HYDROGEOLOGIC FRAMEWORK OF THE NORTHERN ALBUQUERQUE BASIN

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Compilers

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Executive Summary

In January 1992, the New Mexico Bureau of Mines & Mineral Resources (NMBMMR) entered into a cooperative agreement with the City of Albuquerque Public Works Department to develop a conceptual hydrogeologic model for the Bernalillo County area of the northern Albuquerque Basin. The resultant characterization of the study area's hydrogeologic framework, which is described in this report, represents a significant advancement over previous models (e.g. Bjorklund and Maxwell, 1961; Kelly, 1974). The NMBMMR model will, therefore, provide a much improved basis for the development of numerical models of the basin's ground-water flow system (Kernodle, 1992). These, in turn, are absolutely essential for quantitative evaluation of future water-resource development and conservation strategies.

In its simplest form, the conceptual model is a description of the textural character, composition, and geometry of (1) the various parts of the Santa Fe Group, which is the major geological unit that fills the Albuquerque Basin (as well as other intermontane basins of the Rio Grande rift region) and (2) the overlying river-valley and basin-fill deposits. When firmly based on adequate subsurface geological and geophysical data, the model describes the "architecture" of basin and valley fills with respect to the three-dimensional distribution of mappable subdivisions that have distinct differences in geophysical and geological properties, and aquifer characteristics.

The conceptual model has three basic components, which are graphically presented in a map and cross-section format (Plates 1 to 7): (1) **Structural and bedrock features** include basin-bounding mountain uplifts, bedrock units beneath the basin fill, fault zones within and at the edges of the basin that influence sediment thickness and composition, and igneous intrusive and extrusive (volcanic) rocks that penetrate or overlap basin-fill deposits. (2) **Hydrostratigraphic units** comprise mappable bodies of basin and valley fill that are grouped on the basis of origin and position in a stratigraphic sequence. Genetic classes include ancestral-river, present river valley, basin-floor playa, and alluvial-fan piedmont deposits. Time-stratigraphic classes include units deposited during early, middle, and late stages of basin filling (i.e. lower, middle, and upper Santa Fe Group), and post-Santa Fe valley and basin fills (e.g. channel and flood-plain deposits beneath the modern valley floors or preserved as alluvial terraces). (3) **Lithofacies Units** are the fundamental building blocks of the model. Lithofacies are mappable bodies defined on the basis of texture, mineralogy, sedimentary structures, and degree of post-depositional alteration. They have distinctive differences in geophysical and geochemical properties and in hydrologic behavior. In this study, basin deposits are subdivided into ten lithofacies and associated sublithofacies and their three-dimensional distribution is described.

This open-file report has been released primarily to allow immediate use of the information that it contains by the City of Albuquerque and cooperating water resource agencies such as the U.S. Geological Survey and the Bureau of Reclamation. Formal publication is planned in 1993 as part of the NMBMMR Hydrologic Report Series (No. 8). The document is organized into nine major sections, including an expanded list of technical references, with supporting data in eight appendices, and a glossary of geological terms. **The introductory section (I)** summarizes a *six-task* approach followed in meeting the three major objectives of the investigation:

1. To define and map the major hydrogeologic components of the Albuquerque Basin in the Bernalillo County area between the Rio Puerco and the crest of the Sandia-Manzanita-Manzano mountain range.
2. To establish basic mineralogical and petrologic characteristics of basin-filling deposits, with emphasis on study of drill cuttings, core, and geophysical logs of 12 key wells recently drilled by the City of Albuquerque.
3. To develop the conceptual model of the basin's hydrogeologic framework.

Members of the research team (Appendix A) initially worked independently on analyses of data from several sources (tasks 2 and 3), including field drilling records, borehole cutting and core

samples, geophysical logs, other unpublished drilling data, and published information. The refinement of a provisional model (Tasks 1 and 4) based on previous work in basins of the southern Rio Grande rift (Hawley, 1984; Lozinsky, 1987; Hawley and Lozinsky, 1992) proceeded concurrently with the data analysis phase of the study. It is important to note that these initially independent efforts reinforced each other and supported the basic premise of the provisional conceptual model: namely, that distribution patterns of major rift-basin-fill components can be predicted if (1) their geologic history is understood, and (2) adequate high-quality (geological, geophysical, and geochemical) information is available on subsurface conditions.
The final phase of the study (tasks 5 and 6) involved preparation of (1) the map and cross sections (Plates 1 to 7) that graphically portray the conceptual model and (2) the supporting documentation that forms the body of this report.

Section II provides a general geological overview of the entire Albuquerque Basin between the Santo Domingo and Socorro basins. This is the Albuquerque-Belen Basin of many ground-water publications (Kernodle, 1992). Emphasis is on the relatively recent interval of geologic time (~ past 25 million years) when the major structural and topographic elements of present landscape formed. It was a period of regional stretching of the earth's crust, and differential uplift, subsidence and tilting of individual crustal blocks along major fault zones to form basins and ranges. This continental "rifting" process produced the feature we now call the Rio Grande rift, which extends from southern Colorado to northern Chihuahua and western Texas.

The Albuquerque Basin is one of the largest and deepest structural depressions of the rift zone (Figs. I-1 and 2). The fill that was deposited by water- and wind-driven (alluvial, lacustrine, and eolian) processes during the basin-forming interval is designated the Santa Fe Group. The lower to middle part of the Group is locally well indurated and contains a large amount of fine- to medium-grained material (clay, silt and fine sand) that was deposited on the broad central plains of an internally drained complex of intermontane basins. Such units usually do not produce large amounts of good-quality groundwater. Poorly consolidated medium- to coarse-grained deposits (sand and gravel) in the middle to upper part of the Santa Fe sequence form the major aquifers of the region. Widespread channel deposits of the ancestral Rio Grande first appear in upper Santa Fe beds that have been dated at about 5 million years (Figs. I-3).

Expansion of the Rio Grande (fluvial) system into upstream and downstream basins and integration with Gulf of Mexico drainage in the early part of the Quaternary (Ice-Age) Period about one million years ago led to rapid incision of the present river valley and termination of widespread filling of intermontane basins along the Rio Grande rift (ending Santa Fe Group deposition). Cyclic stages of valley cutting and filling, which correlate with expansion of and contraction of Alpine glaciers in the Southern Rocky Mountains (San Juan and Sangre de Cristo), are represented by prominent river-terrace and floodplain deposits that partly fill the Rio Grande and Puerco Valleys.

Channel sand and gravel deposits (<130 ft) below the modern river floodplain constitute a thin, but extensive shallow-aquifer system that is commonly in contact with ancient river channel units of the upper Santa Fe Group. These deposits form the major recharge as well as discharge zone for the basin's ground water, and are quite vulnerable to pollution in this urban-suburban environment.

The relatively simple process of basin filling and valley cutting just summarized is in reality significantly more complex, because structural deformation of basin boundaries and topographic relief between individual basin segments and flanking highlands continued to change over geologic time. For example, during early stages of basin filling (lower Santa Fe deposition) the present bounding range blocks had not formed or had very low relief. Thickest basin-fill deposits (up to 10,000 feet), including much of the middle Santa Fe Group, were emplaced between 5 and 15 million years ago during the interval of most active uplift of the Sandia-Manzanita-Manzano range and deep subsidence of central basin fault blocks. This structure is bounded on the west by a zone of faults (County Dump or West Mesa zone) following the Albuquerque Volcano trend and on the east by the Rio Grande fault, a buried feature near the east edge of the Rio Grande floodplain now covered by recent river sediments.

The conceptual hydrogeologic model and its development are the subject of **Section III.** Graphic portrayal of the model has a combined geologic map and cross-section format (Plates 1-7; Figs. III-1 to 6), with tables (III-1 and 2) and Appendices (C to F) containing supporting data. The plates are published at a horizontal scale of 1:100,000 (approx. 0.6 in/mi), and cross sections have a vertical exaggeration of 10x (approx. 1.2 in/1000 ft). The base elevation of the model is mean sea level and the water table in central basin areas is at about 4,900 ft. The vadose, or unsaturated, zone that overlies this thick sequence of saturated basin fill is locally as much as 1000 ft thick in "mesa" areas outside the Rio Grande Valley. Much of the upper basin and valley fill is an unconsolidated sequence of interbedded sand and gravel, with varying (but relatively small) amounts of silt and clay. However, below depths ranging from 700 to 1000 ft below the water table, there is a significant increase in the percentage of fine-grained material or partly-indurated (cemented) coarser-grained beds. Deeper hydrogeologic features of the basin fill are illustrated on four small scale (isopach) maps (Figs. IV-2 to 5) that show the thicknesses of the major hydrostratigraphic subdivisions of the Santa Fe Group to the maximum depth of the basin fill (about 10,000 ft below sea level). These units are described in the next paragraph.

The basic hydrogeologic mapping unit used in conceptual model development is the *hydrostratigraphic unit*. It is defined in terms of (1) environment of deposition of sedimentary strata, (2) distinctive combinations of lithologic features (lithofacies) such as grain-size distribution, mineralogy and sedimentary structures, and (3) general time interval of deposition. The attributes of four major (RA, USF, MSF, LSF) and two minor (VA, PA) classes into which the area's basin and valley fills have been subdivided are defined in Table III-1 and Appendix C. The Upper, Middle, and Lower hydrostratigraphic units of the Santa Fe Group roughly correspond to the (informal) upper, middle, and lower rock-stratigraphic subdivisions of Santa Fe Group described in Section II. The other major hydrostratigraphic unit (RA) comprises Rio Grande and Puerco deposits of late Quaternary age (<15,000 yrs) that form the upper part of the regional shallow-aquifer system.

The ten lithofacies subdivisions that are the basic building blocks of the model are defined primarily on the basis of sediment texture, (gravel, sand, silt, clay, or mixtures thereof), degree of cementation, and geometry of bodies of a given textural class and their relative distribution patterns. Lithofacies I, II, III, V, and VI are unconsolidated or have zones of induration (strong cementation) that are not continuous. Clean sand and gravel bodies are major constituents of facies I, II, V, and VI; while clay or cemented sand zones form a significant part of facies III and IV. Subdivision IV is characterized by thick eolian sand deposits of the Lower Santa Fe unit (LSF) that are partly cemented with calcite. Coarse-grained channel deposits of the modern and ancestral Rio Grande (lithofacies I and II) are the major components of the upper Santa Fe (USF-2) and river-alluvium (RA) hydrostratigraphic units. They form the most important aquifers and potential enhanced-recharge zones in the basin. Buried arroyo-channel deposits of a large alluvial fan that spread out from the mouth of Tijeras Canyon (facies Vd) form another major hydrogeologic unit (middle and upper Santa Fe; MSF-1 and USF-1) that has greater than average aquifer potential. This ancient complex of fan distributaries is now partly dissected by valleys of the present Embudo, Campus and Tijeras arroyo systems. Lithofacies VII and VIII are partly to well indurated piedmont-slope deposits; while facies IX and X comprise thick sequences of fine-grained basin-floor sediments that include playa-lake beds.

One of the most significant accomplishments of this study has been better documentation of the physical limits of the basin imposed by the structural features (primarily fault zones) and bedrock units that form its boundaries. Seismic-reflection profiles , which were recently released by Shell, Inc. and ARCO, Inc.(Russell and Snelson, 1991; May and Russell, 1991; May et al., 1991) have played a major role in development of the present model and establishing its validity. The model is also based on analyses of well cuttings, core samples, and geophysical logs from deep oil and gas tests that had previously been donated to the NMBMMR by major oil companies working in the basin. Combined seismic and borehole geophysical information provided the basis for generalized geologic model of the entire basin described in Section II (Figures I-1 and 2; Lozinsky, 1988; Lozinsky and Tedford, 1991).

The present model incorporates analyses of samples (cuttings and cores), and geological and geophysical logs from about 30 deep water wells drilled in the metropolitan area. Twelve of these wells were recently drilled for the City of Albuquerque and include very comprehensive suites of geophysical logs (analyzed in Section V) as well as high-quality sets of drill cuttings and core samples of representative lithofacies and hydrostratigraphic units (described in Section IV and Appendices F and G). The water-well data used in model refinement and validation were mainly collected in the Northeast Heights area of the City at depths of less than 3400 ft.

The prediction of hydrostratigraphic unit and lithofacies distribution patterns, and location of bedrock and structural boundary zones beyond the areas of adequate well control or surface geophysical information are based on the concepts of basin structural evolution and depositional history developed in this and previous investigations (e.g. Bryan, 1938; Spiegel, 1961; Titus, 1961, Lambert, 1968; Kelley, 1977; Hawley, 1978; Lozinsky, 1988; Hawley and Love, 1991; Lozinsky et al., 1991).

The conceptual hydrogeologic framework just discussed is primarily based on an independent evaluation of available geologic and geophysical information, and visual and low-power microscopic examination of drill cuttings. The analyses of petrologic and borehole geophysical data described in **Sections IV and V** represent the first stages of quantitative validation of that model. Discussions in this part of the report are necessarily highly technical because of the nature of the petrographic or geophysical data obtained at specific drilling sites

The petrologic investigations described in **Section IV** emphasize the fundamental properties of rock fragments and individual mineral grains that in aggregate form the various lithofacies components of basin deposits. Tools needed to properly describe earth materials at this scale include the light (petrographic) microscope for rock-thin-section analysis, and x-ray diffraction equipment and the scanning electron microscope for characterization of ultra-fine-scale features (e.g. porosity and cementing agents).

Petrologic studies show that the upper 3200 ft of basin fill in the Northeast Heights well fields has a bulk composition of about 60% Precambrian-derived granitic and metamorphic detritus, about 30% volcanic material, and less than 10% detritus derived from Paleozoic and Mesozoic sedimentary rocks (limestone, sandstone, and shale). The granitic and metamorphic material could come from source areas as near as the Sandia-Manzanita uplift or as far as the Sangre de Cristo Range. With the exception of local basalts, volcanic material can only be derived from basin and mountain areas to the north, with the Jemez and Ortiz Mountains being the closest major source areas. Most sedimentary rock particles appear to be derived from the Colorado Plateau area to the west and the Tijeras Canyon watershed.

Alluvial-fan deposits (lithofacies V) that form the upper 100 to 300 ft of basin fill in the Northeast Heights area are almost entirely derived from the Sandia Mountains. Sand- and gravel-size clasts consist primarily of quartz and feldspar derived from weathering of granite (arkosic material). At an elevation of about 5200 ft all wells penetrate an extensive sheet of clean sand and gravel deposited by the ancestral Rio Grande (lithofacies Ib,unit USF-2). Many clasts were derived from the Jemez Mountains and flanking basalt fields that have been sites of very active volcanism during the past 7 million years (Smith et al., 1970; Gardner et al., 1987; Goff et al., 1989; Smith et al., 1991). An extensive upper zone of "braided" river-channel deposits as much as 200 ft thick (mostly facies Ib) was deposited during or just after the Bandelier Tuff eruptions that occurred between 1.6 and 1 million years ago. Ancient river deposits of the upper Santa Fe Group unit (USF-29, facies Ib, II, III) wedge out eastward and intertongue with alluvial-fan deposits (facies V, Vd, Vf) in a broad (3-4 mi wide) zone between Wyoming Blvd. and University Ave. and I-25. This unit is partly above the water table and is usually less than 700 ft thick.

Analyses of core samples of fine-grained Middle and Lower Santa Fe units (MSF and LSF; mainly facies III, V and VII) in the Northeast Heights well field area demonstrate that a small percentage of distinctive volcanic rock types (welded tuffs) are present in these deposits to the maximum sampled depth of about 3200 ft. Some of this material is derived from source areas as far north as the Red River area of northern New Mexico. It appears that a significant amount of the silty clay to fine pebbly material in the older basin fill was washed into the rapidly subsiding northern basin area for a very long period prior to development of the through-flowing Rio Grande system about 5 million years ago. Another significant component of the Lower Santa Fe unit in central and northwestern basin areas is eolian sand (facies IV). Coarse-grained alluvial-fan deposits derived from the rising Sandia-Manzanita uplift probably never prograded very far into the basin (Plates 1 to 7, figs. III-2 to 5).

Thin section analyses of core samples from lithofacies V and VII, and grain mounts of well cuttings from lithofacies Ib and V indicate that the sand and sandstone components of these facies contain a great variety of mineral grains and fine rock fragments. Sand-size framework grains consist of monocrystalline quartz, feldspar, and rock fragments (volcanic, granitic/gneissic, sedimentary, and metamorphic) with lesser amounts of biotite, muscovite, chlorite, and heavy minerals. Volcanic clasts are the most abundant rock-fragment type and consist mainly of plagioclase-dominated porphyries with lesser amounts of rhyolite, including densely welded ash-flow tuffs. The principal non-framework components, which fill spaces between the coarser sand grains are detrital/mechanically infiltrated clay, zeolites, and calcite. Mean grain size ranges from very fine to coarse, with a substantial amount of material larger than 2 mm occurring in conglomeratic sandstones. Sorting ranges from good to poor.

Fine-grained beds sampled by sidewall cores from lithofacies V and VII consist mainly of clay, with lesser amounts of sand and silt. One sample contained abundant calcite cement. The principal clay minerals in the fine-grained beds are smectite, illite, kaolinite, and interlayered illite/smectite. The silt-sized fraction of mudrocks contains a significantly higher proportion of quartz relative to feldspar than in adjacent sandstones. Much of this additional quartz may be eolian.

Petrologic studies support the observation made in Section III that Santa Fe Group sediments below northeastern Albuquerque are mostly unconsolidated or poorly cemented to a depth of approximately 1300 feet (upper Middle and Upper Santa Fe hydrostratigraphic units). Cementation and induration become significant at a depth of approximately 1700 to 2000 feet (lower part of the Middle Santa Fe unit). Major diagenetic events that affected the rocks are calcite, zeolite, and smectite precipitation, and grain dissolution. Grain dissolution resulted in the formation of volumetrically significant secondary porosity. Fractures are present in most of the samples. Many of these fractures probably result from the coring process and may not be present in the actual rock.

Borehole geophysical data (Appendix H) is analyzed in **Section V**. Geophysical-log responses vary from lithofacies to lithofacies. Typically, the response of any single geophysical log is not characteristic of particular lithofacies. Response behavior of suites of logs can be calibrated with drill cuttings from key wells to identify response characteristics that are diagnostic of lithofacies. Such log-suite response characteristics can be used to map the distribution of lithofacies for regions where only borehole geophysical data are available. Preliminary analysis of geophysical-log suites and well cuttings from 12 boreholes in Albuquerque area suggests that combinations of electrical-conductivity, gamma-ray, density, and acoustic-velocity logs can be used for lithofacies interpretation. Such a log suite is widely available for wells in the Albuquerque area, and results suggest that the mapping of lithofacies distribution by this technique holds promise.

Analysis of geophysical logs has identified a potential drilling target for water-resource evaluation west of the Rio Grande. At depths below approximately 1500 ft in the College 1, College 2, and Ladera wells, a thick sand-rich interval is noted. Preliminary analysis of geophysical logs north and south of the College and Ladera wells suggests that the sand-rich interval extends at least several miles in each direction. Additional geophysical log analysis may serve to better define the extent of this interval and to provide a preliminary evaluation of ground-water quality.

In **Section VI** the hydrological properties of the lithofacies were estimated by considering factors such as sand + gravel/silt + clay ratio, bed thickness, bed shape, and bedding continuity. Generalized values for each of these parameters were estimated directly from lithofacies definitions. In turn, the values for the parameters were used to estimate the average hydraulic conductivity and ground-water production potential of the 10 major lithofacies of the Santa Fe Group. Lithofacies with the greatest estimated ground-water production potential include lithofacies Ib, Iv, I, II, and Vd. The least productive lithofacies include III and IX. Application of this analysis to the conceptual hydrogeologic model allows the three-dimensional arrangement of productive ground-water intervals to be estimated in the Albuquerque area.

Discussion. The conceptual model of the Albuquerque area's hydrogeologic framework developed for this report (Plates 1 to 7, and the color-coded 3-D arrangement of these plates) is clearly what its name implies:

1.. It is only a *model* of a very complex real-world system (Kernodel, 1992, pp. 6-7).
2. The intellectual construct that is a *concept* can only be as good as the quality of the scientific information used in its development.
3. The model's graphic portrayal is at least partly an artistic effort that reflects the talents of its creator (or lack thereof).

The authors of this report believe that the major features of the model will stand the test of time, but that there will also always be need (and space) for improvements. The positive feedback loop between assimilation of additional scientific information, and improved conceptualization and artistic skill will continue to be enhanced as the model is being tested and further developed.

Acknowledgments

Financial and logistical support by the City of Albuquerque, Public Works Department, Water Utility Division, and the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) at New Mexico Tech is gratefully acknowledged. A. Norman Gaume, Technical Programs Manager, and Thomas E. Shoemaker, Principal Engineer - Planning, played key supporting roles throughout the study. Dr. Charles E. Chapin, State Geologist and Director of NMBMMR; Jiri Zidek, Chief Editor/Senior Geologist; Rebecca J. Titus, Cartographic Supervisor; and Technical Secretaries Lynne Hemenway and Shelley Lanier were also major contributors to the success of the project.

Special acknowledgment is due to W. K. Summers, formerly with the City of Albuquerque Public Works Department, who was the driving force behind this study. He initially encouraged and supported major involvement of the NMBMMR and New Mexico Tech in basin-wide hydrogeologic research; and he saw to it that the new geological, geophysical and geochemical data essential for the successful completion of this investigation were collected and made available to our research team.

Many individuals and organizations have assisted us, both in the present investigation and during earlier related studies of the Albuquerque Basin. A large number of the authors cited in this report have also made significant personal contributions to the project's success. Many of the basic concepts of basin geology were developed by G. O. Bachman, P. W. Lambert, C. E. Stearns, Zane Spiegel, Frank Titus, and the late Ted Galusha and V. C. Kelley. Other collaborators on geological and geophysical investigations include Steve Barghoorn, Bruce Black, Steve Cather, Ray Ingersoll, Bert Kudo, Dave Love, Mike Machette, Jud May, Dennis McQuillan, Lee Russell, Dick Tedford, and Steve Wells.

The basic structure of the conceptual model used in this investigation was developed between 1981 and 1987 to facilitate numerical modelling of the ground-water-flow system in the Las Cruces-El Paso area. Tom Cliett (formerly with El Paso Water Utilities), Dave Peterson (formerly at NM Tech), Ken Stevens (formerly with the USGS-WRD) and Francis West of the NM State Engineer Office collaborated with Hawley and Lozinsky in that effort.

Personnel of the USGS-WRD District Office in Albuquerque have made many significant contributions to the present investigation. Special thanks are due to Cindy Abeyta, Scott Anderholm, Ben Garcia, Charles Kaehler, Mike Kernodle, Georgiana Kues, Carole Thomas, and Dave Wilkins. Mike Kernodle provided much useful and insightful discussion of the conceptual model and reviewed the final draft of this report. Dave Wilkins and Ben Garcia facilitated digitizing analog geophysical logs of key boreholes; and Ben Garcia has made an exemplary effort to translate digital logs into a usable format.

Site reports and staff communications on recently drilled municipal wells by local consulting firms have materially contributed to conceptual model development. Special acknowledgment is made to Camp, Dresser, and McKee, Inc.; Geohydrology Associates, Inc.; and John W. Shomaker, Inc. for this information. We also thank Mike Spilde of UNM for assistance in scanning electron microscopic (SEM) examination of borehole samples, and Linda Logan (formerly at NM Tech) for her interpretations of ground-water chemistry and lithofacies distribution in basin-fill deposits. Finally, the major contribution of geophysical and geological information on deep-basin structure and basin-fill composition by Shell, Inc. and Arco, Inc., and present or former employees Lee Russell, Sig Snelson and Jud May is gratefully acknowledged.

SECTION I

INTRODUCTION

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J. W. Hawley and C. S. Haase (compilers), 1992, *Hydrogeologic framework of the northern Albuquerque Basin*, New Mexico Bureau of Mines and Mineral Resources, Open-File Report 387, pp I-1 to I-4.

I. INTRODUCTION

With increasing use of ground water and its great potential for both recharge and pollution in the alluvial basins along the Rio Grande valley of New Mexico, water-resource managers need a much better understanding of the hydrogeologic framework of the basin- and valley-fill aquifer system. Suitable numerical models of basin geohydrology require this type of baseline information (Kernodle, 1992). At a minimum, characterization of basin-fill hydrogeology in sufficient detail to support successful numerical modeling activities should include quantitative description of the major lithologic, geochemical, stratigraphic, and structural subdivisions that comprise the aquifer system, and delineation of the basin boundaries and recharge areas.

In this report are described the results of a study characterizing the basin-fill hydrogeology of the Albuquerque Basin within the boundaries of Bernalillo County. The study was conducted by the New Mexico Bureau of Mines & Mineral Resources (NMBMMR) for the City of Albuquerque Public Works Department, and is part of a multiyear, multi-agency program organized by the City of Albuquerque to better understand the character, capabilities, and limits of its water supply. This report is a preliminary document; it is a progress report summarizing data obtained from the stratigraphic analysis, study of well cuttings and side-wall cores, and analysis of borehole geophysical logs from selected key borings including throughout the Albuquerque area. A conceptual hydrogeologic model based on the presented data is developed and discussed. Detailed examination and discussion of all available data are beyond the scope of this report, and will be the subject of future investigations undertaken to improve and refine the conceptual model presented herein.

Background

The NMBMMR proposed this study of the northern Albuquerque Basin because there is an immediate need for detailed investigations related to water-resource management. The area contains New Mexico's largest center of population and economic growth, and both the private and public sectors (except for irrigated agriculture) rely solely on ground water.

The Albuquerque Basin has one of the thickest basin-fill sequences (up to 14,000 feet) in the Rio Grande rift zone of the Basin and Range province. The upper 2000–3000 feet of fill in the central and eastern parts of the basin are poorly consolidated and include the major fresh-water aquifers of the region. A large mass of information (e.g. borehole samples, geophysical logs, and geochemical data) has been collected on this aquifer system, much of it during the past decade. This information, however, has never been analyzed and placed in the framework of a conceptual model that can be readily visualized from either a geologic or a hydrologic perspective.

The NMBMMR developed a comprehensive hydrogeologic model of a similar aquifer system within the Mesilla Basin between Las Cruces and El Paso (Hawley, 1984; Hawley and Lozinsky, 1992). The Mesilla Basin project was completed in cooperation with the U. S. Geological Survey's Water Resources Division, the New Mexico State Engineers Office, and the El Paso Water-Utilities Department. The conceptual hydrogeologic model developed for the Mesilla Basin provided a guide for the characterization of Albuquerque Basin deposits.

Objectives

The study of the hydrogeologic framework of the northern Albuquerque Basin described in this report was sponsored and funded jointly by the City of Albuquerque Public Works Department and the NMBMMR. It has three major objectives:

1. To define and map the major hydrogeologic units that comprise the basin- and valley-fill deposits of the northern Albuquerque Basin, with emphasis on the Bernalillo County area between the Rio Puerco and the Sandia and Manzanita/Manzano Mountains (Plate 1 and Fig. I-1). The hydrogeologic-unit concept combines information on (1) the origin and age

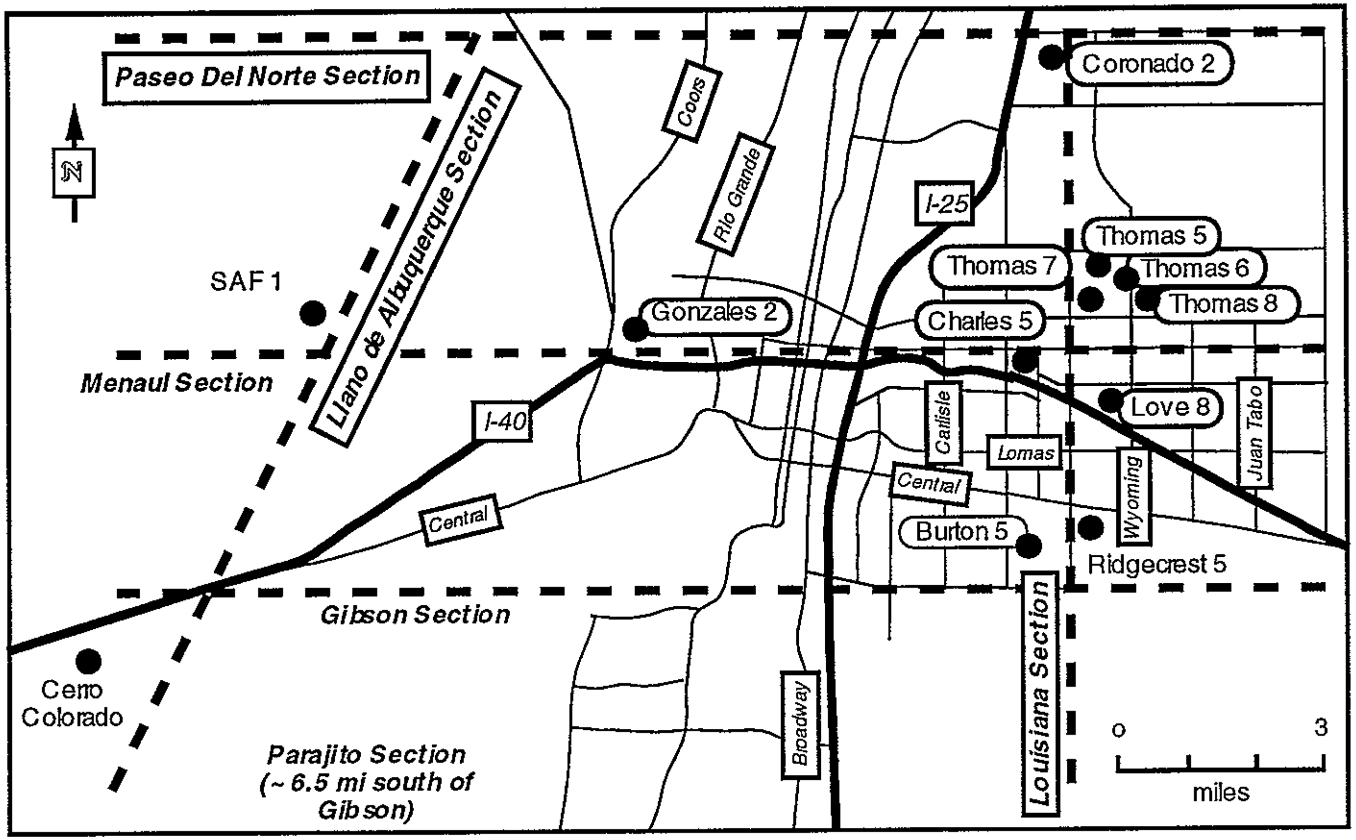

Fig. I-1. Index map to hydrogeologic cross sections and to 12 key City of Albuquerque wells used in the study.

of basin and valley fill—*hydrostratigraphic units*; (2) texture, arrangement of textural classes, and mineralogy of various classes of deposits—*lithofacies units*; and (3) bedrock and geologic structural controls on distribution of basin and valley fill.

2. To establish the basic mineralogic and petrologic characteristics of the hydrogeologic units. Emphasis is on study of data (samples, geophysical and geological logs) from key wells recently drilled in the metropolitan area to investigate the basin-fill aquifer system.

3. To develop a conceptual model of the hydrogeologic framework of basin- and valley-fill deposits in the Bernalillo County study area. This model is designed for development of numerical models that best characterize the hydrology of study area.

Approach

The study was conducted by a team of four professional staff members from the NMBMMR and one faculty member and one graduate student from the Geoscience Department at the New Mexico Institute of Mining & Technology during the period January 1992 through June 1992 (Appendix A), and consisted of six tasks:

1. Development of a preliminary conceptual model based on previous work in basins located in the Rio Grande rift structural zone extending through New Mexico from southern Colorado to western Texas.

2. Analysis of hydrogeologic data generated by both the public and private sectors since about 1960 to further develop and test the preliminary conceptual model. These data included approximately 180 logs of water wells and test borings (water, oil and gas) with detailed information on geophysical and/or lithologic properties of basin and (river) valley fill (see Appendix B). Also examined were numerous reports on both surface and subsurface geology of the area. A major subtask was to better characterize ancient river-channel deposits (ancestral Rio Grande) known to occur in the upper part of the basin-fill "aquifer" system beneath large parts of eastern Albuquerque and adjacent mountain-front areas.

3. Analysis of new hydrogeologic and geophysical data from 12 key water wells and test holes drilled by the city in the past six years, as well as information from approximately 20 additional wells selected for further study during Task 2. This phase of the study included visual examination (with binocular microscope where needed) of much of the large suite of drill cuttings collected during drilling of the 12 key wells, and detailed petrologic studies (e.g. thin-section petrography, x-ray and SEM analyses) of representative cutting and core samples from those wells.

