the Bear Mountain-Mulligan Gulch graben area consists of pinkish-buff interbedded sandstones, siltstones, and mudstones with minor gravel lenses. The gravels increase rapidly in number and thickness at the transition to the fanglomerate facies. The sediments of the playa facies are well stratified with bedding varying from less than an inch to as much as 18 inches thick. The gravel lenses are usually only a few inches thick and about ten feet wide. Pebbles are subrounded to rounded and vary from one inch in diameter to as much as five or six inches in diameter, with the smaller sizes predominating. Cross-bedding is locally abundant.

The sandstones in this area are arkosic wackes in which feldspar is about 40 percent, quartz about 30 percent and lithic fragments about 20 percent. Biotite, hornblende, chlorite, sphene, and magnetite are the common heavy minerals and usually constitute between 10 to 15 percent. The sand grains are poorly to moderately sorted and average about 0.3 mm in diameter with some grains as large as 0.8 mm. The cementing agents are principally silica, clay, and calcite in quantities from 10 to 15 percent of the rock. Secondary overgrowths have not been observed.

The lithology of the clasts for this area is given numerically in Table 5 and diagrammatically on Plate 3. Four pebble counts were taken in the playa facies and all but one are similar. Three pebble counts consist of about 60 to 70 percent felsic volcanic clasts and about 30 to 40 percent andesitic clasts but pebble count 58, located in the landslide scar, consists entirely of andesite and appears to be an interbedded gravel lens from the fanglomerate of Dry Lake Canyon. Clasts derived from late Paleozoic strata occur only in pebble count 60; clasts from Tertiary plutons only in pebble count 50. Andesitic fragments tend to increase in abundance to the north and east where La Jara Peak Andesite is extensively exposed.

The fanglomerate facies consist of poorly sorted gravels and sandstones with the sandstone content decreasing to the west. The unit is usually light-buff in color but where the detritus is composed largely of andesite, a purplish cast develops. The sandstone beds are moderately to well stratified and the bedding varies from 3 to 24 inches in thickness. Large-scale cross-bedding is moderately abundant. Gravel lenses interbedded with the sandstones vary from three to four inches to as much as 18 inches thick and are 5 to 20 feet wide. Pebbles are generally subrounded but angular to well-rounded clasts are present; most of the clasts are three to six inches in diameter with some as much as two feet in diameter. In areas where this facies is entirely conglomeratic, coarser conglomeratic lenses similar to those described above are interbedded with poorly sorted pebble conglomerates in which the pebbles are less than an inch in diameter. Cross-bedding is present throughout most of this facies. In Carrizozo Canyon and near Cedar Spring the facies is interbedded with La Jara Peak Andesite.

The sandstones within the fanglomerate facies are medium- to coarse-grained volcanic wackes. Feldspar and quartz vary between 15 and 30 percent with feldspar commonly about 25 percent and quartz about 20 percent. Lithic fragments usually comprise 45 percent but may be as great as 70 percent. Heavy minerals are biotite, hornblende, clinopyroxene, chlorite, and magnetite; they comprise about 10 percent of the rock. The strata are poorly sorted with subangular to subrounded grains averaging 0.3 mm in diameter, but occasionally reaching 1.8 mm in size. Silica, clay, and calcite are the common cements and make up between 10 and 30 percent of the rock.

The detritus in the fanglomerate facies is derived principally from Tertiary volcanic rocks. Clasts of crystal-rich and crystal-poor welded tuffs and andesitic lava flows dominate. Felsic volcanic fragments are most abundant in the southwestern portion of the area; the number of andesitic fragments increases slightly to the east and greatly to the north. Lithic fragments from Tertiary plutons have been observed locally; fragments of late Paleozoic and Precambrian rocks were not noted in this facies and quartzitic material was observed in only one pebble count.

The fanglomerate of Dry Lake Canyon facies of the Popotosa Formation forms a prominent dip slope along the west side of the Bear

Mountains and is well exposed along Dry Lake Canyon and in road cuts along U. S. Highway 60, 4.5 miles west of Magdalena, sec. 35, T. 2 S., R. 5W. This facies consists predominantly of light-brown to buff, poorly sorted conglomerates, and mudflow deposits with thin interbedded sandstones. The conglomeratic beds are crudely stratified and vary in thickness from one inch to three feet. The pebbles are mostly subangular and subrounded but angular and rounded clasts are present; the clasts are commonly five to six inches in diameter with some as great as 15 inches. Moderately stratified sandstone beds, varying from one to three inches to as much as three feet thick, locally may comprise as much as 10 to 30 percent of this facies. The fanglomerate of Dry Lake Canyon appears to be interbedded with a basalt flow and a white tuff in Council Rock Arroyo; however, these volcanic rocks may have been faulted into this position since the contacts with the fanglomerate of Dry Lake Canyon are obscured by younger sediments.

Pebble counts in the Dry Lake Canyon facies are consistent as shown numerically in Table 6 and diagrammatically on Plate 4. The detritus was derived almost entirely from La Jara Peak Andesite; andesitic clasts constitute over 90 percent of the lithic fragments present. Detritus from the A. L. Peak Formation and the Hells Mesa and the Potato Canyon Rhyolites comprise the remaining 0 to 10 percent of lithic fragments. The larger lithic fragments are embedded in a finer grained matrix of feldspar, quartz, and smaller lithic fragments. Heavy mineral grains of biotite, hornblende, clinopyroxene, and magnetite make up about five to ten percent of the matrix. Silica, clay, and calcite are the major cementing agents.

Thickness and Areal Extent

The Popotosa Formation in the Bear Mountain-Mulligan Gulch graben area is generally obscured by pediment gravel and alluvium and only locally is it well exposed. The attitude of the Popotosa in this area is quite variable which, along with poor exposures, makes thickness estimation difficult. The total estimated thickness of the three facies is a minimum of 1,000 feet and a maximum of 2,000 feet.

The playa facies has an estimated thickness of about 400 feet. This facies crops out in a seven-square-mile area to the southeast of Abbe Spring. The most extensive exposure is the landslide scar on the mesa east of Mesa Cencerro at the location of pebble counts 58 and 59. The fanglomerate facies has an estimated thickness of 700 feet. Discontinuous outcrops of this facies occur to the north and west of the playa facies in about a 14-square-mile area. An accurate thickness estimation for the fanglomerate of Dry Lake Canyon could not be obtained because of faulting and extensive pediment cover. Brown (1972) estimated a thickness of 500 feet for this fanglomerate which seems to be a reasonable value.

Age and Stratigraphic Position

Stratigraphic contacts between the three facies of the Popotosa Formation in the Bear Mountain-Mulligan Gulch graben area are rarely exposed. The playa facies is interbedded with the fanglomerate facies near the base of the formation at the north end of the Bear Mountains; the Dry Lake Canyon facies overlies these two facies in this area and farther to the south. The playa facies exposed in a landslide scar east of Mesa Cencerro contains interbeds of thin andesitic gravel lenses and is capped by andesitic gravels of the fanglomerate of Dry Lake Canyon (fig. 19).

The Popotosa Formation at the north end of the Bear Mountains is in both depositional and fault contact with older Tertiary and Mesozoic rocks. Most of the contacts between the Popotosa and older rocks are obscured by a thin veneer of alluvium. Field evidence suggests that faulting has taken place between the Popotosa Formation and La Jara Peak Andesite on an east teibutary of Carrizozo Canyon. In Carrizozo Canyon and also near Cedar Spring on the east side of the range the basal portion of the Popotosa Formation is interbedded with the uppermost part of La Jara Peak Andesite (fig. 20). In Carrizozo Canyon as much as 150 feet of the fanglomerate facies is interbedded with La Jara Peak Andesite. The fanglomerate facies lies depositionally on a 60-foot-thick flow of La Jara Peak Andesite (figs. 21 and 22) which overlies about 40 feet of interbedded fanglomerate. The underlying andesite flow is about 100 to 150 feet thick and overlies another

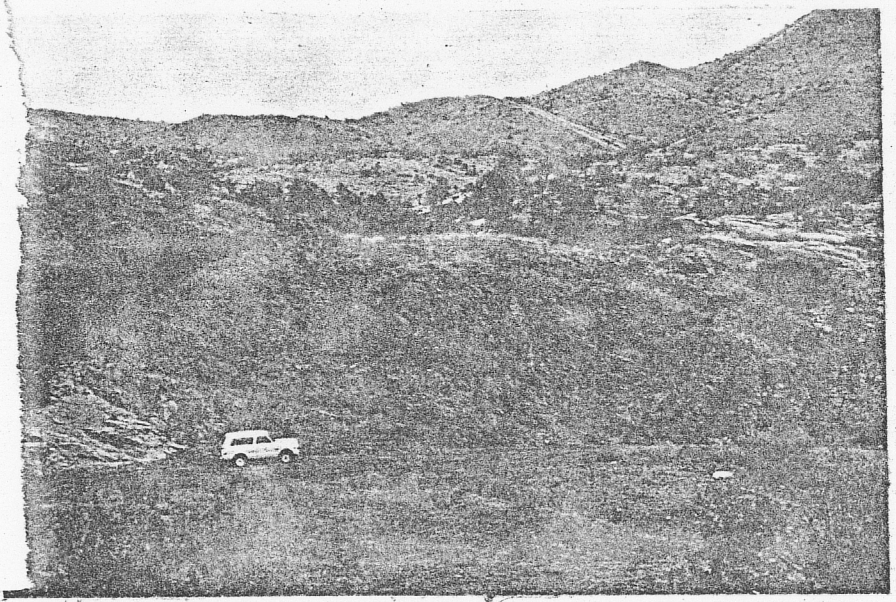


Figure 20. Interbedding of the Popotosa Formation with the La Jara Peak Andesite in Carrizozo Canyon northwest of the Bear Mountains.

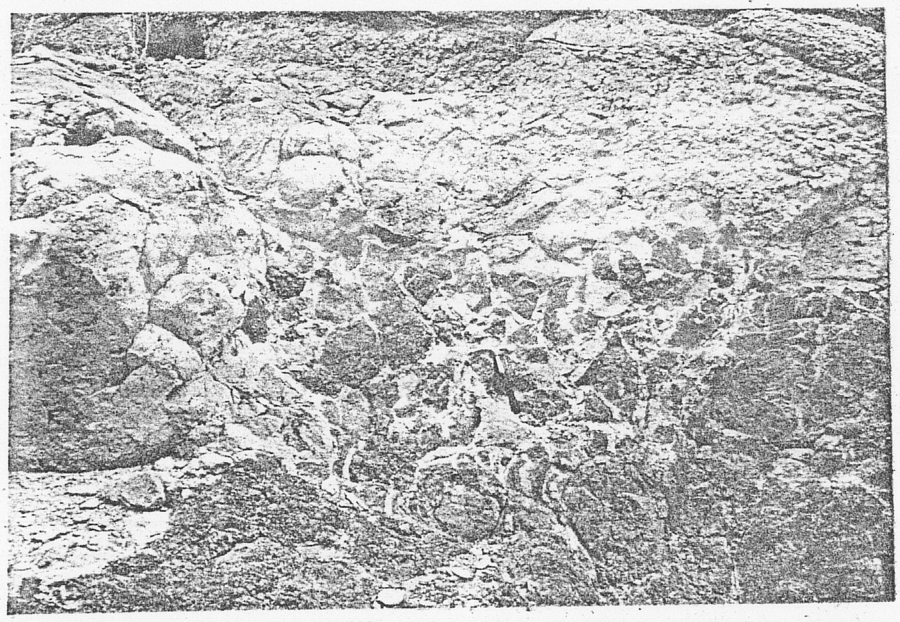


Figure 21. Depositional contact of the Popotosa Formation and the La Jara Peak Andesite in Carrizozo Canyon northwest of the Bear Mountains.

