LATE CENOZOIC GEOLOGY OF THE LOWER RIO PUERCO, VALENCIA AND SOCORRO COUNTIES, NEW MEXICO

by

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All are architects of Fate,
  Working in these walls of Time;
Some with massive deeds and great,
  Some with ornaments of rhyme.

Nothing useless is, or low;
  Each thing in its place is best;
And what seems but idle show
  Strengthens and supports the rest.

(from "The Builders")
Henry Wadsworth Longfellow
1807-1882

Acknowledgments

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ABSTRACT

Late Cenozoic Geology of the Lower Rio Puerco, Socorro and Valencia Counties, New Mexico.

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Sediments in the southern Albuquerque Basin may be divided into two broad categories; 1) the Santa Fe Group which represents a rapidly aggrading fluvial system filling the Albuquerque Basin, and 2) post Santa Fe valley fill sediments which include valley margin deposits and valley floor deposits. The latter group represents processes of erosion and deposition that have prevailed since the entrenchment of the Santa Fe basin fill. Primary difference between basin and valley fill is the geometry of the sedimentary deposits.

The Santa Fe Group is divided into two formations; 1) Miocene-Pliocene Popotosa Formation which consists of piedmont and playa facies deposited in a closed basin, and 2) Pliocene to Mid Pleistocene Sierra Ladrones Formation. The Sierra Ladrones was deposited primarily by a high gradient, low sinuosity, flat-bottomed braided streams. Sierra Ladrones basin fill is characterized by gravelly sand

and sand in very broad sheet-like deposits in a stacked sequence. Two facies are suggested based on composition and texture of gravels: 1) a through-flowing fluvial facies, and 2) an alluvial facies associated with marginal piedmont slopes. Paleocurrent indicators and the presence of Grants obsidian in the Sierra Ladrones fluvial facies indicates a source area to the northwest outside the Albuquerque Basin.

The Llano de Albuquerque landform and associated soil capping the Sierra Ladrones Formation represents a period of surface stability and soil formation on the Albuquerque Basin floor during middle Pleistocene time. The geological history of the basin envolves at least 3, and possibly 4, periods of faulting that began at the time of the development of the soil associated with the Albuquerque surface or earlier.

Valley fill deposits are dominated by narrow, elongate bodies in a stepped sequence of inset fills that can be divided into older and younger valley fill deposits. Two facies are recognized; 1) meandering alluvial facies of the Rio Puerco and associated valley floor deposits, and 2) braided tributary arroyo systems and associated valley margin deposits. Post Santa Fe sediments record a sequence of down cutting and back filling intervals separated by periods of surface stability and soil formation. Cross cutting relationships, gravel composition, and stepped sequences provide evidence for at least three and possibly four major periods of valley down cutting and back filling.

Evidence for at least 3 periods of major channel cutting and back filling are revealed in the younger Rio Puerco Valley fill. Two periods of minor channel back filling are recorded at Comanche Arroyo and stratigraphic site 1. Age of the minor back filling ranges from about 3000 years to the present.

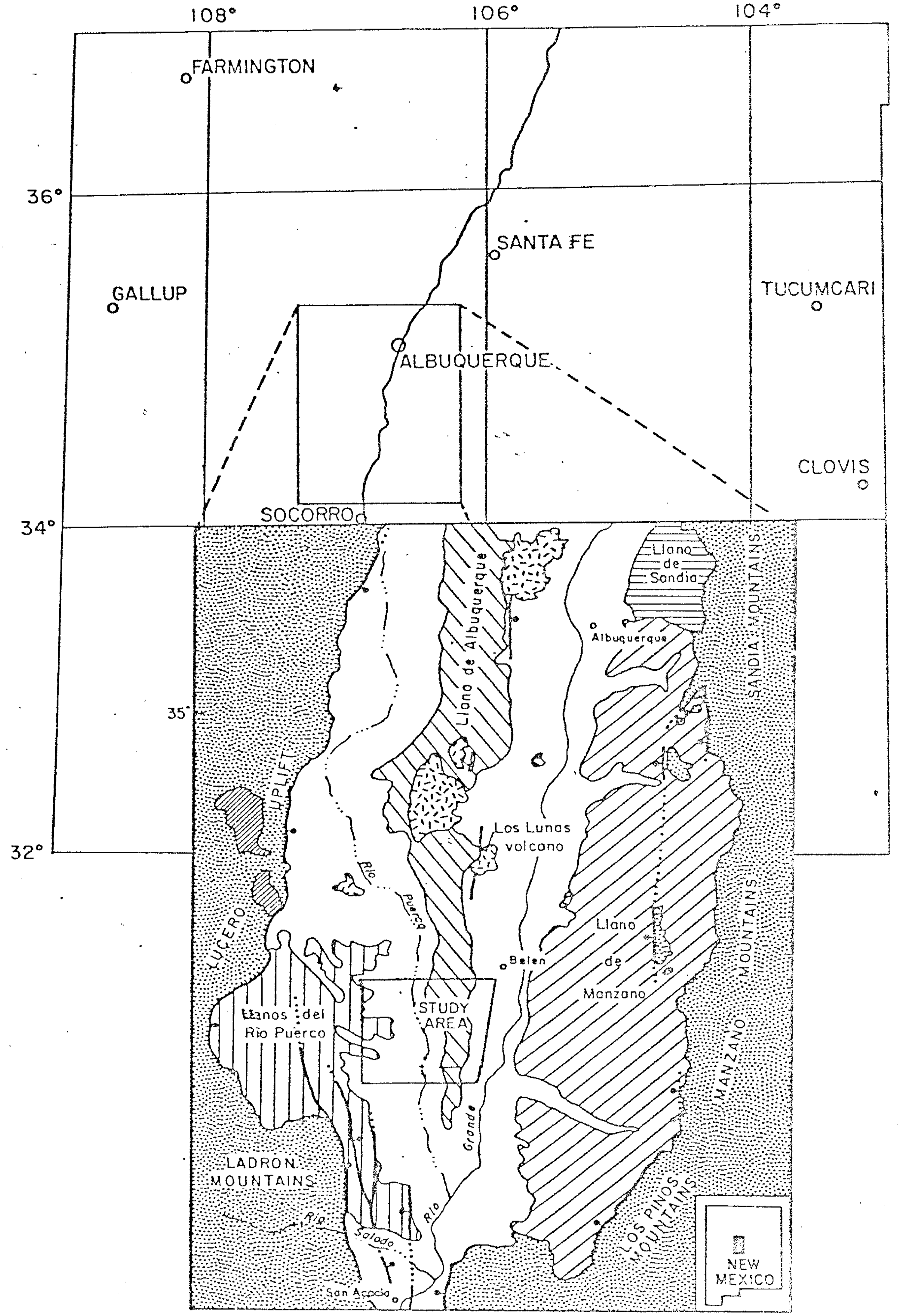
INTRODUCTION

The valleys of the Rio Grande and Rio Puerco in the southwestern Albuquerque Basin of central New Mexico are now entrenched over a hundred meters into a former high level of basin fill (Figure 1). The study of strata and landforms in these valleys offers an excellent opportunity to try to piece together the Late Cenozoic geologic history in generally unconsolidated sedimentary rocks. Most conventional geologic studies fail to provide the information needed to reconstruct this history.

Primary Aims

The primary aim of this study is to determine the Late Cenozoic history of the study area. Detailed study was limited to the Upper Tertiary and Quaternary basin fill. Subsidiary aims are to; 1) describe the stratigraphy, and geometry of the Santa Fe and younger sediments, 2) place these units in a sequence and correlate them laterally with other units, 3) determine the chronology through as much of the sequence as possible, 4) produce a map and cross sections based on this extended stratigraphy, 5) differentiate between gravels of piedmont and axial channel deposits by pebble counts and include a determination of provenance area 6) determine source area or areas of sediments by comparing trace element concentration in collected obsidian to known standards of source areas, and 7) use the map and cross sections as a conceptual model for explaining the Late Cenozoic history of both the study area

Figure 1. Index and general sketch map of the Albuquerque Basin, New Mexico. Lined patterns denote areas where large segments of the ancient (pre-valley) basin topography is preserved.


108°
106°
104°
36°
34°
32°
35°
FARMINGTON
SANTA FE
GALLUP
TUCUMCARI
ALBUQUERQUE
CLOVIS
SOCORRO
Llano de Sandia
Llano de Albuquerque
Albuquerque
SANDIA MOUNTAINS
LUCERO UPLIFT
Los Lunas volcano
Rio Puerco
Llano de Manzano
Belen
MANZANO MOUNTAINS
Llanos del Rio Puerco
STUDY AREA
Rio Grande
LADRON MOUNTAINS
Rio Salado
LOS PINOS MOUNTAINS
San Acacia
NEW MEXICO

and the surrounding region. The maps and cross sections have allowed me to expand on the geologic development of the region.

Location

The area of the Albuquerque Basin encompassed by this study (Figure 1) lies about 65 km southwest of Albuquerque, New Mexico, in Valencia and Socorro Counties (Figure 1). It is bounded by north latitudes 34 30′ and 35 31′ and west longitudes 106 47′30" and 106 57′. Topographic coverage is provided by the USGS Belen SW, and Veguita 7.5′ quadrangle maps and U.S. Corps of Engineers Orthophoto maps (1979).

Regional Geologic and Geomorphic Setting

The Albuquerque Basin is a structural basin that trends in a north-south direction for 125 to 150 km and varies in width from 30 to 50 km. Figure 1 shows the basin and bordering uplifts. Down faulting on the western side of the basin appears to be less than 340 m whereas on the east side it could be as much as 6800-7000 m. (Kelley, 1977). The eastern boundary is formed by the Manzano-Sandia uplift and the western boundary is formed by the Lucero and Ladron uplifts. The southern end of the basin is defined by an alluvial and structural divide at the entrance to the Socorro constriction near San Acacia, New Mexico.

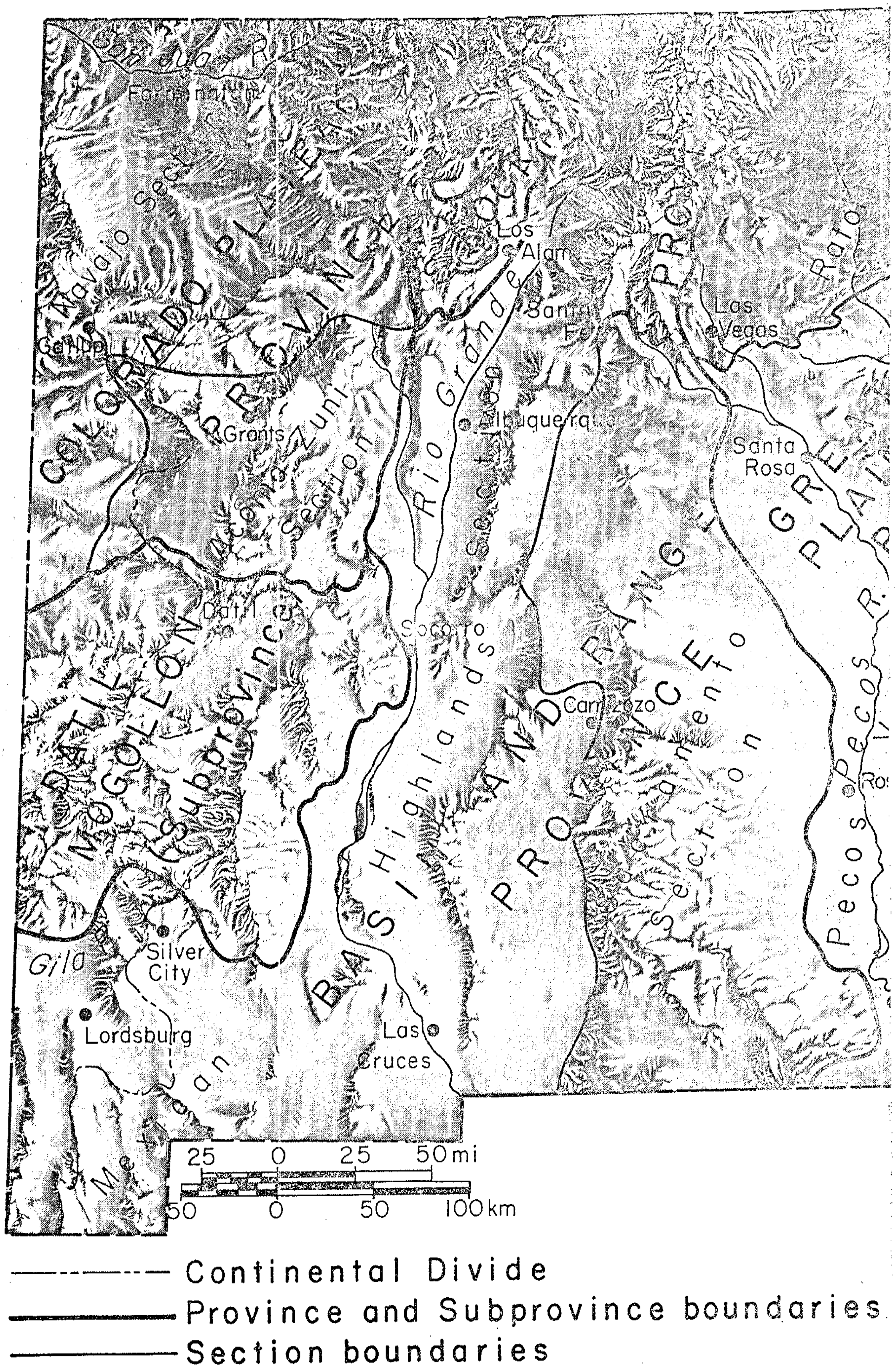
The study area covers a small section within the

Albuquerque Basin which is located within the Mexican Highland section (Figure 2) of the Basin and Range Province (Fenneman, 1931). This part of the Mexican Highland is a deep structural depression between mountains and upland plains flanking the Rio Grande Rift (Hawley, 1978). The Rio Puerco and Rio Grande flow southward through an alternating series of broad and restricted valley reaches coinciding with an en echelon series of structural basins separated by uplifts of resistant rocks.

The Rio Grande drains the eastern and central portions of the basin while the Rio Puerco drains the western portion of the basin. Between the two rivers is a long narrow tableland known as the Llano de Albuquerque. The western rim of the Llano de Albuquerque is known as the Ceja de Rio Puerco or the "Eyebrow of the Dirty River", and the less prominant and less regular eastern rim is known as the Cejita Blanca or the "Little White Eyebrow (Bryan and McCann, 1938)." West of the Rio Puerco are a number of surfaces and associated valley fills that slope, in general, to the main drainages and grade to different elevations above the present flood plain. This composite slope west of the Rio Puerco is referred to as the Llanos del Rio Puerco (Titus, 1963). Major tributaries entering the Rio Puerco from the west are, from north to south , Comanche Arroyo, and Alamito Arroyo.

Previous Investigations

Figure 2, Location of major physiographic features and towns mentioned in the text (from Hawley and Love, 1981).



San Juan R.
Farmington
Navajo Sect.
COLORADO PLATEAU PROVINCE
Gallup
Grants
Acoma-Zuni Section
Los Alamos
Santa Fe
Rio Grande Section
Albuquerque
Las Vegas
Raton
Santa Rosa
GREAT PLAINS
Pecos R.
Pecos Valley
Pecos
Ros
DATIL-MOGOLLON Subprovince
Datil
Socorro
BASIN AND RANGE PROVINCE
Highlands Section
Carrizozo
Sacramento Section
Gila
Silver City
Lordsburg
Las Cruces
Mexican
25 0 25 50 mi
50 0 50 100 km
Continental Divide
Province and Subprovince boundaries
Section boundaries

Any discussion of previous work in the Albuquerque basin should begin with that of Bryan (1925, 1928, 1938, 1940, 1941) and his students. Kirk Bryan wrote his undergraduate thesis in 1909 on the Albuquerque Basin and, as seen by the list of publications, his interest in the area continued for many years. Bryan and McCann (1937, 1938) described the stratigraphy, structure and geomorphology of the Rio Puerco. Denny (1940, 1941, 1967) inquired into the development of fans and pediments in the southwest section of the basin. Wright (1946) made the most important contributions to the understanding of the area with his dissertation dealing with the origin, deformation, and dissection of the basin deposits. Kelley (1952, 1977) began work in the Rio Grande Valley in 1937 and his understanding of the local geology has influenced students since that time. Both Wright and Kelley investigated the evolution of the basin. Lambert (1968) studied the sediments in the Albuquerque region.

A number of authors have contributed toward trying to understand the entrenchment of the modern Rio Puerco. These include: Calkins (1941), Leighly (1936), and Tuan (1966). Betancourt (1980) provided a historical overview of the lower Rio Puerco-Rio Salado drainages.

Schumm (1960, 1961), co-workers (Schumm and Hadley, 1957), and students (Elliott, 1979, and Patton, 1973) examined the dynamics and morphology of modern river systems including the Rio Puerco. The U.S. Geologic Survey and Soil Conservation Service have conducted a number of studies on sediment transport and sediment accumulation. These include: Nordin (1963), Nordin and Curtis (1962), Happ (1948), and Rittenhouse (1944). Thomas and others (1963) studied the effects of drought on the Rio Grande Valley. Pease (1975) and a group from the Soil Conservation Service completed a detailed soil survey in the eastern part of Valencia County. The Socorro County soil survey will be released in the near future.

More recent work has been accomplished by Machette (1978a, 1978b, 1978c, 1978d) who quantified soil development related to episodic movements on faults. Hawley is presently conducting a number of studies on stratigraphy, geomorphology and environmental geology in cooperation with Love (Hawley and Love, 1981, Love and others, 1982).

Methods

Field work for this study was started in January of 1981 and has continued, with occasional interruption, to the present. Reconnaissance field work was also done outside the study area with special attention given to the geology of the Santa Fe Group and post-Santa Fe alluvium.

Geologic units were mapped on 1954 and 1979 air photos (scale 1:48000 and 1:10000 respectively) and contacts were transfered to a base map (Plate 1, scale 1:24000) using a Bausch and Lomb "Zoom Transfer Scope". Contacts were interpreted on aerial photographs only after considerable field observations. Geologic maps were then field checked.

Geomorphic surfaces and associated deposits have characteristics of rock-stratigraphic units in that they include bodies of material with definable boundaries. Geomorphic surfaces are defined as mappable landscape units, specifically defined in terms of space, time and associated pedogenic features (Gile and others, 1981). Morphostratigraphic units (Frye and Willman, 1962) are mappable bodies of earth material related genetically to a constructional phase of a specific geomorphic surface (Gile and others, 1981).

Map units of alluvial sediments and landforms are generalized and include a number of landscape settings. Detailed maps and cross sections of specific areas are included in the report to demonstrate the local complexity encountered in generalized mapping. Several cross sections were constructed to illustrate stratigraphic, structural, and geomorphic relationships of basin and valley fill.

A total of four stratigraphic sections were described and measured using a Brunton compass and Jacob's staff. Color was determined using a Munsell soil color chart. Size was determined using visual comparison with a calibrated size chart. Texture was recorded using terminology outlined by the U.S. Department of Agriculture, Soil Conservation Service. Locations of sections are shown on Plate 2 and measured sections are included in appendices. A generalized composite section is presented below.

Obsidian pebbles collected from measured sections was analyzed using X-ray fluorescence to determine major and minor element concentrations. Trace element concentrations from collected obsidian were then compared to those from known source areas using ternary diagrams.

Ten surficial samples of gravel were collected from locations on structural benches and terraces to characterize facies in the area. Sample locations are shown on Plate 2 and gravel counts are included in the appendix. Samples in the first traverse were taken in three size grades, 13.2 mm to 18.8 mm, 18.8 mm to 38.1 mm and greater than 38.1 mm. In later traverses only gravels greater than 18.8 mm were collected. At each location all gravel greater than 18.8 mm in a 0.06 cu m volume was counted.

Many workers (see Previous Investigations) have commented on the fluvial origin of the sediments in the southern Aluquerque Basin. Fluvial systems in this study are classified into two end-member models according to channel pattern and the degree of sinuosity of the channel. A review of these two systems is presented in appendix A. The two end-member fluvial models or facies are: 1) high-sinuosity meandering stream facies, and 2) low-sinuosity braided stream facies.

GEOLOGIC UNITS

Upper Cenozoic deposits along the lower Rio Puerco may be subdivided into two broad categories based on age, lithology and morphology. These are: 1) Santa Fe Group basin fill which is characterized by piedmont, flood plain, and axial channel facies, and 2) post Santa Fe valley fill which includes valley margin and valley floor deposits. The latter group represents processes of erosion and deposition that have prevailed since the entrenchment of streams through the Santa Fe Group basin fill. Both groups contain many of the same types of sediments that, at times, are difficult to differentiate. The primary difference between basin and valley fill is the geometry of sedimentary bodies. Very broad sheet-like bodies dominate the stacked sequence of basin fill, while narrow, elongate bodies in stepped sequence of inset fills characterize the valley depositional units.

Santa Fe Group

Definition.

The stratigraphic nomenclature of the Santa Fe Group has evolved into a complex and confusing sequence of names that continues in a state of flux. A major obstruction to any study dealing with the Santa Fe is to sort through the labyrinth of terminology. Rocks of the Santa Fe Group extend from central Colorado to Mexico along the drainage of the

Rio Grande. Hayden (1869, c.f., Kelly, 1977) first named outcrops north of Santa Fe as the Santa Fe "Marls". This unit gradually encompassed the fill of other basins and became known as the Santa Fe Formation (e.g. Denny, 1940, Wright, 1946) which was eventually raised to group rank as discussed by Hawley and others (1969, 1976) and Kelley (1977). Hawley and others (1976) state that the proposal by Galusha and Blick (1971) to restrict the term Santa Fe to the Espanola Basin has merit but the term is ingrained in the literature and redefinition now seems illadvised. Kelley (1977) believes that the Group term should not be used in the Albuquerque Basin until the succession can be better and more consistently divided. Machette's (1978c) formation and group concepts developed in the southern Albuquerque Basin are used in the report and are discussed below. The Santa Fe Group as used in this report is the rock-stratigraphic unit that comprises the bulk of the Upper Cenozoic basin fill of the Albuquerque basin. Several deep oil tests have been drilled north of the study area and have estimated the thickness of the Santa Fe Group to be between 1100 and 5000 meters (Hawley, 1978). The Santa Fe Group does not include sediments deposited since the entrenchment of the Rio Grande and Rio Puerco Valleys.

Principal types of deposits.

Santa Fe age deposits related to the development of the Albuquerque Basin are now considered to be Miocene (Kelley, 1977, Hawley, 1978, chart 2) or younger. Chapin and Seager (1975) believes that there are Santa Fe deposits as early as Late Oligocene. Wright (1946, p. 399)) explains the two principal types of deposits found in a developing basin.

