STRATIGRAPHY, SEDIMENTOLOGY, AND SAND PETROLOGY OF THE SANTA FE GROUP AND PRE-SANTA FE TERTIARY DEPOSITS IN THE ALBUQUERQUE BASIN, CENTRAL NEW MEXICO

BY

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DISSERTATION

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ABSTRACT

Basin fill within the Albuquerque basin of central New Mexico was investigated to determine stratigraphic units, thicknesses, provenance, and depositional history. Methods included field mapping, measuring sections, well cutting analyses, borehole geophysical log analyses, and sand petrology.

The Albuquerque basin is one of the largest basins of the Rio Grande rift. It is bounded on the east by the Sandia-Manzano-Los Pinos uplift, and on the west by the southeastern Colorado Plateau and the Lucero-Ladron uplifts. Seismic reflection work by the Shell Oil Company shows that the basin consists of a northern, eastward-tilted half-graben and a southern, westward-tilted half-graben. A southwest extension of the Tijeras fault appears to be the transition zone between the half-grabens. Faults that greatly displace the basin fill do not occur along the topographic margins, but further basinward. Many of these faults are listric according to the seismic profiles.

The major basin-fill unit is the latest Oligocene to middle Pleistocene Santa Fe Group. Pre-Santa Fe Tertiary deposits underlie the Santa Fe and indicate the presence of two basins that pre-date the Albuquerque basin. Pre-Santa Fe Tertiary basin fill is subdivided into a lower unit that is at least partly correlative with the Eocene Galisteo and Baca Formations and an upper unit, the unit of Isleta #2

well, that is equivalent to the Datil Group and the overlying sequence of Oligocene volcanic rocks.

Basin-fill thickness, both within the Santa Fe and pre-Santa Fe Tertiary deposits, varies around the basin. Thicknesses in the Santa Fe Group range from 1,000 to 2,000 m in the basin margin areas to as much as 4,407 m in the central basin area. This thick section, penetrated in the Shell Isleta #2 well, is the thickest documented section of the Santa Fe Group in the entire Rio Grande rift. The Gabaldon badlands in the southwest basin area contain the thickest exposed section of the Santa Fe Group that was measured at 1,138 m, but may be as much as 1,800 m thick. Fossils from the lower and middle part of the section indicate an age of 7-9 Ma for most of the Gabaldon section.

Pre-Santa Fe Tertiary deposits are restricted to the western and central portions of the basin and are not recognized in the eastern margin area. Thicknesses in the Galisteo and Baca deposits are up to 454 m; whereas, in the unit of Isleta #2 well, they are as much as 2,185 m. Within the Isleta #2 well, the unit of Isleta #2 contains an ash-flow tuff that has a K-Ar age of 36 Ma and Eocene fossils were reported from the Galisteo section. It is generally difficult to subdivide the pre-Santa Fe Tertiary units without detailed petrographic analyses of well cuttings and core samples. In thin section, the Galisteo and Baca deposits are quartz-rich (70-80%) and volcanic-poor (<1%)

and unit of Isleta #2 deposits typically contain more volcanic-lithic fragments (>10%) and lesser quartz (50-60%). The underlying Upper Cretaceous contact is marked by an abrupt change to gray shale and sandstone with coal interbeds.

Pre-Santa Fe Tertiary deposits usually can be distinguished from the Santa Fe Group during routine analysis of well cuttings by better induration and a distinct color change from reddish orange to purplish red. Detailed thin section analyses show that Santa Fe Group sediments typically contain less quartz (30-50%) and more lithic fragments (10-20%). Volcanic-lithic fragments usually dominate the lithic fraction (80-90%). In the northwest basin area, Santa Fe sediments contain relatively higher quartz percentages (60-70%) and lower percentages of volcanic-lithic fragments (<10%). Quartz content generally increases with depth and mafic volcanics decrease with depth.

Sedimentary and plutonic terranes were the major source areas for the Galisteo and Baca sediments that were deposited in the Galisteo-El Rito and Carthage-La Joya basins. Laramide wrench faulting formed the basins during the Eocene. These basins continued to receive sediments, the unit of Isleta #2 well, during early to middle Oligocene time. In addition to the sedimentary and plutonic detritus, intermediate to silicic volcanic detritus were also shed into these basins.

During early stages of Santa Fe Group deposition (30-15 Ma), the Albuquerque basin probably consisted of two basins that corresponded to the northern and southern half-grabens. These basins had internal drainage and sedimentation rates ranged from 24 to 75 m/Ma. Sedimentary and silicic to intermediate volcanic terranes were the main source areas for the early Santa Fe sediments. By 10 Ma, Precambrian-derived debris was shedding off the eastern uplift area.

From 10-5 Ma, the sedimentation rates increased as a result of more active tectonism. These rates ranged from 204 m/Ma in the Gabaldon badlands to as much as 600 m/Ma in the central basin area. Rapid aggradation due to increased sedimentation rates eventually produced a single Albuquerque depositional basin. Sedimentary, intermediate to silicic volcanic, and Precambrian debris were derived from the surrounding uplifts. Mafic volcanism also became more active at this time. Basin drainage was still internal.

At about 5 Ma, the basin drainage pattern shifted from closed to through-flowing with the development of the ancestral Rio Grande. Two major tributary drainages from the west and northwest joined the ancestral Rio Grande to form a large plain of fluvial aggradation in the central part of the Albuquerque basin. Sedimentation rates had slowed to about 22 to 33 m/Ma. Detritus continued to be shed off the surrounding uplifts but not in as great a volume as before and the ancestral drainages were delivering a variety of lithologies derived partly from outside the basin. About 0.5 Ma, widespread basin aggradation ceased and Santa Fe Group deposition ended during the first major episode of Rio Grande Valley entrenchment. Several more cycles of river incision have produced the present-day inner valley of the Rio Grande.

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CHAPTER 1. INTRODUCTION

Purpose and Scope

Basin-fill studies of the Rio Grande rift have become increasingly more important because of greater interest in groundwater development, hazardous waste management, and petroleum exploration. Such studies can also contribute to a better understanding of the depositional, tectonic, and volcanic history of rift basins worldwide. The Albuquerque basin of central New Mexico is an excellent area to study the basin-fill because it contains some of the best exposures and has the greatest concentration of oil test wells in the entire Rio Grande rift.

The major basin-fill unit of the Rio Grande rift is the uppermost Oligocene to middle Pleistocene Santa Fe Group. It was deposited contemporaneously with basin subsidence and basin-margin uplift and includes piedmont-alluvial, playa, fluvial (axial river) and eolian deposits. Within the Albuquerque basin, numerous local studies have been completed on the Santa Fe Group and many oil exploration wells have been drilled, but to date little work has been done on incorporating this data into a regional synthesis. Limited exposures, complex faulting, and local access restrictions have been major problems for previous basin-wide studies.

The purpose of this investigation is to study the Santa

Fe Group and pre-Santa Fe Tertiary deposits in the Albuquerque basin by incorporating surface and subsurface data. Emphasis is on the sedimentology, sandstone petrology, and stratigraphy of these basin-fill deposits. Major objectives include: 1) petrographically characterizing the basin-fill deposits; 2) defining petrofacies; 3) determining depositional environments and provenance; 4) identifying pre-Santa Fe Group Tertiary units; and 5) determining thicknesses of Santa Fe and pre-Santa Fe Group Tertiary deposits throughout the basin. The ultimate goal of this study is to develop evolutionary models that depict the depositional history of the Albuquerque basin area and the uplift history of its margins.

Geographic Setting

The Albuquerque basin is located in central New Mexico and covers an area of about 7,400 km^2 (Fig. 1-1 and Plate 1). It is within the northern portion of the Mexican Highland section of the Basin and Range physiographic province (Fenneman, 1931; Hawley, 1986). The basin extends roughly from the confluence of the Jemez River with the Rio Grande in the north to the La Joyita Hills in the south, a distance of about 112 km. Basin width varies from about 20 km in the north to about 60 km in the central basin area. The eastern margin is well-defined by the Sandia-Manzano-Los

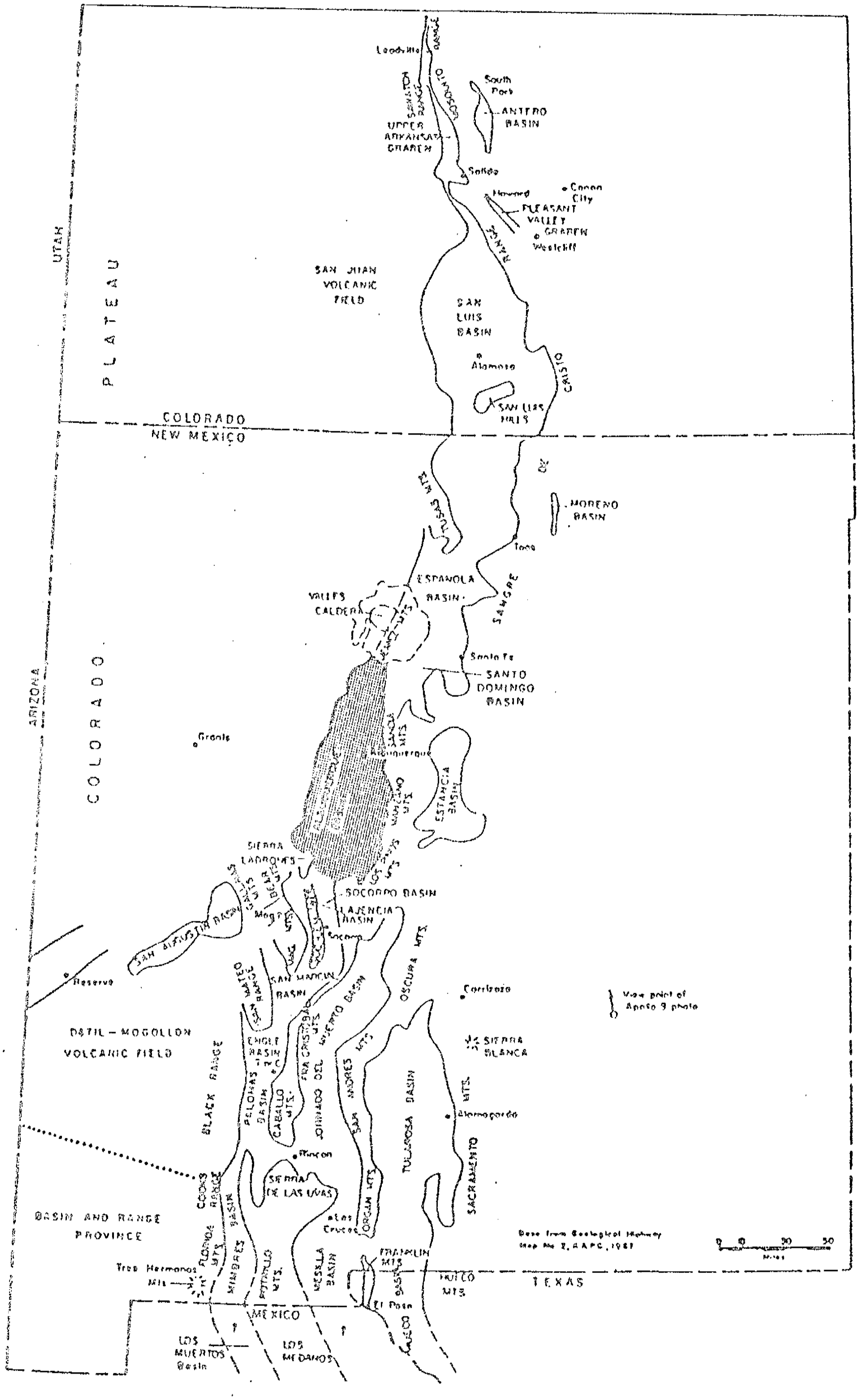


Figure 1-1. Generalized map of the Rio Grande rift showing major basins and margin uplifts. Albuquerque basin shaded. From Chapin (1971).

Pinos mountain chain; however, the western margin is less well-defined by physiographic features and includes the Ladron and Lucero uplifts along the southeastern margin of the Colorado Plateau. Elevations of the margin uplifts are as much as 3,050 m in the east and up to 2,134 m in the west.

Although the Albuquerque basin only comprises about 3% of the total land area of the state, it contains 36% of the state's total population (about 1,450,000), including its largest city, Albuquerque (1980, Census of Population). This population is concentrated mainly along the Rio Grande Valley; outlying areas are only sparsely populated.

Low topographic relief characterizes the area within the Albuquerque basin. Elevations range from about 1,310 m along the Rio Grande to around 1,830 m along the eastern piedmont slope. The valleys of the Rio Grande and Rio Puerco are two of the major landforms in the basin. Minor landforms within the basin include mesas, low hills, inset terraces, and alluvial slopes. Lying between the two rivers is the long, southward-narrowing tableland area known as the Llano de Albuquerque (Plate 1).

Paved and dirt roads provide good access into most areas of the basin. However, certain areas of the basin have restricted access due to private and Indian ownership. Important geographic features (e.g., major roads, towns) are shown on Plate 1.

Climate and Vegetation

The climate of the Albuquerque basin is arid, continental. Average annual precipitation is about 20 cm/yr throughout most of the basin, but this amount generally increases with elevation to about 70 cm/yr in eastern margin uplifts. Typically, more than half of the precipitation falls during the late summer months as brief, intense, localized thunderstorms. Daily summer temperatures can exceed 34°C and daily winter temperatures generally range between 8 and 15°C (climatic data from Hacker, 1977).

Vegetation is mostly sparse. Grasses, small shrubs, cacti, and yucca are the dominate vegetation on mesas and in most valleys. Scattered juniper occur on higher mesas and along basin margins. Tamarisk occur along most drainages and large stands of cottonwood dominate the Rio Grande floodplain.

Geologic Setting

The Albuquerque basin is one of the largest of the structural and physiographic basins that form the approximate 1,000 km long depression known as the Rio Grande rift (Fig. 1-1; Kelley, 1952, 1977; Chapin, 1971, 1979; Chapin and Seager, 1975). These en echelon rift basins are characterized by gravity anomalies (Ramberg, 1978), thin crust (Cordell, 1978), high heat flow (Reiter et al, 1986), young faulting, recent volcanism, and thick basin fills (Seager and Morgan, 1978).

Recent studies suggest that rift extension occurred in two episodes (Chapin and Seager, 1975; Seager et al., 1984; Morgan et al., 1986). Initial extension, possibly related to a back-arc setting, began in latest Oligocene (about 30 Ma) and may have continued to the early Miocene (about 18 Ma; Morgan et al., 1986). This episode of northeast-southwest extension produced low-angle faulting, broad relatively shallow northwest-trending basins, and was accompanied by eruption of basaltic andesite and high-silica rhyolite. The areal extent of these early basins is not well established. The first rifting episode was followed by a mid-Miocene lull (20-13 Ma) where volcanism was minor and tectonism was presumably less active (Morgan et al., 1986).

The second episode of extension represents a renewal or acceleration of block faulting and volcanism that occurred primarily in late Miocene (5-10 Ma) with minor activity continuing to the present (Morgan et al., 1986). This episode was accompanied by regional epierogenic uplift. During the second episode, the extension direction changed from northeast-southwest to east-west, and fragmented the broad northwest-trending basins to produce the generally north-trending series of basins and uplifts that characterize the rift morphology today. Eruptions of basalt and high-angle faulting highlighted the second phase. These basins may have formed along pre-existing weaknesses within the crust (Kelley, 1977; Baars, 1982).

Seismic reflection work by Shell Oil Company on the Albuquerque basin shows that the basin floor is characterized by irregular topography with high local relief. The basin itself is structurally complex and generally composed of a northern, eastward-tilted half-graben and a southern, westward-tilted half-graben. The transition zone between these half-grabens appears to occur just south of Albuquerque along a southwest extension of the Tijeras fault. Santa Fe Group basin-fill covers this half-graben divide and most other structural features within the basin. Magmas of predominately basaltic composition have intruded the Santa Fe Group during and after deposition.

As defined in this study, the Albuquerque basin structurally extends from the San Felipe fault belt in the north to the Joyita uplift in the south (Fig. 1-2). The east and west border features are distinctly different. The eastward-tilted Sandia-Manzano-Los Pinos uplift forms the prominent eastern border. These uplifts consist primarily of Precambrian granitic and metamorphic rocks overlain by upper Paleozoic limestone and sandstone. The western border is more irregular, more varied in structural style, and in some places has only minor amounts of displacement along

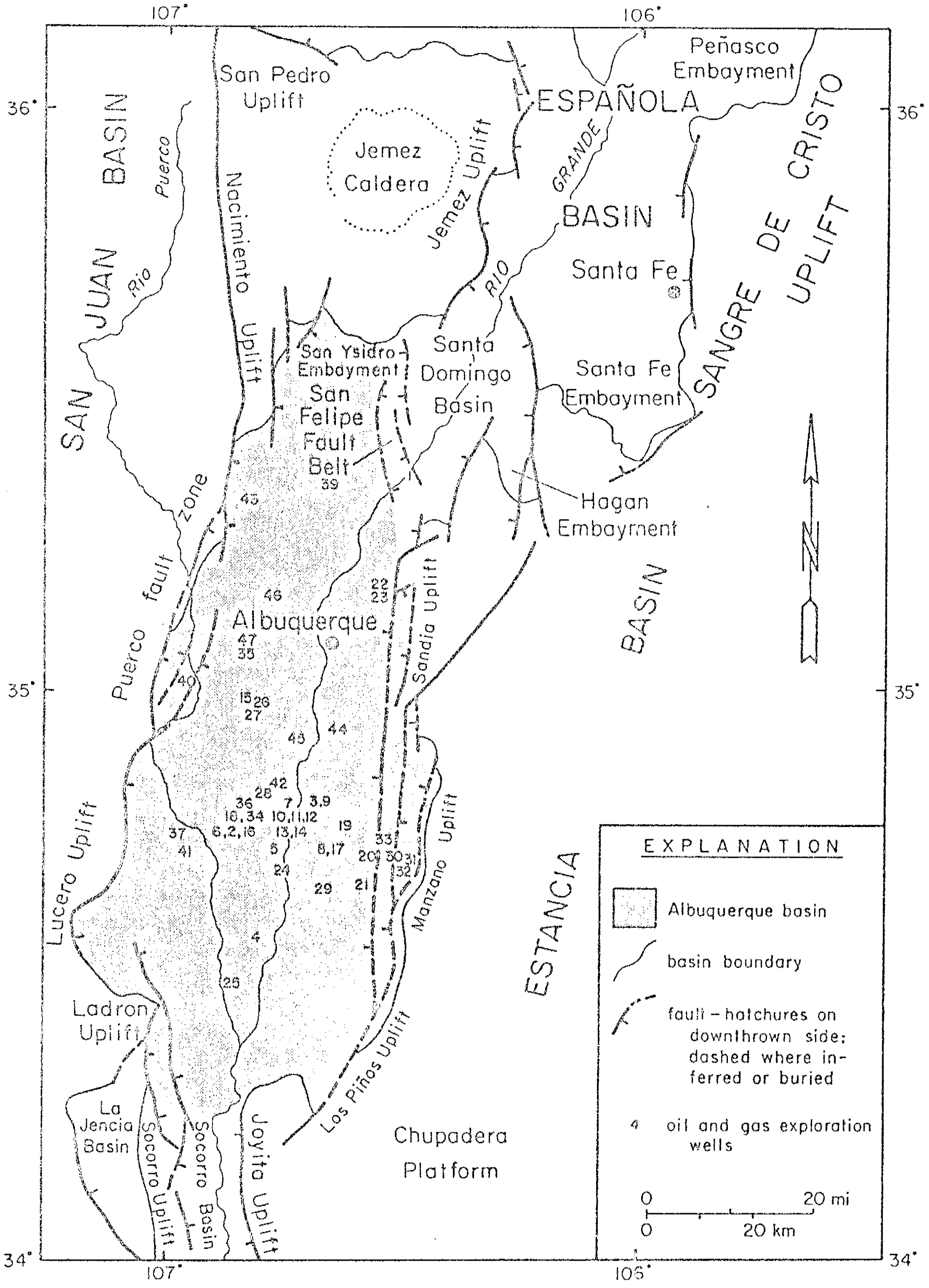


Figure 1-2. Tectonic map of the Albuquerque basin as defined in this study. Numbers refer to oil test wells listed on Table 1-2. Modified from Anonymous (1961) and Woodward et al. (1978).

margin faults.

The Ladron Mountains and the Lucero uplift form the southwestern basin border. The Ladron Mountains are a pyramid-shaped, structurally complex horst that consist mostly of Precambrian granitic and metamorphic rocks with minor upper Paleozoic units. The fault zone that separates the Lucero uplift from the basin is extremely complex and shows Laramide reverse, normal, and possibly strike-slip motion (Callender and Zilinski, 1976; Hammond, 1987). Dipping gently to the west, the Lucero uplift contains mainly upper Paleozoic limestone, shale, and sandstone capped by late Cenozoic basalt flows.

North of the Lucero uplift, the western basin boundary is marked by the Rio Puerco fault zone and lacks a positive physiographic expression. The Rio Puerco fault zone consists of a series of northeast-trending en echelon faults that are downthrown to the west and the east. However, the net displacement of these faults is down to the east (Slack and Campbell, 1976). Rocks exposed directly west of the fault zone include Cretaceous sandstone and shale and, to a lesser extent, Jurassic units. The Lucero uplift and the region west of the Rio Puerco fault zone are part of the Colorado Plateau.

The Sierra Nacimiento uplift and the Jemez Mountains border the basin to the northwest and north, respectively. Precambrian granitic and metamorphic rocks overlain by

Paleozoic and Mesozoic units crop out in the Nacimientos (Woodward, 1987). The Jemez Mountains are part of a large volcanic pile and caldera complex that contain thicknesses as much as 1,524 m of late Miocene to Pleistocene mafic to silicic volcanic rocks (Smith et al., 1970; Gardner et al., 1986).

Previous Work in the Albuquerque Basin

Basin fill deposits of the Rio Grande rift were first named the "Santa Fe Marls" by Hayden (1873) for outcrops occurring in the Espanola basin just north of Santa Fe. Darton (1922) renamed these deposits the "Santa Fe Formation". Bryan (1938, p. 205) made the first definitive statement about the regional extent of the Santa Fe: "The main body of sedimentary deposits of the Rio Grande depression, from the north end of San Luis Valley to and beyond El Paso, is considered to be the same general age and belong to the Santa Fe Formation".

Prior to the 1950's, most reports on the basin-fill stratigraphy used Bryan's terminology of the Santa Fe as a formation; however, with more work facies complexities within the basin-fill became apparent. This prompted Kelley (1952), Kottlowski (1953), and Spiegel (1961) to suggest that the Santa Fe should have group status. Kottlowski further proposed that the "group" be subdivided into an upper and lower unit. Baldwin (in Spiegel and Baldwin, 1963: p. 38-39) formally proposed that the formation be raised to group rank. Galusha and Blick (1971) strongly objected to this concept and believed that each basin should have a separate nomenclature. However, Hawley and Galusha (1978) pointed out that the use of the formation-rank for deposits of individual basins can be utilized to denote differences in these basins and group status for the Santa Fe has become accepted by most workers.

The first study of the Cenozoic fill in the Albuquerque basin was by Bryan and McCann (1937, 1938). Based on paleontologic evidence and outcrop continuity, they were able to extend the Santa Fe Formation into the Albuquerque basin from the north and subdivide it into three informal units based primarily on color: Lower Gray, Middle Red, and Upper Buff. Although their work was concentrated mainly in the northwest part of the basin, these researchers were able to generally define regional relationships in structure, stratigraphy, and geomorphology across the basin. Bryan (1938) also developed a basic facies model of the lithofacies distribution within the Santa Fe Formation and correlated basin fill throughout the "Rio Grande depression" with this formation. Three of his students, Denny (1940), Wright (1946), and Stearns (1953) extended the mapping of basin fill and major structural units into the southern, west-central, and northeastern parts of the basin.

Since the work of Bryan and his students, other researchers in the Albuquerque basin have recognized significant local differences in basin fill characteristics and have created a much more complex nomenclature for the Santa Fe Group (Table 1-1). The units in Table 1-1 will be discussed in more detail later in their appropriate sections.

Kelley's (1977) geologic map, the only one published on the entire basin, shows major outcrops of the Santa Fe "Formation". However, attempts to extend individual stratigraphic units throughout the Albuquerque basin have not been widely accepted because space, time, and petrographic relationships were poorly defined and have not been studied in detail. Only one previous study of sandstone petrology has been done on the Santa Fe exposed within the basin (Gawne, 1973). A number of oil and gas exploration wells have been drilled that penetrate the Santa Fe Group (Table 1-2), but little work on distinguishing Cenozoic units has been attempted (Black and Hiss, 1974; Black, 1982; Grant, 1982).

Table 1-1. Comparative stratigraphic nomenclature chart for the Santa Fe Group in the Espanola, Santo Domingo, and Albuquerque basins.

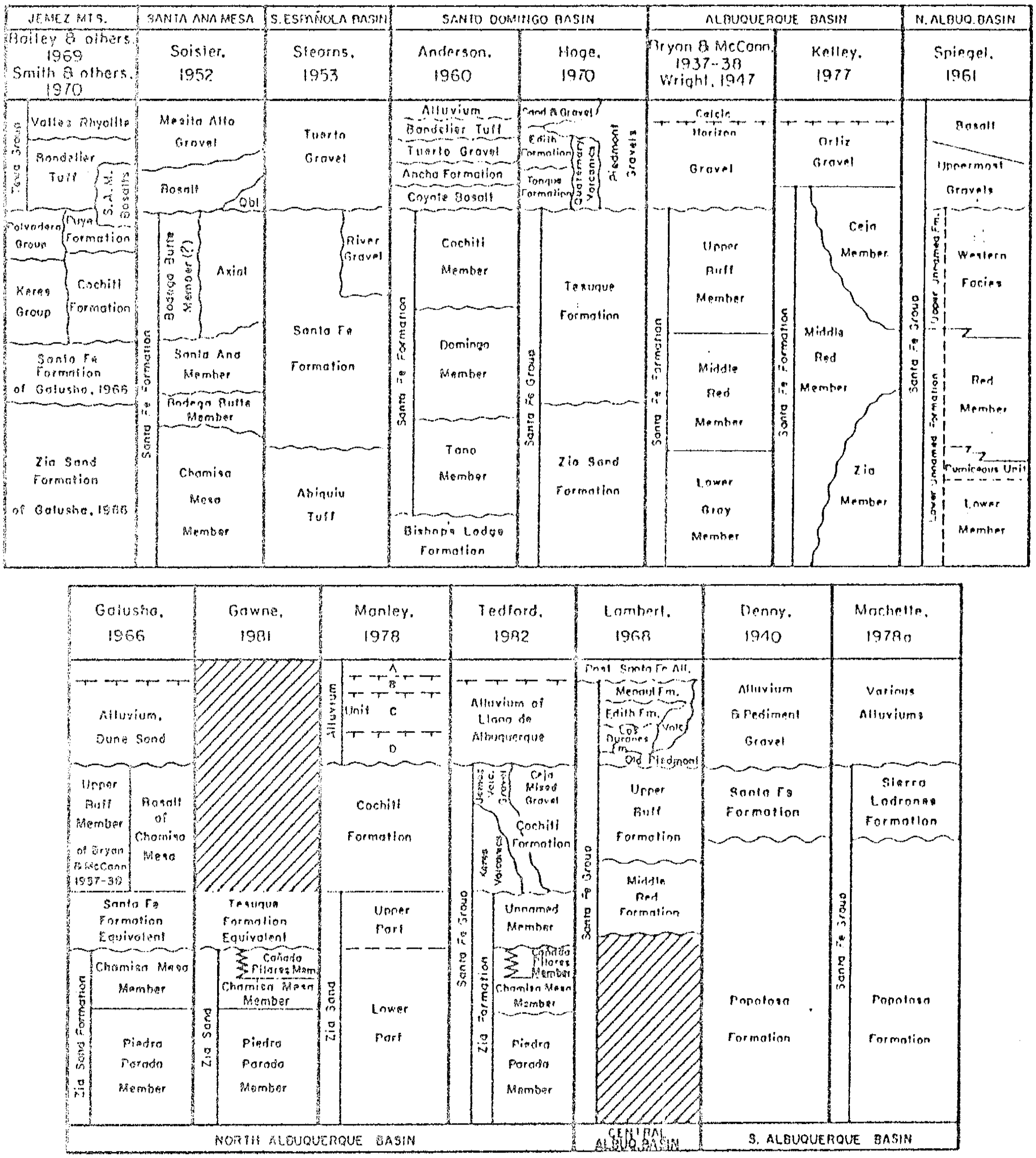


Table 1-2. Oil test wells drilled in the Albuquerque basin. Well numbers refer to those in Figure 1-2.

Well Number	Name	Location	Completion Date	Total Depth	
				ft	m
1.	Tejon Oil and Dev. No. 1	7-14N-6E	7-?-16	1,850	564
2.	Cal-New Mexico Dechares No. 1	8-6N-1E	9-20-26	2,900	884
3.	Stone No. 1	25-7N-3E	6-15-26	1,405	428
4.	Belen Oil-Seipple No. 1	23-4N-1E	7-10-27	3,545	1,080
5.	Gilmore and Sheldon Tome Grant #1	30-6N-2E	12-2-26	1,180	360
6.	Hub Oil-NNTH #1	13-6N-1W	12-31-26	3,425	1,044
7.	Stone Norland No. 1	32-7N-2E	11-4-27	2,144	654
8.	Gilmore and Sheldon Tome #1	30-6N-3E	4-9-28	1,100	335
9.	Stone #2	25-7N-2E	11-12-28	1,976	602
10.	Harlan et al. Harlan #1	5-6N-2E	8-1-30	4,223	1,287
11.	Harlan et al. Harlan #2	5-6N-2E	11-21-30	4,021	1,226
12.	Harlan et al. Harlan #3	5-6N-2E	4-5-31	6,474	1,973
13.	Harlan et al. Harlan #4	5-6N-2E	6-28-31	3,820	1,164
14.	Harlan et al. Harlan #5	5-6N-2E	8-25-31	4,007	1,221
15.	Norins Pajarito Grant #1	22-9N-1E	6-24-33	5,104	1,556
16.	West. Natural Resources Corp. #1	8-6N-1E	9-3-32	1,725	526
17.	Mills Tome #1	29-6N-3E	8-2-33	507	154
18.	Big Three Dalies Townsite #2	5-6N-1E	11-17-37	6,113	1,863
19.	Mills Tome #2	9-6N-3E	11-18-32	446	136
20.	Ringle Dev. Co. Fee #1	36-6N-3E	11-17-35	1,115	340
21.	Ringle Dev. Co. Fugua No. 1	13-5N-3E	3-?-35	100	30
22.	Norins N. Alb. Acres No. 1	19-11N-4E	7-?-35	573	175
23.	Norins N. Alb. Acres No. 2	19-11N-4E	7-8-40	5,024	1,531
24.	Ringle Dev. Co. Ringle No. 1	6-5N-2E	11-14-35	750	229
25.	Central N. Mex. Brown-Livingston	16-3N-1E	11-28-39	2,840	866
26.	Norins Pajarito Grant #2	22-9N-1E	8-?-33	385	117
27.	Norins Pajarito Grant #3	22-9N-1E	4-?-41	2,780	847
*28.	Joiner San Clemente No. 1	23-7N-1E	8-5-39	5,606	1,709
*29.	Grober Fugua No. 1	19-5N-3E	4-?-46	6,300	1,920
30.	Ringle Ringle #1	34-6N-4E	6-29-47	823	251
31.	Ringle Tome #2	34-6N-4E	3-1-47	890	271
32.	Ringle Tome #3	34-6N-4E	10-?-47	597	182
33.	Castleberry Tome No. 1	20-6N-4E	10-19-47	500	152
34.	Bailes & Von Glahan Dales No. 1	5-6N-1E	9-21-49	6,096	1,858
*35.	Carpenter Atrisco No. 1	28-10N-1E	9-29-48	6,652	2,028
*36.	Long Dalies No. 1	32-7N-1E	5-14-52	6,091	1,856
*37.	Humble Oil SFP #1	18-6N-1W	11-18-53	12,691	3,868
38.	Casey 1-A	?	1-9-56	?	?
*39.	Shell SFP No. 1	18-13N-3E	8-28-72	11,045	3,366
40.	Shell Laguna-Wilson Foust #1	8-9N-1W	12-25-72	11,115	3,389
*41.	Shell SFP #2	29-6N-1W	9-24-74	14,305	4,360
*42.	Shell Isleta Central #1	7-7N-2E	7-18-75	16,346	4,982
*43.	Shell SFP #3	28-13N-1E	6-26-76	10,276	3,132
*44.	TransOcean Isleta No. 1	8-8N-3E	11-19-78	10,378	3,163
*45.	Shell Isleta No. 2	16-8N-2E	5-25-80	21,266	6,482
*46.	Shell West Mesa Federal No. 1	24-11N-1E	10-27-83	19,375	5,906
47.	Utex No. 1 Westland Dev. 1J1E	1-10N-1E	7-14-84	16,665	5,080

CHAPTER 2. METHODS AND TECHNIQUES

Field Methods

Mapping and Measuring Sections

Three areas in the Albuquerque basin, the Gabaldon badlands, Bobo Butte, and Trigo Canyon area, were mapped geologically on U.S.G.S. 7.5 minute quadrangles at a scale of 1:24,000. These areas are shown on Plate 1 and the maps are in the back pockets. Vertical, color aerial photographs at a scale of 1:31,000 aided field mapping in the Gabaldon badlands and Bobo Butte. Areas selected for mapping were critical to this study because they contained the best exposed sections of the Santa Fe Group.

Five stratigraphic sections of the Santa Fe Group were measured. Their locations are shown on Plate 1 and their descriptions are in Appendix I. Sections chosen for measurement were generally well-exposed and easily accessible. Most sections were measured using a Jacob's Staff and Abney level. The lower part of unit 1 in the Gabaldon badlands; however, was measured with a theodilite and tape because part of unit 1 is covered by younger alluvium. A Munsell color chart aided in color determination of the deposits.

Paleocurrent Measurements

Paleocurrent directions were determined from imbricated clasts, crossbeds, and parting lineations. These paleocurrent studies aided in source area determination.

In a well-exposed, coarse to very coarse conglomeratic bed, clast imbrication measurements were made on the largest clasts (15-25 cm in diameter) in about a 1 m^2 area using a Brunton compass. The azimuth of the dip direction was recorded and rose diagrams were constructed from the data.

Trough crossbeds are abundant in unit 4 deposits of the Gabaldon badlands. Paleoflow direction in these beds was calculated by measuring the strike and dip of the trough margins with a Brunton compass. These data were then plotted on a stereonet diagram. The resultant girdle on the stereonet indicates the paleoflow direction (method from DeCelles et al., 1983).

Parting lineations were measured on bedding surfaces in sandstone beds with a Brunton compass. These lineations may be the result of imperfections in cementation (Potter and Pettijohn, 1977). The lineations are parallel to the flow direction; however, they only show the line of movement and not the flow direction. Other paleoflow indicators (such as imbricated clasts and crossbeds) must be used in conjection with parting lineations to determine the flow direction.

Clast Counts

Clast counts were also conducted on coarse to very coarse beds that contained pebbly to cobbly material. These counts were used to characterize lithologic types in the deposits and to help in provenance determination. Within a 30 m^2 area, the largest clasts were counted noting rock type in approximate 30 cm intervals. A total of 50 clasts were counted at each location.

Laboratory Techniques

Sample Collection and Preparation

Samples from outcrops, core, and well cuttings were used for petrographic analysis. Outcrop samples were collected mainly from sandy intervals in the measured sections. Point count results from published work on sandstones of Galisteo and Baca Formations exposed in the vicinity of the Albuquerque basin were also utilized. This enabled unknown samples from outcrops and drill holes to be compared with known samples for better identification. Core samples from oil test wells were limited and were used whenever available.

Sample selection from well cuttings was done in two parts. Cuttings from the 12 oil test wells (locations shown on Plate 1) were examined initially with a binocular microscope in order to construct a provisional stratigraphic column for each well and to determine sample intervals for thin section work. Color, grain size, and other major characteristics of the sediments were noted on the stratigraphic columns. Cuttings were analyzed in approximate 6 m intervals. No water well cuttings were examined in this study.

Based on the preliminary cutting analysis, samples for thin-section study were collected at approximate 300 m intervals. Where more detail was needed in zones within the well, shorter sample intervals were used. Wherever possible, medium- to coarse-grained sand or sandstone were sampled. Finer grained samples were used only when coarser samples were unavailable. Ingersoll et al. (1984) have shown that grain size does not affect point counting results in sand size particles. The selected cutting samples where then sieved (2-0.125 mm) to collect only the sand fraction. To guard against possible contamination, the sieved sand was re-examined with a binocular microscope to remove foreign material (i.e., wood, cement, seeds). Also, some samples contained large amounts of metallic bit shavings which were removed with a magnet.

Once the samples were collected from both outcrop and drill holes (cuttings and core), they were prepared for standard thin section analysis. Friable outcrop samples and cuttings were first impregnated with epoxy. The final step in sample preparation was to stain half the thin section slide with sodium cobaltinitrate to facilitate potassium feldspar identification.

Borehole Geophysical Logs

Borehole geophysical logs were available for most of the oil test wells. These logs, primarily resistivity and spontaneous potential, aided in the cutting analysis and in determining contacts between units within the well.

Petrographic Analysis

Thin sections of outcrop and drill hole samples were analyzed using criteria described by Dickinson (1970) and Dickinson et al. (1983) in order to determine detrital modes and provenance. A total of 166 thin sections were examined. Four hundred framework grains per thin section were counted with a Nikon binocular polarizing microscope and Swift point counter. Van de Plas and Tobi (1965) have determined that at the 95% confidence level, precision ranges from 2-4% on counts of four hundred grains. Counts were primarily made at 100x, but other magnifications were sometimes used. Nicols were usually crossed, except for occasional glances at plain light.

Parameters counted and used to define petrofacies are listed in Table 2-1. Although the Gazzi-Dickinson point counting method does not use granitic rock fragments as a counting parameter, they were noted when observed for provenance determination.

One problem in petrographic work is differentiating between polycrystalline quartz (chert) and felsic to silicic volcanic grains. In this study, the grain was counted as a volcanic-lithic grain if crystal laths could be recognized or the groundmass was stained. Otherwise, it was counted as a polycrystalline quartz (Qp).

Based on the point counting data, ternary diagrams were constructed to help in determining petrofacies. After each point count, the thin section was further examined to determine grain size, sorting, roundness, and other important features for provenance interpretations. Only framework grains were counted. Matrix and interstitial space were not counted because most well cutting samples were loosely consolidated and broken apart during the drilling process. To be consistant, no matrix or interstitial space were counted in outcrop and core samples.

Table 2-1. Point count grain parameters. Modified from Dickinson (1970).

Counted Parameters	Recalculated Parameters
Qm = monocrystalline quartz	Qp = Qpt + Qpn
Qpt = tectonic polycrystalline quartz	Q = Qm + Qp
Qpn = nontectonic polycrystalline quartz (inc. chert)	F = P + K
	Lsc = Ls + Lc
P = plagioclase feldspar	L = Lv + Lm + Lsc
K = potassium feldspar	QFL%Q = 100Q/(Q+F+L)
Lv = volcanic lithic fragments	QFL%F = 100F/(Q+F+L)
Lm = metamorphic lithic fragments	QFL%L = 100L/(Q+F+L)
Ls = sedimentary lithic fragments (silt and shale)	LmLvLsc%/Lm = 100Lm/L
Lc = carbonate lithic fragments	LmLvLsc%/Lv = 100Lv/L
M = phyllosilicates	LmLvLsc%/Lsc = 100Lsc/L
	Lst = Qp + Lsc
	LmLvLst%Lm = 100Lm/LmLvLst
	LmLvLst%Lv = 100Lv/LmLvLst
	LmLvLst%Lst = 100Lst/LmLvLst

CHAPTER 3. GENERAL STATEMENT ON THE SANTA FE GROUP AND PRE-SANTA FE TERTIARY DEPOSITS

Introduction

Pre-Santa Fe Tertiary deposits exposed around the Albuquerque basin are discussed in this chapter. These units are buried beneath the Santa Fe Group in at least some parts of the basin as evidenced by cuttings from the oil test wells. Pre-Santa Fe Tertiary deposits are defined in this report as those deposits that range in age from Eocene to Late Oligocene and include deposits that are age-equivalent to the Galisteo-Baca Formations, Datil Group-Espinaso Formation, and the Oligocene volcanic sequence that overlies the Datil Group.

Also in this chapter, the Santa Fe Group is addressed in a regional context without using formation or member names. It is hoped that this will help in better understanding the Santa Fe as the uppermost unit in a thick sequence of continental deposits and also place it within the tectonic framework of the Rio Grande rift.

Pre-Santa Fe Tertiary Deposits

The Galisteo (Stearns, 1953; Gorham and Ingersoll, 1979) and Baca (Cather and Johnson, 1984) Formations are the Eocene deposits exposed around the margins of the

Albuquerque basin. These units represent late Laramide sedimentation that occurred prior to the formation of the Albuquerque basin from Early to Late Eocene (Wasatchian to Duchesnean; Lucas, 1982). Deposits of the Galisteo Formation, up to 1,300 m thick, occur primarily northeast of the Albuquerque basin in the Hagan basin (Gorham and Ingersoll, 1979). One small outcrop also exists in the northwest Albuquerque basin just south of San Ysidro (see Plate 1). Baca deposits crop out in the Joyita uplift area at the extreme south end of the Albuquerque basin and in a belt of discontinuous outcrops extending west of Socorro. Thicknesses range from 315 m in the Joyita uplift up to 760 m in the outcrops west of Socorro (Cather and Johnson, 1984).

The Eocene units consist mainly of non-volcanic, continental clastic detritus that was shed off surrounding Laramide uplifts and deposited in nearby closed-drainage basins. The Galisteo Formation was deposited in the Galisteo-El Rito basin and the Baca Formation was deposited in the Carthage-La Joya basin and Baca basin (Fig. 3-1). Although the lower age limit of the Galisteo Formation is slightly older than the Baca Formation, Lucas (1982) has determined that the deposition of the Baca Formation was in large part synchronous with the Galisteo Formation.

Exposed south and southwest of the Albuquerque basin is an over 1,000 m thick sequence of interbedded ash-flow

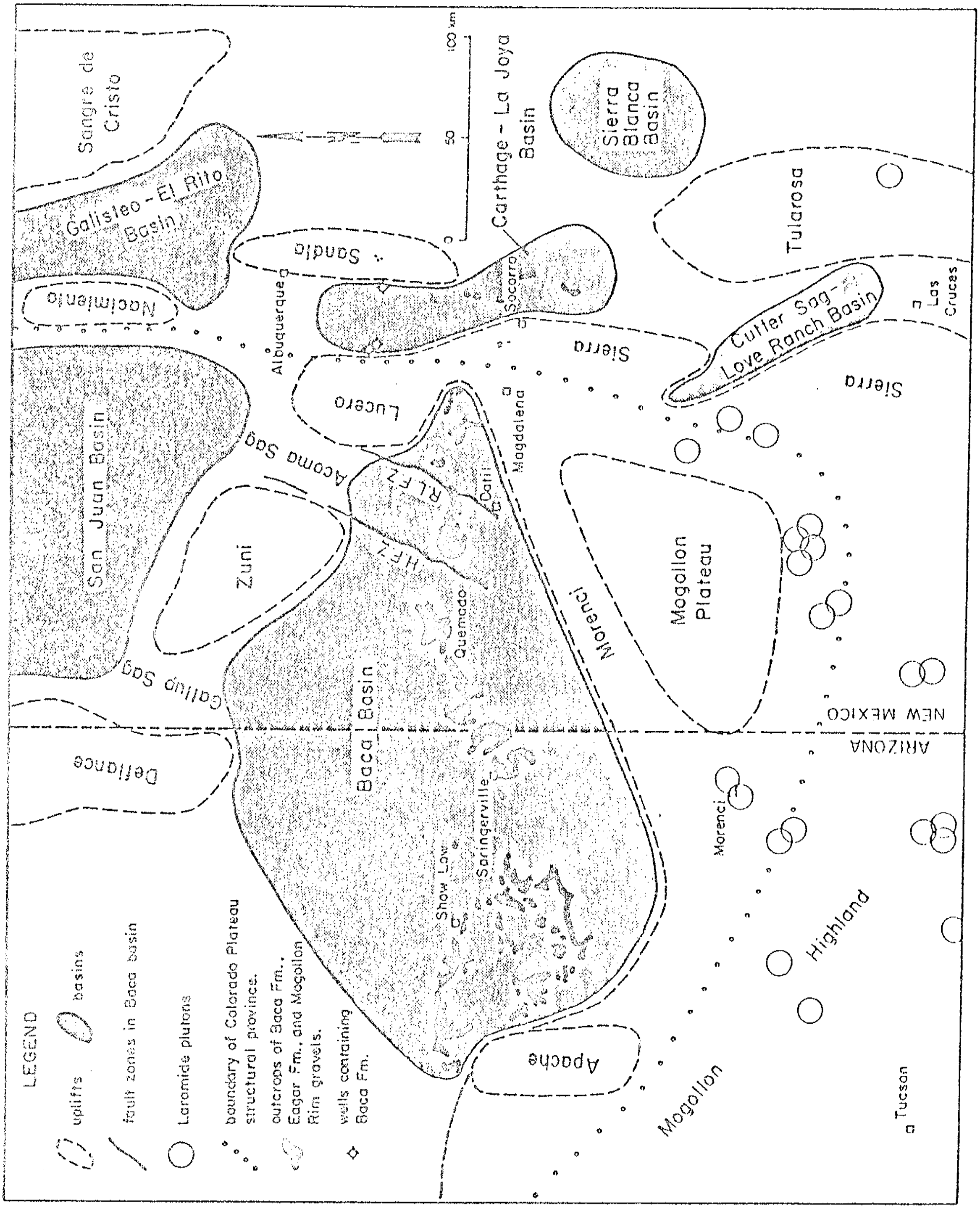


Figure 3-1. Map showing distribution of Eocene uplifts and basins in western New Mexico and eastern Arizona. From Chapin and Cather (1981) and Cather and Johnson (1984).

tuffs, intermediate to mafic lava flows and volcaniclastic rocks of intermediate composition. These rocks comprise the Datil Group and the sequence from Hells Mesa Tuff through South Canyon Tuff and La Jara Peak Basaltic Andesite that overlie the Datil Group (Osburn and Chapin, 1983; see Fig. 3-2). They were produced by volcanism in the northeast Mogollon-Datil field and range in age from Late Eocene to Late Oligocene (about 39-27 Ma; Osburn and Chapin, 1983; Cather et al., 1987). These units were deposited over a wide area including the southern Albuquerque basin where outcrops occur in the Joyita uplift and the northern Ladron Mountains (Machette, 1978b). The abundance of volcanic material clearly distinguishes the Datil Group from the underlying Baca Formation.

Another volcanic-rich unit, the Espinaso Formation, overlies the Galisteo Formation in the Hagan basin and attains thicknesses of up to 430 m. Volcaniclastic rocks of intermediate to silicic composition with locally interbedded ash-flow deposits and lavas comprise the Espinaso Formation (Kautz et al., 1981). Volcanic centers represented by porphyritic intrusions in the present Ortiz Mountains and Cerrillos Hills were the source for this volcanic debris. Ages range from Late Eocene to Latest Oligocene (38-26 Ma) based on radiometric and paleontologic dates (Kautz et al., 1981). Espinaso outcrops have been recognized only in the Hagan basin; no Espinaso deposits have been found in the

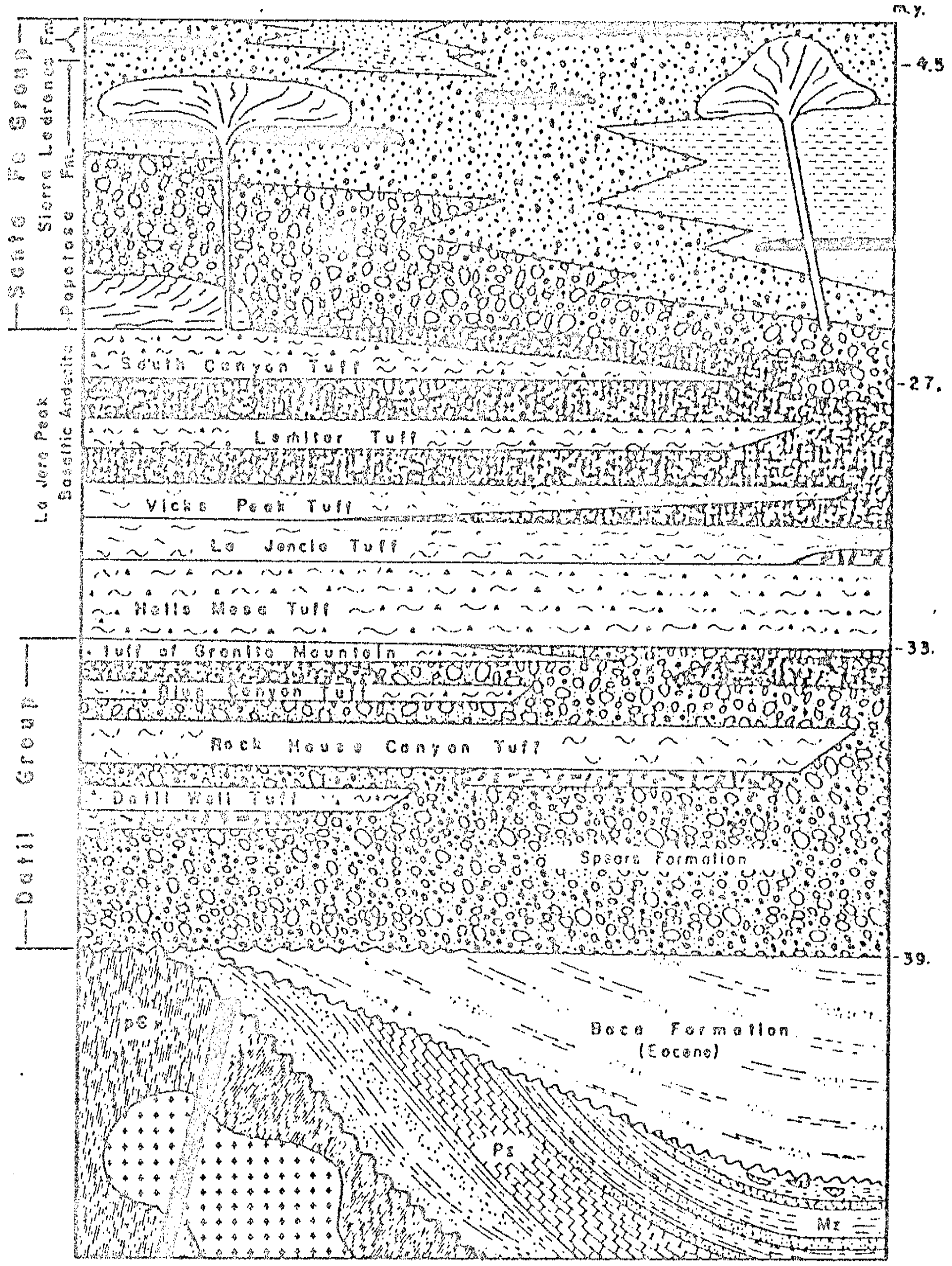


Figure 3-2. Composite stratigraphic column of the northeast Mogollon-Datil volcanic field. From Osburn and Chapin (1983).

Albuquerque basin. For the most part, volcanism in the Espinaso Formation is contemporaneous with volcanism in the Mogollon-Datil volcanic field. Similar to the Datil Group, the abundance of volcanic detritus distinguishes the Espinaso Formation from the Galisteo Formation.

In this investigation, deposits of equivalent age to the Datil Group and the overlying sequence of Hells Mesa - South Canyon Tuffs and La Jara Peak Basaltic Andesite that occur in the oil test wells of the Albuquerque basin are referred to as the "unit of Isleta #2 well". It is hoped that this term will be less cumbersome when referring to deposits of this time interval. These pre-Santa Fe basin-fill deposits contain less volcanic detritus than the Datil Group reflecting more diverse source areas. Deposits within the Isleta #2 well were chosen as the type section because: 1) the complete section can be identified within the well; 2) the top and bottom of the unit is distinguishable on geophysical logs; and 3) the section contains a dated ash-flow tuff.

Santa Fe Group

As first proposed by Kottlowski (1953) and formally defined by Spiegel and Baldwin (1963), the Santa Fe Group can be generally subdivided into an upper and a lower unit based on depositional enivironment and age. The lower Santa

Fe Group represents deposition occurring primarily in closed-drainage basins. Lower Santa Fe basin-fill ranges in age from about 30 to 5 Ma and is dominated by intertonguing piedmont, eolian, and fine-grained basin-floor deposits. Fan and coalescent fan alluvium characterizes the piedmont facies, while playa sediments are the major component of the basin-floor facies. Initial deposition of the lower Santa Fe occurred in broad, shallow, northwest-trending basins that were produced during the first phase of rifting. Deposition of the lower Santa Fe continued into the second phase of rifting that produced the narrow, deep, north-trending basins that exist today. These later basins also appear to have been internally drained. The bulk of the lower Santa Fe was probably deposited between 5 and 10 Ma when tectonism was most active in the rift. With uplift of the margins and subsidence of the basins, more sediment would have been eroded from the uplifts and deposited in the basins.

Lower Santa Fe Group deposition ended about 5 Ma when fills of adjacent closed-basins coalesced and a through-flowing ancestral Rio Grande system developed. Upper Santa Fe Group basin fill is characterized by intertonguing piedmont (alluvial-fan) and axial-river (fluvial) deposits. Basin aggradation during upper Santa Fe time was slower because tectonic activity had decreased. Upper Santa Fe Group deposition ended about 0.5 Ma when initial entrenchment of the present Rio Grande occurred. Since that time, the rift basins have been primarily degradational undergoing several more cycles of river-valley incision. The rift basins had been primarily aggradational during Santa Fe time. Details of post-Santa Fe valley entrenchment have been described by Lambert (1968) and Machette (1978a,c).

Thicknesses in the lower Santa Fe Group are commonly thousands of meters, while those in the upper unit do not exceed a few hundred meters. Major differences between the two units include: 1) dips are usually over 10° in the lower unit; whereas, dips are generally less than 5° in the upper unit; 2) better induration and more reddening is typically seen in the lower unit; and 3) basin-floor facies in the lower unit are dominated by playa deposits; whereas, axial-river deposits dominate the basin-floor facies in the upper unit. However, in some areas there are problems in differentiating piedmont facies in lower and upper units because the composition of source terranes may not have changed much over time. Without datable material in the piedmont deposits, only by tracing them out to see if they intertongue with the ancestral-river facies can one positively distinguish the upper from the lower Santa Fe piedmont facies.

To more clearly describe in detail the Santa Fe Group and pre-Santa Fe Tertiary deposits in the Albuquerque basin, the basin has been divided into four regions: the central, southwestern, southeastern, and northern. Each region is addressed as a separate chapter in this report. A subsequent chapter incorporates the findings within these four regions and discusses the similarities and differences observed.

CHAPTER 4. CENTRAL ALBUQUERQUE BASIN

Introduction

The thickest section of the Santa Fe Group in the Rio Grande rift is in the central Albuquerque basin. This area extends from I-40 south to Bernardo and includes the escarpments bounding the Llano de Albuquerque (Plate 1). However, these thick sections can only be examined in the subsurface by using cuttings and geophysical logs from oil test wells. Outcrops in the central basin area include only the upper Santa Fe Group. No lower Santa Fe Group rocks are exposed. These upper Santa Fe outcrops are restricted mainly to the escarpments that rim the Llano de Albuquerque and around the Los Lunas volcano. The western rim of the Llano is called the Ceja del Rio Puerco (eyebrow of the dirty river); whereas, the less prominent eastern rim is known as the Cejita Blanca (little white eyebrow).

Three outcrop sections were measured and four oil test wells were examined from this area. The four oil test wells are: 1) Joiner San Clemente No. 1; 2) Long Dalies No. 1; 3) Shell Isleta Central #1; and 4) Shell Isleta #2. The Joiner San Clemente No. 1 and Long Dalies No. 1 bottom in the lower Santa Fe Group; whereas, the Isleta Central #1 and Isleta #2 penetrate the Santa Fe Group and a significant section of pre-Santa Fe Tertiary strata.

Several reports have been published on the Santa Fe Group in the central basin area. Denny (1940) studied outcrops around the Llano de Albuquerque and measured a section on the east side of the mesa, just west of Abeytas and about 6 km north of Bernardo. He investigated the sedimentology, determined paleoflow directions, and interpreted exposures along the Llano de Albuquerque to be alluvial-fan deposits. Wright (1946) mapped the Ceja del Rio Puerco south of I-40. Kelley (1977) mapped these outcrops as the Santa Fe Formation undivided, although he could have placed them within his Ceja Member. Machette (1978b,c) grouped these deposits in the Sierra Ladrones Formation.

Santa Fe Group basin fill and interbedded andesite flows flanking the Los Lunas volcanic center were mapped by Kelley and Kudo (1978). They also mapped and reported on K-Ar ages of basalts of the Cat Hills, Cat Mesa, Wind Mesa, and Isleta volcanic fields that lie on the Llano de Albuquerque north and west of Las Lunas. Bachman and Mehnert (1978) report on K-Ar ages of andesitic lavas at Los Lunas and Tome Hill volcanic centers.