4. Construction of 30 stratigraphic columns illustrating *hydrostratigraphic* and *lithofacies* components of the conceptual model and based on analyses of basic data in Tasks 1 through 3.

5. Construction of five provisional maps and six cross sections that provide a three-dimensional view of the basin's hydrogeologic framework. Preparation of a final draft on all project activities through June 30, 1992, including recommendations for future investigations. Submission of the final draft for review and approval by the Public Works Department, Water Utility Division of the City of Albuquerque.

6. After the draft is approved, preparation of a final report to be published initially as a NMBMMR Open-file Report in August 1992. The report will be accompanied by a three-dimensional (wood-and-plastic) model that comprises a "fence diagram" of the hydrogeologic framework between the land surface and sea level in the study area.

Responsibilities
General staff responsibilities for preparation of the report (eight sections, a reference list, and seven appendices) are shown in Table I-1. Resumes of the investigator are in Appendix A.

Table I-1. Staff responsibilities for various phases of the study and report preparation.

Activity/Report Section	Staff Member(s)
Geologic setting of the Albuquerque Basin	Richard P. Lozinsky John W. Hawley
Conceptual hydrogeological model	John W. Hawley
Petrologic data	Peter Mozley Richard M. Chamberlin John Gillentine Richard P. Lozinsky
Borehole geophysical data	C. Stephen Haase
Estimation of hydrologic parameters	C. Stephen Haase Richard P. Lozinsky
Recommendations and future work	C. Stephen Haase John W. Hawley

SECTION II

GEOLOGIC SETTING OF THE ALBUQUERQUE BASIN

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II. GEOLOGIC SETTING OF THE ALBUQUERQUE BASIN

Introduction

The Albuquerque Basin covers an area of about 2100 mi^2 and is one of the largest of a series of north-trending structural basins that comprise the Rio Grande rift (Kelley, 1977; Hawley, 1978; Lozinsky, 1988; Lozinsky et al., 1991). Extending throughout the length of New Mexico, the rifting process was initiated about 30 million years ago when tensional forces began stretching the Earth's crust, causing large blocks to sink and form basins between elevated mountain blocks (Chapin, 1988; Cather, 1992). The Rio Grande flows southward through most of these basins, from the San Luis Basin in southern Colorado to the Mesilla and Hueco Bolsons of southern New Mexico and the western Texas—Chihuahua region.

The Albuquerque Basin is in the northern part of the Basin and Range physiographic province (Hawley, 1986). The Sandia (max. elev. 10,678 ft) and Manzano (max. elev. 10,098 ft) uplifts at the eastern edge of the basin form the highest range in the region. Low topographic relief characterizes much of the area within the basin. Surface elevations range between about 4300 to 5100 ft along the Rio Grande valley to around 6000 ft at the eastern edge of the piedmont slope along the Sandia and Manzano Mountain fronts. The two major erosional features in the basin are the terraced valleys of the Rio Grande and Rio Puerco. The high tableland (mesa) between these valleys is designated the Llano de Albuquerque (Ceja Mesa of Kelley, 1977), and the broad, piedmont alluvial plains between the Rio Grande valley and the Sandia and Manzano Mountains are named, respectively, the Llano de Sandia and the Llano de Manzano (Plate 1; Bryan, 1909, 1938; Lambert, 1968; Machette, 1978c, 1985).

Basin structure

As defined here, the Albuquerque Basin extends southward from the San Felipe fault belt near Algodones to the Joyita uplift at the north end of the Socorro structural basin (Fig. II-1), a distance of about 70 mi. Basin width varies from about 10 mi in the north to about 40 mi in the central basin area. Although the Albuquerque Basin appears topographically as a single feature, geophysical studies and deep drilling (Lozinsky, 1988; Russell and Snelson, 1990) indicate that it consists of two distinct structural basins (northern and southern), each formed by asymmetrical groups of tilted fault blocks (half grabens) that are downdropped relative to adjacent (mountain and plateau) uplifts that are also tilted blocks of the earth's crust (Fig. II-2). The planes of most of the major basin-bounding and intrabasin faults flatten with depth (listric faults) and offset is normal (basinward "dipslip" down a fault plane). South of Los Lunas the dominant basin tilt is westward, while north of Isleta most blocks tilt to the east (toward the Sandia Mountain block). A southwestward extension of the Tijeras fault zone (Fig. II-1), with complex displacement ranging from vertical to horizontal, separates the half-grabens along a west—southwest-trending belt crossing the central basin between Los Lunas and Isleta (Russell and Snelson, 1990; Cather, 1992). Internal basin structure generally consists of a deep inner basin flanked by relatively shallow benches (such as the Hubbell bench; Kelley, 1977, 1982) that step up to the margin areas (Fig. II-2). The benches are separated by listric faults (Russell and Snelson, 1990). Note that faults showing the largest displacements occur several miles basinward from the topographically high basin margins. In the north-half graben, the largest displacement fault, the Rio Grande fault (Plates 1-5) with as much as 10,000 ft of vertical offset, is located under the present Rio Grande (May and Russell, 1991; May et al., 1991).

In early to middle Miocene time, rock debris eroded from adjacent highlands and rift areas to the northeast filled the half-grabens to the point where the intrabasin divide (Tijeras fault zone) was buried to form one topographic basin that continued to aggrade through early Quaternary time. The half-graben morphology is not unusual, it is characteristic of most rift basins (Rosendahl, 1987). The rift (basin and range) style of large-scale structural deformation

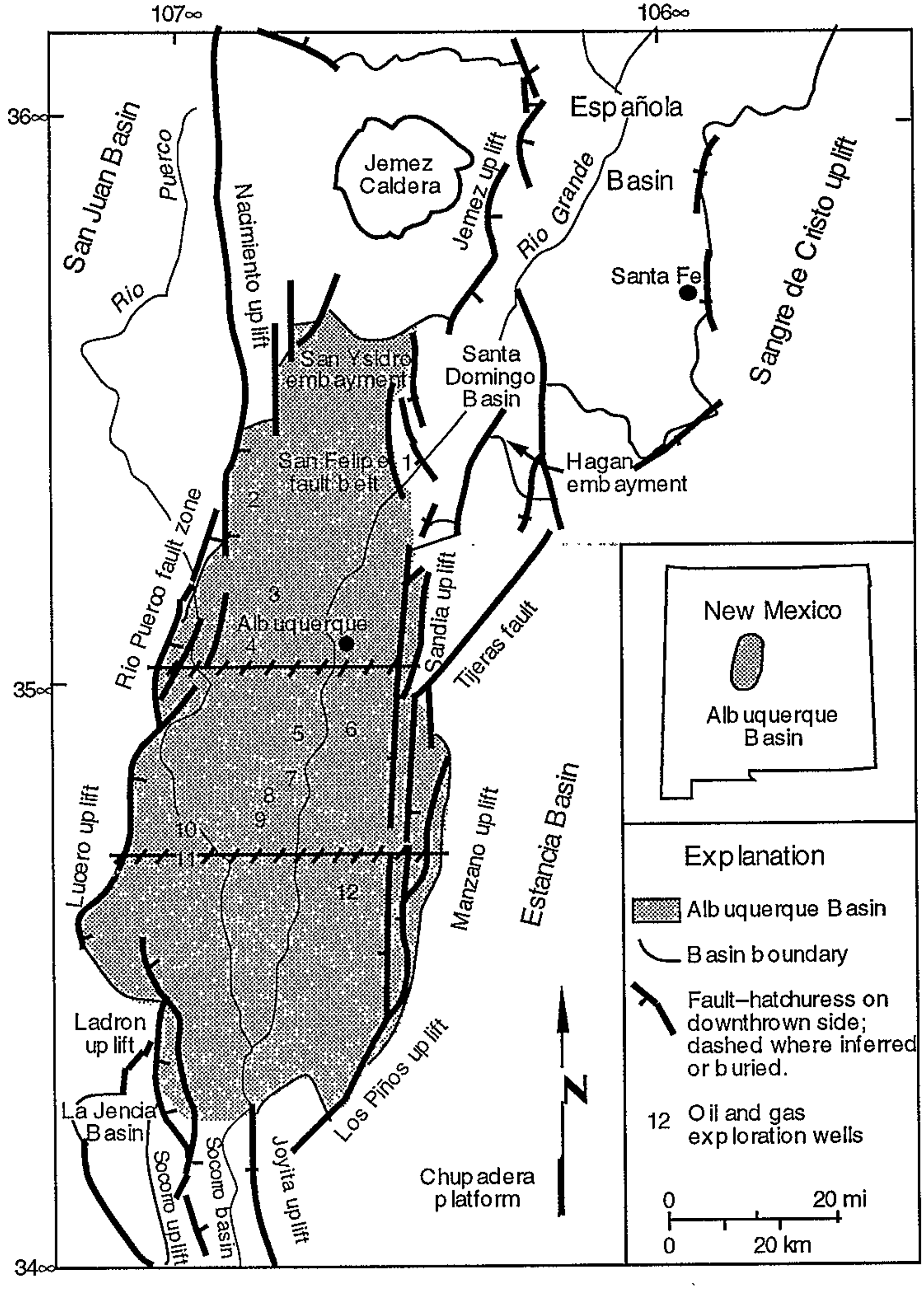

Figure II–1. Index map of the Albuquerque Basin showing location of major boundary faults and geologic cross sections.

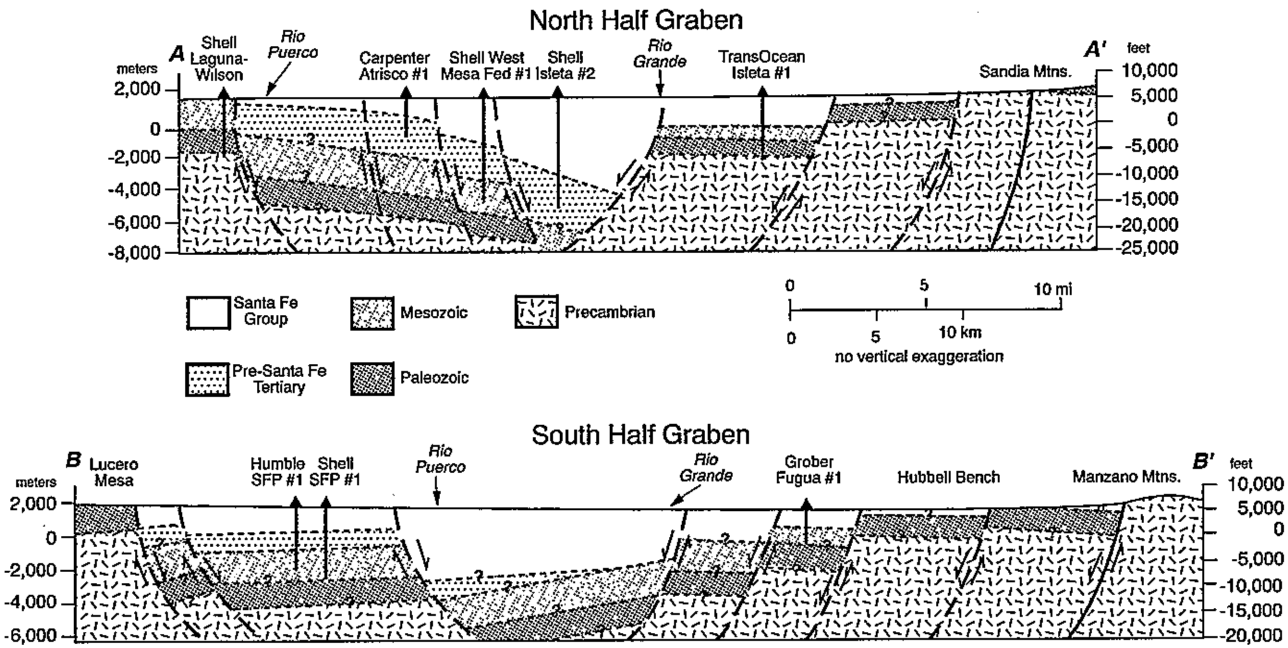

Figure II–2. Diagrammatic geologic cross sections of central Albuquerque Basin, north (top) and south (bottom) of the Tijeras "accommodation" zone. Cross section locations shown in Fig. II–1.

(tectonism) is the major factor controlling the distribution patterns of genetic types and textural classes in basin-fill deposits. These features, along with intrabasin and basin-bounding structures, are the primary components of the conceptual hydrogeologic mode described in this report (Seections III to V).

Uplifts at basin margins
The eastward-tilted Sandia—Manzano—Los Pinos uplift marks the prominent eastern basin boundary (Fig. II-1; Cather, 1992). This uplift consists of Precambrian plutonic and metamorphic rocks unconformably overlain by Paleozoic limestone and sandstone. The western basin boundary with the Colorado Plateau is not well-defined by prominent physiographic features. The Ladron Mountains and Lucero uplift form the southwestern boundary. Mostly Precambrian granitic and metamorphic rocks are found in the Ladron Mountains, whereas Paleozoic limestone, sandstone, and shale capped by late Cenozoic basalt flows occur in the gently west-tilted Lucero uplift. North of the Lucero uplift, the topographically subdued Rio Puerco fault zone marks the basin boundary with the Colorado Plateau. Rocks exposed west of the fault zone include Cretaceous sandstone and shale with some exposures of Jurassic clastic units and gypsum.

The northeastern and southern basin boundaries are marked by topographic constrictions located, respectively, near Algodones and San Acacia; however, basin fill is continuous throughout these constrictions (Fig. II-1). The Nacimiento Mountains and Jemez volcanic center form the northern edge of the basin. Precambrian plutonic and metamorphic rocks overlain by Paleozoic and Mesozoic strata crop out in the Nacimiento uplift (Woodward, 1987) and Cenozoic mafic to silicic volcanic rocks comprise the Jemez uplift (Gardner et al., 1986; Goff et al., 1989). The San Felipe fault zone separates the Albuquerque Basin from the Santa Domingo Basin. The Precambrian-cored Joyita and Socorro (Lemitar) uplifts form the southern constriction and flank the Socorro structural basin.

Basin stratigraphy
Rocks in the Albuquerque Basin are primarily continental sediments interbedded with minor volcanic rocks and can be subdivided into 3 units: 1) pre-Santa Fe Tertiary deposits, 2) Santa Fe Group basin fill, and 3) post-Santa Fe Quaternary deposits (river-valley and basin fill). Pre-Santa Fe Tertiary deposits crop out only in limited exposures within the basin and have been studied mainly by examining samples and geophysical logs from deep oil-test wells (Lozinsky, 1988; Cather, 1992). In most areas these deposits are underlain by Upper Cretaceous strata; however, along the eastern margin they are underlain by lower Mesozoic and Paleozoic units (Fig. II-2).

Pre-Santa Fe Tertiary deposits
These deposits underlie the Santa Fe Group and indicate that at least one depositional basin predated the Albuquerque Basin. Lozinsky (1988) divided these deposits into two units, (1) the Eocene Galisteo—Baca Formations and (2) the overlying late Eocene to late Oligocene "unit of Isleta #2". The Galisteo—Baca deposits are generally less than 1600 ft thick and were derived from nonvolcanic source areas. The unit of Isleta #2 was at least partly derived from volcanic source areas and contains intermediate volcanic flows and ashflow tuffs; the unit is up to 7000 ft thick.

Santa Fe Group
The Santa Fe Group (Spiegel and Baldwin, 1963; Hawley, 1978; Chapin, 1988) is the major fill unit of Rio Grande rift basins. Ranging in age from about 25 to 1 million years, the group was deposited as deep structural basins developed. It consists of alluvium eroded from the nearby mountains, other alluvial material transported from more distant source areas outside the basin, and locally thick playa-lake and eolian deposits (Ingersoll et al., 1990). Volcanic and intrusive igneous rocks are also present in many rift basins. Fill thickness in the Albuquerque

Basin ranges between 3000 to 4000 ft along basin margins and to over 14000 ft in the deeper central basin area (Lozinsky, 1988; Russell and Snelson, 1990). Mafic volcanic flows (or dikes) and ash beds are scattered throughout the section. Oil test-well data show that most of the Santa Fe Group rests on Oligocene sedimentary and volcanic rocks, except along the eastern margin where it rests on Mesozoic strata (Fig. II-2). The Santa Fe Group is subdivided into lower, middle, and upper units based on depositional environments and age.

The lower Santa Fe Group is dominated by intertonguing piedmont-slope, eolian, and fine-grained basin-floor deposits. Fan and coalescent-fan alluvium characterize the piedmont-slope deposits, whereas playa sediments and playa-margin alluvium are the major components of the basin-floor deposits. The deposits range in age from about 30 to 15 Ma and represent deposition in an internally drained basin prior to deep subsidence and uplift of high flanking mountain blocks.

The middle Santa Fe Group was deposited between about 15 and 5 Ma when tectonism was most active in the basin. Piedmont-slope sediments continued at the margins of the basin, but major fluvial systems from the north, northeast, and southwest were also transporting sediments into the basin. Thus, during the middle Santa Fe time, fluvial deposition was also occurring on the basin floor. However, these fluvial systems probably terminated in playa lakes in the southern part of the basin (Lozinsky and Tedford, 1991). Due to the high tectonism and resulting high sedimentation rates, the bulk of the Santa Fe Group was deposited at this time and the two half-basins filled to form a single topographic basin.

After about 5 Ma, the through-flowing ancestral Rio Grande system developed (Lozinsky et al., 1991). In addition, two ancestral tributaries, the Rio San Jose and Rio Puerco, joined the Rio Grande to form a large aggradational plain in the central basin area (Fig. II-3). The upper Santa Fe Group was deposited during the next four million years and is characterized by intertonguing piedmont-slope and fluvial basin-floor deposits. Piedmont-slope deposits (alluvial and debris-flow) consist of poorly sorted, weakly stratified sand and conglomerate commonly with a silt—clay matrix. Basin-floor deposits include cross-stratified ancestral river sediments characterized by thick zones of clean sand and pebble gravel. Fine- to medium-grained overbank sediments were deposited in areas where major river systems were merging and in basin-floor and piedmont-slope transition zones. Thickness of the upper Santa Fe deposits is locally as much as 1500 ft, but usually less than 1000 ft.

Santa Fe Group deposition ceased about 1 million years ago, when the Rio Grande and Rio Puerco started to cut their present valleys. The upper Santa Fe Group (Ceja Member of the Sierra Ladrones Formation) is preserved beneath the dune-covered surface of the Llano de Albuquerque, the broad, constructional plain between the Rio Grande and Rio Puerco (Plates 1-5, 7; Lambert 1974; Kelley, 1977; Machette, 1978a, 1978b; Lambert et al., 1982).

Post-Santa Fe Quaternary deposits

Post-Santa Fe units were deposited during the series of river incision and partial backfilling episodes. During this time, the present Rio Grande and Rio Puerco valleys, and the escarpments that form the eastern and western flanks of the Llano de Albuquerque were formed (the Cejita Blanca and Ceja del Rio Puerco, respectively) (see Plate 1; Bryan and McCann, 1937, 1938; Lambert, 1968; Lambert et al., 1982). Younger basin and valley fills include fan, pediment, inset-terrace, eolian, and floodplain deposits, and basaltic to andesitic volcanics (Kelley and Kudo, 1978).

Rock pediment and graded alluvial slopes generally occur on piedmont surfaces that extend from the bases of the Sandia, Manzanita, Manzano, and Pinos Altos uplifts on the eastern side of the basin. They represent stable periods or intervals of aggradation following erosional episodes and include the Llano de Manzano and Llano de Sandia (Plate 1; Lambert, 1968;

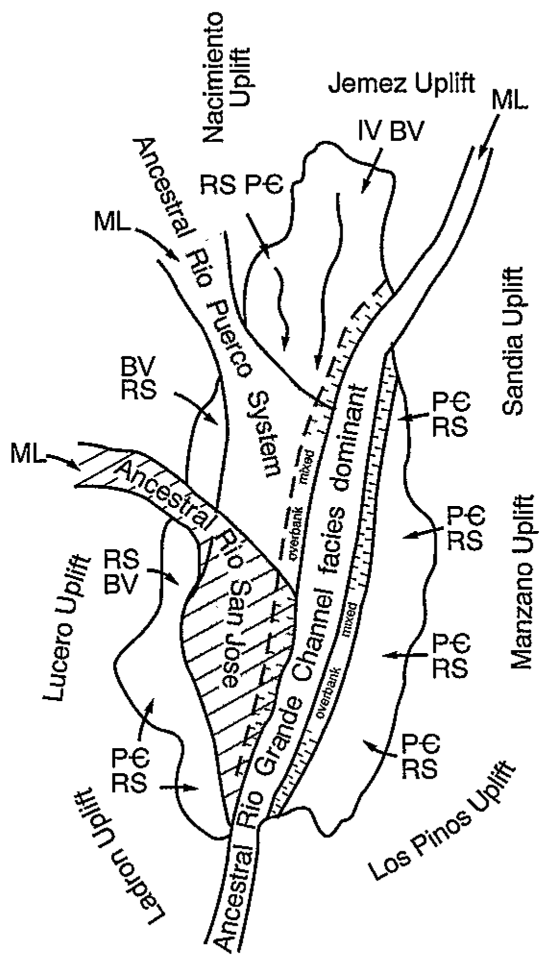

Figure II–3. Schematic drawing showing the contributory drainage system of the Albuquerque Basin during deposition of the upper Santa Fe Group (Sierra Ladrones Formation). Arrows indicate probable sediment-source areas and clast types derived from those areas: pC= Precambrian, RS = reworked sedimentary rocks, IV = intermediate volcanic rocks, BV = mafic (mostly basaltic) volcanic rocks, ML = mixed lithologies.

Machette, 1978c, 1985). Fills related to cutting and partial backfilling of the Rio Grande and Rio Puerco Valleys during middle to Late Quaternary glacial-interglacial cycles form at least three inset terrace deposits and include the Primero Alto and Segundo Alto river terraces along Coors Blvd. (Bryan, 1909, 1938; Bryan and McCann, 1938; Lambert, 1968; Hawley et al., 1976; Machette, 1978a, b, c, 1985; Lambert et al., 1982; and Hawley and Love, 1991). Terrace fills are mapped along the valley border as the Menual, Edith, and Los Duranes alluvium (Lambert, 1968; Lambert et al., 1982). Thicknesses of these units range from 30 to 200 ft. The latest cut-and-fill episode of the Rio Grande-Puerco system produced the channel and floodplain deposits of present inner-valley areas. For about the last 10,000 to 15,000 years the valleys have been aggrading because tributary-streams have been delivering more sediment than the regional fluvial systems can remove. The younger valley fill is up to 130 ft thick and forms the major shallow aquifer in the region (see Section III).

Two volcanic fields were emplaced during middle to late Pleistocene time. The Albuquerque volcanic field erupted between 0.11 and 0.2 Ma (Geisman et al., 1990) and the Cat Hills volcanic field erupted at about 0.13 Ma (Kudo et al., 1977). Both of these fields include cinder cones and basaltic flows and appear to have been erupted along roughly north-trending fissure zones (Kelley and Kudo, 1978). Eolian deposits are scattered throughout the basin particularly on the Llano de Albuquerque and Manzano surfaces (Plate 1). The largest dunes are located along the western edge of the Llano de Albuquerque (Lambert, 1974; Kelley, 1977).

SECTION III

A CONCEPTUAL HYDROGEOLOGIC MODEL AND ITS HYDROSTRATIGRAPHIC, LITHOFACIES, STRUCTURAL AND BEDROCK BOUNDARY COMPONENTS

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J. W. Hawley and C. S. Haase (compilers), 1992, *Hydrogeologic framework of the northern Albuquerque Basin*, New Mexico Bureau of Mines and Mineral Resources, Open-File Report 387, pp. III-1 to III-14

III. A CONCEPTUAL HYDROGEOLOGIC MODEL AND ITS HYDROSTRATIGRAPHIC, LITHOFACIES, STRUCTURAL, AND BEDROCK BOUNDARY COMPONENTS

Introduction

The subject of this chapter is a conceptual model of the basin's hydrogeologic framework and how it was developed. The model's emphasis is on stratigraphic and lithologic characteristics of basin and valley fills, intrabasin geologic structures, and basin-bounding bedrock features that influence the movement, storage, recharge, discharge, and quality of ground water. The area covered extends from the Bernalillo—Sandoval County line to the northern part of Isleta Pueblo, and from the Rio Puerco to the Sandia and Manzanita Mountain front. The base of the model is at mean sea level and, since the water-table elevation in this area is about 4900ft (Kues, 1987; Summers, 1992), the zone of saturation characterized is about 1 mi thick. Much of the ground water is in basin fill that ranges from unconsolidated sand, silt, clay and gravel to partly indurated deposits with layers of sandstone, mudstone, and conglomerate. The highest basin elevations are about 6000 ft, and as much as 1000 ft of basin fill occurs in the unsaturated (vadose) zone outside the Rio Grande valley.

Hydrogeologic information in the conceptual model is presented in a combined map and cross-section format (Plates 1-7; Figs. III-1 to 6) with tables containing supporting data (Tables III-1 and III-2, and Appendices C to F). The plates are being published at a 1:100,000 horizontal scale (approx. 0.6 in. per mile), but they are also available for inspection at the NMBMMR Socorro and Albuquerque offices at a 1:50,000 scale. Vertical scale of the cross sections (Plates 2 to 7) is exaggerated 10 times (approx. 1.2 in. per 1000 ft). Smaller-scale isopach maps (about 1:140,000, Figs. III-2 to 5) show thickness of major basin-fill (Santa Fe Group) subdivisions to the maximum depth of the basin (about 10,000 ft below sea level in the south Albuquerque—Isleta area).

Any valid characterization of a basin's hydrogeology must be based on the best possible understanding of the local and regional geologic framework, particularly in the context of late Cenozoic geologic history (discussed in Section II). The major water-bearing units in the northern Albuquerque Basin occur in the upper 2000 ft of its fill. They are, for the most part, unconsolidated to partly indurated sediments that were washed into the basin from marginal highlands or from upstream areas of the Rio Grande rift. These basin- and valley-fill deposits of late Tertiary and Quaternary age (mostly <15 million years) are locally wind-reworked and contain minor (but significant) amounts of volcanic and intrusive igneous material.

Much of the conceptual model of the northern Albuquerque Basin presented in this report is based on ideas developed by earlier workers, starting with Bryan (1909, 1938) and his students. Details of their contributions are much too large to discuss here, but the following list includes many of the key reports on the geology and ground-water resources of the Albuquerque basin: Bryan and McCann (1937, 1938), Kelley and Wood (1946), Wright (1943, 1946), Reiche (1949), Stearns (1953), Bjorklund and Maxwell (1961), Spiegel (1961), Titus (1961), Galusha (1966), Lambert (1968), Black and Hiss (1974), Kelly (1974), Kelley and Northrup (1975), Kelley (1977), Kelley and Kudo (1978), Manley (1978), and Tedford (1981, 1982). Stratigraphic and depositional facies concepts used in the present model were developed in considerable detail by Bryan (1938), Wright (1946), Stearns (1953), Spiegel (1961), Galusha (1966), Lambert (1968), and Kelley (1977, Fig. 20).

The detailed mapping of the surficial geology of the Albuquerque metropolitan area and analysis of driller's logs of water wells (upper 1000 ft of fill) by Lambert (1968) provided much of the information used in preparation of Plate 1 and the upper parts of Plates 2 through 7. Other important data sources on soils, surficial geologic deposits, and landforms include Hacker (1977), Lambert et al. (1982), and Clary et al. (1984). However, only during the past decade has there been a concerted effort to examine the basin's deeper subsurface structure and fill composition. Geophysical and geological studies related to oil and gas exploration (Section II; Figs. III-1, 2) and regional gravity surveys (Cordell, 1978; Birch, 1980, 1982), have been supplemented by recent investigations of ground-water resources in shallower basin and valley fills in the Albuquerque area (e.g. Wilkins, 1987; Peter, 1987; Anderholm, 1988; Kaehler, 1990; Logan, 1990; Richey, 1991; and a large body of unpublished information recently collected by the City of Albuquerque).

Geologic investigations of similar basin- and valley-fill sequences elsewhere along the Rio Grande rift furnish much additional information on late Cenozoic depositional environments and geologic history (e.g. Spiegel and Baldwin, 1963; Hawley et al., 1976; Smith et al., 1970; Galusha and Blick, 1971; Chapin and Seager, 1975; Hawley, 1978; Seager and Morgan, 1979; Chamberlin, 1980; Gile et al., 1981; Seager et al., 1982, 1987; Love, 1986; Lozinsky, 1987; Chapin, 1988; Brister, 1990; Ingersoll et al., 1990; Gustavson, 1991; Lozinsky and Tedford, 1991; Lohman et al., 1991; Smith et al., 1991).

Hydrostratigraphic-unit subdivisions of basin and valley fills

The basic hydrogeologic mapping unit used in conceptual-model development is the hydrostratigraphic unit. This informal subdivision is analogous to a rock-stratigraphic unit of formational rank: the basic mappable body of rocks (sedimentary, igneous, and metamorphic) or unconsolidated earth materials. The hydrostratigraphic-unit concept used here (as well as in other parts of North America; Back et al., 1988) requires that it be definable in terms of environment of deposition (sedimentary strata) or emplacement (igneous bodies), distinctive lithologic features (textures, mineralogy, sedimentary structures), and general time of deposition or emplacement (in a dated sequence of strata or igneous events). Geohydrologic characteristics must be definable and (of most importance) the unit must be mappable in subsurface as well as on the surface, at a useful map scale in terms of ground-water resource management (e.g. 1:24,000 to 1:250,000). The attributes of four major (RA, USF, MSF, LSF) and two minor (VA, PA) hydrostratigraphic units into which basin and valley fills have been divided are described in Table III-1 and Appendix C. The major subdivisions of Santa Fe Group basin fill (upper, middle and lower units — USF, MSF, LSF) broadly correspond to the informal rock-stratigraphic units discussed in Secton II. River alluvium (unit RA) forms the upper part of the shallow aquifer in the Rio Grande and Rio Puerco Valleys.

A diagrammatic cross section of the northern Albuquerque Basin (Fig. III-1) illustrates a hypothetical (but representative) distribution pattern of hydrostratigraphic units in subsurface. Igneous and metamorphic (PreC) and sedimentary (CenMesPal) bedrock units form the basin margins, and vertical to near-vertical lines show major boundary and intrabasin faults and a volcanic feeder conduit (dike?). Two of the three hydrostratigraphic units that include the major aquifer systems of the Albuquerque Basin (upper and middle Santa Fe units — USF and MSF) are further divided into subunits that characterize environments of deposition and lithologic composition in more detail (e.g. piedmont alluvial-fan deposits USF-1, MSF-1; and basin-floor alluvial-plain and playa deposits USF-2, MSF-2).