> "For the purpose of the present discussion: only two types (of basins) are considered: 1) basins which have surface outflow and 2) basins which do not have surface outflow.
>
> Other factors being equal, basins drained by a surface stream of major size will have two principal types of deposits: (a) alluvial-fan deposits consisting of gravel near the mountains and grading into sand, silt, and even clay toward the axis of the basin, and (b) river gravels distributed along the axis of the basin, with some sand, silt , and clay. If the river originates outside the basin, the river gravels may include resistant well-rounded pebbles derived from a distant source. Basins with no surface outflow will also have two types of deposits: (a) a peripheral band of alluvial-fan material, and (b) a central area of playa or lake deposits consisting of fine sand, silt and clay with gypsum and other chemical precipitates and evaporites."

Formations in the Santa Fe Group.

Dividing the Santa Fe Group into formations or members is also a perplexing situation, all the various names suggested by different authors constitute a long list. Machette (1978c) divides the deposits into units based on the distribution of sedimentary facies found in a developing basin. His nomenclature will be adopted in this study. Nomenclature and major subdivisions of the Santa Fe are briefly described in Table 1.

Popotosa Formation

The lower subdivision of the Santa Fe Group in the southern Albuquerque Basin is the Popotosa Formation (Machette, 1978d). The Popotosa Formation was named and described by Denny (1940) from exposures along Arroyo Popotosa, a small tributary of the Rio Salado. It overlies volcanic rocks of Datil-Mogollon region equivalent to the

Table 1, Outline of Santa Fe Group in and near the southern Albuquerque basin.

Sierra Ladrones Formation; Early Pliocene to Middle Pleistocene; upper formation of the Santa Fe Group. Type area in San Acacia Quadrangle (Machette, 1978c); consists of several intertonguing facies of through-flowing basin type deposits; estimated thickness is about 470 m (Machette, 1978c). Facies include

Piedmont Slope Facies; primarily alluvial fans and coalescent fan deposits intertonguing and overlapping with

Basin Floor Facies; mainly river sands, gravels, and flood plain deposits of a through-flowing axial river or rivers.

Popotosa Formation; Early to Late (?) Miocene; lower formation of the Santa Fe Group; type area in Popotosa Arroyo west of San Acacia, New Mexico (Denny, 1940); Popotosa consists of several intertonguing facies of intermontane basin type deposits; estimated thickness is over 1400 m (Wright, 1946). Facies include

Fanglomerate Facies; primarily gravelly alluvial fan deposits which include two sub-facies, a Ladron Mountain facies and a volcaniclastic facies; Laterally transitional to

Playa Facies: fine to medium grained silt clay to sand. Contains primary (bedded) and secondary (cross-cutting) gypsum.

Datil Formation of early workers. In general the Popotosa is intermontane basin fill, consisting of fanglomerate and playa deposits. Two fanglomerate sub-facies are recognized; Ladron Mountain fanglomerate and volcanoclastic fanglomerate. The unit ranges from Late Oligocene to Late Miocene in age (Chamberlin, 1981; Hawley, 1978, chart 2) Outcrops of the Popotosa are not found in the study area although good exposures occur to the west southwest near the Ladron Mountains and to the south in the San Acacia area. Popotosa equivalents occur in the undifferintiated "middle Red" Santa Fe section mapped in the Gabaldon Badlands by Wright (1946) and Kelley (1977). Tedford (1981) recently described a Late Miocene vertebrate fauna from the upper part of the lower Santa Fe Group of Clarendonian age. Absolute age on the fauna is between 12 and 8 m.y. (Tedford, 1981). The Popotosa and lower Santa Fe correlatives represent the bulk of the Albuquerque Basin fill, although they are only exposed locally around the basin margins (J. Hawley, 1982, personal communication).

Sierra Ladrones Formation, QTsl

Definition.

The upper subdivision of the Santa Fe Group in the study area is the Sierra Ladrones Formation. It is the most extensive Upper Cenozoic deposit exposed in the southern part of the Albuquerque Basin. The Sierra Ladrones

Formation as used here is roughly the equivalent to Wright's (1946) Upper Buff Member; and the upper, very gravelly parts of the Formation are equivalent to Kelley's (1977) Ceja Member. To the south, the Sierra Ladrones more or less correlates with the Camp Rice and Fort Hancock Formations as used by Hawley and others (1976). The type locality for the Sierra Ladrones (Machette, 1978c) is a composite section in the San Acacia Quadrangle. Basalt flows are included in the Sierra Ladrones although none are found in the study area (Machette, 1978c). Sierra Ladrones sediments mark the final stage of aggradation of the Albuquerque Basin , as well as initial development of the Rio Grande system.

Distribution, thickness and contacts.

The most complete exposures of the Sierra Ladrones Formation crop out west of the Rio Grande and east of the Rio Puerco. Best exposures are found directly below more resistant surfical deposits and soils (Figure 3) and adjacent to incised first and second order tributaries. Lower exposures become covered with a thin veneer of alluvium that grades downslope into younger valley border deposits.

The youngest Sierra Ladrones beds underlie constructional components of the Llano de Albuquerque landform (Hawley and others, 1976; Machette, 1978). The term Albuquerque geomorphic surface or Albuquerque surface is informally in this report used to designate relict components of the Llano de Albuquerque associated with well-developed calcic soils. Horizons of carbonate accumulation in these soils are up to several metres thick (Machette, 1978b). They are formed in the uppermost Sierra Ladrones beds and thin veneer of surficial sediments, primarily reworked from the Sierra Ladrones Formation. The contact between the Sierra Ladrones and overlying soils of the Albuquerque surface is commonly slightly discordant and locally exceeds 1 degree. Although the base is not exposed in the study area, it has been suggested that the Sierra Ladrones Formation is angularly unconformable on the Popotosa or older formations (Machette, 1978c).

Figure 3. Sierra Ladrones Formation and overlying Albuquerque surface with associated soil. West of mile post 183 on Inerstate 25.

The upper contact of the Sierra Ladrones is easily established on air photos at the light colored band of calcic soil forming the rim of the Albuquerque Surface. The delineation of the lower part of the exposed section is more arbitrary and is placed at the break in slope between the steeper part of the Ceja del Rio Puerco and Cejita Blanca escarpments and the undulating gentler slope of the valley margin deposits.

Four measured sections from the study area are included in the appendix. The longest section measured was 109 metres.

Lithologic character.

The Sierra Ladrones consists of depositional units 1 to about 8 m thick of gravel, sand, and clay. Bedding is tabular to wedge-shaped and bedding surfaces are generally planar. Gravelly sand and gravel units are most abundant in the upper 45 m although present throughout the section. These coarse-grained units generally contain channels and cross-bedding. Grain size fines upward . Gravel lithology is mixed and contains chert, quartzite, volcanics, sandstone, granite, mudstone, and minor amounts of limestone, and obsidian. Significant amounts of limestone are present in the Sierra Ladrones gravels west of the Rio Puerco. Felsic and mafic volcanics appear to be present in all gravel units. Percentages of obsidian, and other volcanics appear to increase upward in the section. Gravels range in roundness from angular to well rounded and are in the pebble to cobble size range. Beneath the gravelly part of the section, although similar gravels are found scattered throughout the section, the characteristic sediments consist of light brown (10YR7/3) to reddish brown (5YR5/6) sand. Sand units are generally quartz rich and contain very little, if any, clay-silt material. Sand size ranges from fine grained, well sorted to coarse grained, poorly sorted. Sand units generally fine upward. Thin to thick layers of reddish brown (5YR5/6) to strong brown (7YR5/6) overbank clays and loams are scattered throughout the section. Clay units pinch out laterally or change facies. Sand and gravel units are generally nonindurated although discontinuous beds of sandstone and conglomerate cemented with sparry calcite are present. Cemented units exhibit trough cross-bedding and channeling that indicate a southerly current direction, with variations ranging from southeast to southwest. Gravel and cemented sandstone units produce resistant horizons that extend into the valley as structural benches.

Fossils in the Sierra Ladrones Formation

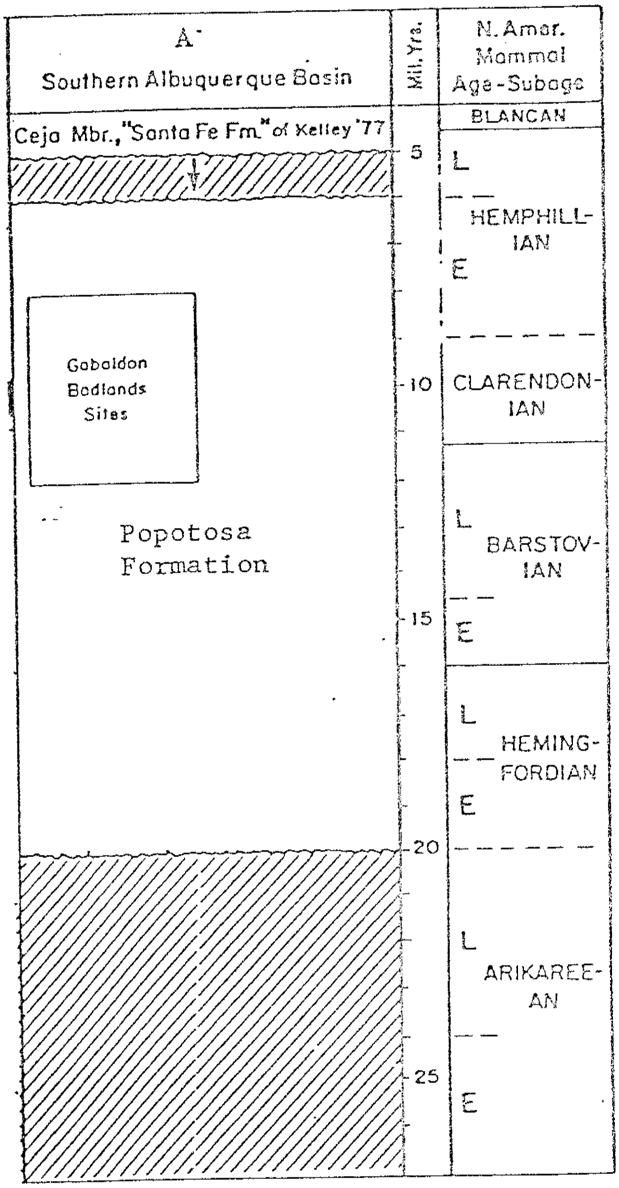
Three concentrations of fragmentary bones and teeth were found in Section 2 (located on Plate 2) at 25, 37, and

57m down from the Albuquerque surface. All concentrations were in sandy gravel. Material includes a fragment of a equine cheek tooth and fragments of elephant tusk enamel (Donald Wolberg, 1982, personal communication). Other material is too badly preserved for identification but includes limb and skull fragments. A limb bone of an elephant was found at a similar level within the Sierra Ladrones Formation west of Belen (H. Kuenzler, 1980, personal comunication).

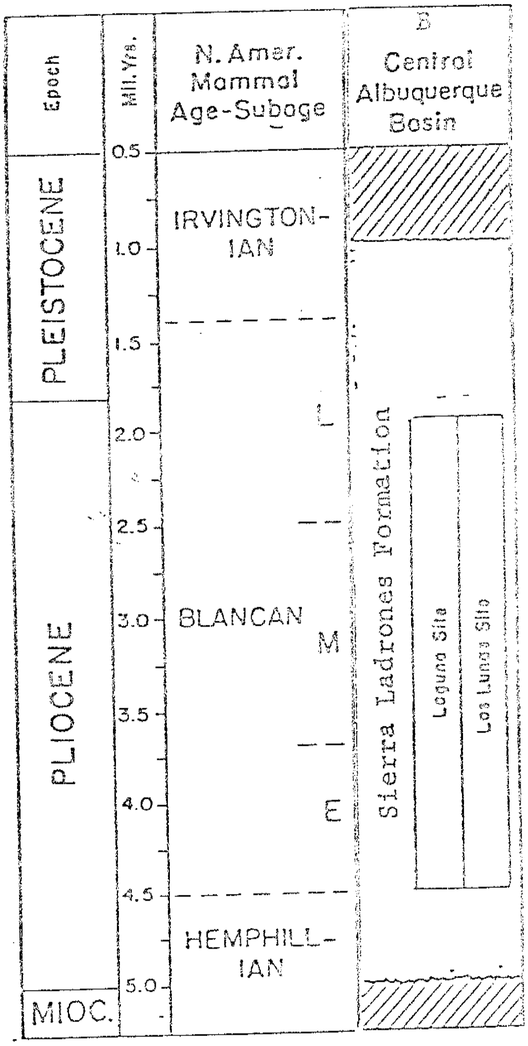
Tedford (1981) reports that southwest of Albuquerque, fossil remains have been found at two sites attributed to the "Ceja Member" (my Sierra Ladrones). A jaw fragment of a giant marmot was collected from the Santa Fe beds near where State Highway 6 ascends the Cejita Blanco scarp. According to Tedford this taxon is confined to the Blancan fauna of the southwest. West of Los Lunas where the boundary of the Isleta Pueblo Grant crosses the Ceja de Rio Puerco the "Ceja Member" contains small mammal, bird and turtle remains. The most abundant taxon in this assemblage is a gopher assigned to a Late Blancan form.

Tedford's (1981) data are best summarized by the columnar section illustrated in his paper. Column A and B (Figure 4) gives the lithostratigraphy of the study area as used by Kelley (1977). This information is then juxtaposed against a relative time scale of biological events that have been calibrated by radiometric dates from widely scattered parts of the United States. Tedford's information indicates that the Sierra Ladrones in the southern Albuquerque basin is probably Blancan and Irvingtonian in age. Absolute age of these faunas is between 4.5 and 1.5 m.y..

Figure 4. Lithostratigraphy and Biochronology of the central Albuquerque Basin.



Miocene



Pliocene to Pleistocene

Llano de Albuquerque landform and Albuquerque surface, Qla.

The Llano de Albuquerque is a constructional landform on the basin fill of the Sierra Ladrones Formation and is the summit of a long (120 km) narrow (20 km in the north, pointed in the south) tableland or mesa that separates the Rio Grande and Rio Puerco drainages. It extends from northwest of Albuquerque at an elevation of 2300m above see level to 1525 m northwest of Bernado. Slope on the plain south of Belen is generally to the southwest. This high-level plain is bounded by relatively steep escarpments that are as much as 100 m high in the southern part of the Albuquerque basin.

The Albuquerque geomorphic surface, an informal term, and associated strong calcic soils occupies the the most stable parts of the Llano de Albuquerque landform. During middle Pleistocene the Albuquerque surface formed part of a broad basin-floor plain, which included aggrading fluvial systems of one or more major streams, and adjacent piedmont slopes (J. Hawley, 1982, personal communication). Soil parent material includes not only the uppermost beds of the Sierra Ladrones Formation but also discountinuous surficial veneers of alluvial-colluvial-eolian material reworked from Sierra Ladrones beds exposed along low fault scarps and upwarped areas of the Llano de Albuquerque. Surficial sediments of the Albuquerque surface are generally composed of a light brown, sandy loam that locally has scattered pebbles. As a mapping convention these materials with superimposed horizons of soil carbonate and clay accumulation are here used to define both the top of the Sierra Ladrones Formation and the Albuquerque surface. The surface of the Llano de Albuquerque has been covered locally by sheets and dunes of eolian sand. Depositional units on the Llano de Albuquerque, which bury or are inset below the strong calcic soil of the Albuquerque surface are excluded from the Sierra Ladrones Formation. Examples of such units include fills of closed depressions and sand deposits. Mapping boundaries for the Albuquerque surface and Llano de Albuquerque are easily established on air photos by the light colored calcic horizon and sharp break in slope.

Calcic soils that underlie the Albuquerque surface have two basic morphologies: 1) one thick zone of pedogenic carbonate or 2) several thinner zones of pedogenic carbonate separated by low-carbonate material (Figure 5). Thickness of the calcic horizon ranges from about 1.5 m to about 3 m. The single thick calcic horizon indicates a long period of stability at the surface. Degree of carbonate-horizonal development is a strong stage III or a weak stage IV (using terminology of Gile and others, 1966). Multiple calcic horizons in a stacked sequence of sediments as much as 20 m thick indicate periods of stability separated by episodes of tectonic or geomorphic instability. Calcic horizons, like those underlying the Albuquerque surface, are considered pedogenic in origin by several lines of evidence; 1) they parallel the soil surface, 2) their upper boundary occurs beneath horizons containing relatively little carbonate, 4) they occur in sediments with a range of composition and textures, and 5) they occur in a morphologic and genetic sequence of development (Gile and others, 1966). Among other factors, this development sequence is also related to time; the amount of carbonate accumulation increases with increasing age of soil. Maturity of the Albuquerque surface soil has been roughly correlated to that of the La Mesa Surface of southern New Mexico and the Mescalero caliche of southeastern New Mexico (Bachman, 1976; Bachman and Machette, 1977). Age of the soil associated with the Albuquerque surface will be discussed below.

Figure 5. Soil associated with the Albuquerque surface showing at least three zones of pedogenic carbonate separated by low carbonate material. Sierra Ladrones Formation (Qtsl), oldest carbonate zone (I), middle carbonate zone (II), youngest carbonate zone (III). West of mile post 161 on Interstate 25.

The Llano de Albuquerque has been offset and warped locally by faulting and folding that forms long narrow valleys which plunge and direct drainage in a southeasterly direction. Closed depressions (upland valley flats (Qut)) are locally filled with playa-like sediments that consist of sandy loam to sandy gravel. The Albuquerque surface is slightly discordant on the deformed Sierra Ladrones beds in stratigraphic Sections 3 and 4. Maximum dip on the surface is about 3 degrees whereas the Sierra Ladrones beds may dip as much as 4 or 5 degrees. In Section 3 the surface appears to truncate a broad fold within the Sierra Ladrones. In other localities an unconformity cannot be detected although the beds seem to be slightly discordant with surficial deposits and soils.

Erosional slopes-badlands and structural benches on the Sierra Ladrones Formation.

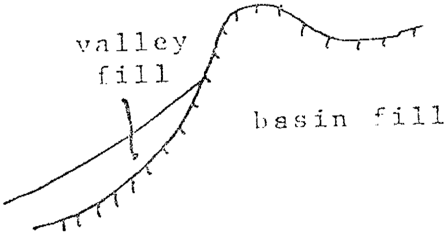
Types of landforms that develop along the lower Rio Puerco are shown in Figure 6 and include: badlands, eolian stabilized slopes, single terraces, stepped terraces, terraces overlain by soils associated with post-terrace geomorphic surfaces, structural benches, and stepped sequences in faulted structural benches. Constructional landforms will be discussed in the following sections.

Sands and fine-grained overbank sediments of the Sierra Ladrones are generally uncemented so they are easily eroded into badland topography. Intensely dissected badlands adjacent to the Albuquerque surface are characterized by long narrow ridge crests. Any soil formed was removed by erosion or the surface was not stable for the period of time needed to develop a soil. Vegetation is sparse. Essentially no part of an interfluve is level. Saddles are common.

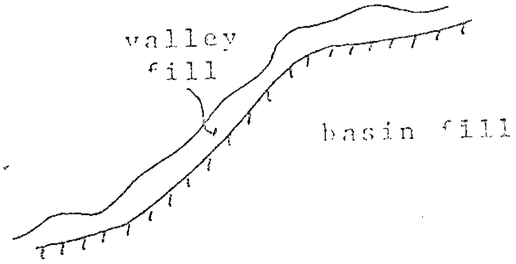
Gravel and locally cemented sand forms resistant units with surfaces that extend toward the Rio Puerco valley as structural benches. Structural benches can be traced up to 2-3 km.

Figure 6. Landforms that develop along the lower Rio Puerco.

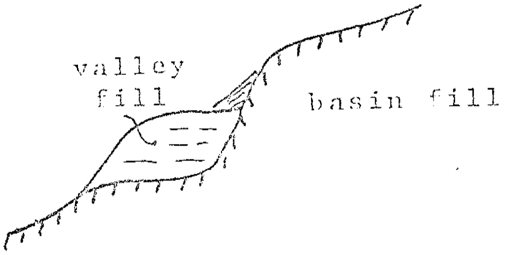
(a) Badlands



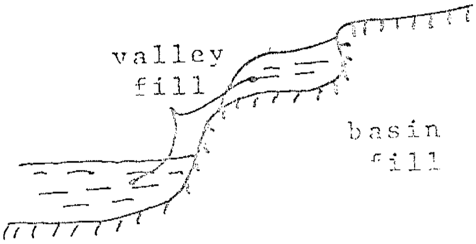
(b) Eolian Slope



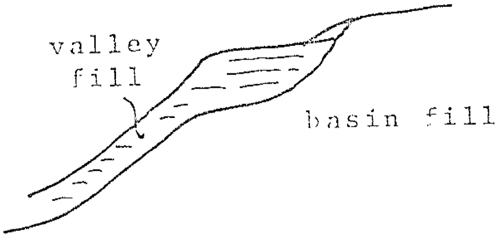
(c) Terrace



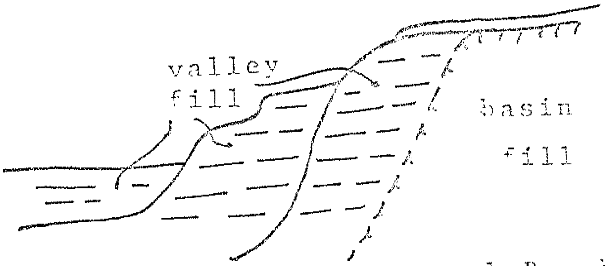
(d) Stepped Terraces



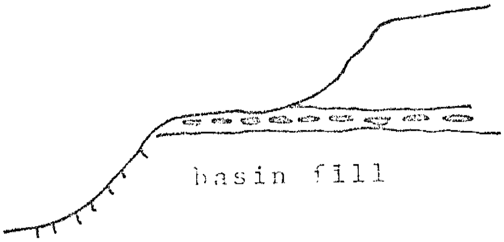
(e) Terrace with foot slope



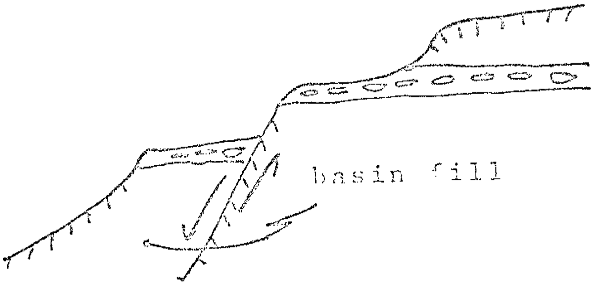
(f) Terrace with overlying calcic soil associated with geomorphic surface



(g) Structural Bench



(h) Faulted Structural Bench



Post Santa Fe Deposits

Post Santa Fe valley deposits can be divided into valley-margin facies and valley-floor facies (Figure 7). These sediments represent processes of erosion and deposition that have prevailed since entrenchment of the basin fill by rivers of the area. The informal rock-stratigraphic terminology used in this study has been adapted from Seager and Hawley (1973).