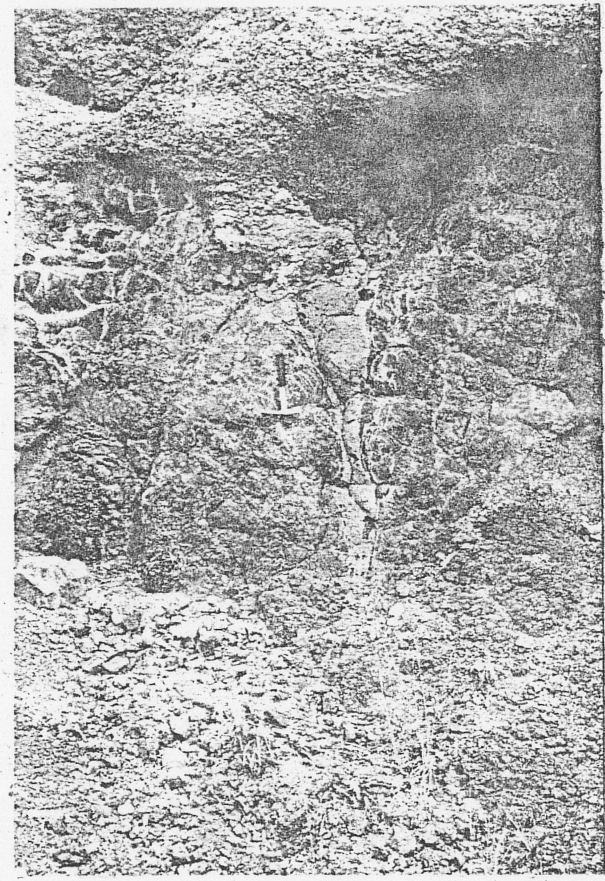


Figure 22. Contact of the Popotosa Formation with the underlying La Jara Peak Andesite in Carrizozo Canyon northwest of the Bear Mountains. Note large clastic dike.

fanglomerate which is about 100 to 110 feet thick. More interbedded fanglomerate facies may be present at depth. It is apparent that interbedding of the Popotosa Formation and La Jara Peak Andesite has occurred over a stratigraphic thickness of about 300 feet. At Cedar Spring about 200 feet of La Jara Peak Andesite overlies about 40 feet of the fanglomerate facies. A sample from the uppermost interbedded andesite in Carrizozo Canyon was taken for radiometric dating by the K/Ar method and yielded an age of 30 m.y. This date is six million years older than a previous date obtained by Chapin (1971b) from a sample of La Jara Peak Andesite collected in Cedar Springs Canyon which probably came from above the interbedded Popotosa. Stratigraphic studies by Brown (1971) and C. E. Chapin (oral communication, 1973) suggest that the 24 m.y. date for La Jara Peak Andesite is probably correct. The older date is probably anomalous and needs to be confirmed. The date of 24 m.y. is considered to be the maximum age for the initial deposition of the Popotosa Formation.

The Popotosa Formation is extensively overlain by pediment gravels of late Pliocene or Quaternary age in the Mulligan Gulch graben. A much dissected series of basalt flows caps these pediment gravels along the east side of the Gallinas Range from Council Rock south to Cat Mountain. The basalt has not been dated.

Relationship to Major Structures

Faulting is common in the Bear Mountains-Mulligan Gulch graben area with vertical displacements varying from a few feet to as much as 1,000 feet or more. The predominant fault trend is north-northwest parallel to that of numerous dikes (Tonking, 1957). Northeast-trending faults are abundant in the southern Bear Mountains and Silver Hill areas where the San Augustin lineament of the Rio Grande rift has superimposed its structural grain on the older north-northwest fabric (Chapin, 1971a). One of the largest faults in this area is the north-trending Hells Mesa fault which can be traced for more than 30 miles from the Lucero uplift southward along the eastern flank of the Bear Mountains and then south-southwestward to where it merges with the bounding faults of the Mulligan Gulch graben in the Silver Hill area. Brown (1972, p. 86) notes that more than a thousand feet of La Jara Peak Andesite has been downfaulted to the west of this normal fault. Farther north, in the Puertecito Quadrangle, Tonking (1957, p. 38) estimated a maximum vertical displacement of about 500 feet. The greatest displacement probably occurs in the Silver Hill-U. S. Highway 60 area where the fanglomerate of Dry Lake Canyon is downdropped against the A. L. Peak Formation. The Hells Mesa fault appears to be part of a system in which sub-parallel faults have been progressively stepped down toward the Mulligan Gulch graben (Brown, 1972).

Sedimentary Structures

Several types of sedimentary structure have been observed throughout the Bear Mountain-Mulligan Gulch graben area. Large scale cross-bedding, 5 to 25 feet, is locally present in both the fanglomerate facies and the fanglomerate of Dry Lake Canyon (fig. 23). Smaller scale cross-bedding is present in the playa facies. Laterally extensive shallow channels produced by scour-and-fill occur in all three facies. Deeper channels are rare but some do occur in the fanglomerate facies with the channel axes trending southeastward. Pebble imbrication is prominent in all three facies; parting lineation is most common in the playa facies with the lineation to the southeast.

Magdalena Mountains

Lithology

In the Magdalena Mountains, the Popotosa Formation is exposed in Water Canyon, on South Baldy, and on Magdalena Peak. Only the fanglomerate facies was observed in these areas. In the Water Canyon area, the Popotosa Formation forms a steep escarpment for about one and a half miles along the east wall of the canyon and extends southeastward about two miles to form a broad mesa between Water Canyon and South Canyon. Outcrops of this facies on South Baldy are poorly exposed and so badly disturbed by frost heaving that it is

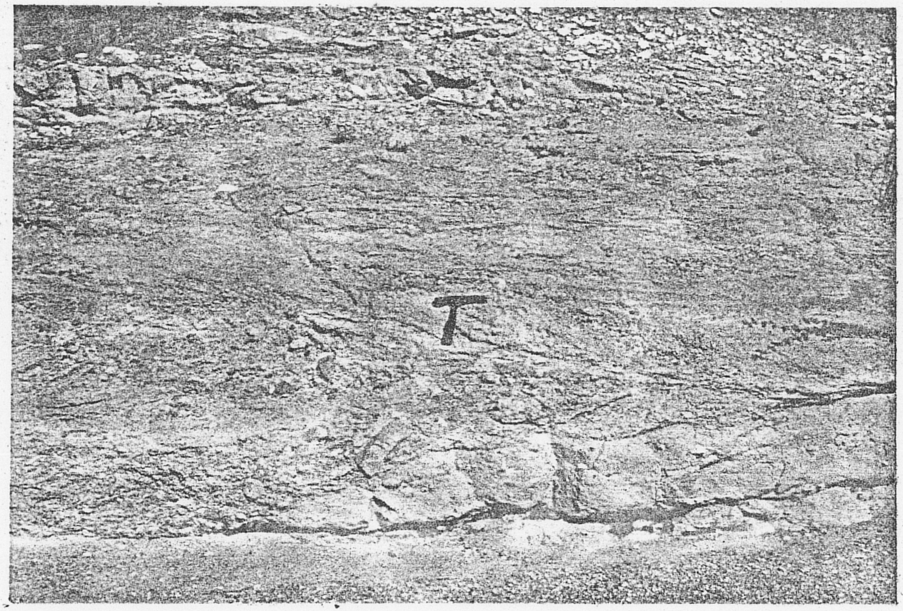


Figure 23. Large scale cross-bedding in the fanglomerate facies west of the Bear Mountains.

difficult to obtain accurate attitudes. On the southeast side of Magdalena Peak, the fanglomerate facies crops out between the volcanic rocks of mid-Tertiary age and the rhyolite flows of Miocene age which cap the peak. Only about 100 feet of conglomerate is present.

In Water Canyon and South Baldy, the fanglomerate facies consists principally of well-indurated reddish-brown mudflow deposits and fluvial conglomerates similar to those in the Socorro-Lemitar Mountains; mudflows are predominate in Water Canyon near the base of the formation. On Magdalena Peak the fanglomerate facies is buff colored and less well-indurated and may be somewhat younger in age.

Stratification of this facies is prominent in the escarpment along Water Canyon. The beds vary from one inch to as much as ten feet in thickness, and average six inches to two feet in thickness. Lithic fragments vary from less than an inch to three feet in diameter and average three to eight inches in diameter; they range in roundness from angular to well rounded but are mostly subangular. Sandstone lenses were not observed. Pebble conglomerate lenses with pebbles less than one inch in diameter occur locally. Imbrication and crude cross-bedding are also present.

The lithology of the clasts in the Magdalena Mountains is given in Table 7 and shown diagrammatically on Plate 5. The pebble counts for the Water Canyon area and the South Baldy area are similar;

detritus from the underlying Tertiary andesites comprises between 60 and 70 percent of the clasts. The remaining clasts were derived from felsic volcanic rocks of mid-Tertiary age, primarily the Potato Canyon Rhyolite. On Magdalena Peak felsic volcanic fragments are the major constituent and comprise about three-fourths of the clasts; the remaining detritus was derived from andesitic rocks and late Paleozoic rocks. The clasts are embedded in a matrix which is petrographically similar to that in the Socorro-Lemitar Mountains. The matrix is composed of lithic fragments, feldspar, and quartz grains. The common cements of the matrix are silica and hematite; hematite is much less abundant in the Magdalena Peak area.

Thickness and Areal Extent

The Popotosa Formation in the Magdalena Mountains varies in thickness from less than 100 feet to a maximum of about 600 feet. The most extensive exposures of the Popotosa are in the area between Water Canyon and South Canyon along the escarpments forming the west and north sides of the mesa. A maximum thickness of 600 feet has been estimated for this area. The fanglomerate facies is discontinuously exposed between South Baldy and Langmuir Laboratory; the thickness of the Popotosa Formation in this area probably varies from 10 to 100 feet. A thickness of 100 feet has been estimated for the Popotosa exposed on the southeast side of Magdalena Peak.

Age and Stratigraphic Position

The fanglomerate facies of the Popotosa Formation represents the youngest indurated rock units present in both the Water Canyon and South Baldy areas. In these areas, the Popotosa usually overlies the Potato Canyon Rhyolite or locally overlies andesites; on South Baldy, the andesites have been mapped as the andesite of South Baldy by D. A. Krewedl (oral communication, 1973). The fanglomerate facies on Magdalena Peak overlies the andesite of Landavaso Reservoir (C. E. Chapin, oral communication, 1973) which is laterally equivalent to the andesite of South Baldy and occupies a stratigraphic position between the A. L. Peak Formation and the Potato Canyon Rhyolite. Cross-bedded, white, air-fall tuffs, belonging to the crater of the Magdalena Peak dome, overlie the Popotosa Formation on Magdalena Peak and, in turn, are overlain by rhyolite flows dated at 14 m.y. by Weber and Bassett (1963). Deposition of the Popotosa Formation in the Magdalena Mountains took place following deposition of the Potato Canyon Rhyolite at 31 m.y. B.P. (Deal and Rhodes, in press); on Magdalena Peak, the beginning of Popotosa deposition can be dated as preceding emplacement of the Magdalena Peak rhyolite flows at 14 m.y. B.P.

Relationship to Major Structures

The Magdalena Mountains area has been actively faulted and uplifted from Laramide time to the present. The area was first uplifted during the Laramide orogeny and was beveled by erosion in Eocene time. The configuration of this uplift is poorly known; however, the later uplifts have resulted in four major fault trends (Chapin and others, in preparation). The area was uplifted in early Oligocene time during deposition of the Spears Formation, along a major west-northwest trending transverse fault extending from North Baldy to the southern Gallinas Mountains. Late Oligocene extensional faults with north-northwest trends followed the emplacement of the youngest ash flows. The Anchor Canyon and Nitt stocks dated at 28 m.y. (Weber and Bassett, 1963) were emplaced during this period of faulting. North-trending faults related to the Basin and Range deformation began in the early Miocene and have continued to the present (Chapin and others, in preparation). The latest faulting has offset exposures of the Popotosa Formation in Water Canyon from those on South Baldy by about 3,000 feet. During this period of Basin and Range deformation, the northern end of the Magdalena Mountains was downdropped by a series of northeast-trending faults related to the San Augustin lineament.

Sedimentary Structures

Sedimentary structures within the fanglomerate facies are poorly developed in the Magdalena Mountains. Crude cross-bedding is occasionally observed in the Water Canyon area. Pebbles usually do not show a preferred orientation, but pebble imbrication is present in some areas.

CORRELATION OF THE POPOTOSA FORMATION

Denny (1940) described the Popotosa Formation only in the type area and in the Joyita Hills; however, field evidence indicates that the Popotosa is far more extensive. An emended definition of the Popotosa Formation based on lithology, age and stratigraphic position is proposed in order to correlate the Popotosa of the type area with that of the other areas.

> The Popotosa Formation of Miocene age consists of conglomerates, mudflow deposits, sandstones, siltstones, and mudstones in which volcanic rocks are interbedded. The Popotosa can be subdivided into several facies: a fanglomerate facies which is generally well-indurated and varies in color from reddish-brown to silver gray and a playa facies which is less well-indurated and varies in color from reddish-brown to buff. Along the west side of the Bear Mountains, a unique facies, the fanglomerate of Dry Lake Canyon, consists almost entirely of detritus from the La Jara Peak Andesite. Another unique facies found along the south and east sides of the Ladron Mountains, the fanglomerate of Ladron Peak, has an unusually large content of Precambrian and late Paleozoic detritus derived from the rapid uplift of the Ladron Mountains. The change from a fanglomerate facies to a playa facies is gradual with subequal quantities of interbedded sandstones and conglomerates present. Detritus is predominantly from Tertiary volcanic rocks but clasts of Precambrian and late Paleozoic rocks are abundant locally. The Popotosa is the basal formation of the Santa Fe Group in Socorro County. It usually overlies Oligocene or Miocene volcanic rocks; locally it overlies prevolcanic rocks. In general, the Popotosa is the youngest well-indurated sedimentary formation present and is usually overlain with angular unconformity by poorly indurated sedimentary deposits of the upper Santa Fe Group.