Areal distribution of these hydrostratigraphic units, both on the surface and in the shallow subsurface, is shown on the hydrogeologic map (Plate 1). Five cross sections illustrate areas of the basin where relatively good subsurface control is available at depths ranging down to 3000 ft below the surface (e.g. upper parts of Plates 2, 3, 4, 6, and 7). In other areas well control is generally lacking, but information from a few deep oil tests and geophysical (including seismic) profiles can be used to make general interpretations of hydrogeologic features (including distribution of hydrostratigraphic units) to depths extending to or below sea level (e.g. Plate 5). Very generalized interpretations of the distribution and total thickness of the Santa Fe Group and its three major hydrostratigraphic-unit subdivisions (USF, MSF, LSF) are also given on the small-scale isopach maps (Figs. III-2 to 5). The boundaries between

Table III-1. Key to hydrostratigraphic units in the Albuquerque Basin (Appendix C)

Unit	Description	Age
RA RAr RAp	River alluvium; channel and floodplain deposits of inner Rio Grande (RAr) and Puerco (RAp) valleys; as much as 120 ft thick.	Holocene to late Pleistocene
VA VAc VAt VAs	Valley-border alluvium; tributary-arroyo (and thin eolian) deposits in areas bordering inner Rio Grande and Puerco valleys, with locally extensive river-terrace deposits, as much as 200 ft thick. Fan, terrace and channel deposits of Calabacillas and Tijeras Arroyos are, respectively, designated VAc and VAt. VAs indicates older valley fill near Calabacillas Arroyo.	Holocene to middle Pleistocene
PA PAt	Piedmont-slope alluvium; coarse-grained alluvium, mainly deposited as coalescent fans extending basinward from mountain fronts on the eastern and southwestern margins of the basin; as much as 150 ft thick; includes surficial deposits mantling piedmont erosion surfaces (including rock pediments). PAt designates deposits of ancestral Tijeras Arroyo system in the depression between I-40 and the SE Central-Ridgecrest Blvd. area (Lambert et al., 1982).	Holocene to middle Pleistocene
SF	Santa Fe Group - undivided; fill of intermontane basins of the Rio Grande rift in New Mexico and adjacent parts of Colorado, Texas, and Chihuahua (Mexico). Includes alluvial, eolian and lacustrine deposits; and interbedded extrusive volcanic rocks (basalts to silicic tuffs). In the Albuquerque Basin, the Santa Fe is as much as 15,000 ft thick. The upper part of the group unit forms the major aquifer in the Albuquerque Basin (and elsewhere in basins of the Rio Grande rift), and is subdivided into three hydrostratigraphic units:	early Pleistocene to late Oligocene, mostly Pliocene and Miocene
USF USF-1 USF-2 USF-3	Upper Santa Fe unit; coarse- to fine-grained deposits of ancestral Rio Grande and Puerco systems that intertongue mountainward with piedmont-alluvial (fan) deposits; volcanic rocks (including basalt, andesite and rhyolite flow and pyroclastic units) and thin, sandy eolian sediments are locally present. The unit is as much as 1200 ft thick. Subunit USF-1 comprises coarse-grained, alluvial-fan and pediment-veneer facies extending westward from the bases of the Sandia, Manzanita, and Manzano uplifts. USF-2 includes deposits of the ancestral Rio Grande and interbedded fine-grained sediments in the structural depression between the Rio Grande and County Dump fault zones in the river-valley area. Alluvial and minor eolian deposits capping the Llano de Albuquerque (West Mesa) between the Rio Grande and Puerco Valleys form subunit USF-3.	early Pleistocene to late Miocene, mainly Pliocene
MSF MSF-1 MSF-2	Middle Santa Fe unit; alluvial, eolian, and playa-lake (minor in northern basin area) basin-fill facies; coarse-grained alluvial-fan deposits intertongue basinward with sandy to fine-grained basin-floor facies, which include local braided-stream and playa-lake facies; basaltic volcanics are also locally present. The unit is as much as 10,000 ft thick in the Isleta Pueblo area of the Rio Grande Valley. Subunit MSF-1 comprises piedmont alluvial deposits derived from early-stage Sandia, Manzanita, and Manzano uplifts including the ancestral Tijeras Canyon drainage basin. MSF-2 comprises sandy to fine-grained basin-floor sediments that intertongue westward and northward with coarser grained deposits derived from the Colorado Plateau and southern Rocky Mountain provinces and Rio Grande rift basins to the northeast.	late to middle Miocene
LSF	Lower Santa Fe unit; alluvial, eolian, and playa-lake basin-fill facies; sandy to fine-grained basin-floor sediments, which include thick dune sands and gypsiferous sandy mudstones; grades to conglomeratic sandstones and mudstone toward the basin margins (early-stage piedmont alluvial deposits). The unit is as much as 3500 ft thick in the central basin areas, where it is thousands of feet below sea level.	middle Miocene to late Oligocene

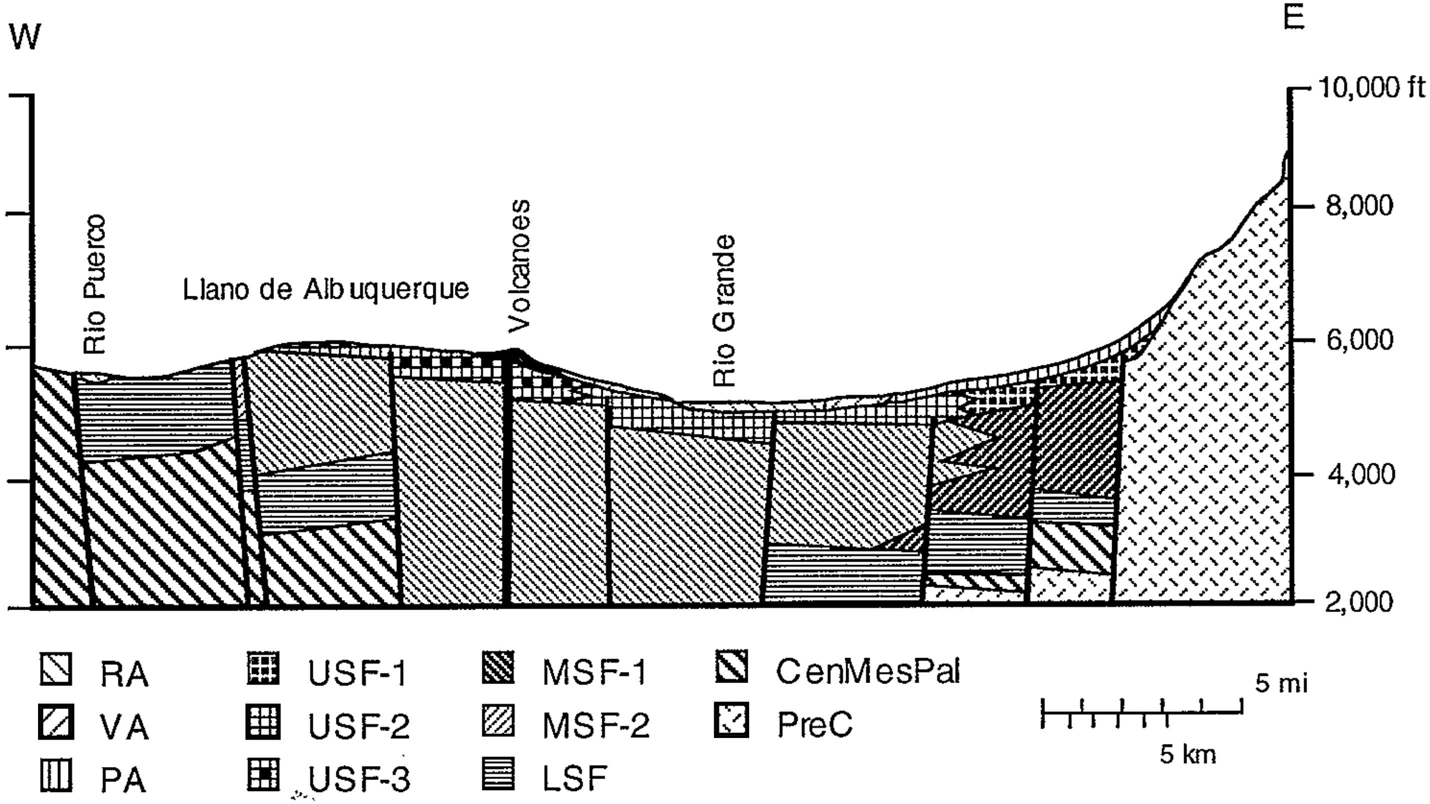

Fig. III-1. Hypothetical distribution of hydrostratigraphic units in the Albuquerque Basin. Units described in text and in Appendix C.

Santa Fe Group Isopach

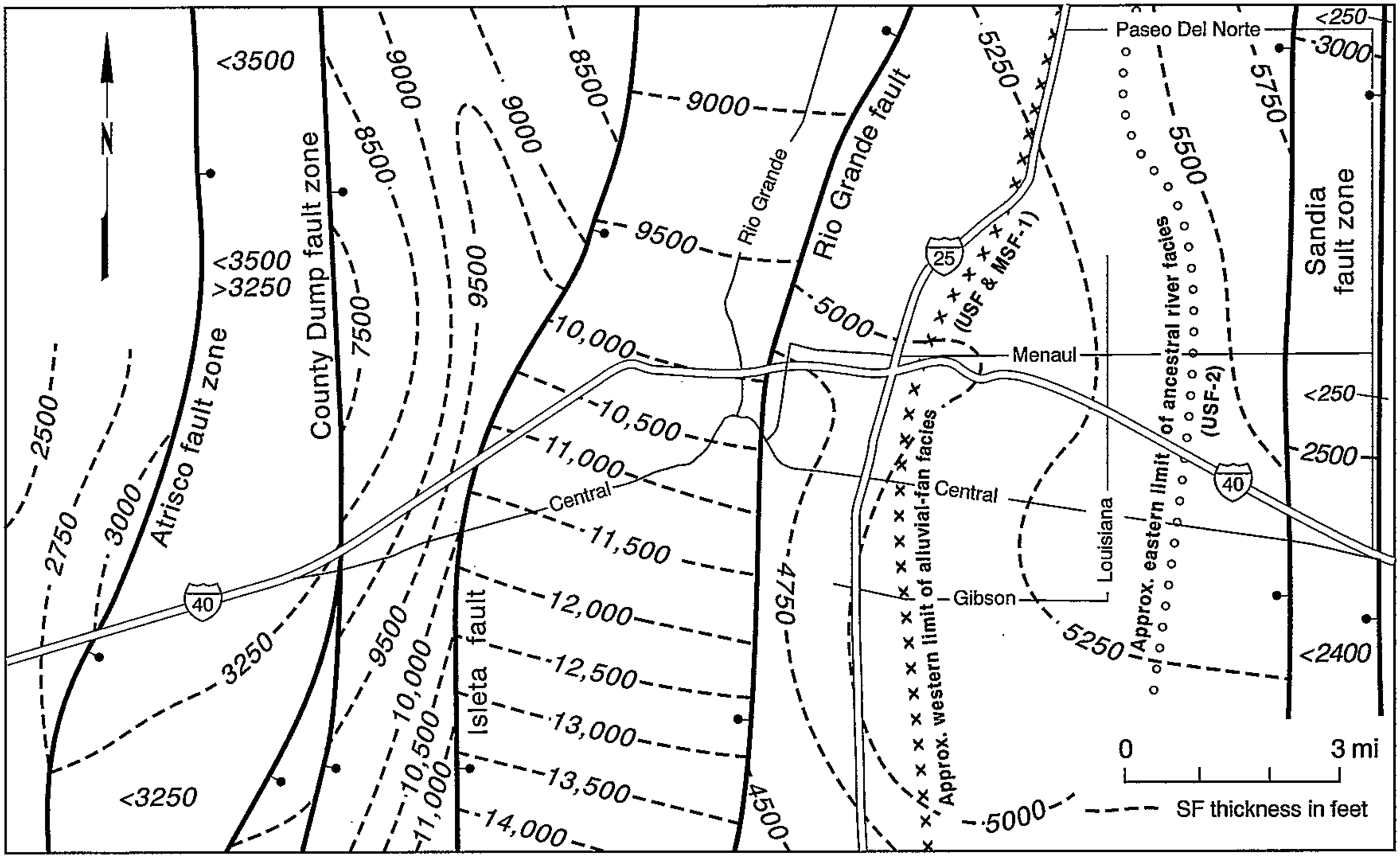

Fig. III-2. Isopach map of the entire Santa Fe Group in the Albuquerque area.

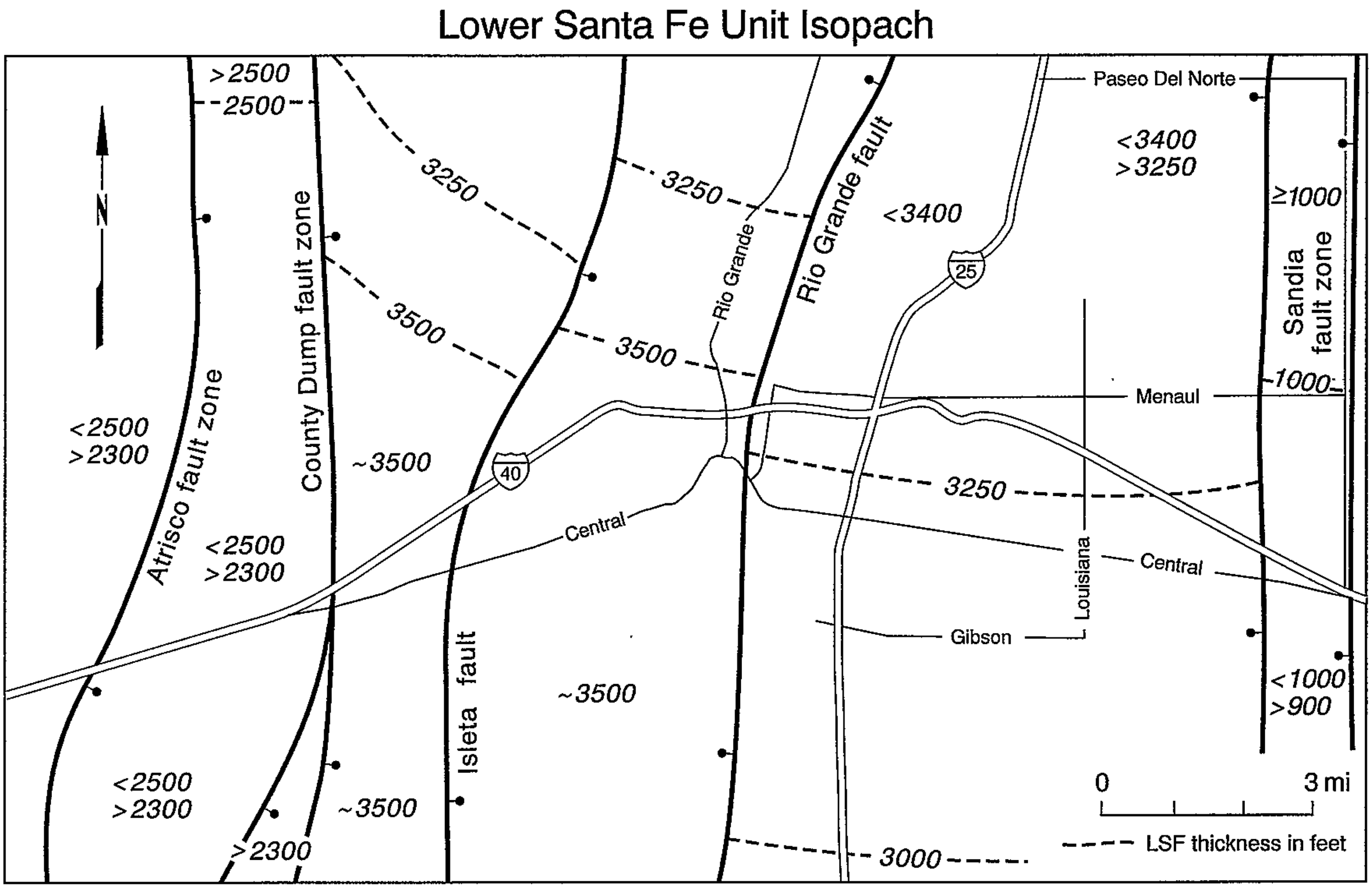

Fig. III-3. Isopach map of the lower Santa Fe Group in the Albuquerque area.

Middle Santa Fe Unit Isopach

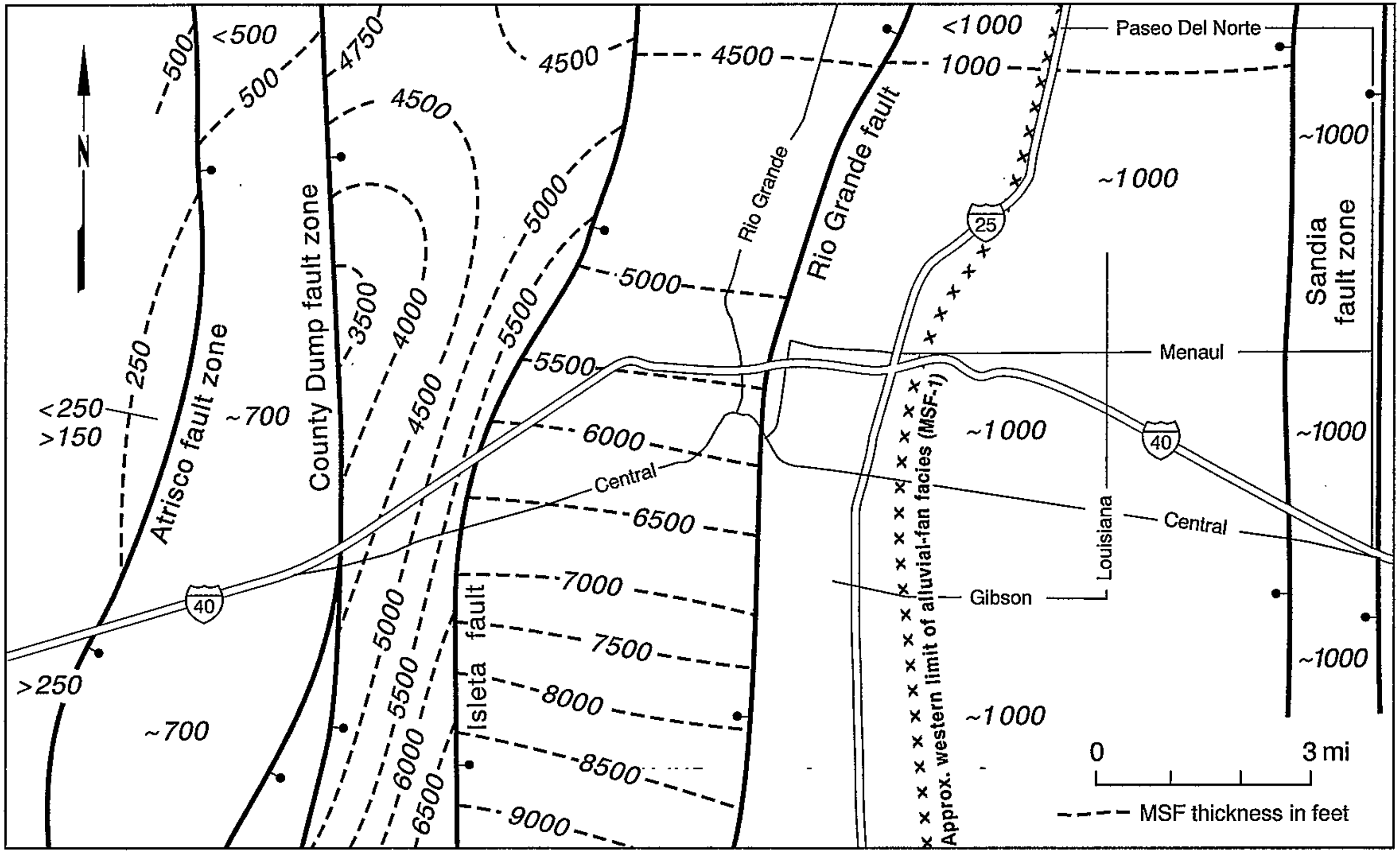

Fig. III-4. Isopach map of the middle Santa Fe Group in the Albuquerque area.

Upper Santa Fe Unit Isopach

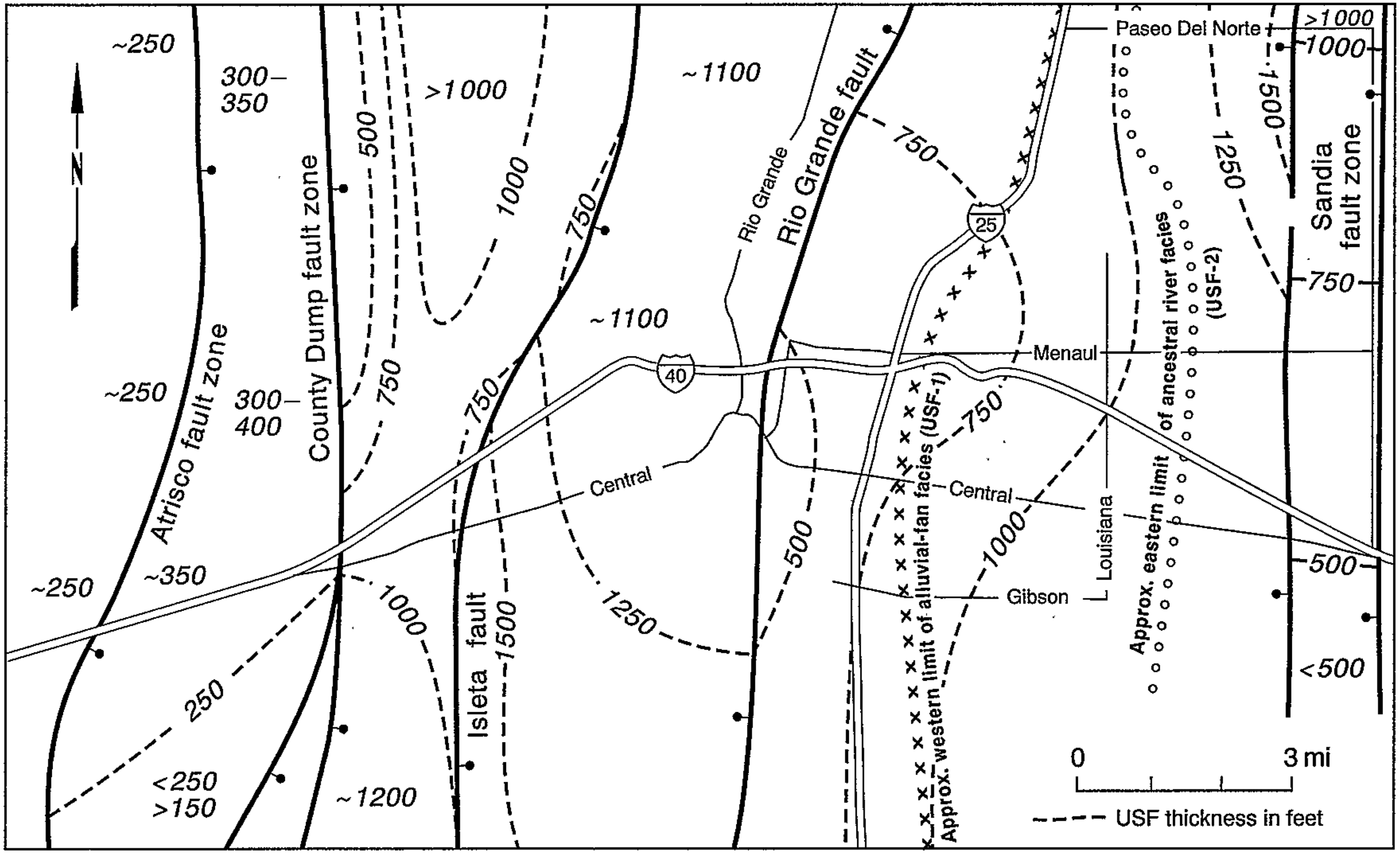

Fig. III-5. Isopach map of the upper Santa Fe Group in the Albuquerque area.

major stratigraphic units, and location of faults and bedrock contacts shown in these plates and figures must be regarded as provisional. They are subject to revision as more subsurface data become available.

Because of the large (x10) vertical exaggeration and diagrammatic nature of the cross sections (Plates 2-7), the inclination (dip) of faults and folds, and internal sedimentary fabric (including stratification) of basin- and valley-fill subdivisions cannot be accurately shown. For the most part, fill units are highly deformed only in zones immediately adjacent to major faults. Eastward dips of lower Santa Fe strata can exceed 20° in the deep basin blocks between the Rio Grande fault and the County Dump (West Mesa) fault zone (Fig. II-2; Russell and Snelson, 1990); however, dips of the upper (USF) unit rarely exceed 10° and usually are less than 5°.

Lithofacies subdivisions of basin and valley fills

The second major feature of the hydrogeologic model developed in this study is the subdivision of basin- and valley-fill deposits into distinct material categories (lithofacies) that are defined primarily on the basis of sediment texture, degree of induration, geometry of bodies of a given textural class, and distribution pattern of zones of contrasting texture. The ten-unit lithofacies classification system used in this study (Fig. III-6, Table III-2, and Appendix D) was originally developed by Hawley (1984; Hawley and Lozinsky, 1992) to facilitate numerical modeling of ground-water systems in the Mesilla Bolson area between Las Cruces and El Paso by the New Mexico Water Resources Research Institute (Peterson et al., 1984) and the U. S. Geological Survey (Frenzel and Kaehler, 1990; Kernodle, 1992). Anderson's (1989) report on "hydrogeologic facies models" relating to "glacial and glacial fluvial sediments" is an excellent account of how lithofacies-unit concepts are being used in ground-water research in other geographical areas.

The lithofacies categories and their subdivisions are defined in Table III-2 and Appendix D; and a hypothetical distribution pattern of these units in Albuquerque Basin fill is illustrated in Fig. III-6. These fundamental hydrogeologic components of basin and valley fills have been recognized in all major basins of the Rio Grande rift in New Mexico and adjacent parts of Colorado, Texas, and Chihuahua (Spiegel and Baldwin, 1963; Hawley et al., 1976; King et al., 1971; Hawley, 1978; Chamberlin, 1980; Gile et al., 1981; Wilson et al., 1981; Seager et al., 1982, 1987; Anderholm, 1987; Lozinsky, 1986, 1988; Chapin, 1988; Brister, 1990; Hearne and Dewey, 1988; Gustavson, 1991). They form the basic building blocks of the conceptual model of this study. Lithofacies units I to VI are unconsolidated or have discontinuous zones of induration. Clean sand and gravel bodies are major components of these units and have relatively high hydraulic conductivity (see Section VII for discussion of geohydrologic properties). Lithofacies VII to X are partly- to well-indurated units with significant amounts of fine-grained material (silt—clay beds or a sand to gravel framework with clay—silt—fine sand matrix). Coarse-grained channel deposits of the modern and ancestral Rio Grande (facies I and II), which are major components of hydrostratigraphic units RA and USF-2, form the most important aquifer and potential enhanced recharge zones in the basin. Distributary channel deposits of the ancestral Tijeras Canyon fan (facies Vd) appear to be another unit with higher than average aquifer potential.

Subsurface distribution patterns of lithofacies in the six hydrostratigraphic units and their subdivisions (Table III-1; Appendix D) at specific sites in the northern Albuquerque Basin are shown on Plates 2 to 7 and in Figs. III-2 to 5 (isopach maps). Documentation of these patterns obviously varies from very good (where drill-cutting and core analyses, bore-hole geophysical logs, and detailed drilling records are available) to strictly inferential (where few or no field data exist). This variation in basic data quality is clearly illustrated in the lithofacies interpretations given on Plates 2 to 7. In the large areas and/or depth zones without adequate subsurface (well) control only the most general features of the major hydrostratigraphic units (Appendix C) can be shown, and the resultant conceptual model is based only on the authors'

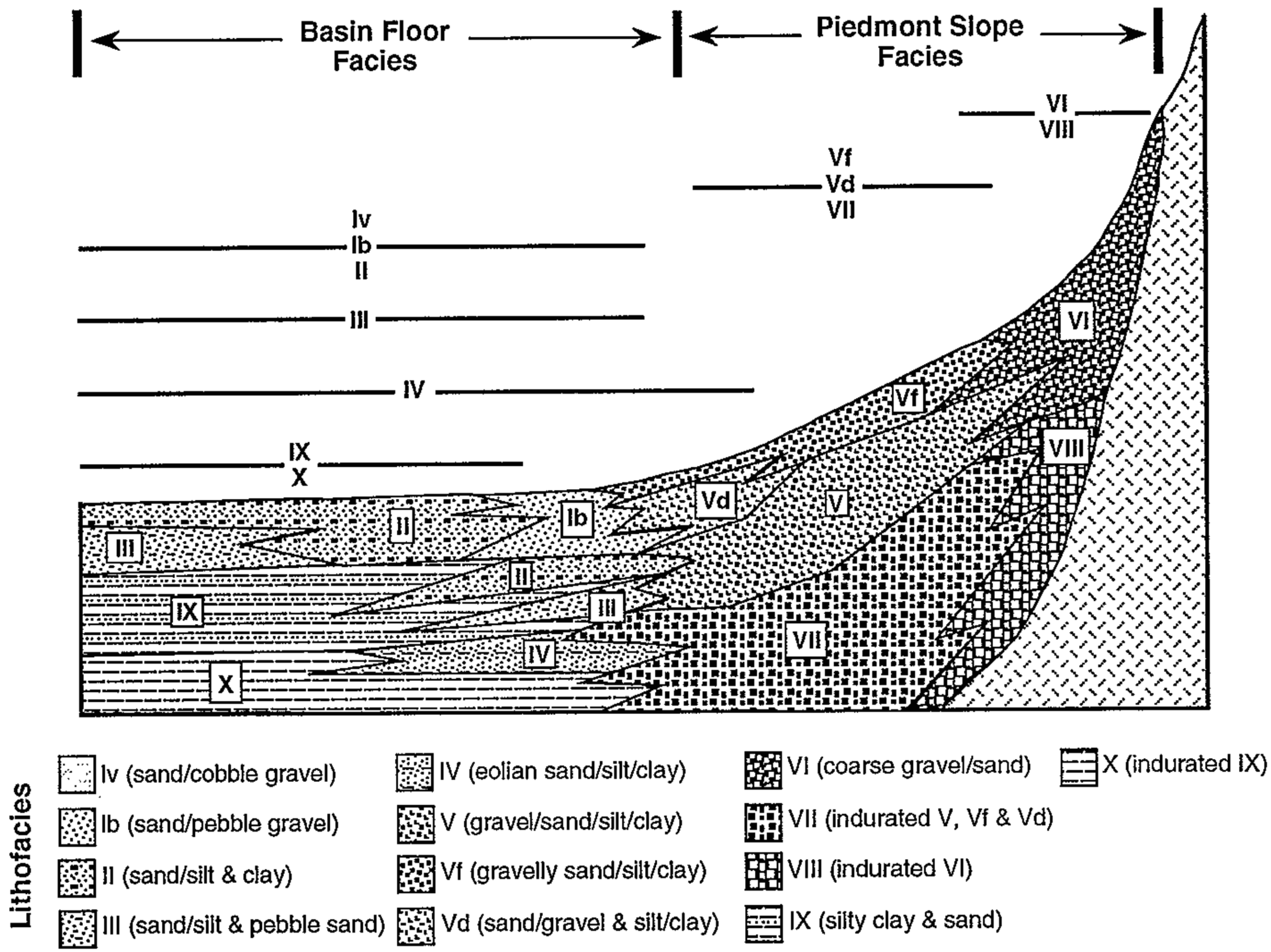

Fig III-6. Hypothetical distribution of lithofacies in the Albuquerque Basin. Units described in Table III-1 and in Appendix D.

TABLE III-2. Summary of lithofacies composition and depositional settings used in Fig. III-6.

Lithofacies designation	Composition	Depositional setting
Iv	sand and pebble to cobble gravel	river valley and basin-floor fluvial
Ib	sand and pebble gravel; lenses of silt and silty clay	river valley and basin-floor fluvial; braided streams
I	cobble to pebble gravel, sand, silt, and silty clay	undifferentiated fluvial
II	sand; lenses of pebbly sand, silt, and silty clay	basin-floor fluvial; locally eolian
III	interbedded sand, silt, and silty clay; lenses of pebbly sand	basin-floor alluvial and playa lake; locally eolian
IV	sand and silt; lenses of silty clay and clay	basin floor eolian and distal piedmont alluvial fan
Vv	sand, silt, silty clay, and gravel (not shown)	arroyo and river-valley border alluvial
Vf	gravelly sand, silt and clay; lenses of sand, gravel, and silty clay	distal to medial piedmont-slope alluvial fan associated with small watersheds; alluvial-fan distributary channel and debris flow
Vd	sand and gravel; lenses of gravelly to nongravelly sand. silt and clay	distal to medial piedmont-slope alluvial fan associated with large watersheds; alluvial-fan distributary channel
V	gravel, sand, silt, silty clay, and clay	undifferentiated distal to medial piedmont-slope alluvial fan
VI, VIf, VId	coarse gravelly sand, silt, and clay; lenses of sand and gravel; cobbles and boulders	proximal to medial piedmont-slope alluvial fan; debris flow; distributary channel
VII	gravel, sand, silt, and clay; indurated Vf and Vd; indurated V, Vf, Vd, Vv	distal to medial piedmont-slope alluvial fan; alluvial-fan distributory channel and debris flow
VIII	coarse gravelly sand, silt, and clay; lenses of sand and gravel; cobbles; indurated VI, VIf, VId	proximal to medial piedmont-slope alluvial fan
IX	silty clay interbedded with silty sand, silty clay, and clay	basin-floor playa lake and alluvial flat; distal piedmont alluvial
X	silty clay interbedded with silty sand, silty clay, and clay; indurated IX	basin-floor playa lake and alluvial flat; distal-piedmont alluvial

inferences (i.e. best guesses).