In Post Santa Fe sediments, two major alluvial facies are recognized, one is the meandering alluvial facies of the Rio Puerco flood plain (Figure 8) and associated deposits and the other belongs to a number of braided alluvial systems (Figure 9) entering the Rio Puerco flood plain at right angles. The two facies have distinct colors, grain textures and depositional geometries. The Rio Puerco is dominated by a suspended-load which produces gray to green fine grained sediments. Tributaries to the Rio Puerco are dominantly bedload channels that contain coarse-grained, light brown to reddish sediments. Alluvium of the Rio Puerco and large tributaries from the west was not deposited during the cutting of the valley. Instead it was deposited by an aggrading stream system after the valleys were cut into the Santa Fe (see cross sections on Plate 1).

Figure 7. Cross section of basin and valley fill showing distribution of stratigraphic units, Sierra Ladrones Formation (QTsl), older valley margin (Qvo), Younger valley margin (Qvy & Qvyc), Rio Puerco flood plain (Qvyf).

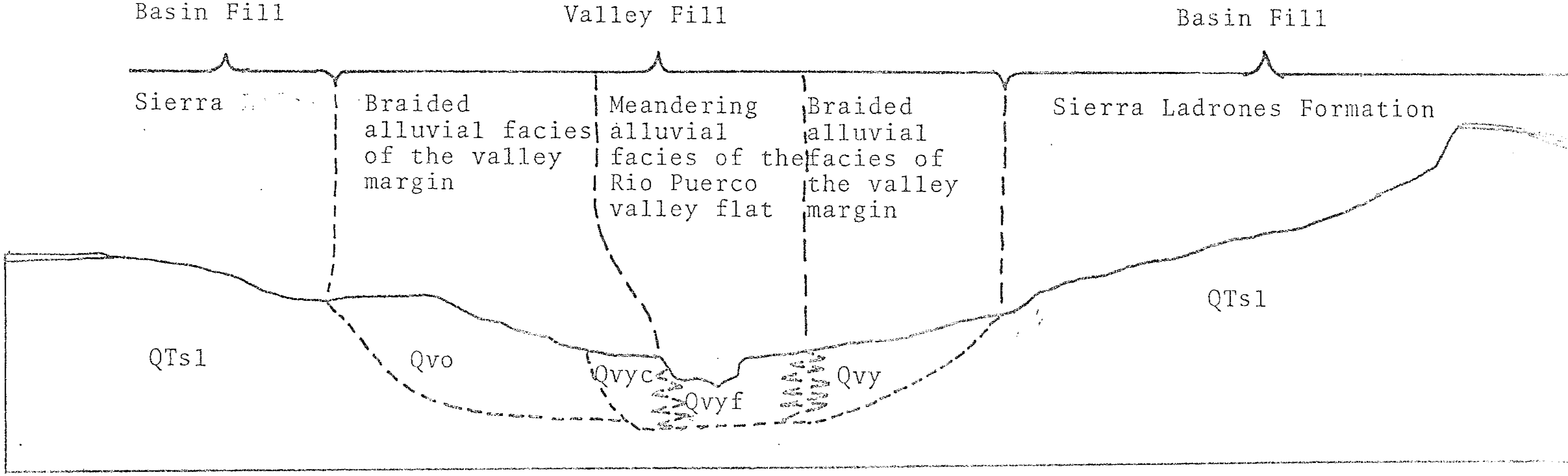

Basin Fill
Valley Fill
Basin Fill
Sierra
Braided alluvial facies of the valley margin
Meandering alluvial facies of the Rio Puerco valley flat
Braided alluvial facies of the valley margin
Sierra Ladrones Formation
QTs1
Qvo
Qvyc
Qvyf
Qvy
QTs1

Figure 8. Meandering alluvial facies of the Rio Puerco. South of Comanche Arroyo.

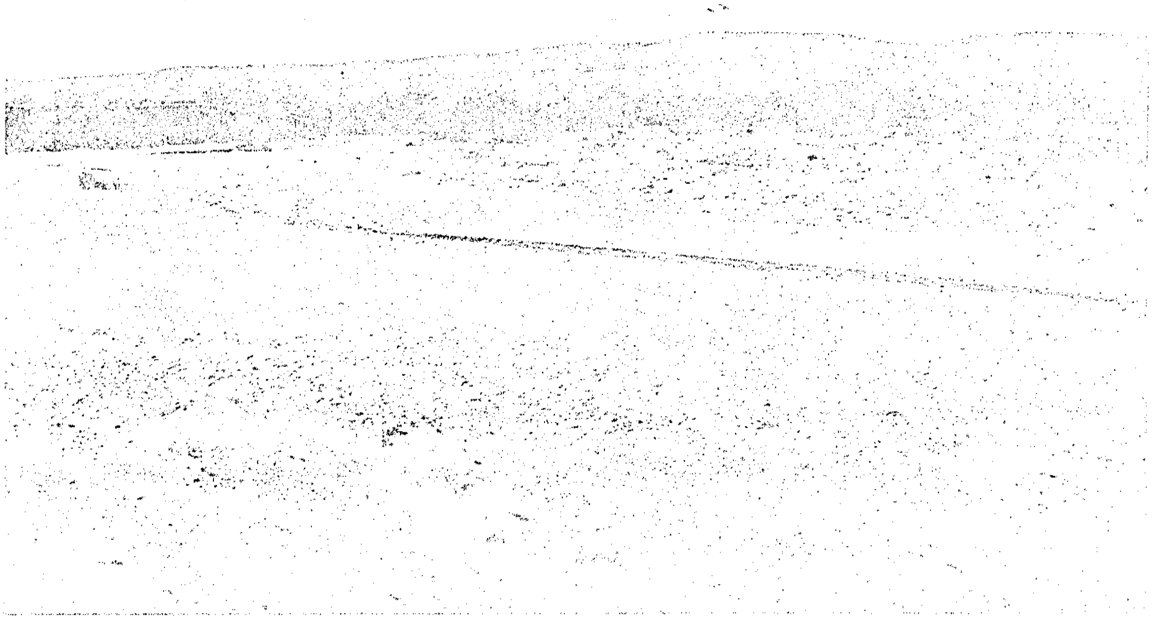


Figure 9. Braided alluvial facies of tributary arroyos. Comanche Arroyo.

Geology of the Valley Margins

Valley margin deposits include geomorphic surfaces associated with calcic soils, older valley-slope deposits associated with major tributaries, younger valley-slope deposits associated with major and minor tributaries, upland valley flats, and eolian deposits. These deposits interfinger laterally, overlap, or grade into other valley margin deposits or valley floor deposits. Valley-margin deposits east of the Rio Puerco rise sharply to the Albuquerque surface. Slopes west of the Rio Puerco are not as steep as those on the east side and rise gently toward Llanos del Rio Puerco. The steepness in slope on the east side is reflected in a more definite contact between the Sierra Ladrones and inset slope unit. Contacts west of the Rio Puerco are much more difficult to define then those east of the river.

Llanos del Rio Puerco and associated soils, Qlp.

West of the Rio Puerco flood plain the land slopes upward, for several kilometers, toward the Lucero uplift. This sloping geomorphic surface, which is a composite of many units, has been called Llanos del Rio Puerco (Titus, 1963) or Sabinas Solas (Wright, 1946). The Llanos del Rio Puerco is similar to the Albuquerque surface in that it is underlain by older basin fill (Sierra Ladrones Formation) and has sedimentary veneers with calcic soils, although are not as prominent as those calcic horizons associated with the Albuquerque surface. The Llanos del Rio Puerco developed sometime after the formation of the Albuquerque surface (Bachman and Mehnert, 1978) and were graded to an ancestral Rio Puerco 60 to 80 m above the present river. Several arroyos drain eastward across the Llanos del Rio Puerco toward the Rio Puerco. Some of these (Comanche and Alamito) have cut deep valleys below the level of the Llanos del Rio Puerco.

Surficial sediment on the Llanos del Rio Puerco is sandy loam that contains scattered pebbles. Thickness of the calcic horizon in soils of the Llanos del Rio Puerco ranges from about 1 m to 3 m. Degree of carbonate-horizon development associated with the Llanos del Rio Puerco surface is a strong stage II or a weak stage III of Gile and others (1966).

Map-unit delineations for the Llanos del Rio Puerco comprise upland areas where no recognizable drainage can be viewed on 1:10000 air photos. Boundaries for this composite map unit are not as easly defined as those for the Llano de Albuquerque.

Older valley margin facies, Qvo.

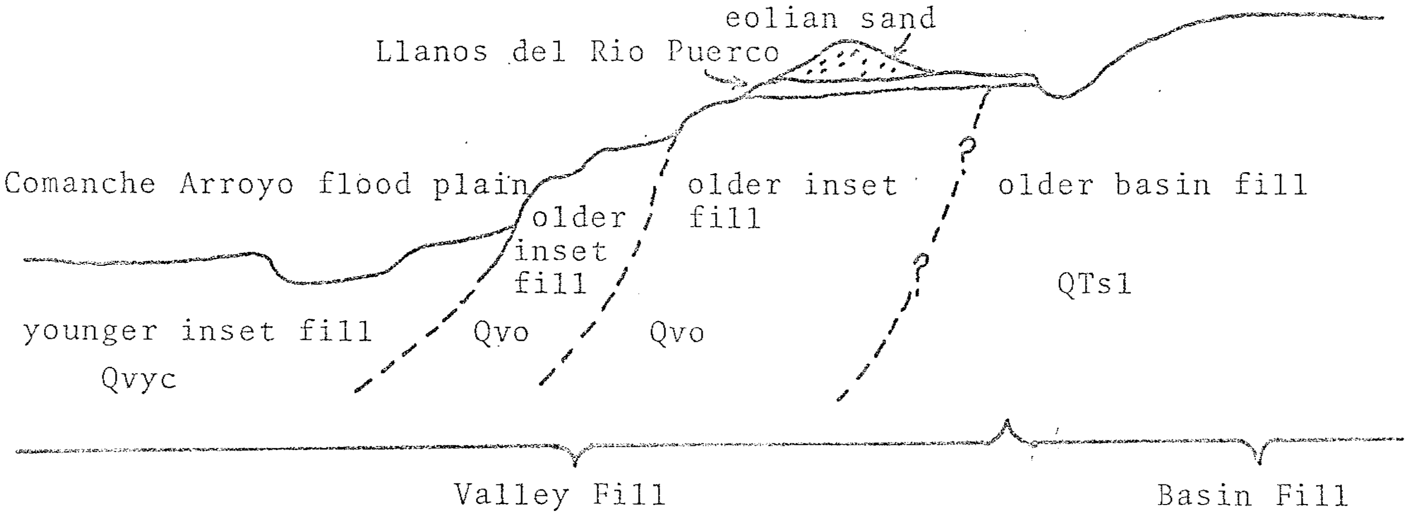
Inset terrace remnants (Figure 10) at one or more levels (commonly 56-61m, 24-30m, 6-8m, and about 3m) above the stabilized flood plain parallel the major tributaries.

Terraces rise in stepped sequence above the local tributaries and were described by Bryan and McCann (1936) as primarily stream-eroded surfaces graded to a successively lower base levels. To avoid confusion, "terrace" is applied to the landform and "terrace fills" or "inset fills" are applied to the associated deposits.

Inset fills (Qvo) appear to be paired and are composed of sediments much younger, with different texture and composition, than those of the older Sierra Ladrones Formation. Valley margin inset fills are separated from older basin fill by erosional scarps (Figure 9). Comanche Arroyo is the only location where erosional scarps are well exposed. Wright (1946) mapped the surface of the highest inset fill of Comanche Arroyo as the Canada Mariana surface. On the west side of the Rio Puerco, inset terraces merge upslope into the Llanos del Rio Puerco.

Older inset fills (Qvo) consist of sandy gravel to clast supported gravels. Composition of the gravels capping the terraces differs from basin fill (Sierra Ladrones Formation) and includes angular to subangular, cobbles and boulders of limestone, sandstone, chert, and basalt. Older inset fill gravels are coarser than Sierra Ladrones gravels. Where contacts are buried beneath slope wash, the only way to differentiate inset terraces from structural benches is by gravel composition. Gravel units that contain more than 50% limestone cobbles that are subangular to angular have been mapped as Qvo units. Locally these gravels may be no more than a thin veneer, although they are thick enough to obscure the underlying basin fill. Scattered zones of moderately cemented units are locally present within the terrace fills.

Figure 10. Schematic cross section of inset fills along Comanche Arroyo. Sierra Ladrones Formation (QTsl), two older valley margin terraces (Qvo), youngest inset fill of Comanche Arroyo (Qvyc).


eolian sand
Llanos del Rio Puerco
Comanche Arroyo flood plain
older inset fill
older inset fill
older basin fill
QTs1
younger inset fill
Qvyc
Qvo
Qvo
?
?
Valley Fill
Basin Fill

younger valley margin facies.

Braided tributaries to the Rio Puerco valley floor exhibit two forms: 1) alluvial deposits of major tributaries from the west including Comanche and Alamito (Qvyc), and 2) smaller tributaries from the east and west producing locally derived alluvial fans and apron deposits (Qvy). Age and lithologies of these two deposits are very similar. Primary difference is the source area for sediments. Qvy deposits derive all sediments from reworked, local Sierra Ladrones sources. Qvyc deposits derive sediments from the Lucero and Ladron uplifts and locally from the Sierra Ladrones Formation. Exposures of younger valley margin material is limited to incised banks of Comanche, Alamito and smaller tributaries.

Comanche and Alamito Flood Plain, Qvyc.

The flood plain of Comanche Arroyo is the surface of the youngest of three inset valley fills (Figure 10). Major tributary flood plain deposits include braided stream and alluvial fan facies that debouch onto the Rio Puerco flood plain from the west. Braided channels of Comanche and Alamito Arroyo have incised their flood plain to about 2 metres. At present these streams are graded to the inner channel of the Rio Puerco but in the past they have produced low-angle (5.9 to 7.6 m/km) fans at their junction with the Rio Puerco Valley floor. Mariana Draw, a major tributary at the southern boundary of the study area, has not incised its flood plain and its form could indicate what the other tributaries looked like in the past.

Channels of Comanche and Alamito Arroyos range from 30 to 150 m wide, with gradients that average 10 m/km. Sediments on the floor of the channels range from sand to gravels. The stabilized flood plain that borders the channels forms a low terrace, 1-3 m high, consisting of finer sediment than that found within the channel. A weak soil is found in the upper 30 cm and a well developed, buried soil is found at a depth of about 1 m. The surface contains an excellent stand of grama grass. Longitudinal bars of gravel are present on the surface of low-angle fans near the junction with the Rio Puerco. Major tributary allvuial deposits overlap, interfinger or are cut off by the flood plain unit of the valley floor facies.

Alluvial sediments of tributary systems consist of light reddish brown (5YR5/6) to light brown (10YR 6/3), loamy sand to sandy gravel. Mudballs, up to 6 cm, are scattered throughout the arroyo wall. Clasts in the gravels appear to be derived from Sierra Ladrones and older, uplifted, local source areas to the west. The base of the unit is not exposed. Maximum thickness is over 11 m where the unit interfingers with Rio Puerco valley flat (Qvyf) deposits.

Mollusk shells have been found in younger valley slope material.

Arroyo Channel, Fan and Apron Deposits, Qvy.

An almost continuous series of alluvial fans, cones and aprons debouch from the upper reaches of the valley borders onto the valley floors of the Rio Puerco, Rio Grande, and major tributaries. Upper reaches of tributary arroyos are areas of intense erosion which provide sediments for downslope fans and aprons via a middle section characterized by a single straight channel. Lower sections of the system are an area of deposition where upslope-derived material builds fans, cones and terrace-like alluvial aprons. Placement of boundaries between terrace-like alluvial aprons and the valley floor facies are more or less arbitrary. At times there is a change in slope between the undulating alluvial slope and flat valley floor, at times there is a compositional difference between the sandy slope unit and the clay of the valley floor, and at times the contact is based on the north-south current direction of the Rio Puerco versus the radial current direction of the fans. The Qvy unit also includes locally derived colluvium and slope wash.

Fans and aprons consist of light brown (10YR 6/3), poorly sorted deposits that range from silty sand through coarse sand to sandy gravel. The base of the unit is not exposed in the area. Maximum thickness is over 11 m and may be as much as 30 m where the fan deposits interfinger with

Rio Puerco valley flat deposits. The unit thins rapidly upslope where sediments are derived from local Sierra Ladrones sources.

Upland Flats, Quf.

Upland flats, or alluvial flats, are level plain deposits that occupy the central portions of northwest trending depressions on the Llano de Albuquerque. These alluvail, and local playa deposits, consist of material that ranges from loamy sand to sandy gravel derived from areas sloping down to the flats. The base of the unit is not exposed but the maximum thickness is estimated to be no more than 3 m. Mapping contacts are placed at the break in slope onto the level valley floor.

Eolian deposits, Qe.

Eolian deposits cover an area of a few square kilometers scattered over the northern section of the Llano de Albuquerque and on the eastern portion of the Llanos del Rio Puerco. Older soils and surfaces are buried by sand although local exposures occur in deflation blowouts. In general, most eolian deposits within the study area are no more than a few feet thick and form either sand sheets or coppice dunes. North of the study area, eolian deposits are much more common and contain thicker accumulations of sand.

Eolian deposits consist of light brown (10YR 6/3), well-sorted sand forming mostly coppice dunes stabilized by grama grass and mesquite. Linear streaks in the sand deposits as viewed from air photos are used to determine transportation direction. Trend of the streaks is approximately N40E, as shown by symbols on map. Source of sand for eolian deposits appears to be from sand units in the Sierra Ladrones Formation.

Geology of the Puerco Valley Floor

The Rio Puerco valley has a broad, flat, floor (Qvyf) into which the Rio Puerco Arroyo has been incised to a depth of 10 or more metres (Figure 11). This featured, here called the valley flat, is an elongate, sinuous plain occupying the center of the study area. The valley flat ranges from 0.8 to 1.5 km wide and slopes down valley with an average gradient of 1.7 m/km. Deposits inset below the valley-flat unit (Qvyf) on the flood plain include inner Rio Puerco Arroyo flood plain (Qia), benches (Qib), terraces (Qit), historical channels (Qir), and colluvium (Qic). Minor amounts of eolian sand (Qe) are present along the valley floor although none are large enough to include on the map. Low topographic relief on the flood plain is due to vegetated hummocks and coppice dunes. Tributaries that originate on the valley flat exhibit two forms: 1) dendritic tributaries and soil pipes receiving run off from adjacent valley floor (Figure 12), and 2) yazoo channels that parallel the main Rio Puerco arroyo. Soil pipes are common on the valley flat adjacent to the Rio Puerco Arroyo and appear to be important in the growth of the arroyo. Through time, soil pipes erode and collapse leading to a poorly integrated, dendritic tributary system.

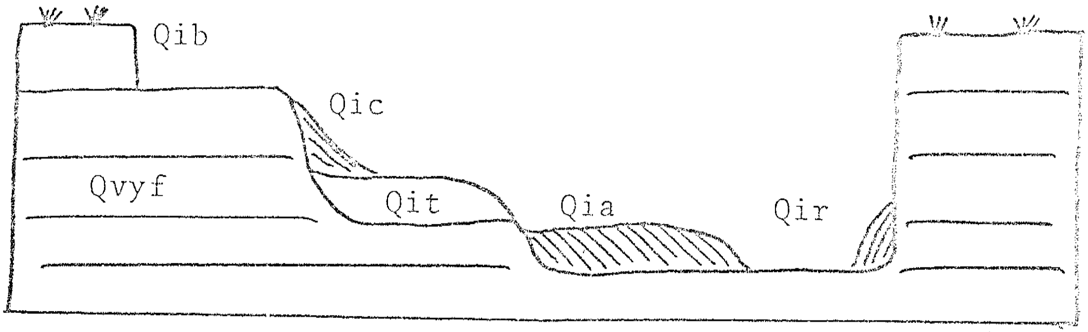


Figure 11. Schematic cross section of the Rio Puerco valley floor and associated deposits. Rio Puerco valley flat (Qvyf), structural bench (Qib), inset fill (Qit), colluvial (Qic), inner arroyo flood plain (Qia), historical channel (Qir).

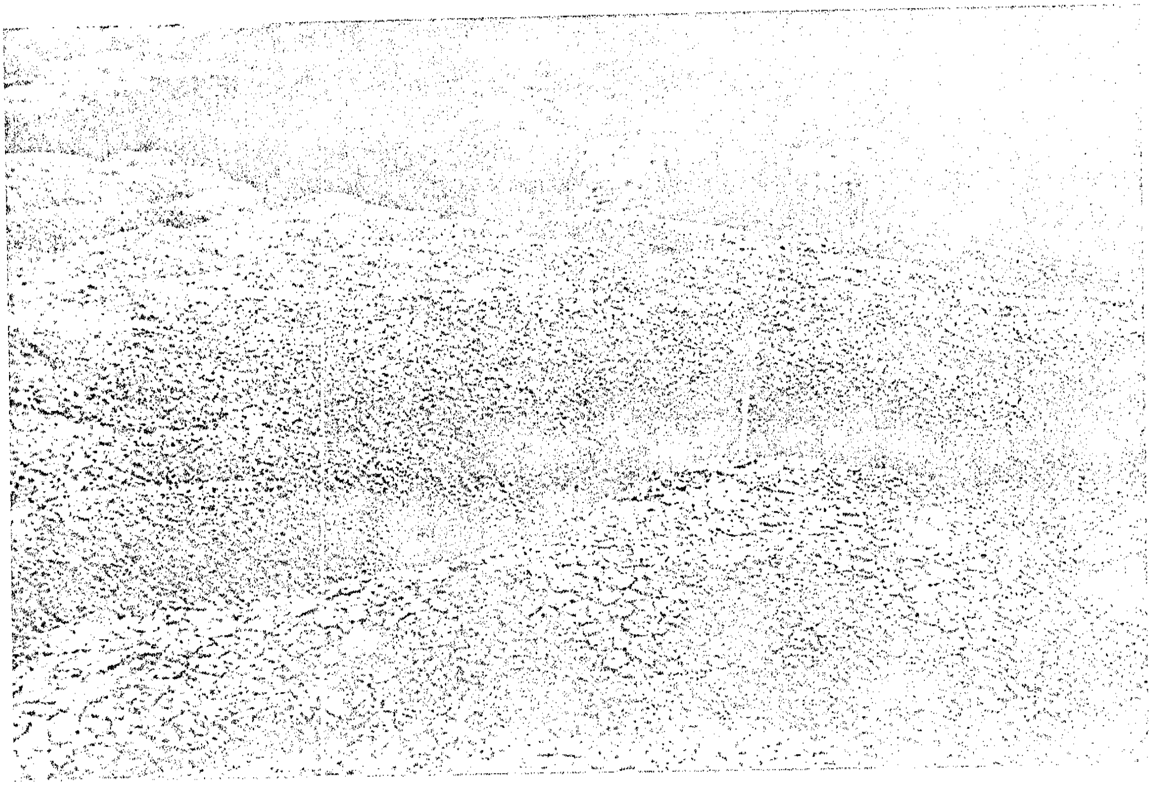


Figure 12. Soil pipes developed in the Rio Puerco valley flat. Southern boundary of study area.