This definition is adequate for differentiating between the Popotosa Formation and rock units that are similar in appearance. Several fanglomerates which were tentatively assigned to the Popotosa Formation during the early stages of this project were eliminated on the basis of this definition. In the Mule Shoe Ranch area, three miles to the southwest of South Baldy, a reddish-brown, well-indurated conglomerate very similar to the fanglomerate facies in the Socorro-Lemitar Mountains crops out. This conglomerate, however, is interbedded with Late Oligocene volcanic rocks approximately 29-30 m.y. in age and represents moat-fill sediments of the Mt. Whithington caldera (E. G. Deal, oral communication, 1972). In the area northwest of the Ladron Mountains fanglomerates, similar in both appearance and induration to the fanglomerate facies in the Silver Creek valley, are exposed. These conglomerates, composed of Precambrian and late Paleozoic detritus, have been called Popotosa Formation by Spiegel (1955). Although they are probably similar in age and origin to the Popotosa, they appear to have been deposited in the Belen basin and are composed of non-volcanic detritus; therefore, they are not considered to be Popotosa in this report. In the area northwest of Magdalena, along the west side of the Silver Hill district, andesitic flows are interbedded with reddish-brown, well-indurated conglomerates similar to the fanglomerate facies in the Socorro-Lemitar Mountains. These conglomerates until recently were considered by the writer to be correlative with the fanglomerate facies of the Popotosa Formation in the area to the north described by Tonking (1957). However, field work by D. B. Simon and C. E. Chapin (oral communication, 1973) has shown that these conglomerates overlie stock rocks dated at 28 m.y. and underlie La Jara Peak Andesite dated at 24 m.y.; therefore, they predate Popotosa deposition.

Lithology

Outcrops of the Popotosa Formation in the type area, the Socorro-Lemitar Mountains, the Bear Mountains-Mulligan Gulch graben, and the Magdalena Mountains are lithologically similar, except for the two unique facies, the fanglomerate of Dry Lake Canyon and the fanglomerate of Ladron Peak. The fanglomerate facies consists of interbedded conglomerates and sandstones in which conglomerates predominate. Conglomeratic mudflow deposits are locally prominent near the base of the Popotosa. This facies is usually well-indurated and reddish-brown in color; minor variants are buff and silver-gray. Detritus is predominantly from Tertiary volcanic rocks; clasts of andesitic rocks comprise a significant percentage (20 to 90 percent) and clasts of felsic volcanic rocks make up most of the remainder. Detritus from Precambrian and late Paleozoic rocks may be present and are locally abundant in the northern portion of the type area in the fanglomerate of Ladron Peak.

The playa facies occurs in all areas except the Magdalena Mountains. The reddish-brown to buff sandstones of this facies are less well-indurated than the fanglomerate facies; the siltstones and mudstones are poorly indurated. Conglomerate lenses may comprise as much as ten percent of the unit in areas where sandstones predominate and are absent in the finer-grained sediments. In areas transitional to the fanglomerates, lenses of gravel-size clasts increase in number until they become predominant. The lithology of the sediments in the playa facies is similar to that in the fanglomerate facies except for generally finer grain size and the presence of bentonitic and gypsiferous beds in the former.

Age and Stratigraphic Position

The upper and lower contacts of the Popotosa Formation within the study area are rarely exposed. Lower contacts of the Popotosa were observed in the Socorro-Lemitar Mountains where the Popotosa overlies the Potato Canyon Rhyolite (30 m.y., Deal and Rhodes, in press) and basaltic andesites similar in appearance to the La Jara Peak and Silver Creek basaltic andesites; locally the Popotosa appears to directly overlie Precambrian rocks. In the Bear Mountains, the basal Popotosa beds are interbedded with La Jara Peak Andesite (23.8 ± 1.2 m.y., Chapin, 1971b). In the Magdalena Mountains, the Popotosa overlies the Potato Canyon Rhyolite (30 m.y., Deal and Rhodes, in press) and the slightly older andesite of South Baldy (D. A. Krewedl, oral communication, 1973). On Magdalena Peak, the Popotosa overlies the andesite of Landavaso Reservoir, which is equivalent stratigraphically to the andesite at South Baldy (C. E. Chapin, oral communication, 1973). The lower contact of the Popotosa Formation has not been observed at the type area, but the playa facies is interbedded with the andesite of Silver Creek which has been dated at 15.8 ± 1.5 m.y. (Weber, 1971).

The upper contact of the Popotosa in the type area is an angular unconformity with poorly indurated gravels of the upper Santa Fe Group. On Socorro Peak, the Popotosa Formation is overlain by a trachyandesite flow and associated tuffs which have been dated at 11.5 m.y. (C. T. Smith, oral communication) and 10.7 m.y. (Burke and others, 1963). Rhyolite flows equivalent to those overlying the Popotosa on Magdalena Peak have been dated at 14 m.y. by Weber and Bassett (1963). Elsewhere in the study area, the Popotosa is overlain by late Pliocene-Quaternary pediment gravels and basalt flows.

At least 5,000 feet of Popotosa was deposited in the study area during the interval 16 to 11 m.y. B.P. Deposition of the Popotosa Formation began about 24 million years ago during emplacement of the upper third of La Jara Peak Andesite and continued at least to late Miocene time when rhyolitic flows and domes were emplaced from the Socorro Peak and Magdalena Peak volcanic centers. However, the upper age limit of Popotosa deposition has not been established.

ORIGIN OF THE POPOTOSA FORMATION

Environment of Deposition

The sedimentary structures and internal fabric of the Popotosa Formation are characteristic of a bolson deposit that developed in an arid to semi-arid climate. The fanglomerate facies, including the fanglomerate of Dry Lake Canyon and the fanglomerate of Ladron Peak, are the result of alluvial-fan deposition. These alluvial-fan deposits graded down slope into basin deposits which are now represented by the playa facies. This mode of deposition has been extensively studied with respect to modern alluvial fans by Eckis (1928), Blissenback (1954), Lustig (1965), Denny (1967), Hook (1967 and 1968), and Bull (1968 and 1972).

The recognition of the coarse conglomeratic units of the Popotosa Formation as an alluvial-fan deposit is based upon a number of criteria. The conglomeratic units of the Popotosa Formation consist of poorly sorted deposits of angular to rounded clasts in which the individual particles range in size from boulders to clay; similar detrital configuration has been noted in recent fan deposits by Blissenback (1954). The matrix of the Popotosa and that of recent fan gravels is sand to mud in size and arkose to graywacke in composition. The Popotosa is mostly volcanic wacke (Williams, Turner, and Gilbert, 1954) in composition. The Popotosa Formation and modern alluvial-fan deposits have facies which change from coarse-grained detritus to fine-grained detritus represented by fanglomerate and playa facies, respectively. The tectonic setting of the Popotosa Formation, a central basin bounded by fault-block uplifts, is typical of recent alluvial-fan development. Further evidence for alluvial-fan deposition is indicated by the scarcity of organic remains in the Popotosa Formation. Recent alluvial fans are oxidized deposits that rarely contain well-preserved organic material. The only organic material observed by the writer in the Popotosa is an undescribed "flotsam" of plant remains found in the playa deposits on Socorro Peak. Similar criteria have been utilized in the recognition of other ancient alluvial-fan deposits by Fernandez and Enlows (1966), Nordstrom (1970), and Steidmann (1971).

Alluvial-fan deposition of the Popotosa Formation resulted in both water-laid and debris-flow deposits. Water-laid deposits on recent fans consist of sheet-flood and stream-channel sediments (Bull, 1972). The Popotosa consists principally of sheet-flood sediments which were deposited by surges of sediment-laden water that spread out from the end of the stream channel over a fan. Deposition is caused by a widening of the flow into a network of braided distributary channels or sheets that decrease in depth and velocity of flow (Bull, 1972). These shallow distributary channels are rapidly filled with sediment and then shifted a short distance to another location; the resulting deposit of sand or gravel is sheet-like. Fluvial sediments are found throughout most of the Popotosa and were formed by stream channels that were temporarily entrenched into the fan. These stream channels were deeper and had a greater velocity than the shallow channels associated with sheet-flood deposits. The increased stream velocity enabled these streams to carry a wider size range of detritus which upon deposition resulted in deposits that are generally coarser grained, more poorly sorted, and less well-stratified than the sheet-flood sediments. Pebble imbrication and cross-stratification are present in all the water-laid deposits.

Debris-flow deposits in the Popotosa are most prevalent in the Socorro-Lemitar and Magdalena Mountains. These deposits occur in arid to semi-arid regions where there is intense rainfall over short periods of time at irregular intervals, steep slopes with insufficient vegetative cover to prevent rapid erosion, and source rocks that provide a matrix of mud (Blackwelder, 1928; Fisher, 1971; and Bull, 1972). The debris-flow deposits in the Socorro-Lemitar and Magdalena Mountains suggest that such conditions existed in these areas. The source area of the debris flows appears to be the Magdalena Mountains which because of their elevation probably received more precipitation than the other uplifts bounding the Popotosa basin. With this higher precipitation conditions conducive to debris-flow deposition are met. Debris-flow deposits in the Popotosa are unsorted and lack well-defined bedding within individual flow sequences; upon close examination, bedding planes between flows can be discerned in outcrop. The nearly random distribution of the larger clasts (Bull, 1972, p. 70) indicates that these flows were quite viscous. Bubble cavities are locally abundant in these debris flows and may have formed from: (1) air incorporated by the debris flows as they moved down slope, or (2) air trapped in the soil beneath the mudflow which moved upward and became entrapped in the mudflow to form bubble cavities (Bull. 1963).

Eolian sands may be incorporated in bolson deposits in dry regions (Blissenback, 1954, p. 182). Dune sand can be derived from four sources: (1) from the breakdown of older rocks or recently cemented sedimentary rocks, (2) from sediments deposited on alluvial fans by ephemeral streams, (3) from deflation of playa deposits, and (4) from coastal beaches bordering the desert. The first three sources were present in this region and could have been available for dune-sand development in the Popotosa Formation. However, eolian deposits have not been observed in the Popotosa Formation within the study area. The prevailing winds during the Miocene probably were from the southwest, as they are today, and would have carried the sand across the playas to the northeast. Eolian deposits may be present to the northeast of the type area outside the region investigated by the author. The San Augustin Plains southwest of Magdalena are now a likely source of dune sand, but the topographic features of this region were not the same in the Miocene as they are now. The San Augustin lineament (Chapin, 1971a), responsible for the development of the San Augustin Plains, apparently did not form until after the deposition of the rhyolites on Magdalena Peak dated at 14 m.y. by Weber and Basset (1963). Most of the Popotosa deposition pre-dates formation of the San Augustin lineament.

Alluvial-fan deposits commonly interfinger with deposits of adjacent alluvial fans as well as deposits of flood-plain and lacustrine environments (Bull, 1972). Alluvial-fan deposits of the Popotosa Formation intertongue with sands, silts, and clays accumulated in playas within closed basins. The fine-grained, uniform texture and the regular planar stratification of these sediments are indicative of a playa environment. Cross-stratification, parting lineation, clay clasts, and clay balls are scarce indicating that streams flowing into the playa were not numerous and probably only carried water during intense rainfall. Mud cracks and ripple marks which are generally present in a playa facies are scarce in the Popotosa Formation which indicates that the playa may have contained water for only short periods of time and during the longer intervals of dryness these structures were destroyed by deflation.

A similar mode of deposition (alluvial-fan/playa) has been postulated for part of the Santa Fe Group at San Diego Mountain about 100 miles south of Socorro. In this area, the basal Santa Fe is represented by the Hayner Ranch Formation; both it and the overlying Rincon Valley Formation are Popotosa-like deposits which have been described by Hawley, et al. (1969), Hawley (1970), King, et al.

(1971), and Seager, Hawley, and Clemons (1971). The Hayner Ranch Formation consists of conglomerates and mudstones similar in character and mode of deposition to the Popotosa Formation. The Rincon Valley Formation occupies essentially the same closed basin and consists of poorly sorted volcanic-pebble conglomerates which appear to transitionally overlie the Hayner Ranch Formation. The conglomerate facies has been interpreted as alluvial-fan deposition which interfingers with the alluvial and lacustrine basin floor sediments.

Source Areas

Deposition in the Popotosa basin resulted from erosion of several highlands at various times. The location of these highlands has been determined by pebble-count and paleocurrent data collected throughout the Popotosa Formation. In the pebble counts, clasts greater than one inch in diameter were counted until about 100 pebbles were identified. The lithologies were catagorized as Tertiary intrusive rocks, Tertiary felsic volcanic rocks, Tertiary andesitic rocks, late Paleozoic rocks, Precambrian rocks, and quartzites of various ages. Tertiary intrusive rocks include clasts from monzonitic and granitic stocks; Tertiary felsic volcanic rocks are made up predominantly of clasts from welded tuffs varying from rhyolite to latite in composition but with some detritus from felsic lavas. Clasts derived from the Spears Formation were seldom observed, probably because of limited exposure of the Spears Formation at the time of Popotosa deposition; these clasts when observed were included with the Tertiary felsic volcanic rocks. Tertiary andesitic rocks are predominantly andesitic clasts but some of basaltic composition are included. Late Paleozoic rocks include clasts from sandstones, siltstones, and limestone. Precambrian rocks include clasts from granites, gneisses and schists. The quartzites include quartzitic rocks of both Precambrian and late Paleozoic age because of the difficulty in distinguishing between them. Paleocurrent data was collected principally by pebble imbrication measurements and by parting lineation and channeling. Paleocurrent data was not corrected for bed rotation as only an average of three and one-half degrees per measurement was noted between the apparent flow direction and the true flow direction. Although cross-stratification is one of the more reliable paleocurrent indicators (Pettijohn, 1962), it was not used because of its scarcity and poor development.