Bedrock and structural elements of the conceptual model
The third major component of the basin's hydrogeologic framework includes the bedrock units (Appendix E) and structural features (e.g. faults and folds) that form important boundary zones with respect to the groundwater- system and vadose-zone processes. Igneous-intrusive bodies and associated extrusive (volcanic) units are also locally significant parts of the hydrogeologic framework. Structural interpretations reflect recent contributions and ongoing research by geologists and geophysicists with Atlantic Richfield and Shell Oil Companies, and Southern Methodist University (May and Russell, 1991; May et al., 1991; Russell and Snelson, 1990, 1991).

Basin-boundary faults and Santa Fe Group thickness
A very important aspect of the conceptual model is the distribution and lithologic character of bedrock units that form the basin boundaries (both bottom and side). One of the most significant results of the recent oil and gas exploration in the Albuquerque Basin (cited above) has been that deep drilling and geophysical profiling have provided much better definition of the basin-fill/bedrock contact. Compare Fig. II–2 (Lozinsky, 1988) with Kelley (1977, Fig. 20).

West of the County Dump fault zone (Nine Mile fault of Kelley, 1977; West Mesa fault of Russell and Snelson, 1990), the basin fill is less than 3500 ft thick and ground water is produced from the lower and middle Santa Fe units. East of the fault zone basin fill abruptly thickens to more than 8,000 ft and locally exceeds 14,000 ft in thickness. From the Rio Grande fault (Plates 2 to 5, Figs. III–2 to 5) eastward to the Sandia frontal fault zone, fill again thins to less than 5,500 ft thick. Ground-water production east of the County Dump fault zone is entirely from the middle and upper units of the Santa Fe Group (MSF and USF) and overlying valley-fill units (RA and VA).

Bedrock units (Precambrian to middle Tertiary in the Albuquerque Basin; Figs. II–1 and 2, Plates 1 to 5) are generally regarded as very low-permeability boundary zones in geohydrologic models (Kernodle, 1992). However, upper Paleozoic (Pennsylvanian—Permian) carbonate rocks such as occur along the Tijeras (shear) and Hubbell fault zones in the southeastern corner of the study area (Plate 1; Meyers and McKay, 1970, 1976; Kelley, 1977, 1982), and other highly fractured bedrock units, may locally provide conduits for significant amounts of ground-water movement.

Structural influences on intrabasin sedimentation patterns
Because the Albuquerque Basin is part of an active tectonic (Rio Grande rift) zone that has been evolving for more than 25 million years (Section II), the distribution pattern of hydrostratigraphic units and lithofacies in space and time (Plates 1 to 7, Figs. III-2 to 5) must be interpreted in terms of ongoing basin extension and subsidence. Active local extension of the earth's crust and differential vertical movement, including rotation, of basin and range blocks are the basic structural controls on basin sedimentation. As is evident from the impact on Quaternary geomorphic processes by climate change related to glacial—interglacial cycles, forces other than Basin and Range tectonism can materially influence erosion, sediment transport, and deposition (Frostick and Reid, 1989). However, on the geologic time and space scale represented by Santa Fe Group deposition, Rio Grande rift structural deformation and associated igneous activity (e.g. Jemez volcanism) are the dominant factors that will be considered here in terms of controls on basin sedimentation.

The Lower Santa Fe hydrostratigraphic unit (early to middle Miocene) and associated lithofacies (primarily IV, VII, VIII, and IX) were deposited in a broad, shallow basin that predated major uplift of the Sandia Mountain block and deep subsidence of inner-basin blocks bounded by the Rio Grande and County Dump fault zones (Plates 1 to 5, Figs. III-2 and 3). Petrologic studies of drill cuttings and core discussed in the next section (IV), as well as less detailed analyses of samples and driller's logs summarized in Appendix F, indicate that depositional environments in the lower Santa Fe hydrostratigraphic unit contrast markedly with those in younger basin fill. During lower Santa Fe time the northern Albuquerque Basin apparently received a major influx of fine- to medium-grained sediments (muds to sands) from northern New Mexico—southern Colorado source areas that were sites of Oligocene to early Miocene volcanic activity. Deep wells in the Northeast Heights area (Plates 2, 3, and 6) do not appear to penetrate coarse clastic material derived from an emergent Sandia Mountain block below an elevation of about 3200 ft.

Distribution patterns of contiguous piedmont-slope and basin-floor lithofacies (I, II, III, V and IX) in upper and middle Santa Fe hydrostratigraphic units (USF-1 and 2, MSF-1 and 2) have been profoundly influenced by differential subsidence of basin fault blocks between the County Dump fault and the Sandia frontal fault zones (Plates 1 to 3, Figs. III-2, 4 and 5). As has been previously noted (Section II) most active subsidence has been along the Rio Grande fault.

The middle Santa Fe unit was deposited during late Miocene time when maximum differential movement between the Sandia and central basin fault blocks occurred (Fig. III-4). East of the Rio Grande valley both the middle and upper Santa Fe units (lithofacies MSF-1 and USF-1) are dominated by coarse clastic material (fan alluvium) derived from the Sandia uplift (Lithofacies Vf) and the ancestral Tijeras Canyon drainage basin (Vd). A subordinate clastic component derived from the north is still present in the middle Santa Fe unit, however, and is discussed below and in Section IV.

Complex intertonguing of piedmont-slope and basin-floor sediments is observed in the Middle Santa Fe unit (MSF-1 and 2; lithofacies II, III, V, and IX; Fig. III-4). Analyses of drill cuttings and upper core samples from the Coronado, Thomas, Charles, Love, and Ridgecrest City Well fields (Chapter IV, Appendices B, F, and G) shows a mixture of alluvial-fan and fluvial facies derived from both local (Sandia—Tijeras) and northern (Rio Grande rift and Rocky Mountain) sources. As suggested in Section II, a precursor to the through-going (ancestral) Rio Grande system, which terminated in the southern Albuquerque (Belen) sub-basin, contributed a large volume of fluvial sand and mud to actively subsiding parts of the basin north of the Tijeras fault zone and along the Rio Grande fault. At times basin-floor aggradation (Unit MSF-2) outpaced basin subsidence and a nearly level alluvial plain extended eastward to within 3 mi of the Sandia frontal fault zone. At other times fan deposits (facies V) prograded westward almost to the present location of I-25.

Similar complex intertonguing of ancestral Rio Grande and piedmont-slope facies (I, II, III and V) characterizes the upper Santa Fe unit (USF-1 and 2) between University and Wyoming Blvds. (Plates 2, 3, and 6). At times progradation of alluvial fans from the Sandia and Manzanita—Manzano uplifts (including ancestral Tijeras Canyon drainage basin) was the dominant process (lithofacies Vf and Vd) and the piedmont alluvial apron expanded as far east as to the present University Blvd. and I-25 (Figs. III-2, 4, and 5). At other times large volumes of sediment were washed into the basin by ancestral Rio Grande tributaries (Fig. II-3) heading as far north as the San Juan and Sangre de Cristo Mountains (Southern Rocky Mountains province). The final phase of widespread river aggradation (lithofacies Ib) occurred during eruptions of the Jemez volcanic center that produced the Bandelier Tuff and the Valles caldera (Smith et al., 1970; Gardner et al., 1986; Goff et al., 1989) 1 to 1.6 million years ago. At that time braided channels of the ancestral Rio Grande shifted across much of the basin-floor area between the future sites of the Albuquerque volcanoes and Wyoming Blvd. (Fig. III-5). The patterns of sedimentation described above are clearly influenced by both local and regional volcanic and tectonic processes, as well as by early Pleistocene and Pliocene climate cycles.

Rapid subsidence of central basin due to major down-to-the-west displacement along the Rio Grande fault has also had a major influence on sedimentation patterns in the upper Santa Fe unit (USF-2) beneath the Rio Grande floodplain and the western belt of river terraces (along Coors Blvd.). This structural deformation has produced more than 2 mi of inner basin subsidence since middle Miocene time (past 15 million years). Hundreds of ft of basin subsidence have occurred along the County Dump, Isleta, and Rio Grande faults in Pliocene and Quaternary time (past 5 million years) and clearly control the distribution of lithofacies (I, II, III, and IX) in the upper Santa Fe hydrostratigraphic unit (USF-2, Plates 3 and 4, Figs. III-2 and 5).

Differential movement of the Rio Grande and associated faults of the County Dump and (inferred) Isleta zones shown on Plates 1 through 5) continued in post-Santa Fe (Quaternary) time and controlled the position of the inner Rio Grande valley and the bordering river terraces. Valley-fill units (VA-g) are definitely offset by faults in the Bernalillo and Isleta areas (Lambert, 1978, Fig. S67; Kelley, 1977, geologic map). In this area young cut-and-fill activity by both the Rio Grande and tributary arroyos would naturally obliterate most surface features produced by faulting. Uncertainty of correlation of upper Santa Fe (USF-2) and river-terrace gravels (VA-g) shown on Plates 2 through 4 west of the Rio Grande fault is at least partly due to the difficulty (or impossibility) of distinguishing ancient fault scarps from river-terrace scarps (bluffs).

In many valley-border areas (e.g. between I-25 and Edith Blvd. and along SE and NE Coors Blvd.), coarse-grained river channel deposits of the upper Santa Fe and younger valley-fill units (USF-2, VA, and RAr) are in direct contact (Lambert et al., 1982; Wilkins, 1986; Peter, 1987; Hawley and Love, 1991). This relationship has a very negative impact in terms of waste management problems (McQuillan, 1982; Stone, 1984; Hawley and Longmire, 1992), but it also offers exciting possibilities for much more efficient conjunctive use of surface- and ground-water resources (e.g. artificial recharge) in a number of valley-border areas south of Bernalillo.

Discussion

The conceptual model of the Albuquerque area's hydrogeologic framework developed for this report (Plates 1 to 7, and the color-coded, 3-D arrangement of these plates) is clearly what its name implies:

1. It is only a model of very complex real-world system (Kernodle, 1992, pp. 6-7).
2. The intellectual construct that is a concept can be only as good as the quality of the scientific information used in its development.
3. The model's graphic portrayal is at least partly an artistic endeavor that reflects the talents of its creator (or lack thereof).

The authors of this report believe that the major features of the model will stand the test of time, but that there will always be need (and space) for improvement. The positive feedback loop between assimilation of more scientific information, and improved conceptualization and artistic skill will continue to be enhanced as the model is being tested and further developed. The late great hydrologist, C. V. Theis, strongly believed that even numerical modelers need to be artists, and that all artists must have models (1966 summer lectures at NMSU College of Engineering).

SECTION IV

PETROLOGIC DATA

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J. W. Hawley and C. S. Haase (compilers), 1992, *Hydrogeologic framework of the northern Albuquerque Basin*, New Mexico Bureau of Mines and Mineral Resources, Open-File Report 387, pp. IV-1 to IV-17

IV. PETROLOGIC DATA

Methods

Sidewall cores and selected cuttings

Petrographic thin sections were prepared for all sidewall core sandstones and several of the mudrocks. The thin sections were impregnated with a blue-dyed epoxy to differentiate true porosity from that formed during thin-section preparation (i.e. plucking of grains). All thin sections were stained for potassium feldspar and plagioclase using standard techniques (see Miller, 1988). Selected sidewall cores and cuttings were examined on a Hitachi S-450 scanning electron microscope (SEM) equipped with a Tracor TN-2000 energy dispersive x-ray analysis system. The Tracor system makes it possible to obtain semiquantitative compositional data for examined phases.

The modal composition and total porosity of the sidewall core samples were determined by point counting (300 points) on a standard petrographic microscope equipped with a Swift automated point-counting device. Percentages of different porosity types (e.g. intergranular, intragranular) were visually estimated. The mean grain size and degree of sorting were visually estimated using the appropriate textural comparitors (grain size, Amstrat Inc.; sorting, Longiaru, 1987).

Grain mounts from selected cuttings

Grain mounts were prepared from loose sand in the cuttings. It was necessary to use grain mounts because sidewall cores are only available for a limited number of depths and wells, and intact cuttings (actual pieces of rock rather than loose sand grains) are rare at depths less than 1900 to 2000 ft. The sand grains were sieved to 0.125 to 2.0 mm size prior to mounting in order to reduce grain-size induced changes in composition and remove drilling mud.

Percentages of different grain types in the mounts were visually estimated using abundance comparitors. Grain mounts contain almost no information about rock textures and cements, so no data are available for the non-framework components or porosity types in these samples. All grain-mount thin sections were stained for potassium feldspar to aid in the rapid identification of feldspar grains.

X-ray diffraction

X-ray diffraction (XRD) was used to determine the mineralogy of selected samples. The XRD analysis was performed at the Clay Mineral Testing Facility in the NMBMMR. The calculated values are semiquantitative. Details of the analytical procedures can be obtained from Dr. George Austin, Senior Industrial Minerals Geologist and Laboratory Manager.

Composition and texture

Sandstones

The sidewall core sandstones are principally lithic arkoses and feldspathic litharenites (Fig. IV-1; classification of Folk, 1974). Framework grains consist mainly of monocrystalline quartz, feldspar, and rock fragments with lesser amounts of biotite, muscovite, chlorite, and heavy minerals (Appendix G: Tables 1 and 2). Rock fragments are mainly volcanic, granitic/gneissic, and sedimentary (Fig. IV-1, Appendix G: Tables 1 and 2). In addition, small amounts of metamorphic-rock fragments were found in a few of the samples. The volcanic-rock fragments exhibit a wide range in texture, composition, and degree of hydrothermal alteration. Plagioclase-dominated porphyries, most likely derived from lavas and possibly from shallow intrusions, are the most abundant type (75 to 80% of total volcanic fraction). Pyroxene andesites are more common than hornblende dacites; olivine basalts are rare. The remaining 15 to 20 % of volcanic fragments are densely welded rhyolite ash-flow tuffs (ignimbrites), spherulitic and "snow flake" textured rhyolites (presumably lavas), and silicified, poorly welded or non-welded tuffs. A densely welded, dark-reddish-brown, crystal-poor ignimbrite

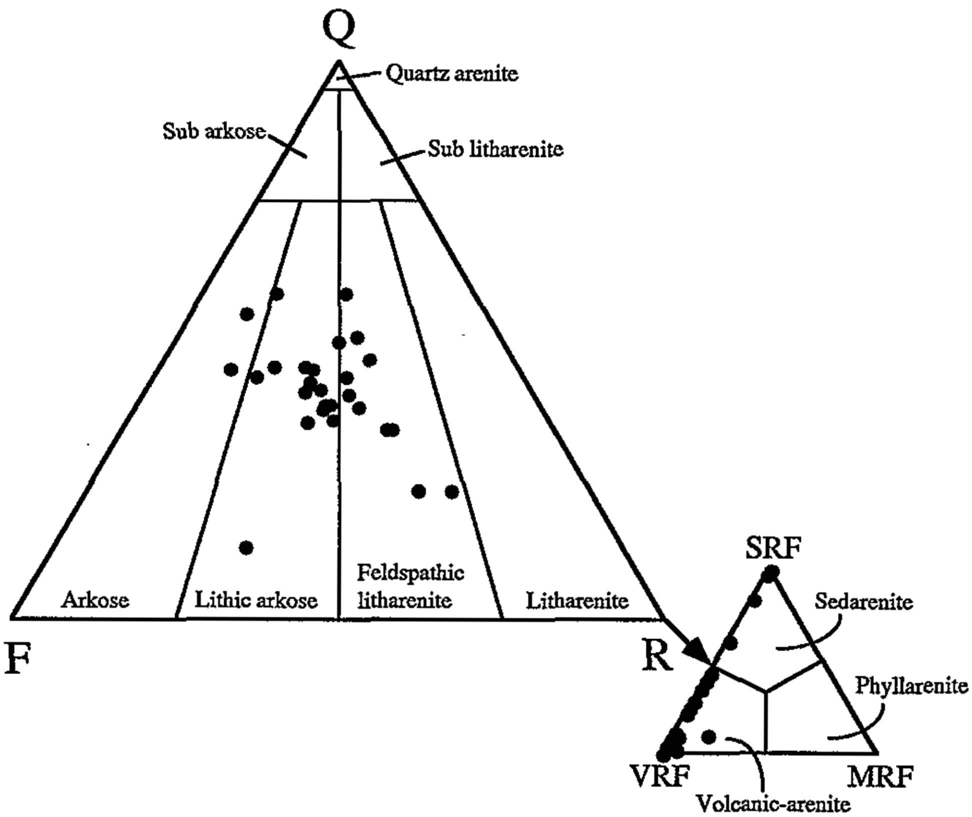


Fig. IV-1. Ternary diagram showing the relative proportions of quartz (Q), feldspar+granitic/gneissic fragments (F), and lithic fragments (L) in sandstones in sidewall cores from the Charles 5 and Love 8 wells. The subsidiary triangle shows the proportions of sedimentary (SRF), volcanic (VRF), and metamorphic (MRF) rock fragments in the samples. Data from Tables 1 and 2, sandstone classification of Folk (1974).

(with sparse resorbed quartz and sanidine) is one of the most distinctive volcanic clasts. The red ignimbrite occurs in trace amounts in most samples. Silicified andesites and tuffs, which represent hydrothermal alteration in the source terrain, are present in a few samples. Glassy volcanic fragments were not observed in the sidewall-core samples. The major non-framework components are detrital/mechanically infiltrated clay, and calcite and zeolite cements (Appendix G: Table 3; calcite and zeolite cements are discussed in more detail in the diagenesis section).

Grain size and sorting of the sandstones are highly variable (Appendix G: Table 4). Mean grain size ranges from very fine to coarse. In addition, many of the sandstones contain material more than 2 mm in diameter and thus classify as conglomeratic (or pebbly) sandstones. As is normal for sandstones, composition is controlled to a certain extent by grain size. Most notably, the abundance of volcanic-rock fragments and polycrystalline quartz increases significantly with increasing grain size (Figs. IV-2 and IV-3). Sorting ranges from well to very poorly sorted.

Mudrocks

The mudrocks consist mainly of clay with lesser amounts of sand- and silt-sized framework grains (Appendix G: Tables 1, 2, and 3). One sample (Charles 5: 3079.1 ft) contains a significant amount of carbonate cement (Appendix G: Table 3). The XRD analysis of the clay fraction (i.e. $< 2\ \mu m$) of mudrocks in a number of wells detected smectite, illite, kaolinite, and interlayered illite/smectite (Appendix G: Table 5). Clay-sized quartz, feldspar and carbonate minerals are also present in the samples.

The average quartz/feldspar ratio of silt- and sand-sized grains in the mudrock samples studied is approximately 3.8. This appears to be significantly higher than the quartz/feldspar ratio of 12 fine- to very fine-grained sandstone samples, which average approximately 1.4. The apparent enrichment of quartz in mudrock samples may reflect additions of eolian quartz to muds accumulating in a basin-floor or playa setting.

Grain mounts

Grain mounts of well cuttings are the only type of sample available from the shallow levels of the wells (above depths of about 1500 ft) where the Santa Fe Group strata evidently lack sufficient induration to allow sidewall coring. Thin sections of grain mounts show that the cuttings contain abundant coarse-grained rock fragments (volcanic and granitic) apparently derived from unconsolidated gravels in the Santa Fe strata. Fragments of fine-grained argillaceous lithic arkose similar to side hole cores (see Fig. IV-1) first appear in the Charles 5 well at a depth of 1350 to 1360 ft. Fragments of fine-grained lithic arkose do not become common in the cuttings (5 to 10 % of total cuttings) until a depth of 1900 to 2000 ft is reached. In terms of equivalent indurated sedimentary rock, the coarse-grained well cuttings range in composition from arkose to litharenite; feldsapthic litharenites are the most common (Appendix G: Table 6; Fig. IV-4).

Grain mounts show three compositional zones in the Santa Fe strata at depths of approximately 0 to 200 ft, 200 to 400 ft, and 400 to 2100 ft. The lower compositional zone may be subdivided into an upper unconsolidated interval (400 to 1700 ft) and a lower indurated interval from about 1700 to 2100 ft. The uppermost zone, approximately 200 ft thick, contains abundant quartz, sericitic plagioclase, microcline, and granitic rock fragments; only trace amounts of volcanic rock fragments (<1 %) are present. Caliche (microcrystalline calcite) and caliche-cemented sandstone fragments are common in the uppermost zone (10 to 15 % in Charles 5: 70 to 75 ft). Fragments of chlorite schist (greenstone) are relatively common (2 to 3 %) in comparison to deeper strata. Also apparently distinctive of the upper zone are rare fragments of fossiliferous limestone.

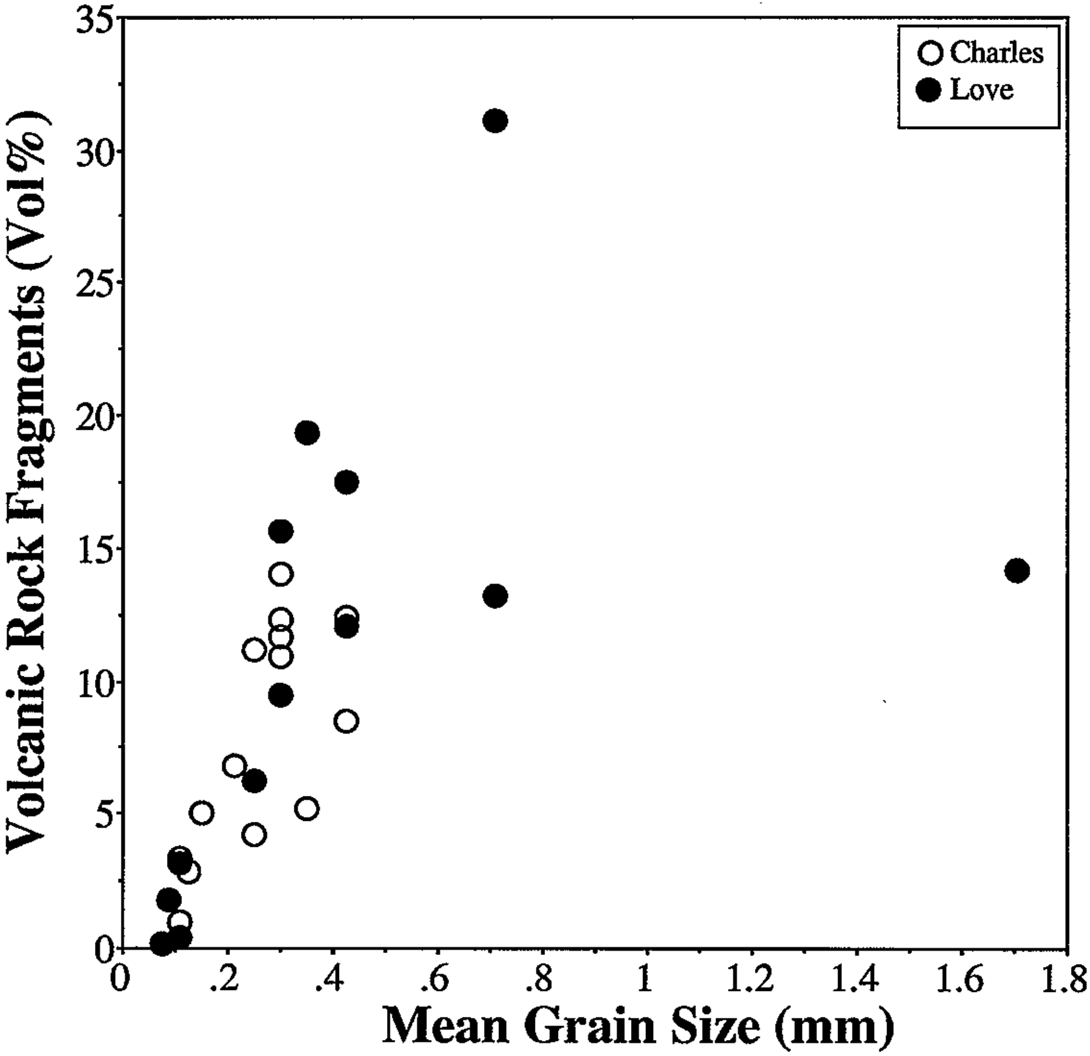


Fig. IV-2. Plot of abundance of volcanic-rock fragments versus mean grain size for sandstones in sidewall cores from the Charles 5 and Love 8 wells. In general, coarser-grained sandstones contain more volcanic-rock fragments than finer-grained sandstones. Data from Tables 1, 2, and 4.

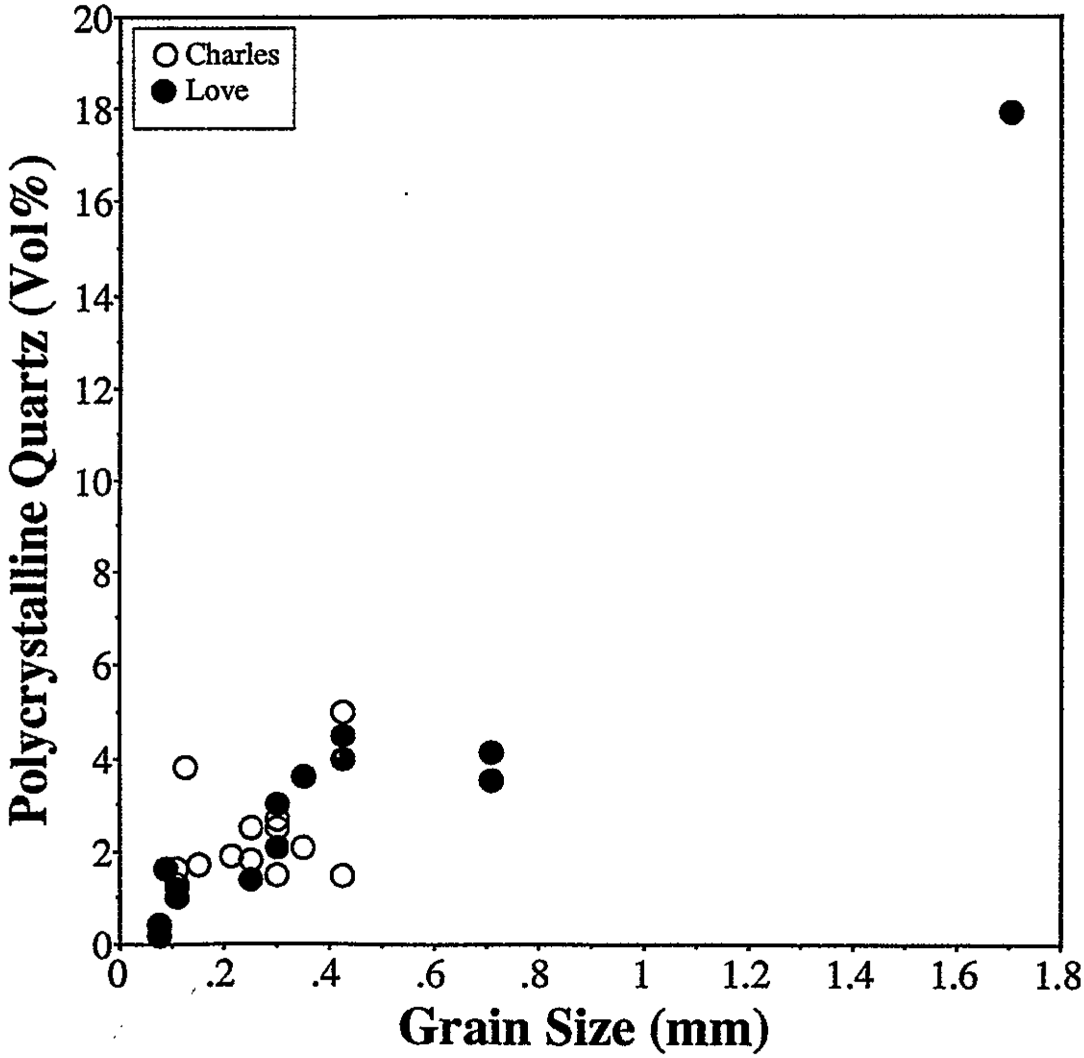


Fig. IV-3. Plot of abundance of polycrystalline quartz versus mean grain size for sandstones in sidewall cores from the Charles 5 and Love 8 wells. In general, coarser-grained sandstones contain more polycrystalline quartz than finer-grained sandstones. Data from Tables 1, 2, and 4.

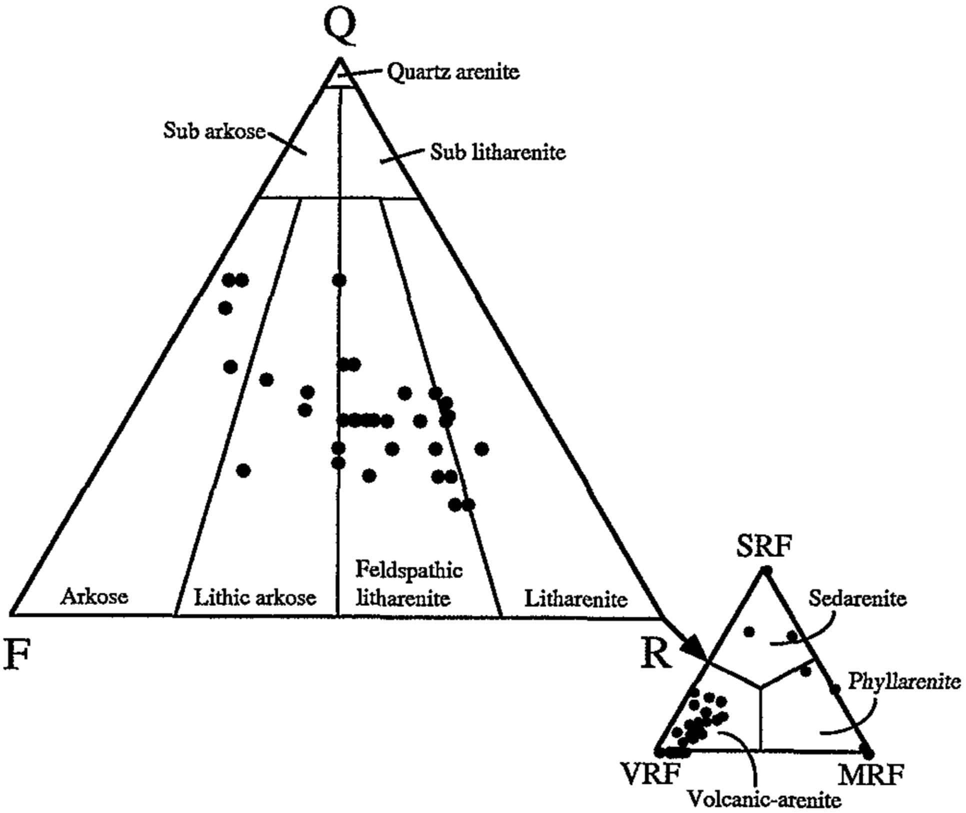


Fig. IV-4. Ternary diagram showing the relative proportions of quartz (Q), feldspar+granitic/gneissic fragments (F), and lithic fragments (L) in grain mounts. The subsidiary triangle shows the proportions of sedimentary (SRF), volcanic (VRF), and metamorphic (MRF) rock fragments in the samples. Data from Table 6, sandstone classification of Folk (1974).

The middle compositional zone, at approximately 200 to 400 ft below the surface, is characterized by relatively common fragments of glassy rhyolite pumice (as much as 5 % of total cuttings). Other volcanic rock fragments (andesite, dacite, rhyolite, and rhyolite ignimbrite) also become relatively abundant at about 200 ft below the surface and persist to the bottom of the wells. Traces of glassy pumice and caliche that occur in deep level cuttings (e.g. Charles 5: 2130 to 2140 ft) are interpreted as contamination derived from washouts in shallow levels of the hole (less than 400 ft deep).

Cuttings from the 400 to 2100 ft depth interval contain subequal concentrations of quartz (35 to 45 %), feldspar (20 to 30 %) and rock fragments (30 to 40 %). Volcanic rock fragments average approximately 25 % of the total cuttings in grain mounts. Detritus of Precambrian derivation (polycrystalline quartz, microcline, sericitic plagioclase, metaquartzite, and granite) comprise approximately 60 % of the total cuttings.

Coarse quartz grains are dominantly polycrystalline and consist of interlocking anhedra similar to that seen in granitic-rock fragments or tightly packed rounded grains similar to metaquartzite fragments. The proportion of polycrystalline quartz to monocrystalline quartz appears to increase with increasing grain size. The dominance of monocrystalline quartz in the relatively fine-grained sidewall cores (Appendix G: Table 1), and the dominance of polycrystalline quartz in coarse-grained cuttings (Appendix G: Table 6) is attributed to differences in average grain size (cuttings are coarser-grained overall). This compositional fractionation is caused by the fact that large polycrystalline quartz grains tend to break down into smaller monocrystalline grains.