Rio Puerco Valley Flat, Qvyf.

The Rio Puerco valley flat deposits consist of a meandering, alluvial facies formed by the Holocene Rio Puerco. Large areas appear to be associated with "flood basin" environments of deposition (Appendix A). Rio Puerco alluvial sediments are derived from mixed local and upstream sources. A test well drilled by the Army Corps of Engineers indicates that the Qvyf unit may be as much as 33m thick.

Surficial sediments of the Rio Puerco valley flat consists of pale brown (10YR 6/3), sticky when wet, hard clay loam. Vegetation on the flood plain is sparse and consists of scattered patches of grass and Four-Wing Salt Bush.

In general the stratigraphy of the valley flat deposits is made up of an alternating sequence of overbank clays, near margin fines, and medium to coarse grained channel sands. Scour horizons are generally overlain by an upward-fining sequence that begins with a pebble sand. Stratigraphy which includes complex cycles of cut-and-fills is described below. Laminated, overbank clays range in color from reddish brown (2.5YR4/4) to dark brown (10YR4/3) although most are a drab gray, green or yellowish brown (10YR5/4). Overbank clays are more competent, cliff-forming units that generally overlie sandy channel units. Sands range in color from light brown (10YR6/3) to reddish brown (2.5YR4/4). Sand size ranges from fine grained, well sorted to coarse grained, poorly sorted. Coarse pebble sands generally fine upward. Within sand units are clay horizons, 2-6 cm thick, which exhibit sand filled shrinkage cracks. Sedimentary structures present include cross-bedding, sand waves, ripples, climbing ripples and parallel lamination. Charcoal, hearths, pottery, and flakes have been found at different levels in the Qvyf unit.

Alluviation

Within the Qvyf sequence exposed in the walls of the Rio Puerco Arroyo are several buried channels of different sizes which are evidence of past incision and filling. "Paleochannels" are channels exposed in the incised walls of the modern Rio Puerco that have aggraded to or buried by the level of the present valley floodplain. Two types of paleochannels are distinguished: 1) minor channels which have a depth less than than the present incised arroyo, and 2) major channels which have a depth greater than the present arroyo. At least two periods of major channel cutting are reflected in the walls of the arroyo. Major channels appear continuously throughout the study area. The sequence of crosscutting relationships and alluvial stratigraphy exposed in the arroyo walls indicate a complex history of down cutting and alluviation. Although the sequence is not completely known, a more or less relative sequence has been determined for several locations. Locations described in the study area are: 1) Comanche Arroyo, 2) Rio Puerco Arroyo, just east of Comanche Arroyo, and 3) Hidden Mountain Dam Site. Identification of units and placing them in a sequence becomes more difficult as the sections grow in length. Problems stem from local absence of exposures, lateral variability in the sediments, and (as seen in cross section) younger sediments which may occur lower in the section than older sediments.

Comanche Arroyo.

The relative sequence (Figure 13) near the mouth of Comanche Arroyo includes (I) horizontally-bedded units of light brown sand and reddish brown to yellowish brown clays, (II) a thin-bedded unit of reddish brown and brown clays and silts along the margin of a minor channel, (III) a 145 m wide and more than 8 m deep major channel filled with exclusively thick-bedded sands, (IV) minor sand channels cutting and reworking older sand fill of III, (V) shallow loam dominated minor channel which appears to migrate laterally and overlays local, sandy channel base (contains Pueblo II-III grayware pottery and flakes at the base of channel), (VI) a veneer of locally derived sandy loam to clay loam overlying the the rest of the exposures with pottery and flakes on the surface and (VII) local coppice dunes on the surface.

Rio Puerco.

Exposures on the east side of the Rio Puerco (Figure 14) and just to the north of the mouth of Comanche Arroyo show the following sequence (Figure 14): (I) laminated dark brown and reddish brown clay, (II) a thick unit of light brown sand, (III) thinly-bedded unit of light brown sand and brown clay, (IV) a minor channel filled with alternating beds of sand and clay, (V) a major thick-bedded sand channel containing a number of smaller minor channels, (VI) a laterally shifting minor channel filled with reddish brown loam, (VII) capped by very minor tributary channels and a 1 to 2 metres thick reddish brown clay.

Figure 13. Schematic cross section of downcutting and back filling along Comanche Arroyo.

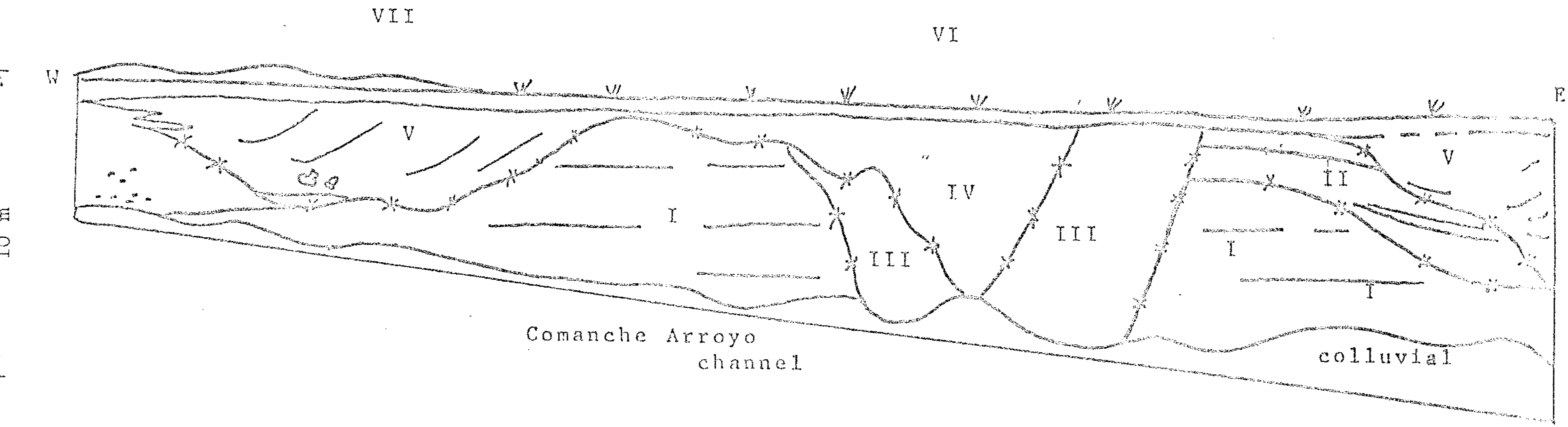
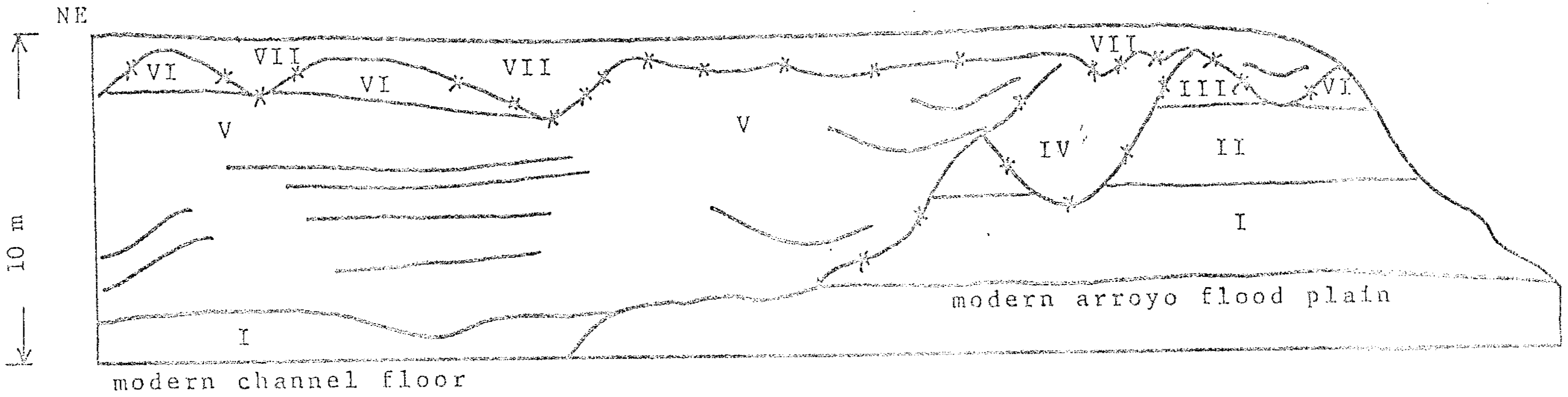

VII
VI
W
E
V
IV
III
III
II
I
I
I
V
Comanche Arroyo channel
colluvial
10 m

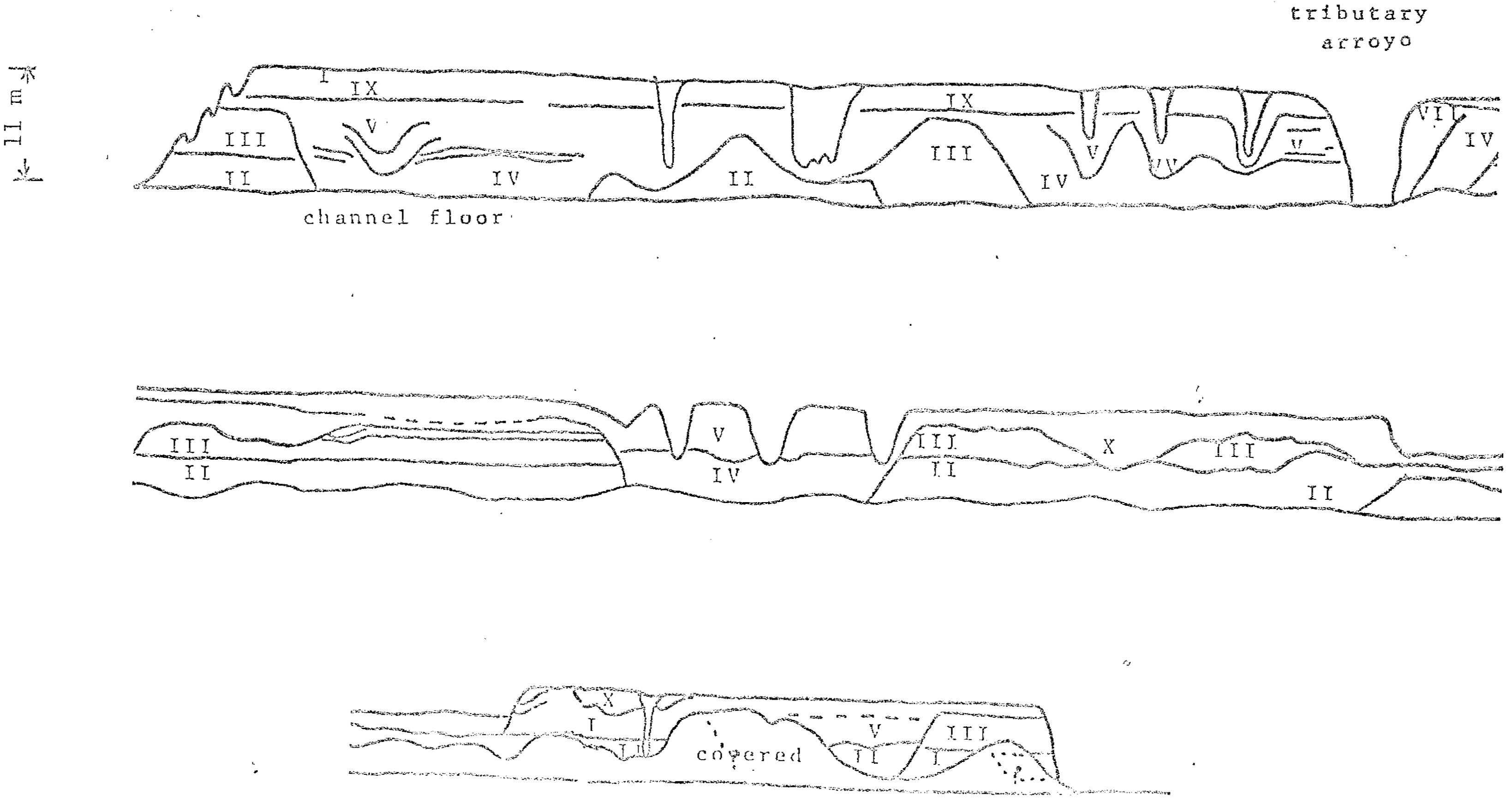
Figure 14, Schematic cross section of down cutting and back filling along the Rio Puerco across from the mouth of Comanche Arroyo.


NE
10 m
VI
VII
VI
VII
V
V
I
modern channel floor
VII
III
VI
IV'
II
I
modern arroyo flood plain

Hidden Mountain Dam Site.

The relative sequence exposed between the Hidden Mountain Dam Site (about .6 km south of Alamito Arroyo) and Alamito Arroyo is (Figure 15) (I) interbedded local red-brown clayey sand and Puerco-derived dark laminated clay, (II) a sequence of extensively turbated, thinly laminated gray and green Puerco-derived clays which may be continuous for more than 1 km, (III) a sequence of interbedded sand, silt, and clay derived from both the Rio Puerco and local tributaries, (IV) one or more major sandy-bottomed Rio Puerco channels, overlain by one or more (V) laminated sands and clays with minor channels cutting older units, (VI) a continuous layer of red clay over the southern exposures, (VII) a major (25m wide) channel filled with locally reworked sand and clay, (VIII) a minor tributary channel filled with locally reworked sand and clay, (IX) a red-brown clayey sand with artifacts and having a soil developed in it, (X) capped by very minor clay-rich channels and featureless gray-brown clay unit.

Figure 15. Schematic cross section of down cutting and back filling between Alamito Arroyo and Hidden Mountain Dam Site.


11 m
tributary arroyo
channel floor
I
IX
III
II
V
IV
VI
X
covered

Sites with Radiometric Dates.

Radiometric dates for a number of sites that reveal different cross cutting relationships have been obtained. At site LA 29254 a date of 2290+70 years was obtained from a hearth which is buried 2 meters. At stratigraphic site 1 a date of 2100+105 years was obtained from a site buried 5.35 meters. This site is within a major channel and is overlain by a minor channel. At site LA 29243 an age of 2610+70 years was obtained from a site buried 0.7 meters.

Rio Puerco Arroyo

The most distinctive feature of the valley floor is the deeply incised (10 to about 13 metres) meandering, inner arroyo flood plain (Figure 16). Width of the arroyo ranges from 30 m to about 300 m, in general the arroyo is nearer to the east side of the valley floor. This may be due to the large fans entering the system from the west. Tamarisk dominate vegetation on the inner flood plain, although willows are common locally. Geomorphic features (Figure 10) across the arroyo are: 1) vertical arroyo walls, 2) gently to steeply sloping arroyo walls, 3) inner arroyo flood plain which includes oxbows and backbasin areas, 4) erosional and/or depositional benches above the inner arroyo flood plain, and 5) historical channels which include levees, splays, and bar forms.

Inner Arroyo Flood Plain, Qia.

The floor of the inner flood plain is covered by the same type of sediments as described in the stratigraphy of the valley flat (Qvvf). Sediments consist of loamy sand to sandy gravel spread out in sheets derived from run off. Local topographic lows contain clay rich overbank deposits. Eolian sands (Qe) and colluvium (Qlc) locally cover all features of the inner arroyo flood plain although generally they are to small too map. Eolian sands are found trapped adjacent to topographic highs which include swales, levees, vegetation, terraces, sand waves and ripples.

Figure 10. Rio Puerco valley flat and entrenched arroyo. Southern boundary of study area.

Historical channel deposits, Qir54/ Qir79.

Historical channel deposits consist of active point bar, present thalweg and natural levees. Point bar and channel deposits consist of light brown (10YR6/3), fine to coarse sands and gravelly sand. Longitudinal bars of gravel and/or mudballs are present locally. A large variety of erosional, transportational, and depositional sedimentary structures are present. Clay deposited in scour depressions ranges in color from reddish brown (2.5YR4/4) to dark brown (10YR4/3). Natural levees on the Rio Puerco are characterized by well sorted, fine-grained sands and silt. Additional bed forms present are scour holes, cresent scours, grooves, rills, terraces, microterraces, fluted steps, and a wide variety of desiccation features, ripple marks and sand waves. Undercutting by the Rio Puerco causes large blocks of flood plain sediments to spall into the channel.

Two periods of channel positions for the Rio Puerco can be mapped on the 1:24000 scale. These positions have been determined from 1954 and 1979 aerial photographs. Width of the now active channel ranges from 10 to about 25m between banks 2 to 4m high (excluding arroyo walls). More than 90% of the modern channel has shifted laterally in the past 35 years. It is clear from the changing position of the channel that it is a very active laterally migrating system. The now active channel of the Rio Puerco ranges from straight to sinuous with an average gradient of 1.2 m/km. Some meanders are very elongate, but average sinuosity is 1.52 (ratio of stream length to straight line distance).

Inner Floodplain Bench, Qib, and Terrace deposits, Qit.

Topographically above the inner floodplain and below the Qvyf unit are a number of erosional and/or depositional benches. Gravel covered bars which include mudballs occur 1 to 2 m above the inner arroyo floodplain. Inset terraces and structural benches occur at different levels adjacent to the vertical arroyo walls. Vegetation is generally sparce or absent from these platforms. Eolian sand (Qe) or colluvium (Qic) commonly covers the surfaces of the benches although to small to map. A number of archeologic sites on these platforms suggests (Marshall, 1980) that they have been there since Basketmaker III time (about 2000 years ago).

Most terraces are composed of fine to medium grained, light brown sandy loam to sand.

STRUCTURE

Much of the structural geology is determined by relationships with the strong calcic soil unit that forms the Albuquerque surface. Faulting was partilly discussed in the section "Llano de Albuquerque landform and Albuquerque surface". A large part of the study area consists of or is covered by loose, unconsolidated deposits which mask most evidence of structural deformation.

Faults.

Late Tertiary or Quaternary structures in the area consist of two normal faults, the Denny fault (see Figure 5) and West fault. Both of these faults are of limited extent (less than 2 km) and displacement down to the west is less than 25m. Trend of the faults is north to northwest. The down dropped block on the Denny fault contains a sequence of calcic paleosols that provides evidence for at least 3 periods of movement on the fault. Erosion has been accelerated along the upthrown block. If the age (Bachman and Mehnert, 1978) of .5 m.y. for the Albuquerque surface is correct, then the most significant thing is that episodic movement has occurred on faults during the last 500,000 years. Machette (1978a) has placed recurrent faulting within the past 400,000 to 25,000 years for the Bernalillo County Dump Fault, further north.

Warping.

Structural warping of the topography is very marked on the Llano de Albuquerque and Llanos del Rio Puerco. Deformed Sierra Ladrones beds are overlain by the less deformed sediments of the Llano de Albuquerque. This sequence of events indicates a progressive deformation that has taken place in the last 500,000 years even though the unconsolidated nature of the material making up the Sierra Ladrones obscures most of the structural deformation. Progressive deformation through time would suggest that river position has been largely controlled by structural deformation.

DISCUSSION

CONTROLS OF SEDIMENTATION

Controls of sedimentation in the Rio Grande Rift and the Albuquerque basin have been a combination of: 1) tectonics which includes size, shape, location, and character of bounding uplifts and basin, 2) lithologies of the surrounding uplifts, 3) climate which has been the primary factor controlling depositional processes in the individual basins and river valley segments (Hawley, 1975), and 4) development of drainage systems which is a product of both tectonics and climate. Drainage systems associated with closed and through-flowing basins were discussed under principal types of deposits. This section is a brief summary of work by Wright (1946), Hawley (1975, 1981), and Chapin and others(1975,1981).

Tectonics.

Location, size and general characteristics of the southern Albuquerque Basin and bounding mountains are controlled by deep-seated tectonic processes. Chapin and Seager (1975) have documented the sequential development of the Rio Grande Rift in the Socorro and Las Cruces areas. It is now generally accepted that the evolution of the Rio Grande Rift, which includes the Albuquerque Basin, is related to movement of lithospheric plates and evolution of the Colorado Plateau. The general sequence of events will be discussed under geologic history.

The amount and rate of subsidence of a basin and uplifts of the surrounding highlands determines in part the gradients of the streams, rates of erosion and deposition, and lithologies of the deposits. If the relative movement is constant, types of deposits at one place will remain constant, other factors being equal (Wright, 1946). It has been suggested that gravels in the Sierra Ladrones Formation reflect episodic uplift on the margin of the basin. If the rate of subsidence is rapid the surface drainage will be disrupted and runoff will be impounded in lakes or playa, depending on the climate. If the basin is drained by a through flowing river, a change in base level outside the basin will effect base level within the basin, thereby changing the rate of erosion and deposition in the center of the basin. Change in base level is one possible explanation for the initial downcutting of the Rio Puerco and Rio Grande systems.

On a regional scale tectonics has had a major influence on lithologies and climate, and thus the geomorphic processes involving mass wasting and water, wind and glacial action.

Lithologies.

The nature and quantity of sediments produced in the source area determines the morphologic character of the river (Schumm, 1981). If the surrounding uplifts of the basin are composed of resistant rock, streams are steep and can carry gravel and coarse sand far into the main basin; if not streams of low gradient can carry the abundant supply of fine-grained material far into the basin. If the highlands are mostly sand they will furnish little but sand to the basin. If the highlands are composed of shale the deposits in the basin will be mostly clay and shale. However if the basin is drained by a through-flowing river much of the clay, silt and sand may be carried out of the basin.

Valley fill derived from the north and transported to the study area by the low gradient Rio Puerco is composed predominately of fine grained material from Mesozoic sandstones and shales. Valley fill derived from the Ladron uplift is composed of preCambrian granitic and metamorphics rocks. Rocks derived from the Lucero uplift are composed of Paleozoic sedimentary rocks and Cenozoic volcanics..

Climate.

Climate controls weathering and determines volume and rate of stream discharge. Weathering controls size and quantity of detritus supplied to streams. Volume and rate of discharge determines competence of the streams. In a climate characterized by cloudbursts and occasional large stream discharge, coarse sediments can be moved on a relatively gentle gradient. In a basin with no surface outflow, total rainfall and evaporation rates will determine whether or not the the basin will be occupied by a lake, or dry playa. The Porotosa playa deposits indicate a closed basin in a dry climate. A basin with a turough flowing river reflects the climate only in alluvial fan deposits.