A detailed study of the stratigraphy and sedimentology of the Santa Fe Group and post-Santa Fe deposits exposed along the lower Rio Puerco was undertaken by Young (1982). He recognized two facies within the upper Santa Fe Group: 1) a through-flowing fluvial unit; and 2) an alluvial facies associated with marginal piedmont slopes. Based on paleocurrent indicators and the presence of obsidian derived from the Grants Ridge area (Kerr and and Wilcox, 1963), Young (1982) concluded that the fluvial facies was derived from the northwest, outside the Albuquerque basin. Love and Young (1983) and Love (1986) developed a model for the depositional history of the lower Rio Puerco. By careful examination of clasts, they were able to determine sediment dispersal patterns in the southwestern and central basin areas.

Measured Sections

The three measured sections in the central part of the basin are located near the Los Lunas volcano, Belen, and Bernardo. Their locations are shown on Plate 1. The stratigraphy, sedimentology, and depositional environment of each section is discussed separately. No identifiable fossils were recovered from the three sections. For more detailed descriptions of these measured sections, see Appendix I.

Los Lunas Volcano Section

As discussed in Appendix I, three subsections were measured in the deeply incised arroyo on the northwest flank of the Las Lunas volcanic center. Combining the three subsections, the total exposed of thickness of basin fill is 181.7 m. This thickness includes 4 m of overlying, post-Santa Fe Group eolian deposits. Most of these beds dip away from the volcano and are locally faulted. Dips of beds decrease upsection from about 12° at the bottom of the section near the volcano to almost flat-lying at the top of the section.

The measured section begins at the angular unconformity exposed at the bottom of the arroyo. Beds below the unconformity dip between 30 and 40° to the northeast and consist mainly of fine- to coarse-grained sand with pebble lenses. Pebble types are similar to those contained in the beds that overlie the unconformity. Channel cuts, up to 3 m deep, occur at the unconformable contact. This angular unconformity may represent the contact between the lower and upper Santa Fe Group or a local unconformity associated with the volcano within the upper Santa Fe Group.

Fine- to coarse-grained, loosely consolidated, mostly moderate to well sorted, locally crossbedded sand dominates the three subsections. Laminated to massive, red (2.5YR 4/6) to olive green (2.5YR 6/6) clay and silt are interbedded with the sand. The olive green clay beds are traceable around the outcrop area. Paleosols, which are rare throughout the section, are charcterized by weakly- to moderately-developed horizons of clay and carbonate accumulation. Scattered pebbles and pebble lenses of subangular to well rounded chert, quartz, sandstone, silicic to mafic volcanic, granite, petrified wood, and limestone occur in the sand beds. Obsidian (apache tears) locally occur scattered in unit 2.5. An ash bed, dated at 1.1 Ma (Izett, 1981), is interbedded with fine-grained sand at the top of the section. Subsection 3 is capped by the dense, locally nonporphyritic andesite of the volcano. The andesite has an K-Ar age that ranges from 1.1 to 1.3 Ma (Bachman and Mehnert, 1978). The contact between the andesite and underlying sediments is uneven and baked. Overall, the Los Lunas volcano section shows a coarsening upward sequence from mostly fine-grained sand and silt to more medium- to coarse-grained sand with pebbles. Clay interbeds also increase upsection.

Most of the sediments in the Los Lunas volcano section are fluvial in origin, especially the middle to uppermost beds. This is evidenced by the good sorting, crossbedding, and coarsness of the deposits. The clay interbeds represent overbank deposits. Finer grained sand and silt beds at the bottom of subsection 2 (units 2.1 and 2.2) are partly fluvial and partly eolian. The good sorting and crossbedding in these units support an eolian origin and the pebble lenses and scattered pebbles suggest fluvial processes. Units 2.1 and 2.2 are very similar to the eolian deposits (unit 1.2) that cap the section.

Belen Section

The Belen section was measured on the east-facing escarpment that lies just west of I-25 about 15 km south of Belen. The section begins on top of the Llano de Albuquerque surface and ends at the base of the escarpment. The total measured thickness is 117.1 m. Beds are relatively undeformed and flat-lying in the measured section; however, Young (1982) found these deposits to be faulted and warped within the local area.

This section consists mainly of interbedded fine- to medium-grained sand, silty sand, silt and clay. Sand and silty sand interbeds are poorly to well sorted, loosely consolidated, reddish yellow (7.5YR 6/6) to light gray (2.5YR 7/2), 30-90 cm thick and locally crossbedded. Clay beds are red (2.5YR 5/6) to light brown (7.5YR 6/4), 30-60 cm thick, and locally contain calcium carbonate concretions. In the lower half of the section, there are also two medium- to coarse-grained sand beds (units 1.2 and 1.6). These beds are light gray (2.5YR 7/2) to very pale brown (10YR 7/4), moderately to well sorted, planar and trough crossbedded, and commonly contain scattered pebbles and cobbles. Clasts are subrounded to rounded and include chert, silicic to mafic volcanics, granite, petrified wood, limestone, and mudballs. The abundance of limestone clasts and mudballs increase up section. Grants obsidian first appears in unit 1.11, about 20 m from the top of the section. In all, the

Belen section shows a slight fining upward sequence, but the largest clasts (up to 50 cm in diameter) occur about 3 m from the top. A 1.5 m thick, pedogenic stage III-IV (Gile et al., 1981) calcic horizon forms the prominent white band near the top of the escarpment.

Most of the beds in the Belen section were deposited by a large and complex fluvial system as evidenced by the abundance of moderately to well sorted, crossbedded sand with rounded pebble lenses. Pebble types also indicate an extrabasinal source. The clay and silt beds represent overbank deposits. The abundant trough crossbedding and low amounts of clay beds in units 1.6 and 1.11 suggest that the large fluvial channels were braided. The Grants obsidian and paleoflow indicators show that these deposits were derived from the northwest. These deposits are interpreted to be laid down by an ancestral Rio Puerco/San Jose fluvial system in an alluvial plain setting that existed near the confluence with the ancestral Rio Grande. In this setting, the ancestral Rio Puerco/San Jose could have separated into several shifting distributary channels near their junction with the ancestral Rio Grande. Overbank deposition would have occurred between these channels. This interpretation concurs with findings from Love (1986).

Bernardo Section

The Bernardo section was measured in a sand and gravel quarry located about 1 km north of Bernardo and between I-25 and NM-85. This quarry has since been partially buried. The section begins on top of a graded hillslope along I-25 and includes a partial section of ancestral Rio Grande fluvial deposits. Although the total exposed thickness was measured at only 9.8 m, the Bernardo section describes an important facies within the upper Santa Fe Group. A detailed description of this section is in Appendix I.

This section consists primarily of pinkish gray (7.5YR 7/2) to light gray (10YR 7/2), well sorted, loosely consolidated, massive to crossbedded (mainly trough), fine- to coarse-grained sand. Well cemented, coarse- to very coarse-grained sand concretions and mudballs are scattered throughout the section. Weak red (2.5YR 5/2) to light reddish brown (5YR 6/3), massive to laminated, jointed, up to 2 m thick clay interbeds occur in the middle and top of the section. Sand beds usually show scoured basal contacts; whereas, clay beds have sharp basal contacts. Pebble imbrications indicate a south to southeast flow direction. Clasts are up to boulder-size (20 x 40 cm) and include chert, granite, silicic to mafic volcanics, sandstone, and quartz. No obsidian was found in the section. The larger clasts are in the lower part of the section.

The trough crossbedding, moderate to well sorted character and high sand-to-clay ratio show that these units were deposited by a large braided river system believed to be the ancestral Rio Grande. The few clay beds are overbank deposits. These deposits may have also received some additional detritus from the ancestral Rio Puerco/San Jose that joined the ancestral Rio Grande just to the west.

Oil Test Wells

Cutting analyses and interpreted stratigraphy of the four wells are discussed below. No upper Santa Fe Group deposits were seen in the well cuttings because sample intervals started below the bottom of the upper Santa Fe. Well locations are shown on Plate 1. In addition, a driller's log from the Central New Mexico Brown-Livingston oil test well is also discussed, although cuttings or core from this well were not available for analysis.

Joiner San Clemente No. 1

The Joiner San Clemente No. 1, completed in 1939, bottomed in the Santa Fe Group at a total depth of 1,709 m. The well was reported dry and abandoned (Black, 1982). Cuttings from this well were only available from 1,250 to 1,709 m. A few side hole cores were also available. Within the available cutting interval, the well penetrated mostly fine- to medium-grained sand with silt interbeds. Coarser sand generally occurs between 1,250 and 1,280 m. A 52 m-thick and a 67 m-thick, mostly reddish clay interval were penetrated at 1,283 m and 1,512 m, respectively. No igneous zones were recognized within the studied interval.

Long Dalies No. 1

This well was completed in 1952 to a total depth of 1,856 m. It too bottomed in the Santa Fe and was reported dry and abandoned (Black, 1982). Within this well, cuttings were available from a depth of 506 m to the bottom of the hole. No core samples were available. Dark, mafic igneous fragments dominate the cuttings from a depth of 506 to 762 m. These mafic fragments continue below this depth mixed with fine- to medium-grained sand down to 975 m. From this depth, the fine- to medium-grained sand with some coarse intervals comprise the bulk of the cuttings down to 1,341 m. Below this depth, fine-grained sand and silt with minor clay comprise the cuttings to the bottom of the hole. Siliceous fragments, up to granule-size, occur around the 1,615 m depth. No igneous fragments were found below 975 m.

Shell Isleta Central #1

Completed in 1974 by the Shell Oil Co., the Isleta Central #1 was the first well drilled in the central basin area that penetrated Cretaceous bedrock. It was drilled to a total depth of 4,982 m with reports of oil and gas shows in the Cretaceous section. However, the well was reported dry and abandoned (Black, 1982). Cuttings from the Isleta

Central #1 well were examined from a depth of 152 to 4,011 m. This interval includes lower Santa Fe Group, pre-Santa Fe Tertiary, and Mesozoic deposits.

Santa Fe Group deposits extend from near the top of the well down to 2,679 m (Fig. 4-1). These deposits consist mainly of weakly consolidated, medium- to coarse-grained, moderately to well sorted sand to 1,240 m. Major clay and silt interbeds occur between 390 and 1,058 m. Mafic fragments were encountered from 1,021 to 1,125 m and probably indicate one or more mafic bodies. Possible gypsum fragments were noted at 1,570 m. Below 1,240 m, the deposits become primarily reddish orange to gray fine-grained sand, silt and clay interbeds with very rare medium- to coarse-grained sand zones.

Pre-Santa Fe Tertiary deposits occur from a depth of 2,679 to 3,670 m and consist of moderately to well indurated, purplish red to reddish brown claystone with siltstone and fine-grained sandstone interbeds. As will be discussed in the sand petrology section, the pre-Santa Fe Tertiary section can be divided into two units based on the amount of volcanic detritus and quartz grains. The upper unit correlates with the unit of Isleta #2 well and the lower is included with the Galisteo Formation. The contact between these two units is placed at a depth of 3,216 m where a change in the geophysical logs occur.

A distinct color change in the cuttings from purplish

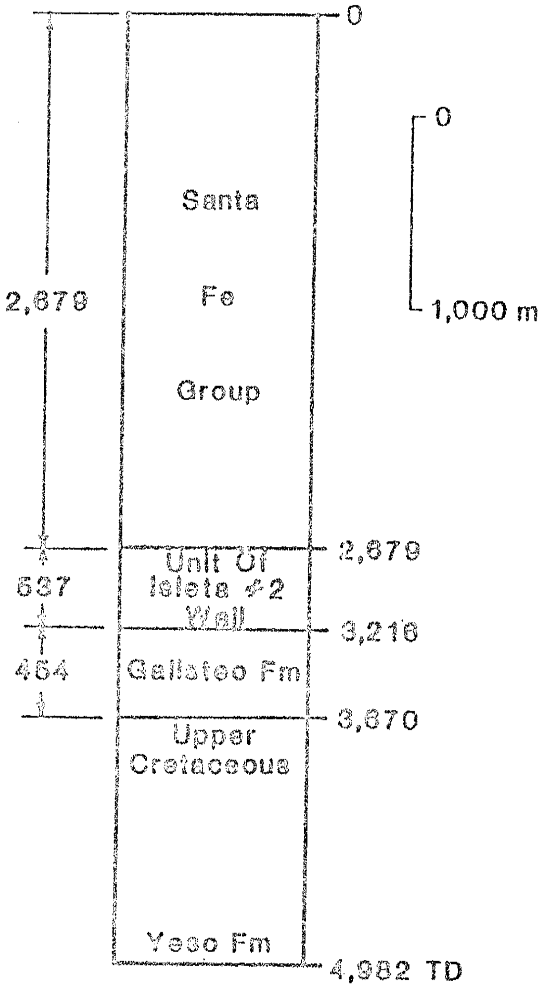


Figure 4-1. Stratigraphic column for Shell Isleta Central #1 showing unit tops and thicknesses. All measurements in meters.

red to gray at a depth of 3,670 m marks the contact between the pre-Santa Fe strata and the Mesozoic section. Gray to dark gray shale with minor fine-grained sandstone interbeds characterize the Mesozoic section. Coal interbeds occur from 3,795 to 3,810 m. The Mesozoic section examined in the cuttings is believed to be Upper Cretaceous because of the dominance of gray shales and the presence of coal.

Shell Isleta #2

The Shell Isleta #2 was drilled to a total depth of 6,482 m without penetrating Cretaceous rock. It bottomed in pre-Santa Fe Tertiary strata. To date, it is the deepest oil test well drilled in the Albuquerque basin. Following completion in 1980, the well was reported dry and abandoned (Black, 1982). Cuttings were examined from 160 m to the bottom of the well. In addition, three 6 m long cored sections were also examined at 4,945, 5,231, and 6,473 m.

Within the Isleta #2, the Santa Fe Group is 4,407 m thick (Fig. 4-2). This is the thickest documented section of the Santa Fe in the entire Rio Grande rift. The top 1,524 m of the Santa Fe consists primarily of weakly consolidated, pinkish-red to brown, fine- to coarse-grained sand with clay and silt interbeds. This interval is in the upper part of the lower Santa Fe Group. At 1,524 m, reddish brown to gray fine-grained sand, silt, and clay interbeds dominate the lower Santa Fe down to the base of the Group at

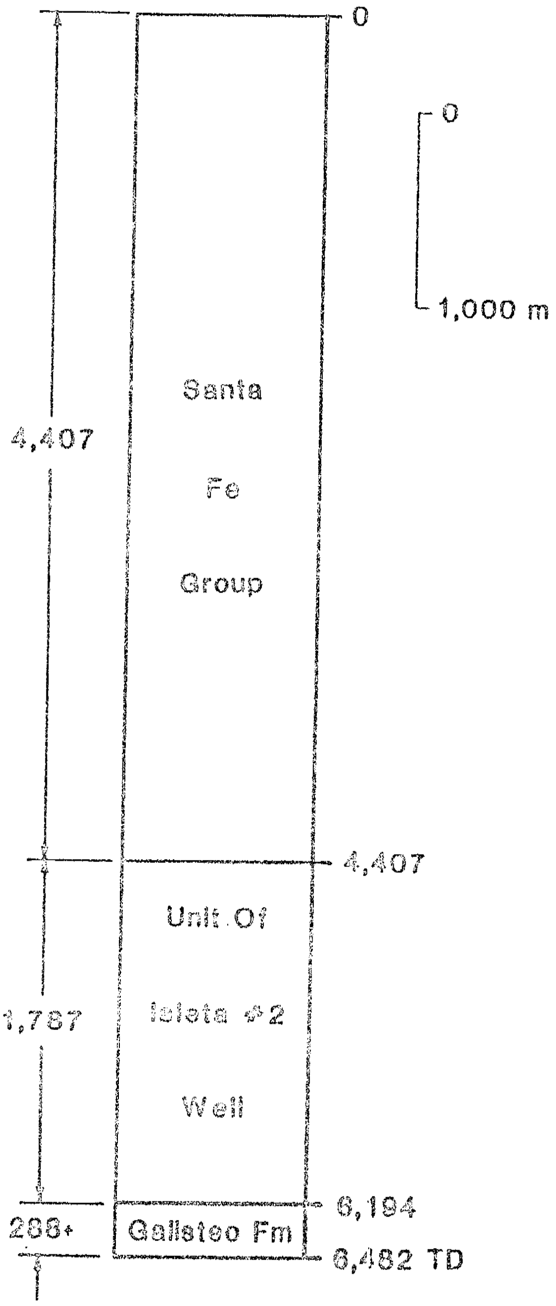


Figure 4-2. Stratigraphic column for Shell Isleta #2 showing unit tops and thicknesses. All measurements in meters.

4,407 m. Beds become increasingly more indurated with depth in this interval. Clay beds can be up to 30 m thick. No intrusive/extrusive bodies were noted within the Santa Fe section. In general, these sediments exhibit a fining downward trend.

Pre-Santa Fe Tertiary deposits extend from the base of the Santa Fe down to the bottom of the well, a thickness of at least 2,075 m. The contact between the Santa Fe and pre-Santa Fe Tertiary deposits is placed where the cuttings change to purplish red to brown, well indurated, fine- to coarse-grained sandstone with claystone and silty sandstone interbeds. There is also a change on the geophysical logs at this depth. The top 60 m consists mainly of medium- to coarse-grained sandstone with minor claystone interbeds. There is no overall fining downward sequence as coarse-grained sandstone interbeds persist down to the bottom of the hole. Dark, possible volcanic fragments were recognized at 5,776 m.

Petrographically, the pre-Santa Fe Tertiary deposits can be divided into two units. The contact between them is placed at 6,194 m. These units are discussed in more detail in the Sand Petrology section.

The cored sections are composed of light gray to gray, very fine- to coarse-grained, well indurated, poorly to moderately sorted sandstone interbedded with purplish gray to light gray, well indurated mudstone. Coarser sandstone beds show grading and weak crossbedding. The mudstone appears to be bioturbated. Calcium carbonate is the chief cement with lesser silica cement.

There is some age control for the pre-Santa Fe Tertiary deposits. Shell Oil reports an K-Ar age of 36.3 ± 1.8 Ma for the ash-flow tuff that occurs at a depth of 5,776 m. This ash-flow tuff is in the upper unit. Based on its reported age, lack of phenocrysts, and shard-rich nature, the ash-flow tuff may correlate with the Rock House Canyon Tuff of the Mogollon-Datil volcanic field (Osburn, pers. comm., 1986). Shell Oil also reports Eocene fossils from the cored section at the very bottom of the well. Thus, the upper unit is at least partly equivalent to Datil Group rocks exposed in the Socorro area and the lower unit is broadly correlative with the Galisteo Formation.

Central New Mexico Brown-Livingston

This well is located about 7 km north of Bernardo on the Llano de Albuquerque in sec. 16 T.3N.R1E. (see well no. 25 on Fig. 1-2 for location). The Brown well was completed in 1939 to a total depth of 866 m according to the driller's log, but Foster (1978) reports a total depth of 908 m. The well bottomed in Cretaceous rock. This is a critical well because it is the only deep well drilled in the southern part of the basin. No cuttings or core were available for analysis, but a driller's log was obtained from the New

Mexico Bureau of Mines and Mineral Resources.

The driller's log shows that the Santa Fe Group is 488 m thick in the well. The upper 143 m consists of "yellow sand and shale" that probably correlates with Sierra Ladrones Formation. This interval corresponds to the Belen and Bernardo measured sections. Below this depth, "red shale" with lesser "gray shale and brown sand" dominates down to the bottom of the Santa Fe. This section is part of the Popotosa Formation.

Interbeds of "red and gray shale, and gray sand with reddish brown streaks" characterize the interval from below the Santa Fe to a depth 640 m. Foster (1978) included this interval in the Santa Fe, but it is not part of the Group based on the driller's log description. It is either a pre-Santa Fe Tertiary unit or part of the Cretaceous section. There are no obvious volcanic units described from this interval; however, without cuttings or core, it is very difficult to accurately determine what unit this interval belongs.

Below 640 m, the presence of "blackish shale and gray sand" clearly indicate that the rest of the well penetrated Cretaceous rocks. This is at the same depth where Foster (1978) places the top of the Cretaceous.

Sand Petrology

Point counts were performed on 57 thin sections from the central basin area. These include 39 from the Santa Fe Group, 16 from the pre-Santa Fe Tertiary deposits, and 2 from the Upper Cretaceous. Most of these thin sections are made from impregnated cutting samples. However, 2 from the Joiner San Clemente and 4 from the Isleta #2 were made from core. Point count results are in Appendix II. Figures 4-3 to 4-6 show the point count results plotted on the ternary diagrams.

Santa Fe Group

Santa Fe Group samples from the measured sections and oil test wells have average sand grain compositions that range from 53.0% quartz, 29.0% feldspar, and 18.0% lithic in the Long Dalies well to 41.8% quartz, 30.9% feldspar, and 27.4% lithic in the Isleta Central #1 well. Two subgroups are distinguishable in the Santa Fe of the Isleta #2 well. Samples above 2,134 m have an average sand grain composition of 37.8% quartz, 42.8% feldspar, and 19.4% lithic; whereas, below 2,134 m it changes to 51.9% quartz, 38.7% feldspar, and 10.3% lithic. Sample SI-035 from Isleta Central #1 was not included with the Santa Fe samples because it is believed to be from a mafic body. In general, sand grains are moderately to well sorted, loosely to well consolidated,

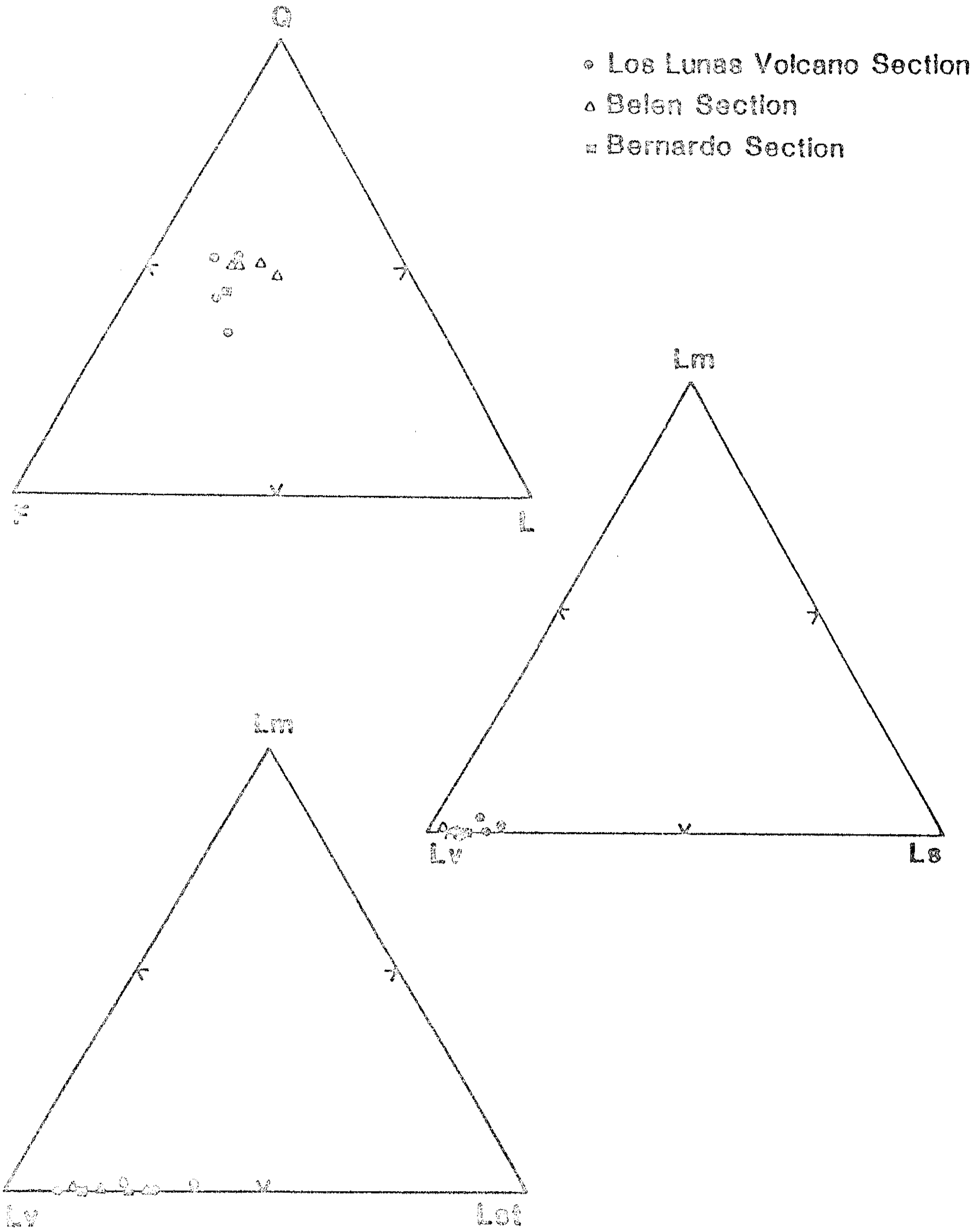


Figure 4-3. Ternary diagrams for measured sections in the central basin area.

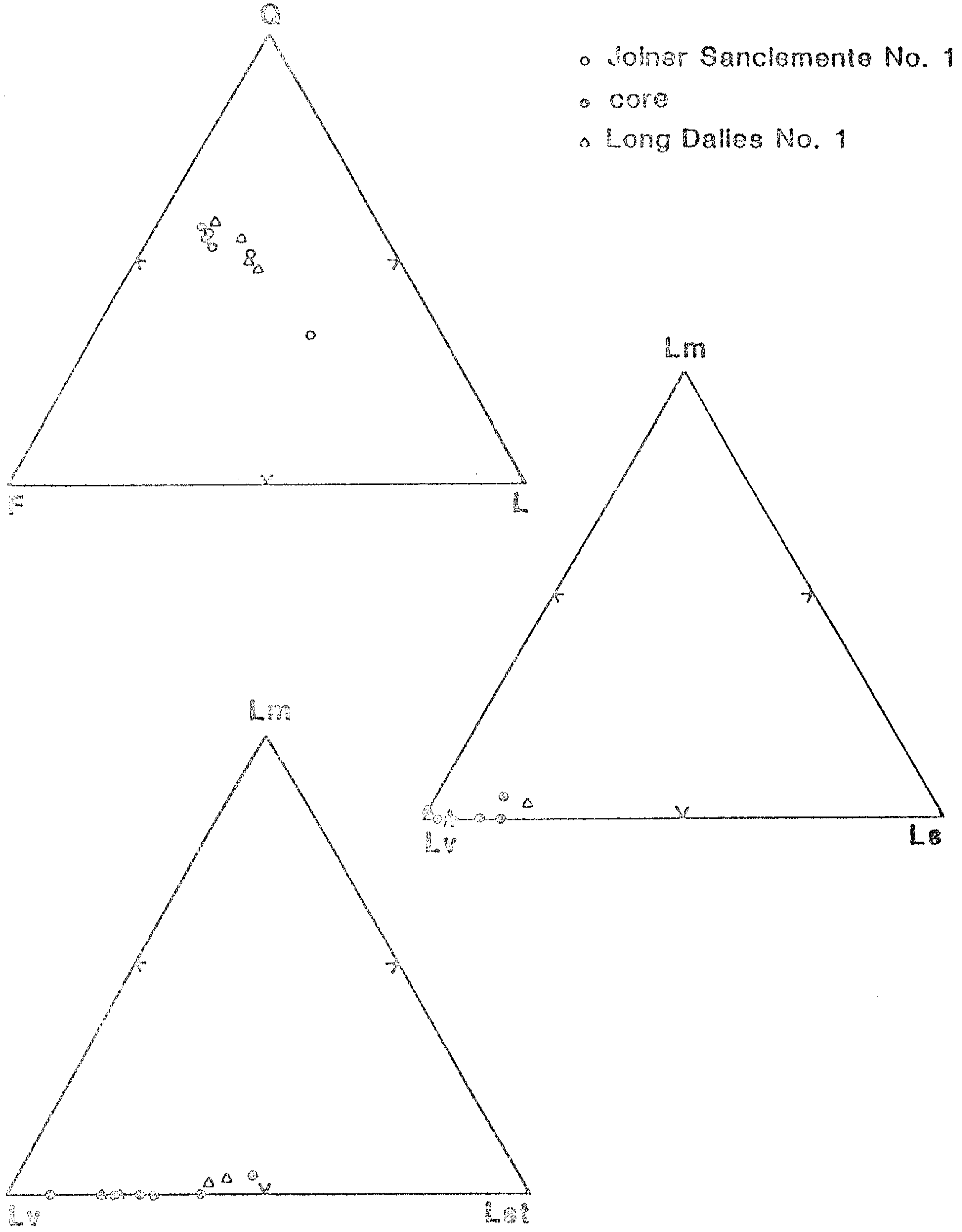


Figure 4-4. Ternary diagrams for Joiner San Clemente No. 1 and Long Dalies No. 1.

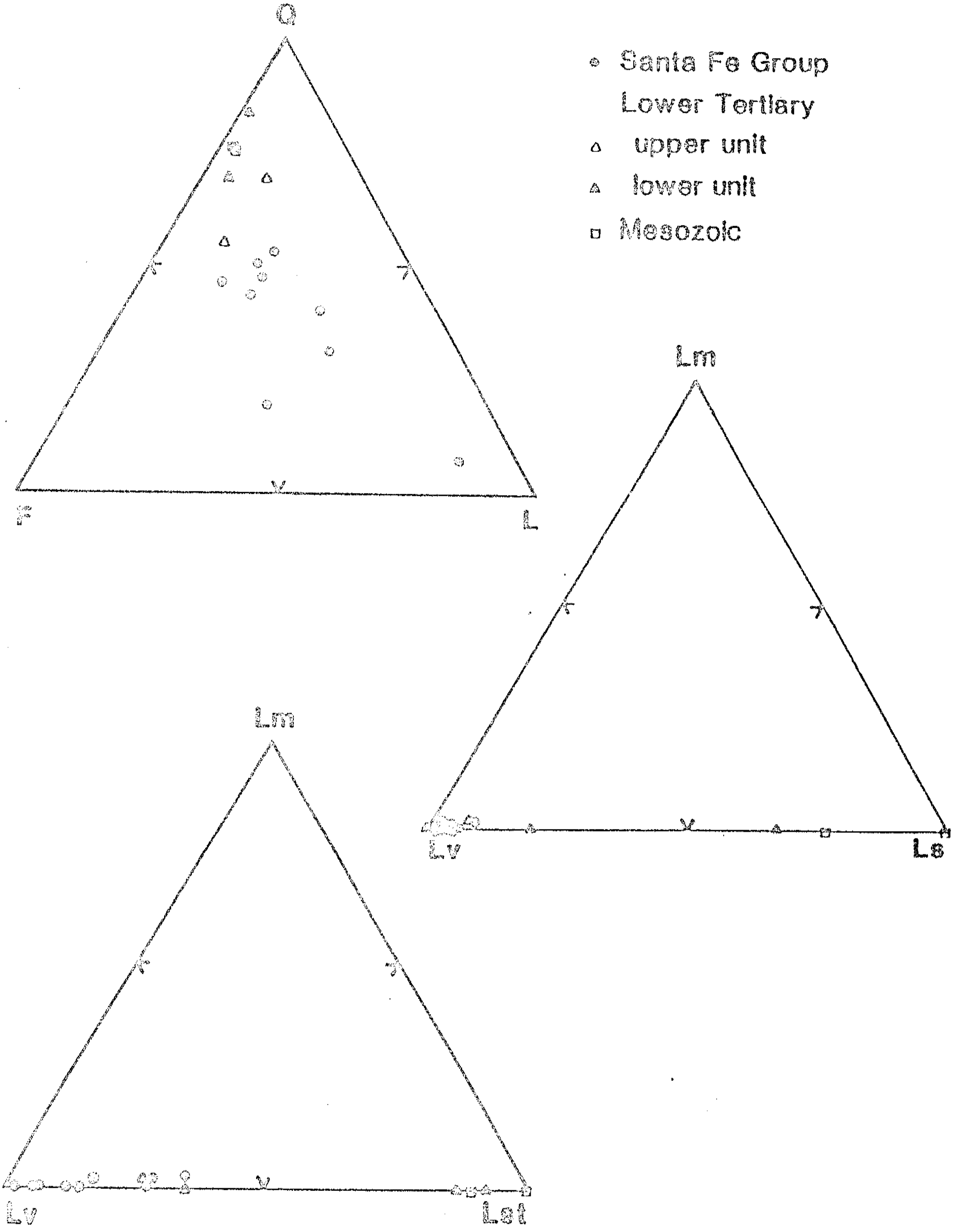


Figure 4-5. Ternary diagrams for Shell Isleta Central #1.

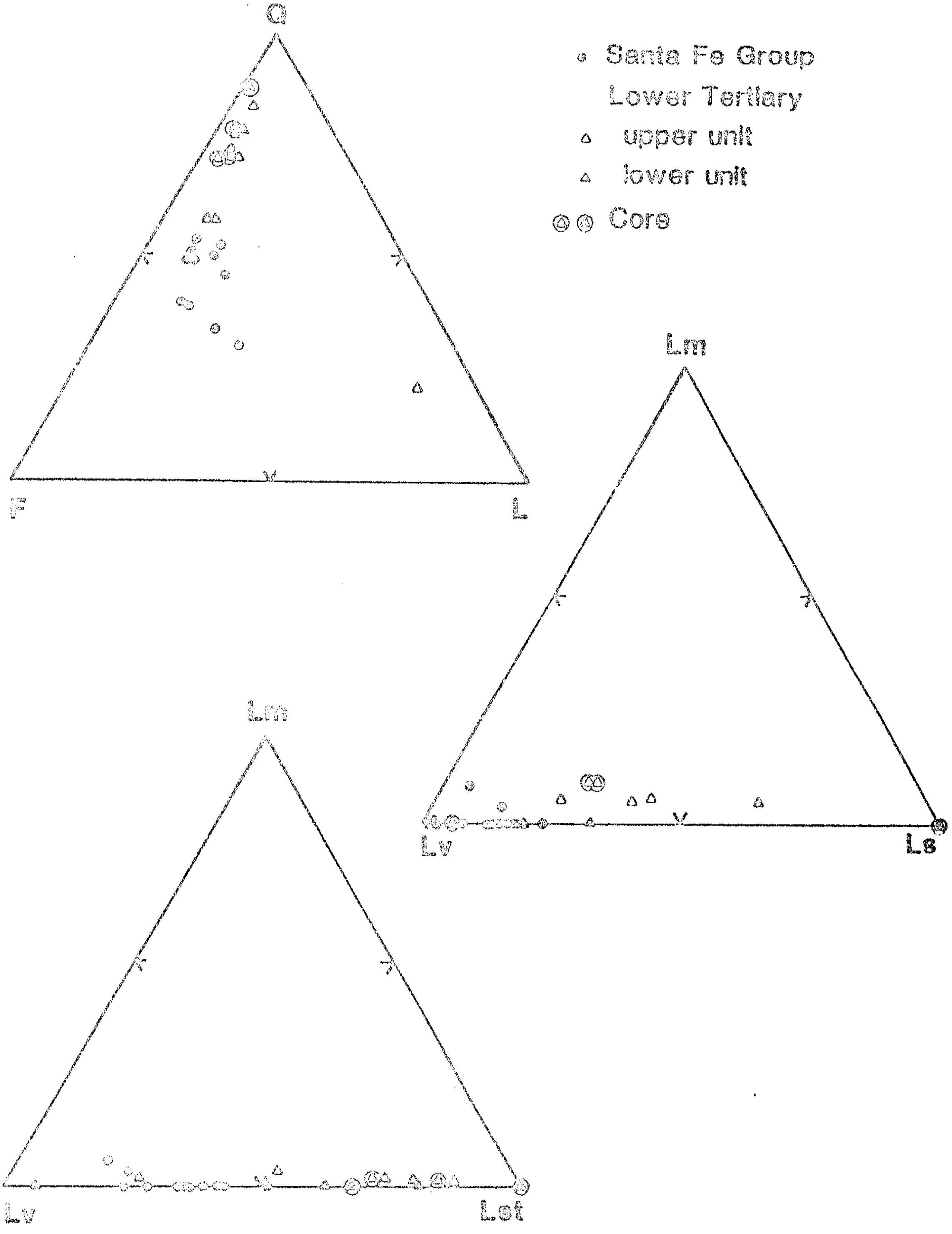


Figure 4-6. Ternary diagrams for Shell Isleta #2.

fine- to coarse-grained and subangular to subrounded (Fig. 4-7). These samples classify as arkose, feldspathic litharenite, and lithic arenite (Folk, 1974).

For the most part, monocrystalline quartz (Qm) is the dominant detrital grain. Exceptions are samples SI-040, SI-074, SI-086 from Isleta Central #1 and JS-041 from the San Clemente. The lower quartz percentages in these samples could be due to nearby mafic bodies. Quartz grains are typically clear, show straight extinction, and seldom have overgrowth rims. A small percentage have undulose extinction and show partial dipyramidal shape. Chert is the main polycrystalline quartz, but tectonic polycrystalline quartz percentages increase slightly towards the top of the Santa Fe. The Qp/Q ratio average ranges from 0.07 in the Belen section to 0.1 in the Long Dalies and Isleta Central #1 wells. These ratios vary little with depth. The QFL diagrams (Figs. 4-3 to 4-6) indicate that quartz percentages generally increase with depth in most wells, but not in the measured sections.

Plagioclase occurs in higher percentages than potassium feldspar as evidenced by the P/F ratio averages that vary from 0.60 to 0.68 in the measured sections and wells. Compositionally, plagioclase ranges from oligoclase to labradorite (determined by Michel-Levy method). These grains are commonly twinned (Albite and Carlsbad) and sometimes exhibit oscillatory zoning. Most potassium

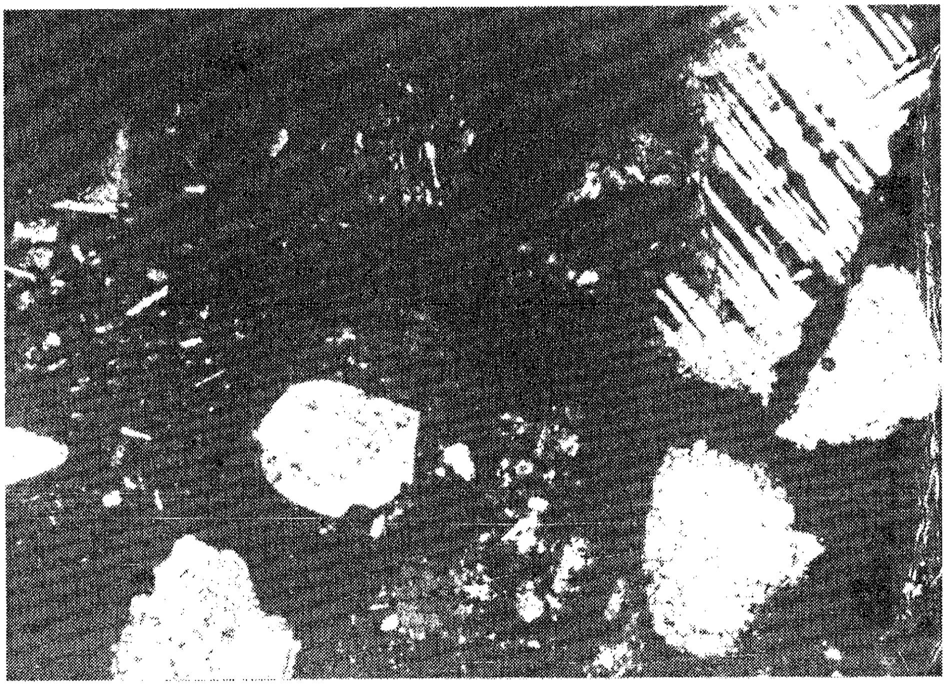


Figure 4-7. Photomicrograph of the Santa Fe Group from a depth of 900 m in the Isleta #2 well. Note abundant volcanic-lithic fragments. Field of view is about 2 mm across; crossed polars.

feldspar grains are orthoclase and sanidine, but microcline and perthite become more abundant towards the top of the Santa Fe. Feldspar grains are usually fresh showing little alteration, but some show sercitic alteration particularly in the deeper samples. Overall, the QFL diagrams (Figs. 4-3 to 4-6) show little change in feldspar percentages with depth.

Lithic fragments are composed mostly of volcanic-lithics. They average over 85% of all lithic fragments in the Santa Fe samples. Most of the volcanic-lithic fragments have porphyritic and microlitic textures and are mainly mafic although compositions range from silicic to mafic. Perentages of mafic fragments increase upsection. Sedimentary-lithic fragments average less than 15% and include shale and carbonates. Metamorphic-lithic fragments (averaging less than 1%) are not common in the Santa Fe section and are not recognized below 1,500 m in the wells. A few granitic fragments were noted above 1,000 m in the wells and in the measured sections.

Pre-Santa Fe Tertiary Deposits

Pre-Santa Fe Tertiary samples were encountered in the Isleta Central #1 and Isleta #2 wells. These samples generally contain higher quartz percentages and lower lithic fragment percentages than the Santa Fe samples. Based on quartz and volcanic-lithic percentages, the pre-Santa Fe

Tertiary samples can be separated into an upper and lower unit.

Sand grain composition for the upper unit averages 71.6% quartz, 22.8% feldspar, and 5.7% lithic in the Isleta #2 well (Fig. 4-8). Sample I-189 was not included in the above average because of its anomolously high volcanic-lithic percentage. Sand grain compositions for the two upper unit samples in the Isleta Central #1 are 55 and 68% quartz, 34 and 19% feldspar, 11 and 13% lithic. The lower unit samples generally contain higher quartz percentages (68 to 88%) and lower lithic fragments percentages (5 to 1%) than the upper unit samples (Fig. 4-9). Sand grains from both units are poorly to moderatley sorted, fine- to medium-grained, well indurated, and angular to subrounded. These samples classify mostly as arkose, subarkose and lithic arenite (Folk, 1974).

In both units, monocrystalline quartz (Qm) is the dominant detrital grain. These grains are clear and show straight extinction, but many have overgrowth rims, especially in the lower unit. The Qp/Q ratios are generally higher in the lower unit samples. Chert is the most common polycrystalline quartz. Tectonic polycrystalline quartz occurs in very low percentages. The Qp/Q ratio shows no systematic change with depth; however, quartz percentages increase with depth.

Plagioclase is the dominant feldspar as seen in the P/F

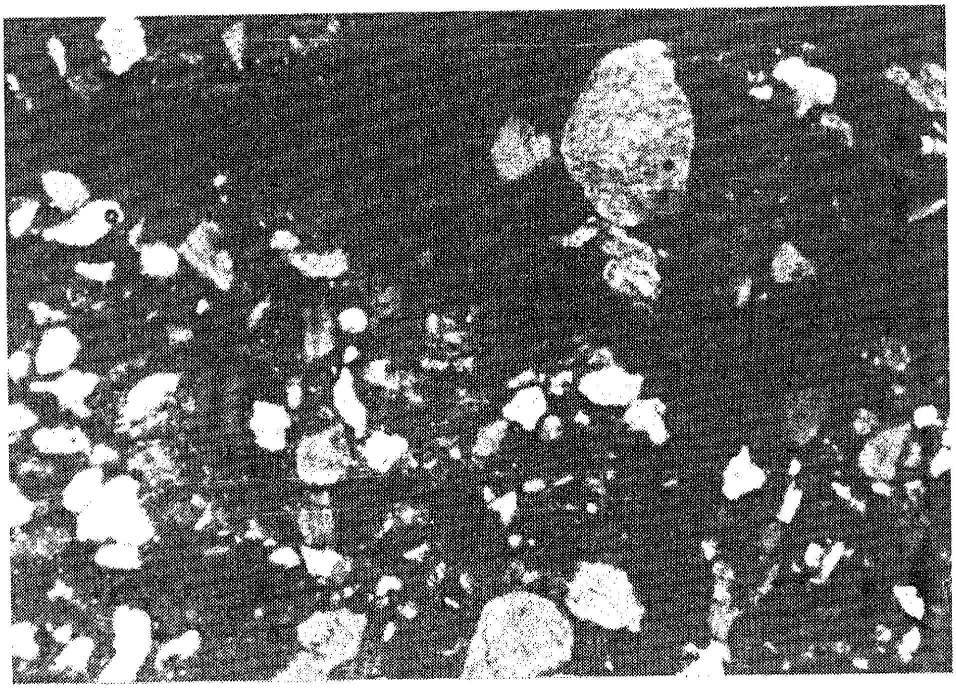


Figure 4-8. Photomicrograph of unit of Isleta #2 from a depth of 4,900 m in the Isleta #2 well. Note increase in quartz grains and decrease in volcanic-lithic fragments. Field of view is about 2 mm across; crossed polars.

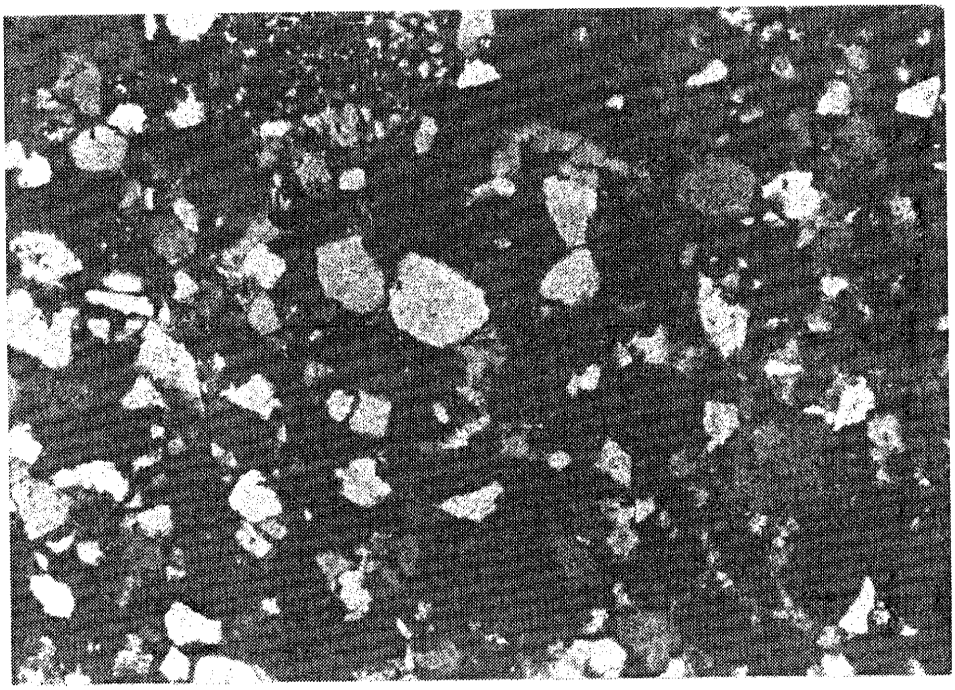


Figure 4-9. Photomicrograph of Galisteo Formation from a depth of 6,480 m in the Isleta #2 well. Note dominance of quartz grains and absence of volcanic-lithic fragments. Field of view is about 2 mm across;crossed polars.

ratio averaging 0.50 or more in both subunits. Plagioclase ranges in composition from oligoclase to labradorite and is usually twinned. Orthoclase and sanidine are the main potassium feldspars. All feldspar grains generally show some degree of alteration. There appears to be a slight decrease in feldspar percentage with depth (Figs. 4-5 and 4-6).

Lithic fragments are mostly volcanic in the upper unit comprising over 50% of all lithic grains. They also appear to be dominant in the lower unit, but their percentages on the LmLvLs plot (Figs. 4-5 and 4-6) are misleading because of the extremely low lithic percentages. For example, sample SI-115 from the Isleta Central #1 shows 100% of the lithic grains are volcanic; however, that is out of a total of only 2 lithic grains for the 400 point count. The LmLvLst plot (Figs. 4-5 and 4-6) gives a better representation of the lithic composition for the pre-Santa Fe Tertiary samples. Some of the volcanics may also be contamination from higher in the hole.

In the upper unit, the volcanic-lithic fragments range from silicic to mafic. Isleta #2 sample I-189, which is from the upper unit, is believed to be an ash-flow tuff because of the high percentage of freshly broken ash-flow tuff fragments (Fig. 4-10). This is the ash-flow tuff that was dated at 36.3 ± 1.8 Ma by Shell Oil. The higher volcanic-lithic percentage in sample I-184 is probably due

Figure 4-10. Photomicrograph of ash-flow tuff that occurs at the 5,760 m level in the Isleta #2 well. Note shard structures within grains. Field of view is about 2 mm across; crossed polars.

to its proximity to the ash-flow tuff.

Sedimentary-lithics percentages are higher in the lower unit. These fragments are mainly siltstone and shale. Volcanic-lithics are rare to nonexistant in the lower unit. Although metamorphic-lithic fragments show percentages up to 8.0%, they are not very abundant. These high percentages are due to the relatively low lithic percentages. No granitic-lithic fragments were noted in the two units.

The two pre-Santa Fe Tertiary units can be correlated with pre-Santa Fe Tertiary deposits exposed around the Albuquerque basin. Based on the abundance of volcanic detritus and the age of the ash-flow tuff, the upper unit is equivalent to the Datil Group and the overlying Oligocene sequence of ash-flow tuffs and basaltic andesites that underlie the Santa Fe. This unit will be referred to as the unit of Isleta #2 well for correlation purposes around the Albuquerque basin.

The lower unit is correlated with the Eocene Galisteo Formation based on its lack of volcanic detritus, Eocene fossils, and stratigraphic position between the unit of Isleta #2 well and Upper Cretaceous strata. These units can also be distinguished on the geophysical logs.

Upper Cretaceous

The two samples from this unit are from the Isleta Central #1 well (Fig. 4-5). They show high quartz percentages (76 and 75%) and low lithic fragment percentages (3 and 4%). These samples classify as subarkose (Folk, 1974). Feldspar percentages are 21% for both samples. Detrital grains are fine- to medium-grained, moderately to well sorted, well indurated, and subangular to subrounded.

The main detrital grain in the Upper Cretaceous samples is monocrystalline quartz (Qm). These grains are clear, but more grains with overgrowth rims occur within these samples than in the Santa Fe and pre-Santa Fe Tertiary samples. The Qp/Q ratio is 0.6 for both samples. Chert is the only polycrystalline grain seen in the point counting. The high quartz percentages in these samples are clearly illustrated in the QFL plot (Fig. 4-5).

Feldspars consist primarily of plagioclase. The P/F ratio is 0.64 and 0.70 for the two samples. Plagioclase ranges in composition from albite to labradorite (determined by Michel-Levy method). These grains are usually twinned (Albite and Carlsbad). Potassium feldspars are mostly orthoclase with lesser microcline. Most feldspar grains show sericitic alteration.

As evidenced by the QFL plot (Fig. 4-5), these samples contain very low lithic fragment percentages. Sedimentary-lithic fragments (shale and silt) are the major lithic grain, although chert is about equally abundant (Figs. 4-5). Volcanic-lithic fragments were recognized in only one sample and no metamorphic or granitic fragments were observed.

Provenance

As evidenced both in outcrop and in thin section, the Santa Fe Group was derived from several source areas in the central basin area. The high volcanic-lithic fragment percentages and the wide compositional range of the volcanics indicate a volcanic source area that ranged from silicic to mafic. The increase in mafic fragment percentage upsection shows that the mafic source area became more dominant later in Santa Fe time. However, the higher mafic volcanic percentages and the occurence of a mafic body encountered in the Long Dalies (which could be a flow) indicate that the source of the mafic material may have been relatively close. Although no volcanic intervals were reported from the Joiner San Clemente, the large, freshly broken-looking mafic fragments in samples JS-041 and JS-055 may be from a intrusive or extrusive igneous body. A reworked sedimentary source is also indicated by the sedimentary-lithics and chert. The low metamorphic and granitic fragment percentages higher in the section show that these terranes became source areas late in Santa Fe time.

The pre-Santa Fe Tertiary deposits show a more restricted provenance than the Santa Fe deposits. High volcanic-lithic percentages in the unit of Isleta #2 well clearly indicate a volcanic source that was diverse compositionally ranging from silicic to mafic. This coupled with an interbedded ash-flow tuff shows that the source area probably contained silicic volcanics and basaltic andesites. A reworked sedimentary source is strongly suggested by the high quartz percentages and the sedimentary-lithics and chert. A metamorphic source area cannot be ruled out because of the presence of metamorphic fragments unless these fragments represent contamination from higher in the hole.

The Galisteo Formation is clearly derived predominantly from a reworked sedimentary source. This interpretation is supported by the high quartz percentages, overgrowth rims on quartz grains, sedimentary-lithic fragments and chert. Low volcanic-lithic percentages (that may actually be contamination from the overlying unit) and a lack of granitic- and metamorphic-lithic fragments rules out major contributions from these source terranes. However, the presence of microcline and perthite may suggest a weak granitic source.

The Upper Cretaceous section examined was derived almost exclusively from reworked sedimentary source terranes. This is supported by the abundance of quartz, chert, and sedimentary-lithic fragments and by the absence of other lithic fragments.

Depositional History of the Central Basin Area

Eocene deposition is recorded in the pre-Santa Fe Tertiary deposits contained within the Isleta Central #1 and Isleta #2 wells. These deposits were derived primarily from sedimentary source areas. No paleoflow directions are known from these deposits, but they were probably laid down within an alluvial plain setting. Thicknesses within the two wells are as much as 454 m.

The influx of volcanic material in the unit of Isleta #2 well records a change in the source area. These deposits were derived from silicic to mafic volcanic source areas in addition to the sedimentary source terranes. Although no paleoflow directions are known from these deposits, the presence of an ash-flow tuff that may correlate with an ash-flow tuff unit within the Mogollon-Datil volcanic field, strongly suggests a source from the south and west. Deposition probably occurred within large alluvial aprons that extended out from the south and west. If these deposits correlate with post-Datil and Datil Group rocks, then deposition of the unit of Isleta #2 well occurred from Late Eocene to late Oligocene. These deposits reached an accumulated thickness of 500-1800 m within the two wells.

Since no dates have been obtained on Santa Fe deposits penetrated by the oil test wells, it is not known when Santa Fe deposition began in the central basin area. The deposits in the lower part of the Santa Fe section are certainly some of the oldest Santa Fe units in the Albuquerque basin, perhaps as old as 30 Ma. These lower units were derived primarily from volcanic and sedimentary source terranes. Because of the fine-grained nature of the sediments below 1,500 m, these beds were probably deposited in a low energy environment, perhaps on the basin floor at the toes of an alluvial fan or near a playa. Deposition within a playa area itself is not strongly suggested because of a lack of thick clay beds.

Above 1,500 m, the Santa Fe begins to show more diverse source terranes as metamorphic and granitic fragments begin to appear in significant percentages. Also volcanic mafic fragments increase in this interval and mafic bodies are ecountered in the wells indicating that mafic volcanic activity had increased in this later stage of Santa Fe deposition. These units also contain coarser grained beds suggesting higher energy environments such as fluvial systems. The Santa Fe beds described above are all from the lower Santa Fe Group and show thicknesses up to 4,200 m.

Upper Santa Fe Group deposition is best interpreted from the outcrop areas rather than the oil test wells. These units are younger than 5 Ma and were deposited by large braided river systems, the ancestral Rio Grande and Rio Puerco/San Jose. Paleoflow directions show that these units were derived primarily out of the north and northwest.

In the central basin area, these two ancestral drainages joined and formed a large alluvial plain. The upper Santa Fe Group is 100-150 m thick in the central basin area.

CHAPTER 5. Southwestern Albuquerque Basin

Introduction

The southwestern region contains the thickest and some of the least-studied exposures of basin-fill deposits in the Albuquerque basin. Major Santa Fe Group outcrops studied occur in the Gabaldon badlands and Bobo Butte area. Located near the Gabaldon badlands are two important oil test wells, the Humble Santa Fe Pacific #1 and Shell Santa Fe Pacific #2. These wells penetrate the Santa Fe Group and bottom in Mesozoic strata. In this chapter, each of the above areas and oil test wells are discussed.

The earliest work on the Santa Fe Group in the southwestern region was by Denny (1940) who reported on the area east and south of Ladron Mountain extending into the northern Socorro and La Jencia basins. He divided the basin fill into two formations: the late Miocene (?) to Pliocene Santa Fe and the late Miocene (?) Popotosa. He also recognized that the Popotosa represented closed-basin drainage whereas the Santa Fe contained both closed-basin and through-flowing basin deposits. Wright (1946) studied and mapped the southwestern basin area using the major Santa Fe "formation" subdivisions of Bryan and McCann (1937). He correlated these subdivisions with Denny's (1940) Santa Fe formation and constructed paleogeographic maps depicting the area during Santa Fe time. Although Wright (1946) believed that the Gabaldon section was similar to the playa deposits in the Popotosa Formation, he did not think that they were correlative because the Popotosa Formation was thought to be an older unit. The type Popotosa Formation localities south and east of Ladron Mountain were also described by Bruning (1973).

Kelley (1977) mapped the southwest region and measured a section in the Gabaldon badlands as part of his basin-wide study. At the southern end of the Albuquerque basin in the San Acacia quadrangle, Machette (1978a) divided the basin fill into two units that essentially coincide with Denny's (1940) Santa Fe and Popotosa formations. However, Machette (1978a) followed modern Santa Fe Group usage and included both of Denny's (1940) formations in the Group, renaming the upper unit, the Sierra Ladrones. In addition, he established general age ranges for these formations (Sierra Ladrones--middle Pleistocene to Pliocene, and Popotosa--Miocene to late Oligocene). Machette (1978b) also mapped the Sierra Ladrones Formation as far north as Albuquerque.

Love and Young (1983) and Love (1986) undertook a detailed study of sediment dispersal patterns of the Santa Fe Group and post-Santa Fe deposits in the southwest basin area. They used this information to interpret the depositional history of these deposits.