Two types of plagioclase feldspar are common in grain mounts of the lower compositional zone. Clear, well twinned, and rarely oscillatory-zoned plagioclase which is similar to that seen in andesite fragments is subequal to cloudy, sericitic, very finely twinned plagioclase (albite?). Sericitic plagioclase is commonly observed in granitic fragments. Volcanic potassium feldspar (sanidine) and volcanic quartz (often embayed) are as rare as the rhyolitic fragments (1 to 4 % of total cuttings) from which they are derived. Pyroxene andesites and hornblende dacites are the most common type of volcanic grain. Rhyolites, in the form of ignimbrites, spherulites, and silicified tuffs comprise about 20 % of the total volcanic fragments. Descriptions of volcanic-rock fragments in the previous section (Sandstones) are applicable to grain mounts as well. Except for apparent differences in degree of induration and grain size, the feldspathic litharenites defined by sidewall cores (at depths of about 1700 to 3200 ft, Fig. IV-1) appear to represent a continuation of the feldspathic volcanic-rich zone of unconsolidated sediment found at depths of about 400 to 1700 ft.

Diagenesis

The major diagenetic events that affected the rocks are discussed below. This discussion is based mainly upon observations from sidewall-core samples from wells Charles 5 and Love 8.

Calcite and zeolite cements

Calcite (mainly micrite and microspar) is present, filling intergranular areas (Plates IV-1A, and IV-2A and B). The micritic nature of the calcite suggests that some of it may have formed very early (i.e. shortly after deposition of the sediments) as caliche. Zeolites are present in intergranular areas (Plates IV-1B and 2C). Energy dispersive x-ray analysis of the zeolites detected calcium, silicon, aluminum and possibly iron (near detection limit). X-ray diffraction analysis of three zeolite-rich whole-rock samples (Love 8: 2520 and 2350 ft, and Charles 5: 2519.9 ft) indicates that the zeolite is stilbite. Zeolite cements are common in rocks containing a significant amount of volcanic detritus and precipitate from alkaline pore waters (Hay and Shepard, 1977).

Plate IV-1

SEM PHOTOMICROGRAPHS

A. Pore-filling calcite cement. Note increasing crystal size near center of pore. Well Charles 5, 1460-1470 ft, cuttings, scale bar = 50 µm.

B. Pore-filling euhedral zeolite (stilbite) crystals. Well Love 8, 2520 ft, sidewall core, scale bar = 50 µm.

C. Grain-rimming authigenic smectite. Well Charles 5, 2318.2 ft, sidewall core, scale bar = 5 µm.

D. Grain-coating detrital/mechanically infiltrated clay. The grain originally coated by the clay has been removed, probably by grain dissolution. Love 8, 290-300 ft, cuttings, scale bar = 50 µm.

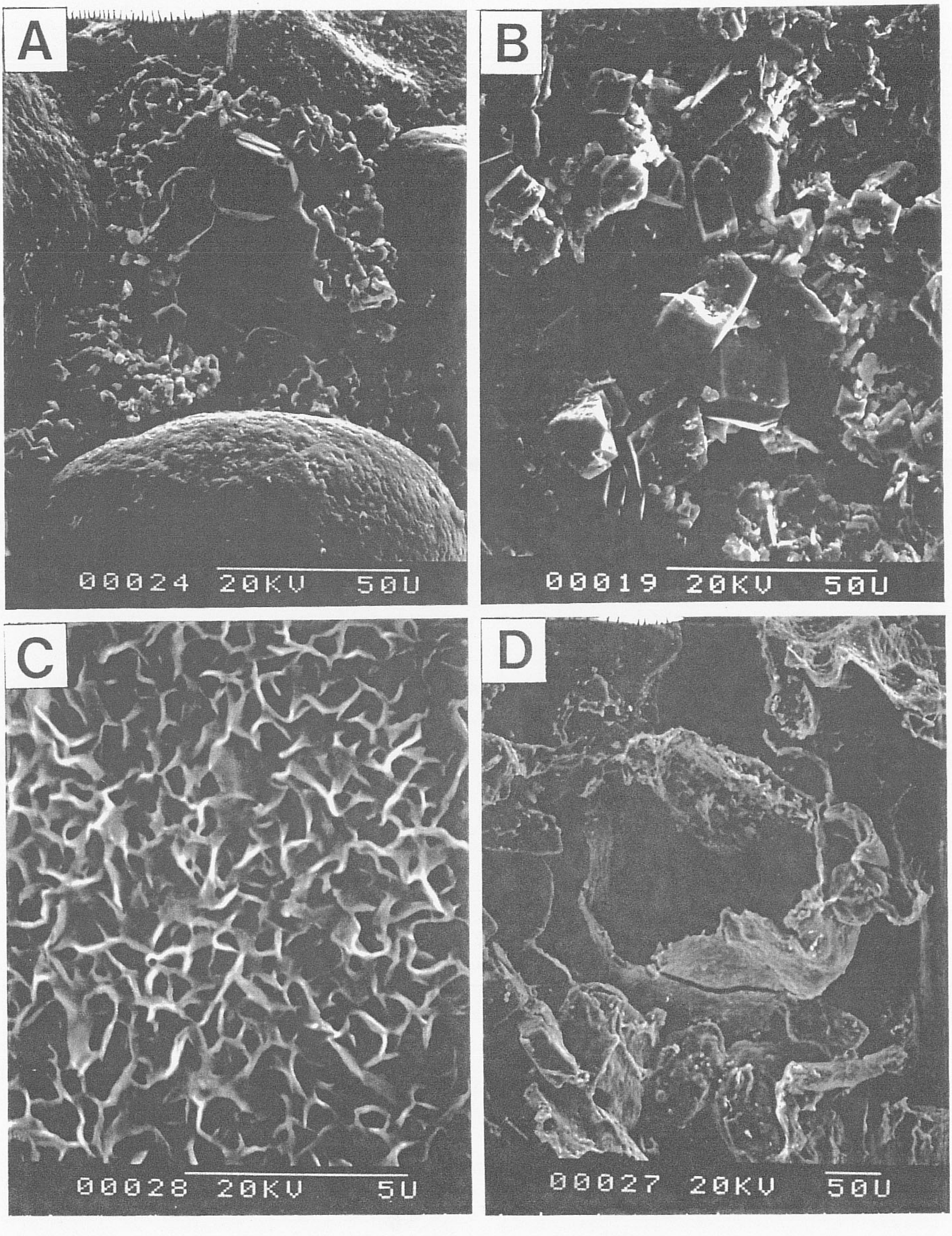

A
00024 20KV 50U
B
00019 20KV 50U
C
00028 20KV 5U
D
00027 20KV 50U

Plate IV-2

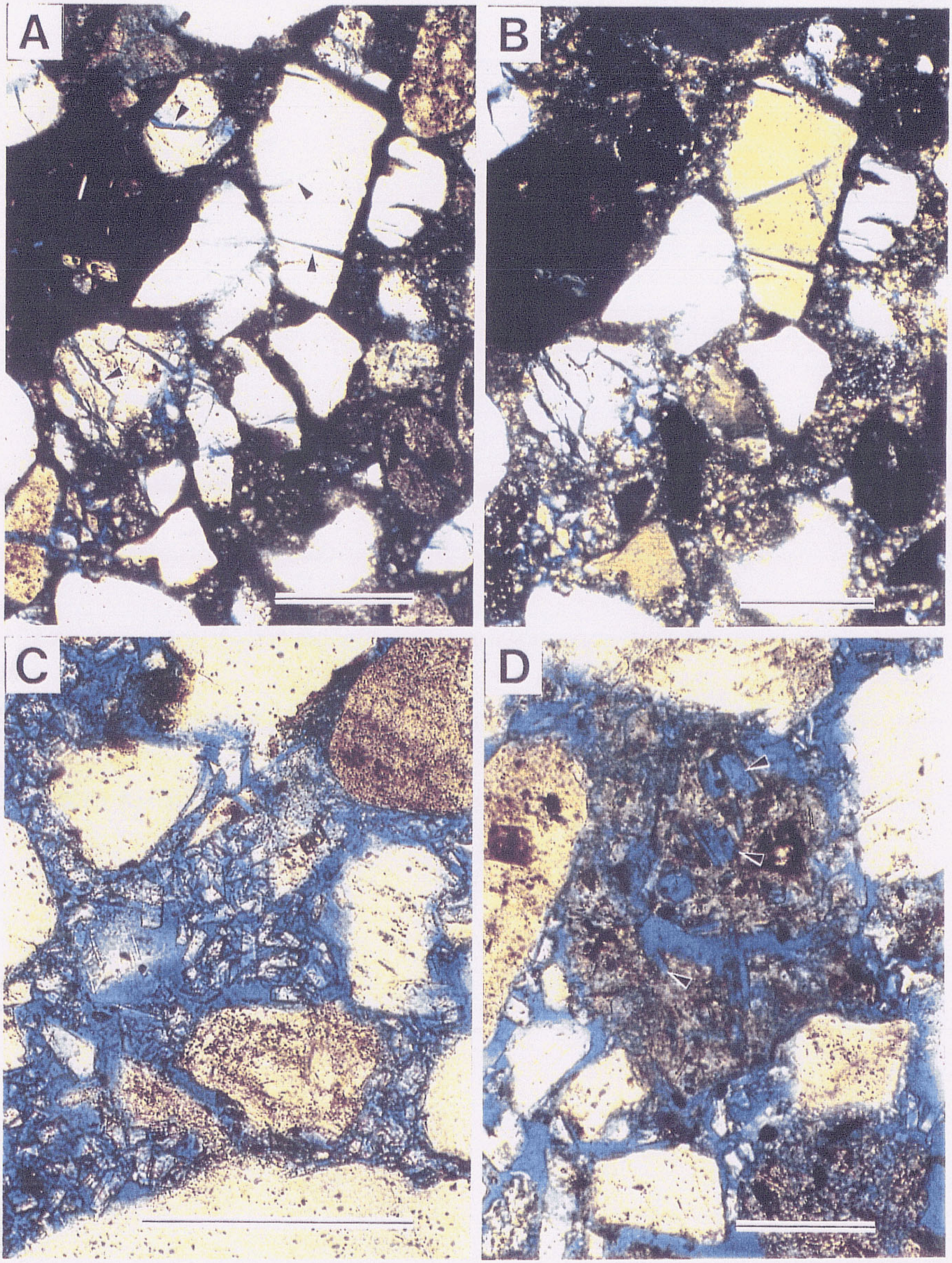
THIN-SECTION PHOTOMICROGRAPHS

A. Pore-filling micritic-calcite cement (dark material surrounding sand grains) in a sandstone. Note abundant intragranular fractures (arrows, blue epoxy). Well Charles 5, 1789.8 ft, sidewall core, plane polarized light, scale bar = 0.25 mm.

B. Same view as Plate IV-2a, but with crossed polarizers.

C. Pore-filling authigenic zeolites (small euhedral crystals in intergranular areas). Porosity is highlighted by blue-dyed epoxy. Well Charles 5, 2519 ft, sidewall core, plane polarized light, scale bar = 0.25 mm.

D. Volcanic-rock fragment containing abundant intragranular macroporosity (arrows, rectangular voids filled with blue epoxy) and microporosity (overall light-blue color). This rock fragment is far too delicate to have been transported in this condition, so the intragranular porosity most likely originated through intrastratal dissolution. Charles 5, 2510.3 ft, sidewall core, plane polarized light, scale bar = 0.25 mm.


A
B
C
D

Authigenic smectite
Grain-rimming authigenic smectite was detected in SEM (Plate IV-1C), but the extremely thin nature (tens of microns or less) of the rims makes them difficult to observe in thin section. It is possible that smectite rims are very common in these rocks, but further SEM study will be necessary to document their abundance. The presence of pore-lining smectite in the sandstones is important in terms of ground-water contaminant transport. Smectite has a high cation-exchange capacity and has the ability to adsorb a number of organic solvents (Austin, 1986). The pore-lining nature and high surface area of the smectite would act to increase its interaction with hazardous solutes.

Fracturing
Many of the samples contain fractures. These fractures occur within individual framework grains (intragranular fractures; Plate IV-1A) and as more continuous through-going fractures that break around and through a large number of grains. Many of these fractures may have been artificially induced during the extraction of the sidewall cores.

Grain dissolution
The presence of intragranular porosity (including lath-shaped voids in volcanic-rock fragments), ghost grains defined by insoluble clay coatings, and other features demonstrate that grain dissolution has affected the rocks (Plates IV-1D and 2D). Unstable framework grains such as plagioclase and volcanic-rock fragments have been preferentially dissolved (Plate IV-2D). In some samples this has resulted in the formation of volumetrically significant secondary porosity.

Porosity
The main control on porosity in the samples is the amount of cement and clay matrix. Samples containing significant amounts of clay and cements have low porosity, whereas those containing minor amounts have high porosity (Figs. IV-5 and IV-6). The degree of sorting is also of importance. Poorly sorted samples can be expected to have lower porosities than their better sorted counterparts.

Intergranular porosity is the dominant porosity type in most of the samples (Appendix G: Table 7). Other types of porosity (e.g. intragranular, microporosity, etc.) are only important in samples that have low total porosity (Fig. IV-7; Appendix G: Table 7). In terms of ground-water flow, intergranular porosity and fracture porosity are the most interconnected types, and consequently contribute significantly to aquifer permeability. Other porosity types do not contribute significantly to permeability due to poor interconnection (e.g. intragranular porosity) and/or small pore diameter (e.g., microporosity, pores less than approximately 0.5 µm in diameter; see Pittman, 1979 for a discussion of the relationship between pore types and flow properties in sandstones).

As discussed above, fracture porosity, which is important in some of the samples, may have formed during extraction of the sidewall cores, so it is difficult to evaluate the importance of this porosity type.

Provenance
Compositional variations in cuttings (grain mounts) and sidewall cores (sandstone thin sections) summarized in previous sections suggest at least three distinct source areas for sediments intersected in all wells examined for this report. The uppermost 200 ft of section represent granitic alluvium deposited on the Tijeras Canyon fan. Chloritic-schist fragments in this interval are probably derived from the Tijeras Greenstone (Kelley and Northrop, 1975). The predominant granitic material is most likely derived from the Sandia Granite. Rare fragments of fossiliferous limestone were probably from the Madera Limestone found on the

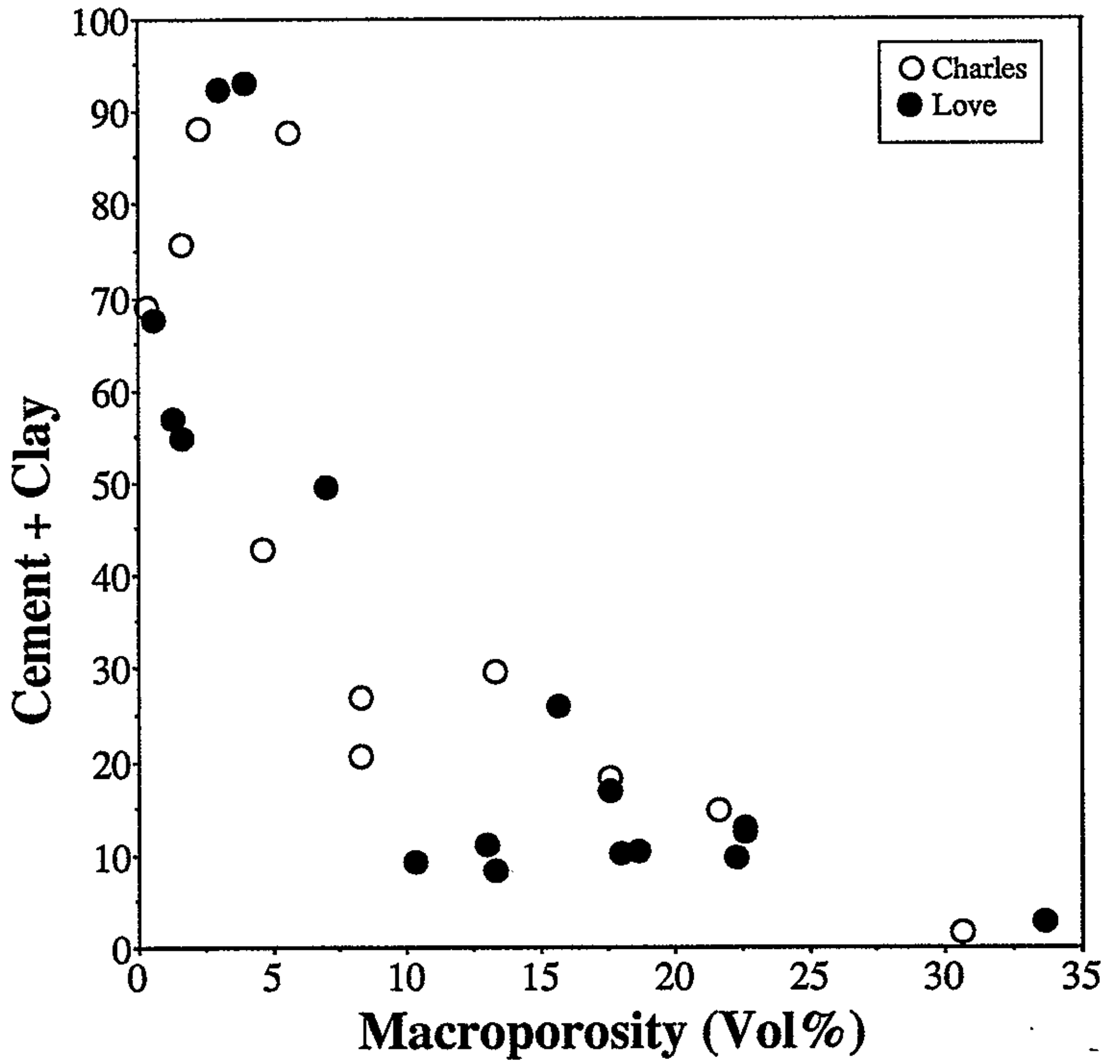


Fig. IV-5. Plot of macroporosity versus clay+cement for sandstones and mudrocks in sidewall cores from the Charles 5 and Love 8 wells. Note decreasing macroporosity with increasing amount of cement and clay matrix. Data from Appendix G (Tables 3 and 7).

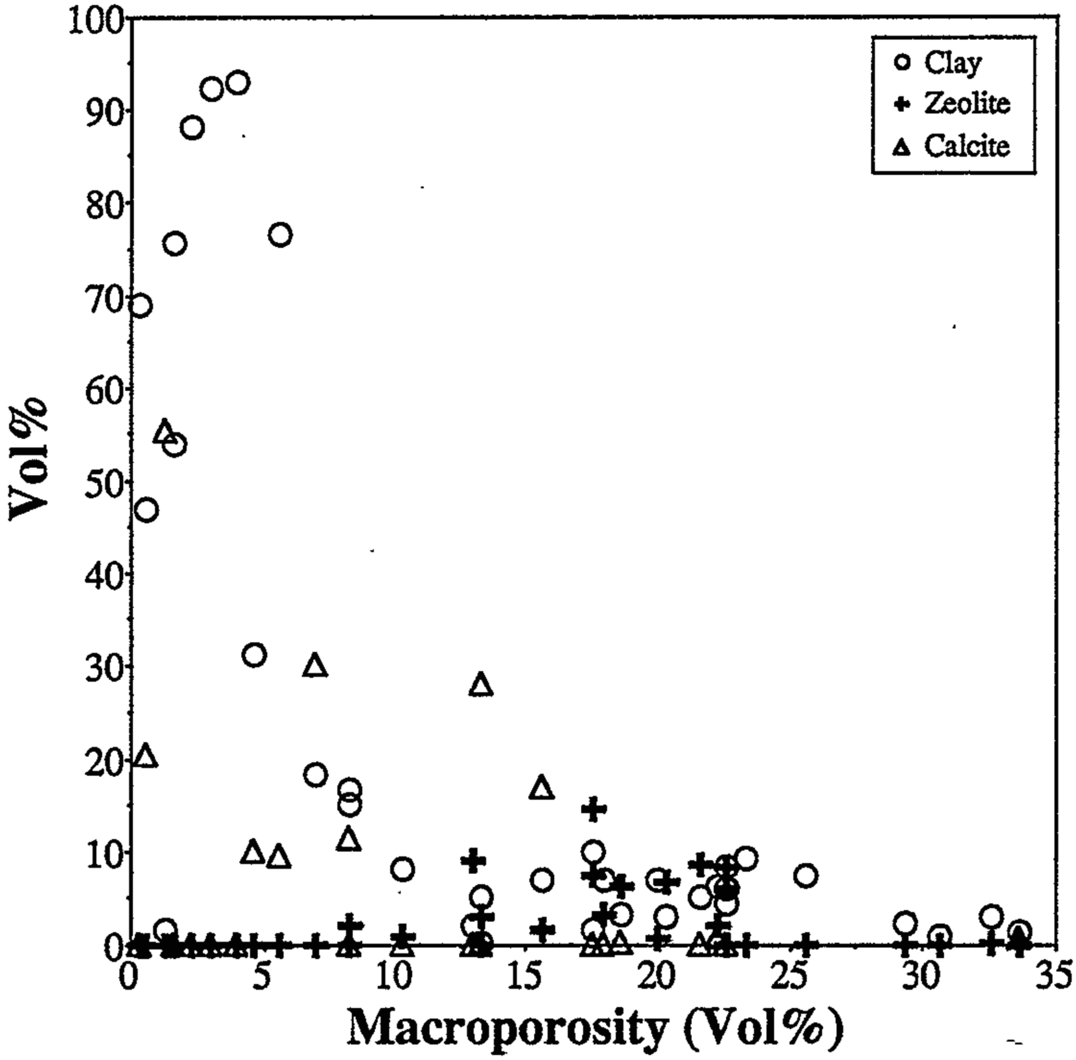


Fig. IV-6. Plot of macroporosity versus percentages of clay, zeolite, and authigenic calcite in sandstones and mudrocks in sidewall cores from the Charles 5 and Love 8 wells. The presence of calcite and zeolite cements and clay matrix acts to reduce macroporosity in these samples. Data from Appendix G (Tables 3 and 7).

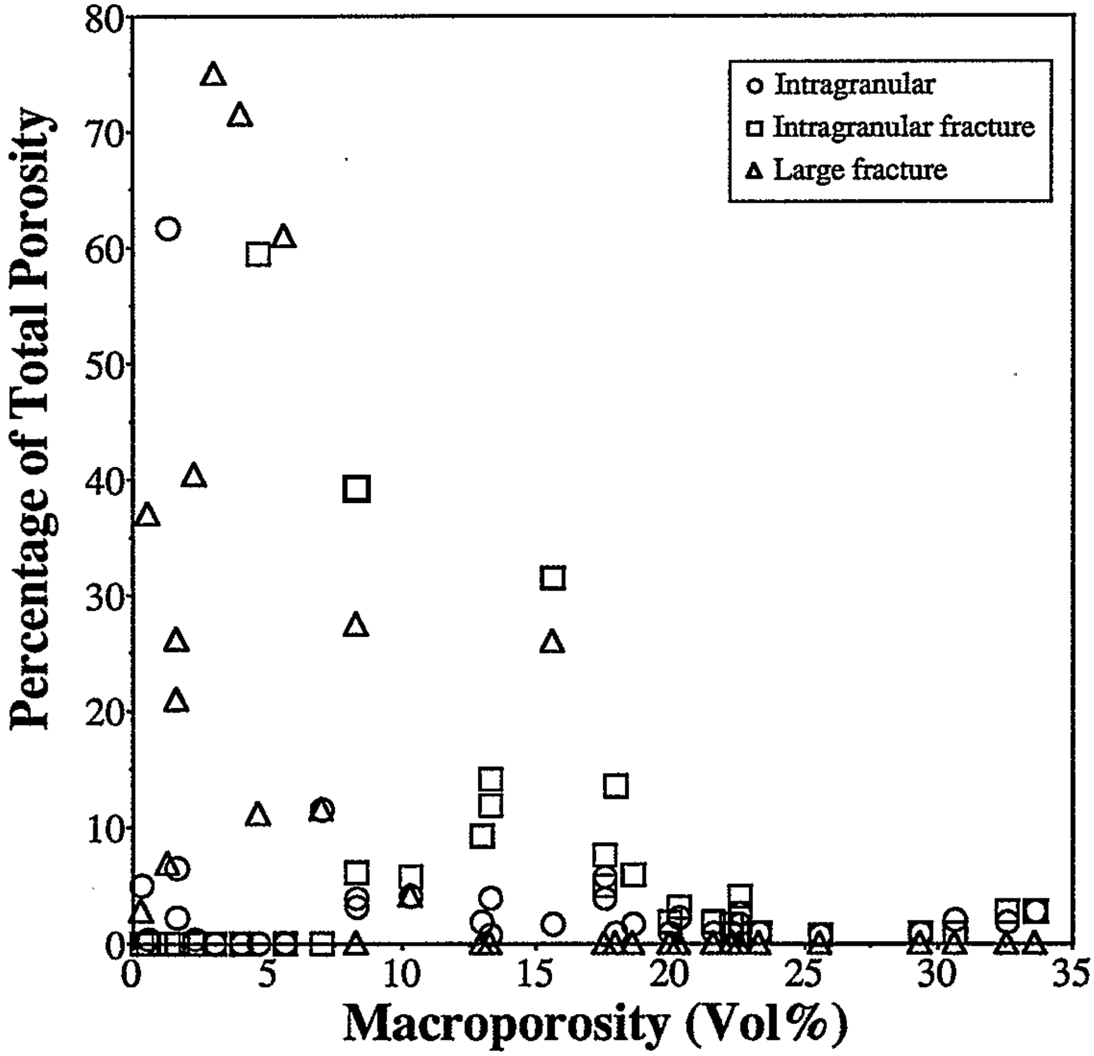


Fig. IV-7. Plot of macroporosity (volume % whole rock) versus less abundant porosity types (shown as a percentage of total porosity). Intergranular porosity is the main porosity type in most of the samples, except for low macroporosity samples where these porosity types make up a greater proportion of total porosity. Data from Appendix G (Table 7).

crest of the Sandia Mountains.

Relatively abundant glassy pumice (3 to 5 %) in the sediment interval from about 200 to 400 ft below the surface is almost certainly derived from an episode of rhyolite eruption in the Jemez volcanic field (Smith et al., 1970). Possible sources would be the Peralta Tuff or an early phase of the Bandelier Tuff. The presence of these pumice fragments implies a southerly direction of sediment transport for this part of the section.

The Santa Fe Group deposits, from depths of 100 to 3100 ft, consist predominantly of granitic and metaquartzitic detritus (~60 %) derived from Precambrian-cored mountain ranges and a smaller fraction of volcanic debris (~30 %) representing a wide variety of volcanic units within a major Tertiary volcanic field (or fields).

The San Juan volcanic field of southwestern Colorado and northern New Mexico (e.g. Latir volcanic field near Questa), or the Mogollon—Datil volcanic field of southwestern New Mexico represent possible sources for the volcanic detritus. The ignimbrite fragments found in these sediments could not have come from the Espinaso volcanics of the Hagan Basin (Ortiz Porphyry belt) or the Jemez volcanic field. The San Juan volcanic field, which would include the Amalia Tuff in the Questa caldera, is the most likely source of the ignimbrite fragments. This would agree with Ingersoll et al. (1990) and Lozinsky (1988), who have suggested a northern source area for volcanic detritus found in the lower Santa Fe Group of the northern Albuquerque Basin. If most of the volcanic detritus is from north-central New Mexico and southern Colorado, then a significant fraction of the granitic—metamorphic component may be derived from the Precambrian terrane of the Sangre de Cristo Mountains as well as from Precambrian rocks in the Sandia Mountains. Although less likely, ignimbrites in the Socorro region of the Mogollon—Datil field represent a potential source that should not be ruled out until more constraining data is available. Sparse sedimentary-rock fragments, mostly chert and well cemented sandstones, are found at all levels of the wells. Potential source areas for the sedimentary fragments are widespread and relatively unconstrained.

Variation in parameters with lithofacies

Little variation in sandstone composition was noted with changes in lithofacies. The major variation was recognized in the upper 200 to 300 ft of the wells where volcanic-rock fragments are rare and granitic/gneissic grains are abundant. Below about 300 ft, volcanic-rock fragments become dominant. This change coincides with the lithofacies change from medial alluvial-fan deposits associated with small watersheds to more basin-floor fluvial deposits. The 200 to 400 ft interval containing the pumice also generally correlates with the basin-floor fluvial deposits suggesting that the pumice was transported by a south-flowing river system.

The absence of significant compositional differences between lithofacies in the rest of the borings is probably due to limited source areas for the deposits. Most of the detritus was derived from only two source areas which may not have varied over the time interval seen in the wells. Therefore, the different lithofacies are probably more due to changing depositional environments which resulted in textural differences.

The change from granite-derived sediment in the uppermost 200 ft of the Albuquerque wells to mixed granitic—volcanic detritus, below this level, generally coincides with the boundary of medial alluvial-fan facies (V) and the underlying basin-floor fluvial facies (Ib). The interval of glassy pumice from approximately 200 to 400 ft depth coincides with the upper part of the basin-floor fluvial facies and provides independent evidence supporting its deposition by a southerly flowing river system.

The occurrence of sparse ignimbrite fragments (presumably from the San Juan volcanic field) at all deeper levels in the Charles 5 and Love 8 wells (from 200 to 3200 ft) also implies a southerly component of transport for deeper strata generally assigned to the alluvial-fan facies (below a depth of 1000 ft). It is possible that the strata below 1000 ft actually represent intertonguing basin-floor (II, III) and piedmont-slope facies (V, VII). Available samples may be too widely spaced to allow the recognition of intertonguing strata of different provenance and composition. Some aspects of the different lithofacies reflect differences in average grain size and degree of compaction or cementation, which are dependent on depositional environment and relatively independent of composition.

SECTION V

BOREHOLE GEOPHYSICAL DATA

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J. W. Hawley and C. S. Haase (compilers), 1992, *Hydrogeologic framework of the northern Albuquerque Basin*, New Mexico Bureau of Mines and Mineral Resources, Open-File Report 387, pp. V-1 to V-18

V. BOREHOLE GEOPHYSICAL DATA

Data sources

Suites of borehole geophysical logs are available for 108 water wells and borings in the Albuquerque area (see Appendix B). Eighty four of these suites were obtained over the past 30 years during construction of City of Albuquerque water wells. The remainder were obtained during construction of water wells in adjacent municipalities, during construction of groundwater monitoring wells, or during other exploratory drilling operations.

The specific logs available within each suite varies (see Appendix H), but typically conductivity, deep induction and shallow resistivity, and spontaneous potential logs are available at a minimum. Comprehensive suites of electric, sonic, and nuclear geophysical logs are available for 12 wells—Burton 5, Cerro Colorado, Charles 5, Coronado 2, Gonzales 2, Love 8, Ridgecrest 5, Soil Amendment Facility 1, Thomas 5, Thomas 6, Thomas 7, and Thomas 8 (see Fig. I-1 for well locations).

Geophysical log data are available in analog format for all wells. Additionally data are directly available in digital format from the logging contractor (Schlumberger Well Surveying) for the 12 wells listed above. Digital data are also available from previous digitizing of analog well logs from selected wells (see Appendix H). Prior to study and analysis, the digital data provided by Schlumberger require translation into a readily readable format. The Albuquerque office of the U. S. Geological Survey's Water Resources Division (USGS/ABQ) provided partial translation of the data from six wells (Burton 5, Cerro Colorado, Coronado 2, Ridgecrest 5, Soil Amendment Facility 1, Thomas 8), and Schlumberger Well Surveying provided a complete translation of the data for one well (Charles 5) for use in this study. The USGS/ABQ digitized selected analog copies of well logs from 15 additional wells for use in this study.

Study scope

An initial activity involved the identification and collection of all existing borehole geophysical logs. Records at the City of Albuquerque Public Works Department, the NMBMMR Subsurface Library, and the USGS/ABQ were examined and copies of all logs obtained. At the conclusion of this study, copies of all logs suites will be permanently archived in the NMBMMR Subsurface Library (see Appendix H).

Detailed study and analysis of all available borehole geophysical well logs was beyond the scope of this study. Because of the breadth of log suites available from the 12 wells cited above, and because samples of cuttings and sidewall cores were also available, efforts were focused on logs from those wells. Specifically, the study focused on (1) geophysical-log response characteristics of the various Santa Fe Group lithofacies and (2) application of the well logs to stratigraphic correlation, and identification and extrapolation of Santa Fe Group lithofacies. Preliminary work on application of geophysical logs to determine lithologic properties, such as amount of clay, and hydrologic properties, such as ground-water quality, was initiated. Such analyses, however, require application of computer techniques and that the well log data be in digital format. Because of problems experienced by the USGS in translation of the digital log data, and the late receipt of the complete log translation from Schlumberger, progress on this task has been limited and will be the major focus of future investigations.