In the type area, flow directions in the fanglomerate facies, except the fanglomerate of Ladron Peak, indicate that the detritus was derived from highlands to the west. The present highlands of the block-faulted Bear Mountains are to the west; but the north end of the Magdalena Mountains, now down-faulted by the San Augustin lineament (Chapin, 1971a), was probably the source of most of the volcanic detritus found in the type area. The Lucero uplift of the Colorado Plateau and the Ladron Mountains presently lie to the northwest of the type area. The Colorado Plateau formed the northwest bounding highlands of the Popotosa basin during most of the deposition of the Popotosa Formation. The Ladron Mountains are a relatively young uplift which shed detritus southeastward to form the fanglomerate of Ladron Peak.

Paleocurrent directions in the Socorro-Lemitar Mountains indicate that streamflow was principally from the west and southwest and to a minor extent from the south and northwest. In this area, only Oligocene volcanic detritus is abundant in the conglomerate lenses in the Popotosa. The westwardly flow direction, as in the type area, suggests that these clasts were derived from the Magdalena Mountains. Flow directions from the south and northwest, found on opposite sides of Polvadera Mountain, suggest that Polvadera Mountain was a slightly positive area during deposition of the Popotosa Formation.

The Popotosa Formation in the Bear Mountains consists of Tertiary volcanic clasts which were derived from the south, west, northwest, and northeast. The Popotosa that is interbedded with and directly overlies La Jara Peak Andesite contains imbricated pebbles which suggest a source to the south, possibly the Magdalena Mountains. The overlying fanglomerate facies and the playa facies reveal flow directions from the west and northwest suggesting a source area in the uplifting Colorado Plateau. The fanglomerate of Dry Lake Canyon, composed largely of andesitic detritus, contains imbricated pebbles showing flow direction to northwest, west, and southwest from the now down-faulted north end of the Magdalena Range.

On Magdalena Peak, pebble imbrication shows a southwest source area for the Tertiary volcanic clasts within the Popotosa. The source area for these clasts was probably the San Mateo Mountains.

The detrital material of the Popotosa Formation in the study area was derived from uplifts to the west, northwest, and southwest. Flow directions from the east have not been observed, but only the western half of the basin has been studied. The eastern half of the Popotosa basin probably has been destroyed by uplift and erosion along the east side of the Rio Grande rift. Sedimentary structures, internal fabric, tectonic setting, and facies changes were used to interpret the environment of deposition of the Popotosa Formation. The environment has been interpreted as a bolson deposit that developed in an arid to semi-arid climate. The surrounding fault-block highlands shed detritus down slope into an enclosed basin; the coarse material was deposited as coalescing alluvial fans while the finer material was deposited farther down slope as playa muds and sands. Paleocurrent and pebble-count data show that the source areas for the detritus were to the west, northwest, and southwest and suggested that only the western half of the Popotosa basin has been preserved.

Tectonic History

An understanding of both the source areas and the environment of deposition is necessary to interpret the tectonic events which have led to the development of the Popotosa Formation. Deposition of the Popotosa began about 24 m.y. B.P., in early Miocene time, during deposition of the upper one-third of La Jara Peak Andesite which occupied a subsiding basin to the north and northwest of Magdalena (fig. 24). Coarse detritus was shed northward, probably from the Magdalena area, over andesitic flows. A northward flow of detritus continued for a short time following emplacement of La Jara Peak Andesite.

Shortly after the last La Jara Peak andesitic flows were emplaced, the Colorado Plateau and the San Mateo-Gallinas uplift began to rise as depicted in Figure 25. Tertiary volcanic rocks which capped the Mesozoic strata of the Colorado Plateau along the north edge of the Datil volcanic field were eroded and transported to the southeast; similar detritus spread eastward from the San Mateo-Gallinas uplift. The coarser material was deposited as coalescing alluvial fans; the finer material was deposited in playas now uplifted along the west flank of the Bear Mountains, and some fine detritus may have been carried as far as playas in the Socorro-Lemitar and type areas.

The next major tectonic uplift was that of the Magdalena Mountains to form a westward-tilted fault-block range, the north end of

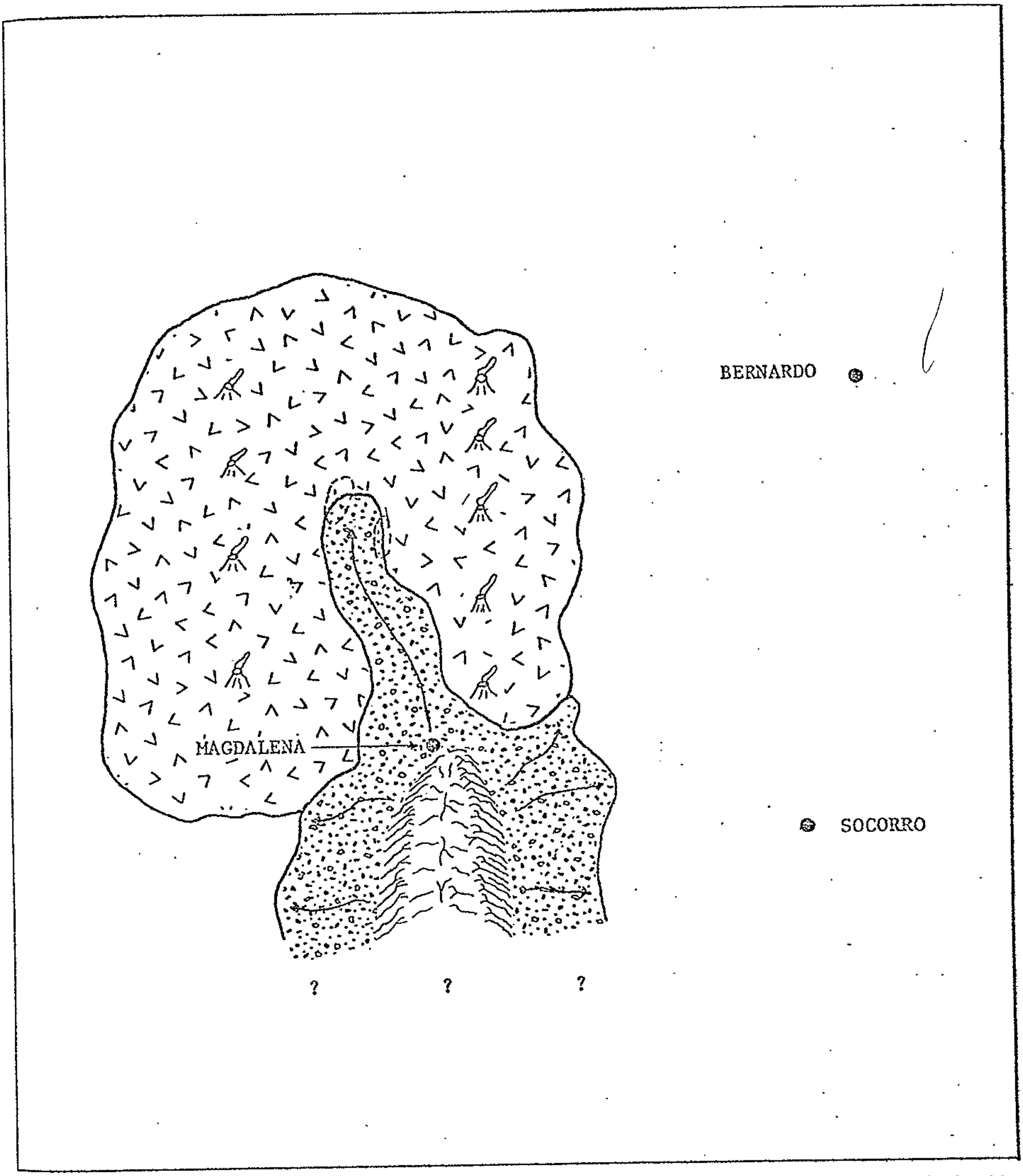


Figure 24. Interbedding of the fanglomerate facies with the La Jara Peak Andesite. 24 m.y.B.P., Fanglomerate facies [pattern], La Jara Peak Andesite [pattern], Volcanic activity [symbol], Outcrop exposures ---, Scale 1 : 500,000.

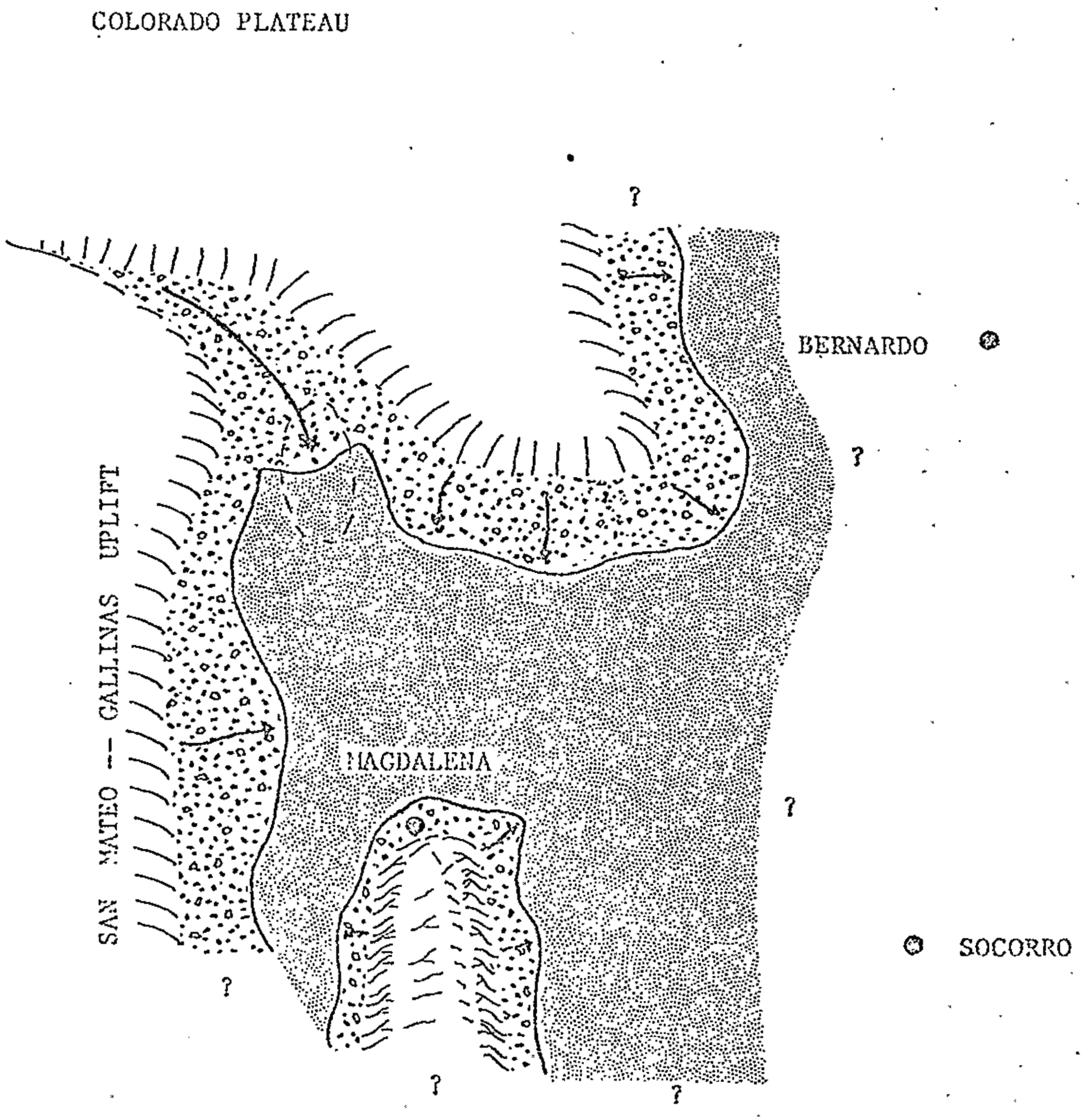


Figure 25. Initial uplift of the Colorado Plateau. About 23 m.y.B.P., Fanglomerate facies [symbol], Playa facies [symbol], Outcrop exposures — — —, Scale 1 : 500,000.

which was capped by La Jara Peak Andesite (fig. 26). The Colorado Plateau probably was still rising but not as rapidly as earlier. Some detritus from the Colorado Plateau may have been carried southward into the graben between the Gallinas Mountains and the ancestral Magdalena Mountains, but most of the Popotosa in this area is covered by pediment gravels and exposures are not adequate to evaluate this possibility. Detritus from the Colorado Plateau lying north of the Ladron Mountains probably was deposited in the Belen Basin. At this time, there were slightly positive areas in both the Ladron and Polvadera Mountains as indicated by flow directions in basal Popotosa in these areas.