Gabaldon Badlands

The Gabaldon badlands, located about 110 km southwest of Albuquerque (Plate 1), contain the thickest exposed section of the Santa Fe Group in the Albuquerque basin. The badlands consist of a thick sequence of westward-dipping Santa Fe Group strata that cover an area of about 125 km^2. The exposures generally occur along an eastward-facing, low escarpment. A remnant geomorphic surface capped with early to middle (?) Pleistocene gravels and a strong calcic paleosol is at the top of the section. The Gabaldon badlands are an excellent example of this type of topography which is characterized by bare surfaces, high drainage densities, and intricate networks of rills and arroyos. The drainage system also includes a complex subterranean network of "pipes", especially in the upper unit 1 deposits. Small upland drainages commonly disappear into sinks and subsurface channel networks, and reappear through openings at the base of hillslopes. Access to the Gabaldon badlands is restricted because portions of the area are privately owned.

Wright (1946) and Kelley (1977) have previously mapped the Gabaldon area and described basin-fill sections. Both workers give general descriptions of broad stratigraphic subdivisions in their measured sections (Wright, 1946, p. 408-409; Kelley, 1977, p. 16-17); however, they did not attempt to define and map individual units. Wright (1946) measured 1,250 m of playa deposits and at least 213 m of alluvial-fan deposits for a total Gabaldon section thickness of at least 1,463 m. It is not known precisely where the section was measured. He correlated these deposits with the lower Gray and middle Red Members (playa deposits) and the upper Buff Member (alluvial-fan deposits) of Bryan and McCann's (1937) Santa Fe formation. Wright (1946) believed that the thick playa deposits may have been part of a larger playa system occupying the southern Albuquerque basin during much of Santa Fe time.

Kelley (1977) also measured a section in the Gabaldon badlands, but he determined its total thickness to be 944 m with the lower 610 m representing playa deposits. Machette (1978b) did not recognize lower Santa Fe units in the Gabaldon area.

Stratigraphy

As measured in this study, the Gabaldon section is 1,138 m (see Appendix I) thick. This is an incomplete section because: 1) a major fault has removed the lower part of the section; 2) another fault has removed an unknown thickness of the lower unit; and 3) 115 m of section is covered by younger alluvium. The actual exposed thickness may be near 1,800 m, if the lower faulted-out section is included. The Gabaldon section was divided and mapped into four units based on facies type, erosional pattern, and dip angle (see Plate 2). Wright's (1946) playa deposits generally correlate with units 1-3 and his alluvial-fan deposits are similar to unit 4. Dips of beds in units 1-3 range from 10 to 15°, but unit 4 beds dip from 4 to 5°. For a more detailed description of these units, see Appendix I.

Unit 1. Unit 1 is the thickest of the units mapped in the Gabaldon badlands and forms the more subdued, rounded hills in the lower part of the section. The total thickness was measured at 585 m, but this is not a complete section because portions of the unit are not exposed or are faulted out (see measured section in Appendix I). Younger alluvial and eolian deposits cover about 115 m of section and a major fault bounds the unit at its base. The section exposed west and southwest of Mohinas Mountain are lower unit-1 deposits that have been faulted-out at the base of the measured section. The approximate thickness of this section is 600 m which brings the total exposed thickness of unit 1 to about 1,200 m. Extensive piping is common in unit-1 deposits.

Interbedded fine-grained sand and clay characterize most of unit 1. Sand beds are usually moderately to well sorted, loosely consolidated, light brown to yellowish brown, 30-60 cm thick, crossbedded and locally well cemented. Climbing ripples occur locally within the sand beds. Clay beds are light brown to reddish brown, typically

30-120 cm thick, laminated (locally wavy and containing mudcracks) and weather to form smooth "popcorn" textured slopes. In two unit-1 samples, Anderholm (1985) determined the clay-fraction to include the following clay minerals (in decending order of abundance): mixed layer illite-smectite, kaolinite, calcium smectite and illite. Scattered nodular calcium carbonate layers and secondary gypsiferous beds also occur. Locally, gypsum rosettes (up to 6 cm in diameter) are found within the gypsiferous beds. The upper 200 m of unit 1 coarsens upward to contain mostly fine- to coarse-grained sand with minor clay interbeds. At the top, scattered pebbles and rare cobbles occur within the sand beds. Unit-1 beds also coarsen northward in the area west and southwest of Mohinas Mountain. Here, unit 1 contains interbeds of coarse- to very coarse-grained sand and lenticular conglomerate that are very similar to those in unit-2 deposits (Table 5-1). Most of unit 1 is barren of fossils, except near the top where a fossiliferous zone was discovered (fossils are discussed in the Age section of this chapter). Two, approximately 15 cm thick, ashbeds are exposed along a major arroyo (see Plate 2 for locations). They are lenticular in shape and mostly water-laid. Paleosols are rare.

The abundance of fine-grained sand and clay indicate that the sediments of unit 1 were deposited within a low- to moderate-energy environment. Sand and clay were deposited

Table 5-1. Clast counts for units in the Gabaldon badlands. Based on 50 counts.

	Unit 1	Unit 2	Unit 2	Unit 4	Unit 4
Rhyolite, Ash flow tuff	50	88	80	18	5
Andesite	--	--	--	--	2
Basalt	--	6	4	7	38
light-colored sandstone (Cretaceous?)	4	2	5	9	31
Red sandstone (Abo)	--	--	--	--	--
Petrified Wood	2	--	--	--	3
Limestone	--	--	3	13	6
Shale	--	--	--	3	--
Chert	21	4	6	17	3
Granitic	--	--	--	15	5
Schist	--	--	--	4	--
Quartzite	--	--	--	5	3
Quartz	23	--	2	9	4
Santa Fe Gp	--	--	--	--	--

mainly by unchannelized, sheetwash that formed the thin, tabular beds. The climbing ripples indicate that deposition rates were probably high. The lack of evaporite deposits and the preservation of sedimentary structures (i.e., wavy laminations, mudcracks) further show that these sediments were not deposited within a saline lake because the growing salt crystals would have destroyed the sedimentary structures. Thus, unit-1 deposits seem to best fit the "dry mudflat and sandflat" subenvironment of Hardie et al. (1978) that exists in basin-floor areas between the distal ends of an alluvial fan and playa. Some of the fine-grained sand is probably eolian. The coarser, unit 2-like beds in the north represent alluvial fan tongues. Evidence for this interpretation is discussed in the next section.

Unit 2. The distinctly redder and stronger cliff-forming beds that overlie the more subdued unit-1 deposits comprise the unit-2 deposits. The cliffs in unit 2 are typically ledgy with rilled faces between ledges (Fig. 5-1). The measured thickness of unit 2 is 193 m. The unit thickens to the north and thins to the south. The southern extent of unit 2 is unknown because younger valley fill (see Plate 2) covers the region south of the measured section. Here, unit-2 deposits form a south-trending chain of isolated outcrops that can be traced until the outcrops end. However, it is unclear if these deposits pinchout because,

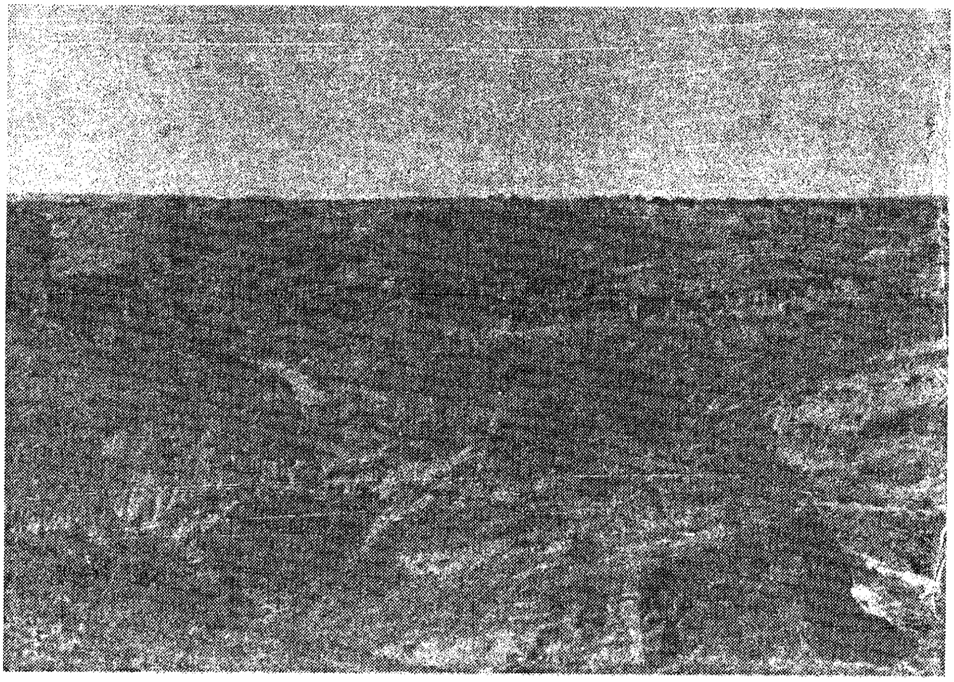


Figure 5-1. Unit 2 of Gabaldon section displaying ledgy cliffs with rilled faces. Subdued and rounded outcrops in foreground is unit 1.

where they should reappear in a north-facing cliff at the southern edge of the badlands, only unit-4 deposits are exposed. It is possible that unit 2 continues in subsurface beneath unit 4.

The contact between units 1 and 2 is gradational. This contact is mapped at the base of the lowest conglomeratic sand that contains abundant cobble-size ash-flow tuff clasts. Unit 2 consists mainly of poorly-sorted, light brown to brown, fine-to very coarse-grained sand and conglomeratic sand with clay and silt interbeds. Conglomeratic zones are usually lenticular and matrix-supported, but do show crude stratification and grading. Clast lithologies are shown on Table 5-1. Note the overwhelming abundance of ash-flow tuff clasts (80-90%). Osburn (pers. comm., 1986) recognizes some of these ash-flow tuff clasts to be La Jencia or Vick's Peak Tuffs of the Mogollon-Datil volcanic field. The red to reddish brown silt and clay beds are typically 30-90 cm thick and locally laminated. Unit-2 deposits generally fine upward into unit-3 deposits.

Near the top and bottom of this unit are two, <15 cm thick, lenticular ash beds (see Plate 2 for locations). A few fossil bones were recovered from the upper part of unit 2. Local 30-60 cm thick red clay zones are interpreted to be paleosols because the beds redden upward and contain abundant clay.

The coarser, sometimes channelized beds show that unit 2 was deposited in a higher energy alluvial environment than unit 1. Some of the silt, sand and conglomeratic sand beds are believed to have been deposited by mudflows and debris flows due to the poorly sorted, matrix-supported and lenticular nature of the beds (Costa, 1984; Reading, 1978). However, many of these beds display grading and stratification that indicate a fluvial origin. These deposits display many of the physical characteristics of an alluvial-fan deposit as described by Bull (1972) and Nilsen (1982). These include:

1) deposit is oxidized and rarely contains well preserved organic material;
2) deposit commonly consists of mudflow and debris-flow and/or water-laid alluvial deposits;
3) Beds within deposit vary in particle-size, sorting, and thickness;
4) deposit has intertonguing relation with units of other depositional environments.

The clay beds, particularly those in the upper part of the unit, are similar to clay beds in unit 1. Therefore, the unit-2 sediments were deposited in a distal piedmont-slope environment and in the adjacent mudflat area. This would be a little higher up the piedmont-slope than unit-1 deposits. The upward fining sequence indicates that the alluvial-fan complex was eventually buried by an expanding basin-floor depositional system.

Unit 3. These deposits can be divided into two subunits: a lower slope-forming, clay-dominated subunit that is similar to unit 1 and an upper cliff-forming, sand-dominated subunit that coarsens upward. Unit thickness was measured at 216 m, but this thickness increases towards the north and south. In most areas, unit-3 deposits overlie unit-2 deposits with the contact mapped at the top of a 1 m thick, well cemented sandstone bed. Both younger alluvium and unit-4 deposits overlie unit 3 in the badland area. In the south, younger alluvium partly buries unit-3 deposits that form another chain of outcrop "islands" (see Plate 2). It is unclear if unit 3 is only underlain by unit 2 or directly overlies unit 1 in some places due to a possible pinchout of unit 2.

The lower third of unit 3 is dominated by clay beds with minor fine- to medium-grained sand interbeds. These light brown to reddish brown clay beds are locally laminated, up to 2 m thick, rarely contain gypsum, and weather to form "popcorn- textured" slopes. Sand beds are light brown to brown, up to 1 m thick, locally crossbedded, and moderately to well sorted. The lower 30 m contain the most fossiliferous zone in the Gabaldon section (Fig. 5-2). Fine- to coarse-grained sand becomes dominant in the upper two-thirds of the unit. In the upper part, sand beds are up to 1.5 m thick, commonly crossbedded, and contain scattered

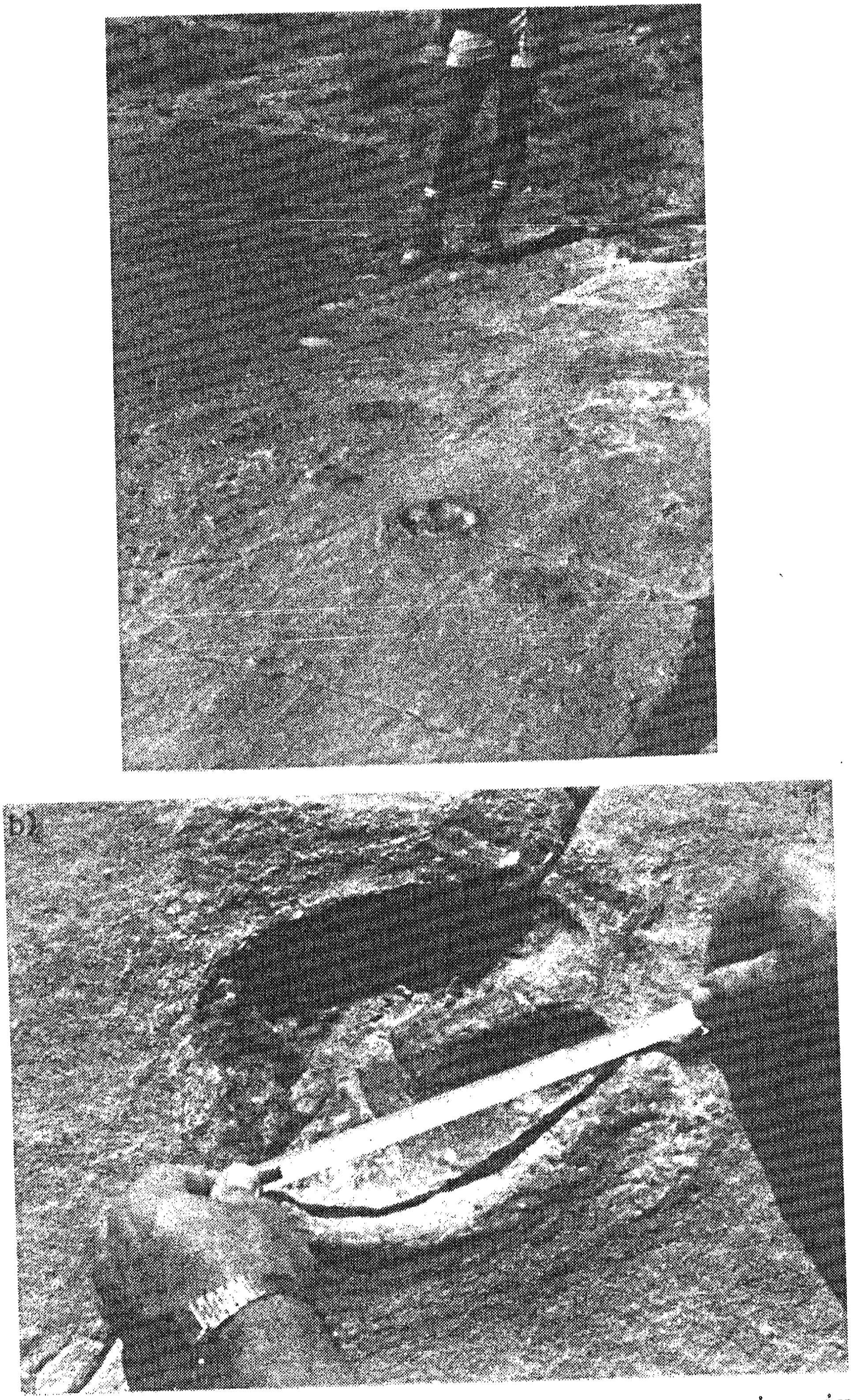


Figure 5-2. a) <u>Alforjas</u> (camel) trackway occurring in tilted, lenticular sandstone of unit 3. Eleven prints are visible. b) Print is about 19 cm long by 15 cm wide.

pebbles which are lithologically similar to those in unit 2. Clay beds are similar to the underlying clay beds, except thicknesses are usually 30 to 60 cm. A few of the red clay zones are believed to be paleosols.

The lower subunit has many of the same sedimentologic characteristics as unit 1. This suggests that the lower subunit was also deposited in the mudflat subenvironment of Hardie et al. (1978), which could have been contiguous with a large playa area. However, the coarsening upward sequence in the upper subunit indicates that it was not deposited on mudflats, but rather in a distal piedmont environment such as that formed by coalescing alluvial fans. The relatively poor sorting, lenticular beds, and variation in bed thickness lend support to this interpretation. The upper subunit deposits are better sorted, more commonly crossbedded, and contain less matrix-supported beds than unit-2 deposits suggesting that this subunit was dominated by more fluvial processes than debris-flow and mudflow deposition. In all, unit-3 deposits display a transition from basin-floor mudflat to distal piedmont-slope environments.

Unit 4. The pale, cliff-forming deposits of unit 4 cap the Gabaldon section. The total thickness of this unit was measured at 146 m. The unit rests with a 4-5° angular unconformity on unit 3 in most places, except in the south where unit 4 directly overlies unit 1 (Plate 2). Within the unit, dips of beds decrease from about 9° at the base to about 4-5° at the top. A constructional geomorphic surface of possible early to middle Pleistocene age is very locally preserved at the top of unit 4. Associated with this surface, in the uppermost and coarsest part of unit 4 is a 60-90 cm thick calcic horizon with stage III-IV morphology (Gile et al., 1981). At one time, unit 4 probably covered a much larger area of the basin. With uplift, these deposits were partly eroded back to expose the Gabaldon section. Locally, very coarse gravel beds are preserved in the uppermost beds of unit 4 along the top of the western escarpment (locations for these beds shown are on Plate 2). Kelley (1977) considered these beds to post-date the Santa Fe and included them with his Ortiz "pediment" deposits. Field evidence shows no unconformity at the base of the gravels and clast types are similar to those in the basal unit 4 beds. In this investigation, these gravels are considered part of unit 4. The coarse beds may represent the western edge of an alluvial unit deposited by a high-energy fluvial system that flowed from the north into the present Gabaldon area. These beds may record the final deposition of the Santa Fe which formed the constructional surface.

Unit 4 is sand dominated with minor clay and silt interbeds. Sand beds are light gray to light brown, loosely consolidated, fine- to very coarse-grained, moderately to well sorted, abundantly crossbedded, and up to 1.5 m thick. Scattered pebbles occur throughout the sand beds. Conglomerate lenses are common in the upper and lower parts of the unit. Clasts are subangular to subrounded, range in size from pebbles to small boulders (30 cm in diameter), and are both clast- and matrix-supported. Clast lithologies in unit 4 are more varied than clasts in the underlying units and include chert, light-colored sandstone, granite, limestone, and silicic to mafic volcanics. Table 5-1 shows the clast types and their relative abundances. Clay and silt beds are reddish brown to light brown, locally laminated, and usually <60 cm thick. Unit-4 deposits generally fine upward from the lower part of the unit into the middle. The middle part of this section (about 50 m thick) forms the more subdued slopes and contains mostly interbedded fine-grained sand, silt, and clay. This middle section contains one possible paleosol and locally, a bed containing abundant ash-flow tuff clasts in the lower part. This ash-flow tuff-rich bed represents a piedmont unit and indicates the location of the western margin of the large fluvial system. The unit then coarsens upward with the largest clasts (cobbles and boulders) in the section occurring in the uppermost beds.

Most of Unit 4 was deposited by a large fluvial system as evidenced by the moderately to well sorted, trough crossbedded sand. Campbell (1976) and Cant and Walker (1978) have determined that trough crossbedding, nondefined channels, and high sand-to-clay ratios are important characteristics for recognizing braided river deposits. Unit-4 deposits exhibit these characteristics and, therefore, are interpreted to have been deposited by a braided river system. These deposits are very similar to the high-gradient fluvial deposits that are described by Blair (1987) for a unit occurring in an ancient rift basin of Mexico. The unit-4 deposits show that the depositional environment of the area changed from a piedmont-slope/internally-drained basin-floor complex with coalescent alluvial-fans and playas, to a basin-floor fluvial plain (and marginal piedmont) with a through-flowing river system, probably occupied by an ancestral Rio San Jose or Rio Puerco. This is an important change because it records the transition from closed-basin drainage to through-flowing drainage.

Mohinas Mountain Area

The large hill in the northeastern part of the mapped area is Mohinas Mountain (Plate 2). This feature has been interpreted as the exhumed lower part of a volcano by Kelley and Kudo (1978). The "Mountain" consists of alkali basalt and olivine diabase that have intruded the lowermost beds of unit 1. A large funnel-shaped intrusion forms the core of the "Mountain" and unit-1 beds around its margin dip inward. Abundant talus and landslide debris cover much of the flanking slopes making study of the Santa Fe beds difficult on the mountain. The intrusives have locally deformed and altered unit-1 deposits. Several basaltic sills and at least two breccia pipes intrude the surrounding deposits in and around the mountain. Hidden Mountain, another volcanic feature that is similar to Mohinas Mountain, is located outside the mapped area about 2.5 km to the north. Both volcanic centers have also been mapped by Gratton (1958) and Kelley and Kudo (1978).

Age of the Gabaldon Section

Part of the Gabaldon section can be dated by using faunal remains and, in one area, volcanic material. Abundant identifiable fossil material have been recovered from the uppermost beds of unit 1 and throughout units 2 and 3. No identifiable fossil material has been recovered from the lower unit-1 beds and only one bone was found in unit 4. Fossil types and ages are briefly discussed below. Dr. Richard Tedford of the American Museum of Natural History identified and assigned (land-mammal) ages to the faunal material. For a more detailed description of the fossils and a discussion of faunal ages, see Tedford's report in Appendix III.

Wright (1946, p. 413) reported the first fossil discoveries from the Gabaldon section. Only one limb bone was identified from his upper "playa" beds, but Wright's discovery prompted Ted Galusha of the American Museum of Natural History to further investigate the badlands area. Galusha and his team collected mammalian fossils from several horizons in the section. In the course of the present investigation, fossils were recovered from 14 sites (shown on Plate 2). Most of these sites are within units previously prospected by Galusha.

Tedford has examined both collections and has compiled a faunal list for the Gabaldon section (Fig. 5-3). No major faunal changes are recognized in the fossiliferous part of the section indicating that deposition was fairly rapid. According to Tedford, this faunal assemblage is of early Hemphillian (land-mammal) age and suggests an absolute age of 7-9 Ma for the fossiliferous zone. Unfortunately, the ash beds that occur in units 1 and 2 are unsuitable for isotopic dating, so independent verification of unit age is not possible. Baldridge et al. (1987) has recently reported a K-Ar date for Hidden Mountain of 8.3 ± 0.2 Ma. These volcanics intrude the lower unit-1 deposits and show the K-Ar date to be consistant with the fossil dates. The 7-9 Ma age range indicates that units 1-3 are correlative with at least the upper part of the Popotosa Formation.

Although the age range of the one identifiable fossil in unit 4 is too large to be useful for dating (Tedford,

Leporidae (rabbits)	*Hypolagus* cf. *vetus* *H.* sp.
Canidae (dogs)	Vulpine, n. gen. et sp. *Epicyon* cf. *E. haydeni validus* cf. *Osteoborus pugnator*
Felidae (cats)	cf. *Nimravides catocapis*
Equidae (horses)	hipparionine
Camelidae (camels)	*Michenia* cf. *yavapaiensis* *Procamelus* sp. *Alforjas* sp.
Antilocarpidae (pronghorns)	cf. *Plioceras* cf. *Osbornoceros*

early Hemphillian age fauna (7-9 Ma)

Figure 5-3. Faunal list for Gabaldon badlands. For a more detailed explanation, see Appendix III.

pers. comm., 1987), the age of these deposits can be approximated by correlation with similar units of known age in other parts of the basin. Based on degree of deformation, stratigraphic position, and thickness, unit-4 deposits are believed to be correlative with the upper Santa Fe--Sierra Ladrones Formation. This formation: 1) shows minimum deformation with dips of beds seldom over 5°; 2) rests with an angular unconformity on Popotosa Formation deposits; and 3) is 470 m thick. If this correlation is correct, the unit-4 deposits range in age from about 5 Ma to possibly as young as 1.0 to 0.4 Ma. During a rapid reconnaissance of the Gabaldon badlands area, Machette (1978b) included all exposed basin fill in the Sierra Ladrones Formation and he did not recognize that units 1, 2, and 3 were actually part of the lower Santa Fe Group.

Structure

Folds and faults deform all Santa Fe units in the Gabaldon section (Plate 2). However, unit 4 shows less deformation than the underlying units; and, within the mapped area, the capping surface shows only minor offset by faulting. As mentioned in the Stratigraphy section, dips of beds generally decrease upsection. Major structures of the Gabaldon badlands are discussed below.

Two major folds occur in the Gabaldon section. The lower part of unit 1 contains a large, asymmetrical, southwest-plunging anticline. The southwest extent of this fold cannot be determined because of alluvial cover. Where observed, the anticline involves unit-1 strata only. The nose of the fold is slightly offset by a fault. In the west-central part of the map area, a large, northeast-plunging syncline deforms all four units; but deformation is less in unit-4 deposits. This syncline is more open and symmetrical than the anticline. Numerous smaller folds occur within the mapped area, particularly in the vicinity of the northeast-trending fault.

Faults are the main structural features in the Gabaldon section. These faults all show normal displacement and generally trend north to northeast. The fault that bounds the section just east of Gabaldon reservoir (Plate 2) is north-trending and down-to-the-east. The amount of stratigraphic throw is unknown; but it is probably not more than about 400 m, because lower unit 1 beds occur on both sides of the fault. To the south, this fault splays into at least three segments. Here, the fault plane dips between 65 and 75° to the east. Further south, the fault appears to offset the capping surface deposits (Qs) as evidenced by the increase in slope across the fault projection. The northern extent of the fault is unclear, but it may merge with the northeast-trending fault immediately to the north. A significant northwest-trending, down-to-the-west fault lies about 1 km west of the anticline. This fault, dipping 65° to the west, has removed an unknown thickness of unit 1.

The most recognizable structure in the region is the northeast-trending fault that cuts obliquely across bedding in the central part of the mapped area. It is a down-to-the-southeast fault and has about 0.5 km of stratigraphic throw. Part of this movement maybe due to strike-slip motion. The fault can be traced for about 3 km from unit 4 until it becomes buried by alluvium. In this area, the fault may die out, but movement may have been taken up by another northeast-trending fault just to the north. Thickness changes in units 1, 2, 3, and 4 across the fault clearly indicate syndepositional movement. This can be easily demonstrated in unit 4 where offset on the fault gradually decreases until the fault dies out. Numerous local faults are associated with Mohinas and Hidden Mountain.

Seismic reflection work by Shell Oil indicates a prominent seismic discontinuity beneath the Gabaldon badlands (see Plate 3). This discontinuity appears to project into the Santa Fe fault, one of the main frontal faults of the Lucero uplift. Reflectors, that are believed to be bedding planes, are truncated by the feature. This discontinuity is interpreted to be a low-angle detachment surface that has cut-off the Gabaldon beds at depth. The decrease in bedding dip angles upsection in the Gabaldon badlands may be explained by rotation along this detachment surface.

Most of the deformation in the Gabaldon badlands area occurred during and before deposition of units 1-3. Activity decreased greatly by unit 4 time as evidenced by less deformation within the unit and by lower bedding dips. This would have been before 5 Ma when Rio Grande rifting was most active. No limit can be placed on the beginning of deformation based on evidence from the Gabaldon section.

Bobo Butte Area

The Bobo Butte area is located along the western edge of the Albuquerque basin about 8 km west of the Gabaldon badlands (Plate 1). Here, the Santa Fe fault has juxtaposed the Santa Fe Group with Triassic strata (Callender and Zilinski, 1976). Bobo Butte is an approximate 150 m high mesa capped with conglomeratic sandstone, siltstone, and travertine that unconformably overlies a sequence of eastward-dipping Santa Fe Group strata (Fig. 5-4). Good exposures of the Group occur just east of the Santa Fe fault. Access into the area is good via a dirt road; however, part of the area is on private land.

Prior to the present investigation, the Santa Fe Group in the Bobo Butte area had not been studied in detail.

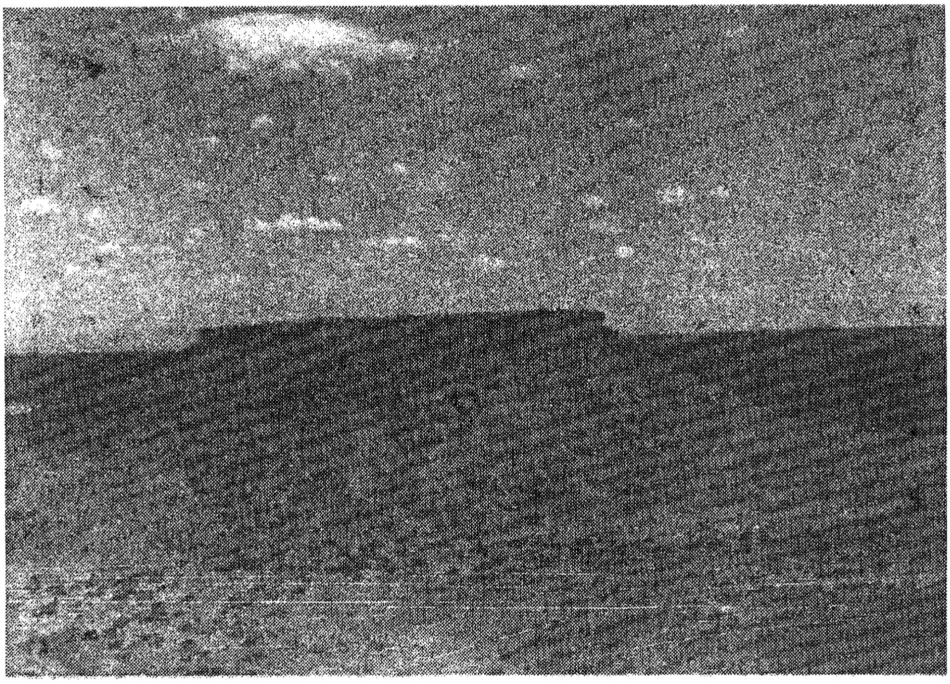


Figure 5-4. North side of Bobo Butte. Note resistant caprock.

Wright (1946, p. 403) mentions the "discontinuous exposures of the Santa Fe along Carrizo (Santa Fe) fault east of Lucero Mesa", but he gives only general discriptions of basin-fill lithologies. The geology and structural history of the Lucero uplift is discussed by Callender and Zilinski (1976). They mapped the Santa Fe Group east of the Santa Fe fault, but did not recognize individual units within the Group. Kelley (1977) briefly mentions some of the Santa Fe outcrops east of the Lucero uplift. Hammond (1987), in a study of the structure of the Navajo Gap area, generally mapped the Santa Fe Group just east of the basin margin fault and noted ash-flow tuff clasts eroding out of the Santa Fe beds.

Stratigraphy

A section of the exposed Santa Fe Group was measured and described between the Santa Fe fault and Bobo Butte (Plate 4). The total measured thickness, including the flat-lying caprock unit, is 246 m. Although the Santa Fe Group strata are faulted and folded throughout this area, the measured section was relatively undeformed. Two units were subdivided from the measured section: the thicker, eastward-tilted, lower sequence, and the relatively flat-lying caprock unit. Appendix I contains the Bobo Butte measured section. This is not a complete section because the base of the unit is fault-bounded and an angular unconformity marks the upper contact with unit 2.

Unit 1. Alternating beds of sand, silty sand, clayey sand, and conglomerate comprise unit-1 deposits. The total measured thickness is 235 m. These beds are typically cliff-formers, except for the silty sand and clayey silt interbeds. Pure clay beds are rare, but, when found, they may be argillic horizons of paleosols. Because of limited outcrop, it is unknown if the unit thickens or thins to the north or south.

Sand beds are fine- to very coarse-grained, moderately to poorly sorted, pale brown to reddish yellow, mostly loosely consolidated, up to 2 m thick, and locally crossbedded and well cemented. The sand beds can also contain pebbly lenses and scattered pebbles. Similar in color and thickness as the sand beds, the poorly sorted conglomerate beds are usually matrix-supported and lenticular. Subrounded to angular clasts are mostly pebble-size with some cobbles. Ash-flow tuffs and calcareous mudstones are the major clast lithologies (Table 5-2). Silty sand and clayey silt beds are red to brown, up to 1 m thick, and locally laminated. In general, the unit coarsens upward in the lower 100 m and then fines upward in the top 135 m.

These poorly sorted and matrix-supported unit-1 beds were deposited mainly by debris-flows. The crude stratification and grading seen indicate that some beds are

Table 5-2. Clast counts for units in the Bobo Butte area. Based on 50 counts.

	Unit 1	Unit 1	Unit 2
Rhyolite, Ash flow tuff	51	48	--
Andesite	--	--	--
Basalt	--	--	8
light-colored sandstone (Cretaceous?)	10	8	7
Red sandstone (Abo)	--	--	42
Petrified Wood	--	--	--
Limestone	6	--	31
Calcareous mudstone	13	20	--
Chert	17	24	4
Granitic	--	--	--
Schist	--	--	--
Quartzite	3	--	1
Quartz	--	--	1
Santa Fe Gp	--	--	6

fluvial deposits. Bull's (1972) criteria for alluvial-fan deposits fits for unit 1. Due to the abundance of sand and conglomerate, these beds appear to have been deposited relatively high on an alluvial fan, probably within the proximal to medial zones.

Unit 2. The well cemented, very coarse, flat-lying caprock on Bobo Butte comprises unit-2 deposits. The measured thickness is 11 m. The unit consists of conglomerate interbedded with sandstone, siltstone, and travertine. Conglomerate beds are matrix-supported, reddish yellow, poorly sorted, up to 2 m thick, and locally lenticular. Clasts are subrounded to angular and mostly pebble- to cobble-size, but some are up to 1 m in size. Clast types and their percentages are shown on Table 5-2. These clast are different lithologically than those in unit 1. Major differences include no ash-flow tuff and abundant Abo sandstone and Paleozoic limestone. Fine- to coarse-grained sandstone and siltstone beds are reddish yellow, up to 60 cm thick, and contain scattered pebbles. Banded travertine ranges in color from white to reddish yellow. Beds in unit 2 coarsen upward.

Clastic beds in unit 2 were also deposited by debris-flows. The travertine beds were deposited by solution in water that perhaps emanated from nearby springs and flowed over the deposits. It is these supersaturated fluids that are responsible for the well cemented nature of the unit-2 beds. The lack of stratification and poor sorting indicate that unit 2 was deposited in the proximal area of an alluvial fan (Bull, 1972).

Age of the Bobo Butte Section

Unfortunately, no datable material (fossils or ash beds) was found in the Bobo Butte area. However, based on correlation with the Gabaldon section, possible ages can be inferred.

Unit 1 of the Bobo Butte section is very similar both lithologically and in the amount of deformation to units 1, 2, and 3 of the Gabaldon section. Clast types are dominated by ash-flow tuffs in both sections. This establishes an age of about 7-9 Ma for unit 1 of the Bobo Butte section or equivalent to the uppermost Popotosa Formation.

Unit 2 is younger than unit 1 because the unit is relatively flat-lying and, as mentioned before, their clast lithologies are quite different. Unit 2 is probably equivalent to part of unit 4 of the Gabaldon section and correlates with the Sierra Ladrones Formation. They both show similar amounts of deformation. It is possible but unlikely that unit 2 postdates unit 4 and represents a post-Santa Fe Group deposit.

Oil Test Wells

Cuttings from two oil test wells were examined from the southwestern basin area, the Humble Oil Santa Fe Pacific #1 (Humble SFP #1) and the Shell Santa Fe Pacific #2 (Shell SFP #2). The locations of these wells are shown on Plate 2. These wells were spudded in Quaternary surficial deposits and then penetrated unit 1 of the Gabaldon section. Gas shows were reported from Cretaceous units; however, both wells were reported as dry and abandoned (Black, 1982).

Humble SFP #1

This well, completed in 1953, was drilled to a total depth of 3,868 m and bottomed in Cretaceous strata. Cuttings from this well were examined from 3 to 3,289 m.

Santa Fe Group beds extend down to 1,494 m and are considered to all be part of unit 1 of the Gabaldon section (Fig. 5-5). The upper 884 m of the well consists mainly of medium- to coarse-grained, pale sand with reddish brown clay interbeds. Subangular to rounded pebbles of quartz, quartzite, chert, basalt, and ash-flow tuff are scattered throughout the top 30 m. These pebbles may be contamination from higher in the hole. This upper interval fines downward and clay interbeds become more numerous near the bottom. Reddish brown to gray clay with silt and fine- to medium-grained sand interbeds dominate the borehole down to 1,494 m.

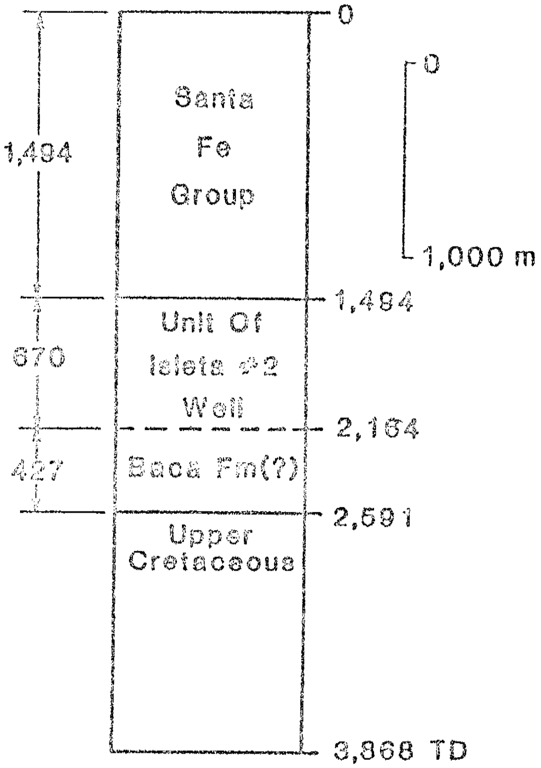


Figure 5-5. Stratigraphic column for Humble SFP #1 showing unit tops and thicknesses. All measurements in meters.

At this depth, the cuttings exhibit a major color change to purplish red claystone and fine- to medium-grained sandstone. This color change marks the beginning of the pre-Santa Fe Tertiary section. Some zones within this interval contain coarse-grained sandstone and scattered pebbles of chert, quartz, and andesite. As will be discussed in the Sand Petrology section, most of the pre-Santa Fe Tertiary units penetrated by this well and by the Shell SFP#2 are correlative with the unit of Isleta #2 well based on volcanic-lithic percentages. However, the very lower part of this section may contain a thin interval of Baca Formation strata. Foster (1978) reported that these wells penetrated Baca deposits.

The Mesozoic section starts at 2,591 m where another major color and texture change occurs. Here, light gray to black shale, siltstone, and fine-grained sandstone are the major lithologic componets down to 3,290 m were the cutting analysis stopped. The Mesozoic section examined is interpreted to be Upper Cretaceous based on the coal beds and dominance of gray shales. The well also penetrated a 94 m thick intrusive of intermediate composition at 2,768 m.

Shell SFP #2

Completed in 1974, this well bottomed in Triassic strata at a total depth of 4,360 m. Cuttings were examined from 128 m down to 3,460 m. This well is shown in the cross section on Plate 3.

The upper 1,460 m of the well is comprised of the Santa Fe Group and is considered to be unit 1 of the Gabaldon section (Fig. 5-6). Fine- to coarse-grained sand with minor light brown to pink silt and clay interbeds dominate the upper 1,280 m of the well. This interval gradually fines downward. From 1,280 to 1,460 m, alternating beds of fine- to medium-grained sand and pinkish silt occur.

At 1,463 m, beds change to mostly purplish red to dark red claystone with lesser fine- to medium-grained, silty sandstone and siltstone of the pre-Santa Fe Tertiary unit. Poorly sorted, silty sandstone beds are more common than claystones below 1,899 m. Beds change to light and dark gray by 2,511 m, but are still mostly silty sandstone. This section is of Mesozoic age, probably Upper Cretaceous. Possible coal interbeds are encountered between 2,694 and 2,841 m. Gray to dark gray claystone beds with minor siltstone and silty sandstone are the main litholgies from 2,896 m down to where the cutting interval ended.

Sand Petrology

Point counts were conducted on 38 thin sections from the southwest basin area; 30 from the Santa Fe Group, 4 from pre-Santa Fe Tertiary units, and 4 from the Upper Cretaceous strata. Point count results are tabulated in Appendix II.

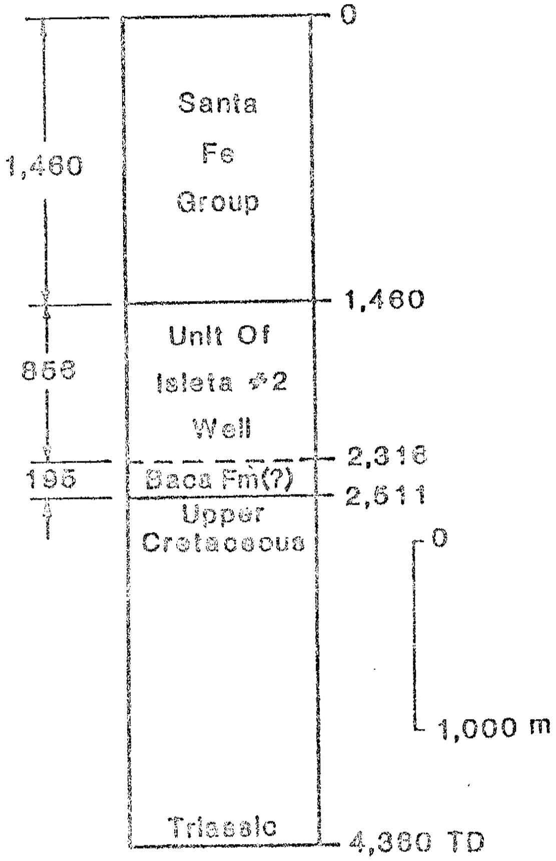


Figure 5-6. Stratigraphic column for Shell SFP #2 showing unit tops and thicknesses. All measurements in meters.

A minimum of 3 samples were collected from each of the mapped units in the Gabaldon section and there locations are plotted on Plate 2. Only unit-1 samples were point counted from the Bobo Butte section. All thin sections from the oil test wells were cut from impregnated cutting samples; no core sections were available. Point count results are plotted on the ternary diagrams (Figs. 5-7 to 5-9).

Santa Fe Group

The average sand grain composition of the Santa Fe samples from the southwest basin area range from 43.4% quartz, 40.8% feldspar, and 15.8% lithic for the Bobo Butte samples to 49.2% quartz, 24.8% feldspar, and 26.0% lithic for the Shell SFP #2. These samples classify as arkose, lithic arenite, and feldspathic litharenite (Folk, 1974). Sand grains are typically fine- to coarse-grained, poorly to well sorted, and subangular to subrounded. Calcium carbonate is the main cement and some grains in non-cemented samples display clay rims.

Clear, monocrystalline quartz (Qm) is the most abundant detrital grain. These grains exhibit straight extinction and seldom show overgrowth rims. Chert (Qpn) is the chief polycrystalline quartz (Qp). Tectonic polycrystalline quartz (Qpt) is rare, but unit 4 samples from the Gabaldon badlands generally contain higher percentages. The Qp/Q ratio averages range from 0.07 in the Humble well to 0.11 in

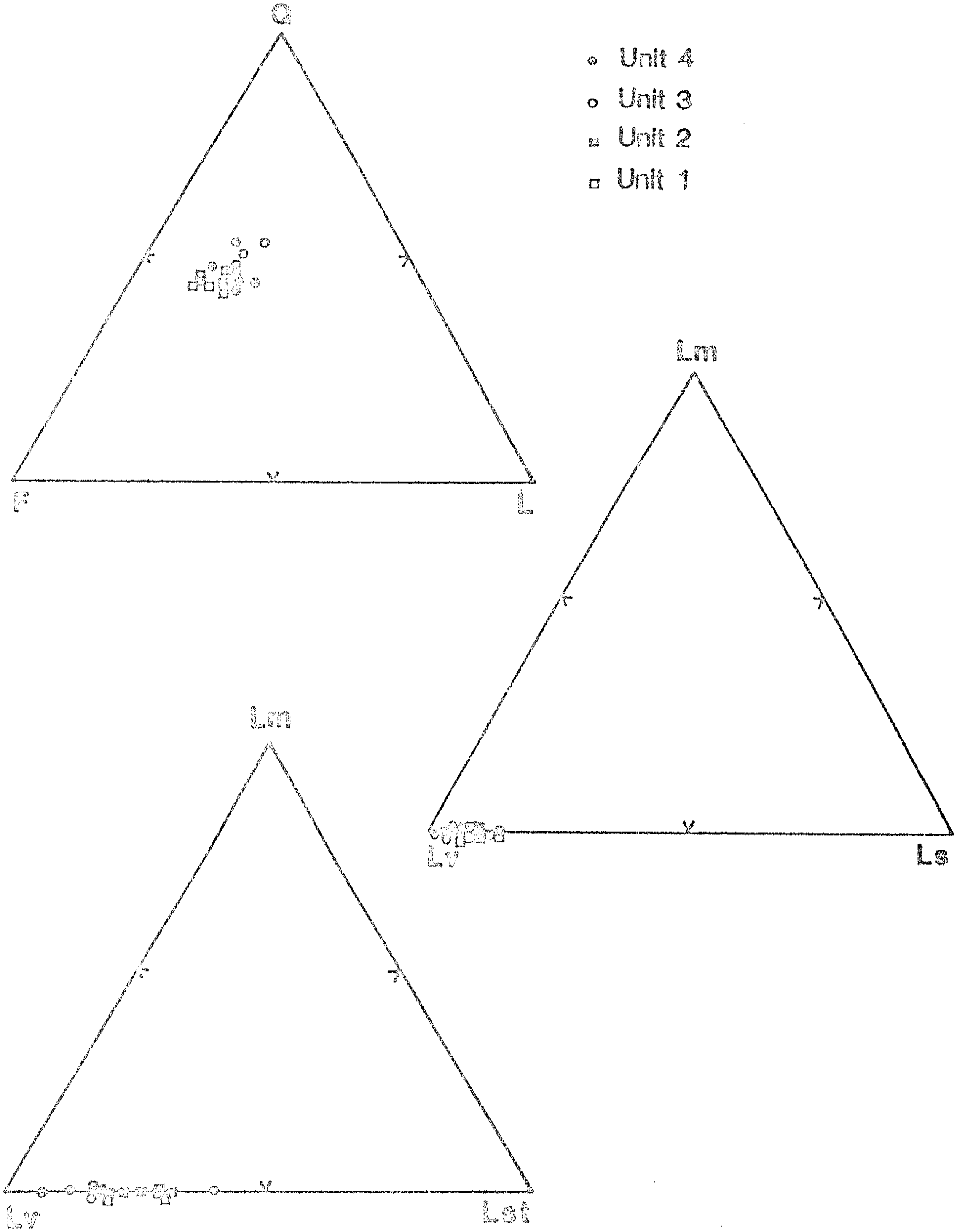


Figure 5-7. Ternary diagrams for Santa Fe units mapped in the Gabaldon badlands.

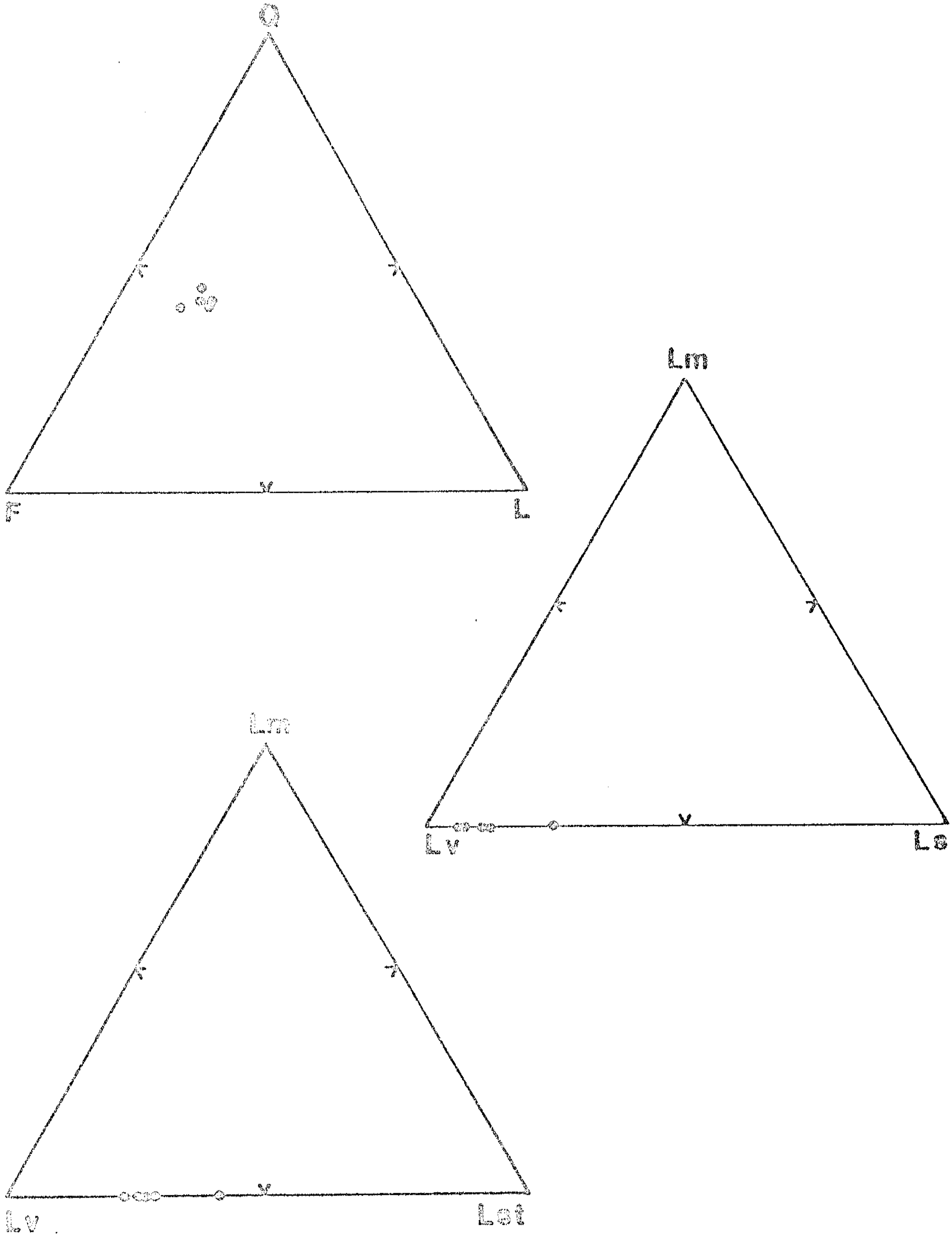


Figure 5-8. Ternary diagrams for unit 1 in the Bobo Butte area.

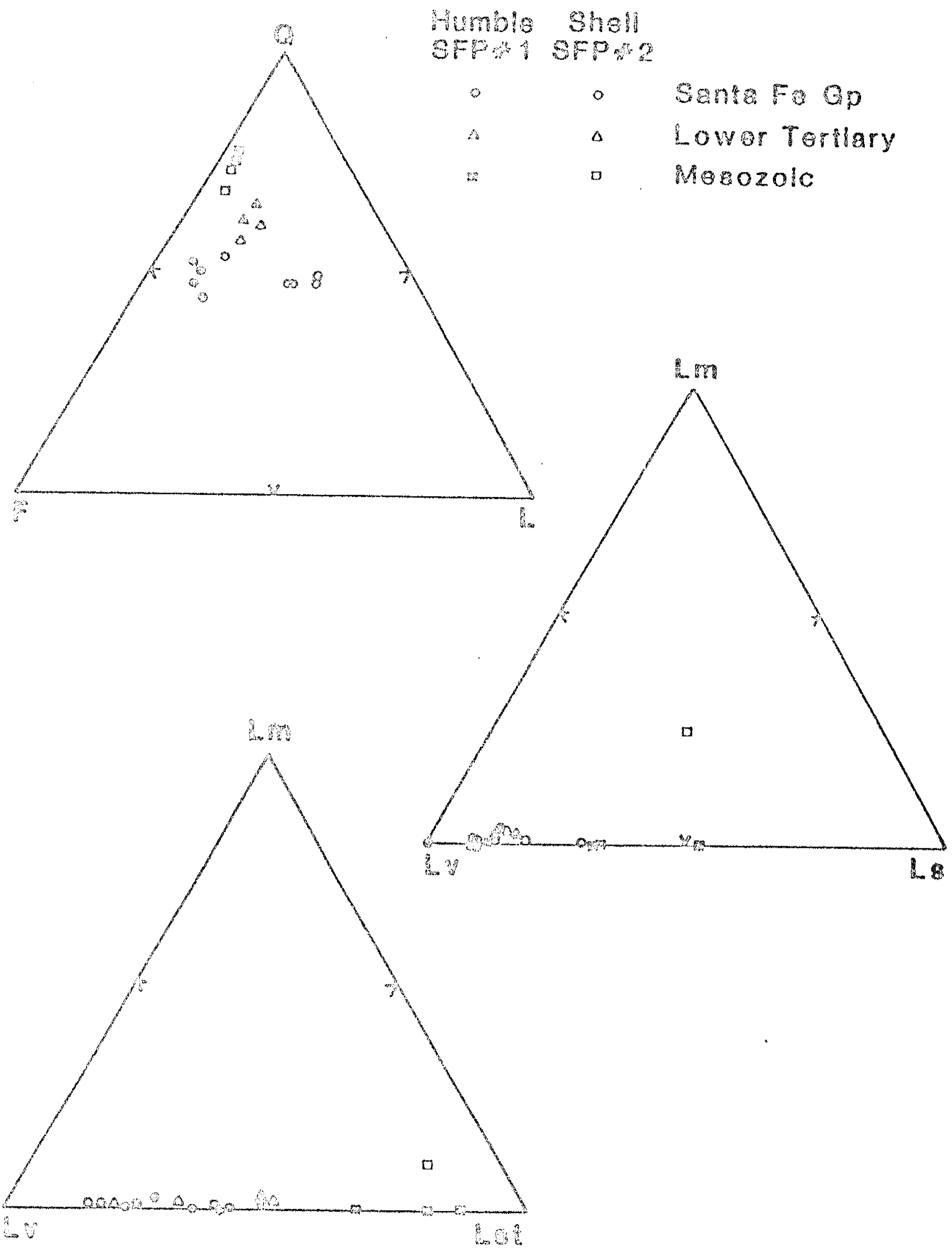


Figure 5-9. Ternary diagrams for Humble SFP #1 and Shell SFP #2.

the Shell well. There is no systematic change in the Qp/Q ratio with depth in both outcrops and oil test wells but there does appear to be a slight increase in quartz percentage on the QFL plots with depth.

Plagioclase is the major feldspar in most samples; however, potassium feldspar is slightly more abundant in the Shell SFP#2 well and Bobo Butte samples. Plagioclase, both as detrital grains and as pheoncrysts, range in composition from oligoclase to labradorite, but most are andesine. These grains are commonly twinned and occasionally show oscillatory zoning. Some grains show sericitic alteration but most are usually fresh. Most potassium feldspars are orthoclase and sanidine. Microcline is more common higher in the section, particularly in Gabaldon unit 4 samples. Feldspar percentages change little with depth.

Volcanic lithic fragments are the dominant lithic grain averaging over 80% of all lithic fragments. These grains are mostly andesitic and silicic displaying both microlitic and porphyritic textures. Mafic volcanics become more common higher in the section. Averages of sedimentary lithics range from 7.6% in the Galbaldon samples to 16.2% in the Shell SFP#2 well samples. They include shale, siltstone, and carbonate rocks. Very low percentages of metamorphic lithic fragments (<1.0%) were recognized in the in the oil test wells only. A few granitic fragments were recognized in the upper 2 samples in the Shell SFP#2 well and in Gabaldon unit-4 samples.

Pre-Santa Fe Tertiary Deposits

These samples are only from the oil test wells (Fig. 5-9). Pre-Santa Fe Tertiary samples have higher quartz percentages than Santa Fe samples averaging 64% quartz, 24% feldspar, and 12% lithic in the Humble SFP#1 and 59.5% quartz, 23.0% feldspar, and 15.5% lithic in the Shell SFP#2. They are lithic arenites and arkoses after Folk (1974). Sand in thin section is fine- to medium-grained, moderately to well sorted, and subangular to subrounded.