In individual basins and river-valley segments during Late Cenozoic time, episodic changes in climate associated with interglacial-glacial cycles have been the primary control of erosion-sedimentation processes (Hawley, 1975, 1981). Post Santa Fe deposits in this arid to semiarid region of the Rio Grande Rift record a sequence of landscape instability interval, interspersed with periods of surface stability and soil formation. These periods reflect cyclic shifts in the climatic-hydrologic regimes and resultant changes in vegetation and land surface form. Waxing parts of glaciations (pluvial) correspond to episodes of increased river discharge, entrenchment of major valleys, and formation of permanent lakes. However, large areas of piedmont and valley-slopes were probably stable due to increased effectiveness of vegetation cover. Aridity and probable rainstorm intensity increased during transitions from glaciation to interglaciation. Decrease in vegetation and increase in erosion-sedimentation led to wide spread erosion and sedimentation on piedmont slopes and valley borders. Decrease in river discharge and increase in storm runoff and sediment production caused eggradation of valley floors and encroachment of arroyo mouth alluvial fans onto flood plains. Paleosols that developed on stable surfaces in the study area indicate the the region has been arid to semiarid.

DEPOSITIONAL ENVIRONMENT-SIERRA LADRONES FORMATION

Size of clasts, lack of fine-grained deposits, thick beds, and shape of channel suggest that the Sierra Ladrones Formation was deposited by a complex braided stream system. Based on composition and texture of gravel, two distinct facies in the Sierra Ladrones are suggested: 1)through-flowing facies; primarily high gradient, low sinuosity (flat bottomed), axial channel deposits; and 2) through-flowing alluvial facies derived from high gradient, flat-bottomed channels that, in part, are composed of alluvium derived from adjacent highlands. The absence of soils and large amounts of fines indicates rapid deposition by a fluvial system dominated by bedload. The change from dominantly sand to gravel in the upper portions of the Sierra Ladrones probably reflects an increase in stream gradient brought about by the rise of the bordering highland or an increase in stream capacity brought about by a change in climate. Scattered clay and loam are interpreted as overbank deposits on a flood plain. Direction of paleocurrent indicators and the presence of Grants obsidian indicate a source area to the northwest.

GRAVEL PROVENANCE

Introduction

Many exposures of gravel have been described by workers as "axial" and "piedmont" (called pediment by some workers). Bryan and McCann (1938) and subsequent workers attributed axial gravels to deposition by the Rio Grande whereas the so-called piedmont gravels have been attributed to deposition by alluvial fans from neighboring highlands. One of many problems in the study area is determining if gravels within the Sierra Ladrones were deposited by an axial Rio Grande or by large tributaries from the northwest.

The purpose of the gravel investigation was to study variation in roundness and composition of gravels from different facies in the study area. The basic concept that through-flowing river gravels are better sorted and are composed of well-rounded, resistant rock types derived from outside the basin (Wright, 1946). Wright states (1946, p. 401) that river clasts are larger than alluvial fan clasts which sometimes reach the center portion of the basin. This implies that gravels derived from local sources will be more poorly sorted, composed of more angular, non-resistant rock types.

Gravel counts reveal considerable variations in size, composition, roundness and relative abundance. Sizes range from 18.8 mm to about 160 mm. Composition varies widely but includes igneous, sedimentary, and metamorphic rocks. Every degree of roundness is present between and including very angular to well rounded. Relative abundance on the surfaces range from 299 pebbles/.06 cu m to 81 pebbles/.06 cu m.

Based on location and nature of accumulated material gravels can be placed into three categories: 1) late-Sierra Ladrones gravels associated with a through-flowing axial river system, 2) late-Sierra Ladrones gravels associated with marginal slopes and 3) Older Valley Slope gravels (inset fill/terraces) associated with post-Santa Fe valley fill (Qvo). Group 2 is probably more of an interfingering zone between distal piedmont material and through-flowing axial river gravels although through-flowing river gravels are still the dominate lithology.

Sierra Ladrones gravels are composed of more resistant rock types which include sandstone, quartzite, chert and granite. Both light and dark volcanics are present in all samples, very minor amounts of obsidian and limestone are present in some gravels. Neither Bryan and McCann (1938), or Lambert (1968, c.f., Kelley, 1977) noted limestone or mudstone in the Sierra Ladrones gravels. Wright (1946) noted limestone in the Upper Buff Member which agrees with my finding. Gravels west of the Rio Puerco show an increase in limestone when compared to gravels east of the river. Visual estimates indicate the limestone percentage may be as much as 25%. Sample Gr4 is the only sample east of the Rio Puerco that shows a high percentage of limestone. It was first assumed that the limestone came from mixing with later terrace gravels. Upon investigation it was learned that the thin conglomerate zone at the base of the gravel also contained a significant amount of limestone clasts. Roundness of Sierra Ladrones gravels range from subangular to well rounded.

Composition of the post-Sierra Ladrones gravels (Qvo) reflects the near-source areas of the Ladron and Lucero uplifts. Gravels along Comanche Arroyo are predominately limestone, mudstone, sandstone and basalt. They also contain minor amounts of other rock types. Gravels along Alamito Arroyo show an increase in granite and metamorphics although still dominately limestone and sandstone. Size of near-source gravels is much larger and the degree of roundness is much more angular than those of through-flowing river systems. Conclusions:

When gravels of the different units are compared (Figure 17 and 18) variations in composition, size and roundness are apparent. Composition of the post-Sierra Ladrones gravels reflects the near-source area lithologies of the Ladron and Lucero Uplifts. Interfingering of through-flowing and near-source gravels is suggested on the west side of the Rio Puerco.

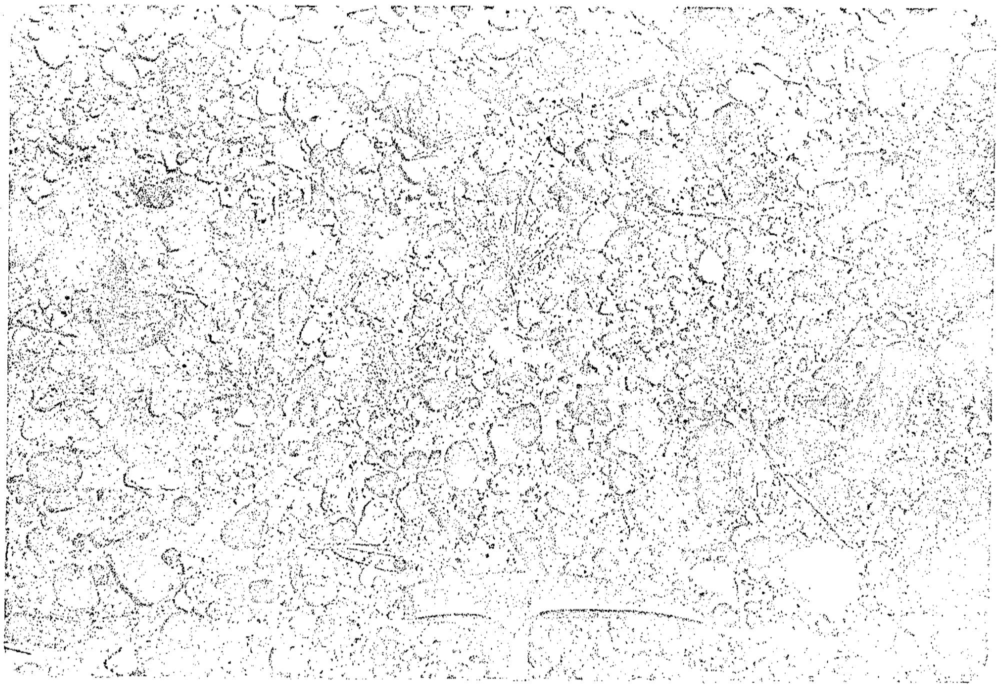


Figure 17, Sierra Ladrones gravel.

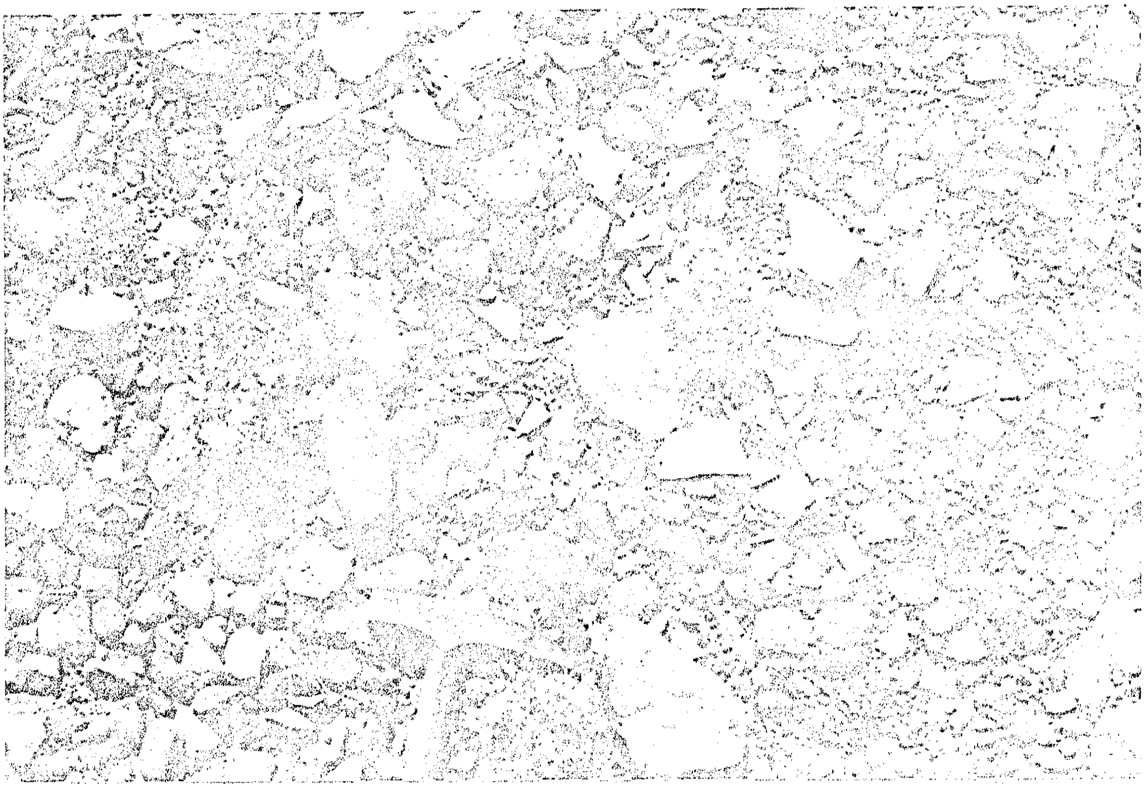


Figure 18. Older valley margin gravel.

Wright (1946) believed that gravels on the numerous benches along the Rio Puerco were remnants of early alluvial fans or slopes. East of the Rio Puerco texture and composition implies that gravels resulted from deposition from a through-flowing river. West of the Rio Puerco an increase in non-resistant rock types would tend to favor the idea of near-source alluvial fans periodically overlapping axial channel deposits in response to episodic uplift at the basin margin. My findings agree with Wright on roundness and sorting and disagree with his statement on size of clasts. I found clasts derived from local sources to be much larger in size then would be expected for through-flowing river gravels.

Obsidian.

Obsidian was investigated to identify the source or sources of obsidian clasts by comparing trace element concentrations in these clasts with that from known source areas. In the past trace element concentrations, as determined by X-rey fluorescence, have been used by anthropologists to trace obsidian to its geologic source. When obsidian samples, with good stratigraphic control are linked to source areas, critical inferences about stratigraphic correlation, and age of sediments can be made. In central New Mexico there are relatively few sources for obsidian which makes the findings even more significant.

Obsidian found in the gravels of the Sierra Ladrones Formation could have been derived from three primary sources. These are: 1) Grants volcanic field associated with and including Mount Taylor (Lipman and Mehnert, 1979), 2) Jemez Mountains source located between Valle San Antonio and Valle Grande , and 3) Polvadara, a short distance north of the Valle Grande location. Obsidian age obtained from the Grants volcanic pile is 3.2 m.y plus or minus .3 m.y. (Lipman and Mehnert, 1980).

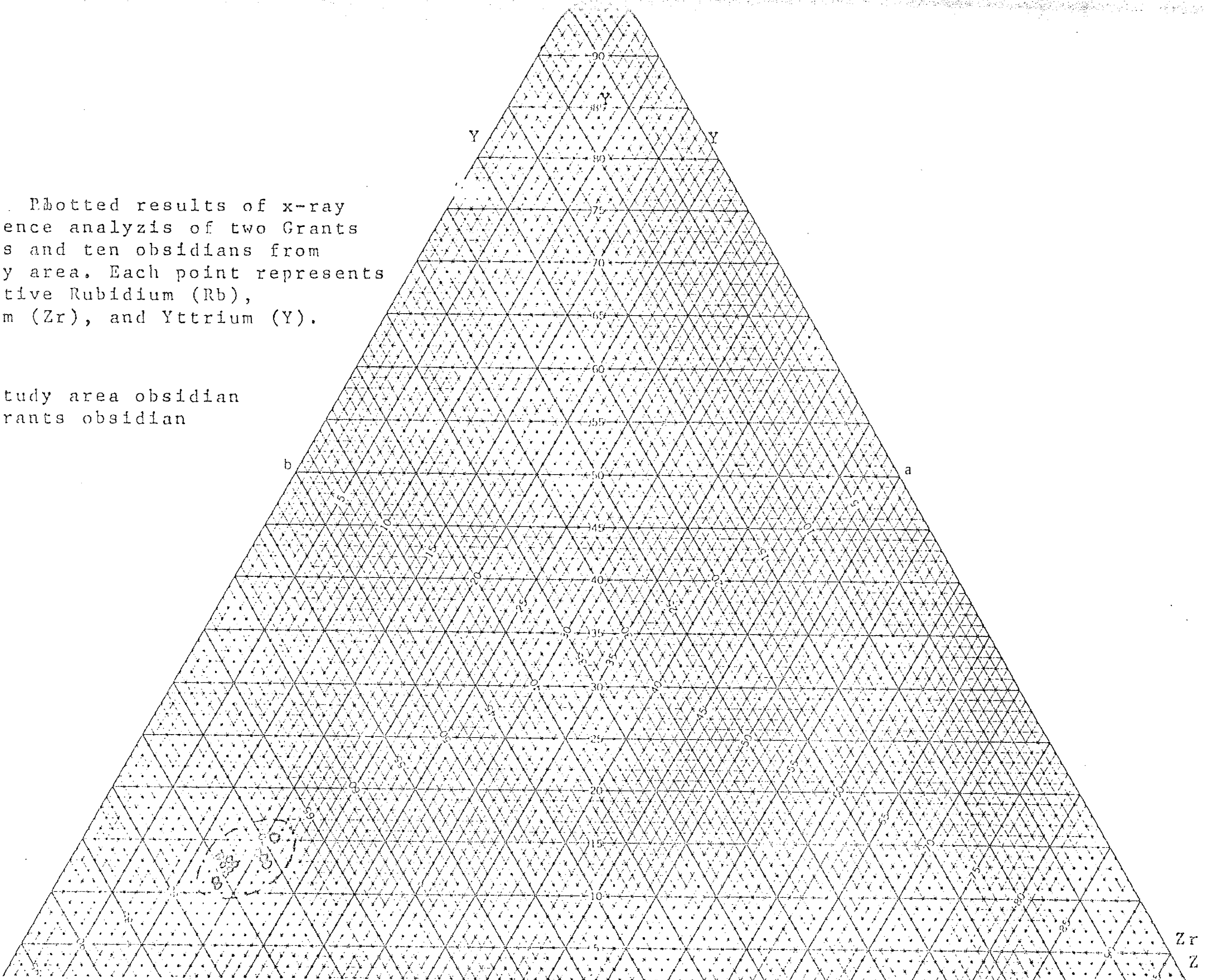
Readers of this report should realize statements are based on a minimum amount of data. As far as I can determine this is the first attempt in New Mexico to use trace element concentrations in obsidian to correlate, determine source area, and establish relative age of sediments in the Sierra Ladrones Formation.

Very close similarities in trace element concentratins were noted with the obsidians from the Grants area of western New Mexico (Figure 19). Other authors (Hester and others, 1974, Sappington and others, 1981, and Meyers and others) have found a wide variation in the trace element concentrations between the three New Mexico sources. This leads me to suggest that the primary source for obsidian in the lower Rio Puerco study area is from the Grants region. It would also suggests that sediment containing in place obsidian are less than 3 m.y. in age. Abundance of obsidian increases between 23 and 27.7 m which indicates a stratigraphic correlation between these units. To reiterate, the data and suggestions made are by no means conclusive. The usefulness of the technique can only be substantiated by analyzing a larger number of samples from each of the source areas.

Figure 19. Ternary Diagram. Plotted results of x-ray fluorescence of two Grants obsidians and ten obsidians from the study area.

Plotted results of x-ray
uorescence analyzis of two Grants
sidians and ten obsidians from
e study area. Each point represents
e relative Rubidium (Rb),
rconium (Zr), and Yttrium (Y).

o= study area obsidian
⊖= Grants obsidian

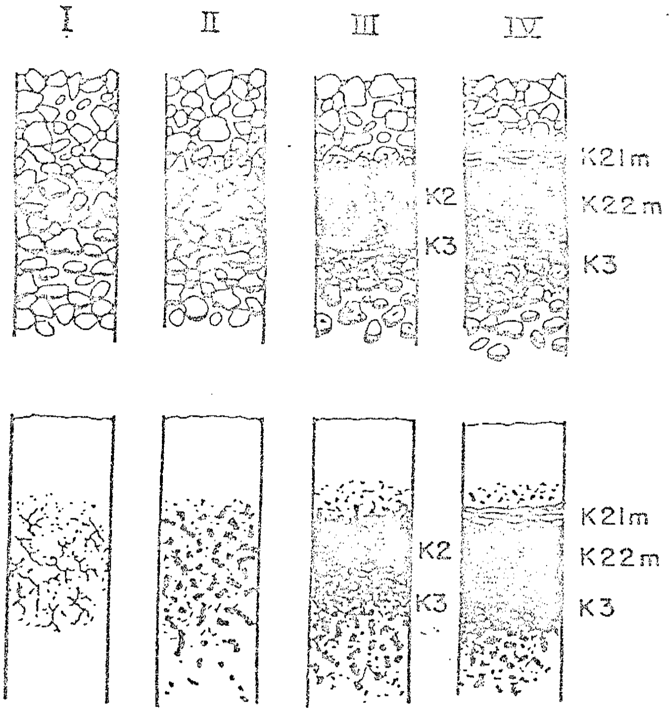


AGE AND CORRELATION OF GEOMORPHIC SURFACES

Chronologic correlation of pre Holocene geomorphic surfaces has been the subject of much controversy. Denny (1940) and Wright (1946) recognized three surfaces on the Llanos del Rio Puerco, two of which are included in the study area. Kelley (1977) mapped these and the Llano de Albuquerque as one large tectonically deformed surface. At best, the study of geomorphic surfaces and associated fills presents an intricate problem in this area. Units for the most part have been warped, faulted, dissected, and in the lower, steeper portions, completely destroyed by erosion (Kelley, 1977). In addition the units must be distinguished from stream terraces and structural benches (shown in Figure 19). Thus determination of the number of units and surfaces represented by the remnants is extremely difficult. The only way to correlate these remnants is with detailed geologic/geomorphic mapping aided by quantitative soil studies. To date this has not been done. According to Bryan and McCann (1938), Kelley (1977), and a number of other authors the Albuquerque surface correlates with the Ortiz Surface of northern New Mexico and developed during Late Pliocene to Pleistocene. Bachman and Mehnert (1978) have obtained radiometric dates that show the "type" Ortiz surface to be about 3 m.y., and the Albuquerque surface to be about 500,000 years old. This makes the Ortiz Surface much older than the the Albuquerque surface. By using buried calcic paleosols Machette (1978c) estimated the soil associated with the Albuquerque surface to be about 500,000 years old.

Degree of development of the calcic soil beneath the Albuquerque surface during the last .5 m.y. is useful for comparing its age with other Quaternary surfaces. Briefly, soil development is dependent on an number of pedogenic controls which include climate, biota, topography, parent material and time. Relative soil age can be estimated by determining the stage of development of total pedogenic calcium carbonate in a section of paleosol. The sequence of calcium carbonate accumulation differs for gravelly and sandy material. The four step sequence in gravelly and sandy material is summarized in Table 2. Degree of development in soil associated with the Albuquerque surface (see Figure 3) ranges from a strong stage III to a very weak stage IV. Degree of development in soils associated with the Llanos del Rio Puerco (Figure 20) appears to range from a strong stage II to a weak stage III. This would indicate that the oldest geomorphic surface in the study area is the Albuquerque surface and the next youngest is associated with the Llanos del Rio Puerco. To reiterate, the Llanos del Rio Puerco is discussed as one unit when in fact it may contain remnants of a number of surfaces that are difficult to differentiate.

Table 2. Stages of carbonate accumulation in the morphogenic sequences (from Gile and others, 1966).



—SCHEMATIC DIAGRAM OF THE DIAGNOSTIC MORPHOLOGY OF THE STAGES OF CARBONATE-HORIZON FORMATION in gravelly and nongravelly materials. Carbonate accumulations are indicated by black forms and shadings for clarity (from Gile and others, 1966, fig. 5, with permission).

Stage and general character	Diagnostic carbonate morphology	
	Gravelly sequence	Nongravelly sequence
I Weakest expression of macroscopic carbonate	Thin, discontinuous pebble coatings	Few filaments or faint coatings
II Carbonate segregations separated by low-carbonate material	Continuous pebble coatings, some interpebble fillings	Few to common nodules
III Carbonate essentially continuous; plugged horizon forms in last part	Many interpebble fillings	Many nodules and internodular fillings
IV Laminar horizon develops	Laminar horizon overlying plugged horizon	Laminar horizon overlying plugged horizon

Figure 20. Soil associated with the Llanos del Rio Puerco. North of Comanche Arroyo.

GEOLOGIC HISTORY-CONCLUSIONS

Introduction.

Geologic history considered in this report spans from Early Popotosa time (Early(?) Miocene or Late Oligocene) to the present. Early basin history is drived from information outside the study area. Dating events is possibly the most difficult aspect of trying to work out the chronology of events along the lower Rio Puerco. Gaps in dates and differences in interpretations are just a few of the many problems with this phase of the study. Geologic dating of deposits has been limited to: 1) fossils remains found in gravel units (Tedford, 1981), 2) superposition with volcanic material (Bachman and others, 1978), 3) incorporation of diagnostic volcanic clasts within the basin fill, and 4) radiocarbon dates in younger valley deposits (this study). At this point, there is no absolute method of correlating the alluvial events with glacial-pluvial or interglacial-interpluvial cycles.

Pre-Popotosa history.