Geophysical-log response characteristics

Electrical-conductivity logs, which measure the electrical conductivity of the sediments and ground-water surrounding the well bore (Asquith, 1982; Keys, 1989; Schlumberger, 1989), are available for almost all suites examined in this study. Additionally, conductivity logs exhibit distinctive variations and patterns that can be readily correlated to lithofacies types within the Santa Fe Group. Because of this, electrical-conductivity logs are the most useful log type for a general analysis of lithofacies within the Albuquerque area.

The following discussion is focused on electrical-conductivity logs. Density logs, which measure the bulk density of sediments and ground-water immediately adjacent to the well bore (Asquith, 1982; Keys, 1989; Schlumberger, 1989), and sonic logs, which measure the interval transit time of sound waves through sediments and ground-water adjacent to the well bore (Asquith, 1982; Keys, 1989; Schlumberger, 1989), will also be discussed as appropriate.

Throughout the remainder of this section, electrical-conductivity logs and columnar sections that illustrate lithofacies distribution determined by analysis of cuttings (data summarized in Appendix C) are presented for several Albuquerque water wells. Additionally, sonic, density, or gamma-ray logs are also plotted, if digital copies of them are available. Because of the nature of the geophyscial-log coverage, logs have not been obtained for all lithofacies within the Santa Fe Group.

Lithofacies Ib

This lithofacies is characterized by an electrical-conductivity signature that has a relatively flat, low conductivity baseline with occasional sharp, high conductivity spikes (Figs. V-1, V-2, and V-3). The low-conductivity portions of the log correspond to sand-rich intervals and the spikes correspond to clay-rich intervals. Typically, the high-conductivity spikes are greatly subordinate to low-conductivity, flat baseline portions of lithofacies Ib intervals. Sonic logs indicate that lithofacies Ib materials have transit times ranging from 135 to 150 µsec/ft. Such values are higher than those obtained for sandstones and weakly indurated sands, but are typical for shales and unconsolidated sands (Asquith 1982, 1984; Schlumberger, 1989, 1991). Bulk density values determined from density logs for lithofacies Ib range from 1.8 to 2.0 g/cm^3. Such density values are Fig. V-1 lower than those for sandstone, but within the range reported for shales and unconsolidated sands (Keys, 1989; Schlumberger, 1989, 1991). Compared to other lithofacies of the Santa Fe Group, the measured interval transit times are slightly greater and bulk-density values slight less than those typical of other lithofacies. Such differences may be due to the shallower depths of burial and corresponding lesser degree of compaction of lithofacies Ib materials.

Lithofacies II

This lithofacies is characterized by an electrical-conductivity log signature generally similar to that for lithofacies Ib, with a relatively flat, low conductivity baseline with occasional sharp, high-conductivity spikes (Figs. V-2, V-3, and V-4). Typically, the high-conductivity spikes are subordinate to equal in extent to low-conductivity, flat baseline portions of lithofacies II intervals. Lithofacies II sediments have interval transit times ranging from 135 to 155 µsec/ft, and bulk density values typically higher than 1.8 g/cm^3. Such values are consistent with unconsolidated sands and shales (Keys, 1989; Schlumberger, 1989, 1991).

Lithofacies III

The electrical-conductivity log signature for lithofacies III differs significantly from those for lithofacies Ib and II. Conductivity logs for lithofacies III are characterized by variable baselines with many small deflections that have generally higher conductivity values that those typical of lithofacies Ib and II (Figs. V-1, V-5, and V-6). Electrical-conductivity logs for lithofacies III are characterized by numerous sharp, high-conductivity spikes (Fig. V-1) which are much more abundant than the relatively flat baseline portions. Lithofacies III materials have interval transit times ranging from 135 to 155 µsec/ft and bulk density values ranging between 1.8 and 2.1 g/cm^3.

Analysis of cuttings (see Section III) and the character of the electrical-conductivity log suggest

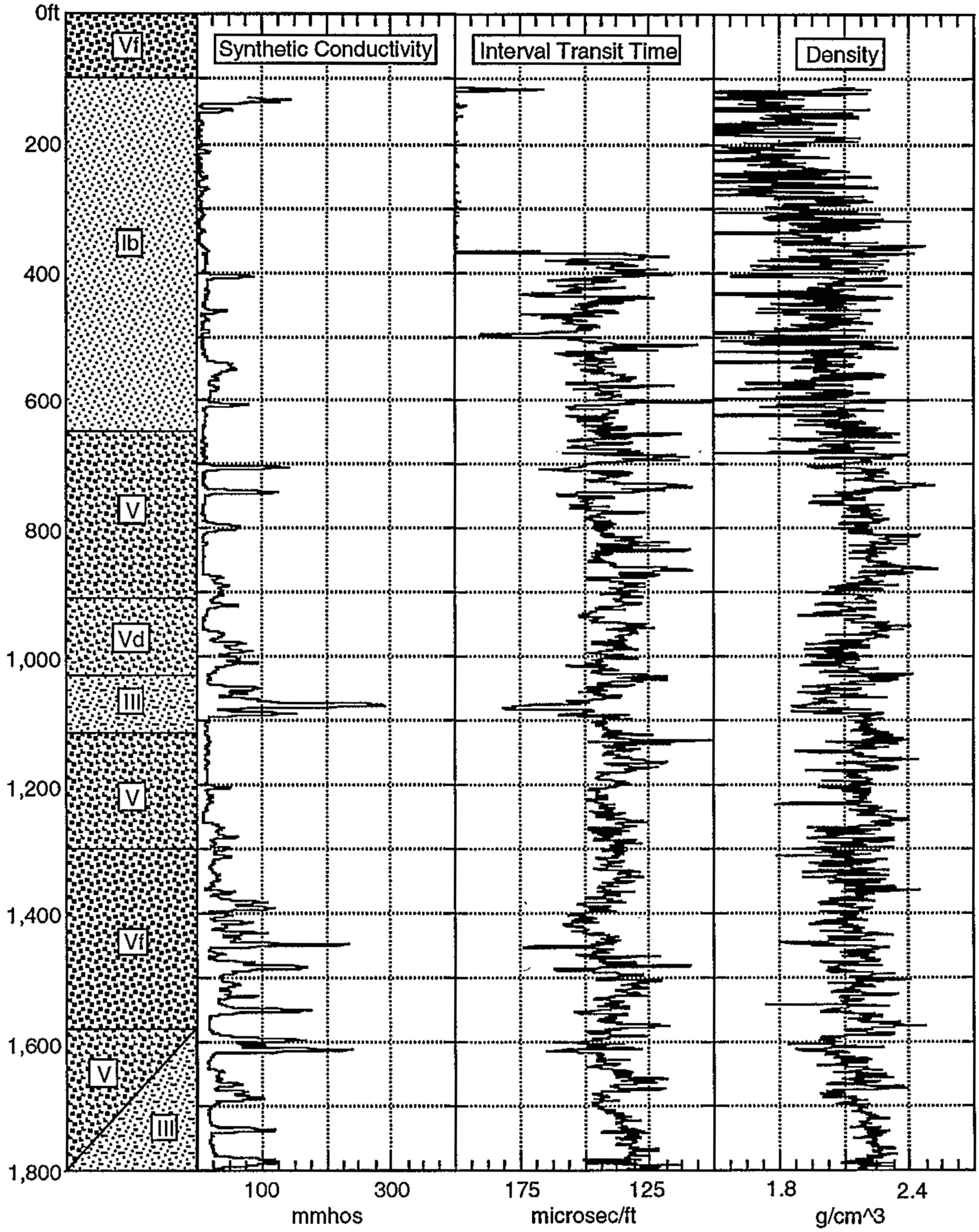

Fig. V-1. Columnar section illustrating lithofacies distribution for the uppermost 1800 ft of well Charles 5 (surface elevation of well head 5219 ft). Geophysical logs illustrated for this interval are the synthetic-electrical-conductivity log (calculated from deep-induction-resistivity log), sonic log (interval transit time), and density log.

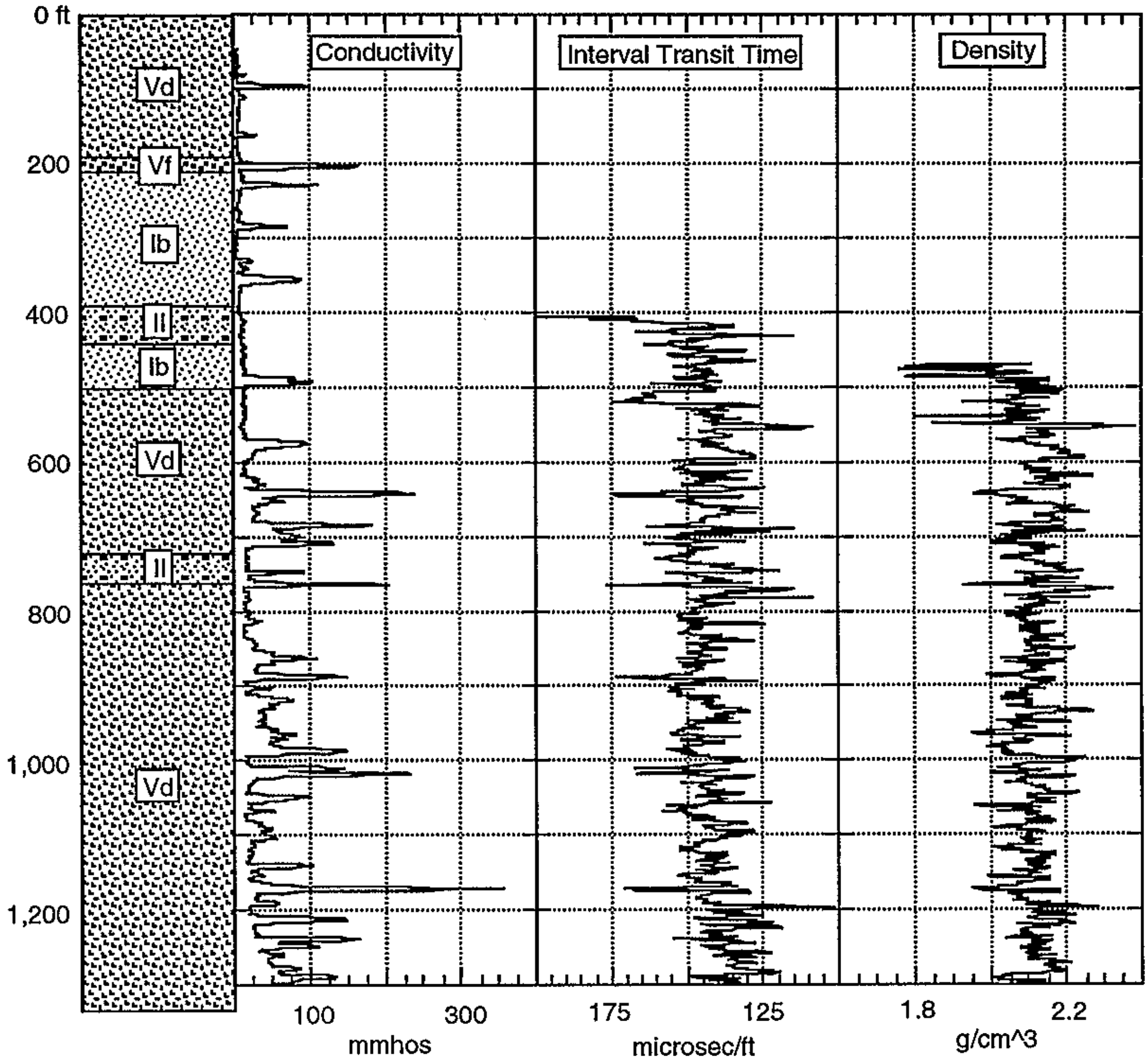

Fig. V-2. Columnar section illustrating lithofacies distribution for well Burton 5 (surface elevation of well head 5275 ft). Illustrated are electrical-conductivity, sonic (interval transit time), and density logs.

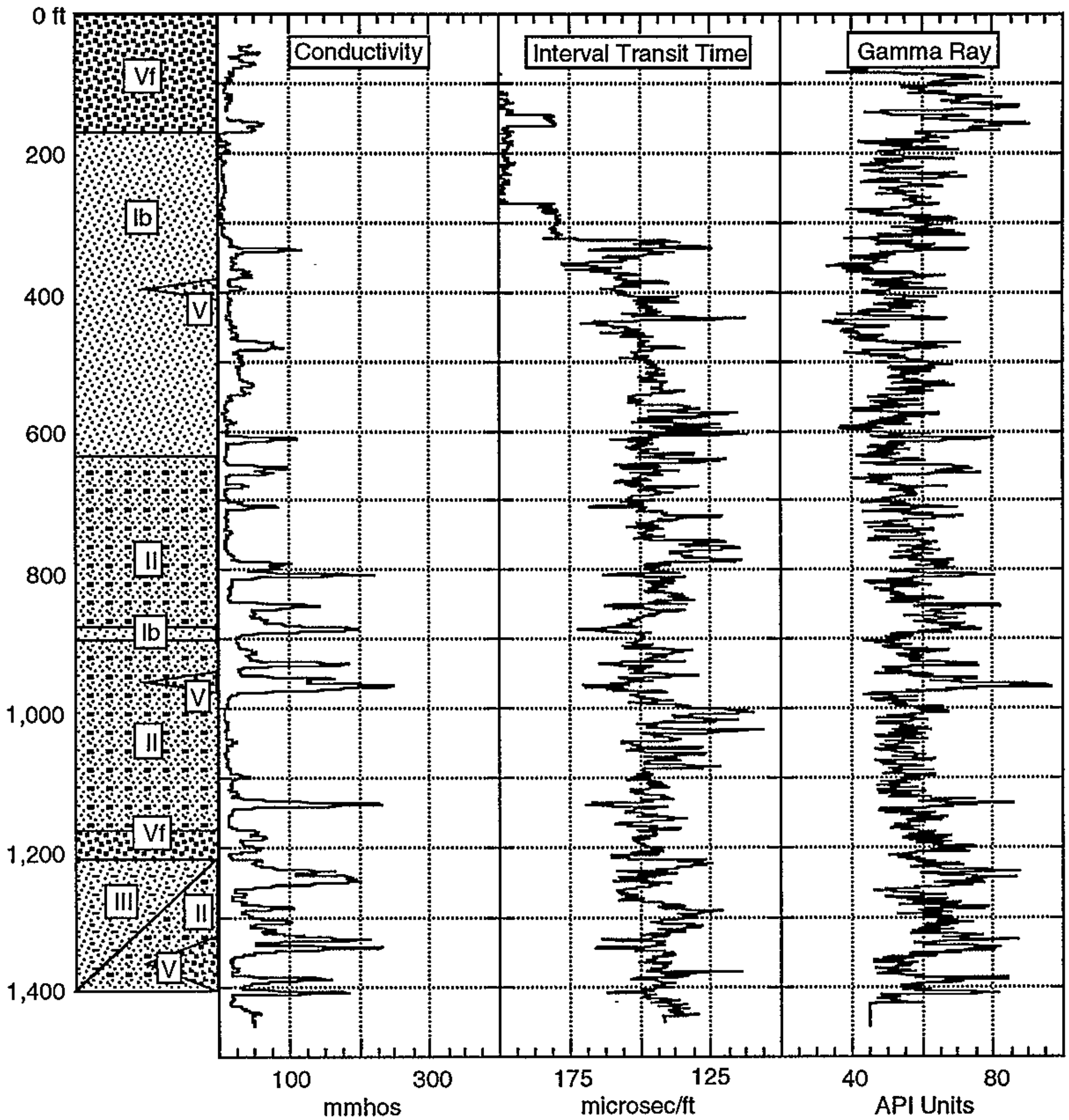

Fig. V-3. Columnar section illustrating lithofacies distribution for well Coronado 2 (surface elevation of well head 5292 ft). Illustrated are the electrical-conductivity, sonic (interval transit time), and gamma-ray logs. Digital version of the density log was not available for plotting.

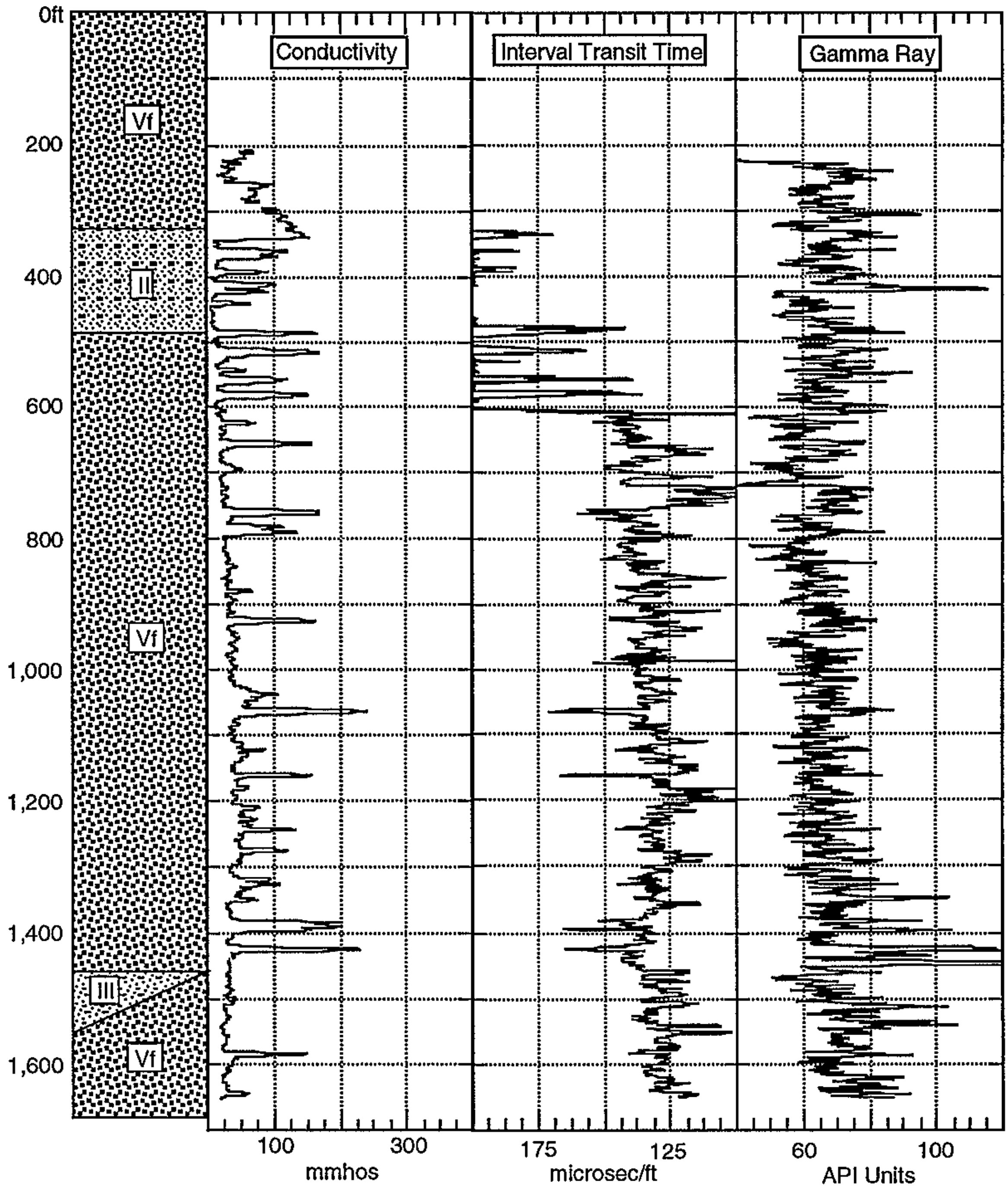

Fig. V-4. Columnar section illustrating lithofacies distribution for well Thomas 8 (surface elevation of well head 5410 ft). Illustrated are electrical-conductivity, sonic (interval transit time), and gamma-ray logs. Digital data were not available for plotting density log.

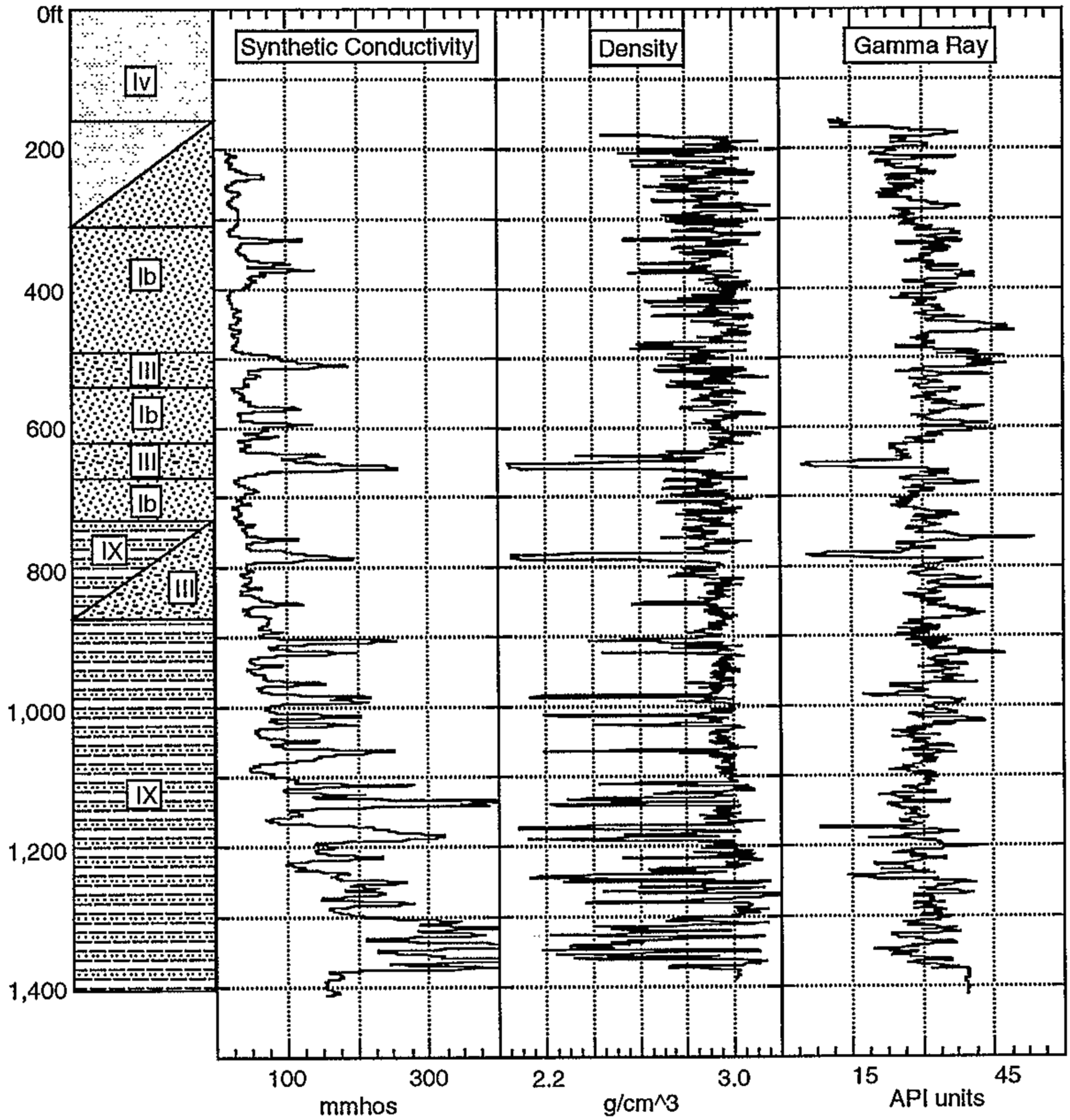

Fig. V-5. Columnar section illustrating lithofacies distribution for well Gonzales 2 (surface elevation of well head 5100 ft). Illustrated are synthetic-electrical-conductivity (calculated from deep-induction-resistivity log), density, and gamma-ray logs. Digital data were not available for plotting sonic log. The density log should be considered qualitative; density values are too high for unconsolidated sediments such as the Santa Fe Group, suggesting that log calibration was in error.

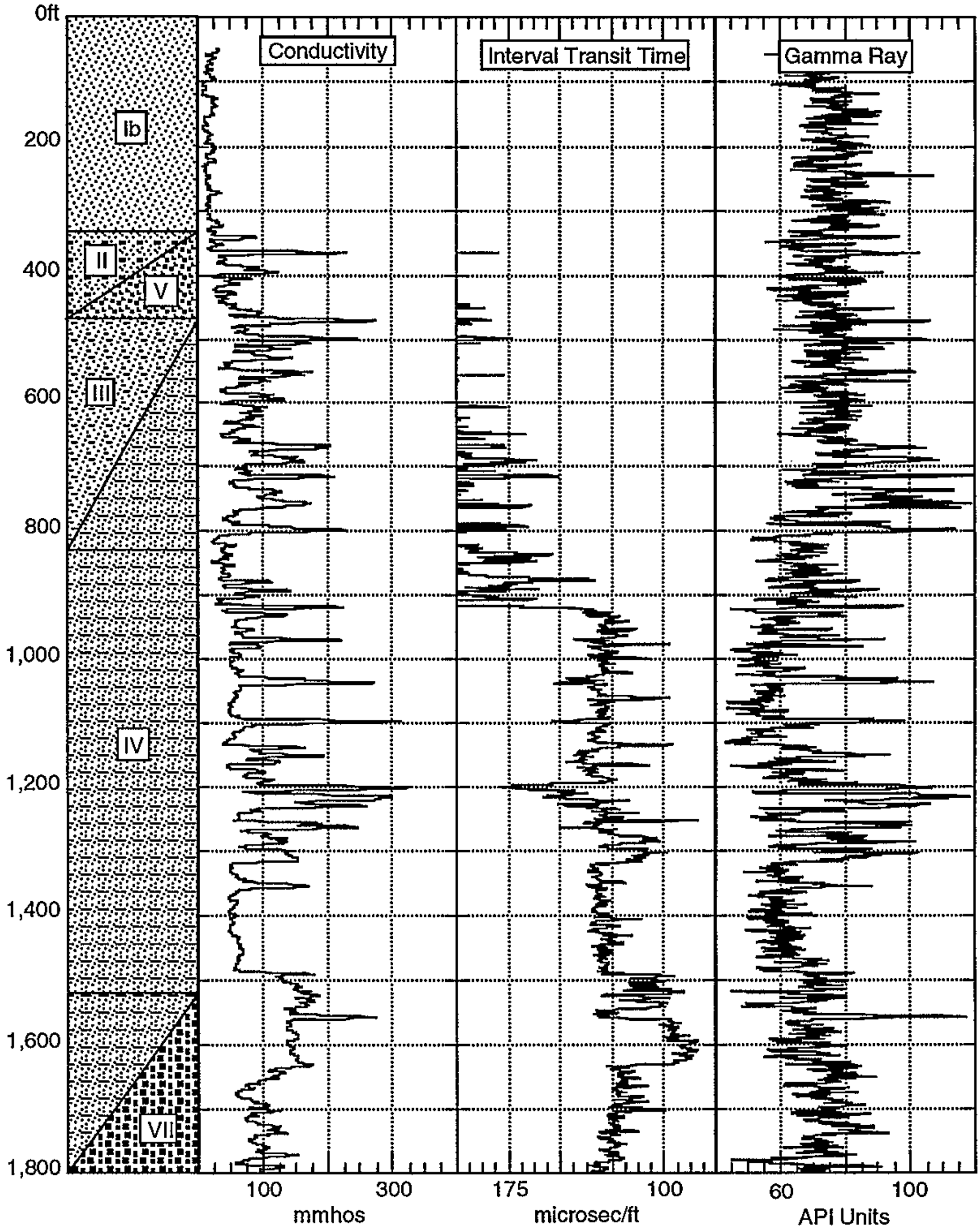

Fig. V-6. Columnar section illustrating lithofacies distribution for the uppermost 1800 ft of well Soil Amendment Facility 1 (surface elevation of well head 5866 ft). Illustrated are the electrical-conductivity, sonic (interval transit time), and gamma-ray logs. Digital data were not available for plotting density log.

that lithofacies III is richer in silt and clay than lithofacies Ib and II, but the interval transit times and density values do not reflect such a compositional change. The density values and interval transit times for lithofacies III are consistent with the wide range of values reported for unconsolidated sands and shales (Keys, 1989; Schlumberger, 1989, 1991). Because such unconsolidated sediments have a large range of values for both density and interval transit times, however, neither log is as diagnostic of the composition change as the conductivity log.

Traditionally, the gamma-ray log, which measures the total gamma-ray activity of material surrounding the well bore (Keys 1989; Schlumberger, 1989), would be used to pick up the increase in clay and silt within lithofacies III. Among other radioactive elements, gamma-ray logs respond to ^{40}K, which occurs in both clay minerals and K-feldspars. Because of the variable amounts of both clays and feldspars throughout all of the Santa Fe Group lithofacies, gamma-ray logs are not always a reliable indicator of increased clay content within a given lithofacies type. At a depth of approximately 1150 ft in well Coronado 2 (Fig. V-3), a slight increase in the baseline of the gamma-ray log is noted between lithofacies III and overlying lithofacies Vf and II intervals. Such a shift is consistent with an increase in clay content of lithofacies III sediments, although such a shift could also be caused solely by a change in the quartz/K-feldspar ratio of sediments within lithofacies III. At depths between 400 and 700 ft in well Gonzales 2, gamma-ray log baseline shifts associated with an interbedded sequence of lithofacies Ib and III sediments do not exhibit a consistent pattern, suggesting that the complex lithological variations typical of Santa Fe Group lithofacies make the application of the gamma-ray log as a clay-content indicator (Asquith, 1984) problematical.

Lithofacies IV

The electrical-conductivity log signature for lithofacies IV generally resembles that of lithofacies III. Conductivity logs for lithofacies IV are characterized by variable baselines, typically with many small deflections, and by numerous sharp, high-conductivity spikes (Fig. V-6). Conductivity baseline levels for lithofacies IV are variable but typically higher than those for lithofacies Ib and II. Additionally, the high-conductivity spikes are much more abundant than the relatively flat baseline portions. Lithofacies IV materials have interval transit times ranging from 120 to 145 µsec/ft and bulk density values ranging between 1.8 and 2.3 g/cm^3. As with lithofacies III, the range of density and interval transit time values observed for lithofacies IV is typical of the wide range of values reported for these parameters in unconsolidated sands and shales (Keys, 1989; Schlumberger, 1989, 1991).

At a depth of approximately 900 ft in well Soil Amendment Facility 1, the gamma-ray log exhibits a baseline shift to lower values. It occurs within an interval of lithofacies IV material, and may represent and increase in the quartz/K-feldspar ratio or a decrease in clay content. Macroscopic examination of cuttings from the well (Chapter III; see Appendix C) and petrographic study of cuttings from lithofacies III and IV (Chapter IV) suggest that lithofacies IV can have significant amounts of quartz rich eolian material. Therefore, the baseline shift likely indicates the presence of significant eolian material within lithofacies IV interval between 900 to 1200 and 1300 to 1500 ft. Additionally, the gamma-ray and the electrical-conductivity logs also suggest that lithofacies IV interval from 1200 to 1300 ft is compositionally distinct from, and likely more clay-rich than, the overlying and underlying intervals.

Lithofacies Vd, Vf, and V

Geophysical-log response patterns for lithofacies V, Vf, and Vd materials are complex, reflecting the interbedding of different sediment types characteristic of piedmont alluvial-fan depositional environments. Lithofacies Vd is characterized by an electrical-conductivity log signature generally similar to that for lithofacies Ib or II, with a relatively flat, low-conductivity baseline with occasional sharp, high-conductivity spikes (Figs. V-1 and V-2). Typically, the high-conductivity spikes are greatly subordinate to low-conductivity, flat baseline portions of lithofacies Vd intervals. The electrical-conductivity log signature for lithofacies Vf and V exhibits more variability than that for lithofacies Vd. Conductivity logs for lithofacies Vf and V have variable baselines with many small deflections, and have numerous sharp high-conductivity spikes (Figs. V-1 and V-4). Additionally, for lithofacies Vf the high-conductivity spikes are much more abundant than the relatively flat baseline portions, although exceptions to this generalization are noted. Lithofacies Vd, Vf, and V materials have interval transit times ranging from 125 to 140 μsec/ft and bulk density values typically higher than 2.0 g/cm^3. Such values are consistent with unconsolidated sands and shales (Keys, 1989; Schlumberger, 1989, 1991).