Monocrystalline quartz and plagioclase are the dominant grains and are similar to those grains described for the Santa Fe Group. Polycrystalline quartz, primarily chert, indicate little change in this unit from the Santa Fe. The P/F ratio varies between the samples (see Appendix II). Lithic fragments average 83.0% volcanic, 15.0% sedimentary, and 2.0% metamorphic in the Humble SFP#1 and 85.5% volcanic, 13.0% sedimentary, and 1.5% metamorphic in the Shell SFP#2. The volcanic lithics are mainly andesitic and silicic, similar to the Santa Fe Group. No granitic fragments were noted in these samples.

Based on the relatively high volcanic-lithic percentages, the pre-Santa Fe Tertiary section in the wells are believed to correlate mainly with the unit of Isleta #2 well. However, no thin sections were examined in the lower part of the pre-Santa Fe Tertiary section from 2,164 m to 2,591 m in the Humble SFP#1 and from 2,316 m to 2,511 m in the Shell SFP#2. Thus, it is possible that Baca Formation strata may be present within this unexamined interval overlying the Upper Cretaceous section.

Upper Cretaceous

These samples were obtained only from the oil test wells (Fig. 5-9) and contain the highest quartz percentages. They average 77.0% quartz, 19.0% feldspar, and 3.5% lithic in the Humble SFP#1 and 71.0% quartz, 24.5% feldspar, and 4.5% lithic in the Shell SFP#2. Samples of Upper Cretaceous rocks are texturally more mature than Santa Fe and pre-Santa Fe Tertiary units and include arkose, subarkose, and sublitharenite (Folk, 1974). Sand grains are generally subangular to rounded, fine- to coarse-grained, and well sorted.

Quartz is dominated by clear, monocrystalline grains, but more grains exhibit undulose extinction with overgrowth rims than quartz grains in the other two units. Chert is most common in these samples, too. The Qp/Q ratio is about the same for both wells. The average P/F ratio is quite high for the Humble SFP#1 (0.83), but fairly low for the Shell SFP#2 (0.36). Feldspars, especially zoned plagioclase, commonly show sericitic alteration. Lithic fragment percentages are low in Mesozoic samples and consist of subequal amounts of volcanic and sedimentary lithic grains. A few metamorphic grains were counted in sample SS-109 only. The volcanic lithic grains may not be representative from this unit and have fallen in from higher in the hole. No granitic fragments were recognized from these samples.

Provenance

Santa Fe Group deposits in the southwest basin area were derived from more than one source area. However, the composition of Gabaldon units 1-3 and Bobo Butte unit 1 shows that most sediments came primarily from two source areas; whereas, unit-4 deposits originated more equally from three or four source terranes.

The abundance of volcanic clasts in outcrop and the high percentages of plagioclase (twinned and zoned) and andesitic-rock fragments in thin section clearly indicate an intermediate volcanic source area for most of the deposits in Gabaldon units 1-3 and Bobo Butte unit 1. A reworked sedimentary source area is suggested by the sedimentary clasts (sandstone, calcareous mudstone, petrified wood, chert, and limestone) in outcrop and by the rounded quartz grains with overgrowth rims in thin section. Most of the clasts represent reworked Cretaceous strata because of their similarity to nearby exposures of known Cretaceous rocks.

The lack of calcareous mudstone clasts in the Gabaldon section may be a result of preferential removal of these clast types due to longer transport distance. Due to a lack of metamorphic and/or granitic rock fragments, a source area from these terranes is ruled out. Thus, these deposits were derived primarily from an intermediate volcanic source area with lesser amounts reworked from a sedimentary terrane.

Unit 4 shows strong evidence for intermediate volcanic and sedimentary source terranes as well as evidence for other source areas. High percentages of volcanic and reworked sedimentary material are also present in both outcrop and thin section lending strong support for source areas from these terranes. Some of the volcanic and sedimentary material may be reworked from the underlying basin fill units. Metamorphic (schists and quartzites) and granitic clasts occur in unit-4 outcrops. Thin section work shows significant amounts of tectonic polycrystalline quartz, strained quartz, granitic rock fragments, and microcline. These data indicate that unit 4 was also derived from metamorphic and/or granitic source areas.

Clast lithologies within Bobo Butte unit-2 deposits are distinctly different than Bobo Butte unit-1 deposits. The abundant limestone and red sandstone clasts were derived out of the nearby Permian San Andres and Abo Formations exposed in the Lucero uplift. Eastward flow directions of imbricated clasts support this interpretation. Only a minor amount of detritus was derived from volcanic source areas as evidenced by the low volcanic percentages. These volcanics are mainly basaltic in composition. Clast types clearly show that metamorphic and granitic terranes were not source areas for unit-2 deposits.

Paleocurrent measurements on imbricated clasts, crossbeds, and parting lineations show that Gabaldon units 1-3 were derived primarily from the west in alluvial-fan facies and from the north in mudflat facies (Fig. 5-10). Imbricated clasts in Bobo Butte unit 1 show that these deposits were derived exclusively from the west in the Lucero uplift. Imbricated clasts and trough crossbeds in the braided river deposits of unit 4 indicate a southeasterly flow direction (Fig. 5-11).

Intermediate volcanic and sedimentary terranes are the major source areas for the unit of Isleta #2 deposits penetrated in the two oil test wells. This interpretation is supported by the high percentages of quartz and volcanic lithic fragments. Although no paleocurrent data exists for these deposits, it seems that they were most likely derived from the Lucero uplift region to the west and southwest. This region was at least partly covered by Oligocene volcanic material that was derived from large calderas that were erupting farther to the south and underlain by Mesozoic and Paleozoic bedrock. Based on the overall fine-grained nature of these deposits, they were deposited in a low

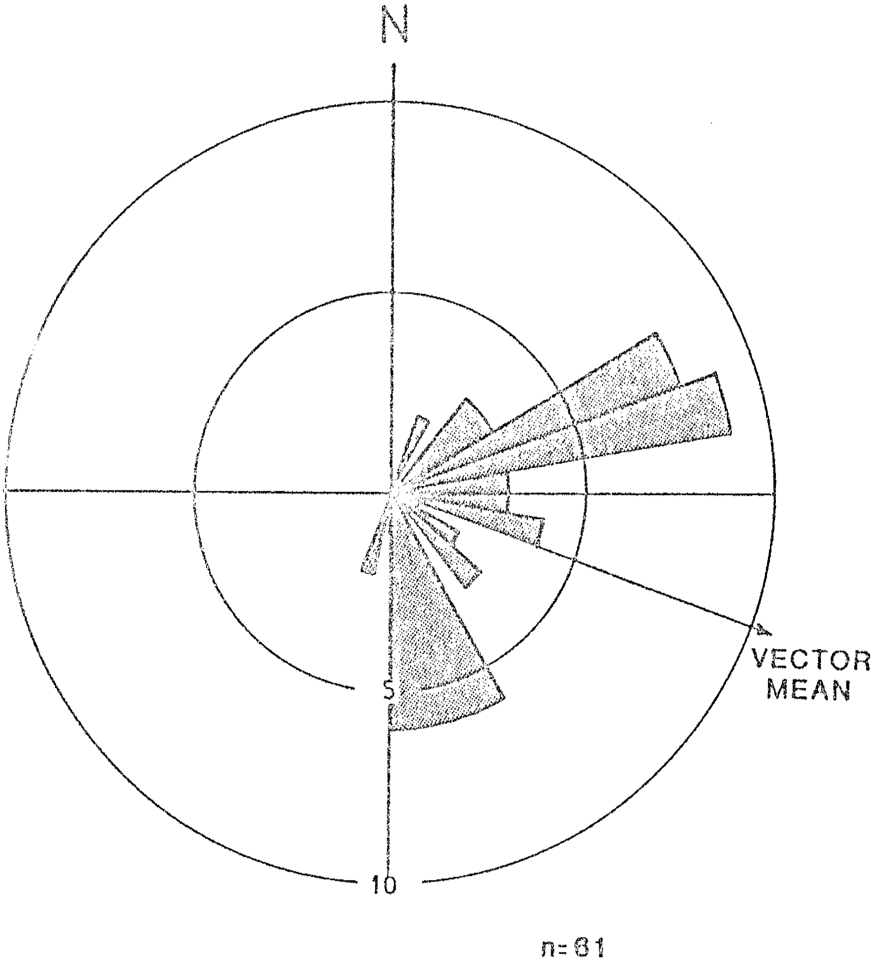
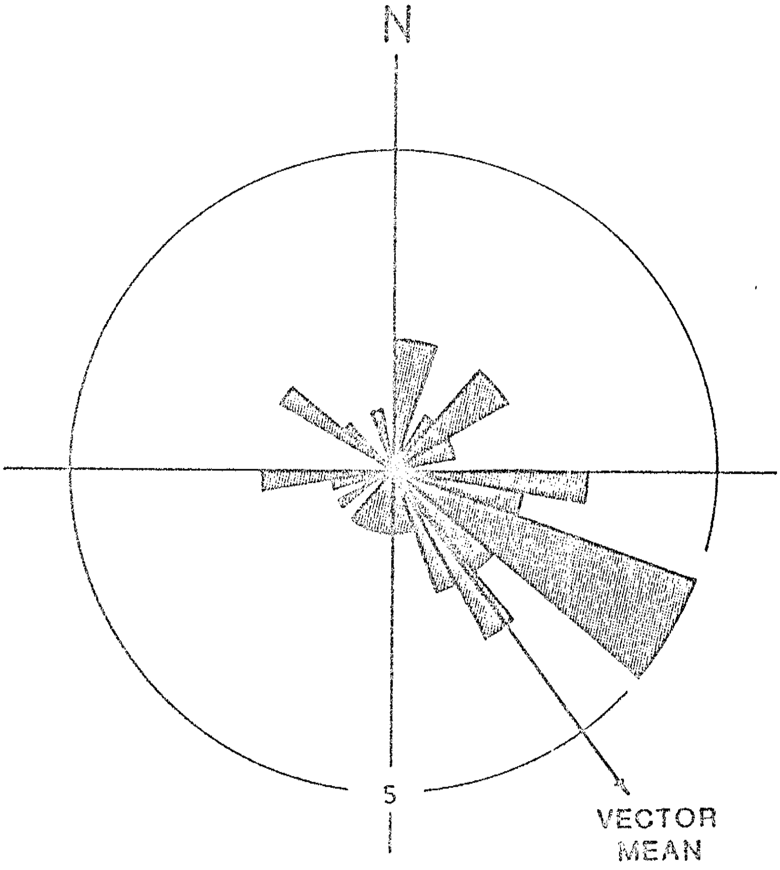


Figure 5-10. Rose diagram indicating paleoflow directions for units 1-3 in the Gabaldon badlands. Based on 61 measurements.



n=50

Figure 5-11. Rose diagram indicating paleoflow direction for unit 4 in the Gabaldon badlands. Based on 50 measurements.

energy alluvial environment.

If Baca Formation equivalent units occur in the oil test wells, then they were probably derived from reworked sedimentary source terranes in the Lucero uplift. However, this cannot be substantiated until thin sections from this unstudied interval are analyzed.

Depositional History of the Southwest Basin Area

The possible Eocene deposits penetrated by the oil test wells indicate that Eocene deposition may have occurred in the southwestern part of the basin. If these sediments are present, then they were probably derived from the Lucero uplift and deposited along alluvial aprons that extended from the uplift area.

Sediments of the unit of Isleta #2 well penetrated by the two oil test wells were derived mainly from intermediate to silicic volcanic and sedimentary source terranes. It is not known from what direction these deposits were derived because no paleocurrent directions could be measured. However, these deposits were most likely derived form the west and southwest where large volumes of volcanic and volcaniclastic rocks were being produced by erupting calderas of the Mogollon-Datil volcanic field (Osburn and Chapin, 1983). The unit of Isleta #2 was deposited mainly by debris-flows and mudflows, perhaps along large alluvial aprons that extended outward from the Ladron/Lucero uplift area. These deposits may also include ash-flow tuffs and intermediate to mafic lava flows although none were recognized in the well cuttings. These deposits attained thicknesses of at least 1,000 m according to the analysis of samples from the oil test wells.

It is not known when Santa Fe Group deposition began in the southwest basin area. The oldest Santa Fe Group beds were penetrated by the oil test wells, but far below the 7-9 Ma deposits in the Gabaldon section. However, based on petrology and textures of well cuttings, the source areas and depositional environments for these older Santa Fe deposits are similar to units 1-3 of the Gabaldon section. This indicates that there was little change in the depositional pattern from the time of initial Santa Fe deposition up until 7 Ma in the southwestern basin area. In this section, the older Santa Fe units in the oil test wells are discussed with the lower Santa Fe units studied in the Gabaldon and Bobo Butte areas.

The lower Santa Fe deposits in the southwestern basin area were derived from the west in the Lucero uplift area as evidenced by paleoflow indicators. Clast counts and sand petrology clearly show that the source area for these deposits consisted mainly of intermediate to silicic volcanic and Cretaceous rocks. None of these rock types are exposed in the Lucero uplift area today. The closest outcrops of these rock types occur in the Bear Mountains located about 50 km to the southwest. The small Oligocene volcanic units exposed along the north side of the Ladron Mountains are not considered a possible source because the paleoflow directions do not point to this area. Thus, there are two possible source areas for these deposits: 1) the Lucero uplift, and 2) the Bear Mountains.

A Lucero uplift source area would require that area to have once been covered by Oligocene volcanic and Cretaceous rocks, which have since been removed by erosion. Transport distance for these deposits would have been relatively short. A Bear Mountain source area would require a complex drainage system to deliver detritus from the Bear Mountains to the basin, perhaps over the Lucero uplift. Transport distance would have been quite long. Clast counts on conglomerate beds in the Gabaldon and Bobo Butte sections show very high percentages of intermediate to silicic volcanic and Cretaceous rocks with very little mixing with other lithologies. If the Bear Mountains were the source area, there would have been more of a chance for mixing with other lithologies. Also, the calcareous mudstone in the Bobo Butte section would not survive long transport and there is no evidence for a drainage system emanating from the Bear Mountains.

Therefore, the Lucero uplift seems to be the most likely source area for the lower Santa Fe deposits in the southwestern basin area. This implies that from the initial Santa Fe deposition until about 5 Ma, the Lucero uplift was covered by volcanic and Cretaceous rocks that were being rapidly eroded and contributing detritus to the basin. Deposition was occurring primarily along alluvial aprons and mudflat areas that extended from the Lucero uplift out into the basin. These deposits probably terminated in a playa system that was located in a large closed-depression in the south-central part of the basin. Deposition rates were fairly rapid during the 7-9 Ma interval as evidenced by the fossil record, however, these depositional rates were probably slower prior to this time when tectonic activity of the basin was less.

By about 5 Ma, or early unit-4 time for the Gabaldon section, the volcanic and Cretaceous rocks were removed from the Lucero uplift area. Unit 4 was deposited by a major braided fluvial system, an ancestral Rio San Jose or Rio Puerco. This indicates a major change in the depositional history of the southwest basin area when the basin went from closed basin drainage to through-flowing drainage. Unit-4 deposits were derived from a much larger variety of source terranes than the lower Santa Fe Group. These source terranes not only included intermediate-silicic volcanic and Cretaceous rocks, but also Paleozoic, metamorphic and granitic lithologies as well. Paleoflow indicators show a northwest source area. The only areas to the northwest that contain metamorphic and granitic rocks are the Zuni Mountains located about 100 km to the west and the Nacimiento Mountains located about 130 km to the north. This suggests that these ancestral drainages had headwaters in one or both of these areas and transported detritus derived from these various source terranes into the basin. Interbedded piedmont deposits in unit 4 further imply that the ancestral drainage was near the western basin margin. This ancestral river probably joined an ancestral Rio Grande in the south-central part of the Albuquerque basin.

Due to lack of age control, it is unknown if unit 2 of the Bobo Butte section is in the Sierra Ladrones Formation (like Gabaldon unit 4) or is a post-Santa Fe unit. Unit-2 deposits are probably 2 Ma or younger. If it is Sierra Ladrones, then it indicates that the Lucero uplift had lost its volcanic and Cretaceous cover by this time and was shedding detritus derived from lithologies that are similar to those exposed on the uplift today.

In summary, the Santa Fe Group deposits of the southwest basin area show a complex depositional history with source areas and drainage systems shifting through time. If the Santa Fe Group section in the oil test wells is added to the Gabaldon section, an accumulated rift basin-fill thickness of about 3,300 m is estimated for this part of the basin.

CHAPTER 6. SOUTHEASTERN ALBUQUERQUE BASIN

Introduction

Santa Fe Group outcrops in the southeastern basin area occur mainly at or near the base of the Manzano Mountains. Two outcrop areas and two oil test wells, the Grober Fuqua No. 1 and Transocean Isleta No. 1, were studied in detail. The wells penetrate the Santa Fe section and bottom in Mesozoic and Precambrain strata, respectively. Locations for these outcrops and oil test wells studied are shown on Plate 1.

Few studies have focused on the Santa Fe Group outcrops in the southeastern basin area. Reiche (1949) mapped the Manzanita and northern Manzano Mountains concentrating primarily on the bedrock exposed in the Manzano Mountains. He mapped the Santa Fe Group exposed along the base of the uplifts. Santa Fe outcrops just west of Trigo Canyon were mapped by Myers and McKay (1972). As part of his basin-wide study, Kelley (1977) mapped the entire western piedmont area of the eastern uplifts. Machette (1978b) also mapped the southeastern basin area and separated the Santa Fe Group into the Sierra Ladrones and Popotosa Formations.

Outcrop Areas

The two outcrop areas studied are near Trigo Canyon and in an area located about 5 km south of Trigo Canyon (Plate 1). Geologic mapping of these areas is shown on Plate 5. Unit descriptions and depositional environments of each area are disscussed separately, but the sand petrology and provenance of the two areas and oil test wells are discussed together.

Trigo Canyon

Santa Fe Group outcrops associated with the Trigo Canyon area are located in the southwest corner of the U.S.G.S. Capilla Peak 7.5 minute quadrangle, just west of Canon del Trigo. Exposures are not extensive and occur within arroyo bottoms and along ridge slopes of the deeply-incised piedmont area (Plate 5). Within these exposures, Santa Fe beds dip westward. Faulting was observed in these beds, but the extent of these faults is unknown because of limited exposure. This area mostly lies on private land, although some outcrops can be observed along the gravel county road that leads to John F. Kennedy campground in Trigo Canyon.

Triassic bedrock is poorly exposed at the eastern end of the dissected piedmont slope (Plate 5). These west-dipping beds are probably Chinle Formation (Dockum Group) and consist of dark red to purplish red mudstone and sandstone. The Manzano fault (Kelley, 1977) is the major range-bounding fault for the Manzano Mountains and it lies buried just east of the Triassic exposures. The contact between the Triassic beds and the Santa Fe Group is covered by colluvium. The Santa Fe outcrops can be divided into lower and upper units.

The lower unit consists of white (10YR 8/1) to pinkish gray (7.5YR 7/2), moderately to poorly sorted, locally crossbedded, weakly indurated, fine- to very coarse-grained sand with scatterd pebbles and cobbles. Clay and silt interbeds are rare. Matrix-supported pebble lenses and pumiceous zones also occur. Clasts are subangular to subrounded and are composed of about 90% rhyolite, ash-flow tuff and basaltic andesite with the remaining 10% comprised of chert, quartz, red sandstone, granite, and schist. These deposits notably lack clast types derived from the adjacent Manzano uplift.

Included within the lower unit is a 6-7 m thick, black, amygdaloidal basalt that has a K-Ar date of 21.2 ± 0.8 Ma (Bachman and Mehnert, 1978). There are two interpretations as to the origin of the basalt. Kelley and Kudo (1978) reported the basalt to be a dike or sill. Bachman and Mehnert (1978) interpret it to be a flow. Field evidence shows that the basalt: 1) is concordant with the lower unit; 2) contains a vesiculated top and a brecciated bottom; and 3) lacks a bake zone at the top. Therefore, the basalt is considered a flow in this investigation. On close examination, it appears that the basalt contains 2 or 3 flow units. Myers and McKay (1972) incorrectly show the location of the basalt on their map; it should be located in the larger canyon to the south as shown on Plate 5.

Based on moderate to poor sorting, crossbedding, and paucity of clay beds, the lower unit was deposited primarily by streams and possibly debris-flows. Some beds may also be of eolian origin. The limited outcrops make further interpretation difficult. Imbricated clasts suggest a possible paleoflow direction from the south and southeast. Kelley (1977) mapped these beds as the Datil Group; however, Machette (1978b) referred to them as the Popotosa Formation. The age of the basalt flow indicates that these deposits are of the lower Santa Fe and equivalent to the Popotosa Formation. These are some of the oldest dated Santa Fe Group deposits in the Albuquerque basin.

The upper unit rests with an angular unconformity on the lower Santa Fe beds and is relatively undeformed, except perhaps near the Manzano and Hubble Springs faults. The upper unit consists of poorly to very poorly sorted, cobble to bouldery conglomerate that is locally cemented with calcium carbonate. Thickness of this unit may be as much as 60 m. Clast types directly reflect derivation from the Manzano uplift and include quartzite, schist, metarhyolite, and gneiss. Angular to subrounded boulders are up to several meters in diameter. This unit caps the piedmont ridgetops and contains a strong calcic soil in the uppermost beds.

These very coarse sediments were deposited in a proximal alluvial fan area mainly by debris-flows. The poor sorting, angularity and size of the clasts clearly support this interpretation. Imbricated clasts show a strong flow direction from the east. These deposits are probably part of the Sierra Ladrones Formation. Machette (1978b) also mapped these deposits as Sierra Ladrones.

South Trigo Canyon Area

These deposits are located in the southeast corner of the U.S.G.S. Tome NE 7.5 minute quadrangle (Fig. 6-1). Similar to the Trigo Canyon outcrops, these units crop out along ridge slopes in a elevated piedmont area adjacent to the Manzano uplift (Plate 5). No measured sections were attempted because of the discontinuous nature of the outcrops. Beds typically dip eastward, except near the Manzano fault where they dip westward. Only the Manzano fault was observed in outcrop, if others occur, they are buried. Access into this area is restricted due to private ownership. These exposures can be divided into three units.

The first unit is exposed on the east side of the piedmont area and west of the Manzano fault. These deposits consist of light reddish brown (5YR 6/4) to reddish brown (2.5YR 5/4), moderately to well indurated, poorly sorted conglomerate with minor silt and sand interbeds. Poorly

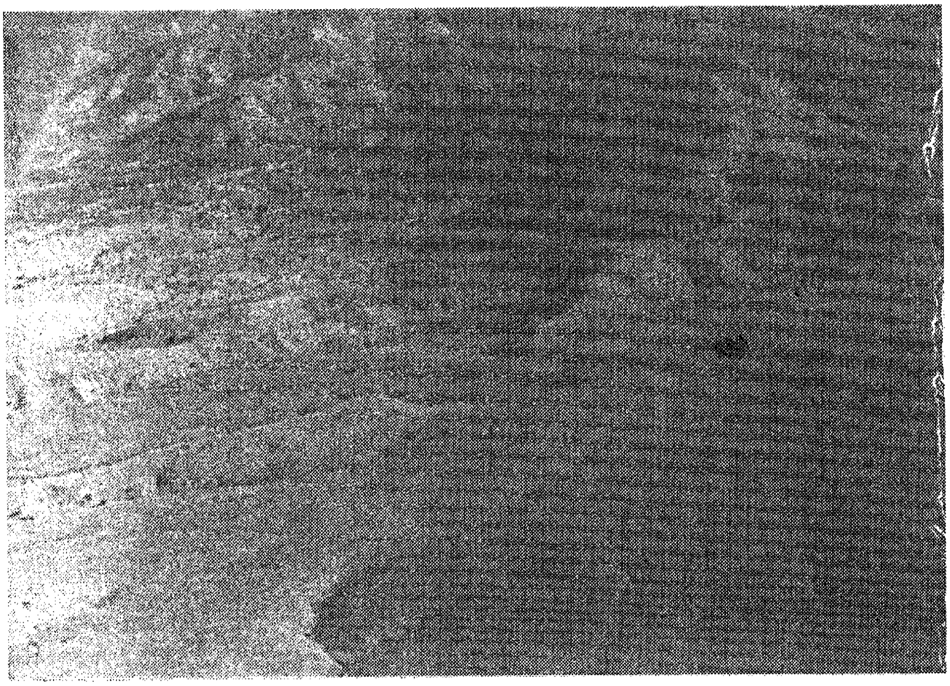


Figure 6-1. Aerial view, looking northeast, of the south Trigo Canyon outcrops along the base of the Manzano Mountains.

defined conglomerate beds are 60-90 cm thick and both matrix- and clast-supported. Angular to subrounded clasts are up to boulder-size and strongly imbricated. Table 6-1 shows clast types and their percentages. Note the abundance of red Abo sandstone. It is within this unit, near the head of the small canyon, that dips of beds abruptly change, perhaps indicating a fault (Plate 5).

The second unit crops out west of unit 1 and apparently overlies it, although the contact is not exposed. A fault may separate the two units, but there is no field evidence to suggest this because dips of beds do not abruptly change across the contact area. Most of the unit is comprised of weakly to moderately indurated, moderately to well sorted, locally crossbedded, pink (7.5YR 7/6) to light reddish brown (5YR 6/4), fine- to coarse-grained sand with scattered pebbles and cobbles. Sand beds are massive to laminated, up to 2 m thick and show fining upward sequences in a few outcrops. Conglomerate beds and lenses, up to 90 cm thick, also occur. Clasts within the conglomerate and scattered in the sand are subangular to subrounded, imbricated and up to cobble-size. Major clast types include limestone, quartzite, light-colored sandstone, and basalt (Table 6-1). Osburn (pers. comm., 1986) interprets some of the ash-flow tuff clasts to possibly be La Jencia Tuff from the Mogollon-Datil volcanic field. Silt and clay interbeds are not common in these outcrops, perhaps because they are

Table 6-1. Clast counts for Baca/SFG? and Popotosa Formation deposits. Based on 50 counts.

	Baca/SFG?	Lower Popotosa	Lower Popotosa
Rhyolite, Ash flow tuff	--	7	4
Andesite	--	--	--
Basalt	--	13	20
light-colored sandstone (Bernal?)	10	20	18
Red sandstone (Abo)	66	8	2
Petrified Wood	--	--	--
Limestone	24	22	24
Shale	--	--	--
Chert	--	--	--
Granitic	--	4	4
Schist	--	2	--
Quartzite	--	24	28
Quartz	--	--	--
Santa Fe Gp	--	--	--

preferentially eroded and buried.

The poor sorting and massive-nature of unit 1 suggest that these sediments are probably debris-flow deposits that were laid down in the medial to proximal area of an alluvial fan system. Clast imbrications show a strong paleoflow out of the east (Fig. 6-2). Unit-2 beds are more fluvial as evidenced by the better sorting, crossbedding, and fining upward sequences. The well sorted, fine-grained sand beds may be eolian. Weak clast imbrications suggest a paleoflow direction from the south and southeast (Fig. 6-3).

Both of these units were previously mapped as the Baca Formation by Kelley (1977) and Machette (1978b). Unit 1 (referred to as Baca/SFG?) could be part of the Baca Formation or it could be an older Santa Fe Group unit. At this time, this is an unresolvable problem because of the lack of datable material and poor stratigraphic control. Unit-2 deposits, however, are definitely not part of the Baca Formation because of the volcanic clasts that post-date the Baca. These deposits are correlated with Popotosa Formation deposits and are probably correlative with the lower Santa Fe units exposed in the Trigo Canyon area.

Unit 3 caps the piedmont ridges and overlies units 1 and 2 with an angular unconformity. This unit is up to 10 m thick and is lithologically similar to the upper unit that caps the ridges in the Trigo Canyon area. The coarseness, poor sorting, and geomorphic setting of this unit indicate

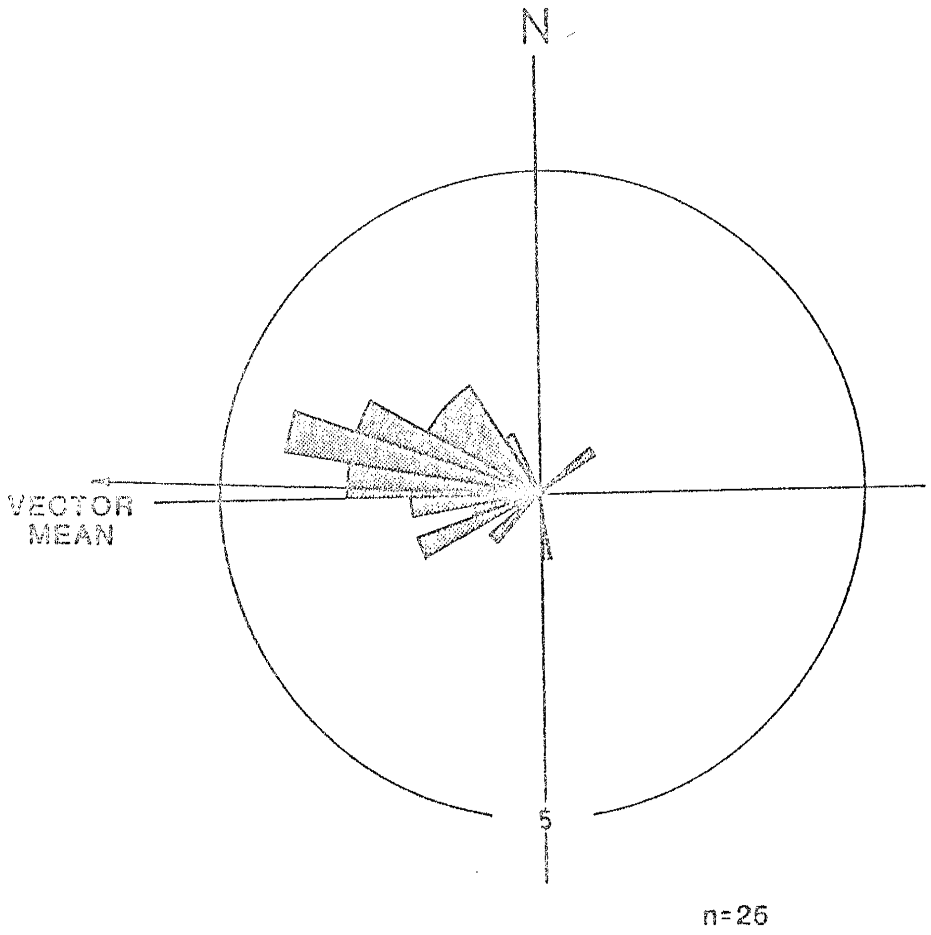


Figure 6-2. Rose diagram indicating paleoflow direction for Baca/SFG? deposits in the south Trigo Canyon area.

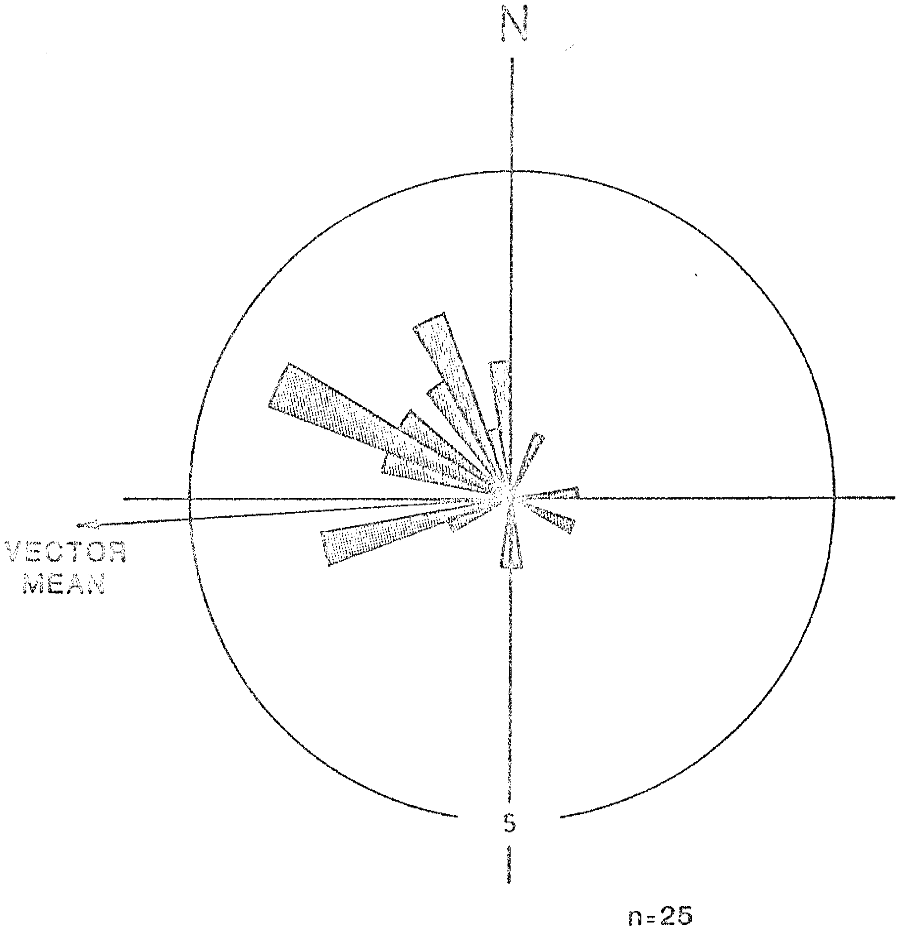


Figure 6-3. Rose diagram indicating paleoflow direction for unit 2 (Popotosa Formation) in the south Trigo Canyon area.

that it is a proximal alluvial-fan deposit. Like the upper unit in the Trigo Canyon area, this unit is part of the Sierra Ladrones Formation.

Oil Test Wells

Cuttings from the two oil test wells are examined in this section. Their locations are shown on Plate 1. Both wells report gas shows, but were abandoned (Black, 1982).

Grober Fuqua No. 1

This well has two completion dates. It was first completed in 1940 to a depth of 1,212 m and then redrilled in 1946 to a total depth of 1,920 m (Fig. 6-4). Cuttings were examined from 799 m to the bottom of the well. No cuttings were available above 799 m. Several side-hole core samples from various levels within the well were used in conjection with the cuttings.

From 799 m down to 1,082 m, the Santa Fe section shows a general fining downward sequence from weakly indurated, very coarse-grained sand with minor silty sand and clay interbeds to fine- to medium-grained sand and clay interbeds. Color typically ranges from light brown (7.5YR 6/4) to pink (5YR 7/3). Sand grains are poorly to moderately sorted and up to granule-size near the top of the well. At 1,082 m, interbedded, light reddish brown (5YR

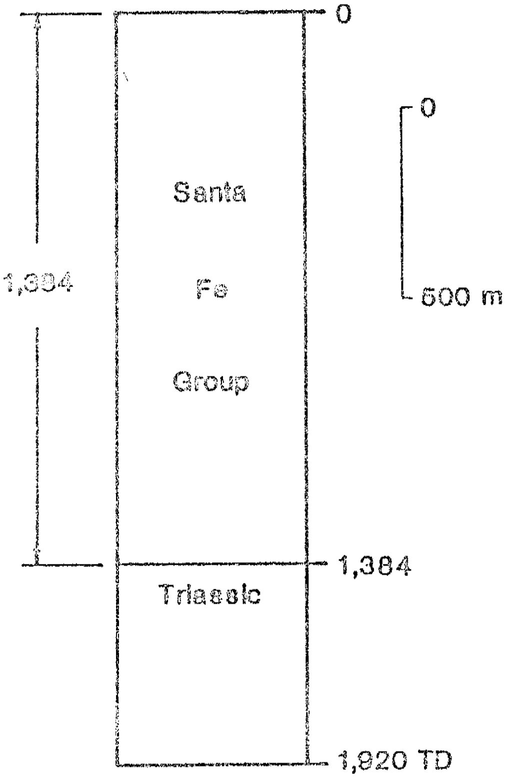


Figure 6-4. Stratigraphic column for Grober Fuqua No. 1 showing unit tops and thicknesses. All measurements in meters.

6/3) to red (2.5YR 5/6) clay, silty sand, and fine-grained sand dominate the section down to 1,384 m. A major color and texture change occurs at this depth, which marks the bottom of the Santa Fe.

At 1,384 m, beds become dusky red (10R 3/2) to pinkish gray (7.5YR 7/2), moderately to well indurated sandstone and claystone. Sandstone is fine- to medium-grained and micaceous. Foster (1978) interpreted this part of the section to represent the Baca Formation and Reiche (1949) believed it to be Upper Cretaceous and possibbly Triassic. However, core samples from this unit are almost identical to rocks mapped as Triassic by Kelley (1977) that are exposed along the Hubble Bench escarpment and just west of Trigo Canyon. The present study supports correlation with part of the Triassic section. No pre-Santa Fe Tertiary rocks are recognized below the Santa Fe section.

Transocean Isleta No. 1

The Transocean Isleta No. 1 was completed in 1978 after reaching a total depth of 3,163 m in Precambrain strata. Cuttings were examined from the top of the well down to a depth of 1,936 m. The bottom level is well within the Cretaceous section. No core samples were available from this well.

The Santa Fe section extends down to 1,536 m (Fig. 6-5). These deposits consist predominantly of fairly clean,

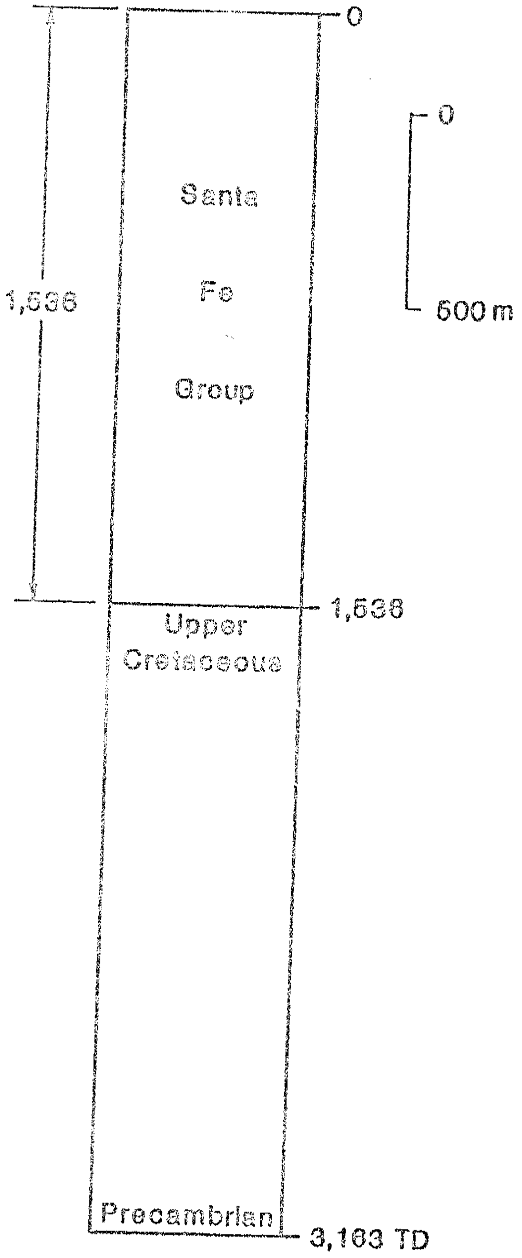


Figure 6-5. Stratigraphic column for Transocean Isleta No. 1 showing unit tops and thicknesses. All measurements in meters.

moderately sorted, light yellowish brown (10YR 6/3) to pink (7.5YR 8/4), medium to coarse-grained sand with very minor silt and silty sand interbeds. The sand beds are weakly indurated and contain up to pea-size gravel, including quartz, chert, and schist (?). Between 591 and 701 m, the section consists mostly of light reddish brown (5YR 6/3), silt and silty sand interbeds. Induration is moderate near the bottom of the Santa Fe section.

Similar to the Grober Fuqua well, no pre-Santa Fe Tertiary deposits are present. The Santa Fe rests directly on Upper Cretaceous sandstone and claystone interbeds at a depth of 1,535 m. The contact is recognized by a sharp color change in the cuttings. These beds are comprised of well indurated, gray to dark gray claystone and fine- to medium-grained sandstone. Coal seams were encountered at depths of 1,676 and 1,874 m.

Sand Petrology

Eighteen thin sections were point counted from the southeast basin area. These include: 12 from the Santa Fe Group, 2 from the Baca/SFG?, 2 from the Upper Cretaceous, and 2 from the Triassic. Four of the Grober samples are side-hole core samples (designated by GC). The alluvial-fan facies of the Sierra Ladrones Formation was not studied in thin section. Point count results are tabulated in Appendix

II and plotted on the ternary diagrams in Figs. 6-6 and 6-7. Sand grains are poorly to well sorted, weakly to well indurated, angular to subrounded, and fine- to medium-grained. Most samples are at least partly cemented with calcium carbonate and some grains have clay rims.

Santa Fe Group

The average sand grain composition ranges from 69.6% quartz, 24.0% feldspar, and 6.4% lithic fragments in the Grober well samples to 54.8% quartz, 26.0% feldspar, and 19.2% lithic fragments in the Transocean samples. Lower Santa Fe Group outcrop samples (TC-1 and TC-2a) contain lower quartz percentages (24 and 30%) and higher lithic fragment percentages (38 and 28%). Feldspar percentages are also higher (38 and 42%). Santa Fe samples classify as arkose, subarkose, and feldspathic litharenite (Folk, 1974). Note the similarity between Transocean sample TO-050 and the Cretaceous samples (see Fig. 6-7).

Monocrystalline quartz (Qm) is the dominant grain in all but one sample (TO-016). Quartz in the Santa Fe samples are typically clear and show straight extinction. Chert is the major polycrystalline quartz, but tectonic polycrystalline quartz occurs in higher percentages than Santa Fe samples from other parts of the Albuquerque basin, especially in the Grober samples above the 1,372 m level. The Qp/Q ratios are higher in the well samples (>0.1) than

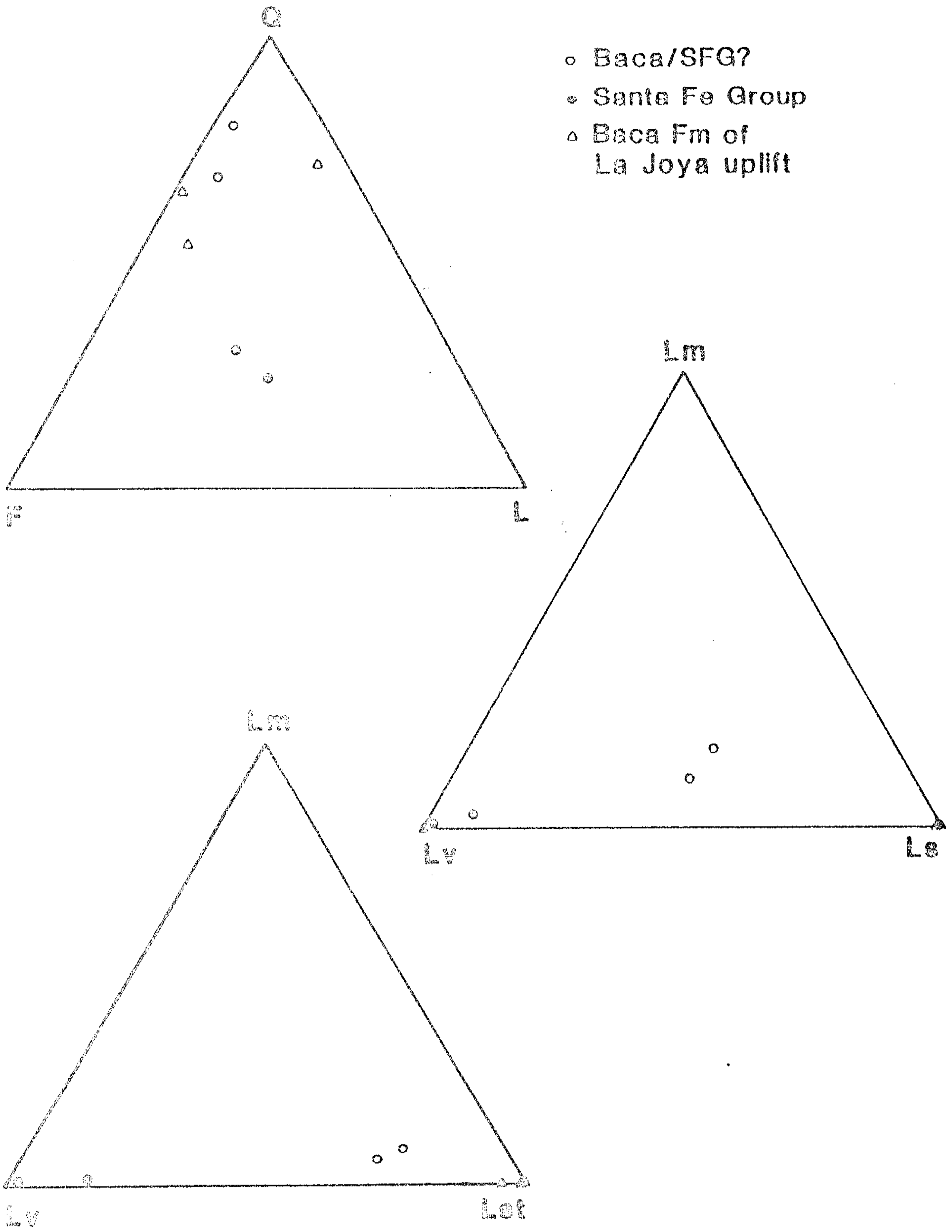


Figure 6-6. Ternary diagrams for Trigo Canyon outcrop areas.

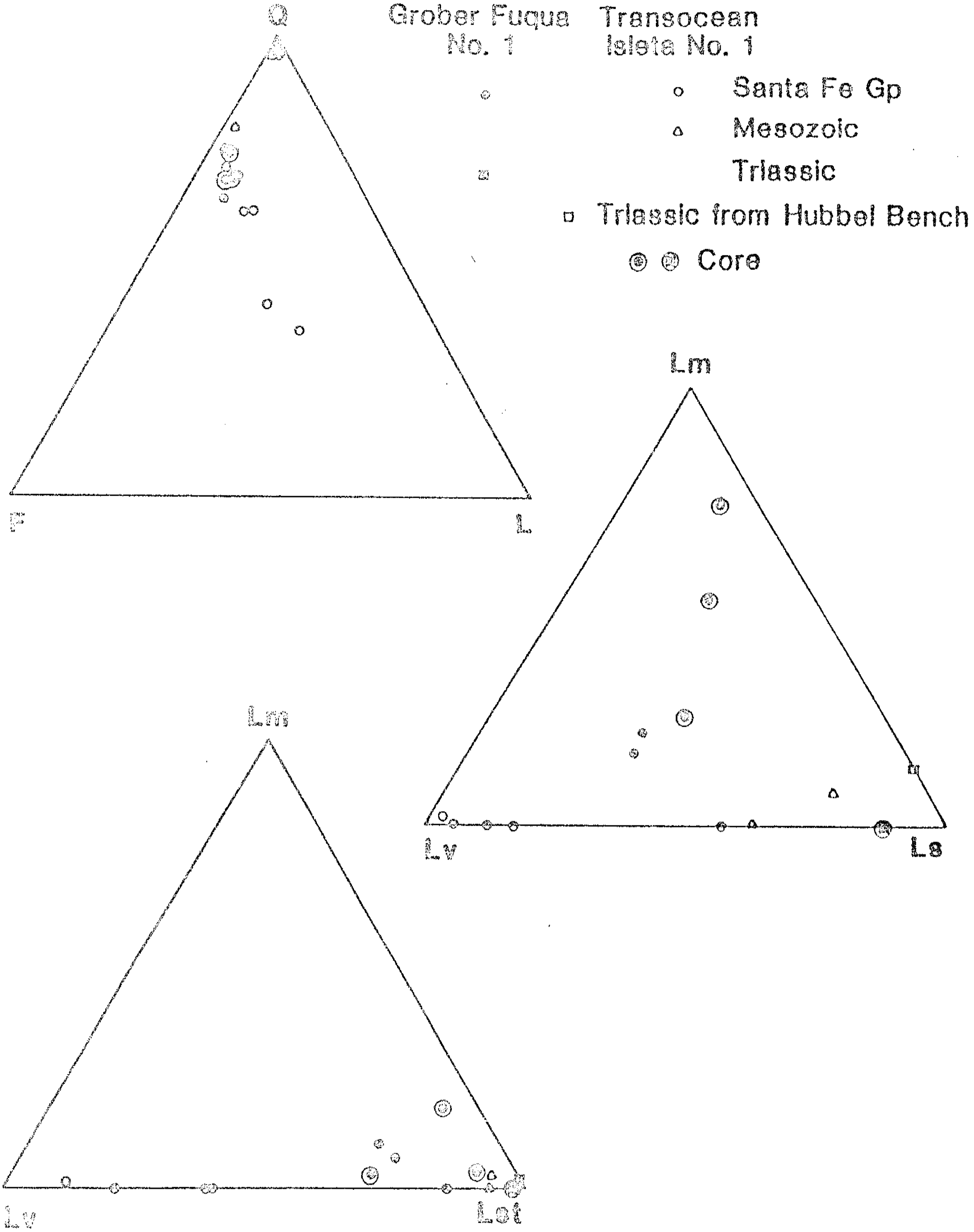


Figure 6-7. Ternary diagrams for Grober Fuqua No. 1 and Transocean Isleta No. 1.

the outcrop samples (<0.1).

Upon examining the QFL plots (Fig. 6-7), there is little change in quartz percentage with depth in the Grober well; however, there is a significant increase in quartz percentage with depth in the Transocean well. The clustering of points on the ternary diagram for the Grober well may at least be partially due to the limited sample interval. Transocean and Grober samples from about the same depth plot in similar fields (see Fig. 6-7).

Overall, plagioclase is dominant in the outcrop samples, but feldspar percentages are about equally divided between plagioclase and potassium feldspar in the well samples. The P/F ratio averages 0.58 in the Grober well and 0.55 in the Transocean well; whereas, in the outcrop samples these ratios are 0.83 and 0.73. The ratios vary little with depth in the Transocean and Grober wells. Plagioclase, both as detrital grains and as phenocrysts in lithic fragments, range in composition from albite to labradorite (determined by Michel-Levy method). These grains are usually twinned and occasionally display oscillatory zoning. Orthoclase is the most common potassium feldspar. Sanidine occurs more frequently lower in the wells and in the outcrop samples. Microcline percentages greatly increase above 1,372 m in both wells. Feldspar percentages vary little with depth (Fig. 6-6 and 6-7).

Lithic fragment percentages in the Santa Fe section are lower in the Grober well than in the Transocean well. The two Santa Fe outcrop samples contain very high lithic fragment percentages. Metamorphic-lithic fragments (primarily schist) are the most common lithic grain in the Grober well in samples above a depth of 1,219 m. Below this level, volcanic- and sedimentary-lithic grains are dominant. In the outcrop samples, volcanic-lithics comprise most of the lithic grains (>85%). The volcanic-lithic grains range in composition from silicic to mafic, but most are silicic to intermediate. Both microlitic and porphyritic textures occur. A few plutonic-lithic grains were also noted in samples above the 1,219 m level, but metamorphic-lithic fragments are more common.

In the Transocean well, volcanic-lithic fragments are the major lithic grain in all Santa Fe samples averaging 81.8%. Sample TO-050, however, shows a higher sedimentary-lithic fragment percentage (56%) than volcanic-lithic (44%). The volcanic-lithics are similar to those in the Grober well. Although metamorphic-lithics were virturally absent in the point counting, a few metamorphic-lithic grains along with some gneissic and/or plutonic lithics were observed in samples above 1,372 m. Plutonic-lithic fragments occur in higher percentages than metamorphic-lithic fragments. This is opposite from the Grober well.

Baca/SFG?

The two Baca/SFG? samples (TC-3 and TC-5a) contain high quartz percentages (67 and 79%) and low lithic fragment percentages (7 and 4%). Feldspar percentages are 26 and 17%. These samples classify as arkose and subarkose (Folk, 1974). Sand grains in the Baca/SFG? samples generally show poorer sorting, better rounding and better cementation with calcium carbonate.

Quartz, mainly monocrystalline, are mostly clear, show straight extinction, and commonly contain overgrowth rims. Chert and tectonic polycrystalline grains are more abundant than in the Santa Fe samples. Potassium feldspar is the dominant feldspar with P/F ratios of 0.25 and 0.20. Microcline is the chief potassium feldspar. Sedimentary-lithic fragments are the major lithic fragment; volcanics are rare. Sedimentary-lithic fragments are mainly silt and clay. These samples contain low metamorphic-lithic fragments, but a few plutonic grains were noted. Some grains show some degree of alteration.

One way to help resolve the Baca/SFG? question is to compare the petrology of this unit with the petrology of known Baca Formation samples. The closest occurrence of Baca Formation outcrops is in the Joyita uplift, located about 50 km to the south. Johnson (1978) point counted three samples from these outcrops. His point count results are in Appendix II and these data have been plotted on Fig.

6-6. As seen on the ternary diagrams, Baca/SFG? samples are similar petrographically to the Baca samples. Both contain high quartz percentages and low lithic fragment percentages, especially volcanic-lithics. These samples are also similar petrographically to the Galisteo Formation samples from the Isleta #2 oil test well. Although the Baca/SFG? samples are similar to the Baca deposits, it is still inconclusive if these deposits are Baca because of limited stratigraphic control and no datable material.

Upper Cretaceous and Triassic

Sand grain compositions in the Cretaceous samples are 75 and 80% quartz, 22 and 18% feldspar, and 3 and 2% lithic fragments. The Triassic sample contains 97% quartz, 1% feldspar, and 2% lithic fragments. Cretaceous samples classify as subarkose and the Triassic sample is a quartz arenite (Folk, 1974).

In these samples, monocrystalline quartz is the most abundant grain. These grains exhibit more overgrowth rims, more embayments, and better rounding than the Santa Fe samples. Qp/Q ratios are similar to those in the Santa Fe samples. Cretaceous samples have about equal percentages of plagioclase and potassium feldspar (both at 0.51). Triassic samples contain very little total feldspar (1.0%). Both groups contain low lithic fragment percentages. Upper Cretaceous samples contain mainly sedimentary-lithic and minor volcanic-lithics.

A thin section was also point counted from the Triassic outcrop sample discussed in the oil test well section. The point count results of this sample are in Appendix II and plotted on Fig. 6-7. These point count results are almost identical to those from the Grober well Triassic sample. Both contain very high quartz percentages and low feldspar and lithic percentages. This further supports the interpretation that the deposits below 1,384 m in the Grober well are Triassic.

Provenance

The Baca/SFG? deposits were derived overwhelmingly from a source area containing Upper Paleozoic sedimentary units. Clast types in outcrop and sand grains in thin section strongly support this interpretation. Paleoflow indicators show that the source area was located to the east.

The lower Santa Fe units in the outcrop areas were derived from several source areas. The abundant volcanic clasts in outcrop and high volcanic-lithic and plagioclase percentages in thin section give convincing evidence for a volcanic source area. These volcanic-lithics ranged in composition from silicic to mafic. The source area may have contained Datil and post-Datil Group rocks as evidenced by the occurrence of La Jencia Tuff clasts in these deposits.

Sandstone and limestone clasts and high quartz percentages in thin section indicate that a sedimentary source terrane was another important contributor. Both metamorphic and plutonic source terranes provided detritus as well to the lower Santa Fe deposits. Clasts of both types are found in outcrop. Paleoflow indicators suggest that these source areas were to the south and southeast.

The lower Popotosa deposits in the oil test wells (those below a depth of 1,219 m) were derived primarily from two source areas in the Transocean well and possibly three in the Grober well. The LmLvLst diagrams (Figs. 6-6 and 6-7) best show this interpretation. The abundant volcanic-lithic fragments and plagioclase indicate a source area comprised of silicic to mafic volcanic rocks. A sedimentary source area is strongly indicated by the sedimentary-lithic fragments and chert. This is very evident in the Transocean samples where the point count plots track directly toward the Cretaceous samples with increasing depth. It appears that sample TO-050 was derived almost exclusively from reworked Cretaceous sedimentary rocks. The Grober well samples also suggest a minor metamorphic source area due to the presence of metamorphic material.

The upper Popotosa samples in the oil test wells clearly show that a metamorphic/plutonic source terrane became an important contributor in addition to the volcanic and sedimentary source areas. The metamorphic source is strongly suggested by metamorphic-lithic fragments and tectonic polycrystalline quartz. Plutonic-lithic fragments and an increase in the amount of microcline and perthite in these samples lend support for a plutonic source area, especially in the Transocean well. The volcanic and sedimentary source areas are supported by the abundance of these rock fragments and chert. Eventually, the volcanic source area became dominant as evidenced by the extremely high volcanic-lithic percentages in Transocean samples above the 600 m depth in the well. It is not known if this is true for the Grober samples because there are no cuttings from the upper part of the well.

No paleocurrent data is available from the wells. However, if the lower Popotosa deposits in the wells are correlative with the Trigo and south Trigo Canyon outcrops, they may have been derived from the south and southeast and are primarily fluvial in origin. The reworked Cretaceous material in the Transocean well may represent detritus deposited in a proximal piedmont-fan area.

The upper Popotosa deposits show a shift to a more metamorphic source, especially in the Grober well. This source area was probably to the east. These deposits recorded the uplift and initial erosion of Precambrian metamorphic/plutonic rocks in the Sandia-Manzano uplift. In the case of the Grober well, there may have been mixing of detritus as fluvial systems from the south and southeast were joined by a piedmont-fan system emanating from the east.

The deposits in the Transocean well show a stronger volcanic source than a metamorphic source. Most of these deposits were probably derived from a source area different than the Grober well, perhaps from the north. The lack of fine-grained deposits and the better sorting in the Transocean samples suggest that these deposits are fluvial. Thus, the Transocean samples may represent a mixing of detritus from the east and north, rather than the east and south.