Pre-Popotosa history involves the deposition of Baca Formation and equivalent deposits in broad down-warps throughout this section of the Basin and Range and Colorado Plateau (Chapin and Seager, 1975). This was followed by the extrusion of massive amounts of volcanic rocks to the west in the Datil volcanic field.

Older basin fill, Popotosa Formation.

As the Colorado Plateau began to rise, volcanic detritus was eroded and transported into the Popotosa Basin where the southern Albuquerque Basin and Socorro-Lemitar Mountains are now located (Chapin and Seager, 1975, Chapin, 1981). Two fanglomerate facies are recognized (Machette, 1978c): volcaniclastic and Ladron Mountain fanglomerates. These two fanglomerates overlap and interfinger with playa deposits that occupied the topographically lower areas of the basins. As uplift continued, and new uplifts were initiated, the Popotosa Formation was progressively deformed and locally beveled. In general, the Popotosa Formation indicates that the southern part of the Albuquerque Basin was partially filled with intermontane basin fill deposits during Miocene (?) to Pliocene (?) time.

Younger basin fill, Sierra Ladrones Formation.

The history of a river flowing through the Albuquerque Basin is a subject of much debate. Bachman and Mehnert (1978) suggest a through-flowing drainage for the Rio Grande developed between 3.0 and 4.5 m.y. ago. Sierra Ladrones axial stream deposits (not necessailly the ancestral Rio Grande) are observed in the study area to a depth of at least 109 m although much more may be buried. Two facies are suggested in the study area based on the composition and texture of gravels. These are: through-flowing fluvial and near-source interfingering marginal alluvial facies.

Paleocurrent indicators, and the presence of Grants obsidian in the gravels indicates a northwest source for the through-flowing facies. Presence of Grants obsidian in the sediments indicates an age of less than 3 m.y. for the upper 53 metres of the Sierra Ladrones Formation. Interfingering near-source material was probably derived from the west. In general, the Sierra Ladrones Formation shows the final stages of a very rapidly aggrading basin fill during Pliocene to mid-Pleistocene time. Progressive deformation continued through this time as evidenced by warping in Sierra Ladrones beds. Slightly warped beds were beveled by erosion at the end of Sierra Ladrones time.

Basin stability and the Albuquerque surface.

The Albuquerque surface represents a period of surface stability and subsequent soil formation in a arid to semiarid climate marking the culmination of basin fill prior to entrenchment of the modern Rio Grande system. The Albuquerque surface formed as part of a broad basin floor (Bachman and Mehnert, 1978). The age of the soil associated with the Albuquerque surface has been estimated by superposition of volcanic material and the degree of soil development to be about 500,000 years old (Bachmen and Machette, 1977).

Faulting.

The geologic history of the basin envolves at least three, and possibly four, periods of faulting that began with the development of the Albuquerque surface soil. Evidence for episodic faulting is provided by multiple soil development adjacent to faults. Faulting and warping probably represent the surface expression of complex horsts and grabens at depth. In the Socorro area, horsts have been elevated through several hundred meters of Cenozoic basin fill (Chapin and Seager, 1975). Structural deformation, which includes faulting and warping has probably been the principal control of river position through the Albuquerque Basin.

Early valley incision and older terraces and fills.

Stabilization of the Albuquerque surface and initial soil developmant soil followed by a complex sequence of major valley cutting followed by partial backfilling. The most dramatic valley cutting and backfilling occurred with the development of the Rio Puerco and major tributaries. Initial valley cutting was caused by one or a combination of 3 possible reasons: 1) tectonic change in base level, 2) climate change resulting in a change in the erosion-sedimentation processed, and/or 3) the integration of a through-flowing river system. Backfilling resulted in a stepped sequence of older valley fill deposits.

Late Quaternary downcutting and backfilling.

Post-Sierra Ladrones valley deposits are divided into two facies: one is associated with the meandering system of the Rio Puerco, and the other is a product of braided tributary arroyo systems. Evidence for the initial downcutting and backfilling can be viewed in the cross-cutting relations in Comanche Arroyo. In Comanche Arroyo older valley fill is inset against Sierra Ladrones fluvial facies. The oldest downcutting and backfilling cannot be dated; however by cross-cutting relationships, the first episode is known to be younger than the Albuquerque surface and older than parts of the Llanos del Rio Puerco. At least two and probably three periods of valley down cutting and backfilling are revealed at this location.

Evidence for at least three major periods of Late Quaternary down cutting and back filling are revealed in the Rio Puerco valley fill. The deepest downcutting may be as much as 30 m as determined by core samples. Two additional periods of major channel entrenchment and back filling are revealed in the cross-sections at Hidden Mountain Dam site and Comanche Arroyo. At this time there is no way to date the major channel cut and fill sequences. Major channels appear to be continuous throughout the area although it is extremely difficult to correlate channels up and down valley.

Two periods of minor channel back filling are recorded in the cross section at Comanche Arroyo and Stratigraphic site 1. The age of these events has been interpreted from associated cultural material which ranges in age from

Basketmaker III to the present, however there is more than one way to interpret the finding and all anthropologists are not in agreement on the age assigned to cultural periods. If the radiometric dates are correct at least two minor channels have been filled between about 2000 and 3000 years ago. Stratigraphic site 1 is 5.53 m deep and is in a channel that has aggraded to the present level during this time range. More recent deposits merely cut and rework these deposits.

Changes in the Rio Puerco Arroyo during thhe 20th century include: 1) widening the arroyo, 2) elongation, migration, and cutoff of meander bends of the inner channel and flood plain, and 3) formation of the inner arroyo flood plain. Evidence for changes in the Rio Puerco Arroyo come from historical documents which include maps, surveyor's notes and photographs (Betancourt, 1980). The two periods of channel position mapped indicate that more than 90% of the modern channel has shifted laterally during the past 35 years.

Future Studies

1) One of the primary aims of this study was to extend the stratigraphic subdivisions of the Upper Cenozoic deposits to fill in gaps. This goal needs additional work as well as being extended to other areas of the Albuquerque Basin.

2) An in depth quantitative study of the gravels in the

Albuquerque Basin to determine the variation in roundness and composition between the axial channel, piedmont and terrace gravels. Additional objectives of the gravel studies would be to determine quantitatively the lateral and vertical variations in compositions and to test the basic assumptions about piedmont and through-flowing gravels.

3) Individuals with specific training in soil science are urgently needed to take a multidisciplinary approach to geology-soil relationships in the area.

4) More detailed chemical analyses are needed to characterize the source areas for obsidians in New Mexico. Such analyses can provide significant information on the mode of distribution of sediments throughout New Mexico.

5) The investigation of sedimentary structures has not been a primary aim of this study although the ephermeral nature of the Rio Puerco provides an excellent area to conduct such a study. Ephermeral streams provide a middle ground between flume experiments and field study of sedimentary rocks, thus they provide the possibility of observation of cause and effect relationships of sedimentary structures.

References Cited

Bachman, G. O., 1976, Cenozoic Deposits of Southwestern New Mexico and the outline of the history of evaporite dissolution: Jour. Research, U.S. Geol. Survey, v. 4, No 2, p 135-149.

Bachman, G. O., and Mechette, M., 1977, Calcic soils and calcretes in the southwestern United States: U.S. Geologic Survey Open-file Report 77-799, 163 p.

Bachman, G. O., and Mehnert, H. H., 1978, New K-Ar dates and the late Pleistocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geol. Soc. America Bull., v. 89, p. 283-292.

Bassett, W. A., Kerr, P. F., Schaeffer, O. A., and Stoenner, R. W., 1963, Potassium-Argon ages of volcanic rocks near Grants, New Mexico: Geol. Soc. of American Bull., v. 75, p.221-226.

Betancourt, J. L., 1980, Historical overview of the lower Rio Puerco-Rio Salado drainages, New Mexico., in M. Wimberly and P. Eidenback, Reconnaissance study of the archaeological and related resources of the lower Rio Puerco and Salado Drainages, Central New Mexico: Tularosa, Human Systems Research, Inc., p. 23-58.

Bryan, K., 1925, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, v. 62, p. 338-344.

———, 1928, Historical evidence on changes in the channel of Rio Puerco, a tributary of the Rio Grande in New Mexico: Jour. Geology, v. 36, p. 265-282.

----------, 1938, Geology and groung-water conditions of the Rio Grande depression in Colorado and New Mexico Washington, Regional Planing pt. 6 Rio Grande joint inv. upper Rio Grande Basin, Nat. Res. Comm., v. 1, pt. 2, sec. 1, p. 197-225.

----------, 1940, Erosion in the valleys of the Southwest: New Mexico Quarterly, v. 10, p. 227-232.

----------, 1941, Pre-Columbian Agriculture in the Southwest, as conditioned by periods of alluviation: Assoc. Am. Geographers Annals, v. 31, p. 219-242.

Bryan, K., and McCann, F.T., 1937, The Ceja del Rio Puerco-a border feature of the Basin and Range province in New Mexico, Part I, Stratigraphy and structure: Journal of Geology, v.45, p.801-828.

------------------------, 1938, The Ceja del Rio Puerco-a border feature of the Basin and Range province in New Mexico, Part II, Geomorphology: Journal of Geology, v. 46, p. 1-16.

Calkins, H. G., 1941, Man and gullies: New Mexico Quarterly, v. 11, p. 69-78.

Chapin, C. E., and Cather, S. M., 1981, Eocene Tectonics and sedimentation in the Colorado Plateau-Rocky Mountain Area: in Relation of Tectonics to Ore Deposits in the Southern Cordillera, eds W. R. Dickinson and W. D. Payne, Arizona Geol. Soc. Digest, v. XIV, p 173-197.

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

Chamberlin, R. M., 1981, Cenozoic stratigraphy and structure of the Socorro Peak volcanic center, central New Mexico: New Mexico Geology, v. 3, No 2, P 22-25.

Denny, C. S., 1940, Tertiary geology of the San Acacia area, New Mexico: Jour. of Geology, v. 48, p. 225-260.

————————, 1941, Quaternary geology of San Acacia area, New Mexico: Jour. of Geology, v. 49, p. 225-260.

————————, 1967, Fans and pediments: American jour. of Science, v. 265, p. 81-105.

Elliot, J. G., 1979, Evolution of large arroyos: the Rio Puerco of New Mexico: unpublished Masters Thesis, Colorado State University, Fort Collins, Colorado. 106 p.

Fenneman, N. M., 1931, Physiography of the Western United States: New York, McGraw-Hill, 534 p.

Frye, J. C., and Willman, H. B., 1962, Morphostratigraphic units in Pleistocene stratigraphy: American Association of Petroleum Geologists Bull., v. 46, p. 112-112.

Galusha, T., and Blick, J. C., 1971, Stratigraphy aof the Santa Fe Group, New Mexico: Am, Mus. Nat. History, Bull., v. 144, art. 1, 128p.

Gile, L. H., Peterson, F. F., and Grossman, R. B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, p 347-360.

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1981, Soil and Geomorphology in the Basin and Range area of southern New Mexico-Guidebook to the Desert Project: New Mexico Bureau of Mines and Meneral Resources, Memoir 39, 222p.

Gile, L.H. and Grossman, R.B., The Desert Project monograph: Soil Conservation Service, U.S. Department of Agriculture, 984 p.

Happ, S. C., 1948, Sedimentatin in the middle Rio Grande Valley, New Mexico: Geol. Soc. of America, v. 59, No. 12, part 1, p 1191-1215.

Hawley, J. W., 1975, Quaternary history of te Dona Ana County region, south-central New Mexico: New Mexico Geological Society, Guidebook 26th field conference, p. 139-150.

———————, compiler, 1978, Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Circ. 163, 241 p.

———————, 1981, Pliestocene and Pliocene history of the International Boundary Area, southern New Mexico: in Geology of the Border , southern New Mexico-norther Chihuahua, published by the El Paso Geological Society, p. 26-31.

Hawley, J.W., Bachman, G.O. and Manley, K., 1976, Quaternary stratigraphy in the Basin and Range and Great Plains Provinces, New Mexico and Western Texas: in Mahaney, W.C., ed., Quaternary Stratigraphy of North America: Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa., p. 235-274

Hawley, J. W., and Kottlowski, F. E., 1969, Quaternary Geology of the south-central New Mexico border region, in Border stratigraphy symposium: New Mexico Bureau of Mines and Mineral Resources, Circ. 104, p. 89-115.

Hawley, J. W., and Love, D. W., 1981, Overview of Geology as related to Environmental Concerns in New Mexico: New Mexico Geological Society, Special Publicatin No. 10, pp 1-10.

Hayden, F. V., 1869, Preliminary field report of the U. S. Geol. Survey of Colordo and New Mexico: U. S. Geol. Survey 3rd Ann. Rept., 155p.

Heede, B. H., 1971, Characteristics and processes of soil piping in gullies: U.S.D.A. Forest Service Research Paper RM-68, 15 p.

Hester, T. R., and Mitchell, J. L., 1974, Source analysis of obsidian artifacts from McMullen County, Southern Texas: Lower Plains Arch. Soc. Bull., v. 4, p. 25-32.

Johnson, B. D., 1978, Genetic Stratigraphy and provenance of the Baca Formation, New Mexico and Eagar Formation, Arizona: unpublished Masters thesis the University of Texas, Austin.

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

---------------, 1977, Geology of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mem. 33, 59 p.

Kelley, V. C., and Kudo, A. M., 1978, Volcanoes and related basalts of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 156, 30p.

Lambert, P.W., 1968, Quaternary stratigraphy of the Albuquerque area, New Mexico: unpublished PhD Thesis University of New Mexico, Albuquerque, New Mexico.

Leighly, J., 1936, Meandering arroyos of the dry Southwest: Geographical Rev., v. 26, p. 270-282.

Lipman, P. W., and Mehnert, H. H., 1980, Potassium argon ages from the Mount Taylor volcanic field, New Mexico: U.S. Geol. Survey Prof. Paper 1124B, p.B1-B8.

Love, D. W., 1977, Dynamics of sedimentation and geomorphic history of Chaco Canyon National Monument, New Mexico: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Jaun Basin III, p. 291-300.

---------------, 1980, Quaternary geology of Chaco Canyon, Northwestern New Mexico: PhD Thesis, University of New Mexico.

Love, D. W., Hawley, J. W., and Young, J. D., 1982, Preliminary report on the geomorphic history of the lower Rio Puerco in relation to archaeological sites and cultural resources of the Lower Hidden Mountain Dam Site: Human Systems Research Inc. (in press).

Machette, M. N., 1978a, Bernalillo County dump fault, in

Hawley, J. W., ed., Guidebook to Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines & Mineral Resources, Circ. 163. p. 153-154.

————————, 1978b, Dating the Quaternary faults in the southwestern United States by buried calic paleosols: U.S. Geological Survey, Journal of Research, v. 6, no. 3P., p. 369-381.

————————, 1978c, Geologic Map of the San Acacia quadrangle, Socorro County, New Mexico: U.S. Geological Survey, Geol. Map GQ-1415, scale 1:24,000

————————, 1978d, Late Cenozoic Geology of the San Acacia-Bernardo area: in Hawley, J. W., ed., Guidebook to Rio Grande rift in New Mexico and Coloardo: New Mexico Bureau Mines and Mineral Resources, Circ. 163, p. 135-137.

Meyers, T., and Ford, R. T., 1980, Neutron Activation obsidian from Arhaeological Sites in New Mexico:unpulished report.

Nordin, C. F., 1963, A prelimimary study of sediment transport parameters,Rio Puerco near Bernardo, New Mexico:U.S. Geol. Survey Prof. Paper 462-C, p. C1-C21.

Nordin, C. F., and Curtis, W. F., 1962, Formation and deposition of clay balls, Rio Puerco, New Mexico: U.S. Geologic Survey Prof. Paper 450-B, p. B-37-B-40.

Patton, P. C., 1973, Gully erosion in the semiarid west: unpublished Masters Thesis. Colorado State University, Fort Collins, Colorado. 129 p.

Pease, D. S., 1975, Soil Survey of Valencia County, New

Mexico, Eastern Part: Soil Conservation Service Publication.

Rittenhouse, G., 1944, Sources of modern sand in the Middle Rio Grande Valley, New Mexico: Jour. of Geol., v. 52, p 145-183.

Ritter, D. F., 1978, Process Geomorphology: Wm. C. Brown Co. Publishers. 603 p.

Sappington, R. L., and Backer, C., 1980, X-ray fluorescence analysis of obsidian flacks from Redondo Creek.

Seager, W. R., and Hawley, J.W., 1973, Geology of Rincon Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 102, 56 p.

Selley, R. C., 1979, Ancient Sedimentary Environments: Cornell University Press, Ithac, New York, 287 p.

Schumm, S. A., 1960, The shape of alluvial channels in relation to the sediment type: U.S, Geol. Survey Prof. Paper 352-B.

______________, 1961, Effects of sediment characteristics on the erosion and deposition in ephemeral-stream channels: U.S. Geol. Survey Prof. Paper 352-C. p. 31-70.

______________, 1981, Evolution and responce of the fluvial system, Sedimentological implications: in Recent and ancient nonmarine depositional environments; Models for exploration: S.E.P.M. special publication 31, p. 19-31.

Schumm, S. A., and Hadley, R. F., 1957, Arroyos and the semiarid cycle of erosion: Amer. Jour. Science, v.225, p. 161-174.

Shepherd, R. G., 1976, Sedimentary processes and structures of ephemeral-stream point bars, Rio Puerco near Albuquerque, New Mexico: Geol. Soc. America Abs. with Programs, v. 8, no. 6, p. 1103.

Shepherd, R. G., and Macke, D. L., 1978, Discrimination of eolian deposits by number-frequency analysis of sediment of sand through silt size from a point bar, Rio Puerco, New Mexico: Jour. Research U.S. Geol. Survey, v.6, no 4, p. 499-504.

Strain, W. S., 1966, Blancan Mammalian fauna and Pleistocene formation, Hudspeth County.

Tedford, R. H., 1981, Mammalian biochronology of the late Cenozoic basins of New Mexico: Geol. Soc. America Bull., v. 92., p. 1008-1022.

Titus, F. B., 1963, Geology and Groundwater conditions in eastern Valencia County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Ground-Water Rept. 7, 113 p.

Tuan, Yi-Fu, 1966, New Mexico Gullies; a critical review and some recent observations: Assoc. Am.Geographers Annals, v. 56, p. 573-597.

Van Devender, T.R., and Spaulding, W.G., 1979, Development of vegetation and climate in the Southwestern United States: Science, v. 204, p. 701-710.

Womack, W.R., and Schumn, S. A., 1977, Terraces of Douglas Creek, northwestern Colorado: an example of episodic erosion: Geology, v. 5, p. 72-76.

Walker, R. G., 1979, Facies Models: Geoscience Canada Reprint Series 1, Published by the Geological Association of Canada, 211 p.

Wright, H.E., 1946, Tertiary and Quaternary Geology of the lower Rio Puerco area, New Mexico: Geol. Soc. America Bull. v. 57, p.383-456.

Appendix A, Depositional Models

Many workers (see Previous Investigations) have commented on the fluvial origin of the Sierra Ladrones Formation. The combination of sedimentary structures, fossil remains and general regional setting indicates an almost irrefutable interpretation of the continental-fluvial origin for the Santa Fe Group. Sierra Ladrones and post-Sierra Ladrones deposits can be characterized by two fluvial models. The two models are discussed as simple end-members when in fact more complicated intermediate models may be the rule rather than the exception. Changing discharge rate, tectonics, or lithologies can cause a meandering stream to become braided.

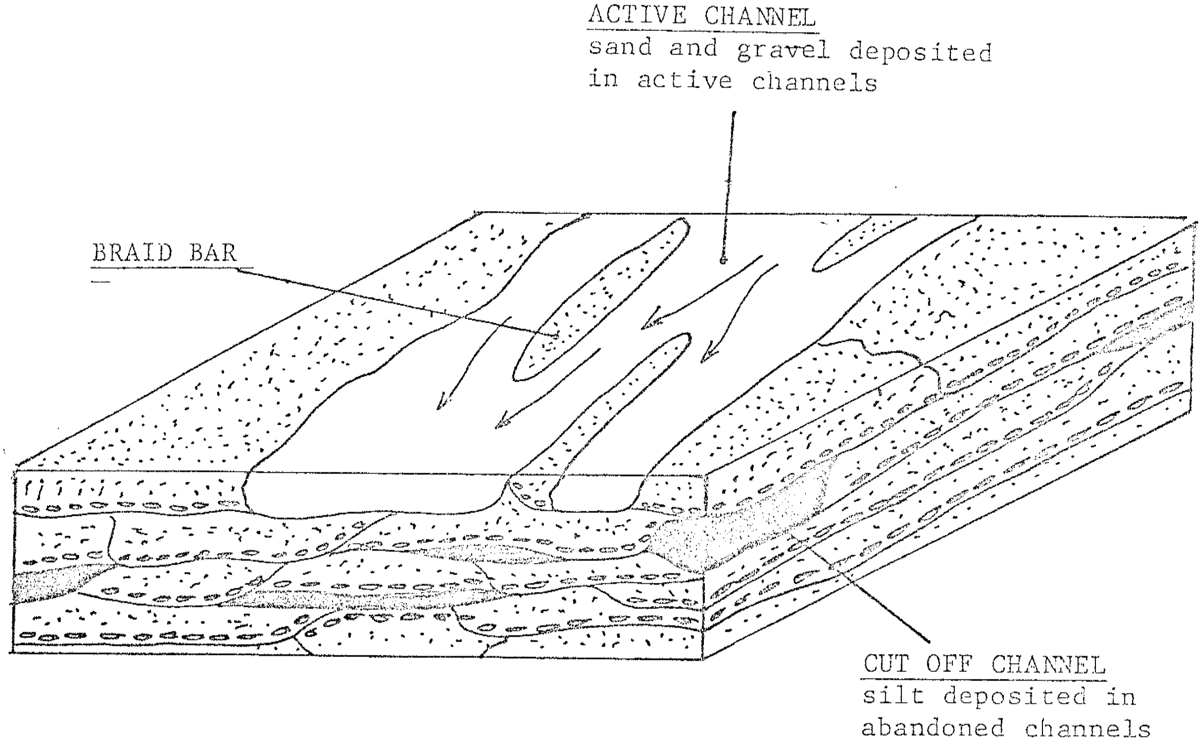
The two end-member fluvial models or facies are; 1) high-sinuosity meandering stream facies, and 2) low-sinuosity braided stream facies. I believe there is little argument that within the study area the dominante fluvial system that deposited the Sierra Ladrones is a bed load, braided stream system. However, west (up Alamito Arroyo) and north (near Los Lunas Volcano) the fluvial system that deposited the late-Sierra Ladrones basin fill takes on the character of a suspended load, meandering stream system. Fluvial models are summarized from Walker (1979) and Selley (1970).

Braided streams model.