The northern Magdalena Mountains began to rise rapidly. The north end of the range was located at least as far north as Bear Springs Canyon along the east side of the present Bear Mountains. It was not until after 14 m.y. B.P. that the Magdalena Mountains north of U. S. Highway 60 were downfaulted along the San Augustin lineament and this portion of the range became the series of north-trending hogbacks observed today between U. S. Highway 60 and Bear Springs Canyon (fig. 27). Detritus derived from the dip slope of La Jara Peak Andesite capping the north end of the Magdalena Mountains was shed westward into the Mulligan Gulch graben. The clasts are composed almost entirely of andesite and form the distinctive andesitic fanglomerate of Dry Lake Canyon. The development of the fanglomerate of Dry Lake Canyon encroached upon the playa facies which had been shed

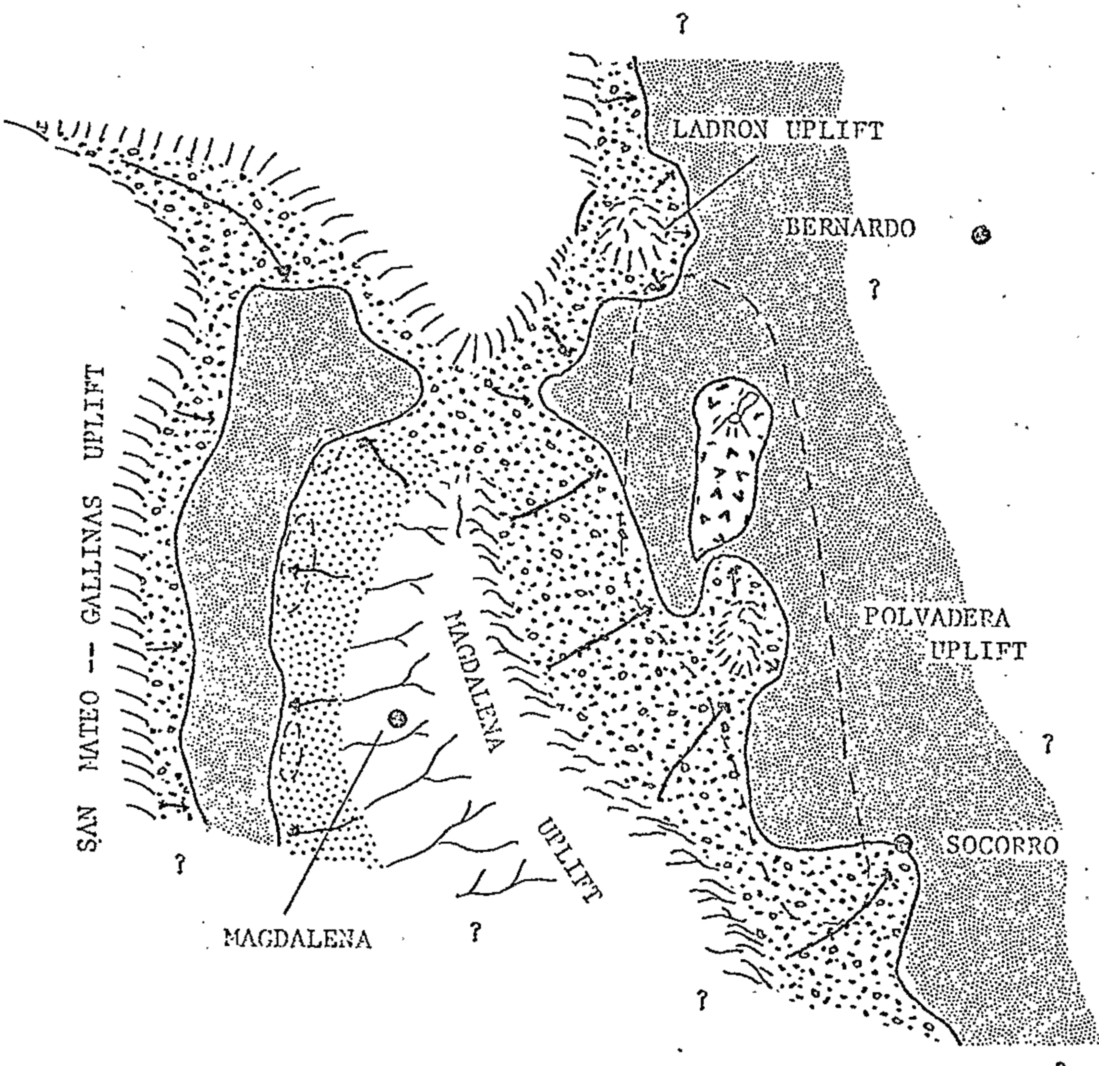


Figure 26. Uplift of the Magdalena Mountains. 23 to 15 m.y.B.P., Fanglomerate facies, Fanglomerate of Dry Lake Canyon, Playa facies, Andesite of Silver Creek, Volcanic activity, Outcrop exposures - - -, Scale 1 : 500,000.

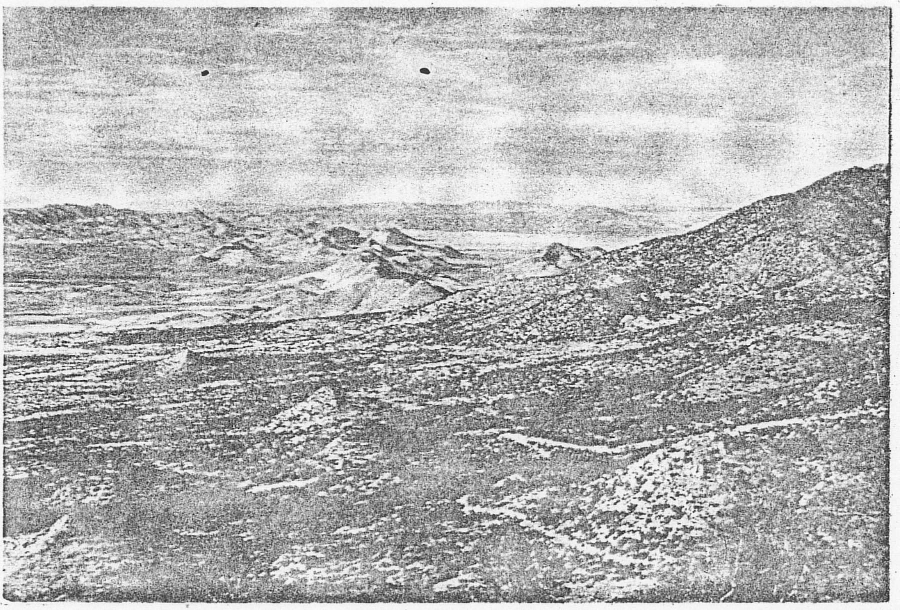


Figure 27. The northern part of the Magdalena Mountains downfaulted into the San Augustin lineament is now represented by a series of north-trending hogbacks in the center. The Magdalena Mountains are located at the right and the Bear Mountains at the upper left of the picture.

southeast from the earlier uplift of the Colorado Plateau. This encroachment can be observed in the landslide scar west of Mesa Cencerro where thin gravel lenses of the fanglomerate of Dry Lake Canyon are interbedded with the playa facies. As the northern Magdalena Mountains continued to rise, coarse gravels of the fanglomerate of Dry Lake Canyon spread out across the playa facies.

Erosion of the steep east-facing escarpment of the Magdalena Mountains formed coalescing alluvial fans which spread eastward into the type area where they overlie the earlier playa deposits. These alluvial fans probably coalesced with fans from the Colorado Plateau to the north and graded down slope into a playa lake east of the type area. Coalescence of these fans is suggested by the presence of pre-Tertiary detritus in the Popotosa in the northern portion of the type area. During this time the andesite of Silver Creek (16 m. y.) and other unnamed andesites were emplaced. After the emplacement of the andesite of Silver Creek, a white, air-fall tuff was erupted from an unknown source; it was partly reworked by alluvial processes and occurs about 100 feet above the andesite of Silver Creek in the type area. This tuff is also present in the Socorro Mountain area where it is interbedded with playa facies, underlies the fanglomerate facies, and overlies pre-Tertiary strata.

Uplift of the southern Magdalena Mountains continued until after 16 m. y. B. P. with the fanglomerates spreading into the Socorro area where they overlie playa sediments. Degradation of the Magdalena Mountains followed the uplift and continued until they were nearly or completely buried beneath their own debris (fig. 28). During this stage of degradation, alluvial fans were deposited in the Water Canyon and South Baldy areas. South of Socorro Mountain, the playa facies overlies the fanglomerate facies indicating that as the supply of coarse detritus diminished, the alluvial fans retreated and the finer grained sedimentation became dominant. Rapid uplift of the Ladron Mountain occurred at this time and the fanglomerate of Ladron Peak developed. The expanding alluvial fans of the Ladron Mountains coalesced with the retreating alluvial fans of the northern Magdalena Mountains in the area to the south and southwest of Ladron Peak. To the east and southeast, the alluvial fans from the Ladron Mountains encroached upon playa deposits; this encroachment can be observed along the Popotosa Arroyo. Rhyolitic lavas were erupted from a vent at Magdalena Peak at about 14 m. y. and flowed southward along the west flank of the Magdalena Mountains where they overlie fanglomerates derived largely from the San Mateo uplift to the southwest. Volcanism then spread to the Socorro Peak area where the fanglomerate and playa facies are intruded by, interbedded with, and overlain by volcanic domes and flows of andesitic to rhyolitic composition. On Socorro Peak, the Popotosa Formation is overlain by a trachyandesite flow and associated tuffs which have been dated at 10.7 m. y. (Burke and others, 1963). No record has been found of Popotosa sediments younger than the Socorro Peak volcanism.

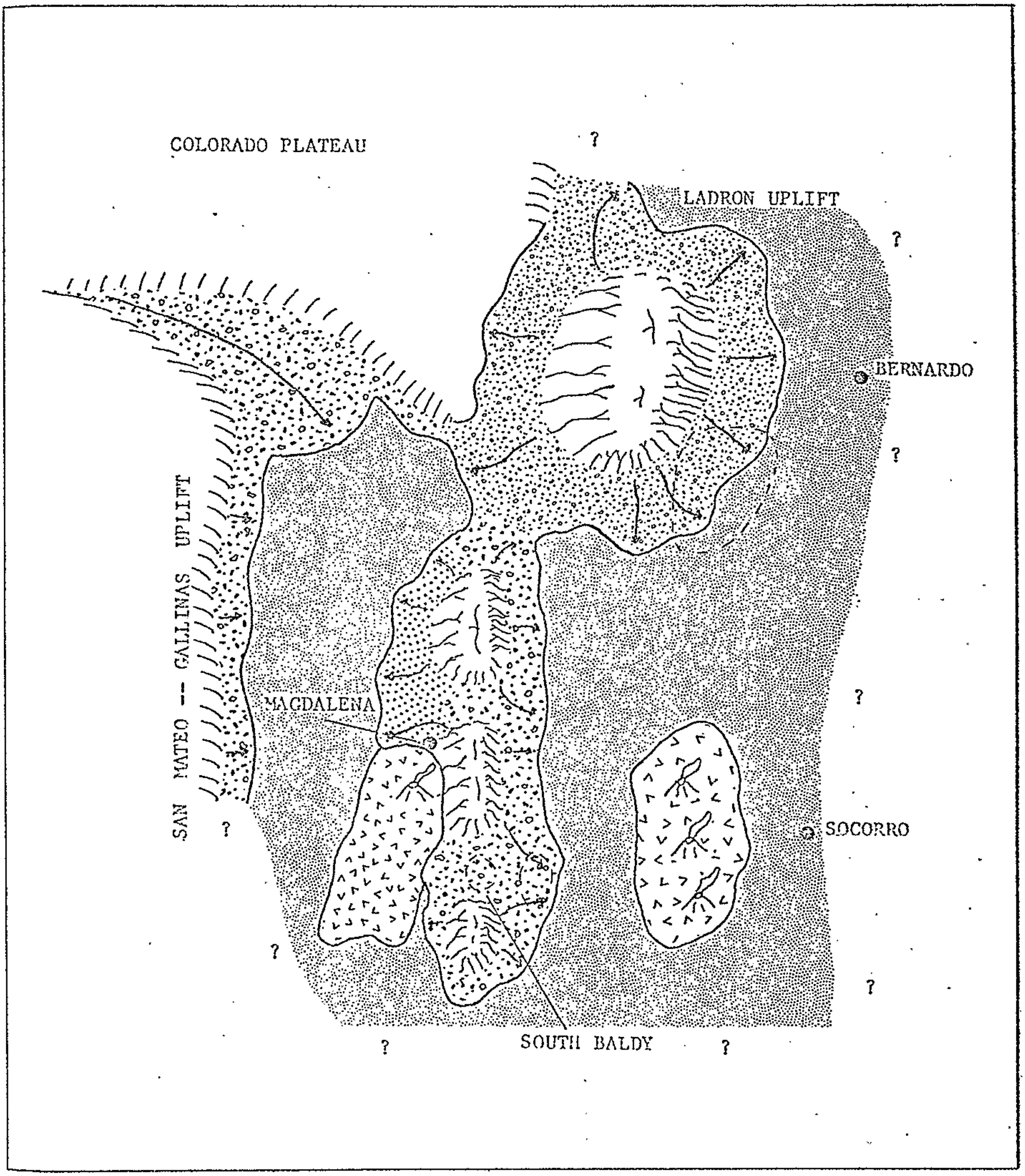


Figure 28. Degradation of the Magdalena Mountains. 15 to 11 m.y.B.P., Fanglomerate facies, Fanglomerate of Dry Lake Canyon, Fanglomerate of Ladron Peak, Playa facies, Socorro Peak volcanics, Magdalena Peak volcanics, Volcanic activity, Outcrop exposures - - -, Scale 1 : 500,000.