Only one source area contributed detritus to the Sierra Ladrones Formation in these outcrops. This source area was comprised almost exclusively of Precambrian metamorphic rocks. Imbricated clasts show that these deposits were derived from the east and the size and sorting of these deposits suggest a short transport distance.

Depositional History of the Southeast Basin Area

It is unclear if Eocene deposition occurred in the southeast basin area because of the age uncertainty for the Baca/SFG? outcrops and the poor well control south of the Grober well. No Eocene deposits were recognized in the cuttings of the two oil test wells. Regardless of their age, the Baca/SFG? deposits record an early unroofing episode of the Manzano uplift that stripped-off the late Paleozoic cover whether it was during the Eocene or Late Oligocene-Early Miocene. These units were deposited in the proximal area of piedmont fans. Baca deposits may underlie the Santa Fe Group in the southernmost basin area, but this cannot be demonstrated because of the uncertainty of the lower units in the Central New Mexico Brown-Livingston well (well discussed in Central Basin chapter).

No pre-Santa Fe Tertiary rocks were recognized in the outcrops or oil test wells except for the possible Baca Formation outcrops south of Trigo Canyon. Thus, these units either were never deposited in this part of the basin or, if deposited, they have been removed by erosion. However, Oligocene volcanics that overlie the Datil Group are exposed in the southernmost part of the basin near Black Butte and Datil Group rocks may occur very near the surface (Osburn, pers. comm., 1986). Black Butte is located about 15 km east of Bernardo (Plate 1). These rocks also crop out along the northern base of the Ladron Mountains (Machette, 1978b). Since these rocks occur on either side of the southern basin area, it is reasonable to assume that they may lie buried beneath the Santa Fe Group within the basin. Again poor well control prohibits testing this hypothesis.

If the Baca/SFG? deposits are Santa Fe in age, then they probably are the oldest Santa Fe units in the southeast basin area. If not, the lower Popotosa deposits are the oldest dated Santa Fe units in this part of the basin. The lower Popotosa deposits in the Trigo Canyon and Grober well areas indicate that this region was receiving sediments from the south and southeast about 22 Ma (earliest Miocene). Primarily, Datil Group (volcanic and volcaniclastic) and pre-Datil sedimentary rocks were being eroded from the source areas. The Joyita uplift was most likely the source because these rock-types are exposed in this area. Fluvial systems delivered the sediments and probably deposited them in an alluvial plain environment.

Source areas for lower Popotosa deposits in the Transocean well appear to have been different than the source areas for the outcrop and Grober well areas. The dominance of reworked Cretaceous strata at the bottom of the Santa Fe section suggest that earliest Santa Fe deposition in the Transocean well area was locally derived, perhaps from the east where Cretaceous and possibly early Tertiary rocks may have been exposed along an early Hubble Bench fault scarp. The eroded Cretaceous detritus was transported a short distance and deposited in a piedmont fan area. Later, volcanic detritus began mixing with the reworked sedimentary material and eventually became the dominant source area late in lower Popotosa time. It is not certain from where the volcanics were derived, perhaps from the north.

Upper Popotosa deposition probably began 10-12 Ma when tectonic activity of the basin became most active resulting in the uplift and eventual exposure of Precambrian rocks in the Sandia-Manzano uplift. Upper Popotosa deposits in the two wells record the initial influx of Precambrain strata into the Albuquerque basin. However, the Grober well deposits indicate a different Precambrian source area than the Transocean well deposits. The Grober well upper Popotosa deposits contain more metamorphic-lithics (mainly schists) than plutonic-lithics; whereas, the Transocean upper Popotosa deposits contain more plutonic-lithics than metamorphic-lithics. This is interpreted to indicate that the Precambrian component of the Grober well deposits were derived from the Manzano uplift were the metamorphic rocks are dominant over plutonic rocks. The Transocean Precambrian component is believed to be derived from the Sandia uplift where plutonic rocks are much more abundant than metamorphic rocks. Sheet 1 in Condie and Budding (1979) shows this relationship between the Precambrian strata.

Therefore, upper Popotosa deposits in the Grober well were derived from the newly elevated Manzano uplift and also from the Joyita uplift area to south. Basin-floor fluvial systems originating in the Joyita uplift were probably being joined with piedmont alluvial fans that were delivering Precambrian detritus from the east. On the other hand, the upper Popotosa Transocean deposits were derived from the north and transported by basin-floor fluvial systems that were receiving detritus from alluvial fans emanating from the Sandia uplift. The fluvial systems from the north were carrying mainly volcanic and reworked sedimentary material probably derived from outside the Albuquerque basin to the north and northeast. Possible source areas include the Jemez uplift, Cerrillos Hills and Los Pinos uplift area. Upper Popotosa sedimentation continued until about 5 Ma.

Deposition after 5 Ma is represented by the Sierra Ladrones Formation deposits in the Trigo Canyon area. These units unquestionably show that they were derived from the Manzano uplift and deposited in a proximal piedmont-fan area. Although not clearly distinguishable from the upper Popotosa deposits on the basis of sand petrology, the Sierra Ladrones Formation units in the Transocean well are very coarse and were deposited by a large fluvial system. Sierra Ladrones outcrops that occur near the well are ancestral Rio Grande deposits derived from outside the Albuquerque basin to the north. These deposits are the same type described in the Bernardo section.

The depositional history of the southeast basin area shows that early Santa Fe deposits were derived from the south, perhaps in the Joyita uplift area. Some sediments may have also originated more locally and from the north in the Transocean well area. By 10-12 Ma, Precambrain detritus derived from the Sandia-Manzano uplift were being deposited in the basin along with detritus derived from the north and south. At about 5 Ma, large alluvial fans had formed at the base of the Manzano uplift consisting of Precambrian detritus and the ancestral Rio Grande was depositing sediments on the basin-floor in the Transocean well area.

CHAPTER 7. NORTHERN ALBUQUERQUE BASIN

Introduction

Basin-fill outcrops in the northern basin area have been the focus of more stratigraphic studies than any other area in the Albuquerque basin. These studies have influenced most of the concepts concerning basin-fill stratigraphy of the Rio Grande rift. In this investigation, outcrops on the King Ranch and samples from four oil test wells were examined. The oil test wells are: 1) Carpenter Atrisco No. 1; 2) Shell West Mesa Federal No. 1; 3) Shell Santa Fe Pacific No. 1; and 4) Shell Santa Fe Pacific No. 3. Plate I shows the locations of the King Ranch and oil test wells.

Outcrops in the northwestern basin were the subject of Bryan and McCann's (1937; 1938) pioneering work on the stratigraphy of basin-fill exposed along the northern Ceja del Rio Puerco and western Rincones de Zia (Plate 1). Their original subdivisions of the Santa Fe "Formation"; Lower Gray, Middle Red, and Upper Buff Members, are still used by many workers to generally describe the basin fill. Wright (1946) extended these subdivisions southward from the King Ranch area into the lower Rio Puerco region. Stratigraphic subdivisions from the above studies and from the studies discussed below are shown on Table 1-1.

North of the King Ranch, Galusha (1966) undertook the first detailed studies of vertebrate fossils and biostratigraphy in the Lower Gray and Middle Red type area. Galusha formally defined the Lower to Middle Miocene Zia Sand Formation and demonstrated that it correlated with the Lower Gray member. However, he did not include the Zia Sand in the Santa Fe Group (Galusha and Blick, 1971). Campbell (1967) mapped the Santa Fe using Bryan and McCann's subdivisions in the central Rio Puerco fault belt; and Slack (1973) mapped the Zia Sand Formation of Galusha (1966) along the northwestern part of the Rio Puerco fault zone.

Gawne (1973; 1981) examined in detail the stratigraphy, sedimentology and sand petrology of the Zia Sand in Galusha's type area and on the King Ranch where considerable work by Galusha is still unpublished. Age relationships between Santa Fe units in the northern basin area are discussed by Tedford (1981). Ongoing research by Drs. Richard Tedford and Steve Barghoorn of the American Museum of Natural History involves expanding Galusha's and Gawne's work at the King Ranch. Tedford (1982) gives an excellent historical review of stratigraphic studies in the northwest basin area.

Basin-fill studies in the northeastern Albuquerque basin and adjacent parts of the Santo Domingo and southern Espanola basins include Soister (1952), Stearns (1953), Anderson (1960), Spiegel (1961), Lambert (1968), Hoge (1970), and Manley (1978). Importantly, these workers were able to correlate units recognized in the northern Albuquerque basin with units in their respective study areas. Stearns (1953) work is the definitive and most detailed early effort on the middle and late Cenozoic history of the northeastern basin area.

Spiegel (1961) mapped the basin-fill exposures in the Jemez River Valley from the eastern limit of Bryan and McCann's (1937; 1938) Ceja del Rio Puerco area to the Rio Grande Valley near San Felipe Pueblo, and he was the first to use modern Santa Fe Group terminology and concepts in the Albuquerque basin. He broadly correlated his mapping units with Bryan and McCann's three subdivisions and incorporated some map-unit concepts developed by Soister (1952) in the area north of the Jemez River. The interfingering relationships between rocks of the Jemez volcanic field and the basin-fill of the northern Albuquerque and Santo Domingo basins were described and mapped by Bailey et al. (1969) and Smith et al. (1970). Specifically in the Albuquerque basin, they retained usage of Galusha's Zia Sand and Santa Fe Formation and demonstrated that at least part of the Upper Buff is equivalent to their Cochiti Formation (Bailey et al. (1969). New radiometric dates and recent mapping have enabled Gardner et al. (1986) to better define upper Cenozoic stratigraphic units near the northeastern margin of the basin.

Part of Spiegel's area, the U.S.G.S. 7.5 minute

Bernalillo NW quardrangle, was remapped by Manley (1978). In this area, she noted only minor differences between the Zia Sand Formation and the overlying Santa Fe Formation equivalent of Galusha (1966) and decided to enlarge the Zia Sand to include his Santa Fe Formation equivalent. The U.S.G.S. has accepted this redefination of the Zia Sand. Tedford (1982) agrees with this redefination, but he believes the unit should be renamed the Zia Formation to reflect the diverse lithologic character of the upper unit.

Kelley (1977) mapped the entire northern Albuquerque basin using stratigraphic subdivisions that are generally similar to Bryan and McCann's. He also measured sections of the Santa Fe in three areas: 1) on the Benevidez Ranch south of the King Ranch; 2) along the west limb of the Ziana anticline, just north of the Shell Santa Fe Pacific No. 1; and 3) in Maria Chavez arroyo north of Placitas. Lambert (1968) mapped the Upper Buff and Middle Red Members in the Albuquerque metropolitan area. Lambert chose to include the inset terrace fills of the Rio Grande as part of the Santa Fe Group. In this study, the inset terrace fills are not considered part of the Santa Fe Group.

Unfortunately, some of these previous studies were conducted on Indian or private lands where access at the present time is not possible.

King Ranch

A thick section of Santa Fe Group deposits is exposed along the Ceja del Rio Puerco that lies between the Llano de Albuquerque and the Rio Puerco west of Rio Rancho (Plate I). This escarpment contains the most complete section of Santa Fe deposits in the north basin area. In some areas, the section rests unconformably on Upper Cretaceous and, locally, on Galisteo (?) strata. In other areas, the Moquino fault juxtaposes the lower Santa Fe with Upper Cretaceous strata. The Llano de Albuquerque marks the top of the section. Santa Fe beds dip generally 4-6° to the east. Two major faults, the Moquino and Sand Hill, complicate the section and are the major basin-bounding faults in this region.

The Santa Fe Group outcrops on the King Ranch are the southernmost exposures studied by Bryan and McCann (1937; 1938). In this area, they noted that the lower part of the section consisted mostly of sand with minor clay and gravel interbeds; whereas, the upper part contained more of a mixture of sand, clay and gravel beds. Color was also an important distinguishing characteristic. Hence, they divided the lower part into the Lower Gray and Middle Red Members, and the upper became the Upper Buff Member.

Wright (1946) measured several stratigraphic sections along the Ceja del Rio Puerco as he traced these units southward. In these sections, Wright (1946) noticed that the color distinction between the Lower Gray and Middle Red disappears toward the south. Within the King Ranch, Wright (1946) studied the Sand Hill fault zone and recognized the episodic movement history recorded in the deformed sediments.

Gawne (1973; 1981), continuing work (unpublished) started by Galusha, examined the Zia Sand exposures along the Canada Pilares and Canada Moquino drainages on the King Ranch. In mapping this area, she recognized both of Galusha's (1966) members, the Piedra Parada and Chamisa Mesa, and defined a new upper member, the Canada Pilares (see Table 1-1). Gawne (1973; 1981) did not examine the Santa Fe (her Tesuque Formation equivalent) deposits that overlie the Zia Sand in this area.

Current research by Drs. Richard Tedford and Steve Barghoorn have concentrated on expanding Galusha's and Gawne's mapping area to the north and south. They are also subdividing and mapping the Santa Fe Group outcrops that overlie the Zia Sand of Gawne (1973; 1981). In mapping, the expanded Zia Formation of Tedford (1982) is used. The Tesuque Formation equivalent of Gawne (1973; 1981) is placed in this expanded unit and it is called the Unnamed Member. Their work includes detailed measured sections and biostratigraphic and magneto-stratigraphic studies. Specific details of Gawne's and Tedford and Barghoorn's work are discussed in more detail below.

Since the King Ranch area has been and is currently being studied by other workers, detailed field investigations were not made during this study. However, rocks were examined and a suite of thin section samples was collected from the Canada Pilares section of Gawne and Tedford. This section extends from the Mesaverde and possible Galisteo strata at the base, through the Zia Formation, and terminates in the upper Santa Fe Group at the top of the escarpment. The King Ranch is privately owned and access is restricted.

Stratigraphy

Unit descriptions of the Santa Fe outcrops on the King Ranch are based on the published and unpublished Canada Pilares measured sections of Gawne (1973; 1981) and Tedford and Barghoorn (written comm., 1985), respectively. The sections are located in sec. 12 T.12N. R.1W. and secs. 7, 8, and 18 T.12N. R.1E. On the U.S.G.S. Sky Village 7.5 minute quadrangle, Canada Pilares is located in the upper part of the Arroyo Benavidez drainage basin. Exposures are generally good and two major faults, the Sand Hill at the top and the Pilares near the base, occur within the section. The stratigraphic subdivisions of Tedford (1982) are used in the descriptions of the Zia Formation. Upper Santa Fe Group gravel and sand cap the section. In addition, thicker upper

Santa Fe Group deposits that lie south of the King Ranch are also discussed.

Zia Formation. Four members comprise the Zia Formation (in ascending order): the Piedra Parada, Chamisa Mesa, Canada Pilares, and the Unnamed. The Zia rests with an angular unconformity on the Upper Crevasse Canyon Formation of the Mesaverde Group (mapped as the Gibson Coal Member by Hunt, 1936) and locally on a less-than-8 m-thick, green clay that Gawne (1973; 1981) correlated with the Galisteo Formation. Outside the King Ranch, Zia outcrops have been mapped north and south of the Jemez River and as far west as the Apache Graben area about 50 km west of Albuquerque (Kelley, 1977). No Zia outcrops have been mapped south of I-40.

The basal member of the Zia, the Piedra Parada, was measured to be 80.5 m thick by Gawne (1973; 1981). Scattered along the basal contact are polished and faceted clasts that are ventifacts. These clasts are composed mostly of quartzites and intermediate volcanics and range in size from pebbles to small boulders. The Piedra Parada is almost exclusively composed of poorly to moderately indurated, massive to crossbedded, moderately to well sorted, pink to gray, fine- to medium-grained sand. Crossbed sets, up to 5 m in length, are mainly tabular. There is very little clay or silt. Gawne (1973; 1981) interpreted these deposits to be mostly eolian. Crossbed orientations indicate winds were predominately out of the west.

The Chamisa Mesa Member, measured at 15.5 m, conformably overlies the Piedra Parada. The unit fines upward from poorly to moderatley indurated, well sorted, gray to pink sand into massive to laminated, pink to gray mud and silt interbeds. Gawne (1973; 1981) believes the fining upward sequence shows a transition from eolian to alluvial deposition.

The Canada Pilares Member which conformably overlies the Chamisa Mesa, has only been recognized in the King Ranch area of the Ceja del Rio Pureco. Gawne (1973; 1981) formally defined this area as the type section. It is not recognized in Galusha's (1966) type Zia section at the north end of the Llano de Albuquerque. The unit is measured at 28 m thick and consists of pink to red clay, silt and fine- to medium-grained sand. Because of the fine grained nature of these sediments, Gawne (1973; 1981) interpreted them to be floodplain deposits.

The Unnamed Member is the new unit included in the Zia Formation by Tedford (1982; Fig. 7-1). It conformably overlies the Canada Pilares Member and has a measured thickness of 121 m. Three units basically comprise the Unnamed Member. The lower 40 m consists mostly of friable, pinkish gray (5YR 7/2) to pale red (10R 6/4), fine- to medium-grained sand with large scale crossbeds and minor

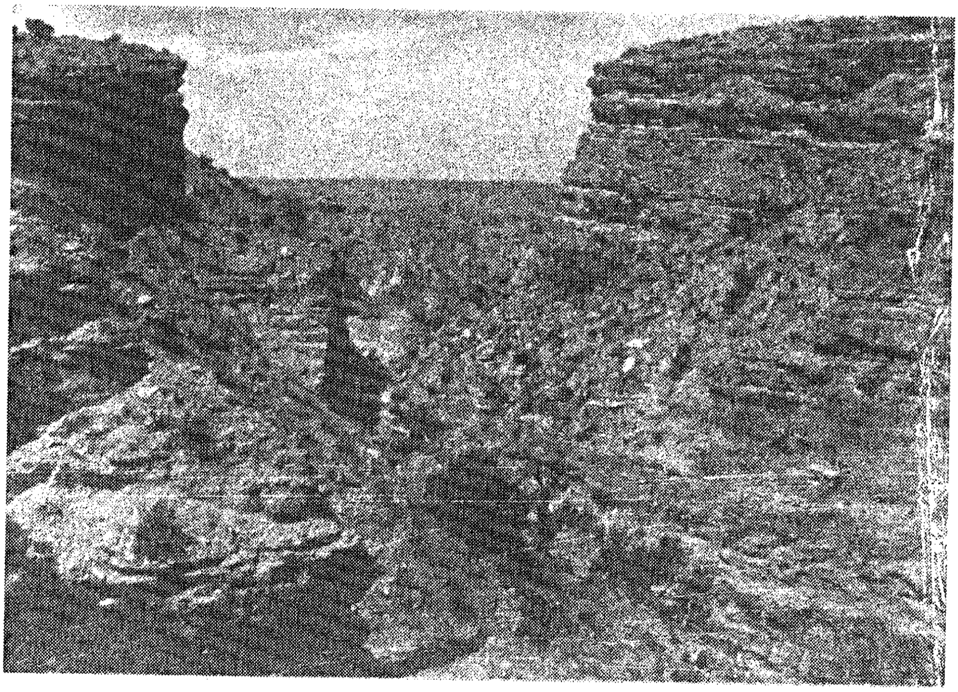


Figure 7-1. Zia Formation outcrops on King Ranch. Mesa Chivato in far distance.

silty sand and clay interbeds. This is overlain by about 17 m of similarly colored, 30-90 cm thick beds of fine- to medium-grained sand, silty sand, silt and clay. Two, very prominent, 60-120 cm thick, green clay beds and scattered calcium carbonate nodules are included. Algal tufa heads are associated with the upper green clay (Fig. 7-2). The upper 60 m are mainly 60-120 cm thick beds of reddish yellow (5YR 6/6) to red (10R 5/6), fine- to medium-grained sand with clay and silt interbeds. Thin volcanic ash beds are scattered throughout the member. This sequence within the Unnamed Member shows a transition from eolian to lacustrine to more fluvial deposition.

Upper Santa Fe Group. In the Canada Pilares section, the upper Santa Fe Group rests unconformably on the Unnamed Member. The contact is scoured and uneven. These deposits are referred to as the Cochiti Formation by Tedford (1982), but Kelley (1977) mapped them as the Ceja Member. They will be referred to as the Ceja Member in this report. These deposits are probably equivalent to the uppermost beds of the Upper Buff of Bryan and McCann (1937), Wright (1946), and Lambert (1968). The Ceja Member also correlates with at least the upper part of the Sierra Ladrones of Machette (1978b). The latter formation appears to be generally equivalent to the Upper Buff Member as defined by Lambert (1968).

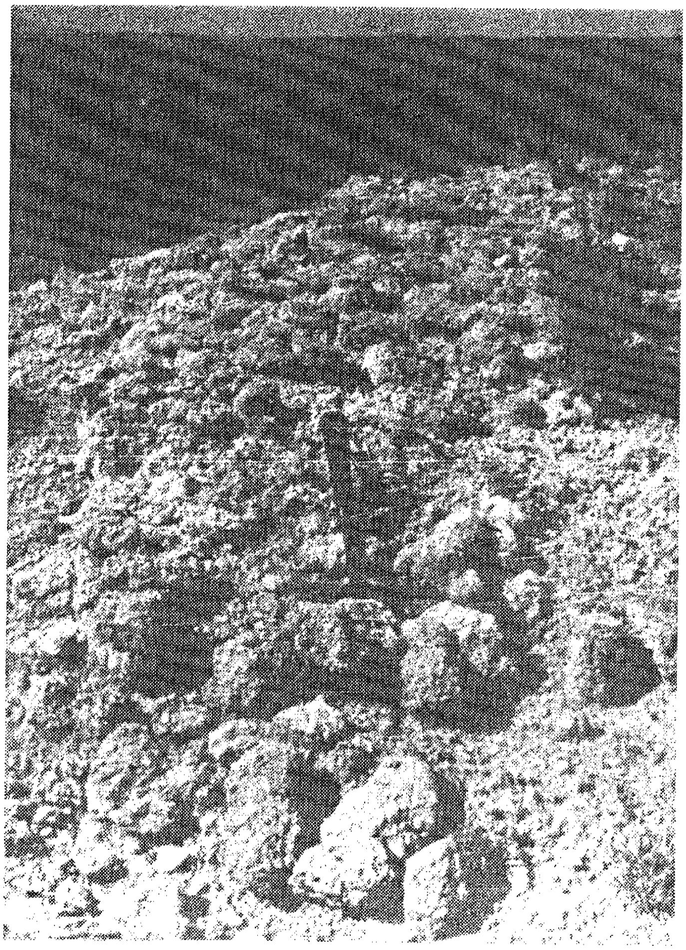


Figure 7-2. Tufa heads weathering-out of Unnamed Member.

The Ceja is about 4 m thick in the Canada Pilares measured section of Tedford (written comm., 1985) which is west of the Sand Hill fault. However, east of the fault in the same area, the Ceja Member and underlying (sand and pebble) beds of the Upper Buff member are as much as 50 m thick. Poorly sorted, cobble to boulder conglomerate with coarse pebbly sand comprise the bulk of the Ceja Member. Clasts are angular to subrounded, locally exceed 1 m in size, and include mafic to silicic volcanics, Cretaceous sandstone, quartzite, granite, chert, and quartz. The Ceja Member is capped with a strong calcic soil. Wright (1946) reports that the volcanic clasts gradually decrease southward.

The upper Santa Fe Group thickens south of the Canada Pilares section. About 25 km south of Canada Pilares, the Upper Buff as defined by Lambert (1968) is 85 m thick at his El Rincon section. In this area, the unit makes up almost all of the Ceja escarpment. Wright (1946) and Kelley (1977) have also measured Upper Buff-Ceja Member sections in this area and report thicknesses of 59 m and 64 m, respectively. Based on water and oil test well data, Lambert (1968) estimated that the maximum thickness of his Upper Buff unit ranged from 120 to 240 m. The thickest section occurs along the eastern edge of the Llano de Albuquerque.

In the El Rincon section, Lambert (1968) recognized an upper and lower subdivision in his Upper Buff. The lower 48 m consists mostly of weakly consolidated, fine- to medium-grained sand and clay interbeds. Sand beds are very pale brown (10YR 7/4) to pinkish gray (5YR 7/2), 30-120 m thick, poorly to well sorted, locally crossbedded, and contain scattered pebbles. Kelley (1977) correlates the lower unit with an unnamed pre-Ceja member of his "middle" Santa Fe Formation. The bottom of the section is buried.

The upper 37 m is much coarser than the lower part and contains less clay and more crossbedding. This unit contains weakly consolidated, white (10 YR 8/2) to light gray (5Y 7/2), fine- to very coarse-grained sand and pebbly to bouldery sand with clay and silt interbeds. Clasts are subangular to subrounded, up to 1 m in size, and include granite, quartzite, Cretaceous and Abo sandstone, chert, and silicic to mafic volcanics. A strong calcic soil caps the section. The upper unit is the type Ceja Member described in Kelley's (1977, p. 20) El Rincon section and is correlated with thinner upper Santa Fe deposits exposed in the Canada Pilares area. The lower unit has not yet been recognized outside the small area of the Ceja del Rio Puerco mapped by Lambert (1968). It may be absent in the Canada Pilares area or is a facies of the Unnamed Member (upper) of the Zia Formation. Northward, the coarse Ceja deposits may correlate with Manley's (1978) Qad unit that caps her Cochiti Formation in the Bernalillo NW quadrangle (Hawley, pers. comm., 1988). Lambert's (1968) Upper Buff is probably correlative with Unit 4 (Sierra Ladrones Formation) in the Gabaldon badlands area, but its basal part may also include upper Cochiti Formation and unit 3 (Gabaldon section) equivalents.

The Upper Buff-Ceja (as defined by Lambert, 1968) is mainly fluvial in origin. He interprets these units to have been deposited within a large alluvial plain with a general southeastern slope. The coarsness, roundness, and sorting indicate a relatively short transport distance for some of the deposits and long distances (from north and west) for others. Finer grained units probably represent overbank deposition. The boulders suggest that stream gradient must have been fairly high.

Age of Deposits

Ages for the Zia Formation and overlying upper Santa Fe Group are based primarily on paleontological data. Identifiable vertebrate fossils have been recovered from both units. Dates reported below are mainly from Gawne (1973; 1981) and Tedford (1981). These dates can also be applied to the Santa Fe deposits in the oil test wells.

The lower part of the Zia Formation (the Piedra Parada, Chamisa Mesa, and Canada Pilares Members) contain faunas that range in age from 15 to 21 Ma (Hemingfordian to late Arikareean). Faunas in the upper Zia (Unnamed Member) have ages from 10 to 15 Ma (early Clarendonian to late

Barstovian). Thus, these deposits are older than units 1-3 in the Gabaldon badlands section, but are of similar age to deposits in the Trigo Canyon area that contain the dated basalt flow. Deposits of similar age to the Gabaldon units 1-3 do not occur in the King Ranch area.

Faunas from the Upper Buff-Ceja are less than 5 Ma (Blancan). This date indicates about a five million year hiatus between the Zia and the upper Santa Fe Group. As determined by Tedford (1981), Lambert (1982) and Lucas (pers. comm., 1988), the uppermost beds in the Ceja Member located near the mouth of Tijeras Arroyo are latest Pliocene to early Pleistocene (1-2 Ma). These beds are probably correlative with the Ceja Member that unconformably overlies the Zia Formation in the Canada Pilares area. If so, then the hiatus between the Zia and the Ceja near Canada Pilares may be closer to 8 million years.

In the Apache Graben, Campbell (1967) reports a volcanic ash in the uppermost beds of the Upper Buff. Izett and Wilcox (1982) have correlated this ash with the Lava Creek B ash dated at about 0.62 Ma. The capping Llano de Albuquerque surface is considered to have become geomorphologically stable at about 0.5 Ma (Hawley et al., 1976; Bachman and Machette, 1977; Machette, 1985). These dates indicate that the Upper Santa Fe Group in the north basin area ranges in age from about 5 to 0.5 Ma.

Oil Test Wells

Cutting analysis results and interpreted stratigraphy of the four oil test wells are discussed in this section. A short discussion on the Norins Realty No. 2 well is also included, although cuttings from this well were unavailable.

Carpenter Atrisco No. 1

The Carpenter Atrisco No. 1 was completed in 1948 to a total depth of 2,208 m. Lambert (1968) examined a driller's log from this well down to 552 m and interpreted that the top 128 m to be the Upper Buff. Foster (1978) and Kelley (1977) both report that the Atrisco well bottomed in the Santa Fe; however, this study shows that the well actually penetrated the Santa Fe and bottomed in pre-Santa Fe Tertiary strata. The El Rincon measured section of Lambert (1968) is about 3 km northwest of the Atrisco well. The well was reported dry and abandoned (Black, 1982).

Cuttings were examined from the top of the hole down to the bottom at 2,208 m. The Santa Fe is 1,006 m thick (Fig. 7-3) and consists generally of loosely consolidated, fine- to medium-grained sand with few silt and clay interbeds. Medium- to coarse-grained sand comprises most of the section down to 122 m, with the upper 45 m containing very coarse-grained to pebbly sand beds. The upper Santa Fe Group includes this 122 m-thick interval. The coarse-grained and

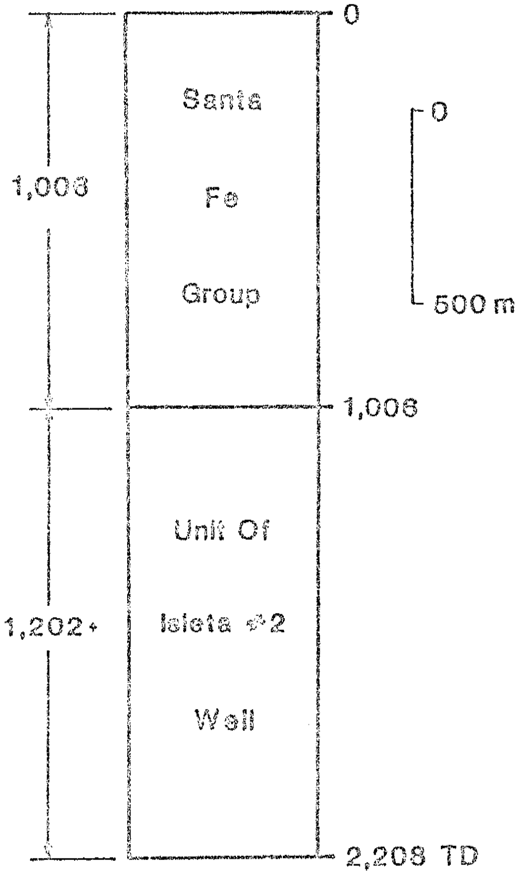


Figure 7-3. Stratigraphic column for Carpenter Atrisco No. 1 showing unit tops and thicknesses. All measurements in meters.

well sorted nature of these deposits demonstrate that these deposits are mainly fluvial.

Beds below 122 m include deposits that mostly post-date the Zia Formation (5-10 Ma) and some that are part of the Zia Formation (Unnamed Member). Silty sand dominates the section between 259 and 375 m and 588 and 655 m. A distinct color change occurs at 811 m where the beds change from reddish orange to mostly light gray; and intermediate volcanic grains become dominant. The gray-colored section below 811 m may correlate with the eolian-dominated lower Zia seen in the Canada Pilares section on the King Ranch.

The pre-Santa Fe Tertiary strata penetrated by the Atrisco well consist mostly of light gray to purplish red, fine- to medium-grained sandstone with minor claystone interbeds down to a depth of 1,936 m. Interbedded zones containing abundant intermediate volcanic (?) fragments that may be flows are also present. Mafic igneous bodies were penetrated from 1,021-1,052 m, 1,497-1,506 m, and 1,676-1,716 m. A 3 m thick, light-colored tuffaceous zone occurs at 1,061 m. Due to the presence of mafic to silicic igneous material, these beds are correlated with the unit of Isleta #2 well containing the 36 Ma ash-flow tuff.

Beneath the interval containing the igneous material down to the bottom of the hole, dark reddish brown to purplish brown shale dominates. It is unknown if these beds are part of the unit of Isleta #2 well or belong to the

Galisteo Formation. However, based on the thickness of the unit of Isleta #2 in the West Mesa well (see below), the shale dominated interval is probably part of the unit of Isleta #2.

Shell West Mesa Federal No. 1

Completed in 1983, the West Mesa well bottomed in Jurassic strata at a depth of 5,906 m. This well has been referred to as the "discovery well" because Shell Oil reported significant gas shows within the Mesozoic section. Despite the gas shows, the well was plugged and abandoned. Cuttings were examined from a depth of 162 m down to 4,880 m. Upper Santa Fe units occur above 162 m and were not sampled. A 9 m core section was also examined and it begins at 5,082 m; this is below the cutting interval studied. No cuttings or core sections were available from the Mesozoic section.

The Santa Fe Group deposits extend down to 2,603 m (Fig. 7-4). The upper 1,646 m consists mainly of light orange to red orange, loosely consolidated, moderately to well sorted, fine- to coarse-grained sand with minor red brown clay and silt interbeds. These beds may correlate partly with the Unnamed Member of the Zia Formation, but most of the section probably post-dates the Unnamed Member and were deposited 5-10 million years ago. Between 427 and 701 m, clay and silt beds are more numerous.

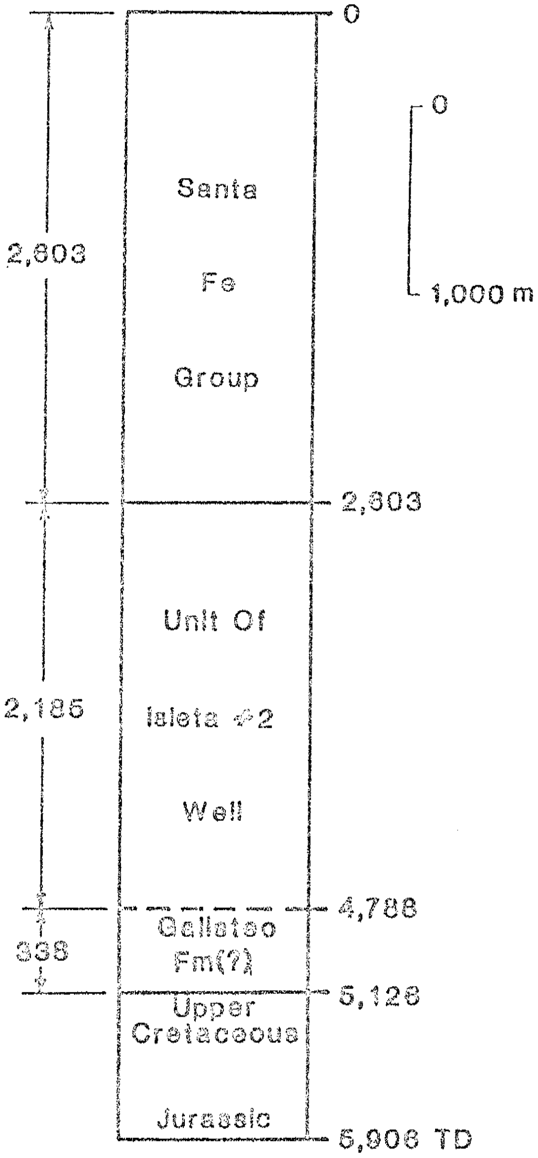


Figure 7-4. Stratigraphic column for West Mesa Federal No. 1 showing unit tops and thicknesses. All measurements in meters.

Between 1,646 and 2,573 m, the Santa Fe is mostly moderately to well sorted, fine- to medium-grained sand and silty sand. A 20 m thick, very coarse-grained sand interval occurs within this zone. The basal 30 m of the Santa Fe is dominantly red brown to brown clay and fine-grained sand interbeds. These beds appear to be part of the Zia Formation and have similar depositional environments as units cropping out on the King Ranch. This interpretation is based on sorting and grain sizes. However, a clay-rich zone (similar to the Canada Pilares Member of Gawne, 1981) is at the base of the West Mesa section rather than a thick (eolian) sand sequence.

The top of the pre-Santa Fe Tertiary strata is marked by a distinct color change. These deposits are mainly light gray to purplish red and minor green mudstone, siltstone, and fine-grained sandstone and extend down to where the cutting samples ended at 4,880 m. Mainly mafic with some intermediate igneous rocks were encountered between 4,231-4,788 m. The beds containing the igneous bodies almost certainly correlate with the unit of Isleta #2.

The cored interval at 5,082 m consists of well indurated, moderately to well sorted, light gray to reddish gray, fine- to very coarse-grained sandstone. Most of the core is microlaminated, but crossbedding and graded bedding do occur. This cored section indicates that these deposits are at least partly fluvial. They are interpreted to have been deposited in an alluvial plain setting similar to the deposits penetrated near the bottom of the Atrisco well.

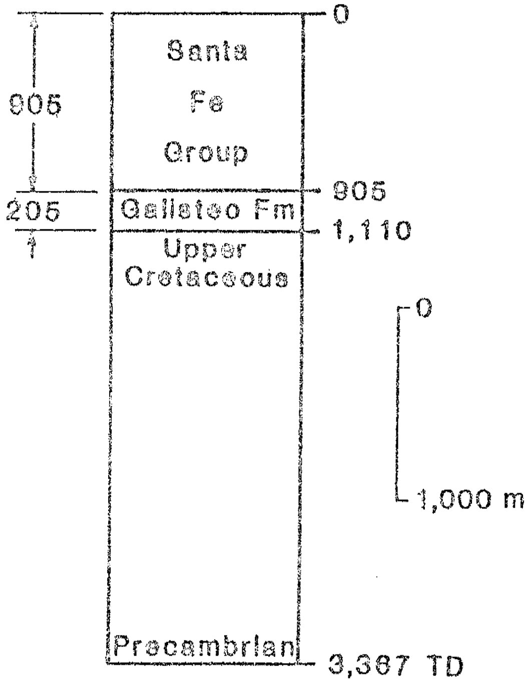
The section below the igneous bodies (including the cored interval) down to the Upper Cretaceous strata may be part of the Galisteo Formation. However, as will be discussed in the petrology section, this section does contain some volcanic material making the correlation with the Galisteo somewhat problematic.

Shell Santa Fe Pacific No. 1

The Santa Fe Pacific No. 1 (SFP No. 1) was the first well drilled by Shell Oil in their ambitious Albuquerque basin exploration program during the 1970's. It was completed in 1972 reaching a total depth of 3,366 m in Precambrian strata. The well was spudded on the south-plunging nose of the Ziana anticline of Black and Hiss (1974). Gas shows were encountered in the Cretaceous section, but the well was abandonded (Black, 1982). Unit thicknesses (including the Santa Fe) have previously been reported from this well by Black and Hiss (1974).

Cutting analysis was performed on the interval from 183 to 1,676 m. The basal part of the sampled interval is within the Cretaceous section. No core sections were available from this well. The sample interval begins below the bottom of the upper Santa Fe unit.

The Santa Fe extends down to 905 m (Fig. 7-5) and can



igure 7-5. Stratigraphic column for Shell SFP #1 showing nit tops and thicknesses. All measurements in meters.

be divided into two parts. The upper part is comprised of interbedded light brown to light pink, loosely consolidated, poorly to moderately sorted, fine- to medium-grained sand, silty sand, silt, and clay. These beds appear to be mainly fluvial in origin.

At 454 m, the Santa Fe section becomes moderately to well sorted, fine- to medium-grained sand and silt with very minor clay interbeds. Resistivity logs indicate that these beds are very porous, and massive to thickly bedded. The thickly-bedded section represents the Zia Formation; whereas, the upper part probably post-dates the Zia and was deposited in the interval between 5-10 million years ago. The thickly-bedded section mainly contains eolian with lesser fluvial deposits based on similarity with lower Zia deposits. Within the Santa Fe section, Black and Hiss (1974) report a major change at 853 m that separates the Santa Fe from the Zia Sand of Galusha (1966). No major change was observed at this depth during the cutting analysis.

Light brown to reddish brown, moderately indurated, fine- to medium-grained sandstone, siltstone, and claystone interbeds underlie the Santa Fe Group. These deposits are correlated with the Galisteo Formation due to absence of volcanic material in the cuttings and in thin section. This unit is 205 m thick and primarily fluvial in origin.

The Upper Cretaceous section begins at 1,110 m and consists of light gray to dark brown clay and fine-grained sand interbeds with coal down to where the cutting interval ended. According to Black and Hiss (1974), these beds comprise the Menefee Formation, Point Lookout Sandstone, and the Mancos Shale.

The tops determined for the Galisteo and Upper Cretaceous sections in this study agree with those reported by Black and Hiss (1974). Kelley (1977, p. 15, Table 5) measured 290 m of interbedded sand and clay in an exposure near the SFP No. 1. His unit descriptions are similar to the upper part of the Santa Fe seen in the well.

Shell Santa Fe Pacific No. 3

This well, completed in 1976, is located about 5 km north of the Canada Pilares measured section. It bottomed in Triassic strata at a total depth of 3,132 m. Minor gas shows were reported, but the well was abandoned (Black, 1982).

Cuttings were examined from 18 m down to 2,012 m. No core sections were available from this well. The Santa Fe Group comprises the upper 1,218 m of the well (Fig. 7-6) and, similar to the SFP No. 1, consists of two parts. The upper 497 m is mainly interbedded, loosely consolidated, moderately sorted, medium- to coarse-grained sand and silt. Coarse- to very coarse-grained sand dominates the top 90 m and probably represents the upper Santa Fe Group. Similar

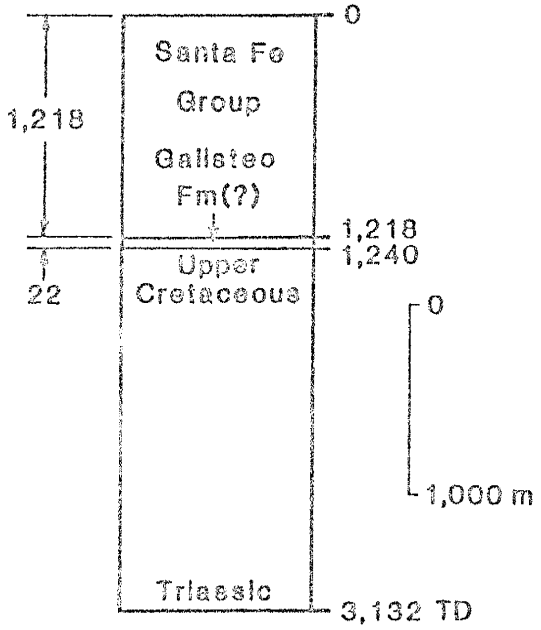


Figure 7-6. Stratigraphic column for Shell SFP #3 showing unit tops and thicknesses. All measurements in meters.

to the upper unit in the SFP No. 1, the rest of this 497 m thick interval most likely post-dates the Zia and represents deposition occurring 5-10 million years ago.

The 497-1,218 m interval is primarily loosely consolidated, well sorted, fine- to medium-grained sand with rare clay and silt interbeds. Within this interval, a 43 m-thick zone of interbedded clay and silt occurs between 753 and 796 m and may correlate with the Chamisa Mesa Member. Sand beds are generally massive and very porous as indicated by the resistivity logs. They mainly comprise the Zia deposits and are probably for the most part eolian in origin.

Possible Galisteo deposits may unconformably underlie the Santa Fe from 1,218 m to 1,240 m. These deposits are coarser and more thinly bedded (based on resistivity logs) than the Santa Fe deposits. Thin sections need to be examined from this interval to support this interpretation. They may also be fluvial as interpreted for the Galisteo deposits in the SFP No. 1. Cuttings from this possible Galisteo interval are similar to Galisteo Formation deposits exposed about 15 km north of the well in the Windmill Hill area as described by Lucas (1982). In this area, Galisteo outcrops consist of about 186 m of interbedded medium- to coarse-grained sandstone, mudstone, and conglomerate (Gorham, 1979; Lucas, 1982). They also occur in the same stratigraphic position. Unconformities bound the unit at the top and bottom. The thinner section in the well may be due to erosion.

Upper Cretaceous strata begin at 1,240 m. The contact is marked by a sudden change from orange red to buff sandstone to dark gray to light gray interbeds of siltstone, shale, and fine-grained sandstone with scattered coal.

Norins Realty North Albuquerque Acres No. 2

This well is located about 6 km west of the Sandia Mountains in sec. 19 T.11N. R.4E. and it was completed in 1940 to a total depth of 1,531 m (see well no. 23 on Fig. 1-2 for location). The Norins No. 2 is an important well because it is the deepest well drilled in the piedmont area between the Sandia uplift and the Rio Grande Valley. No cuttings or core were available for analysis, but a driller's log was obtained from the New Mexico Bureau of Mines and Mineral Resources.

According to the driller's log, the upper 655 m is dominated by "coarse gravel, boulders, and granite wash" interbedded with "arkose and shale". The uppermost part of this sequence is probably equivalent to the upper Santa Fe Group and may correlate with the Sierra Ladrones deposits in the Trigo Canyon area that cap the dissected pediments. However, the bulk of this sequence correlates better with the upper Popotosa Formation units recognized in the Transocean and Grober wells that recorded the initial erosion of Precambrian material from the Sandia-Manzano uplift. Stearns (1953) referred to this interval as the "Santa Fe Formation".

The lower 875 m penetrated in the well is described as primarily interbedded "gray sand and shale". This interval appears to be very similar to the Popotosa deposits exposed in the Trigo Canyon area that contain the 21 Ma basalt flow and to the lower Santa Fe deposits in the Transocean well. Stratigraphically, this lower interval is also correlative with the Zia Formation. Stearns (1953) also believed that these lower deposits were younger than the Galisteo Formation and older than the Santa Fe Formation, which places these deposits in the general stratigraphic position of the Zia Formation.

Undoubtedly, the upper coarse-grained section represents medial to proximal alluvial-fan deposits that were derived from the adjacent Sandia uplift. The lower section may be fluvial and eolian in origin, if they are similar to the Trigo Canyon outcrops.

Sand Petrology

A total of 52 thin sections were point counted from the northern basin area. These include 32 from the Santa Fe Group, 16 from the pre-Santa Fe Tertiary deposits, and 4 from the Upper Cretaceous. Most of these thin sections are from impregnated cutting samples, but four are from core obtained in the West Mesa well. Each of the units in the Canada Pilares section were sampled for thin section work, including one sample each from the Mesaverde and Galisteo (?) beds. Point count results are tabulated in Appendix II.

Santa Fe Group

The Santa Fe Group samples from the King Ranch (Canada Pilares section) and oil test wells have average sand grain compositions that range from 40.8% quartz, 36.7% feldspar, and 22.5% lithic fragments in the Canada Pilares section to 75.8% quartz, 16.8% feldspar, and 7.4% lithic fragments in the West Mesa well. These samples classify mostly as arkose, lithic arenite and feldspathic litharenite (Folk, 1974). Sand grains are generally fine- to coarse-grained, subangular to subrounded, and poorly to well sorted. However, samples from the lower Zia oftentimes contain grains that are primarily fine- to medium-grained, subrounded to well rounded, and well sorted. Calcium carbonate is the chief cement in these samples. Point count results are plotted on the ternary diagrams on Figs. 7-7 to 7-9.

The Santa Fe samples from the north basin area contain the overall highest quartz percentages when compared with Santa Fe samples from other regions in the Albuquerque basin. Monocrystalline quartz is generally the dominant

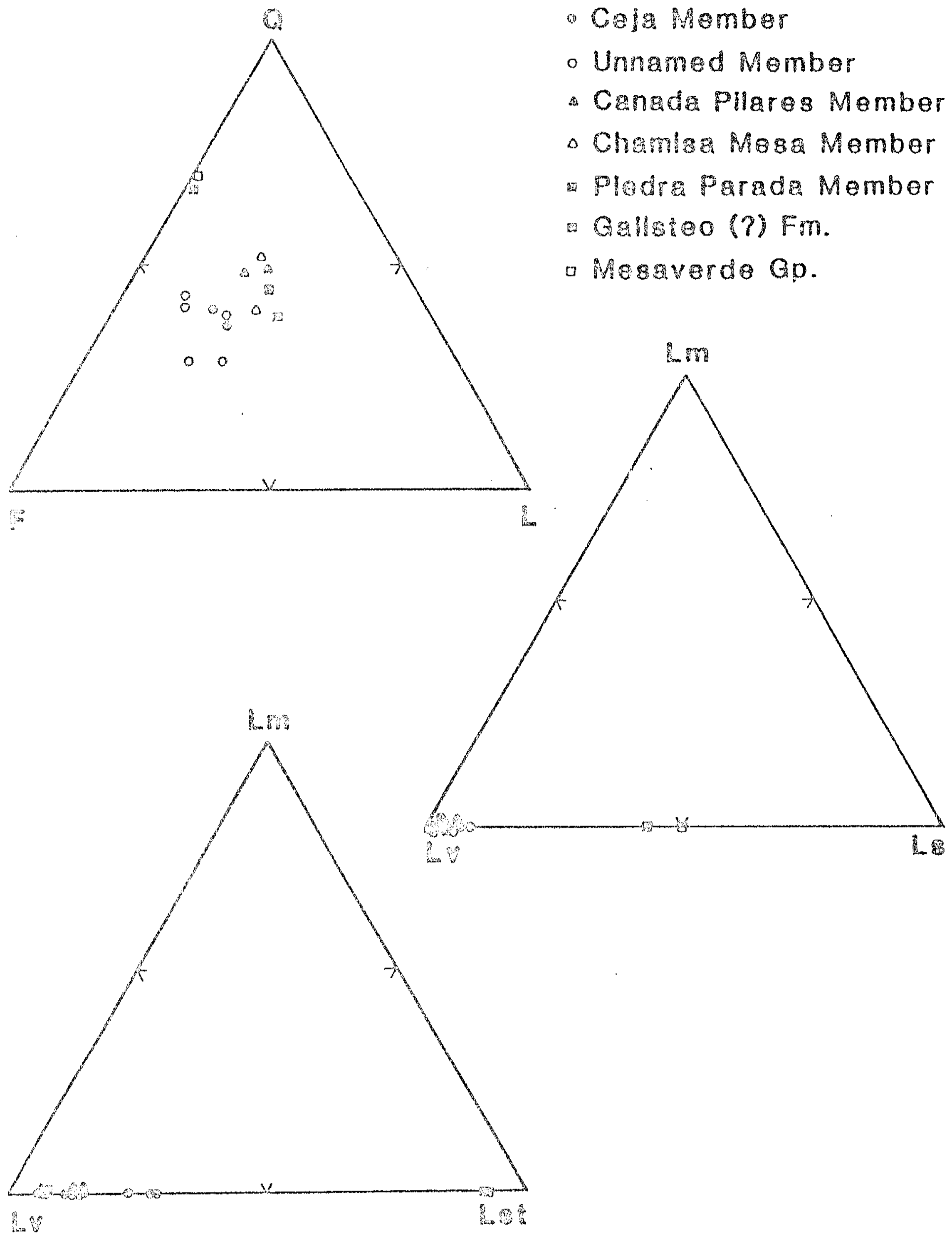


Figure 7-7. Ternary diagrams for King Ranch outcrops.

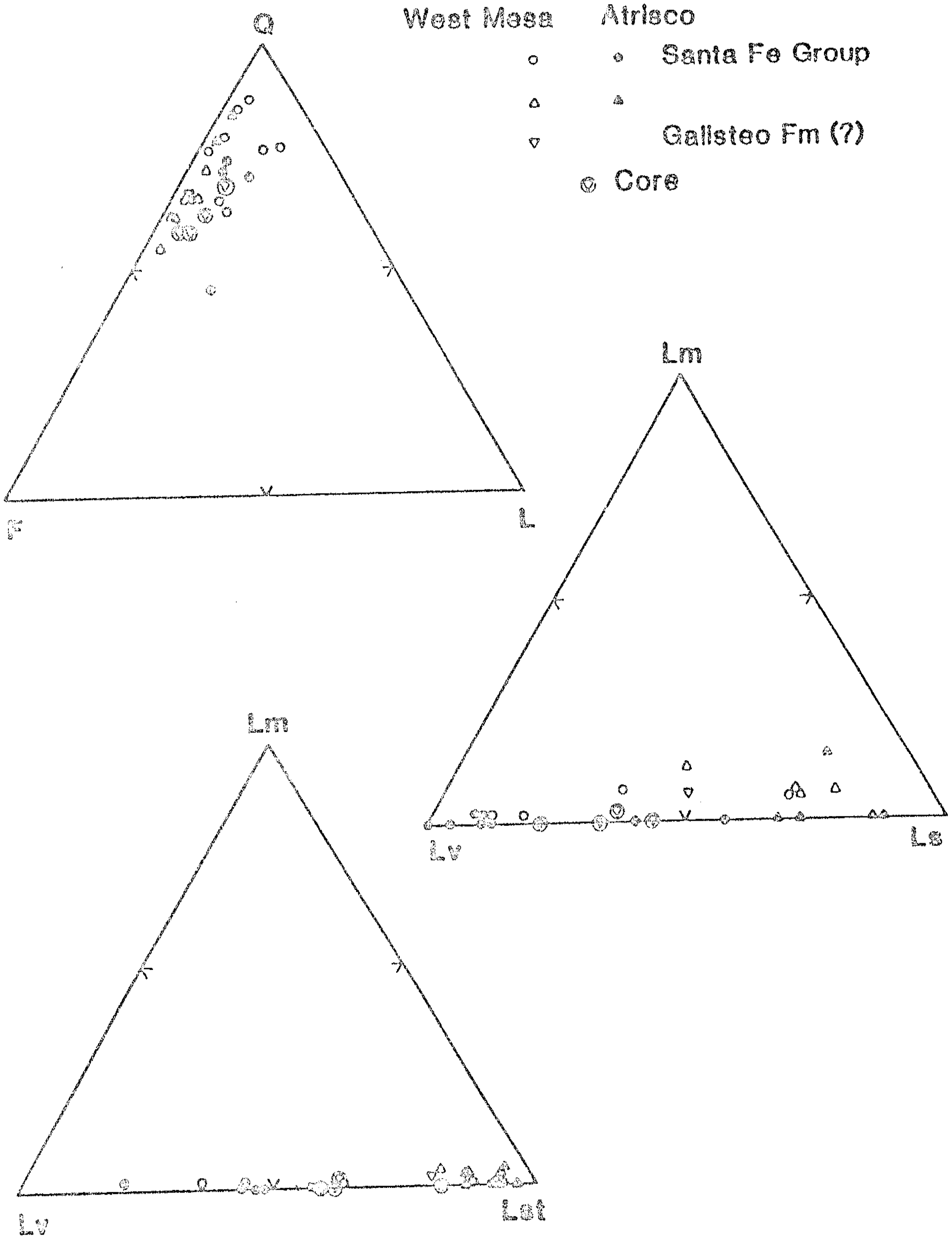


Figure 7-8. Ternary diagrams for Carpenter Atrisco No. 1 and West Mesa Federal No. 1.

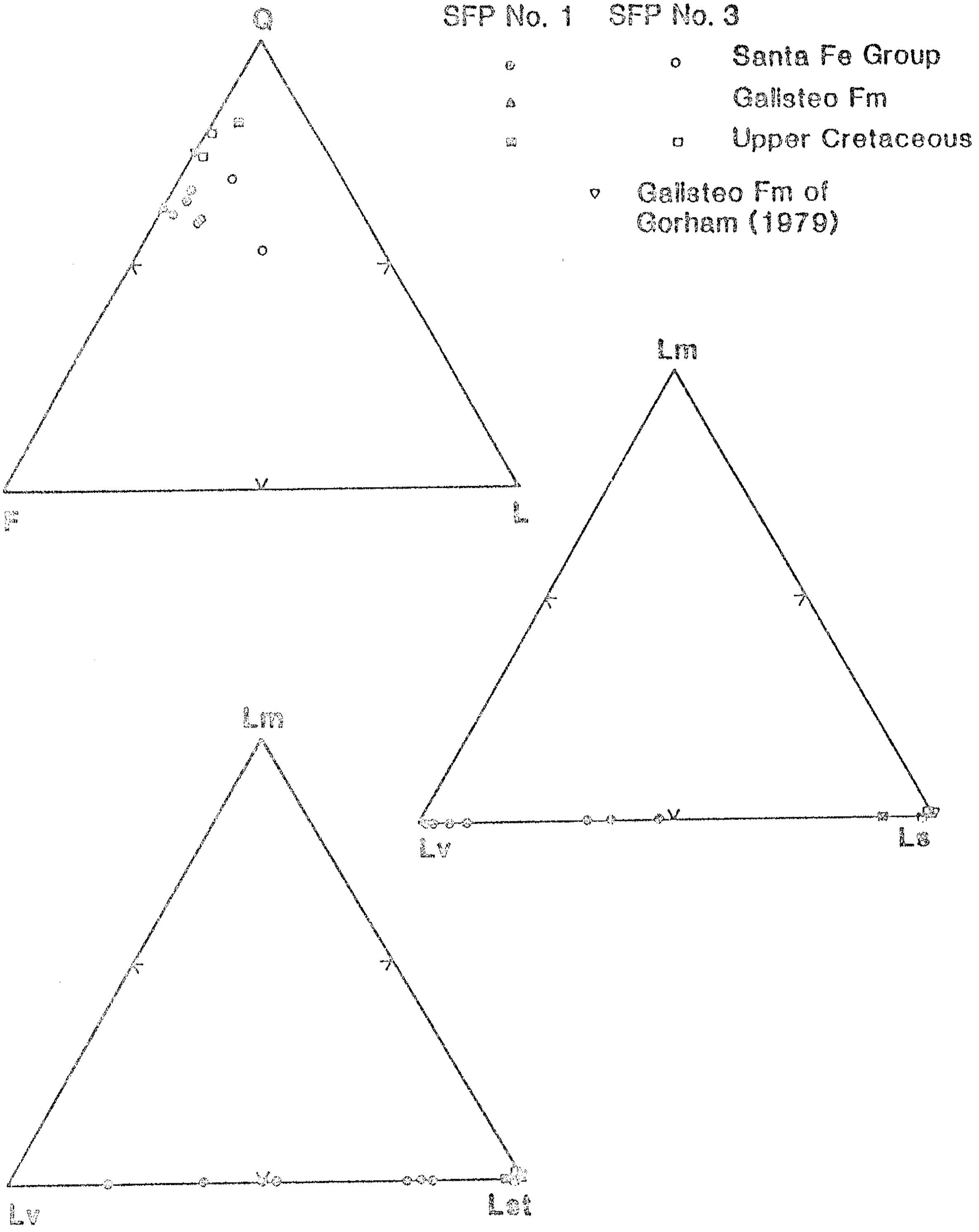


Figure 7-9. Ternary diagrams for Shell SFP #1 and SFP #3.

detrital grain. These grains are typically clear, show straight extinction, and some grains have dipyrimidal form. Within the lower Zia Formation, well rounded quartz, some with overgrowth rims, are fairly common. Chert is the major polycrystalline quartz. The Qp/Q ratio averages range from 0.07 for the King Ranch samples to 0.15 in the West Mesa well. The higher ratio in the West Mesa well is due to anomalously high chert percentages in the lower part of the Zia. These high chert percentages in the lower Zia were not recognized in the other wells or outcrops. There is an overall increase in quartz percentage with depth.