Lithofacies VII
Lithofacies VII electrical-conductivity-log responses resemble those observed for lithofacies Vf and V. Such a correspondence is expected because lithofacies VII differs from lithofacies V only in degree of induration (see Chapter III). Conductivity logs for lithofacies VII have variable baselines with many small deflections, and numerous sharp, high-conductivity spikes (Fig. V-5). Additionally, the high conductivity spikes are much more abundant than the relatively flat baseline portions, although exceptions to this generalization are noted. Lithofacies VII, which defined as indurated lithofacies Vd, Vf, and V materials, has interval transit times ranging from 125 to 140 μsec/ft and bulk density values typically higher than 2.0 g/cm^3. The ranges exhibited by these parameters are similar to those noted for lithofacies Vd, Vf, and V, and are consistent with unconsolidated sands and shales (Keys, 1989; Schlumberger, 1989, 1991).

Lithofacies IX
The electrical-conductivity-log signature for lithofacies IX resembles those for lithofacies III and IV. The conductivity logs for lithofacies IX are characterized by variable baselines, typically with many small deflections, and by numerous sharp, high-conductivity spikes. (Fig. V-5). Conductivity baseline levels for lithofacies IX typically are greater than those for lithofacies Ib and II. Additionally, the high-conductivity spikes are much more abundant than the relatively flat baseline portions. Lithofacies IX materials have interval transit times ranging from 135 to 155 μsec/ft and bulk density values ranging between 1.8 and 2.1 g/cm^3. As with lithofacies III and IV, the range of density and interval transit time values observed for lithofacies IX is typical of the wide range of values reported for these parameters in unconsolidated sands and shales (Keys, 1989; Schlumberger, 1989, 1991).

Stratigraphic correlation
Three stratigraphic cross sections are presented and discussed to illustrate application of borehole geophysical logs to stratigraphic correlation within the Santa Fe Group. The cross sections employ electrical-conductivity logs which are widely available for wells in the Albuquerque area and are excellent for stratigraphic-correlation purposes. As demonstrated in the subsequent discussion, the lithologic complexity of the Santa Fe Group makes correlation of individual spikes and features on well logs unlikely, if not impossible. However, groups spikes or patterns of deflections on geophysical logs can be correlated over distances of several miles with confidence.

Paseo del Norte Section
A cross section along a portion of Paseo del Norte Avenue is presented in Fig. V-7, and locations of the seven wells used to construct the section are illustrated in Fig. V-8. Note that the cross section is not to scale in the horizontal dimension. The lithofacies distribution for well Coronado 2, based on examination of cuttings, is illustrated (see Appendix F). Also illustrated is an extrapolation of the lithofacies from well Coronado 2 to the other wells on the cross section.

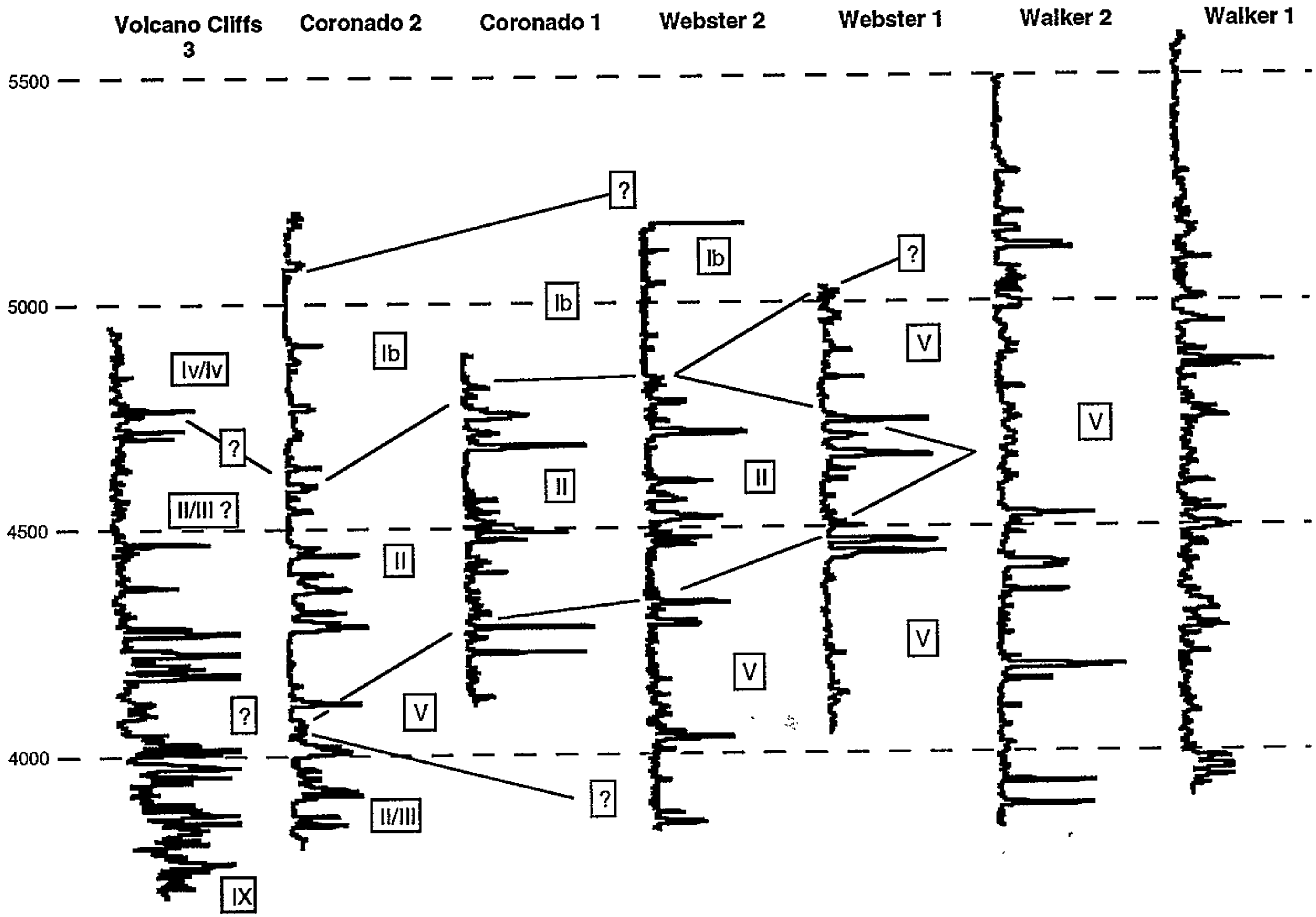

Figure V-7. Geophysical log-based cross section along a portion of Paseo del Norte Avenue. Locations of wells plotted are illustrated in Fig. V-8. Figure is not to scale in the horizontal direction. Proposed well-to-well correlations of Santa Fe Group lithofacies based on study of cuttings from well Coronado 2 are illustrated.

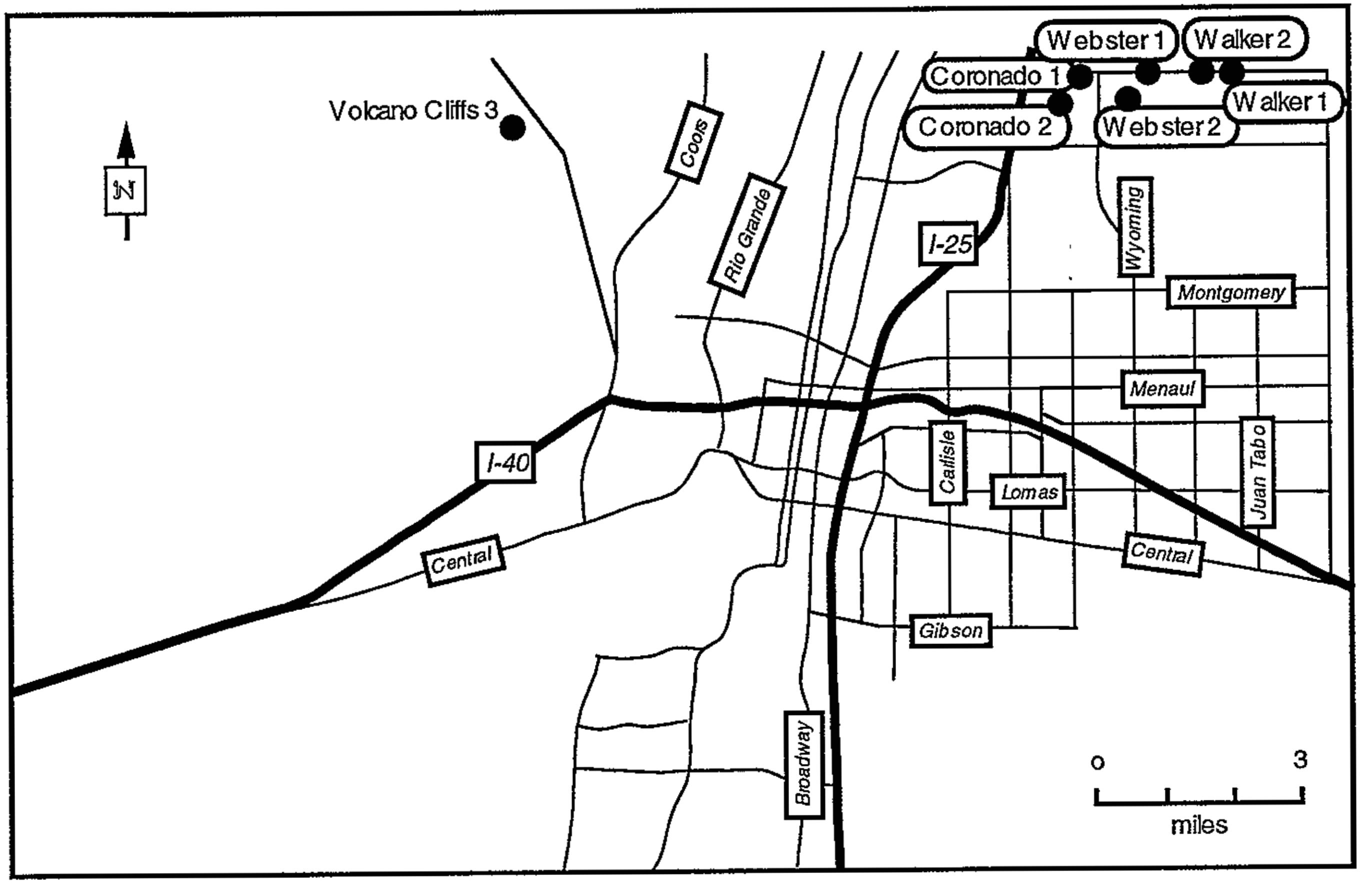

Figure V-8. Location map for wells used in the Paseo del Norte Avenue cross section illustrated in Fig. V-7.

The pinchout of lithofacies II and the disappearance of lithofacies Ib, eastward from well Coronado 2 to well Webster 1, can be traced. Such transitions establish the eastward limit of the fluvial-dominated portion of the upper Santa Fe Group at this locality to be in the immediate vicinity of well Webster 1. Additionally, the conductivity logs suggest that the interval of lithofacies II material mapped in well Coronado 2 contains interbedded lithofacies III material similar to that noted in the bottom of well Coronado 2. Such material was not identified during analysis of cuttings , but the conductivity logs clearly suggest its presence.

The nature of the conductivity log in well Walker 2 is typical of lithofacies V or Vd and that for well Walker 1 typical of lithofacies V or Vf, suggesting that both wells are located in vertically extensive alluvial fan deposits. A westward-extending tongue of alluvial-fan material, lithofacies Vd or V, runs from well Walker 2 to well Coronado 2.

Correlation with well Volcano Cliffs 3 is difficult because of its location far to the west of the other wells on the cross section (see Fig. V-9). Additionally, several major faults separate the Volcano Cliffs well from the other wells, making correlation without additional wells in between almost impossible.

Menaul Section
A cross section along a portion of Menaul Avenue and the westward extension of its alignment is presented in Fig. V-9, and locations of the seven wells used to construct the section is illustrated in Fig. V-10. Note that the cross section is not to scale in the horizontal dimension. The lithofacies distribution for wells Charles 5 and Gonzales 2, based on examination of cuttings, are illustrated (see Appendix F). Also illustrated is an extrapolation of the lithofacies from wells Charles 5 and Gonzales 2 to the other wells on the cross section.

Lithofacies Ib can be correlated eastward through wells Duranes 3, Santa Barbara 1, and Charles 5. The thickness of lithofacies Ib material in well Charles 5 suggests that the eastward limit of the fluvial facies along the Menaul Section is considerably further to the east. Correlating to the west, the westward limit of lithofacies Ib appears to be in the vicinity of well College 2, although the apparent thinning of this lithofacies may be due to faulting in the vicinity of wells College 2 and Ladera (see Plates 2 and 3). A thin interval of lithofacies III material occurs underneath the fluvial material of lithofacies Ib in the vicinity of wells Gonzales 2 and Ladera; this material pinches out further to the west.

Several hundred ft of basin-floor material, lithofacies IX, occur in wells College 1, College 2, Ladera, Gonzales 2, and Duranes 2. This material appears to be down-dropped and thickened in the vicinity of wells Ladera and Gonzales 2, which is likely the effect of major faults that occur in the vicinity of these wells (see Plates 2 and 3). Beneath lithofacies IX material is sediment of unknown lithofacies. From its geophysical-log characteristics it appears to be relatively sand-rich and may resemble fluvial material similar to that of lithofacies Ib or II. It also could represent eolian sand. Examination of geophysical logs north and south of the section suggests that this material has a wide lateral extent. Such material may represent a potential groundwater reservoir and its characteristics should be further investigated.

Correlation between wells Duranes 3 and Santa Barbara 1 is difficult because of the complexity of lithofacies distribution in the Santa Fe Group, the distance involved, and the occurrence of major faults between the wells. Geophysical-log traces for both wells Santa Barbara 1 and Charles 5 exhibit the appearance of alluvial-fan deposits of lithofacies V and Vd. Additionally, the thin interval of lithofacies III material noted in well Charles V thickens westward toward well Santa Barbara 1. It is possible that the lithofacies III material can be correlated with that in well Duranes 3, but such a correlation cannot be made with certainty.

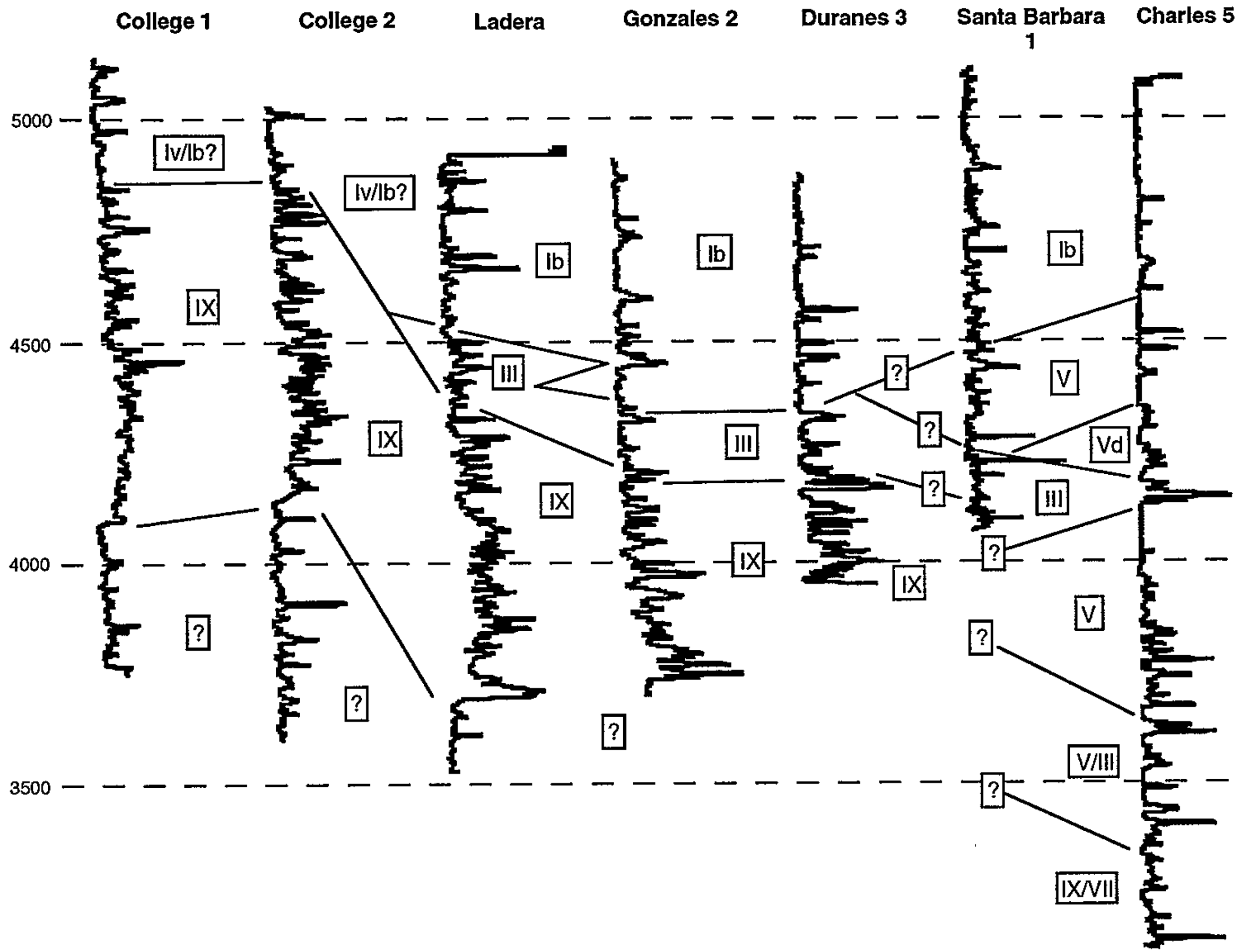

Fig. V-9. Geophysical-log-based cross section along a portion of Menaul Avenue and a projection of its alignment west of the Rio Grande. Locations of wells plotted are illustrated in Fig. V-10. Figure is not to scale in the horizontal direction. Proposed well-to-well correlations of Santa Fe Group lithofacies based on study of cuttings from well Gonzales 2 and Charles 5 are illustrated.

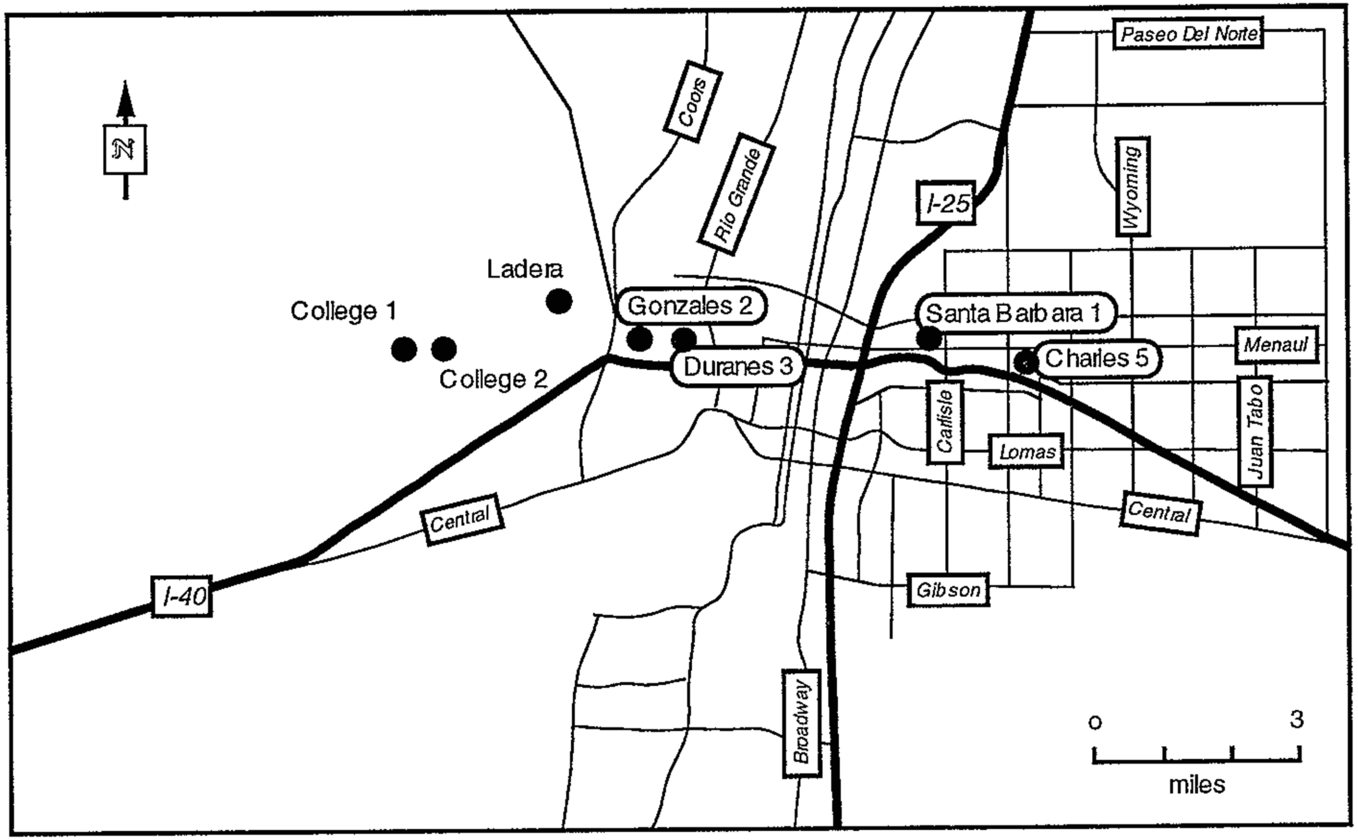

Fig. V-10. Location map for wells used in the Menaul Avenue cross section illustrated in Fig. V-9.

Gibson Section
A cross section along a portion of Gibson Avenue is presented in Fig. V-11, and locations of the seven wells used to construct the section are illustrated in Fig. V-12. Note that the cross section is not to scale in the horizontal dimension. The lithofacies distribution for wells Burton 5 and Ridgecrest 2, based on examination of cuttings, are illustrated (see Appendix F). Also illustrated is an extrapolation of the lithofacies from these wells to the other wells on the cross section.

Alluvial-fan material of lithofacies Vd is a major constituent of the intervals penetrated by all of the wells on the section. The pattern of the conductivity logs from wells Lomas 1 and Lomas 2 is characteristic of lithofacies V material. Additionally, several hundred feet thick sections of lithofacies Vd material occur westward up to well Burton 5. Such material occurs both beneath and above a 400 to 600 ft thick interval of lithofacies Ib and II fluvial material. A thin, but laterally persistent interval of lithofacies Vf material occurs at the top of the lithofacies Ib interval and can be traced eastward to well Lomas 1 within lithofacies V material.

The fluvial material of lithofacies Ib and II is thinning in well Love 4. The several hundred ft thick lithofacies Ib interval in well Love 4 suggests, however, that the margin of this material is still eastward of the well and somewhere in between wells Love 4 and Lomas 2. A similar eastward extent is suggested for the thin tongue of lithofacies II material contained within the lithofacies Ib interval.

The bottom interval of well Lomas 2 encounters material of unknown character, but with a log signature distinctly different from the overlying alluvial-fan material. The character of the logs suggests that this material may be lithofacies III or IX.

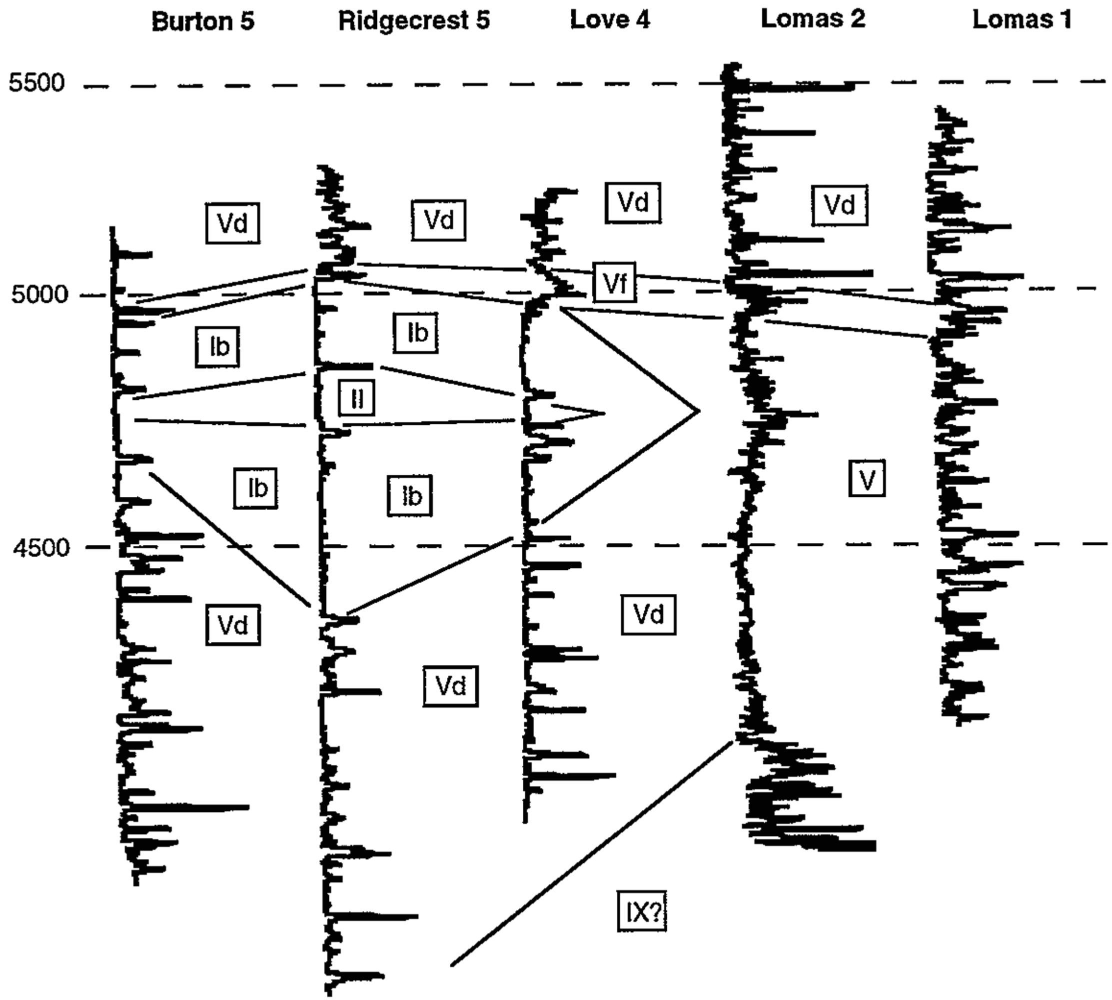

Figure V-11. Geophysical-log-based cross section along a portion of Gibson Avenue. Locations of wells plotted are illustrated in Fig. V-12. Figure is not to scale in the horizontal direction. Proposed well-to-well correlations of Santa Fe Group lithofacies based on study of cuttings from well Burton 5 and Ridgecrest 5 are illustrated.

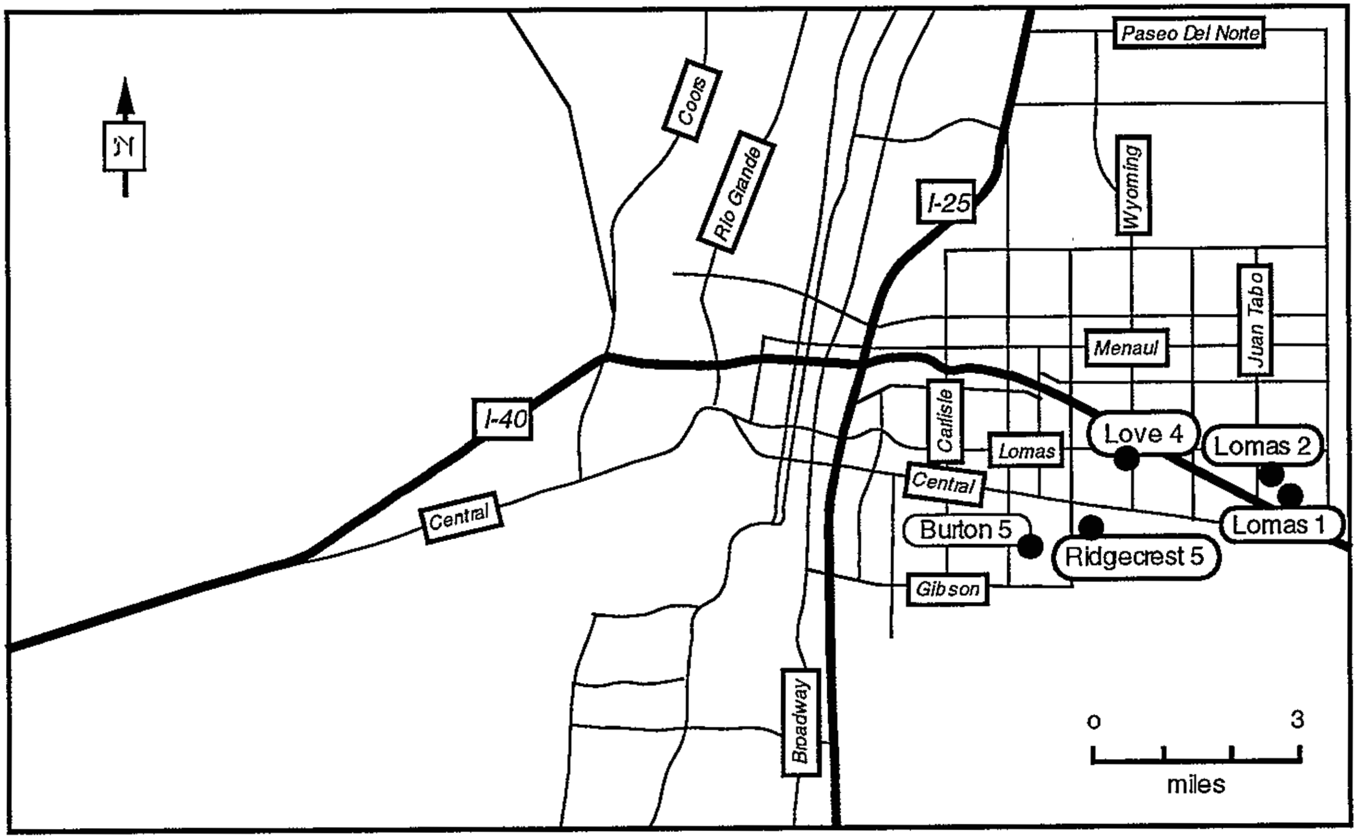

Fig. V-12. Location map for wells used in the Gibson Avenue cross section illustrated in Fig. V- 7.

SECTION VI

ESTIMATION OF HYDROLOGIC PARAMETERS

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J. W. Hawley and C. S. Haase (compilers), 1992, *Hydrogeologic framework of the northern Albuquerque Basin*, New Mexico Bureau of Mines and Mineral Resources, Open-File Report 387, pp. VI-1 to VI-3

VI. ESTIMATION OF HYDROLOGIC PARAMETERS

Introduction

Measurements of specific hydrologic properties of the Santa Fe group, such as hydraulic conductivity and transmissivity, have been obtained from pumping tests on individual wells (e.g., John W. Shomaker, Inc., 1990; 1991) throughout the Albuquerque area. The generalized distribution of such properties and of the water producing potential of the various Santa Fe Group lithofacies, however, has not been determined. In the remainder of this section four geological parameters, sand/clay ratio, bedding thickness, bedding configuration, and bedding continuity, will be assessed for the various Santa Fe Group lithofacies, and estimates of the permeability and water productivity of the lithofacies will be made. Results of the assessment are presented in Table VI-1.

Geological Parameters

Sand + gravel/silt + clay ratio

As discussed in Section III of this report (see Table III-2), the 10 lithofacies and sublithofacies have variable amounts of sand-, gravel-, silt-, and clay-sized material. Such grain-size differences exert a major influence on the hydraulic conductivity of a particular lithofacies, with the more coarse-grained sediment typically exhibiting higher hydraulic conductivity than finer-grained sediments (Dominico and Schwartz, 1990). In Table VI-1, sand + gravel/silt + clay ratios are categorized as high (>2), moderate (0.5 to 2), and low (<0.5).