POST-DEPOSITIONAL HISTORY OF THE POPOTOSA FORMATION

Diagenesis

The variation in the rocks of the Popotosa Formation with respect to induration and color is largely due to post-depositional alteration. The degree of induration appears to be controlled by the composition of the cement and by particle size. Blissenbach (1954) states that the most common cement in alluvial-fan deposits is calcium carbonate which is precipitated from ascending or descending ground water and coats fan particles as solid layers or concretions, or is disseminated as minute calcite crystals in the matrix. The conglomerates and sandstones in the Popotosa are moderately to well indurated whereas the finer grained sandstones, siltstones, and claystones are poorly to moderately indurated. Varying amounts of clay in the matrix and hematite and silica cement are also common throughout much of the Popotosa. Rocks which are cemented by calcium carbonate commonly occur adjacent to rocks which are cemented by silica and hematite; furthermore, some samples are cemented by all three materials. In most samples it is difficult to discern which cement came first; in one sample, overgrowths of calcite on quartz suggest that quartz came first. Although the coarser grained rocks are as a rule better indurated than the fine grained rocks, all types of rocks cemented by silica and hematite are better indurated than those cemented by calcite. Extremely well-indurated rocks of the Popotosa occur in the Socorro and Magdalena mountains. These rocks were deposited as alluvial fans from the Magdalena Mountains and are generally cemented by hematite with varying amounts of silica. Apparently, an abundance of clay, hematite, and silica dispersed throughout the matrix develop a strong bond which is responsible for the extreme induration.

The colors of recent alluvial-fan deposits are due to the type of rocks which are present and also the the depositional climate (Blissenbach, 1954). Color variations in the Popotosa are due, in part, to lithology; for example, the fanglomerate of Ladron Peak is generally silver-gray in color as a result of abundant late Paleozoic limestone clasts. The fanglomerate facies commonly develops a purplish cast where there is a large component of andesitic detritus. However, most of the fanglomerate and playa facies in the Popotosa are reddish-brown in color but contain only minor amounts of red-colored clasts. One possibility for the red color is the reworking of Mesozoic and late Paleozoic red beds. However, in areas where the red coloration is most pronounced, the detritus is from Tertiary volcanic rocks with little or no detritus from older red beds. A more plausible explanation for the red color is an in situ alteration such as postulated by Walker (1963, 1967a, 1967b and 1968) and Walker and others (1967). Walker attributes the development of reddish-brown coloration in sediments to the alteration of ferromagnesian minerals by oxidizing interstitial waters in a semi-arid terrestrial depositional environment. Examination of thin sections of the matrix shows extensive alteration of the detrital hornblende and biotite to reddish-brown iron oxides.

Authigenic quartz, feldspar, and zeolites are present in minor amounts in some samples. Such authigenic minerals are common in volcaniclastic sandstones. A possible source of the chemical constituents of these minerals is volcanic glass which, as it devitrifies, provides pore water with all the components needed to form the authigenic minerals (Pettijohn, Potter and Siever, 1972, p. 428). However, volcanic glass was not an abundant constituent of the detritus which formed the Popotosa Formation. Diagenetic alteration and intra-stratal solution of the volcanic detritus seems a more likely source.

Deformation and Erosion

A long period of regional tectonic adjustments, principally uplift and block faulting, followed the deposition of the fanglomerate of Ladron Peak, the degradation of the Magdalena Mountains, and the volcanism in the Magdalena and Socorro Peak areas. Extensive volcanic activity in the Socorro area ceased about 11 m.y. B.P. The Popotosa basin was subsequently disrupted by a number of intra-basin horsts, such as those of the Socorro-Lemitar Mountains and the Bear Mountains, and Popotosa beds were tilted and eroded.

During this period of uplift and erosion, the Popotosa Formation was stripped from the northern Magdalena Mountains and the Bear Mountains were uplifted and tilted to the west. A thick section of La Jara Peak Andesite and the interbedded and overlying conglomerates of the Popotosa Formation were exposed along the western flank of the Bear Mountains. During Pliocene and Quaternary time, erosion dissected the tilted fault blocks of the Bear Mountains and developed extensive alluvial fans and pediment surfaces sloping into both La Jencia Basin on the east and the Mulligan Gulch graben on the west. In the Mulligan Gulch graben, pediment gravels sloping eastward off the Gallinas uplift have buried much of the fanglomerate of Dry Lake Canyon. A playa facies intertonguing with the fanglomerate of Dry Lake Canyon may exist farther to the west beneath these pediment gravels.

As a result of continued sporadic uplift in Pliocene and Quaternary time much of the Popotosa in the southern Magdalena Mountains was removed by erosion. The retreating alluvial fan depicted in Figure 28 is now represented in the present Magdalena Mountains by the fanglomerate facies located on South Baldy and in Water Canyon. During this latest episode of deformation, outcrops of the Popotosa Formation have been uplifted by as much as 5,000 feet in elevation relative to the basins. The Popotosa has been almost completely eroded on South Baldy and must have been greatly reduced in volume in the Water Canyon area.

The Socorro-Lemitar Mountains were uplifted and tilted to the west by numerous north-trending faults of Basin and Range style. The large vertical displacement along the eastern flank of the Socorro-Lemitar Mountains and the down dropping of La Jencia Basin to the west have imposed a westerly dip on most of the strata. Erosion following this deformation stripped much of the Popotosa that once covered the Oligocene volcanic rocks. The Popotosa Formation in the type area would also have been greatly reduced in volume if it had not been preserved by down-faulting along the San Augustin lineament. This prominent fault system truncates the north end of the Lemitar Mountains and forms the southern boundary of a downthrown trough that lies between the Lemitar Mountains on the south and the Ladron Mountain on the north (T. M. Woodward, oral communication, 1973). According to Woodward, the vertical displacement on the southern fault system of the San Augustin lineament is at least 2,500 feet in the area northeast of the Lemitar Mountains. The Cerro Colorado fault zone bounding the southern and eastern portions of the Ladron Mountain has a vertical displacement of several thousand feet and probably represents the bounding fault system of the lineament on the north. The type area has been extensively deformed by movements along the north-trending faults which were responsible for the uplift of both the Socorro-Lemitar and Ladron Mountains. During the Pliocene period of deformation and erosion, younger alluvium of the Santa Fe Group was deposited upon the tilted Popotosa Formation. In Late Pliocene or Early Pleistocene, another period of uplift deformed these younger Santa Fe beds (Denny, 1940, 1941). The major structural trends responsible for the tectonic development and deformation of the Popotosa Formation in the study area are shown in Figure 29.

These late Tertiary tectonic adjustments have greatly modified the original Popotosa basin. The western limit of the Popotosa basin has not been established with certainty but probably was the east flank of the Gallinas-San Mateo uplift. The eastern limit of the basin has not yet been delineated; however, exposures of volcanic conglomerates and mudflow breccias which are very similar in appearance to the Popotosa Formation occur in the Joyita Hills and suggest that the basin extended at least that far to the east. This would indicate that the Popotosa basin was at least 35 miles wide in an east-west direction. The northern boundary of the basin probably is along the southern border of the Colorado Plateau but the southern boundary prior to the uplift of the Magdalena Mountains is unknown. The uplifts of the Ladron, Bear, Socorro-Lemitar, and Magdalena Mountains are intrabasin horsts which have greatly modified the original Popotosa basin. Deformation is still active in the study area as indicated by the high seismicity in the Socorro area (Sanford, 1963, 1968, and Sanford, et al., 1972) and by the presence of numerous Pleistocene and Holocene fault scarps (Budding and Toppozada, 1970).

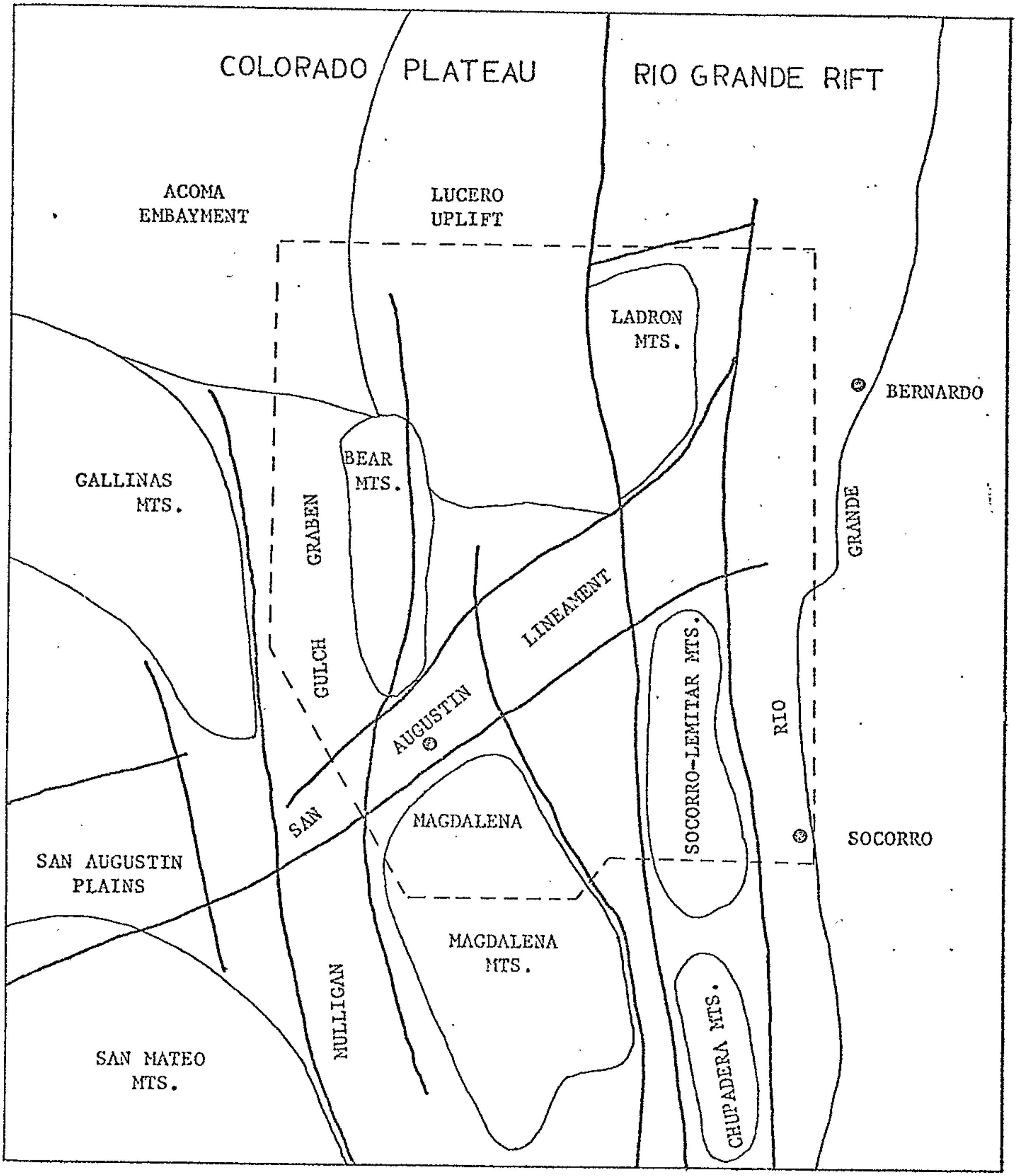


Figure 29. The major structural trends responsible for the tectonic development and deformation of the Popotosa Formation in the study area. Major fault zones ⁀, Scale 1 : 500,000.

CONCLUSIONS

1) The Popotosa Formation represents the basal Santa Fe Group along the east edge of the Mogollon-Datil volcanic field in Socorro County. It usually overlies volcanic rocks of Oligocene or Miocene age, but locally it overlies prevolcanic rocks. In general, it is the youngest well-indurated sedimentary unit present and is commonly overlain with angular unconformity by poorly indurated sedimentary deposits of the upper Santa Fe Group which contain higher proportions of prevolcanic detritus. Deposition of the Popotosa Formation began about 24 m. y. B. P. during the emplacement of the upper third of La Jara Peak Andesite and continued at least to late Miocene time when rhyolitic flows and domes were emplaced from the Socorro and Magdalena Peak volcanic centers. The upper limit of Popotosa deposition has not been established but it is believed not to have continued much beyond 11 m. y. B. P.

2) The Popotosa Formation is made up of conglomerates, sandstones, siltstones, and mudstones and to a lesser extent volcanic rocks. The sedimentary units contain a variety of clasts including silicic welded tuffs, andesite, basalt, granite, schist, quartzite, chert, limestone, and sandstone. Volcanic detritus greatly predominates except in the fanglomerate of Ladron Peak. Flow directions and diverse lithology indicate multiple source areas: the Colorado Plateau to the northwest; the Gallinas, San Mateo, and Magdalena

Mountains to the west, southwest, and south; the Ladron Mountains to the north; and the Polvadera Mountains in the center of the basin.