Plagioclase is the most common detrital feldspar grain in most of the Santa Fe samples as indicated by the P/F ratios. This is especially true in the Atrisco well. However, the lower Zia samples in the Canada Pilares section and in the SFP No. 1 well show about equal percentages of plagioclase and potassium feldspar. Plagioclase grains range in composition from oligoclase to labradorite (determined by Michel-Levy method), are usually twinned and sometimes display oscillatory zoning. Orthoclase and sanidine are the most common potassium feldspar. Microcline and perthite percentages increase upsection and are particularly common in the upper 600 m. Some feldspars show sericitic alteration. Feldspar percentages increase slightly upsection.

In the north basin, lithic fragment percentges are generally lower than percentages from other parts of the basin. Volcanic-lithic fragments are the most abundant lithic fragment averaging over 90% in all Santa Fe samples except in the West Mesa and SFP No. 1 (see LmLvLs plots in Figs. 7-7 to 7-9). The volcanic-lithic grains typically exhibit porphyritic and microlitic textures and are mostly intermediate in composition. Some grains with stained groundmasses are considered to be silicic volcanics. Mafic volcanics become more numerous higher in the section. Sedimentary-lithic fragments (including carbonates) comprise between 3 and 40% of all lithic fragments with the higher percentages in the West Mesa and SFP No. 1. Very low percentages (0.2%) of metamorphic-lithic fragments were observed. A few granitic-lithic fragments were noted, mostly in the upper 800 m of the deposits. Except for the Canada Pilares section, the ternary diagrams suggest a slight increase in lithic fragments upsection.

On closer examination of the Canada Pilares section, samples plot in two distinct fields on the QFL diagram (Fig. 7-7) that correspond to lithologic units. One field contains the three lower Zia samples (Piedra Parada, Chamisa Mesa, and Canada Pilares) and the other contains samples from the Unnamed and Ceja Members. In addition, plagioclase percentages are about equal to potassium feldspar percentages in the lower Zia samples; whereas, plagioclase is dominant in the upper Zia and Ceja samples. These changes indicate a shift in the source areas between Piedra Parada and Unnamed Member time.

Gawne (1973) performed point counts on eight lower Zia samples. Her overall results are similar to the results obtained in this study. These include: 1) no major petrographic changes through her sampled interval; 2) quartz as the dominant detrital grain; and 3) volcanic-lithics, mainly intermediate, are the dominant lithic grain. She does recognize a few more metamorphic grains than were seen in this study.

Pre-Santa Fe Tertiary Deposits

These deposits tend to have higher quartz percentages and lower lithic fragment percentages (especially volcanic-lithics) than the Santa Fe samples. An exception is the West Mesa well samples where quartz percentages are lower than in the Santa Fe. These samples classify as arkose and subarkose (Folk, 1974). Quartz grains are dominated by monocyrstalline grains. Overall, the plagioclase to potassium feldspar ratio is about equal. Again, the West Mesa samples are different because they contain higher plagioclase percentages. Both the quartz and feldspar grains are similar to those described in the Santa Fe samples.

Lithic fragments consist primarily of sedimentary-lithics, but volcanic-lithics (mainly intermediate) also occur. The West Mesa and Atrisco samples contain the highest volcanic-lithic percentages. Metamorphic- and granitic-lithic fragments occur in very low percentages.

In the West Mesa well, the four core samples are from depths of 5,084, 5,085, 5,089, and 5,091 m. These levels are below the cutting interval examined, but still within the pre-Santa Fe Tertiary deposits. They are quite similar petrographically to pre-Santa Fe Tertiary samples from higher in the hole, except they contain higher volcanic-lithic percentages.

It is difficult to separate a volcanic-rich unit from a volcanic-poor one in the West Mesa and Atrisco wells due to the high quartz and relatively low to moderate volcanic-lithic percentages. The abundant intermediate igneous material seen in the two wells suggest that these intervals are equivalent to the volcanic-rich unit in the Isleta #2 well.

The section below 4,788 m in the West Mesa well may be part of the Galisteo Formation, although it contains low volcanic-lithic percentages. Gorham (1979) reports that the upper part of the Galisteo Formation in the Hagan basin includes low percentages of intermediate volcanic-lithic fragments. Thus, the cored interval may correlate with the upper Galisteo Formation.

No volcanic material was seen in the pre-Santa Fe Tertiary deposits in the SFP No. 1 and so this entire interval is believed to represent the Galisteo Formation. Gawne (1973; 1981) interpreted the green clay that underlies the Zia Formation to be Galisteo. Gorham (1979) point counted a sample from the Galisteo outcrops in the Windmill Hill area (point count result shown in Appendix II). The point count results of Gorham (1979) compare favorably with these other samples (Fig. 7-9).

Upper Cretaceous

Upper Cretaceous deposits were ecountered in the SFP No. 1 and 3 wells and at the base of the Canada Pilares section. They commonly contain very high quartz and low lithic fragment (especially volcanic-lithics) percentages. The Upper Cretaceous samples classify as arkose and subarkose (Folk, 1974). Petrographically, they are very similar to the Galisteo samples which makes distinguishing between the two difficult based soley on petrography. However, in cutting analyses, color and texture provide good criteria for separation of Upper Cretaceous and Eocene rocks.

Provenance

Galisteo deposits were derived from two source areas in the SFP No.1 and 3 wells and from three source areas in the Atrisco and West Mesa wells. The high percentages of monocrystalline quartz and chert plus the presence of granitic-lithic fragments indicate a source area that contained primarily sedimentary and basement rocks for the SFP No. 1 and 3 wells. This agrees with Gorham's (1979) provenance interpretation for the Windmill Hill Galisteo outcrops. Paleocurrent indicators in these outcrops show a source area to the northwest, probably in the Nacimiento uplift or in the San Juan Basin.

The possible Galisteo deposits in the Atrisco and West Mesa wells were also derived from sedimentary and basement source areas with a lesser amount coming from an intermediate volcanic source. The Lucero uplift may have been the area that contained the source rocks because of its proximity to the wells and potential to have had volcanic material. The volcanic material would have been derived very late in Galisteo time.

There is no record of Oligocene (Espinosa Formation equivalent) deposition in the SFP No. 1 and 3 wells. However, the Atrisco and West Mesa wells penetrated a fairly thick section of pre-Santa Fe Tertiary deposits that contain volcanic material. These deposits were derived from a sedimentary and an intermediate volcanic source area that was probably located in the Lucero uplift region. This is supported by the high quartz and chert percentages and the occurence of intermediate volcanic-lithic fragments.

Based on clast lithologies and point count data, Santa

Fe sediments in the northwest basin area were derived mostly from volcanic and sedimentary source terranes. Minor amounts of detritus were contributed from granitic and metamorphic sources. The abundant volcanic clasts in outcrop and high percentages of volcanic-lithic fragments and twinned plagioclase in thin section leave little doubt for a volcanic source. However, the composition of the volcanic source shifted some with time. During Zia deposition, the volcanic source area contained mainly silicic to intermediate volcanics. By late Zia through Ceja time, mafic volcanics became increasingly more prominent in the source area.

The high percentages of monocrystalline quartz coupled with clasts of Cretaceous sandstone, chert, and petrified wood firmly indicate that much of these deposits are reworked from a sedimentary source area. This source area contained Mesozoic, Paleozoic, and perhaps early Tertiary units. The granitic and metamorphic clasts suggest that a basement area also contributed some detritus or some may be re-cycled out of the sedimentary source area.

Gawne (1973) also concluded that the lower Zia sediments were derived mainly from a complex volcanic and sedimentary source area. Likewise, Lambert (1968) determined that the Upper Buff originated from volcanic, Mesozoic, and Paleozoic source areas.

Paleoflow indicators observed in the field suggest that the Santa Fe deposits in the Canada Pilares section were derived from the north and northwest. Based on crossbedding, Gawne (1973) concurs with this interpretation. Both Lambert (1968) and Kelley (1977) use imbrications and crossbedding to conclude that flow directions in the Upper Buff were from the north, northwest, and west.

In the northeast basin area, data from the Norins No. 2 well indicate two distinct periods of deposition. If the gray clay and sand deposits in the lower part of the well are equivalent to the lower Popotosa deposits in the Transocean well and Trigo Canyon area, then they were derived mainly from sedimentary and volcanic source areas probably to the northeast and east. Ingersoll et al. (1987) has identified the San Juan Mountains as a possible volcanic source for the Zia Formation. This possible source area would also apply to the Zia deposits in the north and northwest basin area.

There is little doubt that the granite-dominated detritus in the upper part of the well was derived from the east in the Sandia uplift.

Depositional History of the North Basin Area

In the north basin area, the Galisteo Formation was derived from two different uplift regions. Deposits in the SFP No. 1 and 3 wells along with Galisteo outcrops in the

Windmill Hill area and possibly the King Ranch originated primarily from sedimentary and granitic source areas in the Nacimiento uplift. High-energy fluvial systems transported these sediments southeastward and deposited them within a large alluvial plain (Gorham, 1979).

Galisteo deposits in the Atrisco and West Mesa wells area were reworked out of a sedimentary and minor granitic source area along with some intermediate volcanic material late in Galisteo time. The granitic material may also be re-cycled from Mesozoic and Paleozoic units. These units were probably derived from the Lucero uplift area and transported eastward and northeastward to be deposited in a large alluvial apron. The accumulated thickness of the Galisteo in these two areas is about 338 m.

There is no record of Oligocene volcanic-rich deposition in the King Ranch and Windmill Hill outcrops nor in the SFP No. 1 and 3 wells. These deposits appear to be restricted to the Atrisco and West Mesa well areas. Due to a lack of paleoflow indicators, it is not certain where these deposits were derived. However, it is most reasonable to assume that they originated in the Lucero uplift area where intermediate volcanic material was probably present. Thus, at this time, the Lucero uplift was shedding primarily sedimentary and volcanic material into this part of the basin. These deposits are similar to the Oligocene volcanic-rich deposits (unit of Isleta #2) seen in the oil test wells in the Gabaldon badlands area and in the central basin area. Deposition probably occurred within large alluvial aprons that extended eastward from the Lucero uplift. The intermediate to mafic igneous bodies penetrated within the well suggest that these deposits may also include some flows.

The lower Zia outcrops on the King Ranch are some of the oldest dated (at 21 Ma) Santa Fe deposits in the Albuquerque basin. However, there are probably older Santa Fe deposits penetrated by the oil test wells that could be as old as 28-30 Ma. The source areas and depositional environments of these deposits did not change significantly through Zia time. Zia deposits consist primarily of eolian and fluvial sediments that were laid down within alluvial fans and basin-floor areas. Source areas consisted primarily of sedimentary and intermediate to mafic volcanic rocks that were located around the basin margins to the north, east, and west. Within the Unnamed Member, the algal tufa heads indicate that a large fresh-water lake existed within the basin east of the Ceja del Rio Puerco during part of Zia time.

By late Zia time (10 Ma), the Precambrian core of the Sandia uplift became exposed. Detritus eroded from the uplift was deposited along alluvial fans that formed at the base of the uplift. Mafic volcanism also became dominant at this time. However, the King Ranch outcrops do not contain sediments that represent the period of most active tectonism in the basin (5-10 Ma). Evidently, the King Ranch area was uplifted and became part of the basin margin prior to this active-tectonic period. Deposition shifted farther eastward. These 5-10 Ma sediments are seen in the oil test wells and include the interbedded sequence (probably part of the Cochiti Formation) and perhaps part of the upper thickly-bedded sand interval. These deposits comprise the bulk of the Santa Fe section observed in the wells. The interbedded nature and coarsness of these deposits suggest that they were laid down by fluvial systems and within alluvial fans. The total accumulated thickness for these deposits may be 3,000 m or more.

At about 5 Ma, large, high-energy fluvial systems began to deposit the upper Santa Fe sediments. These fluvial systems were flowing from the northeast and northwest and were the Rio Grande and Rio Puerco ancestral drainage systems. Coarse material was also being shed off the surrounding uplifts and deposited along alluvial fans. Upper Santa Fe deposition ended with the development of the Llano de Albuquerque at about 0.5 Ma.

CHAPTER 8. DISCUSSION ON THE STRUCTURE AND BASIN FILL WITHIN THE ALBUQUERQUE BASIN

Introduction

In this chapter, data presented in the previous four chapters are integrated into a basin-wide overview. Discussions are centered on basin structure, basin fill thickness, and on basin fill facies and petrographic variations within the Albuquerque basin. Table 8-1 summarizes data on the 12 oil test wells studied. These data are used to construct the cross sections and isopach maps.

Basin Structure

As discussed in Chapter 1, seismic reflection work by the Shell Oil Company shows that the Albuquerque basin is generally composed of a northern, eastward-tilted half graben and southern, westward-tilted half graben. A southwest extension of the Tijeras fault appears to form the transition zone between the half grabens. This zone is also an area of increased volcanism and Reiter et al. (1986) reports that it is associated with relatively high heat flow. The transition zone is also a subsurface high because as it is approached from the north, the basin fill thickness decreases from 4,407 m in the Isleta #2 well to 2,679 m in

Table 8-1. Oil test well data. QTsf = Santa Fe Group; Tvs = unit of Isleta #2; Tg = Galisteo-Baca Formations; K-Tr = Cretaceous or Triassic.

Well no.	Name; location	Surface elevation (m)	Total depth (m)	Tops (m)			Thickness (m)		
				Tvs	Tg	K-Tr	QTsf	Tvs	Tg
1	SHELL SANTA FE Pacific #1; 18-13N-3E	1,747	3,366	NR	905	1,110	905	NR	205
2	SHELL SANTA FE Pacific #3; 28-13N-1E	1,917	3,132	NR	1,218	1,240	1,218	NR	22
3	SHELL WEST MESA Federal #1; 24-11N-1E	5,774	5,906	2,603	4,788	5,126	2,603	2,185	338+
4	CARPENTER ATRISCO #1 28-10N-1E	1,766	2,028	1,006	NP	NP	1,006	1,202+	NP
5	SHELL ISLETA #2; 16-8N-2E	1,524	6,482	4,407	6,194	NP	4,407	1,787	288+
6	TRANSOCEAN ISLETA #1; 8-8N-3E	1,909	3,163	NR	NR	1,536	1,536	NR	NR
7	SHELL ISLETA #1; 7-7N-2E	1,537	4,982	2,679	3,216	3,670	2,679	537	454
8	JOINER SAN CLEMENTE #1; 23-7N-1E	?	1,709	NP	NP	NP	1,709+	NP	NP
9	LONG DALIES #1; 32-7N-1E	1,620	1,856	NP	NP	NP	1,856+	NP	NP
10	HUMBLE SANTA FE PACIFIC #1; 18-6N-1W	1,552	3,868	1,494	(2,164?)	2,591	1,494	670	(427?)
11	SHELL SANTA FE PACIFIC #2; 29-6N-1W	1,583	4,360	1,460	(2,316?)	2,511	1,460	856	(195?)
12	GROBER FUQUA #1; 19-5N-3E	1,531	1,920	NR	NR	1,384	1,384	NR	NR

NP = not penetrated NR = not recognized

the Isleta Central #1 well. Seismic profiles through the zone are generally unclear.

Based partly on the Shell seismic work and partly on the oil test well data, a diagrammatic cross section was constructed for each half graben (Fig. 8-1). Their locations are shown on Plate 1. The cross sections are placed in areas where well control is best.

The structure of the basin generally consists of a deep, inner graben that is flanked by relatively shallow ramps (such as the Hubble Bench) leading up to the margin areas. These ramps are faulted and form a step-down progression into the deep inner basin. Note that faults with major throws do not occur near the topographically high margins, but rather occur further basinward. By measuring the vertical distance between the Precambrian strata on top of the eastern margin uplifts and within the deepest part of the basin, the structrual relief of the basin is well over 10,000 m.

In the north half graben, the major-throw fault is located under the present position of the Rio Grande. This is supported by the basin fill thickness difference between the Transocean and the Isleta #2 wells. In a distance of 8 km (see Plate 1), the basin fill thickness increases from 1,536 m in the Transocean well to 4,407 m in the Isleta #2 well. Thus, a large displacement fault (with at least 2,871 m of offset) must lie between the two wells. Based on

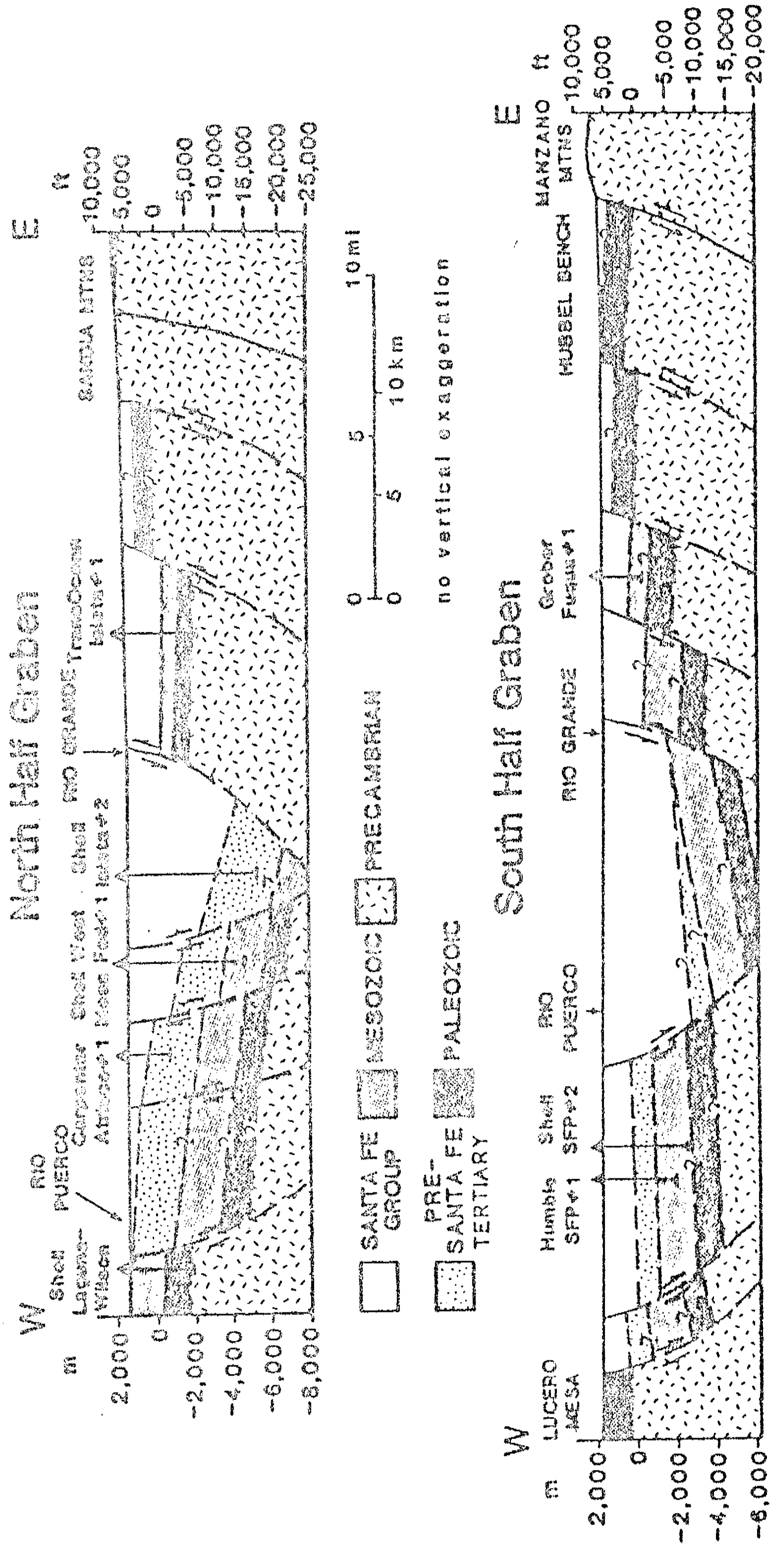


Figure 8-1. Diagrammatic cross sections of the north and south half-grabens. Cross section locations shown on Plate 1.

seismic data, the major-throw fault in the south half graben appears to occur under the present position of the Rio Puerco. Well control in this area is too poor to confirm the location of the fault, but on the water-table contour map of Titus (1963), a major drop in the groundwater level occurs across this zone, perhaps indicating a fault.

Many of these faults appear to be listric according to Shell's seismic work. This is particularly apparent in the seismic line that passes through the Gabaldon badlands (see structure section discussion in Chapter 4). On the seismic lines, the low-angle faults are not cut by high-angle faults suggesting that the low-angle structures have continued to be active at least into late Santa Fe time. The high-angle faults toe into the low-angle features. Some of the low-angle faults project into the basin-bounding faults.

Other workers have also interpreted listric faults in the Albuquerque basin. Birch (1982) suggested that one way to explain the large gravity gradients within the basin are with listric faults. In studying the COCORP deep seismic-reflection profile in the southern part of the basin, Cape et al. (1983) believed that listric faulting is the dominant extensional style of faulting in that part of the basin. In re-interpreting the same COCORP line, Wu (1986) did not recognize listric faults. Instead, he sees a folded detachment surface and a set of reverse faults.

In studying East African rift basins, Rosendahl (1986) found that half-grabens are quite common in rift basin systems. This appears to be true in the Rio Grande rift as well because many of the rift basins display half-graben morphologies (i.e., Albuquerque basin, this study; Engle and Palomas basins, Lozinsky, 1987). Based on his East African rift studies, Rosendahl (1986) has proposed several models showing how half-grabens may be linked into rift systems. The Albuquerque basin seems to best fit his Case D "non-overlapping opposing half-graben" model (see fig. 6b, p. 470). In this model, the opposing half-grabens are linked by a "strike-slip accomodation zone" that may correspond with the transition zone between the half-grabens.

Basin Fill Thickness

Basin fill thickness varies considerably around the Albuquerque basin, both within the Santa Fe Group and within the pre-Santa Fe Tertiary deposits. Using the data on Table 8-1, isopach maps were constructed for: 1) the Galisteo-Baca Formations (Fig. 8-2); 2) unit of Isleta #2 well (Fig. 8-3); and 3) for the Santa Fe Group (Fig. 8-4). Figures 8-2 and 8-3 delineate depositional basins that pre-date the Albuquerque basin and Rio Grande rift. Shell's seismic work shows no major angular unconformities within the Santa Fe Group or pre-Santa Fe Tertiary deposits in the central portions of the basin.

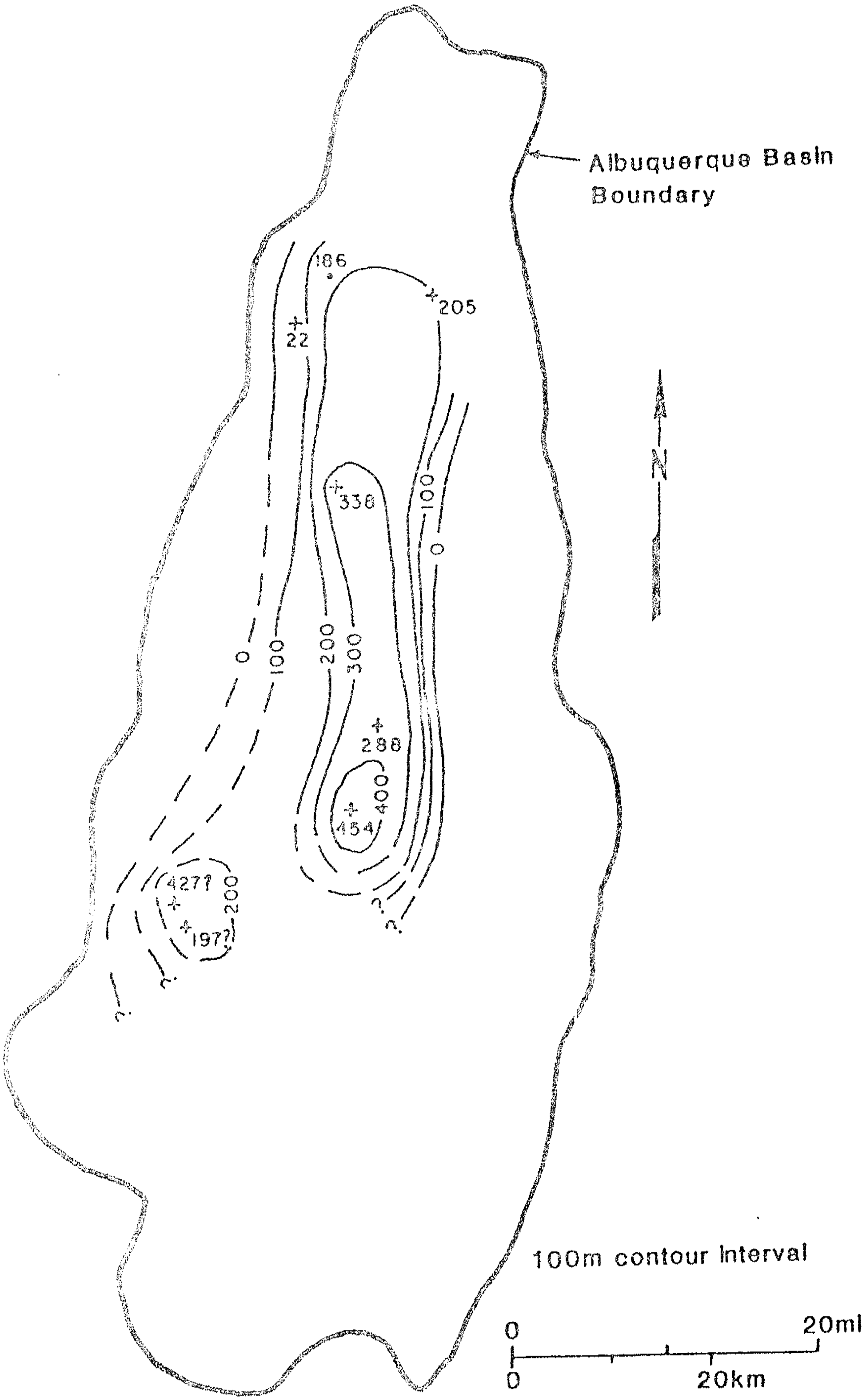


Figure 8-2. Isopach map of Galisteo-Baca Formations. Dashed lines are inferred contours.

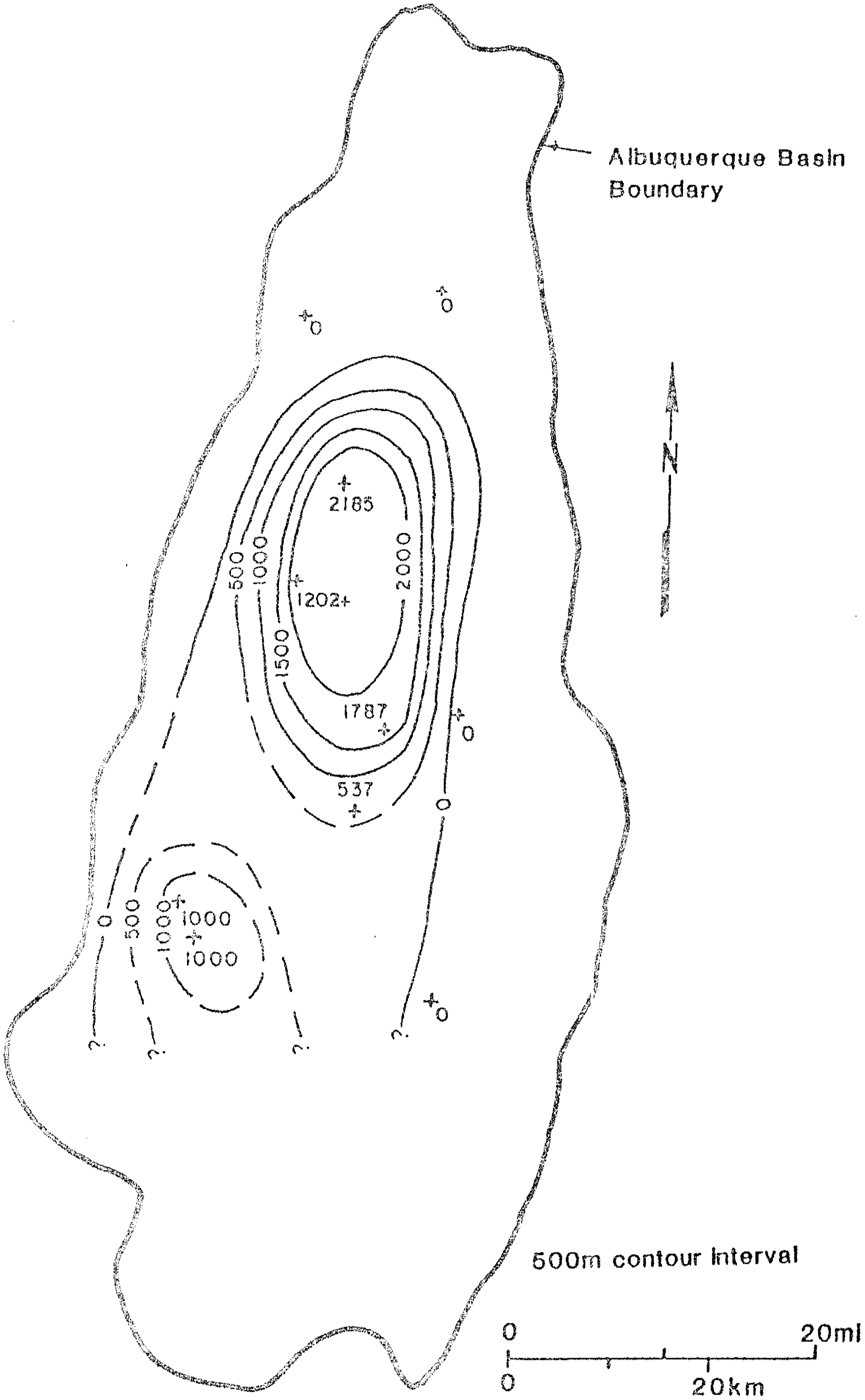


Figure 8-3. Isopach map of unit of Isleta #2 well. Dashed lines are inferred contours.

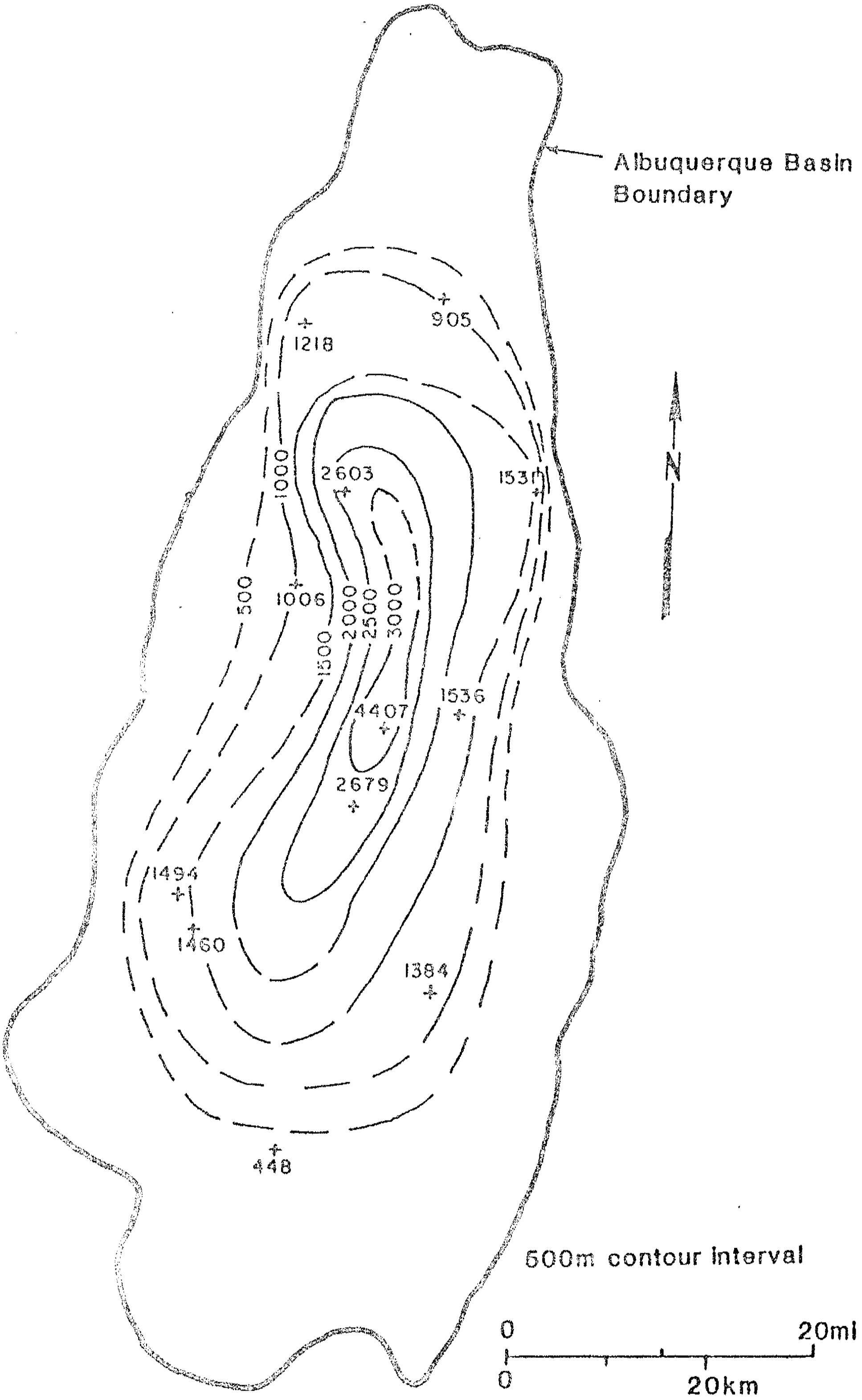


Figure 8-4. Isopach map of Santa Fe Group. Dashed lines are inferred contours.

Galisteo-Baca Formations

These deposits are generally restricted to the western and central portions of the basin and are not recognized along the eastern margin area (unless the Baca/SFG? deposits are part of the Baca Formation; Fig. 8-2). This is based on the Grober and Transocean wells where the Santa Fe Group rests directly on Mesozoic strata. The Galisteo-Baca deposits are thicker in the central basin and thin towards the north. Thicknesses are generally less than 500 m. Two, pre-rift depositional basins are apparent on Fig. 8-2. The northern basin is much better defined because of more well control.

The northern basin is relatively narrow and north-elongated with deposits thickest in its southern end. Due to poor well control in the northeastern area, it is not known how far north the deposits extend. They probably continue into the Hagan basin and tie-in with Galisteo deposits in that region. This pre-rift basin is believed to be part of the Galisteo-El Rito basin of Gorham and Ingersoll (1979).

The southern pre-rift basin is less well defined because of the general absence of well control in the southern part of the Albuquerque basin. These deposits may extend southward and connect with the Baca deposits exposed in the Joyita Hills. This southern pre-rift basin also appears to be relatively narrow and have a northwesterly trend. These deposits in the southern pre-rift basin are included in the Carthage-La Joya basin of Chapin and Cather (1981) and Cather and Johnson (1984).

The areal extent of these pre-rift basins appears to be limited to the present Albuquerque basin. Chapin and Cather (1981) suggest that the Cathage-La Joya and Galisteo-El Rito basins were formed during an early Eocene episode of wrench faulting along the eastern margin of the Colorado Plateau. The Laramide-age wrench faulting generated compression and right-lateral shear that produced a series of northwest- to north-northwest-trending, en echelon basins. They classify these basins as Echo Park-type. This study gives corroborating evidence for these basins by better constraining their areal extent and orientation beneath the Santa Fe basin fill. On Fig. 8-1, the Carthage-La Joya basin and the southerly-extended Galisteo-El Rito basin exhibit a north to northwesterly trend and an en echelon pattern that is consistant with Echo Park-type basins.

Unit of Isleta #2 Well

The unit of Isleta #2 well is significantly thicker than the Galisteo-Baca deposits. In the West Mesa well, it reaches thicknesses up to 2,185 m. Similar to the Galisteo-Baca deposits, this unit is restricted to the western and central portions of the Albuquerque basin and is not recognized along the eastern margin area. Cuttings from the two northern wells (SFP Nos. 1 and 3) show that the Isleta #2 unit does not extend into the northern basin area.

Two depositional basins are distinguishable on the Fig. 8-3. Again, the northern depositional basin is better delineated than the southern depositional basin because of more well control. The southern extent of these deposits is unclear. They may tie-in with outcrops exposed in the Black Butte area and Joyita Hills. The origin of these basins is also unclear. However, due to their similarity to the Laramide-age basins, they are probably remnants of the early basins that continued to subside and receive sediments into the Oligocene as evidenced by the thicker deposits. Since these deposits are not recognized in the SFP Nos. 1 and 3 wells, they were not deposited as far north as the Galisteo-Baca deposits.

Santa Fe Group

Santa Fe Group thickness varies greatly within the Albuquerque basin. Thicknesses range from 1,000 to 2,000 m along the margin areas, to over 4,000 m in the central basin area (fig. 8-4). This is much thicker than the 1,000 to 2,000 m average thickness of the Group as determined by Birch (1982). Santa Fe thicknesses also decrease toward the north and south. The deep inner basin flanked by the ramps leading to the basin margins are clearly illustrated on the the isopach map. However, the two half grabens are not distinguishable on the map because of poor well control in the south basin area. Shell's seismic lines show that the basin fill in the south half-graben is thickest on the west side and that it may be as much as 4,000 m thick.

Upon comparing Figures 8-2 to 8-4, the deeper parts of the Albuquerque basin generally coincide with the deeper portions of the pre-rift basins indicating that the depositonal centers have not changed significantly through time. This suggests that many of the basin-bounding faults were also the basin-bounding faults during Eocene and Oligocene time.

Petrographic Overview

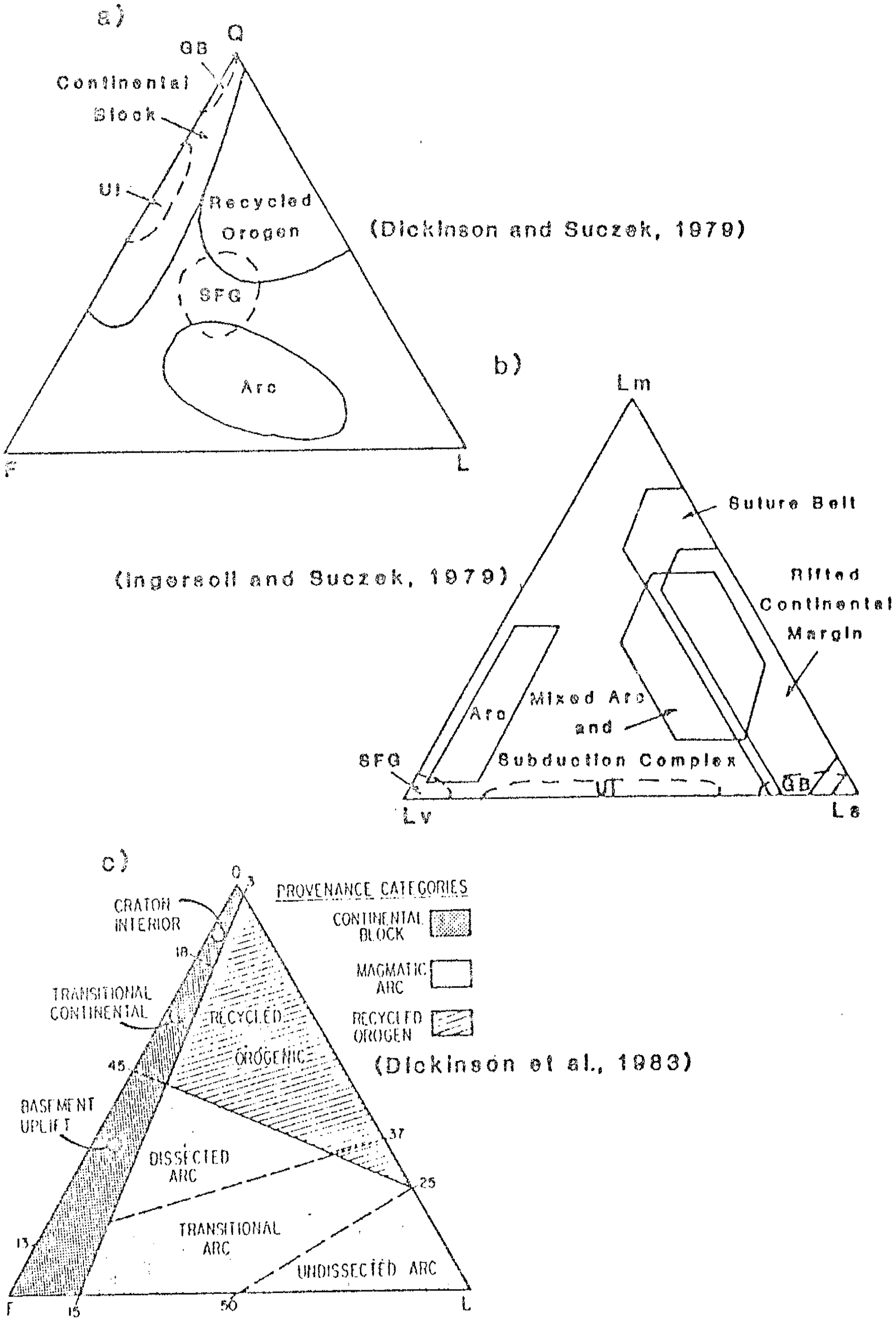
Sandstone compositions of pre-Santa Fe Tertiary rocks show little petrographic change around the Albuquerque basin. They generally contain higher quartz percentages and lower lithic fragment percentages than the Santa Fe samples. These rocks are primarily comprised of monocrystalline quartz and plagioclase. The plagioclase percentages in the Galisteo-Baca samples from the Albuquerque basin are generally higher than plagioclase percentages reported from the Galisteo Formation by Gorham (1979) and the Baca Formation by Johnson (1978). This difference may be due to different source areas. The Galisteo-Baca samples may have been derived primarily from a sedimentary terrane; whereas, the other Eocene formations were derived mostly from a plutonic terrane. Lithic fragments in the Galisteo-Baca samples are usually sedimentary but those in the unit of Isleta #2 well samples typically contain both sedimentary- and volcanic-lithic fragments.

Santa Fe Group samples generally have similar sandstone compositions around the Albuquerque basin. Monocrystalline quartz and plagioclase are usually the dominant detrital grains. Volcanic-lithic fragments are by far the most numerous lithic fragment. On closer examination, however, there are some significant differences both spacially and vertically. Quartz percentages generally increase with depth; whereas, potassium feldspar percentages usually increase upsection. Volcanic-lithic grains are mostly intermediate to silicic lower in the section, but mafic grains become dominant higher in the section. An exception is in the eastern margin area where metamorphic- and plutonic-lithic grains increase upsection and quartz percentages decrease with depth. The most apparent change is seen in rocks from the northwest basin area. Most of the samples from the northwest basin area (except those from the King Ranch) contain very high quartz percentages (some higher than the pre-Santa Fe Tertiary samples) and lower lithic fragments, particularly volcanic-lithics.

The similarity of the pre-Santa Fe Tertiary samples and variations recognized in the Santa Fe samples are directly attributed to the source areas. Pre-Santa Fe Tertiary samples had source areas that did not change significantly with time. On the other hand, Santa Fe samples were subjected to constantly changing source areas as volcanism shifted to more mafic and the Precambrian-cored eastern uplifts became exposed. Thus, there seems to be a close relationship between tectonic setting and sandstone compositions.

Dickinson and Suczek (1979), Ingersoll and Suczek (1979), and Dickinson et al. (1983) have recognized a similar relationship between plate-tectonic setting and sandstone composition. By plotting percentages of detrital grains on triangular diagrams, they found that samples from similar plate-tectonic settings tended to group in similar fields (Fig. 8-5). Pre-Santa Fe Tertiary samples from this study tend to plot in the continental block field (Fig. 8-5a and c). On the LmLvLs diagram (Fig. 8-5b), Galisteo-Baca samples plot near the Ls pole in the rifted continental margin field and unit of Isleta #2 samples group in an region that does not correspond to a plate-tectonic setting. These plots generally correspond to the "correct" plate-tectonic setting as indicated on the diagrams, although the unit of Isleta #2 samples probably should correlate better with an arc setting. This discrepancy is most likely due to mixing of detritus from an arc and continental block.

The upper Santa Fe and most of the lower Santa Fe



gure 8-5. Ternary diagrams indicating plate-tectonic elds. Dashed lines show fields from this study. Fields "a" also apply in "c". GB = Galisteo-Baca field; UI = t of Isleta #2 field; SFG = Santa Fe Group field.

sediments were deposited in a continental rift area which corresponds to a continental block setting. Most Santa Fe Group samples, however, generally plot in or near the arc field (Fig. 8-5a and c). For the most part, samples from the northwest basin area plot in the continental block field. The oldest Santa Fe deposits (>10 Ma) were deposited in a back-arc setting and should plot near the arc field, if a back-arc setting is included as part of an arc orogen. But, if a back-arc setting is considered part of a continental block, then it is incorrectly plotted.

Mack (1984) found these "error populations" to also be characteristic for upper and lower Santa Fe deposits in the southern rift area. He concluded that these "errors" where the result of sediments being derived from source rocks of an older tectonic setting. Thus, it is important to understand the tectonic setting of an area so anomalous sandstones can be identified.

The "erroneous" sandstone compositions in the unit of Isleta #2 well and Santa Fe Group also reflect source terranes that were produced by an older tectonic setting. Prior to Santa Fe time and in early Santa Fe time, arc and back-arc volcanism was dominant in the Albuquerque basin area. In Santa Fe time, these rock types were eroded and deposited in the basin. Although the plate-tectonic setting shifted to a continental rift, the bedrock terranes produced by the previous tectonic setting were the main source area for the Santa Fe sediments. The Santa Fe deposits in the northwest basin fit better in regard to plate-tectonic setting because their source rocks did not include arc-derived deposits.

CHAPTER 9. DEPOSITIONAL HISTORY OF THE ALBUQUERQUE BASIN

Introduction

The depositional history of the basin is based on the observations and inferences discussed in the previous chapters. To more clearly present this history, it has been divided into six stages that range in age from the Eocene to the present. Each stage includes a paleogeographic map that depicts major depositional events for that stage. The legend in the upper right-hand corner of Fig. 9-1 indicates rock types derived from the source areas in all the stages. In the legend, mixed lithologies refer to a combination of volcanic, sedimentary, and Precambrian rocks or all the rock types listed above.

Stage 1 - Galisteo-Baca Deposition

The depositional history begins in the Eocene before formation of the future Albuquerque basin (although this basin is shown with a dashed line for reference, Fig. 9-1). The Galisteo-El Rito and Carthage-La Joya basins were the main depositional centers at this time. The areal extent of the Galisteo-El Rito basin is determined by drawing a line around the oil test wells that contain Galisteo strata; whereas, the areal extent of the Carthage-La Joya basin can only be approximated due to very poor well control. These

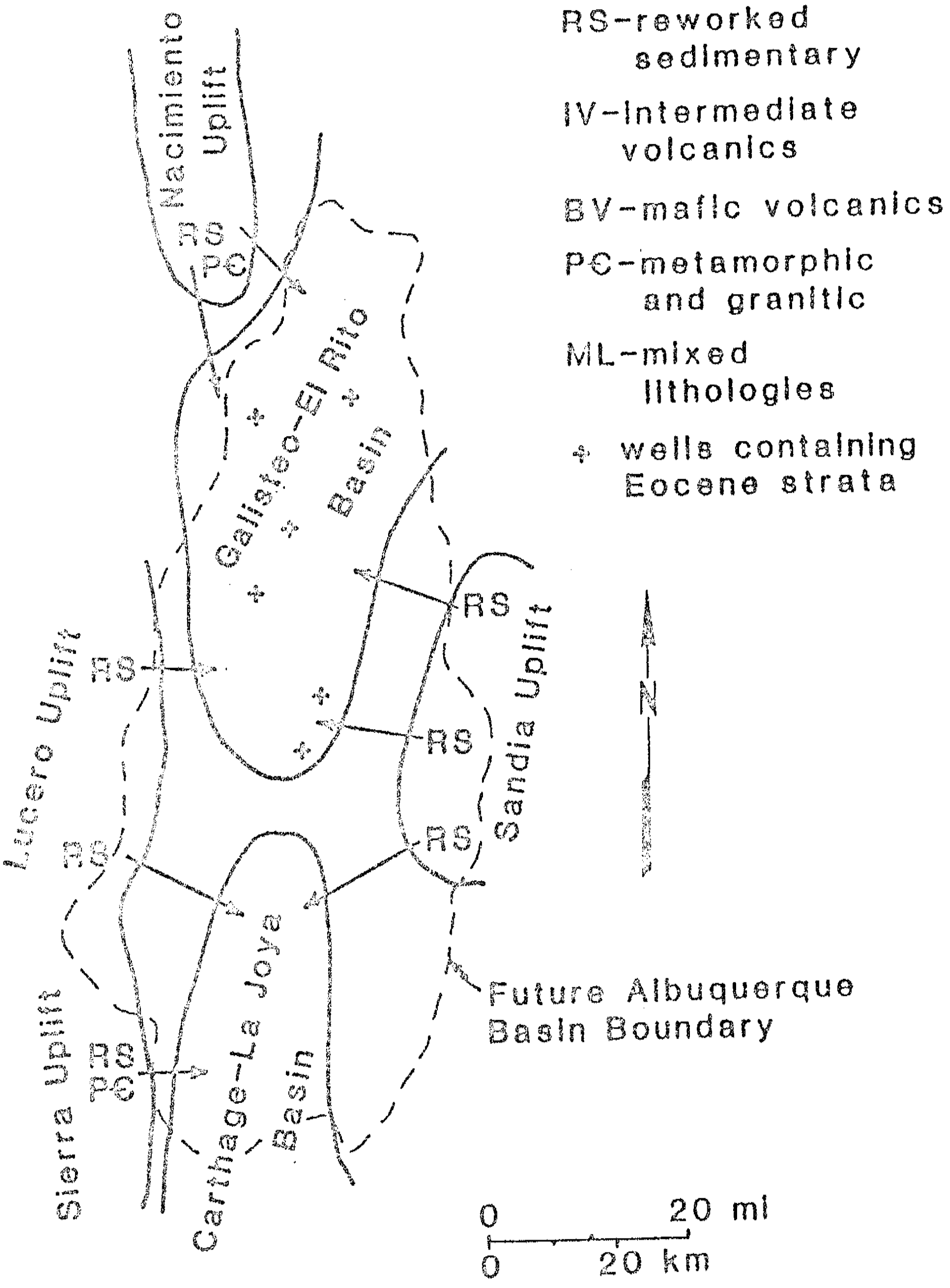


Figure 9-1. Stage I - Galisteo-Baca deposition.

basins formed as a result of Laramide-age wrench faulting along the eastern margin of the Colorado Plateau (Chapin and Cather, 1981). There may also have been a drainage divide that separated the basins positioned along a southwest extension of the Tijeras fault.

Limited paleoflow data for these deposits prohibits definite source area determinations. Gorham (1979) reports the only paleoflow direction for Galisteo outcrops in the Windmill Hill area in the north basin. He measured a southeast flow direction indicating that these deposits were derived from the Nacimiento uplift. However, based on previous work (Kelley, 1977; Gorham and Ingersoll, 1979; Chapin and Cather, 1981; Cather and Johnson, 1984), several positive areas of Eocene age have been recognized around the Albuquerque basin that probably served as source areas. They include: the Nacimiento, Lucero, and Sandia uplifts for the Galisteo-El Rito basin; and the Lucero, Sierra, and Sandia uplifts for the Carthage-La Joya basin. These uplifts were shedding primarily reworked sedimentary and Precambrian detritus into the basins. The deposits reached an accumulated thickness of less than 500 m. This thickness indicates that the basins where relatively shallow when compared to the later basins.

Stage II - Unit of Isleta #2 Well Deposition

Deposits of the Isleta #2 well range in age from Late Eocene to Late Oligocene. At this time it is important to note the extensive volcanism that was occurring southwest of the Albuquerque basin in the Mogollon-Datil field (Fig. 9-2). Great volumes of ash-flow tuff, rhyolite, and basaltic andesite where produced from caldera eruptions and collapses (Osburn and Chapin, 1983). Deposition of these Mogollon-Datil volcanic and associated volcaniclastic units was widespread and extended farther north than the present-day outcrops indicate to include the Sierra and Lucero uplifts. At least one ash-flow tuff was deposited as far north as the location of the Isleta #2 well. There was also another small volcanic center northwest of the basin in the Ortiz Mountains-Cerrillo Hills area, but there is no evidence to suggest that these units were eroded and deposited in the Albuquerque basin.

The earlier Eocene basins continued to subside and receive sediments into the Oligocene, although the northern basin appears to have decreased in size. The areal extent of these basins is not well established, particularly in the southern basin. The basins and margin uplifts must have subsided and rose, respectively, at greater rates than those in the Laramide to account for the greater thickness of the unit of Isleta #2 deposits. Cather et al. (1987) determined

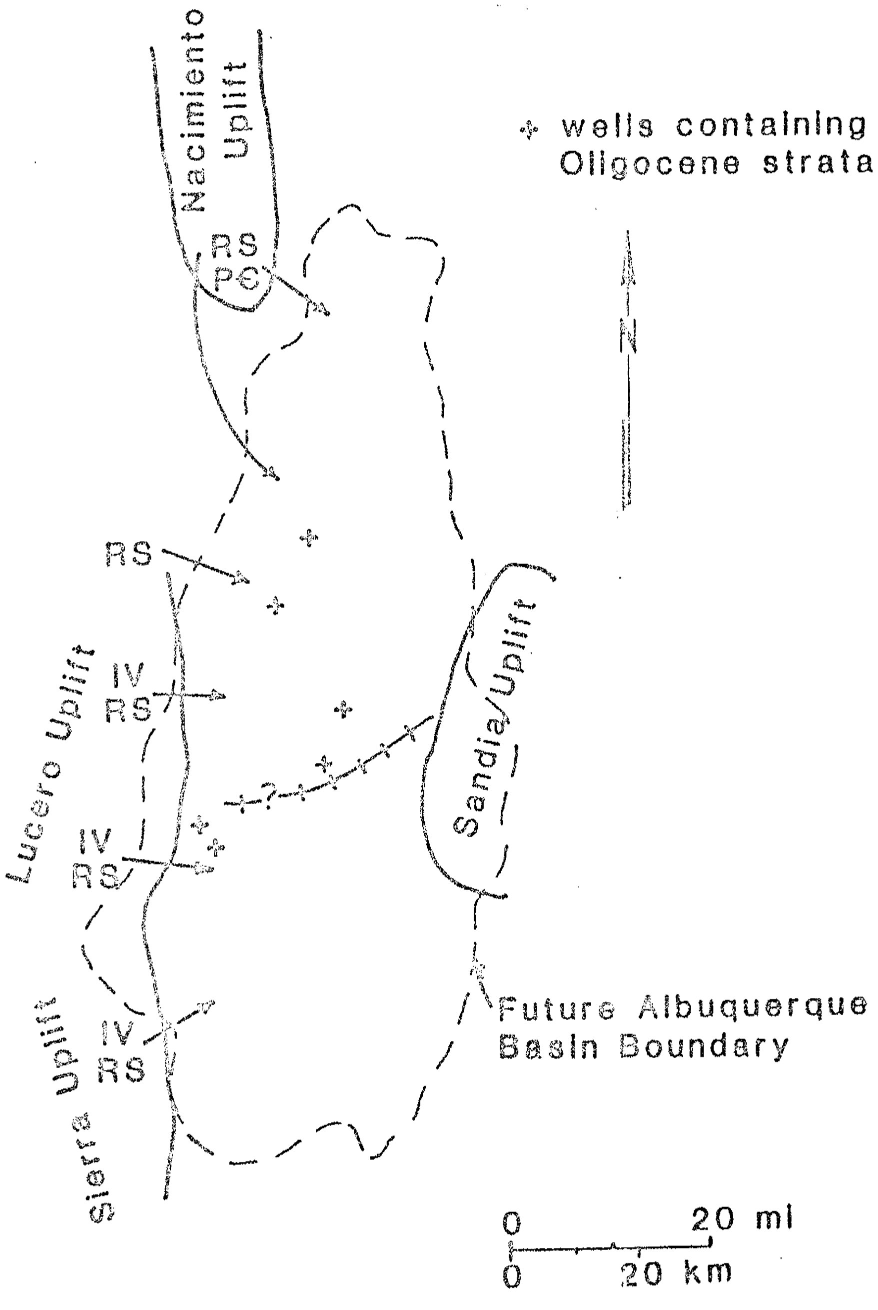


Figure 9-2. Stage II - Unit of Isleta #2 deposition.

that sedimentation rates in the Datil Group (correlative with the lower part of the unit of Isleta #2 well) ranged from 32 to 177 m/Ma.