Channels of braided streams (Figure 21) tend to be variable in depth and width and do not show the simple channel shape of a meandering stream. Braided stream systems consist of an interlaced network of low sinuosity channels. The channel floor is no sooner cut than it is choked in its own detritus. This is dumped as bars around which new channels are formed. Repeated bar formation and channel branching generates a network of braided channels over the entire depositional area. Alluvium of braided streams is typically composed of sand and gravel to the exclusion of fine-grained overbank deposits. Bedforms in the deeper channels tend to be sinuous crested dunes that give rise to trough cross-bedding.

One major point of contrast with meandering systems is that braided streams tend to have easily eroded banks and no clay plugs. Thus the area occupied by a braided river may be very wide. Vertical accretion deposits (if formed) will tend to be quickly eroded because of rapid lateral migration of channels. Deposits of braided streams represent a dominance of bedload under conditions of high flow regime. In general, high-sinuosity meandering streams tend to be narrow and deep and are characterized by fine-grained loads that are transported in suspension (Ritter, 1978). Low-sinuosity braided streams tend to be wide and shallow, and transport coarse material as bed load.

Figure 21. Braided stream model and the origin of alluvial sub-facies.


ACTIVE CHANNEL
sand and gravel deposited
in active channels
BRAID BAR
CUT OFF CHANNEL
silt deposited in
abandoned channels

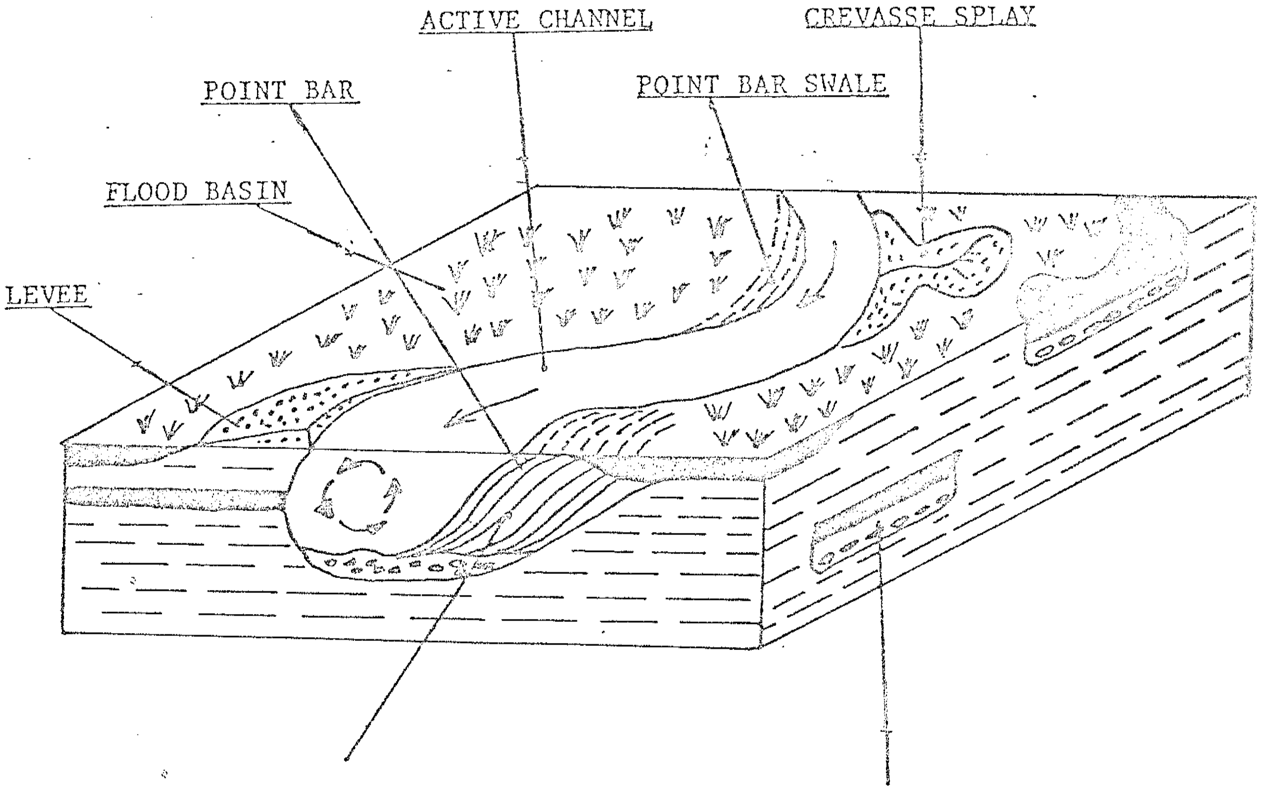
meandering stream model.

High-sinuosity meandering river channels typically develop where gradients and discharge are relatively low compared to those of braided channel systems. The main elements of a modern meandering system are shown in Figure 22. Sandy deposition is normally restricted to the main channel, or to partially or completely abandoned meander loops; deposition of fines (silt and clay) occurs on levees and in flood basins. The deposition of meandering streams can be divided into 3 sub-facies formed in three different sub-environments; the main channel, floodplain, and abandoned channel.

The lateral migration of a meandering channel erodes the outer concave bank, scours the river bed and deposits sediments on the inner bank (point bar lateral accretion). This produces a characteristic sequence of grain size and sedimentary structures by lateral accretion. At the base of the channel is an erosional surface overlain by a coarse lag deposit; which in turn is overlain by a sequence of sands with a general upward decrease in grain size. Massive, flat bedded and trough cross-bedded sands grade up into tabular planer cross-bedded sands of diminishing cross bed height. These pass up into flat-bedded sands which grade up into silts of the floodplain sub-facies.

Outside the main channel deposition takes place by the addition of material during flood stage (vertical accretion). Sheets of fine sand, silt and clay are deposited on the overbank areas of the rivers floodplain. These deposits are sometimes laminated, ripple- marked, and often contain sand filled shrinkage cracks.

Figure 22. Meandering stream Model and the origin of alluvial sub-facies.



<u>active channel sequence</u>

silt: overbank floodplain
sand: point bar
gravel: channel floor

<u>abandoned channel sequence</u>

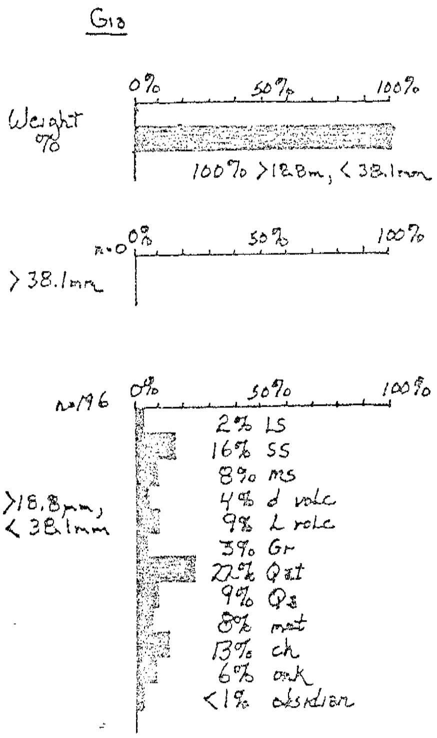
silt: channel fill
gravel: channel floor

Curved shoestrings of fine grained deposits infill abandoned channels (oxbows) and are referred to as clay plugs. These fine grained sediments abruptly overlie channel lag with no intervening point bar sand sequence.

Appendix B. Gravel

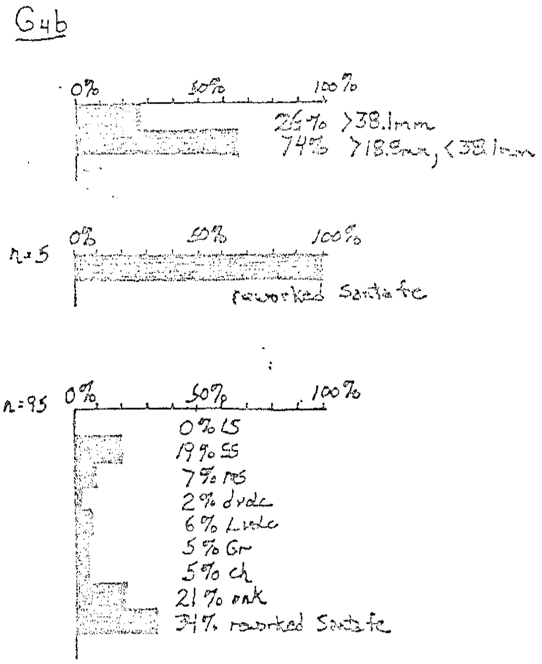
Samples of gravel were taken on and beneath a number of surfaces. Location of collecting sites is shown on Plate 2. The tabulated data has been converted into a graphic form depicting percentages and compositioned and is presented in Figures 23a-23e.

G1a



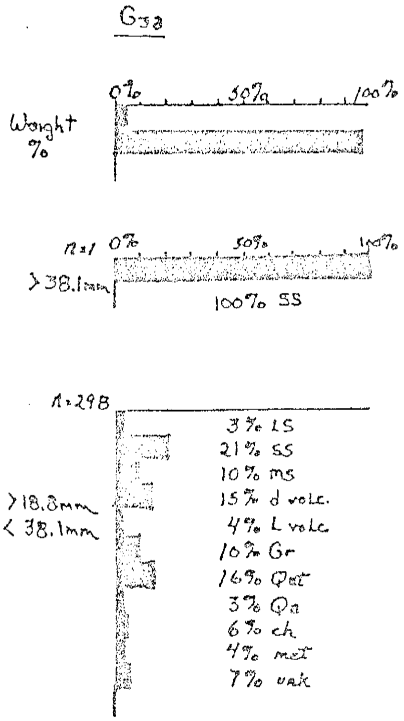
subangular to
well rounded

G4b

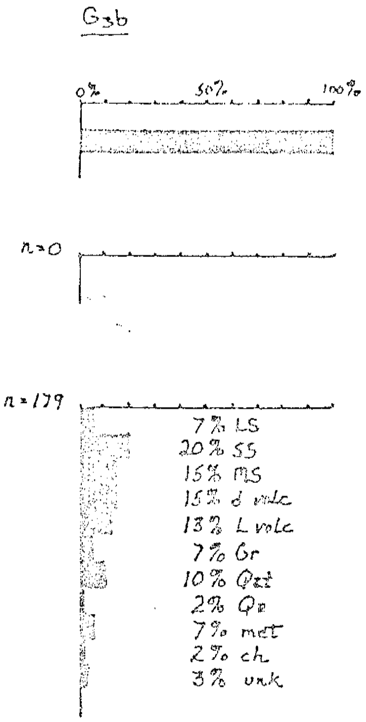


Subangular to
well rounded

G3a

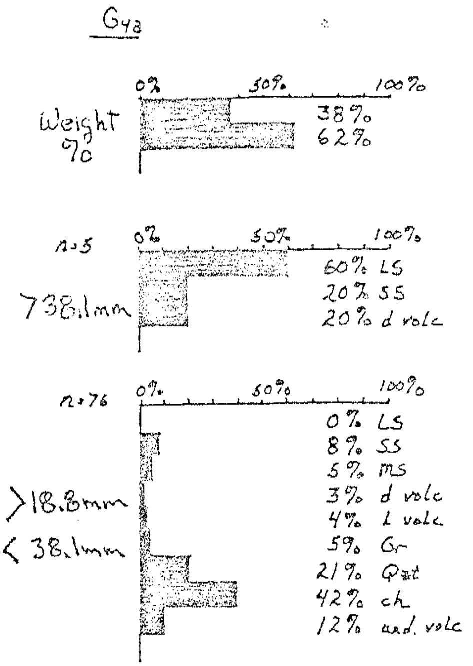

G3a
0%
50%
100%
Weight %
n=1
0%
50%
100%
>38.1mm
100% SS
n=298
>18.8mm
<38.1mm
3% LS
21% SS
10% MS
15% d volc.
4% L volc
10% Gr
16% Qzt
3% Qz
6% ch
4% met
7% unk

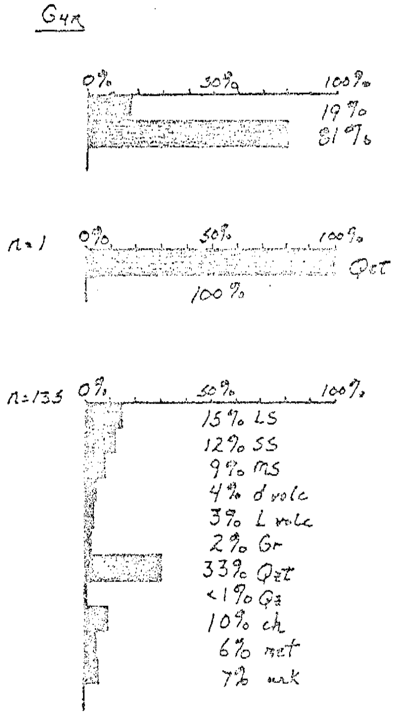
G3b


G3b
0%
50%
100%
n=0
n=179
7% LS
20% SS
15% MS
15% d volc
13% L volc
7% Gr
10% Qzt
2% Qz
7% met
2% ch
3% unk

G4a

G4r

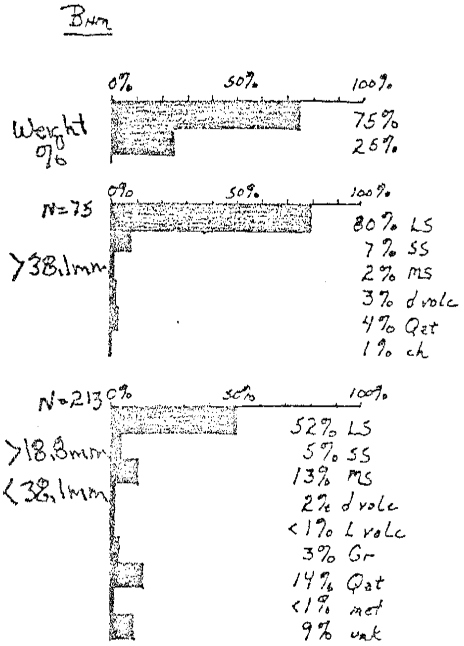




subangular to
well rounded

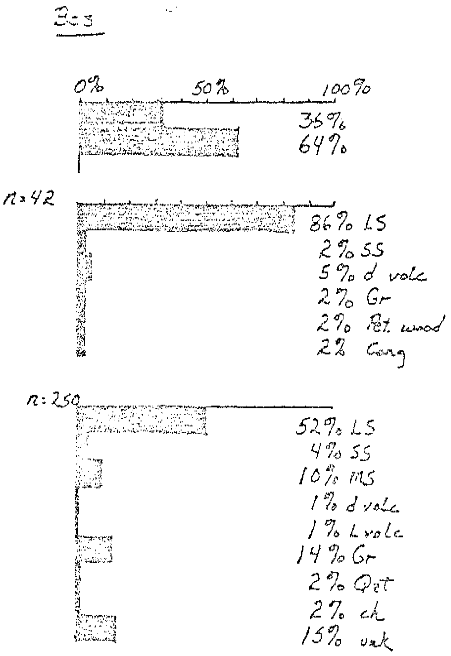
subangular to
well rounded

Bhm



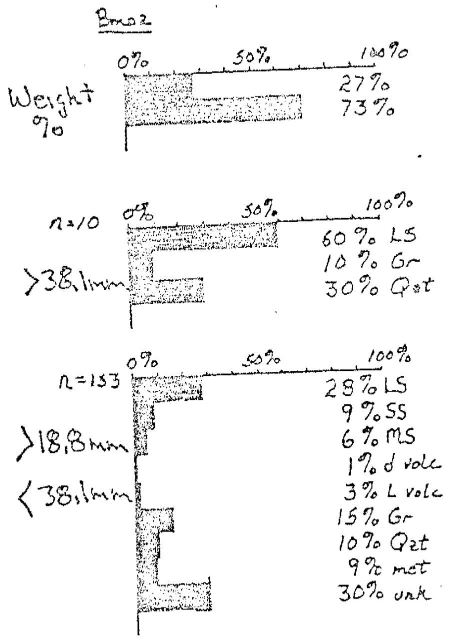
very angular to subrounded

Bc3



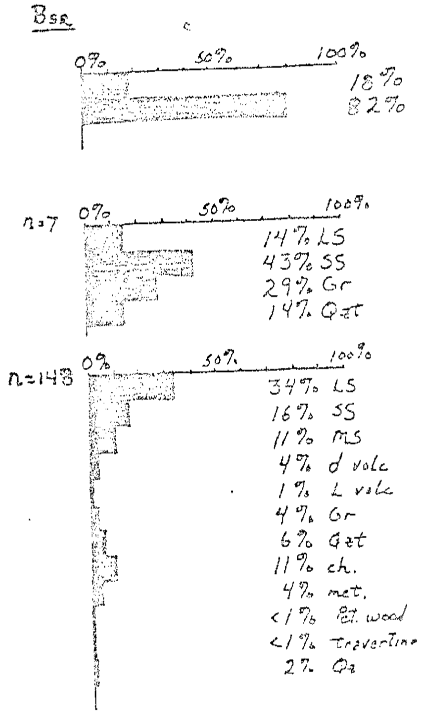
very angular to angular

Bmd



angular to
subrounded

Bsr



angular to
subrounded

Figure 23. Tabulated gravel data. From the top to the bottom of the page the data appears as: 1) weight percent, 2) percentage of each rock type larger than 38.1mm, and 3) percentage of rock types between 18.8mm and 38.1mm. Total number of clasts for that size ranges is presented at the upper left hand corner of the graph.

Appendix C, obsidian

Ten obsidian samples were collected from measured stratigraphic sections in the study area. Only obsidian inferred to be in place was collected. Sample numbers, stratigraphic sections and levels are listed in Table 3. An opportunity also arose to analyze samples from the Grants area when Catherine Cameron donated two samples to the project.

Samples were placed in a plastic sample bag and broken into smaller pieces using a rock hammer. weathering rinds were carefully removed from the samples. Samples were then reduced to a fine powder by grinding with an agate mortar and pestle. All samples were processed in the same manner. Concentrations of major and trace elements were determined by the New Mexico Bureau of Mines and Mineral Resources X-ray department. The four trace elements recorded are Rb, Sr, Y, and Zr. The results are summarized in Table 4. Major element oxide percents are included in Table 5.

Table 3, Obsidian Samples

SAMPLE	STRATIGRAPHIC SECTION #	LEVEL
JYa	3	21m
JYb	3	25m
JYc	3	53m
JYd	4	24.4m
JYe	4	37.5m
JYf	old tank	in caliche
JYi	2	24m.
JYp	bench	terrace 6m. Rio Puerco
JYj	2	14m.
JYk	1	27.7m
G1	Grants #1	
G2	Grants #2	

Samples with a "JY" prefix are from the study area. Samples with a "G" are from the Grants area, and a "JZ" indicates the Jemez Mountains.

Table 4, Parts per millions, and normalized counts ppm.

	Parts per million*				normalized counts of ppm.		
Sample	Rb	Sr	Y	Zr	Rb	Y	Zr
JYa	526	--	101	115	71	13.6	15.5
JYb	533	3	93	92	74.2	13	12.8
JYc	544	--	99	97	73.5	13.4	13.1
JYd	510	7	97	105	71.6	13.6	14.7
JYe	527	--	94	92	73.9	13.2	12.9
JYf	561	3	84	94	75.9	11.4	12.7
JYj	548	-	82	91	76	11.4	12.6
JYk	510	-	97	111	71	13.5	15.5
JYl	521	3	92	89	74.1	13.1	12.7
JYp	511	--	113	115	69.1	15.3	15.6
G1	542	--	98	92	74	13.4	12.6
G2	542	--	95	92	74.3	13	12.6

* Rb=+5%, Sr=+5%, --=below lower limits of determination, Y=+20%, Zn=+10%.

Appendix D, Stratigraphic Sections

Stratigraphic sections from four locations are presented. Terminology presented is essentially that used by the U.S. Soil Conservation Service. Color code is in accordance with the Munsell soil color chart. Location of the measured sections are ploted on Plate 2.

SECTION #1, DENNY FAULT SECTION

GROUP AND FORMATIONS: Santa Fe Group, Sierra Ladrones Formation and Llano de Albuquerque Morphostratigraphic Unit.

LOCATION: west of mile 181.5 on I-25, between Belen and Bernado, New Mexico.

MEASURED BY: John Young, assisted by David Love.

Unit	Total Cumulative Thickness (meters)	Description
1	1.5	Loamy sand, pale brown (10YR6/3), slightly hard, moderately calcareous, scattered pebbles.
2	3	Loamy sand to sand impregnated with soil carbonate, pinkish white (7.5YR8/2),

		very hard, laminated at top, weak stage of development.
3	3.2	Carbonate nodules, white (possible soil), in clay matrix, like unit 4.
4	4	Clay, reddish brown (5YR4/3), overbank deposit, carbonate nodules at base, reddish yellow (7.5YR6/4).
5	12	Gravelly sand, light brown (7.5YR6/4), medium grained, with pebbles to 4cm, a thin clay unit at 8m.
6	12.40	Clay, white carbonate nodules at top (possible paleosol).
7	13.5	Sand, fine grained, yellowish red (5YR6/6), well sorted.
8	18	Gravelly sand, coarse grained, poorly sorted.
9	19	Sand, reddish yellow (5YR6/6), fine grained, well sorted.
10	21.5	Alternating sands and clays, overbank deposit.
11	24.1	Gravelly sand with small channels filled with cross-bedded, coarse grained sands, poorly sorted, light brown (7.5YR6.4).
12	24.5	Sandy loam, calcareous (soil (?)),
13	27.75	Gravelly sand with small channels (~30cm) filled with cross-bedded coarse grained sands, obsidian (JYK) collected.

14	28.25	Sandstone with basal conglomerate, undulating bottom contact, medium to coarse grained, cross-bedded, light gray.
15	34	Sands, fine to medium grained, light brown (7.5YR6/4), upward fining sequence, carbonate nodules at 29.5 m.
16	40	Gravelly sand with cut and fill structures of gravel, locally cemented sandstones, basalt and light colored volcanics present.
17	44	Sand, well sorted, fine grained, light brown (10YR6/3) with local, reddish brown clays.
18	51	Gravelly sand with cut and fill structures, medium to coarse grained, (medium sands are well sorted, coarse sands are poorly sorted), with pebbles to 3cm, obsidian (JYl)in place, units pinch out laterally, sandstones at 47 and 49 m.
19	58	Sands, fine to medium grained, yellowish red (5YR6/6) upward fining, local dark reddish brown (5YR3/4) clays at 53.5 and 55.5 m, clays pinch out laterally.
20	60	Gravelly sand, poorly sorted, coarse grained.
21	63	Clay, reddish brown, alternating silts and clay in upper meter.
22	64	Sandy loam, calcareous (soil (?)).
23	68.5	Gravelly sand, coarse grained, loose obsidian.
24	71	Sandstone, white, cross-bedded, poorly sorted,

		medium grained.
25	76	Alternating sands and gravels, sands are medium grained, light brown (19YR6/3), thin basal sandstone.
26	77	Clay, reddish yellow, overbank.
27	78.5	Sand, coarse grained, poorly sorted.
28	79.5	Sandstone with basal gravelly sand, very coarse, trough cross-bedding at ±80 degrees.
29	88	Alternating silt and clay, thinly bedded.
30	92	Gravelly sand, coarse grained at base, medium at top, upward fining, pink.
31	95.5	Clay, overbank deposit, dark reddish brown (5YR3/4), loamy sand and sandstone at 94m mark.
32	100	Gravelly sand, upward fining, poorly sorted.
33	101.5	Sandstone, coarse grained, poorly sorted, pebbles to 2cm.
34	105.5	Sand to loamy sandy, fine, well sorted, light brown (10YR6/3).
35		Sandstone at base of section at least 3m thick, coarse to very coarse, conglomerate lenses.