3) Maximum exposed apparent thickness of the fanglomerate facies, playa facies, and fanglomerate of Ladron Peak is about 5,500 feet; however, numerous faults make it difficult to determine the true thickness. The western half of the basin of deposition extends for a distance of at least 25 miles eastward from the Gallinas Mountains to the type area. The eastern half of the basin is outside the study area and appears to have been largely destroyed by erosion. The basin extends north-south at least 30 miles from the Magdalena Mountains to the Ladron Mountains. The original size and shape of the basin can be only partially reconstructed from the outcrop evidence not available.

4) The Popotosa Formation represents bolson deposition in an arid to semi-arid climate. Erosion of the surrounding highlands produced bordering alluvial fans which are now the fanglomerates. The coarse conglomerate facies were deposited principally by sheetfloods and partially by stream channels and debris flows. The alluvial-fan deposits are made up of poorly to moderately sorted fragments ranging from boulder to clay in size with a wide range in angularity. The coarse-grained sediments of the alluvial-fan deposits intertongue with the finer-grained sediments of the playa deposits. The change from the fanglomerate facies to the playa facies is gradational through an interval in which subequal quantities of inter-

bedded sandstones and conglomerates are present. The playa deposits consist of sandstone, siltstone, and mudstone of uniform texture that were deposited as thin, planar beds.

5) Deposition of the Popotosa Formation began about 24 m.y. B.P. during the emplacement of La Jara Peak Andesite. The Colorado Plateau began to rise shortly thereafter and shed detritus from the northwest into the Popotosa basin. The original basin was modified by uplift of the Magdalena Mountains; a long period of erosion ensued until this highland was buried beneath its own debris. During the degradation of the Magdalena Mountains, the Ladron Mountains were rapidly uplifted and the fanglomerate of Ladron Peak developed.

6) Sporadic volcanism occurred during deposition of the Popotosa Formation. The upper one third of La Jara Peak Andesite (24 m.y.) was emplaced during Popotosa deposition; very similar basaltic andesites were erupted later in the type area (andesite of Silver Creek, 16 m.y.) and along the Lemitar-Socorro Mountains. White ash-fall and water-laid tuffs were erupted from an unknown source shortly after emplacement of the andesite of Silver Creek. Silicic domes and flows were erupted at Magdalena Peak (14 m.y.) and Socorro Peak (11 m.y.) where they intrude Popotosa sediments.

7) A long period of block faulting, erosion, and deposition has formed the present topography. The original Popotosa basin has been greatly modified by uplift of several intrabasin horsts, such as the Bear, Magdalena, and Socorro-Lemitar Mountains. The

north end of the Magdalena Mountains has been truncated by downfaulting along the northeast-trending San Augustin lineament; the Popotosa Formation in the type area has been preserved by downfaulting along this lineament. Differential uplift of the central and southern parts of the Magdalena Mountains has vertically displaced the Popotosa by 3,000 feet between South Baldy and Water Canyon. The study area is still being actively deformed as indicated by the high seismicity and the presence of numerous Pleistocene and Holocene fault scarps.

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APPENDIX

Statistical Data for Pebbles

Legend of Abbreviations:

Detailed Lithology of Clasts

And	=	andesite
XRT	=	crystal-rich tuff
XPT	=	crystal-poor tuff
Ash	=	ash
FBR	=	flow-banded rhyolite
Gr	=	granite
Mo	=	monzonite
Qtz	=	quartzite
Sc	=	schist
Ls	=	limestone
Cht	=	chert
Ss	=	sandstone
MISC	=	miscellaneous
TP	=	total percent
TC	=	total number of clasts counted

Generalized Lithology of Clasts

T And	=	Tertiary andesites; And and MISC
T FV	=	Tertiary felsic volcanics; XRT, XPT, Ash, and FBR
TI	=	Tertiary intrusives; Mo
TV	=	Total Tertiary volcanics
LP	=	Late Paleozoic; Ls, Cht, and Ss
P€	=	Precambrian; Gr and Sc
Qtz	=	Quartzites
MISC	=	Miscellaneous
TP	=	Total Percent

Table 1. Lithology of clasts in the fanglomerate facies west of the Silver Creek fault.

Location	83	71	73	86	72	27	5	6	20	21-22	23	9-10	8	18
						Detailed Lithology of Clasts								
And	94.0	99.0	77.9	57.7	99.0	75.5	80.6	71.4	75.5	29.4	28.2	64.3	78.0	90.2
XRT			3.8	12.5		12.8	8.2	7.1		48.2	50.0	10.0	3.4	
XPT	4.0	1.0	18.3	26.9	1.0	3.2	11.2	11.9	13.2			12.8	13.6	3.9
Ash												1.2		
FBR														
Gr										2.7	1.9	.7		
Mo						7.4		1.2		1.8	1.0		3.4	3.9
Qtz				1.0						.6	1.9	1.3		2.0
Sc				1.9							1.0	3.5		
Ls									1.9	3.0	1.9	2.7	1.7	
Cht										.6				
Ss						1.1			8.5	13.7	14.1	3.4		
MIC	2.0								1.0					
TP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	100.0	100.0	99.9	100.1	100.0
TC	100	100	100	104	100.0	94	98	84	53	87	100	125	59	51

						Generalized Lithology of Clasts for Plate 2a								
T And	96.0	99.0	77.9	57.7	99.0	75.5	80.6	71.4	76.5	29.4	28.2	64.3	78.0	90.2
T FV	4.0	1.0	22.1	39.4	1.0	16.0	19.4	19.0	13.2	48.2	50.0	24.0	17.0	3.9
TI						7.4	100.0			1.8	1.0		3.4	3.9
TV	98.0	100.0	100.0	97.1	100.0	98.9		90.4	88.7	79.4	79.2	88.3	98.4	98.0
LP						1.1		7.2	10.4	17.3	16.0	6.1	1.7	
PC				1.9				1.2		2.7	2.9	4.2		
QTZ				1.0				1.2		.6	1.9	1.3		2.0
TP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	100.0	100.0	99.9	100.1	100.0

Table 1. (cont.) Lithology of clasts in the fanglomerate facies west of the Silver Creek fault.

Location	15
Detailed Lithology of Clasts	
And	100.0
XRT	
XPT	
Ash	
TBR	
Gr	
Mo	
Qtz	
Sc	
Ls	
Cht	
Ss	
MIC	
TP	100.0
TC	35

Generalized Lithology of Clasts for Plate 2a	
T And	100.0
T FV	
TI	
TV	
LP	
PC	
QTZ	
TP	

Table 2. Lithology of clasts in the playa facies west of the Silver Creek fault and in the fanglomerate of Ladron Peak.

	playa facies			
Location	84	85	26	25
		Detailed Lithology of Clasts		
And	87.2	77.7	51.8	70.9
XRT	1.0	3.9	13.3	7.6
XPT	11.8	16.5	28.9	6.3
Ash			4.8	
FBR				
Gr				
Mo			1.2	15.2
Qtz				
Sc				
Ls				
Cht				
Ss				
MIC		2.0		
TP	100.0	100.1	100.0	100.0
TC	102	103	83	79

		Generalized Lithology of Clasts for Plate 2b		
T And	87.2	79.7	51.8	70.9
T FV	12.8	20.4	47.0	13.9
TI			1.2	15.2
TV	100.0	98.1	100.0	100.0
LP				
PC				
QTZ				
TP	100.0	100.1	100.0	100.0

able 2. (cont.) Lithology of clasts in the playa facies west of the Silver Creek fault and in the fanglomerate of Ladron Peak

	fanglomerate of Ladron Peak											
Location	1	47	48	46	24	7	11	17	37	38	39	13
Detailed Lithology of Clasts												
And	32.2	29.1	26.0	51.1	30.0	14.1	18.8	23.8	17.7	28.3	68.8	59.7
XRT	5.7	17.5	12.5	14.7	5.6	4.7	12.9		5.7		1.1	3.9
XPT	10.0	17.5	9.6	7.4			12.9	1.0	6.3	.9	21.5	2.6
Ash	6.7							1.0				
FBR												
Gr		1.0	1.9	3.2		20.0	21.2	25.7	31.0	58.5	4.3	
Mo				1.1								
Qtz	2.2	1.0	1.9	3.2	3.3	3.5			13.7	2.8	3.2	6.5
Sc	8.9	2.0	1.0	1.1		16.5	4.7	44.6	9.5	9.4		18.2
Ls	21.1	23.3	36.5	12.8	56.7	40.2	27.1		15.8			2.6
Cht												
Ss	13.3	8.8	8.7	5.4	4.4	1.0	2.4	3.9			1.1	6.5
MIC			1.9									
TP	100.1	100.2	100.0	100.2	100.0	100.0	100.0	100.0	99.9	99.7	100.0	100.0
TC	90	103	104	94	90	85	85	101	158	106	93	77

Generalized Lithology of Clasts for Plate 2b												
T And	32.2	29.1	27.9	51.1	30.0	14.1	18.8	23.8	17.7	28.3	68.8	59.7
T FV	22.4	35.0	22.1	22.3	5.6	4.7	25.8	2.0	12.0	.9	22.6	6.5
TI				1.1								
TV	54.6	64.1	48.1	74.5	35.6	18.8	44.6	25.8	29.7	29.2	91.4	66.2
Lp	34.4	32.1	45.2	18.2	61.1	41.2	29.5	3.9	15.8		1.1	9.1
PC	8.9	3.0	2.9	4.3		36.5	25.9	70.3	40.5	67.9	4.3	18.2
QTZ	2.2	1.0	1.9	3.2	3.3	3.5			13.9	2.8	3.2	6.5
TP	100.1	100.2	100.0	100.2	100.0	100.0	100.0	100.0	99.9	99.9	100.0	100.0

Table 3. Lithology of clasts in the fanglomerate facies east of the Silver Creek fault.

Location	57-92	87	94	98	68	96	82	80	81	70	67	69	77	79
						Detailed Lithology of Clasts								
And	72.8	47.2	19.3	41.4	34.4	37.4	23.2	50.5	71.4	55.9	45.5	48.4	35.2	30.3
XRT	.9	5.6	10.1	3.6	2.1	52.3	12.5	21.3	5.1		24.7	5.2	12.0	7.9
XPT	3.1	10.1	8.2	18.0	63.5	10.3	64.3	28.2	23.5	43.0	24.7	42.3	47.2	59.6
Ash										1.1	2.1			
FBR	23.2	37.1	61.4	36.9										
Gr											1.0			
Mo														
Qtz												2.1	3.7	2.2
Sc													1.8	
Ls											1.0			
Cht														
Ss											1.0			
MIC														
TP	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	99.9	100.0
TC	102	89	109	111	98	107	112	98	98	93	97	97	108	103

Location	57-92	87	94	98	68	96	82	80	81	70	67	69	77	79
						Generalized Lithology of Clasts for Plate 2c								
T And	72.8	47.2	20.3	41.4	34.4	37.4	23.2	50.5	71.4	55.9	45.5	48.4	35.2	30.3
T FV	27.2	52.8	79.7	58.5	65.6	62.6	76.8	49.5	28.6	44.1	51.5	47.5	59.2	67.5
TI														
TV		100.0	99.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	97.0	95.9	94.4	97.8
LP											2.0	2.1		
PC											1.0		1.8	
QTZ												2.1	3.7	2.2
TP	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	99.9	100.0

Table 3. (cont.) Lithology of clasts in the fanglomerate facies east of the Silver Creek fault.

Location	2	3	4	35
Detailed Lithology of Clasts				
And	37.0	38.0	30.9	.8
XRT	23.4	24.1	23.6	
XPT	4.9	16.5	14.7	.8
Ash	1.2			
FBR				
Gr				30.2
Mo	1.2			
Qtz	4.9	1.3	5.9	14.3
Sc	3.7	6.3	7.4	19.8
Ls	12.3	1.3	5.9	32.5
Cht				.8
Ss	11.1	12.7	11.8	.8
MIC				
TP	99.7	100.2	100.2	100.0
TC	81	79	68	126

Generalized Lithology of Clasts for Plate 2c				
T And	37.0	38.0	30.9	.8
T FV	29.5	40.6	38.3	.8
TI	1.2			
TV	67.7	78.6	69.2	1.6
LP	23.4	14.0	17.7	34.1
PC	3.7	6.3	7.4	50.0
QTZ	4.9	1.3	5.9	14.3
TP	99.7	100.2	100.2	100.0

Table 4. Lithology of clasts in the playa facies east of the Silver Creek fault.