No paleocurrent data is known from the unit of Isleta #2 well, but the Sierra and Lucero uplifts were most likely the source areas. They contributed primarily reworked sedimentary and intermediate to silicic volcanic detritus into both basins. The Nacimiento uplift probably contributed reworked sedimentary and Precambrian detritus into the northern basin. There is no evidence from this study to suggest that the Sandia uplift was a positive area at this time. However, recent work by Kelley and Duncan (1986) indicate that "uplift and erosion was in progress in the Sandia Mountains near Albuquerque.....at least 30-35 Ma".

Deposition mainly occurred along alluvial aprons that extended out from the uplift areas. It is unknown if volcanism occurred within the basin; however, basaltic andesite flows crop out in the Joyita uplift area and cuttings from the West Mesa and Atrisco wells indicate the possibility of volcanism within the basin. The drainage divide that separated the two basins may have been more pronounced during this stage because it appears that the divide prevented large amounts of volcaniclastic debris from being deposited in the northern basin. This drainage divide was not high enough; however, to have stopped the large ash-flow tuff sheet deposited in the Isleta #2 well area.

Stage III - Early Santa Fe Group Deposition

Initial Santa Fe deposition began between 25 and 30 Ma. It is not known if there was a hiatus between unit of Isleta #2 well deposition and early Santa Fe deposition. Seismic profiles do not indicate a major angular unconformity between these units. As the tectonic regime in the area became more extensional due to back-arc spreading (Morgan et al., 1986), displacement was taken up along pre-existing structures, such as those produced in the Laramide. The Albuquerque basin, in its earliest stage, probably consisted of two basins that corresponded to the northern and southern half-grabens with a drainage divide located along a southwest extension of the Tijeras fault. The areal extent of these basins is unclear, but they may have been more extensive than shown on Fig. 9-3 (the present extent of the Albuquerque basin is shown on the map). However, by about 10 Ma, the eastern uplifts were rising rapidly enough to clearly define the eastern margin region.

Tectonism was relatively low during the early stage of Santa Fe deposition and, accordingly, so were sedimentation rates. In the Zia Formation on the King Ranch, sedimentation rates ranged from 24 to 75 m/Ma. Deposition was occurring primarily within alluvial fans that bordered

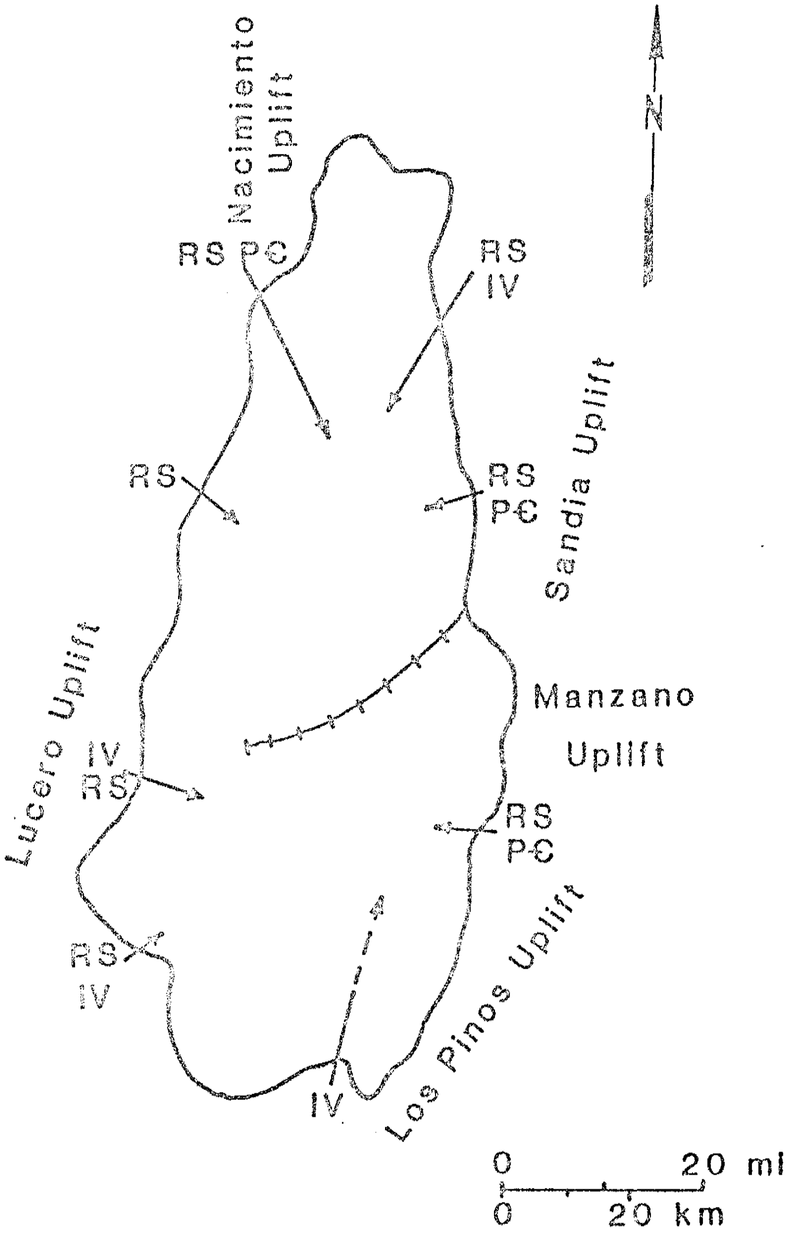


Figure 9-3. Stage III - Early Santa Fe Group deposition. Hatched line indicates drainage divide.

the basin and within large eolian dune fields in the central basin area. Source areas for these sediments in the north basin were the Nacimiento uplift and the northwest margin area (west of the Rio Puerco fault zone). Reworked sedimentary and Precambrian debris were derived from these areas with some intermediate to silicic volcanic detritus shed off the northern Lucero uplift. The southern basin source areas included the Lucero and Joyita uplifts. These areas contributed intermediate to silicic volcanic and reworked sedimentary material. In the southern basin, fluvial systems appear to have transported this material as far north as the Trigo Canyon area. The overlying sedimentary units on the eastern margin uplifts were also eroded and deposited within the basin. By 10 Ma, the Precambrian-core of the eastern uplifts became exposed and metamorphic and plutonic debris began to be shed into the basin.

Each basin may have had closed-basin drainage and perhaps small playas. At least one perennial lake existed in the basin as evidenced in the King Ranch area by the tufa deposits. There may have been other perennial lakes at this time scattered across the basin. Volcanism was relatively low for much of this stage which generally corresponds to the mid-Miocene lull in volcanism for the Rio Grande rift. However, Black Butte (24.3 Ma; Bachman and Mehnert, 1978) and the basalt flow at Trigo Canyon (21.2 Ma) were emplaced just prior to this lull. Other intrusives/extrusives may have also been emplaced at this time, but, if so, they lie buried beneath the bulk of the Santa Fe Group and have not yet been recognized. During this period, the Santa Fe Group probably reached thicknesses of only about 1,000 m as evidenced by the thickness of the Zia Formation recognized in the cuttings of the oil test wells.

Stage IV - Middle Santa Fe Deposition

This is the period (10-5 Ma) when tectonism in the Rio Grande rift was most active as the tectonic regime changed to continental rifting that fragmented the earlier basins. The surrounding uplifts of the Albuquerque basin rose to near their present elevations and the basins subsided at a faster rate. Correspondingly, sedimentation rates were also higher. In the Gabaldon badlands, sedimentation rates were calculated to be 204 m/Ma, but in the central basin area, they may have been as high as 600 m/Ma. This enabled the basin fill to aggrade to an high enough level that eventually buried the drainage divide separating the two basins and formed the single Albuquerque basin of today (Fig. 9-4). The bulk of the Santa Fe Group was deposited at this time, probably to thicknesses of as much as 3,000 to 4,000 m in the central portion of the basin.

Sedimentary, intermediate to silicic volcanic, and

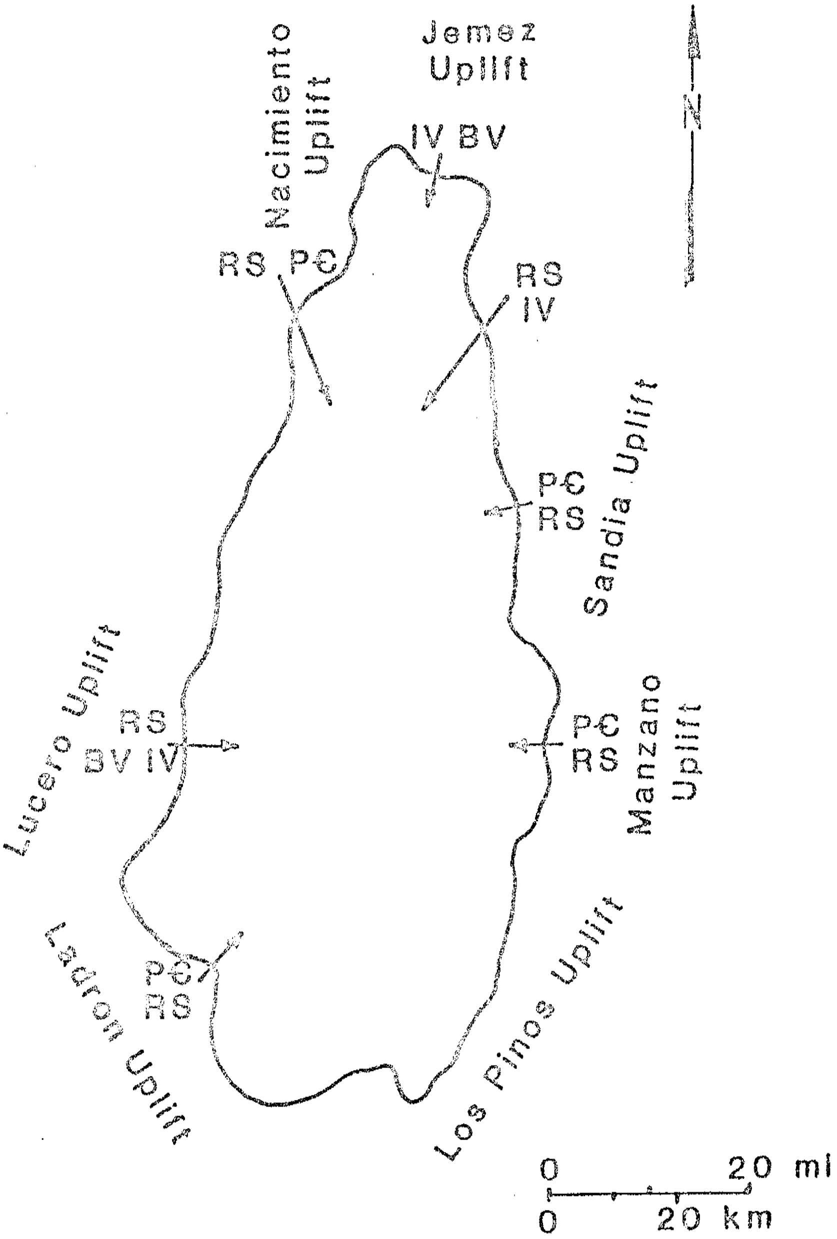


Figure 9-4. Stage IV - Middle Santa Fe Group deposition.

Precambrian debris were derived from the surrounding uplifts. These deposits were mainly laid down as alluvial fans. Two major fluvial systems, one flowing out of the northeast and the other flowing out of the northwest, were also transporting debris from more distant source areas (i.e., San Juan volcanic field) outside the Albuquerque basin. These fluvial systems probably terminated in a large playa area in the southern part of the basin because there is no evidence to suggest that through drainage was established into the Socorro basin until latest Miocene or earliest Pliocene time.

Volcanism also became more active during this stage, both within the basin and along its margins. The composition of the volcanism became more mafic. Eruptions were occurring in the Lucero uplift and within the central portions of the basin. Thus, mafic detritus become more prominent in the basin-fill deposits.

Stage V - Late Santa Fe Deposition

A major change in the depositional pattern occurred at about 5 Ma when drainage in the Albuquerque basin shifted from internal to through-flowing with the integration of the ancestral Rio Grande (Fig. 9-5). Two other ancestral drainages, the Rio Puerco and Rio San Jose, joined the Rio Grande within the Albuquerque basin to form a large

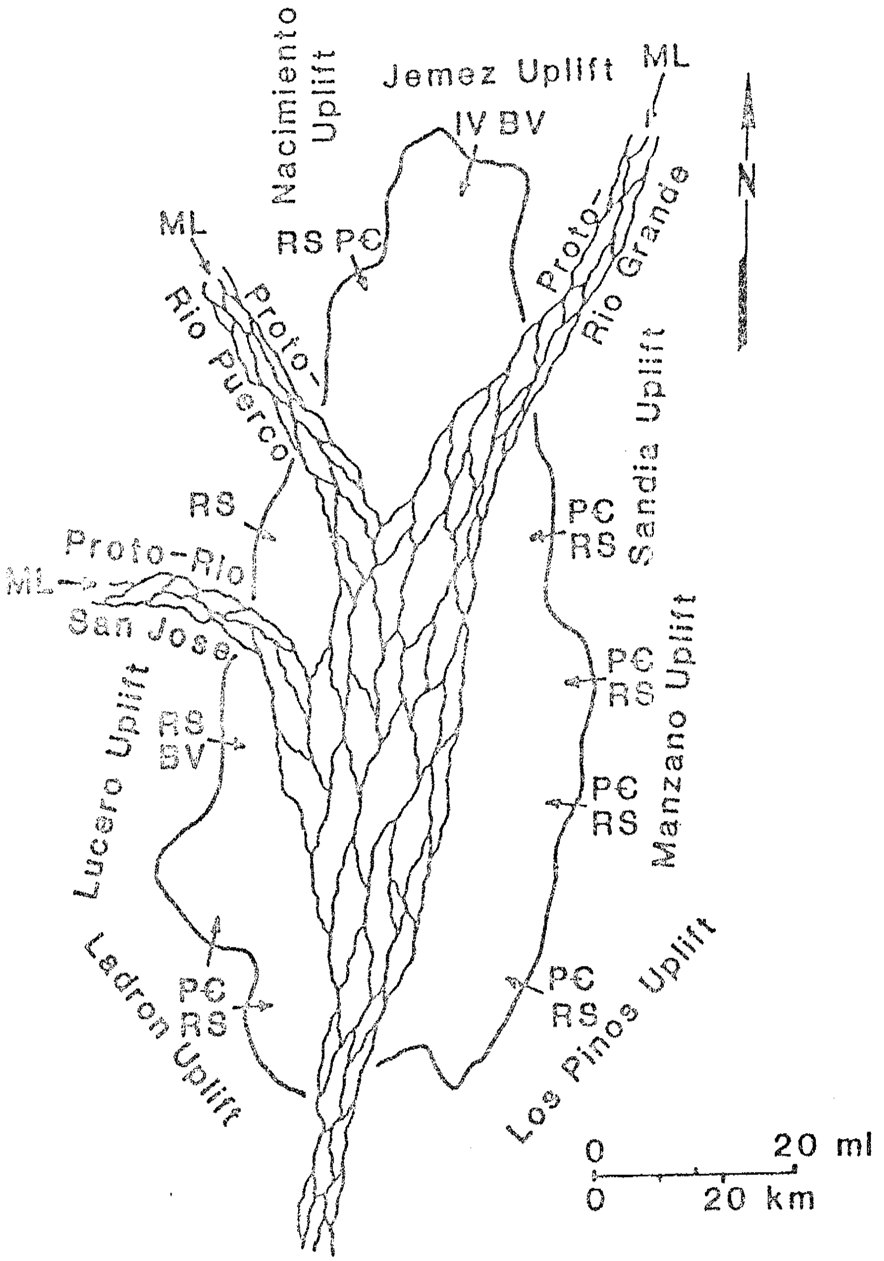


Figure 9-5. Stage V - Late Santa Fe Group deposition.

contributary system. The shifting channels of this system created a large alluvial plain in the central basin floor area.

Both tectonism and sedimentation rates had slowed considerably by early Pliocene time. The accumulated thickness of the upper Santa Fe Group during this time interval (5-0.5 Ma) is only about 100-150 m. This roughly calculates to a sedimentation rate of between 22 and 33 m/Ma. Detritus was continuing to be shed off the surrounding uplifts, but not in the great volumes seen in the previous stage. Alluvial fans did not extend more than about 10 km from the mountain fronts. Most of the deposition was occurring along the braided river systems in the central portion of the basin. These river systems were bringing in detritus of mixed litholgies from considerable distances outside the Albuquerque basin.

Volcanism, primarily mafic, continued both in the Lucero uplift and within the basin. Volcanic ash, erupted from the Jemez caldera and as far away as the Yellowstone area, were also deposited within the basin (Izett, 1981).

Stage VI - Post-Santa Fe Group Deposition

By about 0.5 Ma, another major change in the depositional pattern occurred when the Rio Grande underwent its first major incision episode (Fig. 9-6), perhaps in

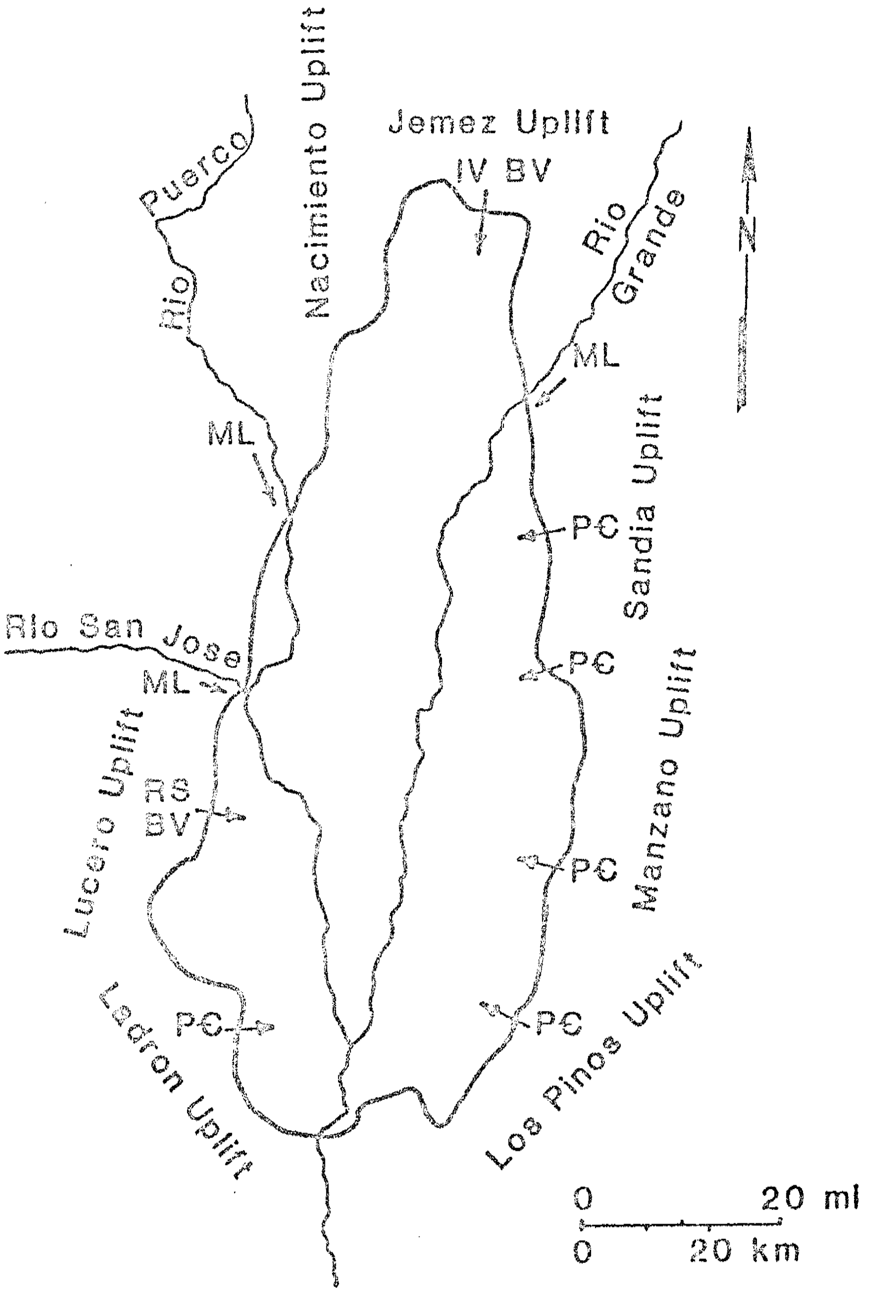


Figure 9-6. Stage VI - Post-Santa Fe Group deposition.

response to becoming integrated with the Gulf of Mexico (Seager et al., 1984). Before this incision event, the ancestral Rio Grande flowed into a large closed-basin area in the present Texas-New Mexico-northern Mexico region near El Paso. This depositional change is a critical event in the late Cenozoic history of the basin because, prior to this time, the basin had been undergoing net aggradation. Subsequently, however, the basin has been subjected to net degradation as several more cycles of river incision produced the present-day inner valley of the Rio Grande. This initial episode of valley entrenchment also marked the end of Santa Fe Group deposition and isolated basin-floor areas such as the Llano de Albuquerque from further amounts of significant deposition.

Tectonism has been relatively low in the past 0.5 Ma. Uplifts around the basin continue to shed detritus into the basin, but not as extensively as before. There are large areas within the basin that are receiving relatively little deposition (i.e., Llano de Albuquerque). However, significant aggradation has occurred in the major drainages during back-filling episodes as inset terrace deposits and undissected valley fill. These fluvial systems are still delivering mixed lithologies derived in part from outside the basin. Volcanism also continued in the northern Llano de Albuquerque from Las Lunas to near Bernalillo, and in the Lucero uplift.

CHAPTER 10. CONCLUSIONS

The Albuquerque basin of central New Mexico consists of a northern, eastward-tilted half graben and a southern, westward-tilted half graben. The transition zone between these two structures occurs along a southwest projection of the Tijeras fault. Each half-graben has an deep, inner graben and relatively shallow, flanking margins. Major-throw faults do not occur along the topographic margins, but further basinward. Based on seismic reflection work by Shell Oil, many of these faults appear listric. The latest Oligocene to middle Pleistocene Santa Fe Group is the major basin-fill unit within the basin.

Pre-Santa Fe Tertiary deposits underlie the Santa Fe Group and indicate the existence of depositional basins that pre-date the Albuquerque basin. These deposits are subdivided into an Eocene unit that is correlative to the Galisteo-Baca Formations and an overlying unit, the unit of Isleta #2 well, that is correlative to the Datil Group and an overlying sequence of Oligocene volcanic rocks that was formerly included in the upper Datil (see revised Datil Group definition of Osburn and Chapin, 1983). The unit of Isleta #2 contains an ash-flow tuff dated at 36 Ma. It is generally difficult to distinguish between these units in well cuttings, but petrographic analysis of thin sections show that Galisteo-Baca deposits are volcanic-poor (<1%) and quartz-rich (70-80%); whereas, the unit of Isleta #2 contains some volcanic debris (>10%), and lesser quartz (50-60%). Pre-Santa Fe Tertiary deposits are restricted to the western and central portions of the basin and are not recognized in the eastern margin area. Thicknesses are up to 454 m in the Galisteo-Baca deposits and as much as 2,185 m in the unit of Isleta #2 well.

In well cuttings, the pre-Santa Fe Tertiary deposits also can be distinguished from the Santa Fe Group by better induration and a color change from reddish orange to more purplish red. Thin section analysis shows that Santa Fe sediments contain typically less quartz (30-50%) and higher lithic-fragment percentages (10-20%), particularly mafic volcanics (80-90% of all lithic fragments). These sediments consist mainly of quartz and plagioclase with the lithic fragments dominated by volcanics. Quartz percentages generally increase with depth; whereas, mafic volcanics decrease with depth. The Santa Fe Group ranges in thickness from 1,000 to 2,000 m in the basin margin areas to as much as 4,407 m in the central part of the basin. This thick section was penetrated in the Isleta #2 well and it is the thickest documented section of the Santa Fe Group in the entire Rio Grande rift.

The thickest exposed section of the Santa Fe Group occurs in the Gabaldon badlands in the southwestern basin area. The measured thickness is 1,138 m, but the section may be as much as 1,800 m thick. The section is divided into four mappable units. Fossils from the lower to middle part of the exposed section indicate an age of 7-9 Ma for these deposits, and indicates a sedimentation rate of 204 m/Ma.

Galisteo-Baca deposits were derived mainly from sedimentary and plutonic terranes. Unit of Isleta #2 deposits were derived from sedimentary and silicic to intermediate volcanic terranes. Early Santa Fe deposits were derived mostly from sedimentary and silicic to intermediate volcanic source areas. Later in Santa Fe time, mafic volcanic and plutonic/metamorphic source areas were also contributing detritus into the basin. Sedimentation rates during early Santa Fe deposition ranged from 24 to 74 m/Ma, but by middle Santa Fe time, they may have increased to as much as 600 m/Ma. This high rate of basin aggradation corresponds to the late Miocene period of greatest tectonic activity.

During early Santa Fe deposition (30-15 Ma), the Albuquerque basin probably consisted of two depositional basins. With the increase in sedimentation rates after about 10 Ma, these basins filled to the point where deposits coalesced to form a single aggradational feature. All of these early basins had internal drainage. In the southeast basin area, Santa Fe sediments indicate that the Precambrian core of the eastern uplifts were probably not exposed until about 10 Ma. Prior to 7-9 Ma, the Lucero uplift was covered by Upper Cretaceous strata and by one or more ash-flow tuff sheets. These deposits have since been removed by erosion. At least one ash-flow tuff sheet extended at least as far north as the Isleta #2 well.

Development of through-flowing drainage in the Albuquerque basin and integration of an ancestral upper Rio Grande system occurred early in late Santa Fe time about 5 Ma. Two other ancestral drainages joined the Rio Grande from the west and northwest to form a large basin-floor alluvial plain. Late Santa Fe time experienced sedimentation rates that ranged from 22 to 33 m/Ma.

Santa Fe deposition ended about 0.5 Ma when the Rio Grande began a series of downcutting episodes that eventually formed the present inner valley of the Rio Grande. Santa Fe time was characterized by basin aggradation; however, since Santa Fe time, fluvial dissection has resulted in net degradation of basin fill.

Further work is needed to compile more detailed maps and cross sections of the Albuquerque basin that show basin-fill facies distributions and intrabasinal structures based on geophysical and oil test well data. Studies on heavy minerals and geochemistry of the basin fill sediments may be useful in refining source area determinations. Further work is also needed on comparing the Eocene Galsiteo and Baca Formations in the Albuquerque basin with the Eocene San Jose Formation in the San Juan Basin. Recent studies suggest that the San Jose Formation was deposited by a large fluvial system which may have terminated in the present Albuquerque basin area. A detailed examination of the upper one or two thousand meters of the Santa Fe Group utilizing all available water-well data would be very useful for groundwater studies as well as for development of basin-structure and facies-distribution maps and cross sections.

APPENDIX I

MEASURED SECTIONS

Las Lunas volcano

Belen

Bernardo

Gabaldon badlands

Bobo Butte

Los Lunas Volcano Section

Three subsections were measured in the exposed Santa Fe Group sediments located on the northwest flank of the Los Lunas Volcano. Subsections 1 and 2 were measured on the east-facing wall of the deeply incised arroyo and include the angular unconformity at the base of the subsection and a 1.1 Ma ash bed (dated by Izett, 1981) near the top of the subsection. Subsection 3 was measured on the northwest flank of the volcano and includes the andesite flow of the volcano. These subsections partly overlap making correlations between units possible.

Subsection 1

Subsection 1 was measured to better document the stratigraphic relationships between the ash bed, upper Santa Fe Group units, and younger overlying units than were possible at the top of Section 2. It is located in the bulldozer cut on the west side of the arroyo and begins at the top of the vegetated dunes.

Unit	Lithology	Thickness	
		ft	m
1.2	Fine-grained sand, pale brown (10YR 6/3). Sand is weakly indurated and well sorted. Scattered pebbles and cobbles occur throughout unit. This unit forms coppice dunes. Slope-former. Possibly rests on the Llano de Albuquerque surface.	13	4.0
1.1	Mostly fine-grained sand and silty sand, very pale brown (10YR 7/4) to reddish brown (5YR 5/4). Top 3 m contain 3-4 stripped surfaces that may represent a series of paleosols. Andesitic cobbles, small boulders and calcic zones and/or concretions mark the top of each stripped surface. Uppermost stripped surface maybe the Llano de Albuquerque surface. Lower 9 m of unit is covered by reworked bulldozer sediments that makes description difficult. Lowermost bed is a 0.5 m thick ash that has been dated a 1.1 Ma. The flat-lying ash bed was deposited in a swale cut into dipping beds. About 1.5 m of fine-grained sand overlie ash bed. This unit represents the top of Santa Fe Group deposits. Weak cliff-former. Partly overlies clay bed (unit 2.7) and basalt boulders.	40	12.2
	Total thickness of subsection 1:	53	16.2

Subsection 2

Subsection 2 is located about 90 m north of subsection 1. It begins on the top of the olive yellow clay bed below the eolian deposits and extends down to the angular unconformity exposed along the present arroyo bottom. Minor north-trending faults disrupt section, but they were avoided during measurement.

Unit	Lithology	Thickness	
		ft	m
2.7	Mostly fine to medium grained sand with lesser clay beds. Sand beds are light gray (10YR 7/2) to light brown (7.5YR 6/4), weakly indurated, locally crossbedded, 60-120 cm thick and locally contain scattered pebbles and pebbly lenses. Clay beds are reddish yellow (5YR 6/6) to light brown (7.5YR 6/4), mostly massive, and generally 60-90 cm thick. The 1.1 Ma ash bed ocurrs in a swale that lies about 6 m to the south and can be projected into unit 2.7 about 3 m from the top. A 1 m thick, olive green (2.5Y 6/6) clay bed caps the unit. Cliff-former. Scoured base.	24	7.3
2.6	Alternating beds of clay and fine-grained sand. Clay beds are mostly olive green (2.5Y 6/6) with minor reddish brown (2.5YR 5/4), massive and up to 1 m thick. Sand beds are light yellow brown (10YR 6/4) to light brown (7.5YR 6/4), well sorted, 30-60 m thick and locally crossbedded. Olive yellow clay beds (usually 2-3) clearly distinguishes this unit. Cliff-former. Sharp basal contact.	29	8.8
2.5	Alternating beds of fine- to medium-grained sand and clay. Sand beds are very pale brown (10YR 8/3) to pale yellow (2.5Y 8/4), weakly to cross laminated, locally poorly sorted and weakly indurated. Sand bed thickness increases from 30-60 cm near base up to 2 m at the top. Locally, sand beds contain scatterd pebble-size apache tears (obsidian). Clay beds are red (2.5YR 4/6) to yellowish red (5YR 5/6), 30-60 cm thick and locally laminated. Rare, <30 cm thick, well indurated sandstone beds also occur. Sand sample LL-2 is from uppermost part of unit. Weak cliff-former. Sharp basal contact.	45	13.7
2.4	Medium- to very coarse-grained sand, very pale		

	brown (10YR 7/4) to light brown (7.5YR 6/4). Sand beds are very planar crossbedded, moderately indurated, and contain subangular to rounded of abundant pumice with lesser clay chips, chert and quartz. The top 60 cm becomes silty and may be a paleosol. Cliff-former. Scoured base.	20	6.1
2.3	Fine- to coarse-grained sand, light brown (7.5YR 6/4) to very pale brown (10YR 7/4). Sand beds are massive, moderately sorted and contain scattered pebbles. Clast lithologies are similar to those in unit 2.1. Cliff-former. A well indurated gravel bed marks the scoured base.	25	7.6
2.2	Mostly fine-grained, well sorted sand with rare clay interbeds. Sand beds are reddish brown (7.5YR 6/6), weakly indurated, locally weakly laminated to crossbedded and contain very scattered pebbles and calcium carbonate concretions. Portions of unit poorly exposed. Clay beds are reddish yellow (5YR 6/6), <30 cm thick and weakly laminated. Slope-former. Scoured basal contact.	96	29.3
2.1	Silty sand fines upward into sandy clay. Silty sand beds are reddish yellow (7.5YR 6/6), planar crossbedded and contain subangular to subrounded pebbles and rare cobbles of chert, quartz, Cretaceous sandstone, basalt, granite and limestone. Sandy clay bed caps unit and is yellowish red (5YR 5/6), massive and about 1 m thick. Cliff-former. Silty sand bed rests on angular unconformity with a very scoured basal contact. Channel cuts into the underlying unit are up to 3 m deep with silty sand filling channels.	7	2.1
	Total thickness of subsection 2:	246	75

The beds that underlie the angular unconformity dip between 30 and 40° to the northeast and consist of pinkish white (7.5YR 8/2) to light brown (7.5YR 6/4), fine- to coarse-grained sand with pebble lenses and pumaceous zones. Sand sample LL-1 is from this steeply-dipping unit.

Subsection 3

Subsection 3 was measured across the arroyo from subsection 2 on the northwest flank of Los Lunas volcano.

The top of this subsection is at the Santa Fe Group/andesite contact and the base is the lowermost olive green bed that is equivalent to the base of unit 2.6.

Unit	Lithology	Thickness	
		ft	m
3.8	Fine- to medium-grained sand with silt and clay interbeds. Sand and silt beds are very pale brown (10YR 8/3) to light yellow brown (10YR 6/4), locally ripple laminated, up to 1 m thick and locally contain calcium carbonate nodules near top. Clay beds are light brown (7.5YR 6/4) to brown (7.5YR 5/4), up to 60 cm thick and locally laminated. Upper contact with andesite is uneven and contains a 30 cm thick, yellowish red (5YR 5/6) baked zone with calcium carbonate nodules. No soil recognized at this contact. Overlying andesite is gray to light purple, and dense. Cliff-former. Sharp basal contact.	20.5	6.2
3.7	Mostly medium- to coarse-grained sand with minor clay interbeds. Portions poorly exposed. Sand beds are light yellow brown (10YR 6/4) to light brown (7.5YR 6/4), moderately to well sorted, 90-120 cm thick, locally trough crossbedded and locally contain scattered pebbles. Clast types are similar to those in unit 3.4. Clay beds are reddish brown (5YR 5/4) to brown (7.5YR 5/4), 30-60 cm thick, and can be lenticular. Slope-former. Sharp basal contact.	63	19.2
3.6	Fine- to medium-grained sand with minor clay interbeds. Sand beds are pale brown (2.5YR 7/4) to light brown (7.5YR 6/4), mostly well sorted, locally trough crossbedded and locally contain granule and pebbly lenses. Clay beds are similar to those in unit 3.7. Top 2 m grades into silty sand may represent a buried soil. Sand sample LL-4 is from lower part of unit. Slope-former. Sharp basal contact.	35.5	10.8
3.5	Mostly medium- to coarse-grained sand with minor silt and clay interbeds. Sand beds are brownish yellow (10YR 6/6) to light gray (10YR 7/2), trough and planar crossbedded, 60-90 cm thick, well sorted and contain lenses of pebble- to cobble-size clasts. Clasts are similar to those in unit 3.4. Rare silt and clay beds are reddish brown (5YR 5/4) to light gray (10YR 7/2) and 30-60 cm thick. Slope-former. Sharp basal contact.	27	8.2

3.4	Medium- to coarse-grained sand, light brown (7.5 6/4) to light gray (10YR 7/2). Sand beds are well sorted, trough crossbedded and contain abundant pebbles and pebbly lenses. Pebbles are subangular to well rounded and include chert, quartz, basalt, granite, reworked Santa Fe Group sandstone, Cretaceous sandstone, petrified wood and rhyolite. Cliff-former. Scoured basal contact.	16.5	5
3.3	Alternating beds of fine- to coarse-grained sand and clay. Sand beds are very pale brown (10YR 7/4) to pale yellow (5Y 8/4), 30-90 cm thick and locally trough crossbedded. Upper sand beds contain scattered pumice fragments. Clay beds are reddish brown (5YR 4/3), 30-60 cm thick and weakly laminated. Rare well cemented, <30 cm thick, coarse-grained sandstone beds and lenticular calcium carbonate zones also occur. Cliff-former. Sharp basal contact.	24	7.3
	Offset section 60 m to the west.		
3.2	Fine- to coarse-grained sand with minor silty sand and clay interbeds. Sand beds are very pale brown (10YR 7/4) to reddish yellow (7.5YR 7/6), moderately to well sorted, 90-120 cm thick, mostly massive but locally trough crossbedded or laminated and contain scattered pebbles and mudballs. Pebbles are similar to those in unit 3.4. Clay and silty sand beds are strong brown (7.5YR 5/6) to brownish yellow (10YR 6/6), weakly laminated to massive and 30-60 cm thick. Less than 30 cm thick, nodular calcium carbonate beds occur in the middle part of unit. Sand sample LL-3 is from this unit. Slope-former. Scoured basal contact.	86	26
3.1	Same as unit 2.7.	24.5	7.5
	Total thickness of subsection 3:	297.0	90.2
	Total thickness of the three Los Lunas subsections:	596.0	181.7

Belen Section

This section includes the Llano de Albuquerque and the upper Santa Fe Group deposits exposed along the east-facing escarpment just west of I-25 near Belen. The section is located near the Socorro/Valencia county line (see Plate 1 for location) and is described from the top of the Llano de Albuquerque surface down.

Unit	Lithology	Thickness ft	m
1.13	Mostly fine-grained, well sorted sand and silt near top; coarsens down to poorly sorted, fine- to coarse-grained sand with scattered pebbles at base. Light gray (2.5YR 7/2) to light brown (7.5YR 6/4). A 1.5 m thick, plugged, pedogenic stage III-IV calcic horizon occurs in center portion of unit. This horizon forms the white-colored zone along the top of the cliff. Bottom 60 cm contains a basal conglomerate with clasts up to 45 cm in dia. Cliff-former. Scoured basal contact.	17.5	5.3
1.12	Clay, strong brown (7.5YR 5/6) to reddish brown (5YR 5/4). Beds are 60 cm thick and contain discontinuous zones of calcium carbonate concretions. Cliff-former. Scoured base.	10	3
1.11	Fine- to medium-grained sand with minor silty sand, pebbly conglomerate and clay interbeds. Sand beds are very pale brown (10YR 7/4) to light yellowish brown (10YR 6/4), 60-90 m thick, weakly cemented, locally crossbedded, moderately to well sorted and locally contain scattered pebbles and pebble lenses. Clasts are similar to those in unit below with the addition of Grants obsidian. Clay beds are light brown (7.5YR 6/4) to reddish brown (5YR 5/4), up to 60 cm thick and locally laminated. Well cemented, sandstone beds and lenses (less than 15 cm thick) occur near base. Generally a slope-former. Sample B-5 is from capping sand bed. Scoured base.	68	20.7
1.10	Mostly fine to medium-grained sand with scattered, ledge-forming, coarse-grained sand and pebble lenses and minor chert. Sand beds are similar as those above but do not contain Grants obsidian. Calcium carbonate concretions occur in lower part of		

sand beds. Clay beds are similar to those above. Lower 120 cm contains a well-cemented bed that grades up from low-angle crossbedded medium-grained sandstone to pebbly and cobbly conglomeratic sandstone. Clasts are rounded to well-rounded and contain chert, quartz, granite, mudballs, tuff, basalt, andesite, petrified wood, Cretaceous sandstone, and limestone. Unit has a scoured base and is usually a ledgy slope-former. 27 8.2

1.9 Mostly fine- to medium-grained sand with a capping and basal clay bed. Sand beds are yellowish red (5YR 5/6) to light yellowish brown (10YR 6/4), commonly trough crossbedded, moderately to well sorted, 30-60 m thick, locally laminated, weakly indurated and contains well-cemented, medium-grained sandstone lenses near base. Clay beds are light brown (7.5YR 6/4) to pink (5YR 7/4), locally laminated, 60-90 m thick and locally silty. Slope-former with rare ledges. Sharp basal contact. 32 9.8

1.8 Fine-grained sand and silt upper 4 m and medium- to coarse-grained sand with pebbles in lower 4 m Sand and silt beds are reddish yellow (7.5YR 7/6) to very pale brown (10YR 7/4), moderately to well sorted, and 60-90 m thick. Coarse-grained, less than 30 m thick sandstone lenses and disseminated calcium carbonate zones occur in middle part of unit. Clasts are similar to those above. Sand beds are commonly trough and planar crossbedded near base. Weak cliff-former.
Scoured base. 23.5 7.1

1.7 Clay with minor sandstone lenses. Clay beds are light brown (7.5YR 6/4) to reddish yellow (5YR 6/8), 30-90 m thick, and contain 10 cm thick zones of calcium carbonate. Fine-grained sandstone lenses are pink (7.5YR 7/4) to light brown (7.5YR 6/4), well-cemented and well sorted. Cliff-fromer. Sharp basal contact. 20.5 6.2

1.6 Moderately to well sorted, loosely consolidated, medium- to coarse-grained sand with well cemented gravel and very coarse-grained sandstone lenses. Sand beds are light brown (7.5YR 6/4) to very pale brown (10YR 7/4), locally trough and planar crossbedded and 90-120 cm thick. Clast types are similar to those in unit 1.11. Weak, ledgy cliff-former. Scoured base. Sand sample B-3 is from upper third of unit. 56.5 17.2

1.5 Sand, silty sand, gravelly sand and clay interbeds.

	Sand is poorly sorted, loosely consolidated and fine- to coarse-grained. Sand beds are pinkish gray (7.5YR 7/2) to white (5YR 8/1), up to 2 m thick, locally crossbedded and contains scattered pebbles. Clast types are similar to those in unit 1.11. Unit is capped with a 2 m thick, red (2.5YR 5/6), weakly laminated, clay bed. Cliff-former. Scoured base. Sand sample B-2 is from upper part of unit.	28	8.5
1.4	Clay with fine-grained sand and silty sand interbeds. Clay beds are yellow red (5YR 5/8), 30-90 cm thick and coarsen upward into silty sand in upper 2 m. Silty sand and sand beds are poorly to moderately sorted, reddish yellow (7.5YR 7/6) and locally occuras well cemented lenses. Cliff-former. Sharp basal contact.	18	5.5
1.3	Mostly sandy silt and silt with lenses of medium- to coarse-grained sandstone. Sandy silt and silt beds are reddish yellow (7.5YR 6/6) to very pale brown (10YR 7/4), 30-90 cm thick and weakly laminated. Well cemented sandstone is light brown (7.5YR 6/4) to pinkish white (7.5YR 8/2), <30 cm thick and locally contain clay rip-up clasts. Unidentifiable fossilized bone fragments were recovered from lower part of unit. Ledgy cliff-former. Sharp basal contact.	44	13.4
1.2	Mostly medium- to very coarse-grained sand with rare clay lenses. Sand beds are light gray (2.5YR 7/2) to very pale brown (10YR 7/4), gravelly, 60-90 cm thick, moderately to well sorted, and locally are planar and trough crossbedded. Gravel clasts are 10-12 cm dia., subrounded to rounded and include chert, tuff, quartz, andesite, granite, petrified wood and basalt. Clay beds are pink (7.5YR 8/4), <30 cm thick and weakly laminated. A 18 cm thick calcium carbonate layer caps the unit. Imbricated clasts show a southerly flow direction. Sample B-1 is from top of unit. Weak cliff-former. Scoured base.	13.5	4.1
1.1	Clay, silt, and fine-grained sand interbeds. Clay and silt beds are red (2.5YR 5/6) to light reddish brown (5YR 6/4), 30-60 cm thick, locally laminated and contain scattered calcium carbonate concretions. Sand beds are light brown (7.5YR 6/4) to reddish yellow (5YR 6/6), 30-60 cm thick, well sorted, loosely consolidated and locally cross laminated. A 60-90 cm thick, planar cross-bedded, medium- to coarse-grained sandstone bed with		

	very coarse clay rip-up clasts occurs in the middle part of the unit. The lower 3 m of unit contains a zone disturbed by a bulldozer. Cliff-former. Section ends where buried by colluvium at base of cliff.	26.6	8.1
	Total thickness:	385.1	117.1

Bernardo Section

This section begins on top of hill and includes Rio Grande ancestral river facies. It only contains a part of the ancestral-river facies. The section located in a sand and gravel quarry just north of the I-25/U.S.60 interchange near Bernardo (see Plate 1 for location).

Unit	Lithology	Thickness	
		ft	m
1.5	Massive, fine- to medium-grained sand, gray pale brown (10YR 7/8). Very loosely consolidated and well sorted with scattered coarse-grained sand concretions and red clay balls. Locally laminated and cross-bedded. Includes a 30 cm thick disturbed zone on top. Scoured basal contact.	3.1	1.0
1.4	Massive, jointed clay, weak red (2.5YR 5/2). Bedding poorly expressed. Unit is cut-out on both sides in about 5 m and filled with overlying unit 1.5. Sharp basal contact.	3.2	1.0
1.3	Mostly massive, loosely consolidated, fine- to medium-grained sand, very pale brown (10YR 7/3). Near top, a trough crossbedded unit caps the massive unit and it is in turn capped by a laminated sand. Near base, massive beds grade into a 30 cm thick, well cemented, laminated, fine- to medium-grained sandstone. At the base, sand is very coarse to granular and includes calcium carbonate chips. Scoured basal contact.	7.3	2.2

Section offset 3 m to the north along clay contact.

1.2 Massive, jointed clay, weak red (2.5YR 5/2) with discontinuous interbeds of contorted, 9-12 cm thick, pale red (2.5YR 6/2) clay laminae. Locally, clay ranges in color from light reddish brown (5YR 6/3) to pink gray (5YR 7/2). Sharp basal contact. 6.2 1.9

Section offset 15 m to the north along clay contact.

1.1 Medium- to coarse-grained, trough crossbedded, clean, loosely consolidated sand, light gray (10YR 7/2) with pebble and cobble lenses. Clasts are up to 50 cm in dia. and include chert, granite, silicic to mafic volcanic, sandstone, and quartz (no obsidian noted). CLasts are up to boulder size and are composed of clay and silty clay. Imbrications of clasts show a south to southeast flow direction. Crossbeds are up to 40 cm thick. Unit capped with a 30 cm thick, weakly laminated, pinkish gray to light gray (7.5YR 7/2 - 10YR 7/2) silty clay. This silty clay unit grades down into the trough crossbedded sand. Bottom is buried. Sample BE-1 is from this unit. 12.8 3.9

Total Thickness: 32.6 10.0

Gabaldon Badlands Section

This section includes all four units mapped in the area. The section is located on Plate II and begins on top of capping surface at the west end of the exposed section.

Unit	Lithology	Thickness ft	Thickness m
4.3	Alternating beds of fine- to coarse-grained sand with conglomeratic lenses, silty sand and clay that show a general upward coarsening. Clasts are up to small boulder-size (30 cm in diameter), but mostly in the pebble to small cobble range. Shape and lithologies of clasts are similar to unit 4.1 as are the colors and textures of the beds. Unit is capped with a 60-90 cm thick stage III-IV calcic horizon. Samples GB-15, 15a, and 17 are from this unit. General cliff-former. Gradational		

basal contact. 233 71

4.2 Sand and pebbly sand with interbeds of clay. The top and basal part of the unit contains a 3 m thick sequence of alternating fine-grained sand and clay. Sand beds are up to 1 m thick, crossbedded, moderately to well sorted, pinkish-gray (7.5YR 7/2) to very pale brown (10YR 7/4). Clasts are commonly pebble-size, but may be up to cobble-size. Clast lithology similar to unit 4.1. Clay beds are 30-60 cm thick, reddish brown (5YR 5/4) to reddish yellow (5YR 6/6) and locally laminated. White (10YR 8/1), 8 cm thick, platy calcareous claystone beds occur scattered throughout unit. The unit is a slope-former, except for the top and basal beds. Sample GB-16 is from this unit. Gradational basal contact. 160 49

4.1 Fine to very coarse sand and conglomerate with few silt and clay interbeds. Sand beds are weakly cemented, light gray (7.5YR N7/) to reddish yellow (5YR 6/6), up to 1.5 m thick and contain both planar and trough crossbeds. Sand grains are moderately to well sorted. Clasts are subangular to rounded and include ash-flow tuff, chert, limestone, sandstone, metamorphic fragments, basalt, petrified wood, fossil shells, quartz, and shale. Clast lithologies are more varied in unit 4 than clasts in underlying units. Silt and clay beds are less than 60 cm thick and range in color from light red brown (5YR 6/4) to light brown (7.5YR 6/4). Conglomerate beds are commonly lenticular, but pebbles are scattered throughout the sand beds. Sample GB-14 is from this unit. Cliff-former. Unit rests with an angular unconformity of 4-5° on unit 3.5. 86 26

Total thickness of unit 4: 479 146

3.5 Coarsening upward sequence from interbedded clay, silt, and fine- to medium-grained sand near base to medium- to coarse-grained sand at the top. Scattered pebbles occur throughout most sand beds. Clast composition is similar to unit 2. Clay and silt beds are 30-60 cm thick and are reddish yellow (7.5YR 6/6) to reddish brown (5YR 5/3). Sand beds are 30-120 cm thick, poorly to moderately sorted, crossbedded, and range in color from light yellowish brown (2.5YR 6/4) to brown (10YR 7/3). Sample GB-12 is from this unit. Cliff-former. Scoured basal

	contact.	196	60
3.4	Generally similar to unit 3.1, except unit is more dominated by sand and silt near the top and clays range in color from reddish brown (7.5YR 6/6) to brown (7.5YR 5/4). Unit is a slope-former and contains fossil site 3e. Gradational basal contact.	191	58
3.3	Fine- to coarse-grained sand and poorly sorted pebbly sand and sandstone with clay interbeds. Sand beds are 30-90 cm thick, locally contain well-cemented sandstone lenses, crossbedded, and are very pale brown (10YR 7/3) to brown (10YR 5/3). Sand grains are moderately to poorly sorted and pebbles are lithologically similar to those in unit 2. Clay beds are light red (2.5YR 6/6) to light reddish brown (5YR 6/3), locally laminated and up to 90 cm thick. Generally a cliff-former and contains fossil sites 3a and 3b. Sample GB-13 is from this unit. Gradational basal contact.	143	44
3.2	Interbedded clay and fine- to medium-grained sand. Clay beds are reddish brown (2.5YR 5/4) to reddish yellow (5YR 6/6), locally laminated, and 1-2 m thick. Sand beds are 30-90 cm thick, brownish yellow (10YR 6/6) to brown (10YR 7/3), and locally crossbedded. A few well-cemented, medium- to coarse-grained sandstone beds with scattered pebbles also occur. One of these sandstone beds contains 14 _Alforjas_ camel prints. Sample GB-11 is from this unit. Slope-former. Gradational basal contact.	104	32
3.1	Clay with sand interbeds. Clay beds are 30-90 cm thick, reddish brown (5YR 5/3) to red (2.5YR 5/6), and locally contain wavy laminations. Sand beds are light yellowish brown (2.5YR 6/4) to white (2.5YR 8/2, fine- to medium-grained, locally crossbedded, 60-120 cm thick, and moderately to well sorted. This horizon is the most fossiliferous in the section and contains fossil sites 6 and 7. Generally a slope-former. Sharp basal contact with well-cemented sandstone of unit 2.5.	72	22
	Total thickness of unit 3:	706	216
2.5	Interbedded sand and clay. Clay beds are similar to unit 2.2 but less red. Sand beds are light brown (7.5YR 6/4) to very pale brown (10YR 7/3),		

	poorly cemented, moderately to well sorted, crossbedded, and up to 2 m thick. Well-cemented sandstone bed caps unit. Weak cliff-former. Sample GB-10a is from this unit. Sharp basal contact.	78	24
2.4	Unit is similar to 2.3 except that it only contains scattered pebbles within sand beds and numerous well-cemented sandstone beds. Clast types similar to those in unit 2.1. Unit is a ledgy slope-former and contains bone fragments. Sharp basal contact.	180	55
2.3	Unit is very similar to unit 2.1 except the grains are only up to pebble-size and are restricted to lenses within sand beds. Clast types are the same as in unit 2.1. Sand beds are moderately to well sorted. Very few well-cemented sandstone beds. Bone fragments occur near the top. Generally a cliff-former. Scoured basal contact.	102	31
2.2	Mostly rythmetrically bedded clay and fine- to medium-grained, poorly-cemented sand. Clay beds are light red (2.5YR 6/6) to reddish yellow (5YR 6/6), locally laminated, and are 1-2 m thick. Sand beds are brownish yellow (10YR 6/6) to brown (10YR 7/3), locally planar crossbedded, range from <30-90 cm thick and locally contain 3-5 cm diameter limey concretions with rare well-cemented fine- to medium-grained sandstone lenses. Sand beds <30 cm thick are usually white (5Y 8/1). Unit begins on top of well-cemented, medium- to coarse-grained sandstone bed. Slope-former and grades down into unit 2.1.	170	52
2.1	Fine- to very coarse-grained sand and conglomeratic sand and sandstone with clay and silt interbeds. Sand beds are very pale brown (10YR 7/3) to brown (10YR 7/3), 60-120 cm thick, locally contain well-cemented sandstone lenses, and are usually trough and planar crossbedded. Clasts within the conglomeratic beds are up to cobble-size, angular to subrounded (ash-flow tuffs are commonly rounded), and include 80-90% ash-flow tuff and less than 10% Cretaceous sandstone, scoriaceous basalt, limestone, and quartz. Clay, silt, and sandy silt beds are light red brown (5YR 6/3), locally laminated, and are up to 60 cm thick. Unit reddens and becomes more clay-rich near the top. Cliff-former. Sample		

GB-9 is from this unit. Scoured basal contact. 103 31

Total thickness of unit 2: 633 193

1.14 Fine- to very coarse-grained, light brown (7.5 6/4) to very pale brown (10YR 8/4), locally crossbedded, up to 2 m thick, sand with well-cemented sandstone lenses. Scattered pebbles (some up to cobble-size) include quartz, chert, ash-flow tuff, and feldspar. Reddish brown (2.5YR 5/4) to light brown (7.5YR 6/4), up to 60 cm thick, clay, silty sand, and clayey sand interbedded throughout the unit. Three, <15 cm thick layers of limestone concretions (about 8 cm in dia.) occur in lower part of the unit. Basal 3 m is very fossiliferous and contains fossil site 9. In general, the unit is a cliff-former and coarsens upward. Sample GB-6 is from this unit. Sharp basal contact. 206 63

1.13 Fine- to medium-grained sand with scattered lenses of very coarse to granular sand and sandstone with minor clay interbeds. Unit is very similar in color and texture to unit 1.11 but coarser. Slope-former. Scoured basal contact. 55 17

.12 Mostly claystone with sand interbeds. Unit very similar to unit 1.8. Some sand beds contain limey concretions and one bed has calcium carbonate rosettes up to 5 cm in dia. Slope-former. Sharp basal contact. 34 10

.11 Sand with minor clay interbeds. Sand is very pale brown (10YR 8/4) to reddish yellow (7.5YR 7/6), up to 1 m thick, planar to trough crossbedded, fine- to coarse-grained with scattered granular grains, poorly to well sorted, poorly cemented with rare well cemented lenses. Clay beds are light brown (7.5YR 6/4) to reddish yellow (7.5YR 7/6), locally laminated, and <30 cm thick. Cliff-former. Sharp basal contact. 22 7

.10 Sand and clay interbeds. Sand is fine- to medium-grained, light brown (7.5YR 6/4) to strong brown (7.5YR 4/6), locally crossbedded, poorly cemented, and moderately to well sorted. Sand beds locally contain medium- to coarse-grained, well cemented sandstone lenses. Clay beds are commonly <60 cm thick and brown (7.5YR 5/4) to reddish brown (7.5YR 6/6). Unit contains less well cemented sandstone lenses than unit 1.9. Cliff-former. Scoured basal contact. 51 16

1.9 Sand and clayey sand with clay interbeds. Sand beds are light brown (7.5YR 6/4) to brown (7.5YR 5/4), fine- to medium-grained, poorly cemented, moderately to well sorted, 30-120 cm thick and locally crossbedded. Clay beds are generally light red brown (5YR 6/4) to light brown (7.5YR 6/4), <60 cm thick, and contain scattered 3-5 cm in diameter, strong brown (7.5YR 5/6) calcium carbonate concretions. Well cemented, medium- to coarse-grained, light brown (7.5YR 6/4) to strong brown (7.5YR 5/6), moderately sorted, sandstone beds occur throughout unit. An unidentifiable fossil fragment was recovered. Cliff-former. Sharp basal contact. 145 44

1.8 Interbeds of clay, sandy clay, and sand. Clay and sandy clay beds are typically pink (7.5YR 7/4) to brown (7.5YR 5/4), 30-120 cm thick, and locally laminated. Sand beds light brown (7.5YR 6/4) to brown (7.5YR 5/4), poorly cemented, moderately to well sorted, fine- to medium-grained, and laminated to slightly crossbedded. Well cemented, medium- to coarse-grained, moderately sorted, 10-15 cm thick, brown (7.5YR 5/4) to dark brown (7.5YR 4/4) sandstone lenses and 5-7 cm calcium carbonate rosettes occur rarely. Slope-former. Gradational basal contact. 55 17

1.7 Reddish brown (2.5YR 5/4) to light brown (7.5YR 6/4), 30-90 cm thick, sometimes laminated clay and sandy clay with interbeds of very pale brown (10YR 7/3) to light gray (5Y 7/2), <30 cm thick, well sorted, poorly cemented, fine- to medium-grained, locally crossbedded sand. Scattered calcium carbonate concretions also occur. Slope-former. 97 30

Fault - Unit 1.6 is situated between two faults. Section measured 90 m south of original traverse to include thickest part of tectonic slice.