SECTION #2, NORTHEAST CORNER SECTION

GROUP AND FORMATION: Santa Fe Group, Sierra Ladrones Formation and Llano de Albuquerque Morphostratigraphic Unit.

LOCATION: west side of Llano de Albuquerque, northeast corner of study area, 1.9 miles south of sub-station

MEASURED BY: John D. Young, assisted by David Love.

Unit	Total Cumulative Thickness (meters)	
1	1.4	Sand to sandy loam, thickens to the west, <10% pebble gravel, calcareous.
2	4.75	Loam to loamy sand impregnated with soil carbonate, weak stage #4 development, primary texture mostly destroyed, about 10% pebble gravel, laminated at top, hard, nodular at base, white, erosioan contact at base.
3	5.2	Calcic nodule horizon set in clay matrix, reddish yellow (7.5YR6/4).
4	6.5	Sand, with cut and fill structures of pebble gravel, light brown (10YR6/3).
5	7.2	Sandy conglomerate, cross-bedded, ledge

		forming unit.
6	9.4	Sand, clean, well sorted, medium grained, light brown (10YR6/3), sandy loam at top, strong brown (7.5YR6/3) clay at base.
7	19.75	Sand and gravel with small channels of cross-bedded sand, sand is clean, coarse grained, and light brown (10YR6/3), Gravel is clean with obsidian (JYj collected) and basalt present.
8	22.5	Sandy loam, fine grained.
9	23.5	Clay, light yellowish brown (10YR6/4), overbank deposit.
10	25.9	Sand, medium grained, light brown (10YR6/3), with cut and fill structures of gravelly sand, locally cemented, obsidian (JYi) collected at 23.75m.
11	28	Clay, reddish brown (5YR5/6), overbank deposit.
12	37.3	Alternating sand and clay, sand ranges in size from coarse to fine grained, color ranges from light brown (10YR6/3) to reddish yellow (7.5YR6/6), clay ranges in color from reddish brown (7YR6/6) to light brown (7.5YR6/4).
13	47	Sand with small channels of cross-bedded pebble sand to gravel. Sand is coarse

		grained, poorly sorted, reddish yellow (7.5YR7/6).
14	48.5	Sandstone, medium grained, poorly sorted, cross-bedded.
15	52.5	Sand, fine grained, light brown (10YR6/3).
16	53.5	Clay, strong brown (7YR5/6), overbank deposit.
17	57	Sand, clean, medium grained, pale brown (10YR6/3), thin clay at 55.5m.
18	61.5	Gravelly sand with small channels of clast supported gravels, light brown (10YR6/3), concentration of bones on surface.
19	64.5	Silt, very fine grained, well sorted, very pale brown (10YR7/4), with local seams of reddish clay.
20	67	Laminated clays and silts, strong brown (7YR5/6).
21	71.5	Sand, clean, light brown (10YR6/3), medium grained, grades laterally to silt.
22	74	Clay, strong brown (7.5YR6/5), overband deposit.
23	76	Sand to loamy sand, fine grained, reddish yellow (7.5YR6/5).
24	82.5	Alternating clays, silts, and carbonates, color ranges from light brown (10YR6/3)

		to reddish brown(10YR5/4).
25	86	Gravelly sand, upward fining.
26	87	Silty loam, reddish yellow (7.5YR6/5).
27	92	Pebble sand, very coarse, clean, pebbles to 2cm., strong brown clay at 89.5m.
28	95.5	Alternating sand and clay, locally cemented, clay range from strong brown (7.5YR5/5) to reddish brown (5YR5/4).
29	96.5	Sandstone, coarse grained, current direction to the southeast (145 degrees), light gray weathered to dark gray.
30	100.5	Sand, locally cemented, medium grained, pale brown (10YR7/4).
31	105.25	Sandstone, white, cross-bedded, medium grained, current direction to south (175 degrees).
32	103.5	Clay with salts, reddish brown (5YR5/4), overbank deposit.
33	105.5	Loamy sand to sand, medium grained, strong brown (7.5YR5/6).
34	106.5	Sandstone with basal conglomerate, pebbles to 3cm., poorly sorted, cross-bedded.
35	107.5	Clay with carbonate nodules, reddish brown (5YR5/4).

SECTION #3, WEST FAULT

GROUP AND FORMATION: Santa Fe Group, Sierra Ladrones Formation and Llano de Albuquerque Morphostratigraphic unit.

LOCATION: Socorro county, New Mexico, west side of Llano de Albuquerque, about 1/2 miles south of county line, section measured along spur that extends into Rio Puerco valley.

MEASURED BY: John D. Young, assisted by James Boyle

Unit	Total Cumulative Thickness (meters)	Description
1	1.5	Loamy sand, pale brown (10.YR5/3), slightly calcareous, slightly hard, scattered pebbles.
2	4	Loamy sand to sand impregnated with soil carbonate, little primary texture remaining, white, < 20% gravel, hard, stage #4 development.
3	5.3	Gravel, cobbles to about 6cm, includes clasts of basalt, light colored volcanics, chert, quartzite, and obsidian.

4	8.5	Sand, very fine to medium grained, yellowish brown to yellowish red (10YR5/6 to 5YR6/6).
5	10.75	Clay, upward coarsening to silt, dark reddish brown (5YR3/4).
6	15	Loamy sand to very fine sand, pale brown (10YR7/4), dark reddish brown clay at 12.5m.
7	21	Sand, upward fining from very coarse to medium grained, pale brown (10YR7/4).
8	23	Sandstone, well cemented, coarse grained, poorly sorted, light gray weathered to dark gray, cross bedded, with gravel lenses, obsidian (JYa) collected.
9	26.5	Sand, medium grained, locally cemented, light brown (10YR6/3), obsidian (JYb) on surface.
10	27.5	Sand, medium grained, upward fining, light brown (10YR6/3), with a strong brown clay seam.
11	28.5	Sandstone, well cemented, cross bedded, coarse grained with pebbles to 2cm, light gray weathered to dark gray.
12	30	Clay, strong brown (10YR5/6), overlain by thin, light brown (10YR6/3), fine grained sand.
13	34.5	Sand, well sorted, pale brown (10YR6/3), very fine grained, coarsening upward to medium grained.
14	35.5	Clay to sandy clay, strong brown (10YR4/6).

15	36.5	Sand, medium grained, strong brown ([illegible]), moderately sorted.
16	38	Sandstone, well cemented, medium grained, poorly sorted, obsidian on resistant bench.
17	41.4	Clay, strong brown (10YR4/6), overlain by light green clay which pinches out laterally, locally altered to a yellow.
18	46	Sand, coarse grained, poorly sorted, contains pebbles and mudballs, very clean, no fines, upward fining to well sorted, fine grained, light brown (10YR6/3).
19	48	Gravel, clast supported channel deposits, gravel imbricated to the southwest, channel trending north south.
20	49	Sandy loam, light brown (10YR6/3), with scattered pebbles.
21	53	Sand, fine grained, well sorted, light yellow brown (10YR6/4).
22	56	Pebble sandstone, poorly sorted, very coarse, cross bedded, light gray weathered to dark gray, obsidian (JYc) collected.
23	59	Sand, fine grained, well sorted, light brown (7.5YR64), slightly cemented, yellowish red (5YR4/6) clay at 58m.
24	59	Clay, Strong brown (7.5YR5/8).
25	62	Loamy sand to loam, light brown (7.5YR5/8).
26	64.5	Sandy gravel, with very coarse sand, unsorted.

27	69.5	Pebble sandstone, light gray weathered to dark gray, coarse grained, unsorted.
28	77	Sand, alternating coarse to fine grained, light brown (10YR6/3), pea gravel at 74.5m.
29	78	Sandstone, coarse grained, light gray weathered to dark gray.
30	79	Clay, yellowish red (5YR5/6), with thin reddish yellow sand (7.5YR6/8).
31	80.1	Sand, well sorted, medium to coarse grained, light brown (10YR6/3), contains scattered white nodules.

SECTION 14, COUNTY LINE SECTION

GROUP AND FORMATION: Santa Fe Group, Sierra Ladrones Formation and Llano de Albuquerque morphostratigraphic Unit.

LOCATION: west side of Llano de Albuquerque on the country line road.

MEASURED BY: John D. Young, assisted by James Boyle

Unit	Total Cumulative Thickness (meters)	Description
1	1.5	Loamy sand with scattered pebbles, slightly calcareous, slightly hard (soil).
2	3	Loamy sand to sand impregnated with soil carbonate, primary texture mostly destroyed, <20% gravel, white, moderately hard, stage #4 development.
3	3.6	Gravelly sand, coarse grained, poorly sorted, white, thin calcareous horizon at base.
4	5.6	Sand, poorly sorted, coarse grained with scattered pebbles.
5	6	Sandstone with basal gravel, very coarse

		grained (gravel sample #G1).
6	6.5	Clay, strong brown (10YR4/6) to reddish brown (5YR3/4), overbank deposit.
7	7.5	Sand, coarse grained, poorly sorted.
8	8.75	Clay, strong brown (10YR4/6) to reddish brown (5YR3/4), overbank deposits.
9	13.5	Sand, moderately sorted, fine to medium grained, light brown (10YR6/4).
10	14.5	Clay, reddish brown (5YR4/4) to strong brown (10YR4/6), overbank deposit.
11	20.1	Sand to loamy sand, medium grained, light brown (10YR6/3) to reddish yellow (7.5YR6/6).
12	20.6	Sandstone, silty, fine grained, light gray.
13	23.5	Sand, fine grained, well sorted, with some clay, light brown (10YR6/3).
14	24.5	Sandstone, very coarse with lenses of conglomerate, cross-bedded, obsidian in place, sample (JYd), gravel sample #G2.
15	27.4	Alternating fine grained sand and sandy loam, yellowish red (5YR5/6) to reddish brown (5YR4/4).
16	32	Sand, upward fining, coarse grained at base, fine grained at top, light brown (10YR6/3), thin, strong brown (10YR4/6) clay at 29m, conglomerate at base.
17	35.5	Sandy silt to sandy clay loam, with minor

scattered pebbles, pink (7.5YR7/4) to strong brown (10YR4/6), pebbles to 1cm.

18 40 Gravelly sand to sandy gravel, coarse grained, very clean, no fines, conglomerates at 36 and 37.5m, obsidian (JYe) collected at 37.5m.

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

Adviser

David B.

May 14, 1982

Date

PLATE 1

GEOLOGIC MAP OF A PART OF THE NORT
HATCHET MOUNTAINS, SOUTHWESTERN

Volcanology and Geochemistry of the Late Cretaceous Hidalgo Formation:
Volcanic Center, Southwestern New Mexico

M.S. Thesis New Mexico State University

BY JOHN R. YOUNG

EXPLANATION

TERTIARY

Tm	Silicified rocks
Tri	Rhyolite intrusion
TKd	Undifferentiated dikes and intrusions
TKm	Biotite monzonite (TKm of Zeller,1970?)

INTRUSIVE CONTACT

CRETACEOUS

Khv	Hidalgo Formation (undifferentiated)
? Khv$_m$	Mega-breccia horizon found in the Hidalgo Formation
Khv$_l$	Limestone cobble breccia horizon found in the Hidalgo Formation
Kr	Ringbone Formation (undifferentiated)
Kru	Upper Ringbone Formation
Kru$_l$	Upper part of Ringbone Formation lava flow
Krm	Middle part of Ringbone Formation

UNCONFORMITY

Kh	Hell-to-Finish Formation (undifferentiated)

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inferred, dotted where conce
position is speculative

Normal fault, ball and bar on
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speculative; arrow shows dip

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toward viewer, A is away fron

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where concealed or speculati

Syncline, showing plunge; da
approximately located dotted

Line of section of figure A ⊢

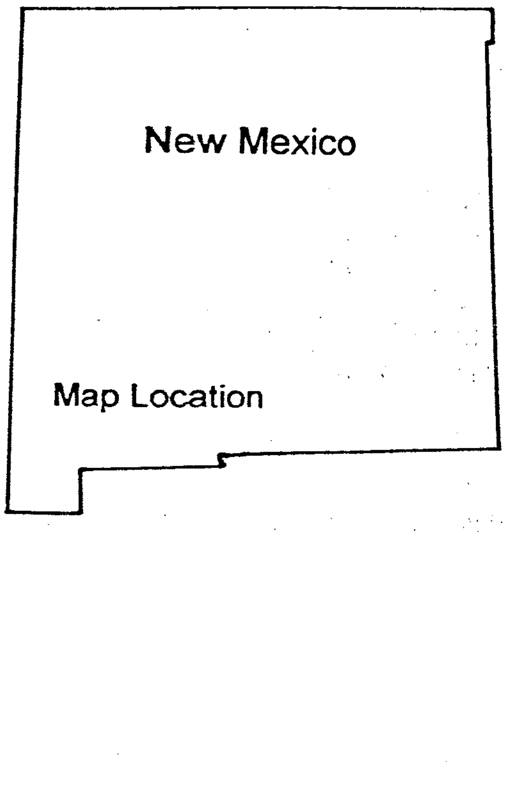
Strike and dip of beds 64

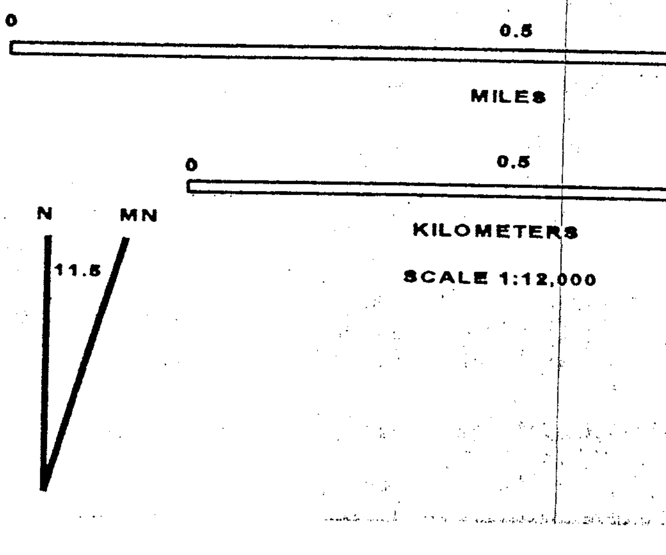
Strike and dip of vertical beds

Strike and dip of overturned b

Strike and dip of overturned b
by primary stratigraphic featur

Analyzed sample location





E NORTHERN LITTLE
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o Formation: Remnant of a Laramide
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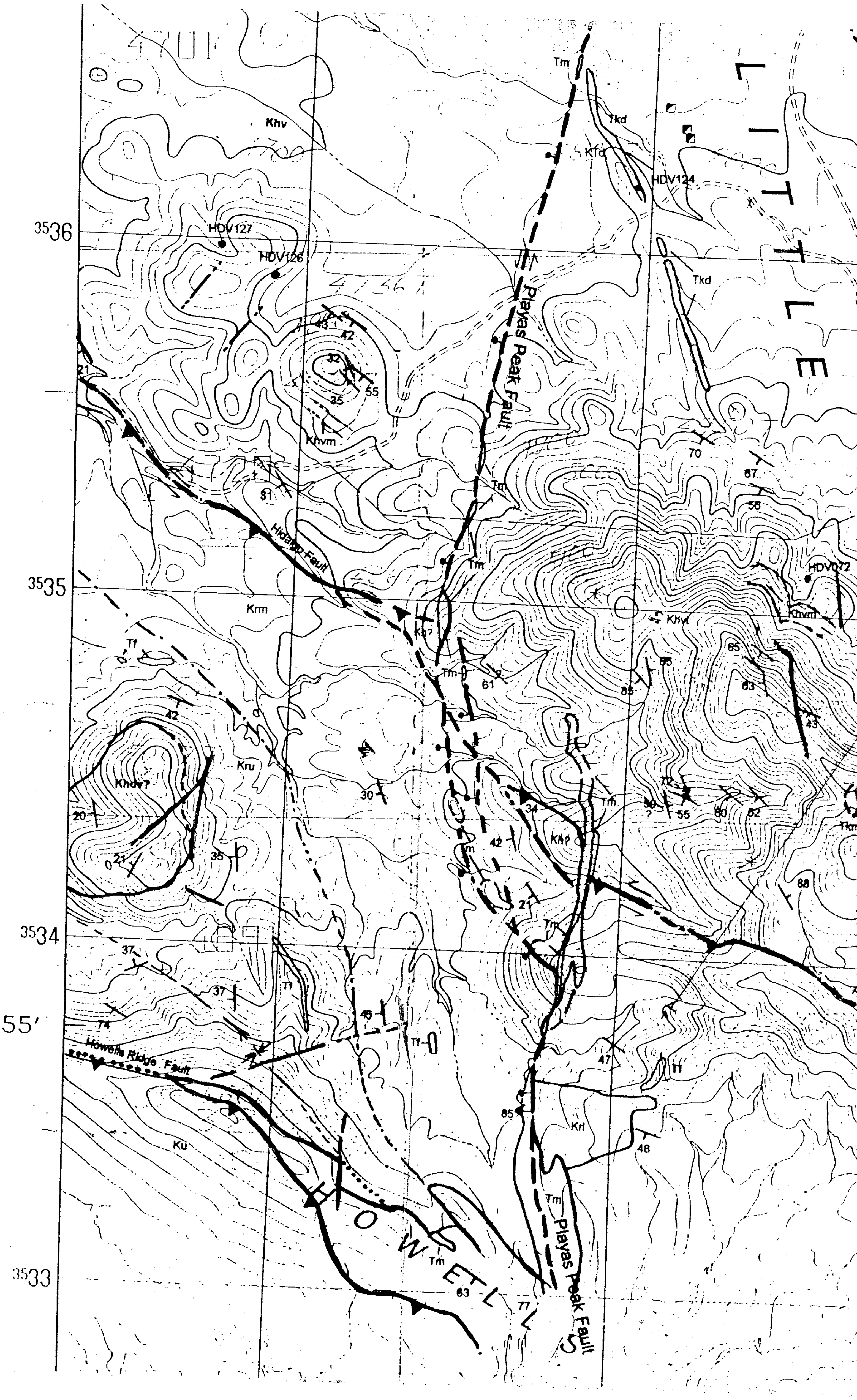

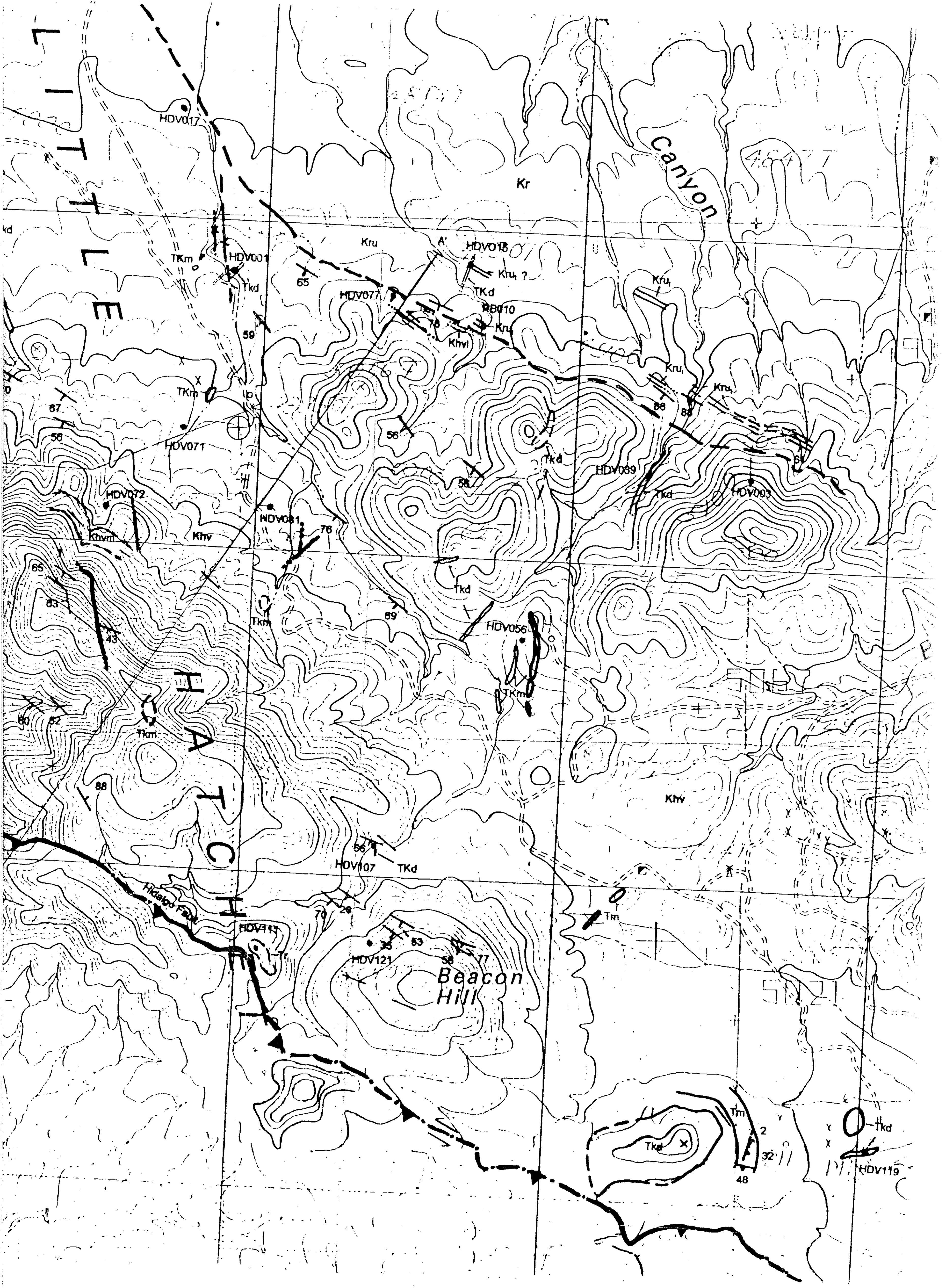
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