Location	91	97	95	78	29	32	31	34	36	76
Detailed Lithology of Clasts										
And	28.6	23.2	47.1	54.9	45.2	47.1	38.8	51.4	24.4	
XRT	7.6	3.2	24.5	16.8	8.6	16.7	14.3	14.7	3.4	
XPT	10.5	72.6	25.5	26.5	43.0	15.7	23.5	11.9	1.7	
Ash					2.2					
FBR	53.3	1.1								
Gr									23.5	
Mo										35.7
Qtz			2.9	1.8	1.1	7.8	8.2	1.8	11.8	
Sc									4.2	12.5
Ls						3.9	3.1	6.4	28.6	25.0
Cht										26.8
Ss						8.8	12.2	13.8	2.7	
MIC										
TP	100.0	100.1	100.0	100.0	100.1	100.0	100.1	100.0	100.3	100.0
TC	105	95	102	113	93	102	98	109	119	112
Generalized Lithology of Clasts for Plate 2d										
T And	28.6	23.2	47.1	54.9	45.2	47.1	38.8	51.4	24.4	
T FV	71.4	76.9	50.0	43.3	53.8	32.4	37.8	26.6	5.1	
TI										
TV	100.0	100.1	97.1	98.2	99.0	79.5	76.6	78.0	29.5	
LP						12.7	15.3	20.2	31.3	26.8
PC									27.7	60.7
QTZ			2.9	1.8	1.1	7.8	8.2	1.8	11.8	12.5
TP	100.0	100.1	100.0	100.0	100.1	100.0	100.1	100.0	100.3	100.0

Table 5. Lithology of clasts in the fanglomerate and playa facies west of the Bear Mountains.

	fanglomerate facies										
Location	65	64	61	53	62	63	51	90	52	88	99
	Detailed Lithology of Clasts										
And	27.7	25.7	37.2	17.1	23.4	23.0	54.3	67.3	67.9	76.0	49.5
XRT	41.0	35.4	11.6	35.1	26.6	44.0	1.1	.9	2.6		16.8
XPT	31.4	38.9	50.0	47.7	46.8	32.0	44.7	31.8	25.7	21.0	33.7
Ash			1.2								
FBR										1.0	
Gr											
Mo					3.2	1.0			3.8		
Qtz										2.0	
Sc											
Ls											
Cht											
Ss											
MIC											
TP	100.1	100.0	100.0	99.9	100.0	100.0	100.1	100.0	100.0	100.0	100.0
TC	83	113	86	111	94	100	94	107	78	100	101
	Generalized Lithology of Clasts for Plate 3										
T And	27.7	25.7	37.2	17.1	23.4	23.0	54.3	67.3	67.9	76.0	49.5
T FV	72.4	74.3	62.8	82.8	73.4	76.0	45.8	32.7	28.3	22.0	50.5
TI					3.2	1.0			3.8		
TV	100.1	100.0	100.0	99.9	100.0	100.0	100.1	100.0	100.0	98.0	100.0
LP											
PC											
QTZ										2.0	
TP	100.1	100.0	100.0	99.9	100.0	100.0	100.1	100.0	100.0	100.0	100.0

Table 5. (cont.) Lithology of clasts in the fanglomerate and playa facies west of the Bear Mountains.

	playa facies			
Location	60	59	50	89
	Detailed Lithology of Clasts			
And	38.0	100.0	36.6	28.7
XRT	17.7		2.4	
XPT	40.5		56.2	71.3
Ash	1.3		1.2	
FBR				
Gr				
Mo			3.7	
Qtz				
Sc				
Ls				
Cht				
Ss	2.6			
MIC				
TP	100.1	100.0	100.1	100.0
TC	79	85	82	94
	Generalized Lithology of Clasts for Plate 3			
T And	38.0	100.0	36.6	28.7
T FV	59.5		59.8	71.3
TI			3.7	
TV	97.5		100.1	100.0
LP	2.6			
PC				
QTZ				
Tp	100.1	100.0	100.1	100.0

Table 6. Lithology of clasts in the fanglomerate of Dry Lake Canyon.

Location	103	102	54	104	58
			Detailed Lithology of Clasts		
And	94.0	92.1	98.8	96.0	
XRT	2.0	5.0			
XPT	3.0	3.0		4.0	
Ash					
FBR					
Gr					
Mo			1.2		
Qtz	1.0				
Sc					
Ls					
Cht					
Ss					
MIC					
TP	100.0	100.1	100.0	100.0	
TC	100	101	83	100	

			Generalized Lithology of Clasts for Plate 4		
T And	94.0	92.1	98.8	96.0	
T FV	5.0	8.0		4.0	
TI			1.2		
TV	99.0		100.0	100.0	
LP					
PC					
QTZ	1.0				
TP	100.0	100.1	100.0	100.0	

Table 7. Lithology of clasts in isolated fanglomerate facies and upper Santa Fe Group exposures.

	Fanglomerate Facies					Upper Santa Fe Group Type Area		
	Cedar Spring	South Baldy	Water Canyon					
Location	75	14	55	56	93	A 19	B 35	C 40
Detailed Lithology of Clasts								
And	86.7	62.0	67.9	70.8	22.8	2.6	.8	
XRT	3.1	38.0	29.6	29.2	10.7			
XPT	10.2		2.5		38.1	2.6	.8	
Ash								
FBR					27.4			
Gr						4.4	30.2	
Mo								35.9
Qtz						.9	14.3	
Sc							19.8	33.7
Ls						75.4	32.5	30.5
Cht						6.1	.8	
Ss					1.0	8.0	.8	
MIC								
TP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1
TC	98	99	99	96	84	114	126	92
Generalized Lithology of Clasts for Plate 5								
T And	86.7	62.0	67.1	70.8	22.8	2.6	.8	66.4
T FV	13.3	38.0	32.1	29.2	76.2	2.6	.8	33.7
TI								
TV	100.0	100.0	100.0	100.0	99.0	5.2	1.6	
LP					1.0	89.5	34.1	
PC						4.4	50.0	
QTZ						.9	14.3	
TP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1

This dissertation is accepted on behalf of the faculty of the Institute by the following committee:

Charles E. Chapin
Adviser

Robert H. Weber

Allan R. Sanford

A. J. Budding

Christian L. Back

6/29/1973
Date

GENERALIZED GEOLOGIC MAP OF NORTHCENTRAL SOCORRO COUNTY, NEW MEXICO

JAMES E. BRUNING

1973

PLATE I

EXPLANATION

RECENT — 10,000 Y. — LATE MIOCENE—PLEISTOCENE — 11 M.Y. — MIOCENE — to — 24 M.Y. — OLIGOCENE—MIOCENE — to — 37 M.Y. — EOCENE — 65 M.Y.

Qal — Alluvium and stream gravels

Qt — Talus, landslide and colluvium

QTb — Basalt Flows

QTss — Upper Santa Fe Sediments overlain by sediment, terrace, and other deposits of sand, gravel, and caliche

QTsv — Santa Fe volcanics and intrusives

Basal Santa Fe Group

- Tpdl — Fanglomerate of Dry Lake Canyon
- Tpl — Fanglomerate of Ladron Peak
- Tpf — Fanglomerate facies
- Tpp — Playa facies
- Tps — Andesite of Silver Creek
- Tpa — Andesite undifferentiated

POPOTOSA FORMATION

SANTA FE GROUP

Ta — Tertiary andesites

Tfv — Tertiary felsic volcanics

Ti — Tertiary intrusives

Tb — Baca Formation

M — Mesozoic undifferentiated

P — Late Paleozoic undifferentiated Mississippian, Pennsylvanian, and Permian

p€ — Precambrian undifferentiated

Contact

Facies boundary

High angle fault U upthrown side D downthrown side

Primitive road

Unimproved road

Graded and drained road

Intermittent stream

Strike and dip of bedding

Strike and dip of foliation

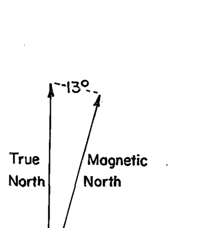
Flow direction

Pebble or cobble count location

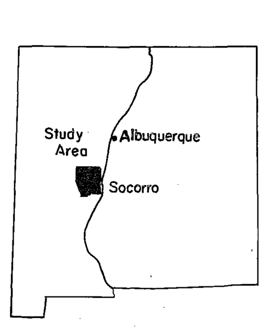
A — A' Type Section

SOURCES OF DATA

1. Black, B.A., 1964, Univ. New Mexico, masters thesis
2. Brown, D.K., 1972, New Mexico Tech, masters thesis
3. Burton, C., 1971, New Mexico Tech, unpub. report
4. Chapin, C.E., 1973, oral communication
5. Kelly, V.C., & Wood, G.H., Jr., 1946, U.S. Geol. Survey Oil and Gas Inv. Prelim., map 47
6. Kreweld, D.A., 1973, oral communication
7. Loughlin, G.F., & Koschmann, A.H., 1942, U.S. Geol. Survey Prof. Paper 200
8. Lowell, G.R., 1967, New Mexico Tech, unpub. report
9. Simmons, D.B., 1973, oral communication
10. Tonking, W.H., 1957, N.M. State Bureau of Mines & Mineral Resources, Bulletin 41
11. Woodward, T.M., 1973, oral communication



Approximate Mean Declination, 1964



Index map of New Mexico

Base map from General Highway, Socorro County, New Mexico, No. 28

SCALE 1:62500

GENERALIZED GEOLOGIC MAP OF NORTHCENTRAL SOCORRO COUNTY, NEW MEXICO

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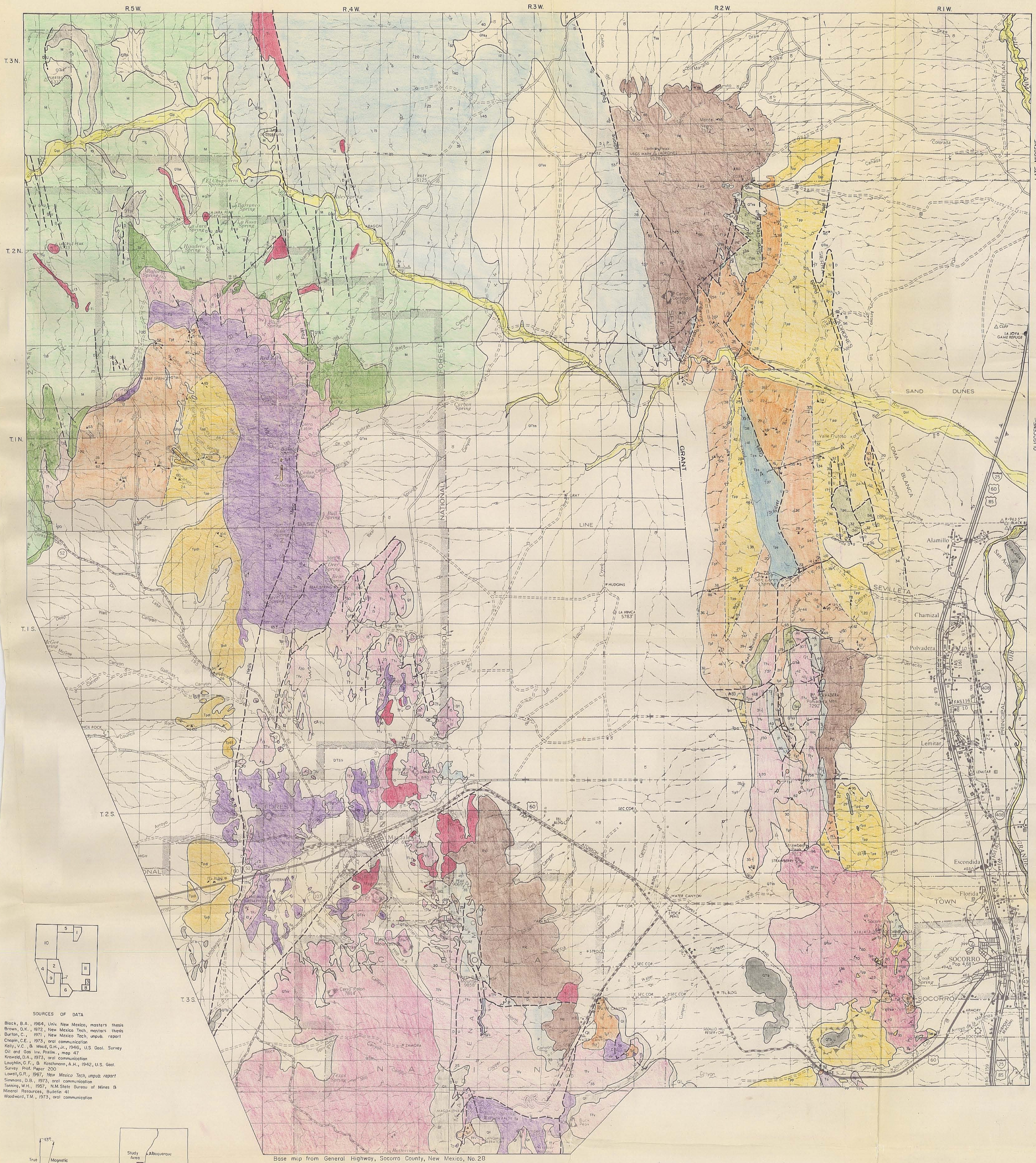
1973

PLATE I



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D downthrown side

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1 0 1 2 3 4 Mi.

3000 0 3000 6000 9000 12000 15000 18000 21000 Ft.

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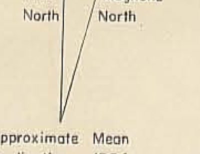

Approximate Mean Declination, 1964

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