1.6 Mostly massive to laminated, dark reddish brown (5YR 3/5) to brown (7.5YR 5/4) clay and sandy clay with minor interbeds of <30 cm thick, fine- to medium-grained, poorly-cemented clayey sand and sand. Basal 2 m contains abundant powdery gypsum. Middle brownish beds contain abundant gypsum rosettes up to 8 cm in diameter. Sand bed near top of unit contains lenticular, platy, well-cemented, crossbedded, medium- to coarse-grained (with some scattered volcanic granular grains), brown (7.5YR 4/2) sandstone. Some thin sand beds show mottles of reddish yellow (7.5YR 6/8) to olive yellow (2.5YR 6/6). Slope-former. 45 14

Fault - Unknown thickness of unit 1 missing.

1.5 Interbedded sand, silty sand and clay. Sand and silty sand beds are poorly-cemented, well to moderately sorted, fine- to medium-grained, locally lenticular and crossbedded, pinkish white (7.5YR 8/2) to brown (7.5YR 5/4). Bed thickness ranges from 15 to 90 cm, but two beds near base are up to 2 m. Well-cemented, fine- to medium-grained, moderately sorted, <30 cm, very pale brown (10YR 7/3) to brown (7.5YR 5/2) sandstone beds are scattered throughout. Clay beds are brown (7.5YR 5/4) to reddish brown (5YR 5/4), 30-60 cm thick, and locally show wavy laminations and mudcracks. Top 12 m consist mainly of clay beds with <30 cm thick, pinkish gray (7.5YR 7/2), very fine- to fine-grained, poorly cemented sand layers with a few scattered layers of dark reddish gray (5YR 5/4) calcite rosettes. Thick sand beds form low cliffs with smooth "popcorn" textured clayey slopes. Sample GB-5 is from this unit. Sharp basal contact on sand bed. 102 31

1.4 Alternating beds of clay, sandy clay and sand. Clay and sandy clay beds are reddish brown (2.5YR 5/4) to light red (2.5YR 5/6), 30-90 cm thick, and locally show wavy laminations and mudcracks. Sand beds are very pale brown (10YR 7/4) to reddish brown (5YR 5/4), fine- to mediun-grained, poorly cemented, 30-60 cm thick, and locally contain both planar and trough crossbedding. Well cemented, lenticular, light brown (7.5YR 6/4) to strong brown (7.5YR 5/6), medium- to coarse-grained, <30 cm thick sandstone and 5-7 cm thick, pinkish white (7.5YR 8/2), platy, limey concretions also occur. Unit generally forms rounded hills with minor cliff faces that have abundant "popcorn" textured slopes. Top 10 m has undergone extensive piping. Sharp basal contact on sand bed. 477 145

1.3 Rythmitric interbeds of fine- to medium-grained sand, clayey sand and clay. Sand beds are commonly <30 cm thick, pinkish gray (7.5YR 6/3) to pale brown (10YR 6/3), moderately sorted and locally crossbedded. Clay beds are up to 60 cm thick, usually laminated, and are light brown (7.5YR 6/4) to reddish brown (5YR 5/4). Near the top and bottom of unit are discontinuous 15-20 cm thick layers of well cemented crossbedded, medium- to coarse-grained sandstone. Top 2 m of unit contains massive, fine- to medium-grained, pale brown (10YR 6/3) to pinkish gray (7.5YR 6/3), planar laminated sandstone and a 5-7 cm thick, platy, light gray (10YR 7/2) nodular limestone zone. Slope-former. Gradational basal contact. 56 17

1.2 Interbeds of clay, silty clay, and sandy clay with minor sand and sandstone. Clay beds are light brown (7.5YR 6/4) to reddish brown (5YR 5/3), up to 1 m thick, and locally contain wavy laminations and mudcracks. Silty and sandy clay beds are similar. Sand beds are light yellowish brown (10YR 6/4) to pinkish gray (7.5YR 6/3), fine- to medium-grained (but can contain very coarse to granule size grains), poorly sorted, 30-60 cm thick, and can be massive or crossbedded. Within the sand beds, well-cemented, lenticular, coarse- to very coarse-grained sandstone sometimes occur. Rare 3 cm in diameter calcium carbonate concretions are scattered throughout unit. A 5-7 cm thick, dense, nodular, light reddish brown (5YR 6/3) to reddish brown (5YR 4/4) limestone bed caps the unit. Generally a slope-former with occasional sandstone ledges. Sample GB-3 is from this unit. Base of unit is buried by alluvium. 40 12

nit 1 covered by alluvial flat and eolian sediments for 456 m. 378 115

1.1 Mostly fine- to medium-grained sand with minor clay and coarse-grained sand interbeds. Sand beds are yellowish brown (10YR 6/4) to dark brown (7.5YR 4/4), well sorted, 30-90 cm thick, and locally crossbedded. Well cemented, 30 cm thick, coarse-grained sandstone lenses also occur. Clay beds are light brown (7.5YR 5/4) to reddish brown (5YR 5/3), <15 cm thick, and locally laminated. Slope-former. Samples GB-1 and 2 are from this unit. Truncated at base by normal fault. 154 47

ection ends at wood stake located 842 m along a line of N43.71E from the northwest corner of section 31, T6N R1W.

Total thickness of unit 1: 1,917 585

Total thickness of Gabaldon section: 3,732 1,138

Bobo Butte Section

This section includes the flat-lying caprock (unit 2) on Bobo Butte and the eastward-dipping Santa Fe Group deposits (unit 1) exposed from the Santa Fe fault east to the Butte. The section is located on Plate I and it begins on top of the northwest side of Bobo Butte.

Unit	Lithology	Thickness ft	 m
2.3	Conglomerate, reddish yellow (7.5YR 7/6). Conglomerate is matrix-supported, poorly sorted and well indurated with calcium carbonate cement. Silty sand matrix. Clasts are subrounded to angular, mostly pebble- to cobble-size, but can be up to 1 m in size and include (in decending order of abundance) red sandstone (Abo Formation), limestone, basalt, light brown (Cretaceous) sandstone, chert, reworked Santa Fe Group sandstone, travertine, and quartz. Imbricated clasts show an eastward flow direction. Resistant cliff-former. Grades down into lower unit.	5	1.5
2.2	Mostly banded travertine with minor sandstone and siltstone interbeds. Bands range in color from white (10YR 8/2) to pink (5YR 7/3) to reddish yellow (5YR 6/6). Band thickness ranges from 3 to 6 cm. Sandstone and siltstone beds are similar to those in unit 2.1. Very resistant cliff-former. Lower gradational contact.	5	1.5
2.1	Conglomerate with sandstone and siltstone interbeds. Conglomerate beds are similar to those in 2.3, but are thinner (beds up to 1 m thick and locally are lenticular. Sandstone is reddish yellow (7.5YR 7/6), well indurated, fine- to coarse-grained and locally contains scattered pebbles. Siltstone is similar in color to the sandstone beds. Resistant cliff-former. Rests with a slight angular unconformity on unit 1.7.	25	8
	Total Thickness of Unit 2:	35	11

1.7 Alternating beds of sand, silty sand and clayey silt with minor scattered pebbles and pebbly lenses. Sand and silty sand beds are weakly consolidated, moderately to well sorted, up to 2 m thick, fine- to coarse-grained, reddish yellow (7.5YR 6/6) to light reddish brown (5YR 5/6) and locally laminated to crossbedded with a few well indurated sandstone layers. Clayey silt beds are brown (7.5YR 5/4) to red (2.5YR 5/6) and up to 40 cm thick. Pebble types are similar to those in unit 1.3. Sample BB-5 is from this unit. Upper 6 m of unit becomes progressively more cemented near the top makeing the unit a cliff-former. Gradational basal contact. 69 21

1.6 Mostly fine- to medium-grained sand and silty sand with minor clayey silt and pebbly zones. Bed colors are similar to unit 1.7. Sand and silty sand beds are moderately to well sorted, poorly indurated and locally crossbedded. Bed thickness ranges from 1-3 m. Clayey silt beds and pebbly zones are similar to those in unit 1.7. Upper 6 m of unit is mostly covered by colluvium. Slope-former. Gradational basal contact. 164 50

1.5 Interbedded sand, silty sand, clayey silt, and conglomerate. Beds are similar to those in unit 1.6. Clasts range in size from 2-5 cm and are similar lithologically to those in unit 1.3. Middle part contains well cemented medium- to coarse-grained sandstone beds about 4-10 cm thick. Except for the sandstone beds, the unit is generally a slope-former. Grades downward. 125 38

1.4 Interbedded pebble conglomerate, silty sand, sand and clayey silt. Fine- to coarse-grained sand and conglomerate beds are up to 2 m thick, have similar colors to unit 1.3, locally planar and trough crossbedded, and have scoured bases. Conglomerate beds also are poorly sorted, locally lenticular, matrix-supported, weakly to moderately indurated and clast types are similar to unit 1.3. Unit is generally similar to unit 1.3 except that unit 1.4 contains less sand and more conglomerate. Clayey silt beds are less than 1 m thick, light red brown (5YR 6/4) to light red (2.5YR 5/6), and are commonly laminated. Sample BB-4 is from this unit. Generally a cliff-former with resistant ledges separated by rilled cliffs. Grades downward. 120 37

1.3 Fine- to very coarse-grained sand and poorly sorted conglomerate with minor silty sand and clayey silt interbeds. Sand and conglomerate beds are light yellowish brown (10YR 6/4) to reddish yellow (7.5YR 6/6), up to 1 m thick and locally trough or planar cross-bedded. Clasts in conglomerate beds and scattered in sand beds are subrounded to angular, up to 4 cm in size, and include 50% ash-flow tuff, 20-25% calcareous shale, 20% chert, and less than 10% limestone, quartz and quartzite. A few well cemented sandstone beds also occur. Imbricate clasts show an eastward flow direction. Clayey silt and silty sand beds are less than 6 cm thick and are red (2.5YR 5/6) to reddish yellow (5YR 6/6). Sample BB-3 is from this unit. Ledgy cliff-former. Scoured basal contact. 52 16

1.2 Interbedded fine- to medium-grained sand, silty sand and clayey silt. Poorly sorted sand and silty sand beds are brown (7.5YR 5/4) to reddish yellow (5YR 6/6), up to 1 m thick, locally well cemented, and cross-bedded. Clayey silt beds are brown (7.5YR 5/4) to light reddish brown (5YR 6/4), <10 cm thick, and locally laminated. Samples BB-1 and BB-2 are from this unit. Slope-former. Gradational basal contact. 203 62

1.1 Fine- to coarse-grained sand and silty sand that contains scattered pebbles and pebble lenses with minor silty clay interbeds. Sand and silty sand beds are very pale brown (10YR 7/3) to reddish brown (5YR 5/4), up to 1 m thick, poorly sorted, poorly cemented and locally crossbedded. Pebbles are lithologically similar to those in unit 1.3. Silty clay beds are light red (2.5YR 6/6) to light reddish brown (5YR 5/4) and 5-8 cm thick. Unit becomes steeply dipping (58°) and very sheared near base where it is in fault (Santa Fe fault) contact with the Triassic Chinle Formation. Weak cliff-former. 35 11

Total thickness of Unit 2: 768 235

Total Thickness of section: 803 246

APPENDIX II

POINT COUNT RESULTS

CENTRAL ALBUQUERQUE BASIN

Los Lunas Volcano Section

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
LL-1	155	1	10	104	63	58	2	5	1	1
LL-2	195	1	16	73	49	58	0	4	3	1
LL-3	136	0	5	111	51	90	0	2	3	2
LL-4	193	2	13	76	71	38	1	4	2	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
LL-1	42	42	16	0.62	0.07	88	9	3	76	22	2
LL-2	53	31	16	0.60	0.08	89	11	0	71	29	0
LL-3	35	41	24	0.68	0.04	95	5	0	90	10	0
LL-4	52	37	11	0.52	0.07	85	13	2	63	35	2

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	45.5	37.8	16.7	0.6	0.08	89.3	9.5	1.2	75.0	24.0	1.0
s	8.6	5.0	5.4	0.1	0.01	4.2	3.4	1.5	11.3	10.7	1.2

Belen Section

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
BL-1	181	2	10	64	40	99	1	3	0	0
BL-2	184	2	14	69	63	64	0	0	4	0
BL-3	189	1	14	80	31	81	0	3	1	0
BL-4	180	2	17	71	66	60	0	2	2	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
BL-1	48	26	26	0.62	0.06	96	3	1	86	13	1
BL-2	50	33	17	0.52	0.08	94	6	0	76	24	0
BL-3	51	28	21	0.72	0.07	95	5	0	81	19	0
BL-4	50	34	16	0.52	0.10	94	6	0	72	28	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	47.80	30.20	20.00	0.60	0.07	94.80	5.00	0.20	78.80	21.00	0.20
s	1.20	3.90	4.50	0.10	0.01	1.00	1.40	0.50	6.10	6.50	0.50

Bernardo Section

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
BB-1	167	3	4	73	81	66	0	3	2	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
BB-1	44	38	18	0.47	0.04	93	7	0	85	15	0

Joiner Sanclemente No. 1

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
JS-041	121	0	12	84	20	158	0	3	2	0
JS-047	190	1	19	82	27	72	0	2	7	0
JSC-49	194	5	20	70	69	34	2	2	4	0
JSC-51	222	0	9	82	53	31	0	2	0	1
JS-052	204	0	10	98	39	46	0	2	1	0
JS-055	211	0	15	88	46	34	0	5	1	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
JS-041	33	26	41	0.81	0.09	97	3	0	91	9	0
JS-047	52	28	20	0.75	0.10	89	11	0	71	29	0
JSC-49	55	35	10	0.50	0.11	81	14	5	51	46	3
JSC-51	58	34	8	0.61	0.04	94	6	0	74	26	0
JS-052	54	34	12	0.72	0.05	94	6	0	78	22	0
JS-055	56	34	10	0.66	0.07	85	15	0	62	38	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	51.30	31.80	16.90	0.68	0.08	90.00	9.20	0.80	71.20	28.30	0.50
s	9.20	3.80	12.60	0.11	0.03	6.10	4.90	2.00	13.70	12.80	1.20

Long Dalies No. 1

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
LD-021	171	6	15	73	38	92	1	3	1	0
LD-031	184	0	14	77	40	80	0	3	1	1
LD-045	193	0	27	73	39	53	3	9	3	0
LD-056	210	3	22	79	46	39	1	0	0	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
LD-021	48	28	24	0.66	0.11	95	4	1	78	21	1
LD-031	50	29	21	0.66	0.07	95	5	0	82	18	0
LD-045	55	28	17	0.65	0.12	78	18	4	56	41	3
LD-056	59	31	10	0.63	0.11	98	0	2	60	38	2

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	53.00	29.00	18.00	0.65	0.10	91.50	6.70	1.80	69.00	29.50	1.50
s	5.00	1.40	6.00	0.01	0.02	9.10	7.80	1.70	12.90	11.70	1.30

Shell Isleta Central #1

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SI-005	165	5	19	76	74	54	1	2	3	1
SI-016	163	3	25	54	64	85	0	3	2	1
SI-027	195	8	8	71	30	83	2	1	1	1
SI-035	28	0	0	36	14	321	0	0	1	0

SI-040	136	3	21	39	52	147	0	2	0	0
SI-053	168	0	9	71	63	86	0	0	3	0
SI-064	177	4	24	64	50	76	1	0	3	1
SI-074	75	1	4	164	7	143	0	1	5	0
SI-086	114	0	9	67	31	173	0	2	2	2

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SI-005	47	38	15	0.51	0.13	90	8	2	64	34	2
SI-016	48	30	22	0.46	0.15	94	6	0	72	28	0
SI-027	53	25	22	0.70	0.08	96	2	2	81	17	2
SI-035	7	12	81	0.72	0.00	99	1	0	99	1	0
SI-040	40	23	37	0.43	0.15	99	1	0	85	15	0
SI-053	44	34	22	0.53	0.05	97	3	0	88	12	0
SI-064	51	29	20	0.56	0.14	95	4	1	70	29	1
SI-074	20	43	37	0.96	0.06	96	4	0	93	7	0
SI-086	31	25	44	0.68	0.07	98	2	0	93	7	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	41.80	30.80	27.40	0.60	0.10	95.60	3.80	0.60	80.80	18.60	0.60
s	11.20	7.00	10.40	0.17	0.04	2.80	2.30	0.92	11.00	10.40	0.92

Pre-Santa Fe Tertiary

upper unit (unit of Isleta #2 well)

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SI-090	209	2	10	69	65	39	1	1	2	2
SI-092	259	1	11	47	30	41	0	0	10	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SI-090	55	34	11	0.51	0.05	91	7	2	71	27	2
SI-092	68	19	13	0.61	0.04	80	20	0	65	35	0

lower unit (Galisteo Formation)

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SI-106	243	1	26	54	56	6	0	9	4	1
SI-115	307	1	27	36	26	2	0	0	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SI-106	68	27	5	0.49	0.10	32	68	0	13	87	0
SI-115	84	15	1	0.58	0.08	100	0	0	7	93	0

Upper Cretaceous

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SI-124	286	0	17	53	30	3	0	9	1	1
SI-131	283	0	18	58	25	0	0	14	1	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SI-124	76	21	3	0.64	0.06	23	77	0	10	90	0
SI-131	75	21	4	0.70	0.06	0	100	0	0	100	0

Shell Isleta #2

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
I-020	101	5	12	114	49	102	9	6	0	2
I-032	168	2	13	99	42	67	0	5	1	3
I-042	125	0	10	100	74	72	4	7	5	3
I-051	136	3	15	115	68	51	0	5	4	3
I-062	143	3	15	120	66	50	0	0	1	2
I-072	198	4	12	102	54	22	0	6	1	1
I-091	184	2	17	102	56	33	0	2	3	1
I-110	182	2	16	106	40	43	0	6	3	2
I-121	175	2	18	109	50	38	0	2	5	1
I-131	184	2	9	104	63	30	0	4	2	2
I-142	196	2	14	86	52	43	0	3	4	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
I-020	30	41	29	0.70	0.14	87	5	8	76	17	7
I-032	46	36	18	0.70	0.08	92	8	0	76	24	0
I-042	34	44	22	0.57	0.07	82	14	4	74	22	4
I-051	39	46	15	0.63	0.12	85	15	0	65	35	0
I-062	40	47	13	0.64	0.11	98	2	0	72	28	0
I-072	54	39	7	0.65	0.07	76	24	0	49	51	0
I-091	51	40	9	0.64	0.09	87	13	0	58	42	0
I-110	50	37	13	0.73	0.09	83	17	0	61	39	0
I-121	49	40	11	0.68	0.10	84	16	0	58	42	0
I-131	49	42	9	0.62	0.06	83	17	0	64	36	0
I-142	53	34	13	0.62	0.08	86	14	0	65	35	0

Mean of Samples

Sample	QFL%Q	QFL%F	QFL/L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	45.00	40.60	14.40	0.65	0.09	85.70	13.20	1.10	65.30	33.70	1.00
s	8.00	4.00	6.40	0.05	0.02	5.60	6.10	2.60	8.60	10.10	2.30

Pre-Santa Fe Tertiary

upper unit (unit of Isleta #2 well)

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
I-147	212	2	16	106	27	23	2	3	5	4
I-156	286	2	17	33	44	9	1	4	3	1
I-162	300	2	32	29	20	10	0	3	2	2
IC1-1	270	2	39	65	10	8	1	4	0	1
I-171	259	5	32	52	30	12	1	4	4	1
IC2-1	254	2	29	77	21	16	0	1	0	0
IC2-2	251	4	32	68	19	16	2	7	0	1
I-184	216	2	12	89	39	40	1	0	0	1
I-189	79	0	5	33	10	264	0	3	2	4
I-201	259	3	26	34	49	22	0	3	2	2

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
I-147	58	34	8	0.80	0.08	70	24	6	45	51	4
I-156	77	19	4	0.43	0.06	53	41	6	25	72	3
I-162	84	12	4	0.59	0.10	67	33	0	20	80	0
IC1-1	78	19	3	0.87	0.13	62	30	8	15	83	2
I-171	74	21	5	0.63	0.12	57	38	5	20	78	2

IC2-1	71	25	4	0.79	0.11	94	6	0	33	67	0
IC2-2	72	22	6	0.78	0.12	64	28	8	27	70	3
I-184	58	32	10	0.70	0.06	98	0	2	73	25	2
I-189	21	11	68	0.77	0.06	98	2	0	96	4	0
I-201	72	21	7	0.41	0.10	81	19	0	39	61	0

Mean of Samples (not including I-189)

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	71.60	22.80	5.60	0.67	0.10	71.80	24.30	3.90	33.00	65.20	1.80
s	8.70	6.80	2.30	0.16	0.02	15.90	13.90	3.40	17.80	18.00	1.50

lower unit (Galisteo Formation)

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
I-209	285	0	26	41	28	6	1	8	4	1
IC3-2	298	4	50	39	3	0	0	5	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
I-209	78	17	5	0.59	0.08	63	32	5	13	85	2
IC3-2	88	11	1	0.93	0.15	0	100	0	0	100	0

SOUTHWEST ALBUQUERQUR BASIN

Gabaldon Badlands

Unit 1

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
GB-1	157	2	16	105	55	60	0	2	3	0
GB-2	154	0	14	104	50	72	0	2	3	1
GB-3	169	0	11	124	43	46	0	4	3	0
GB-5	166	4	12	128	35	49	0	2	3	1
GB-6	171	1	12	114	49	47	0	3	3	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
GB-1	44	40	16	0.66	0.10	92	8	0	72	28	0
GB-2	42	38	20	0.68	0.08	94	6	0	79	21	0
GB-3	45	42	13	0.74	0.06	87	13	0	72	28	0
GB-5	45	41	14	0.78	0.09	91	9	0	70	30	0
GB-6	46	41	13	0.70	0.07	89	11	0	71	29	0

Unit 2

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
GB-8	169	0	13	104	44	66	0	4	0	0
GB-9	166	2	10	101	47	66	0	6	1	1
GB-10a	173	0	14	112	34	60	0	4	3	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm

GB-8	46	37	17	0.70	0.07	94	6	0	80	20	0
GB-9	45	37	18	0.68	0.07	90	10	0	78	22	0
GB-10a	47	36	17	0.77	0.07	90	10	0	74	26	0

Unit 3

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
GB-11	201	1	11	62	46	75	0	3	1	0
GB-12	184	3	9	70	65	66	0	1	2	0
GB-13	199	1	3	83	45	67	0	1	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
GB-11	53	27	20	0.57	0.06	95	5	0	82	18	0
GB-12	49	34	17	0.52	0.06	96	4	0	81	19	0
GB-13	51	32	17	0.65	0.02	98	2	0	93	7	0

Unit 4

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
GB-14	186	13	14	77	50	52	0	2	6	0
GB-15	163	2	10	82	59	78	0	2	2	2
GB-15a	177	0	10	93	62	54	0	1	2	0
GB-16	174	1	6	80	56	78	0	2	3	0
GB-17	166	3	7	82	43	91	0	1	7	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
GB-14	53	32	15	0.61	0.13	87	13	0	60	40	0
GB-15	44	35	21	0.58	0.07	95	5	0	83	17	0
GB-15a	47	39	14	0.60	0.07	95	5	0	81	19	0
GB-16	45	34	21	0.59	0.04	94	6	0	87	13	0
GB-17	44	31	25	0.66	0.06	92	8	0	84	16	0

Mean of all Units

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	46.60	36.00	17.40	0.66	0.07	92.40	7.60	0.00	77.30	22.70	0.00
s	3.30	4.20	3.30	0.07	0.02	3.20	3.20	0.00	7.90	7.90	0.00

Bobo Butte Area

Unit 1

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
BB-1	148	2	13	110	50	69	0	5	2	1
BB-2	148	0	14	141	44	39	0	6	7	1
BB-3	175	1	11	112	45	50	0	5	1	0
BB-4	158	2	15	104	55	60	0	2	4	0
BB-5	161	1	15	97	58	59	0	4	4	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
BB-1	41	40	19	0.31	0.09	91	9	0	76	24	0
BB-2	41	46	13	0.24	0.09	75	25	0	59	41	0

BB-3	47	39	14	0.29	0.06	89	11	0	74	26	0
BB-4	44	40	16	0.35	0.10	91	9	0	72	28	0
BB-5	44	39	17	0.37	0.09	88	12	0	71	29	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	43.40	40.80	15.80	0.30	0.09	86.80	13.20	0.00	70.40	29.60	0.00
s	2.50	2.90	2.40	0.05	0.02	6.70	6.70	0.00	6.60	6.60	0.00

Humble Santa Fe #1

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
HS-008	162	0	12	133	36	46	2	4	3	2
HS-023	161	1	22	112	63	37	0	1	3	0
HS-033	156	0	9	103	62	28	0	0	0	2
HS-043	184	2	15	108	51	36	0	3	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
HS-008	44	42	14	0.79	0.07	84	13	3	69	28	3
HS-023	46	44	10	0.64	0.12	90	10	0	58	42	0
HS-033	52	41	7	0.62	0.04	100	0	0	76	24	0
HS-043	50	40	10	0.68	0.08	92	8	0	64	36	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	48.00	41.80	10.20	0.68	0.08	91.50	7.80	0.70	66.80	32.50	0.70
s	3.60	1.70	2.90	0.08	0.03	6.60	5.60	1.50	7.60	8.10	1.50

Pre-Santa Fe Tertiary

unit of Isleta #2 well

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
HS-060	211	4	34	77	25	40	1	5	1	2
HS-071	222	4	35	38	49	39	1	6	2	4

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
HS-060	62	26	12	0.75	0.15	85	13	2	49	49	2
HS-071	66	22	12	0.44	0.15	81	17	2	47	52	1

Upper Cretaceous

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
HS-086	283	0	31	63	9	8	0	2	2	2
HS-099	252	6	42	63	18	8	0	6	3	2

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
HS-086	79	18	3	0.88	0.1	67	33	0	19	81	0
HS-099	75	20	4	0.78	0.16	47	53	0	12	88	0

Shell Santa Fe Pacific #2

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SS-007	169	4	21	28	42	113	1	5	12	5
SS-018	172	2	12	24	50	122	2	5	7	4
SS-028	175	4	12	42	48	101	1	5	7	5
SS-039	154	6	32	75	43	71	1	6	11	1
SS-047	200	2	12	61	77	33	0	11	3	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SS-007	49	18	33	0.4	0.13	86	13	1	74	25	1
SS-018	47	19	34	0.32	0.08	90	9	1	83	16	1
SS-028	48	23	29	0.47	0.08	89	10	1	80	19	1
SS-039	48	30	22	0.64	0.2	80	19	1	59	40	1
SS-047	54	34	12	0.44	0.06	70	30	0	56	44	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	49.20	24.80	26.00	0.45	0.11	83.00	16.20	0.80	70.40	28.80	0.80
s	2.80	7.00	9.10	0.12	0.06	8.20	8.60	0.40	12.20	12.60	0.40

Pre-Santa Fe Tertiary

unit of Isleta #2 well

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SS-063	231	0	16	22	68	52	2	6	3	0
SS-076	223	2	6	64	51	44	0	4	2	4

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SS-063	61	23	16	0.24	0.06	83	14	3	66	32	2
SS-076	58	29	13	0.56	0.03	88	12	0	79	21	0

Upper Cretaceous

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SS-091	245	2	23	29	77	14	0	5	2	3
SS-109	267	3	26	39	47	6	4	5	1	2

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SS-091	68	27	5	0.27	0.09	67	33	0	68	32	0
SS-109	74	22	4	0.45	0.1	38	37	25	14	76	10

SOUTHEAST ALBUQUERQUE BASIN

Trigo Canyon Area Outcrops

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
TC-1	93	0	2	125	25	148	2	0	1	4
TC-2a	113	1	6	122	44	97	3	8	2	4

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
TC-1	24	38	38	0.83	0.02	98	1	1	97	2	1
TC-2a	30	42	28	0.73	0.06	88	9	3	83	15	2

Baca/SFG?

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
TC-3	249	4	14	26	78	11	3	12	0	3
TC-5a	302	5	10	13	53	6	3	8	0	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
TC-3	67	26	7	0.25	0.07	42	46	12	25	68	7
TC-5a	79	17	4	0.20	0.05	35	47	18	19	72	9

La Joya Uplift Baca Formation Outcrops (from Johnson, 1978)

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
26	35	17	2	10	20	1	0	0	0	0
27	56	10	6	1	5	0	0	24	0	0
28	29	8	3	7	25	0	0	6	0	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
26	64	35	1	0.33	0.35	100	0	0	5	95	0
27	70	6	24	0.17	0.22	0	100	0	0	100	0
28	51	41	8	0.22	0.28	0	100	0	0	100	0

Grober Fuqua No. 1

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
GC-1	230	16	29	12	82	2	20	3	2	4
G-5	232	12	19	76	27	14	6	2	7	5
GC-2	227	14	33	75	25	5	13	6	1	1
GC-3	222	17	57	60	26	6	4	6	0	2
G-6	227	5	40	54	37	16	5	5	5	6

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
GC-1	69	24	7	0.13	0.16	7	19	74	3	69	28
G-5	67	26	7	0.74	0.12	48	31	21	23	67	10
GC-2	69	25	6	0.75	0.17	20	28	52	7	75	18
GC-3	74	22	4	0.70	0.25	38	37	25	7	89	4
G-6	69	23	8	0.59	0.16	52	32	16	21	72	7

Mean of Samples

QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm	LvLsLm	LvLsLm	LvLstLm	LvLstLm	LvLstLm

						%Lv	%Ls	%Lm	%Lv	%Lst	%Lm
x	69.60	24.00	6.40	0.58	0.17	33.00	29.40	37.60	12.20	74.40	13.40
s	2.60	1.60	1.50	0.26	0.05	19.10	6.60	24.70	9.10	8.70	9.70

Triassic from well and Hubble Bench outcrop

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
GC-4	323	0	61	3	2	1	0	6	0	4
HB-1	342	0	47	2	1	0	1	4	3	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
GC-4	97	1	2	0.60	0.16	14	86	0	2	98	0
HB-1	97	1	2	0.67	0.12	0	88	12	0	98	2

Transocean Isleta No. 1

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
TO-005	146	7	14	68	52	106	0	5	2	0
TO-016	129	8	7	78	31	139	3	3	2	0
TO-026	225	0	24	51	48	46	0	2	4	0
TO-044	223	3	22	47	49	49	0	3	4	0
TO-050	252	2	33	45	50	8	0	9	1	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
TO-005	42	30	28	0.57	0.13	94	6	0	79	21	0
TO-016	36	27	37	0.72	0.10	95	3	2	86	12	2
TO-026	62	25	13	0.52	0.10	88	12	0	61	39	0
TO-044	62	24	14	0.49	0.10	88	12	0	60	40	0
TO-050	72	24	4	0.47	0.12	44	56	0	15	85	0

Mean of Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	54.80	26.00	19.20	0.55	0.11	81.80	17.80	0.40	60.20	39.40	0.40
s	15.10	2.50	13.10	0.10	0.01	21.40	21.70	0.89	27.70	28.10	0.89

Upper Cretaceous

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
TO-054	270	0	28	45	44	2	1	9	0	1
TO-060	276	2	41	36	34	4	0	7	0	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
TO-054	75	22	3	0.51	0.09	17	75	8	5	92	3
TO-060	80	18	2	0.51	0.13	36	64	0	6	94	0

NORTH ALBUQUERQUE BASIN

King Ranch

Ceja Member

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-15	136	0	22	102	60	77	0	1	0	2
KR-15b	137	1	11	105	55	87	0	3	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-15	40	41	19	0.63	0.14	99	1	0	77	23	0
KR-15b	37	40	23	0.66	0.08	97	3	0	85	15	0

Unnamed Member

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-11	105	0	11	134	44	103	0	2	0	1
KR-11b	107	0	4	146	59	82	0	0	1	1
KR-12	144	1	9	91	64	87	0	2	1	1
KR-13	147	3	14	131	50	50	0	2	1	2
KR-14	160	0	14	125	54	41	0	3	1	2

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-11	29	45	26	0.75	0.09	98	2	0	89	11	0
KR-11b	29	51	20	0.71	0.04	99	1	0	94	6	0
KR-12	39	39	22	0.59	0.06	97	3	0	88	12	0
KR-13	41	46	13	0.72	0.10	94	6	0	72	28	0
KR-14	44	45	11	0.70	0.08	91	9	0	71	29	0

Canada Pilares Member

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-9	188	1	7	33	69	95	1	4	1	1
KR-10	178	0	11	41	84	82	0	3	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-9	49	26	25	0.32	0.04	94	5	1	88	11	1
KR-10	48	31	21	0.33	0.06	96	4	0	85	15	0

Chamisa Mesa Member

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-5	149	2	9	56	51	130	0	2	1	0
KR-8	201	0	7	59	41	87	0	3	1	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-5	40	27	33	0.52	0.07	98	2	0	92	8	0
KR-8	52	25	23	0.59	0.03	96	4	0	89	11	0

Piedra Parada Member

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-4	142	2	7	67	66	113	0	2	0	1
KR-7	171	2	7	54	56	106	1	2	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-4	38	33	29	0.50	0.06	98	2	0	93	7	0
KR-7	45	28	27	0.49	0.05	97	2	1	91	8	1

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	40.80	36.70	22.50	0.54	0.07	96.50	3.30	0.20	85.70	14.10	0.20
s	6.90	8.80	6.00	0.18	0.03	2.30	2.20	0.40	7.60	7.80	0.40

Galisteo (?) Formation

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-2	235	4	27	18	108	3	0	4	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-2	67	31	2	0.14	0.12	43	57	0	9	91	0

Mesaverde Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
KR-1	254	5	21	24	92	2	0	2	0	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
KR-1	70	29	1	0.21	0.09	50	50	0	92	8	0

Carpenter Atrisco No. 1

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
CA-002	175	1	8	101	46	61	1	4	3	0
CA-017	249	2	35	62	24	28	0	0	0	0
CA-024	252	1	27	62	12	41	1	3	1	0
CA-028	269	2	23	66	15	22	0	1	2	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
CA-002	46	37	17	0.69	0.05	88	10	2	78	20	2
CA-017	71	22	7	0.72	0.13	100	0	0	43	57	0
CA-024	70	18	12	0.84	0.10	89	9	2	55	43	2
CA-028	74	20	6	0.81	0.08	88	12	0	44	56	0

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	65.30	24.20	10.50	0.76	0.09	91.20	7.80	1.00	55.00	44.00	1.00
s	12.90	8.60	5.10	0.07	0.03	5.80	5.30	1.20	16.30	17.20	1.20

Pre-Santa Fe Tertiary

[illegible]

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M

CA-044	265	2	42	39	39	2	2	9	0	0
CA-054	285	4	41	29	27	4	0	9	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
CA-044	77	20	3	0.50	0.14	15	70	15	4	92	4
CA-054	83	14	3	0.52	0.14	31	69	0	7	93	0

Shell West Mesa Federal No. 1

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
WM-008	234	1	17	51	47	43	1	3	3	0
WM-023	227	4	29	65	39	32	0	4	0	0
WM-032	255	2	46	22	15	57	0	3	0	0
WM-043	243	2	58	31	17	39	1	9	0	0
WM-051	294	8	45	29	8	4	1	9	1	1
WM-060	261	7	48	38	33	7	1	4	0	1
WM-066	273	6	60	31	16	6	0	7	1	0
WM-078	266	3	34	47	43	3	0	2	0	2

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
WM-008	63	25	12	0.52	0.07	86	12	2	63	35	2
WM-023	65	26	9	0.62	0.13	89	11	0	51	49	0
WM-032	76	9	15	0.59	0.16	95	5	0	53	47	0
WM-043	76	12	12	0.64	0.20	80	18	2	36	63	1
WM-051	87	9	4	0.78	0.15	27	67	6	6	93	1
WM-060	79	18	3	0.54	0.17	58	34	8	11	88	1
WM-066	85	12	3	0.66	0.20	43	57	0	8	92	0
WM-078	76	23	1	0.52	0.12	60	40	0	7	93	0

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	75.8	16.8	7.4	0.61	0.15	67.3	30.5	2.2	29.4	70.0	0.60
s	8.4	7.2	5.3	0.09	0.04	24.2	22.9	3.1	24.0	24.0	0.74

Pre-Santa Fe Tertiary

unit of Isleta #2 well

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
WM-087	244	0	19	84	36	4	1	10	1	1
WM-094	264	1	24	78	21	2	1	7	2	0
WM-104	252	1	12	82	41	3	0	5	3	1
WM-113	227	0	21	123	21	1	0	5	2	0
WM-123	205	0	17	150	16	3	1	7	1	0
WM-138	249	0	16	108	18	4	1	4	0	0
WM-146	235	0	15	110	33	1	0	5	1	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
WM-087	66	30	4	0.70	0.07	25	69	6	11	86	3
WM-094	72	25	3	0.79	0.09	17	75	8	5	92	3
WM-104	66	31	3	0.67	0.05	27	73	0	12	88	0
WM-113	62	36	2	0.85	0.08	12	88	0	4	96	0
WM-123	55	42	3	0.90	0.08	25	67	8	11	86	3
WM-138	66	32	2	0.86	0.06	44	44	12	16	80	4
WM-146	62	36	2	0.77	0.06	14	86	0	5	95	0

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	64.1	33.2	2.7	0.79	0.07	23.4	71.7	4.9	9.1	89.0	1.9
s	5.2	5.4	0.8	0.08	0.01	10.8	14.6	4.9	4.5	5.7	1.8

Galisteo Formation (?)

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
WM-159	243	0	21	92	31	6	1	6	0	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
WM-159	66	31	3	0.75	0.08	46	46	8	18	79	3

Core Samples

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
WMC-1	236	0	17	84	34	19	0	9	1	0
WMC-2	244	1	29	68	28	23	0	6	1	0
WMC-3	215	1	20	108	27	18	1	9	1	0
WMC-4	201	0	31	115	36	9	0	6	1	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
WMC-1	63	30	7	0.71	0.07	66	34	0	41	59	0
WMC-2	68	24	8	0.71	0.11	77	23	0	38	62	0
WMC-3	59	34	7	0.80	0.09	62	35	3	36	62	2
WMC-4	58	38	4	0.76	0.13	56	44	0	19	81	0

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	62.00	31.50	6.50	0.74	0.10	65.00	34.00	1.00	33.50	66.00	0.50
s	4.50	6.00	1.70	0.04	0.02	8.80	8.60	1.50	9.90	10.10	1.00

Shell Santa Fe Pacific No. 1

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SO-006	226	0	30	78	51	10	0	1	4	0
SO-012	221	1	21	84	64	5	0	1	2	1
SO-024	239	1	24	65	56	8	0	5	2	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SO-006	64	32	4	0.60	0.12	67	33	0	22	78	0
SO-012	61	37	2	0.57	0.09	62	38	0	17	83	0
SO-024	66	30	4	0.54	0.09	53	47	0	20	80	0

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	63.7	33.0	3.3	0.57	0.10	60.7	39.3	0.0	19.7	80.3	0.0
s	2.5	3.6	1.2	0.03	0.02	7.1	7.1	0.0	2.5	2.5	0.0

Galisteo Formation

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SO-031	228	0	18	91	62	0	0	0	1	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SO-031	62	38	0	0.59	0.07	0	100	0	0	100	0

Upper Cretaceous

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SO-041	289	4	29	35	21	2	0	15	4	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SO-041	81	14	5	0.62	0.10	10	90	0	4	96	0

Shell Santa Fe Pacific No. 3

Santa Fe Group

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SP-002	217	0	24	88	41	27	0	2	1	0
SP-012	233	2	40	54	32	38	0	1	0	0
SP-023	193	0	22	68	23	93	0	1	0	0
SP-034	217	0	17	91	42	31	0	1	1	0

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SP-002	60	32	8	0.68	0.10	90	10	0	50	50	0
SP-012	69	21	10	0.63	0.15	97	3	0	47	53	0
SP-023	53	23	24	0.75	0.10	99	1	0	80	20	0
SP-034	59	33	8	0.68	0.07	94	6	0	62	38	0

Mean of all Samples

	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
x	60.2	27.3	12.5	0.7	0.10	95.0	5.0	0.0	59.8	40.2	0.0
s	6.6	6.1	7.5	0.1	0.03	3.9	3.9	0.0	15.0	15.0	0.0

Upper Cretaceous

Sample	Qm	Qpt	Qpn	P	K	Lv	Lm	Ls	Lc	M
SP-044	280	0	12	72	32	0	0	4	0	0
SP-057	273	1	40	66	16	0	0	3	0	1

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
SP-044	73	26	1	0.69	0.04	0	100	0	0	100	0
SP-057	79	20	1	0.80	0.13	0	100	0	0	100	0

Galisteo Formation of Windmill Hill area from Gorham (1979)

Secondary Parameters

Sample	QFL%Q	QFL%F	QFL%L	P/F	Qp/Q	LvLsLm %Lv	LvLsLm %Ls	LvLsLm %Lm	LvLstLm %Lv	LvLstLm %Lst	LvLstLm %Lm
12/16	74	26	0	0.13	0.03	0	100	0	0	100	0

APPENDIX III

Late Miocene Fossil Mammals from the Santa Fe Group, Gabaldon Badlands, Southwestern Albuquerque-Belen Basin, New Mexico.

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Contents

Introduction

Fossil mammal remains were first discovered in the Gabaldon Badlands, southwestern Albuquerque-Belen Basin, New Mexico by H. E. Wright Jr. in 1940 while mapping the lower Puerco Valley for his Ph.D. dissertation at Harvard University under the direction of Kirk Bryan. Only a fragment of a limb bone was obtained from the "upper portion of the playa beds in the Gabaldon Badlands" (Wright 1946, p. 413) identified by Frank C. Whitmore "as belonging to any of three genera of pronghorns namely *Ramoceros*, *Plioceros* or *Osbornoceros*" (Ibid). This report initiated an investigation of the area in 1946 by Ted Galusha of the Frick Laboratory, American Museum of Natural History, New

York. Galusha and assistants spent about 14 days in the Gabaldon Badlands during June, August and October of 1946, May of 1947, and August of 1951 recovering fragmental fossil remains from several horizons. The total collection contains 51 field numbers and perhaps twice as many specimens. This collection resides in the American Museum of Natural History (acronym F:AM). It served as the basis for Tedford's (1981) remarks on the nature and age of the composite fauna recorded from interval.

In the course of mapping the Gabaldon Badlands, Richard Lozinsky made a further collection from 13 sites most of which include the same stratigraphic intervals explored by Galusha. These collections reside in the New Mexico Bureau of Mines and Mineral Resources, Socorro (acronym NMBM). The present report makes use of the American Museum and New Mexico collections.

Biostratigraphy

Galusha recognized five fossiliferous intervals in the Gabaldon section, the most productive of which appear to be equivalent to three of those from which Lozinsky also obtained material. Galusha's measured section and those of Lozinsky provide a basis for correlation of the results of both investigators.

Lozinsky grouped the strata exposed in the Gabaldon badlands into four units that dip to the southwest beneath a blanket of caliche-indurated surficial gravels. Fossil mammal remains occur in sandy deposits usually near the facies changes that mark the boundaries of Lozinsky's units. These are in descending order:

Unit 4: Interbedded sand, silt, clay and conglomeratic sand. A single camelid astragalus is the only fossil recovered from this youngest exposed Tertiary unit (Lozinsky Site 14, Level G).

Unit 3: Interbedded sands and clays. This is the most fossiliferous unit, three of Galusha's and two of Lozinsky's fossil-bearing levels occur within it: The lowest level occurs at the base (Galusha's 2nd fossiliferous horizon; Lozinsky's sites 6 and 7 and Level C of this report); about 60 ft. higher, is Galusha's 3rd horizon, Lozinsky's sites 3 and 4 (Level D); Galusha's 4th horizon is about 110 ft. from the top of the unit (Level E), and his 5th is about 55 ft. from the top (Level F) as recognized by the first prominent occurrence of gravels that mark the base of Unit 4.

Unit 2: Interbedded fine to coarse sandstone, claystones, basal conglomerate with abundant volcanic clasts. Galusha's lowest level occurs at the base of this unit as does Lozinsky's sites 8, 11 and 13 (Level B).

Unit 1: Interbedded clays and fine sands. Sands in the upper part of the unit contain fossil mammals, Lozinsky's sites 9 and 10, the lowest occurrence of fossils discovered (Level A).

The collections available are mostly highly fragmented fossil bones and rarer jaw fragments with broken teeth. Articulation of bones of a single individual are recorded for a few specimens. Such a fragmental and relatively small collection limits the biostratigraphic conclusions that can be drawn because of the difficulties in close identification of the material.

Systematics

Order Lagomorpha

Family Leporidae

A small *Hypolagus* is represented by a left P_3 in a fragment of a ramus from NMBM Site 6b, Level C. The P_3 is nearly identical to *Hypolagus vetus* from the early Hemphillian 1000 Creek deposits of northwestern Nevada. Two calcanea, F:AM Rio P. 42 and NMBM site 7c from Level E and C, repectively, pertains to a larger rabbit the size of an undescribed form sometimes referred to *Hypolagus vetus* that often accompanies the smaller taxon in early Hemphillian sites.

Order Rodentia

Family Castoridae

Dipoides sp. cf. D. vallicula

Part of a right ramus with complete cheek tooth dentition of a small beaver (F:AM 65126) was collected by Galusha in 1947 from his "second horizon" (fossiliferous Level C of this report). The P_4 is in early wear and besides showing persistent para- and mesostriids has a short metastriid as well. The M_{1-2} at this stage of wear have achieved the "S-pattern", the striids of which are broad at their terminations and the M_3 shows a parastriid. Of described beavers this specimen most closely matches Dipoides vallicula Shotwell 1970. It is smaller than the hydodym from the type locality in the Chalk Butte Formationof the eastern Columbia Plateau of Oregon. The genus Dipoides, as presently conceived, is confined to the Hemphillian and early Blancan and the species D. vallicula is confined to the Hemphillian, the type locality is early Hemphillian in age.

Order Carnivora

Family Canidae

Subfamily Caninae

Two fragments of the same fox right ramus (F:AM Rio P. 5 and 7) from Level D show the roots of $P_{1.2}$, the crown of P_3, roots of P_4, talonid of M_1 and broken crown of M_2. This specimen belongs to an undescribed genus of vulpine characterized by elongate M_2 relative to the length of the carnassial and anterior premolars well separated by diastemata. The Gabaldon specimens is closely similar in size and morphology to others from early Hemphillian sites in the Great Basin.

Subfamily Borophaginae

A proximal end of a femur (F:AM Rio P. 1) from Level C; a metacarpal III (F:AM Rio P. 33) from Level F; and a partial tibia (F:AM Rio P 44) from Level C represent borophagine canids of medium to large size. The most easily identified element is the tibia which represents a large form most closely similar to _Epicyon haydeni validus_ from early Hemphillians sites in the southern Great Plains. The smaller femur and metacarpal are of appropriate size to belong to a single taxon which seems closest to early Hemphillian _Osteoborus_ species such as _O_. _pugnator_ that coexist with _E_. _h_. _validus_ in the early Hemphillian of the Great Plains.

Family Felidae

Nimravides sp. cf. _N_. _Catocopid_

A fragment of the distal end of a large cat humerus (F:AM Rio P. 45) from Level C matches those of _Nimravides catocopis_ from the southern Great Plains. This is the largest known cat in the early Hemphillian and its remains are often found with those of the above identified canids.

Order Perissodactyla

Family Equidae

A distal end of a stout median phalanx of a lateral metapodial (F:AM Rio P. 24) from Level C represents a tridactyl equid, most likely a hipparionine horse if these deposits are of early Hemphillian age.

Order Artiodactyla

Family Camelidae

The collection consists of fragments of limb bones, podial elements and a few broken jaw fragments but since this is the most abundantly represented group the material allows recognition of four genera.

Subfamily Camelinae

Tribe Prontolabidini

Michenia sp. cf. *M. yavapaiensis*

The most abundant camelid is a small, slender-limbed form with relatively short metapodials (estimated to be shorter than skull length); high-crowned, transversely compressed, molars with reduced styles; P_2 is lacking and $P_{3.4}$ are very reduced in size relative to the molars. This combination of features indicates a small protolabidine very close to *M. yavapaiensis* Honey and Taylor, 1978 described from late Clarendonian deposits in central Arizona, and recognized in the earlier Clarendonian Avawatz Formation of the Mojave Desert in southeastern California (where a K-Ar date of 11.3 Ma is available). A similar taxon is represented by rare remains in the late Clarendonian Round Mountain Quarry in rocks referred to the Chamita Formation in the western Espanola Basin, New Mexico. No early Hemphillian occurrences of the genus or species have been recorded, but a related, somewhat larger, form of similar morphology is common in the late Hemphillian faunas of Nevada and Arizona.

From the Gabaldon Badlands this taxon ranges nearly throughout the fossiliferous part of the section. Particularly useful material is recorded from Level A (broken jaw fragments of immature individuals from NMBM Site 9), Level C (F:AM Rio P. 12 jaw fragment with roots of $P_{3.4}$; F:AM 47971 nearly complete metatarsal), Level D (NMBM Site 3d, left maxillary fragment with broken $P^{3-4}M^{1-3}$, Level E (F:AM 68388, partial skeleton without skull or mandible; F:AM 68385 fragment of right ramus with parts of $M_{1.3}$) and Level F (F:AM 47969 distal end of metatarsal).

Tribe Lamini

<u>Hemiauchenia</u> sp.

A right astragalus of a small llama was obtained from Unit 4, Level G (NMBM Site 14). This element is nearly twice the size as those of *Michenia*, and half the size of the larger lamines reported below. Its identification as *Hemiauchenia* is mainly from these size relationships and the common occurrence of species of this genus (*H. vera*) with the layer lamines in Late Clarendonian and Hemphillian faunas.

Procamelus sp.

A jaw fragment with roots of P_{1-4} (F:AM Rio P 1) from Level B represents a large form of *Procamelus* comparable with undescribed material from the early Hemphillian of the Texas panhandle and adjacent Oklahoma. The lack of strong reduction of the premolars distinguishes this form from contemporary *Aepycamelus* of similar size.

Alforjas sp.

Two jaw fragments (F:AM 41426, roots $I_{1.3}$ CP_1, P_3 P_4, M_1 talonid M_3, Level F.; F:AM 47936, $P_{3.4}$ $M_{1.3}$, Level C) represent a large llama lacking P_2, having P_3 reduced relative to P_4, weak anteroexternal styles and laterally compressed C_1 roots. These features characterize *A. taylori* Harrison, 1979, but the individuals are larger than the late Hemphillian Edson Quarry (Kansas) sample used to typify that taxon. They more closely approximate the size of the sample referred to the genus from Wray, northeastern Colorado of later early Hemphillian age. Many large limb fragments may pertain to this genus, none seem large enough to represent Megatylopus a similar form belonging to the Camelini and often found with Alforjas. Most indicative of Alforjas is a radius (F:AM 41425, Level C) and metatarsals and associated proximal median phalanx (F:AM 41429, Level F).

Family Antilocapridae

Subfamily Antilocaprinae

Remains of pronghorns are second to camels in abundance in the Gabaldon exposures. They have been found at all levels except the lowest one. Unfortunately, horn cores are rare as the taxonomy of the group is largely based on the morphology of the adult cranial appendages. There is no clear evidence of the presence of merycodont antilocaprids although the dental and appendicular remains overlap the range in size of larger merycodonts. The lack of abundant merycodont horncore fragments compared with the relative abundance of antilocaprid remains, especially at Level C, suggests that merycodonts were absent.

Two types of horn cores are present. One is represented by a juvenile right core and orbital roof associated with two maxillae ($Dp^{3-4}M^{1-3}$, F:AM Rio P. 37, Level E). The horn rudiment is held erect on the orbital roof. It is a transversely flattened structure formed of a single blunt point situated posteriorly extended forward by an anterior crest. The horncore is oriented slightly anteroexternally on the orbit. This structure is similar enough to adult *Plioceros* cores that it could represent a species of that genus. The associated upper dentition is larger than most species of the genus except *P. blicki* from the late Clarendonian of Espanola Basin.

The second horncore type is represented by a fragment of the base of a left core and attached ortibal and cranial structures (F:AM Rio P. 50, Level C) and the tip of a horncore from the same locality. Two associated fragments of the shaft of a horncore (NMBM Site 7c) are superficially merycodont-like but are provisionally assigned here. This horncore has a strongly triangular cross-section apparently with an acute angle or flange oriented anterolaterally on the orbit much in the manner of *Osbornoceras osborni*. Like the latter genus the shaft of the horncore makes a wide angle with the sagittal plane, the horns sweeping outward and posteriorly. The shaft fragments are flattened oval in cross-section, as in some individuals of *O. osborni*, and have a slight torsion. This taxon seems closely related to *O. osborni* but its horns are smaller than that late Hemphillian form from the Espanola Basin. Isolated dentitions from Level C (NMBM Site 7a right Dp$_{3-4}$M$_{1-2}$), Level D (NM8M Site 3b, right P$_{3.4}$ M$_{1-3}$) and Level F (F:AM Rio P. 36, right Dp$_{3.4}$M$_{1.2}$) are similar in size and height of crown to *O. osborni* or *P. blicki* and could represent either genus in the Gabaldon collection. The same applies to the limbs although a considerable range in size is apparent which may have taxonomic significance.

Biochronology and Zoogeography

Tedford (1981, p. 1016) gave the first faunal list for the fossiliferous interval in the Gabaldon Badlands mentioning "the dog *Epicyon* cf. *E*. *haydeni*, the camels *Michenia*, *Alforjas*, *Megatylopus* and *Aepycamelus*; and the antilocaprine pronghorns *Plioceros* or *Texoceros*." He speculated that the fauna was of late Clarendonian age possibly extending into the early Hemphillian in the younger part of the fossiliferous interval. The present work extends and confirms part of these identifications and rejects others to yield the following list:

Leporidae	*Hypolagus* sp. cf. *H*. *vetus*
	H. sp.
Castoridae	*Dipoides* sp. cf. *D*. *vallicula*
Canidae	Vulpine, n. gen. et sp.
	Epicyon sp. cf. *E*. *haydeni validus*
	Osteoborus sp.
Felidae	*Nimravides* sp. cf. *N*. *catocopis*
Equidae	hipparionine
Camelidae	*Michenia* sp. cf. *M*. *yavapaiensis*
	Hemiauchenia sp.
	Procamelus sp.
	Alforjas sp.

Antilocarpidae *Plioceras* sp.
Osbornoceros sp.

With the exception of the record of *Hemiauchenia*, all the taxa in the above list occur together, or in overlapping local stratigraphic ranges in fossiliferous levels B through F. We will apply the term Gabaldon Fauna to this interval. The fauna may also be represented in Level A, by *Michenia* sp. cf. *M. yavapiensis*, but as this is the only taxon present there, and is a form better known from Clarendonian rocks, it is possible that that level could be of late Clarendonian age. Likewise, Unit 4, which represents a major shift in depositional regime (Lozinsky and Tedford, 1986), could be significantly younger than the closed-basin deposits underlying it. The record of *Hemiauchenia* in Unit 4 does not closely constrain these deposits for species of the genus of similar size range into the Pleistocene.

Taken as a whole, and with respect to the level of identification possible with the material at hand, the Gabaldon Fauna as restricted is of early Hemphillian age. Some taxa occur in older late Clarendonian faunas, others extend into the late Hemphillian, but the combination of forms, especially the beaver and the carnivores are uniquely early Hemphillian. As presently calibrated by K-Ar dating of mammal faunas of early Hemphillian age from the Great

Basin to the Great Plains this subdivision of the late Miocene spans the interval from about 7-9 Ma.

The ungulate fauna of the Gabaldon outcrops is dominated by camels and pronghorns; horses are rare and rhinos and mastodonts unrecorded. This is in strong contrast to early Hemphillian faunas of the Great Plains in which horses are taxonomically diverse and usually equally or more abundant than camels; rhinos and mastodons are usually conspicuous members of such samples. Late Clarendonian and Hemphillian sites of the southern Great Basin are similar to the Gabaldon Fauna in relative abundances of ungulates suggesting the region was a distinctive zoogeographic province especially characterized by the survival of small, very hypsodont, protolabidine camels into latest Miocene time.

Paleontological dating of the upper part of the Santa Fe Group outcrops in the Gabaldon Badlands in the southwestern Albuquerque-Belen Basin provides a basis for correlation of this part of the section with the sedimentary and volcanic sequence exposed in the northern part of the basin. Units 2 and 3, containing the Gabaldon Fauna, can be correlated with the lower part of the Cochiti Formation and the interfingering volcanics of the Keres Group, deposits which record the first influx of coarse detritus into the northern part of the basin probably upon initiation of uplift of the Jemez volcanic center.

In the north-central part of the Espanola Basin the lower part of the type section of the Chamita Formation contains the canid Epicyon sp. cf. E. haydeni validus in rocks reinterpreted by Tedford (1981, pp. 1013-1014) to belong to "Chon 7" between 6.7 and 8.2 Ma. The Chamita Formation is the youngest unit deposited in the closed Espanola Basin. It was truncated after 5.5 Ma by structural events associated with the northern Jemez volcanic center and the development of through-flowing drainage.

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