Bedding thickness

Bedding thickness is a measure of the vertical extent of an individual bed. Thickness of individual beds influences both the hydraulic conductivity and the water productivity of a lithofacies. In general, the thicker the bedding within a sedimentary unit, the higher the expected water productivity (Fetter, 1988) from the unit. Bedding thickness for the Santa Fe Group lithofacies is summarized in in three categories, <1 ft thick, 1 to 5 ft thick, and >5 ft thick (Table VI-1). See also Section III, Table III-2; and Appendix B.

Bedding configuration

Beds of the Santa Fe Group, typical of alluvial-fan and fluvial depositional systems (Fetter, 1988), can be described as elongate (length to width ratios >5), planar (length to width ratios 1 to 5), and lobate (asymmetrical or incomplete planar beds). Bed configuration can influence water productivity through the impact of bed boundaries acting as hydraulic barriers to ground-water movement (Fetter, 1988). In the analysis described in this section, planar- or elongate-bedded lithofacies are assumed to have higher ground-water productivity. Bedding configurations for the lithofacies of the Santa Fe Group are summarized in Table VI-1.

Bedding continuity

Bedding continuity is a measure of the lateral extent of an individual bed of given thickness and configuration. Bedding continuity influences the ability of ground water to flow through a bed and between different beds (Fetter, 1988). All other parameters being equal, greater bedding continuity favors increased ground water productivity. Bedding continuity for the Santa Fe Group can be divided (see Chapter III, Table III-1) into >500 ft, between 100 and 500 ft, and <100 ft, and are summarized in Table VI-1.

Estimated parameters

Bed connectivity

This parameter is an estimation of the ease with which ground water can flow between individual beds within a particular lithofacies. In general, high sand + gravel/silt + clay ratios, thick beds, and high bedding continuity favor high bedding connectivity. All other parameters being equal, the greater the bedding connectivity, the greater the ground water productivity of a sedimentary unit (Fetter, 1988). Estimated bedding connectivities for the Santa Fe Group are

TABLE VI-1. Summary of parameters that influence ground-water production potential of Santa Fe Group lithofacies.

Lithofacies	sand + gravel / *silt + clay*	Bedding thickness (ft)	Bedding *configuration*	Bedding continuity (ft)	Bedding connectivity	Hydraulic conductivity	Ground-water production potential
Iv	high to moderate	>5	elongate	>500	high	high to moderate	high
Ib	high	>5	elongate	>500	high	high	high
I	high to moderate	>5	elongate	>500	high	high to moderate	high to moderate
II	high to moderate	>5	elongate	>500	moderate to high	high to moderate	high to moderate
III	low	1 to 5	planar	>500	low	low	low
IV	low to moderate	1 to 5	planar to elongate	100 to 500	low to moderate	moderate to low	moderate to low
Vf	moderate	1 to 5	elongate to lobate	100 to 500	moderate	moderate to low	moderate to low
Vd	moderate to high	>5	elongate to lobate	100 to 500	high	moderate to high	moderate to high
V	moderate	1 to 5	elongate to lobate	100 to 500	moderate to high	moderate	moderate
VI	high	>5	lobate	<100	moderate	moderate to high	moderate
VII	moderate	1 to 5	elongate to lobate	100 to 500	moderate to high	moderate to low	moderate to low
VIII	high	>5	lobate	<100	moderate	moderate to low	moderate to low
IX	low	<1	planar	>500	low	low	low
X	low	<1	planar	>500	low	low	low

summarized in Table VI-1.

Hydraulic conductivity
This parameter was estimated principally from the sand + gravel/silt + clay ratio. High ratios were taken to correspond to high hydraulic conductivities. Additionally, the parameters of bedding continuity and bedding connectivity were considered to a lesser degree. High values for both of these parameter corresponds to high hydraulic conductivity values. For the lithofacies of the Santa Fe Group, hydraulic conductivity values are categorized in Table VI-1 as high (>30 ft/day), moderate (0.3 to 30 ft/day), and low (<0.3 ft/day).

Ground-water potential
This is a qualitative parameter that considers all of the preceding geological and estimated parameters. It is a generalized indicator of the suitability or desirability of a particular lithofacies for development of ground-water resources.

Discussion

The parameters summarized in Table VI-1 suggest that lithofacies I, Iv, Ib, II, and Vd have the highest potential as ground-water sources. Lithofacies I, Iv, Ib, and II were deposited in a fluvial setting. Lithofacies Vd was deposited as a major distributary channel within a large alluvial fan (see Section III) and, therefore, under conditions similar to those in a fluvial setting. Because of the high sand + gravel/silt + clay ratio of the material deposited, and the laterally extensive, thick, and connected nature of the bedforms, fluvial systems resulted in sediments with the highest potential for ground-water production within the Santa Fe Group.

SECTION VII

SUMMARY

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VII. Summary

A conceptual hydrogeologic model for sediments in the northern portion of the Albuquerque Basin has been developed. The model describes the architecture of the major basin-fill unit, the Santa Fe Group; thin overlying basin-fill deposits on piedmont slopes extending westward from the Sandia and Manzanita-Manzano Mountain fronts; and locally thick inset fills of the Rio Grande and Rio Puerco valleys. The conceptual model has three basic components: (1) **Structural and geologic features**, such as basin-bounding mountain uplifts, bedrock units beneath the basin fill, fault zones within and at the edges of the basin that influence sediment thickness and composition, and intrusive and extrusive igneous rocks that penetrate or overlap basin-fill deposits. (2) **Hydrostratigraphic units,** major basin- and valley-fill mappable units that are grouped on the basis of the origin and age of a stratigraphic sequence of deposits. Genetic classes include ancestral-river, present-river valley, basin-floor playa, and alluvial-fan piedmont depositional environments. Time-stratigraphic classes include units deposited during early, middle, and late stages of basin filling (e.g. lower, middle, and upper Santa Fe Group) and post-Santa Fe valley and basin fills (e.g. channel and flood-plain deposits beneath the modern-valley floors or preserved as alluvial terraces). and (3) **Lithofacies units**, which are the fundamental building blocks of the model. Ten lithofacies and associated sublithofacies, each of which formed in different depositional settings, are defined, and the three-dimensional distribution of the lithofacies is described. The lithofacies are mappable units that are characterized by particular bedding and compositional properties and have distinctive geophysical and geochemical properties and in hydrologic behavior.

Lithofacies I, including sublithofacies Ib and Iv, and lithofacies II formed in fluvial conditions associated with the ancestral Rio Grande or with earlier rivers that entered the developing Albuquerque Basin. Sediments of these lithofacies are rich in sands and gravels and form extensive, elongate deposits typically along the distal edge of alluvial-fan deposits associated with the edges of the Albuquerque Basin. Lithofacies Ib and II are major components of the upper Santa Fe hydrostratigraphic unit (USFII-2, and -3). Fluvial sand and gravel of lithofacies Iv are the major constituents of the valley-fill underlying the Rio Grande.

Lithofacies V (including sublithofacies Vf, Vd, and Vv) and lithofacies VI (including sublithofacies VIf and VId) and their indurated equivalents, lithofacies VII and VIII, respectively, formed in an alluvial-fan depositional setting. Lithofacies VI formed closest to the basin margin, and consists of lobate, heterogeneous deposits of sand-, gravel-, and cobble-sized material. Lithofacies V formed further from the basin margin, and consists of lobate to lenticular deposits of sand and gravel. In large alluvial fans, lithofacies V sediments also exhibit elongate, sand-rich deposits that are essentially fluvial in nature, but that formed in distributary channels that dissected the medial to distal portions of the alluvial fan. Lithofacies V is a major component of the upper middle (MSF-1) and upper (USFI-1) Santa Fe hydrostratigraphic unit.

Lithofacies III, IV, and IX, and lithofacies X, which is an indurated equivalent of lithofacies IX, formed on the basin floor, well away from the margins of the developing basin. Lithofacies III sediments are sand-, silt-, or clay-rich planar deposits that formed on the basin floor or in playa lakes on the basin floor. Lithofacies IV sediments are sand- and silt-rich planar to lenticular deposits that formed under predominantly eolian conditions on the basin-floor or in distal alluvial-fan depositional settings. Lithofacies IX sediments are silt- and clay-rich planar deposits that formed in playa lakes and alluvial flats on the basin floor. Lithofacies II, III, IV, and IX are major constituents of middle and lower Santa Fe Hydrostratigraphic Units (MSF-2 and LSF). The upper Santa Fe hydrostratigraphic unit (USF-2) locally contains thick intervals of lithofacies III and IX.

Sandstones from lithofacies V and VII sampled by sidewall cores are mainly lithic arkoses and feldspathic litharenites, and analysis of grain mounts of well cuttings from lithofacies Ib, V, Vf, and Vd suggests that sandstone composition ranges from arkose to feldspathic litharenite. Within sandstones framework grains consist of monocrystalline quartz, feldspar, and rock fragments (volcanic, granitic/gneissic, sedimentary, and metamorphic), with lesser amounts of biotite, muscovite, chlorite, and heavy minerals. Volcanic fragments are the most abundant rock type and consist mainly of plagioclase-dominated porphyries with lesser amounts of rhyolite, including densely welded ash-flow tuffs. The principal non-framework components are detrital/mechanically infiltrated clay, zeolites, and calcite. Mean grain size ranges from very fine to coarse, with conglomeratic sandstones containing a substantial amount of material greater than 2 mm. Sorting ranges from well to very poorly sorted.

Mudrocks sampled by sidewall cores from lithofacies V and VII consist mainly of clay, with lesser amounts of sand and silt. One sample contained abundant calcite cement. The principal clay minerals in the mudrocks are smectite, illite, kaolinite, and interlayered illite/smectite. The silt-sized fraction of mudrocks contains a significantly higher proportion of quartz relative to feldspar than in adjacent sandstones. Much of this additional quartz may be eolian.

Three compositional zones characterize Santa Fe Group strata below the Albuquerque Northeast Heights area. The upper zone of arkosic sediment averages about 200 ft in thickness and contains caliche-cemented sandstones. Volcanic rock fragments become very common (20 to 40 %) in the middle and lower compositional zones. In the middle part of upper Santa Fe unit (USF-2, lithofacies Ib and II) the presence of sparse glassy pumice (3 to 5 %) distinguishes the middle compositional zone (at depth of 200 to 400 ft) from the lower volcanic-rich zone which lacks glassy pumice. Trace amounts of reddish-brown ignimbrite (<1 %) are present in most samples and at all levels of the volcanic-rich middle and lower zones from a depth of about 200 ft to 3200 ft (includes sidewall-core samples). Andesite and dacite porphyries are the most common type of volcanic fragments. The bulk composition of well cuttings is estimated to be approximately 60 % granitic-metamorphic detritus of Precambrian derivation, 30 % volcanic detritus of middle Tertiary derivation and less than 10 % sedimentary detritus of Paleozoic or Mesozoic derivation.

Santa Fe Group sediments below northeastern Albuquerque are mostly unconsolidated or poorly cemented to a depth of approximately 1300 ft (upper middle and upper Santa Fe hydrostratigraphic units). Cementation and induration become significant at a depth of approximately 1700 to 2000 ft (lower part of the middle Santa Fe hydrostratigraphic unit). Major diagenetic events that affected the rocks are calcite, zeolite, and smectite precipitation, and grain dissolution. Grain dissolution resulted in the formation of volumetrically significant secondary porosity. Fractures are present in most of the samples. Many of these fractures probably result from the coring process and may not be present in the actual rock.

Geophysical-log responses vary from lithofacies to lithofacies. Typically, the response of any single geophysical log is not characteristic of a particular lithofacies. However, response behavior of suites of logs can be calibrated with cuttings from key wells to identify response characteristics that are diagnostic of lithofacies. Such log-suite response characteristics can be used to map the distribution of lithofacies for areas where only borehole geophysical data are available. Preliminary analysis of geophysical log suites and well cuttings from 12 boreholes in the Albuquerque area suggests that combinations of electrical-conductivity, gamma-ray, density, and acoustic-velocity logs can be used for lithofacies interpretation. Such a log suite is widely available for wells in the Albuquerque area and results suggest that the mapping of lithofacies distribution by this technique holds promise.

Analysis of geophysical logs has identified a potential drilling target for water-resource evaluation west of the Rio Grande. A sand-rich interval is noted, at depths below approximately 1500 ft in wells College 1, College 2, and Ladera. Preliminary analysis of geophysical logs north and south of the College and Ladera wells suggests that the sand-rich interval extends al least several miles in each direction. Additional geophysical log analysis may serve to better define the extent of this interval and to provide a preliminary evaluation of its groundwater quality.

The hydrological properties of the lithofacies have been estimated by considering factors such as sand + gravel/silt + clay ratio, bed thickness, bed shape, and bedding continuity. Generalized values for each of these parameters were estimated directly from lithofacies definitions. In turn, the values for the parameters were used to estimate the average hydraulic conductivity and ground-water production potential of the 10 major lithofacies of the Santa Fe Group. Lithofacies with the highest estimated ground-water production potential include lithofacies Ib, Iv, I, II, and Vd. The least productive lithofacies include III and IX. Application of this analysis to the conceptual hydrogeologic model allows a three-dimensional arrangement of productive groundwater intervals to be estimated in the Albuquerque area.

VIII. Recommendations

Principal recommendations for future studies in the Albuquerque area are: (1) completion of the analysis of all geophysical-log suites available for City of Albuquerque wells and boreholes; (2) application of the conceptual hydrogeological model to analyze the hydrological response of specific Albuquerque wells and well fields, and to interpret water-quality trends in the Albuquerque area; and (3) application and further development of the conceptual model in valley and mountain-front areas where hydrogeologic information is needed for better understanding of surface- and ground-water interactions (recharge) and vadose-zone (undersaturated) processes.

Geophysical-log analysis

The geophysical-log suites for City of Albuquerque wells represent a significant resource that has not be fully exploited. The analysis and interpretation of borehole geophysical logs should be completed to maximize the investment in this resource. Proposed components of future work include:

(1) *Determination of basic stratigraphic relationships within the Santa Fe Group.* Initial stratigraphic correlation and subsurface lithofacies mapping based on geophysical-log response patterns were completed in the initial study. Additional stratigraphic correlation and lithofacies mapping based on geophysical logs should be completed for all City of Albuquerque wells. Such mapping would establish the extent and geometry of lithofacies types, and would provide the most complete three-dimensional picture of the Santa Fe Group ever obtained. Additionally, it would allow extrapolation of lithologic and lithofacies interpretation to new wells throughout the Albuquerque area. The lithofacies mapping and stratigraphic correlation also could be used to define areas suitable for exploration for new ground-water resources.

(2) *Calibration of geophysical-log response characteristics.* Initial interpretation of geophysical-log responses patterns to identify lithofacies types has been completed for two key wells. Such interpretations should be compared to similar interpretations based on the analysis of sidewall core and cuttings from the remaining 10 key wells that were identified in the initial study. The results of such comparisons, will be used to refine and calibrate the interpretation of geophysical-log responses, so that geophysical-log suites from wells without cutting samples can be interpreted with a greater confidence.

(3) *Lithologic and hydrologic interpretation of geophysical-log suites* Interpretation of geophysical-log suites using computer-based synthetic log and cross-plotting approaches (Asquith, 1982; Schlumberger, 1989) should be completed to retrieve the maximum amount of lithologic, hydrologic, and water-quality data possible. Additionally, the applicability of the neural-network approach to interpret complex lithologies, such as the Santa Fe Group, should be evaluated. Application of this technique has shown great promise elsewhere in complex lithologic sequences (Rogers et. al., 1992).

To facilitate the above activities several specific tasks must be completed. These include: (1) translation of all remaining digital geophysical log data for wells Burton 5, Cerro Colorado, Coronado 2, Love 8, Thomas 5, Thomas 6, Thomas 7, Thomas 8, Ridgecrest 5, and Soil Amendment Facility 1 from Schlumberger LIS format into ASCII format. This task should be completed by Schlumberger, so that it is done correctly and in a timely manner. (2) A computer tape of digital data for well Gonzales 2 should exist, because that well was logged during the period when data were recorded digitally. A search for such a tape should conducted, and, if it is located, the tape should be translated to ASCII format by Schlumberger. (3) All available logs for City of Albuquerque wells should be digitized; approximately 57 log suites remain to be digitized completely, and approximately 10 log suites are only partially digitized.

Additionally, it is imperative to continue a comprehensive borehole geophysical logging program using a full-service commercial logging contractor (e.g. Schlumberger or Dresser/Atlas). Such log suites represent powerful sets of data that provide a unique look at in-situ subsurface conditions and permit the hydrogeologic setting of new wells to be interpreted within the context of the conceptual hydrogeologic model presented in this report.

Geophysical-log suites for all new wells should include complete sets of sonic, nuclear, and electric logs. The focus of future logging programs should be on primary logs; computed logs or synthetic logs that are based on primary logs should be minimized. The geophysical-log suite for well Charles 5 is a good example of the logs that should be obtained for all new wells. Addition of a full waveform sonic log to the logging suite should be evaluated. Such a log has proven useful elsewhere when applied to lithologic and hydrogeologic interpretation of unconsolidated sediments (Crowder et al., 1991).

Application of hydrogeologic model

The conceptual hydrogeologic model developed in this study can be used to re-examine many aspects of ground-water behavior in the Albuquerque Basin. The model provides a powerful tool to relate such features as ground-water chemistry, ground-water production capacity, and well performance to basic geological parameters. Proposed components of future work include:

(1) *Subsurface mapping of lithofacies and analysis of well production behavior within major Albuquerque well fields.* A detailed mapping of lithofacies distribution within and immediately adjacent to Albuquerque well fields will provide a basis for correlation of well yield, drawdown, and pumping characteristics to a particular lithofacies. Such an analysis can be used to evaluate whether the behavior of a particular well is influenced by geological or well-construction factors.. Additionally, such an analysis will provide predictive capabilities that can be used for an initial evaluation of proposed locations for new wells.

(2) *Completion of Santa Fe Group petrologic characterization and analysis of sidewall core sand well cuttings.* The majority of samples from wells Charles 5, Coronado 2, Love 8, Ridgecrest 5, Thomas 5, Thomas 6, and Thomas 8 remain to be studied. Such an analysis is important because the flow characteristics of aquifers are ultimately a function of the composition and texture of the rock. Additional data from sidewall cores and cuttings are needed to provide a complete picture of compositional and textural variation in the Albuquerque Basin. Detailed characterization of lithofacies should be particularly useful in predicting where basin deposits may be subject to excessive mechanical deformation, land subsidence, and earth-fissure formation at some future time due to processes such as consolidation, hydrocompaction, and piping. Such saturated- and vadose-zone phenomena are widely observed in other alluvial basins of the American Southwest where poorly consolidated basin and valley fills have been subject to intensive urban and agricultural development.

(3) *Determination of basin-wide porosity distribution.* With increasing depth within a particular lithofacies, porosity may be significantly reduced by compaction or by the precipitation of zeolite, authigenic clay, and calcite cements, or both. As has been noted elsewhere, porosity reduction due to compaction is particularly effective in lithic-rich sandstones, and increased cementation with depth is common in sandstones rich in volcanic detritus, as in the Santa Fe Group (Galloway, 1979). Alternatively, there is the possibility that creation of secondary porosity (i.e. porosity formed by dissolution of grain, cement, or both) may actually increase porosity at depth. Study of all available sidewall cores and well cuttings over as wide a range of depths as possible would provide a more detailed picture of porosity distribution within the basin.

(4) *Comparison of basin-wide water quality patterns and lithofacies distribution.* The geochemical data and interpretations of Anderholm (1988) and Logan (1990) need to be re-evaluated in light of the new conceptual hydrogeological model. Relationships between geochemical trends in ground-water and lithofacies distribution should be explored and lithofacies-related controls on ground-water composition documented. Such information can be used to evaluate whether certain chemical characteristics, such as elevated arsenic content, are associated with a particular lithofacies, or whether they are characteristic of specific ground-water sources that flow into the Albuquerque Basin.

Characterization of river valley and mountain-front areas

Detailed characterization of hydrogeology in river-valley and mountain-front areas is required for a better understanding of vadose-zone processes and ground-water recharge mechanisms. Beneath the Rio Grande floodplain and in many valley-border areas between Bernalillo and Isleta, coarse-grained river-channel deposits in the upper Santa Fe Group and river-valley-fill units (hydrostratigraphic units USF-2, VA, and RAr; lithofacies Ib, and Iv) are in direct contact. Such areas provide direct "windows" for water to move into the deeper subsurface and recharge the Santa Fe Group aquifer, and hold promise for development of artificial recharge programs. Throughout the Albuquerque area, sites need to be identified where the effectiveness of ground-water recharge can be significantly improved. Of more sobering significance is the fact that river-valley and bordering stream terraces of the inner river-valley zone provide a direct pathway for the introduction of contaminants into the aquifer and, therefore, are most susceptible to pollution of the shallow aquifer system. Because of their potentially major role in ground-water recharge and contamination sensitivity, river-valley areas within the northern Albuquerque Basin need to be characterized and the physical and geochemical parameters that influence recharge quantified.

Other areas where more detailed hydrogeologic investigations are recommended include upper piedmont slopes along the base of the Sandia and Manzanita Mountains, and the lower reaches of major mountain canyons that contain springs and channel segments with perennial or intermittent surface flow. A significant component of streamflow contributes to subsurface water in the vadose zone, and, ultimately, some becomes ground-water that recharges the Santa Fe Group aquifer. Of particular interest are hydrologic factors influencing mountain front and canyon recharge in the Tijeras fault zone and Hubbell Bench area between Tijeras and Hell's Canyon arroyos.

IX. REFERENCES

Anderholm, S. K., 1987, Hydrogeology of the Socorro and La Jencia Basins, Socorro County, New Mexico. U.S. Geological Survey Water-Resources Investigations Report 84- 4342.

Anderholm, S. K., 1988. Groundwater geochemistry of the Albuquerque-Belen Basin, Central New Mexico. U.S. Geological Survey Water-Resources Investigations Report 86-4094, 110 pp.

Anderson, M. P., 1989, Hydrogeologic facies models to delineate large-scale spacial trends in glacial and glacial fluvial sediments. Geological Society of America Bulletin, v. 101, pp. 501-511.

Asquith, G. B., 1982. Basic Well Log Analysis for Geologists. American Association of Petroleum Geologists, Tulsa, Oklahoma, 216 pp.

Asquith, G. B., 1984. Log Evaluation of Shaly Sandstones: A Practical Guide. American Association of Petroleum Geologists, Continuing Education Course Notes No. 31, 59 pp.

Austin, G. S., 1986, The role of clay minerals in disposal and storage of hazardous materials. New Mexico Geology, v. 8, pp. 79-82.

Back, W., Seaber, P. R., and Rosenshein, J. S., editors, 1988, Hydrogeology. The Geology of North America, Volume O-2, Boulder, Colorado, Geological Society of America, 534 pp.

Birch, F. S., 1980a, Geophysical evaluation of basin hydrologic characteristics in the central Rio Grande, Part I, Gravity models of the Albuquerque-Belen basin. Unpublished report prepared under U.S. Geological Survey contract 14-08-00001-17879, 30 pp.

Birch, F. S., 1980b, Geophysical evaluation of basin hydrologic characteristics in the central Rio Grande, Part II, New gravity maps of the Albuquerque-Belen basin. Unpublished report prepared under U.S. Geological Survey contract 14-08-0001-17879.

Birch, F. W., 1980c, Three-dimensional gravity model of the basin hydrologic parameters in New Mexico. Unpublished report prepared by the University of New Mexico under U.S. Geological Survey contract 14-08-0001-17899, 27 pp.

Birch, F. W., 1982, Gravity models of the Albuquerque basin, Rio Grande rift, New Mexico. Geophysics, v. 47, no. 8, pp. 1185-1197.

Bjorklund, L. J., and Maxwell, B. W., 1961, Availability of ground water in the Albuqurque area, Bernalillo and Sandoval Counties, New Mexico. New Mexico State Engineer Technical Report 21, 117 pp.

Black, B. A., and Hiss, W. L., 1974, Structure and stratigraphy in the vicinity of the Shell Oil Co. Santa Fe Pacific No. 1 Test Well, Southern Sandoval County, New Mexico. New Mexico Geological Society, Guidebook 25, pp. 365-370.

Brister, B. S., 1990, Tertiary sedimentation and tectonics: San Juan sag - San Luis Basin region, Colorado and New Mexico. Unpublished Ph.D. dissertation, New Mexico Institute of Mining and Technology, 267 pp.

Bryan, K., 1909, Geology of the vicinity of Albuquerque. University of New Mexico, Bulletin 51, Geological Series, V. 3, 24 pp.

Bryan, K., 1938, Geology and groundwater conditions of the Rio Grande depression in Colorado and New Mexico, IN U.S. Natural Resources Planning Board, The Rio Grande Joint Investigations in the upper Rio Grande Basin. U.S. Government Printing Office, Washington, D.C., v. 1, pt. 2, pp. 197-225.

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

Bryan, K., and McCann, F. T., 1938, The Ceja de Rio Puerco, A border feature of the Basin and Range province in New Mexico, Part II. Journal of Geology, v. 46, pp. 1-16.

Cather, S. M., 1992, Suggested revisions to the Tertiary tectonic history of north-central New Mexico. New Mexico Geological Society, Guidebook 43 (in press).

Chamberlin, R. M., 1980, Cenozoic stratigraphy and structure of the Socorro Peak volcanic center, central New Mexico. Unpublished Ph.D. dissertation, Colorado School of Mines, 495 pp.

Chapin, C. E., 1988, Axial basins of the northern and central Rio Grande rifts; IN Sloss, L. L. (ed.), Sedimentary cover--North American Craton (U.S.). Geological Society of America, Geology of North America, v. D-2, pp. 165-170.

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

Clary, J. H., Korecki, N. T., and Mondragon, R. R., 1984, Geology of Albuquerque, New Mexico. United States of America. Bulletin of Association of Engineering Geologists, v. 21, no. 2, pp. 127-156.

Cordell, Lindrith, 1978, Regional geophysical setting of the Rio Grande rift. Geological Society of America, Bulletin, v. 89, pp. 1073-1090.

Crowder, R. E., LoCoco, J. J., and Yearsley, E. N., 1991. Application of full waveform borehole sonic logs to environmental and subsurface engineering investigations, IN Proceedings of the Symposium on the Application of Geophysics to Environmental and Engineering Problens, Knoxville, Tennessee, March 10-14, 1991, pp. 200-213.

Dominico, P. A. and Schwartz, F. W., 1990. Physical and Chemical Hydrogeology. John Wiley & Sons, New York, New York, 824 pp.

Dresser Atlas, 1982. Well Logging and Interpretation Techniques, Dresser Atlas Industries, Houston, Texas, 225 pp.

Fetter, C. W., 1988. Applied Hydrogeology. Merrill Publishing Company, Columbus, Ohio, 592 pp.

Folk, R. L., 1974, Petrology of sedimentary rocks. Austin, Hemphill, 182 pp.

Frenzel, P. F., and Kaehler, C. A., 1990, Geohydrology and simulation of ground-water flow in the Mesilla Basin, Doan ana County, New Mexico, and El Paso County, Texas, <u>with a section on</u> Water quality and geochemistry, by S.K., Anderholm. U.S. Geological Survey Open-File Report 88-305, 179 pp.

Frostick, L., and Reid, I., 1989, Is structure the main control of river drainage and sedimentation in rifts? Journal of African Earth Sciences, v. 8, nos. 2/3/4, pp. 165-182.

Galloway, W. E., 1979, Diagenetic control of reservoir quality in arc-derived sandstones: implications for petroleum explorations, IN P. A. Scholle and P. R. Schluger, eds., Aspects of diagenesis. SEPM Special Publication No. 26, pp. 251-262.

Galusha, T., 1966, The Zia Sand Formation, new early to medial Miocene beds in New Mexico. American Museum Novitates, no. 2271, 12 pp.

Galusha, T., and Blick, J. C., 1971, Stratigraphy of the Santa Fe Group, New Mexico. American Museum of Natural History Bulletin, v. 144, article 1, 127 pp.

Gardner, J. N., Goff, F. Garcia, S., and Hagan, R. C., 1986, Stratigraphic relations and lithologic variations in the Jemez volcanic field, New Mexico. Journal of Geophysical Research, v. 91, pp. 1763-1778,

Geissman, J. W., Brown, L., Turrin, B. D., McFadden, L. D., and Harlan, S. S., 1990, Brunhes chron excursion/polarity episode recorded during the late Pleistocene, Albuquerque Volcanoes, New Mexico, U.S.A.. Geophysical Journal International, v. 102, pp. 73-88.

Gile, L. H., Hawley, J. W., and Grossman, R. B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico Guidebook to the Desert Project. New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222 pp.

Goff, F., Gardner, J. N., Baldridge, W. S., Hulen, J. B., Nielson, D. L., Vaniman, D., Heiken, G., Dungan, M. A., and Broxton, D., 1989, Excursion 17B: Volcanic and hydrothermal evolution of Pleistocene Valles caldera and Jemez volcanic field, IN Chapin, C. E., and Zidek, J. (eds.), Field excursions to volcanic terranes in the western United States, Volume I; Southern Rocky Mountain region. New Mexico Bureau of Mines and Mineral Resources, Memoir 46, pp. 381-434.

Gustavson, T. C., 1991, Arid basin depositional systems and paleosols: Fort Hancock and Camp Rice Formations (Pliocene-Pleistocene) Hueco Bolson, West Texas and adjacent Mexico. University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 198, 49 pp.

Hacker, L. W., 1977, Soil survey of Bernalillo County and parts of Sandoval and Valencia Counties, New Mexico. U.S. Soil Conservation Service, 101 pp.

Hawley, J. W., compiler, 1978, Guidebook to Rio Grande rift in New Mexico and Colorado. New Mexico Bureau of Mines and Mineral Resources, Circular 163, 241 pp.

Hawley, J. W., 1984, Hydrogeologic cross sections of the Mesilla Bolson, New Mexico and Texas. New Mexico Bureau of Mines and Minerals Resources, Open-file Report 190, 10 pp.

Hawley, J. W., 1986, Physiographic provinces of New Mexico; IN Williams, J. L. (ed.), New Mexico in maps, 2nd edition. University of New Mexico, Albuquerque, pp. 23-27.

Hawley, J. W., Bachman, G. O., and Manley, K., 1976, Quaternary statigraphy in the Basin and Range and Great Plains provinces, New Mexico and Texas, IN Mahaney, W. C., ed., Quaternary stratigraphy of North America. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pennsylvania, pp. 235-274.

Hawley, J. W., and Parsons, R. B., 1980, Glossary of selected geomorphic and geologic terms. West Technical Service Center, Soil Conservation Service, USDA, Portland, Oregon, 30 pp.

Hawley, J. W., and Longmire, P. A., 1992, Site characterization and selection (Chapter 3); IN Reith, C. C., and Thompson, B. M. (eds.), Deserts as dumps? The disposal of hazardous materials in arid ecosystems. University of New Mexico Press, Albuquerque.

Hawley, J. W., and Love, D. W., 1991, Quaternary and Neogene Landscape evolution: A transect across the Colorado Plateau and Basin and Range provinces in west-central and central New Mexico. New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, pp. 105-148.

Hawley, J. W., and Lozinsky, R. P., 1992, Hydrogeologic framework of the Mesilla Basin in New Mexico and western Texas. New Mexico Bureau of Mines and Mineral Resources, Open-file Report 323 (in preparation).

Hay, R. L. and Shepard, R. A., 1977, Zeolites in open hydrologic systems, IN F. Mumpton, ed., Mineralogy and geology of natural zeolites, Reviews in Mineralogy, v. 4. Washington, D.C., Mineralogical Society of America, pp. 93-102.

Hearne, G. A., and Dewey, J. D., 1988, Hydrologic analysis of the Rio Grande basin north of Embudo, New Mexico, Colorado and New Mexico. U.S. Geological Survey Water-Resources Investigations Report 86-4113, 244 pp.

Ingersoll, R. V., Cavazza, W., Baldridge, W. S., and Shafiqullah, M., 1990, Cenozoic sedimentation and paleotectonics of north-central New Mexico: Implications for initiation and evolution of the Rio Grande rift. Geological Society of America Bulletin, v. 102, pp. 1280-1296.

Kaehler, C. A., 1990, Lithology of basin-fill deposits in the Albuquerque - Belen basin, New Mexico. U.S. Geological Survey, Water-Resources Ivestigations Report 89-4162, 14 pp.

Kelley, V. C., 1977, Geology of Albuquerque Basin, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Memoir 33, 59 pp.

Kelley, V. C., 1982, Albuquerque, its mountains, valley, water, and volcanoes. New Mexico Bureau of Mines and Mineral Resources, Scenic Trips to the Geological Past No. 9, 106 pp.

Kelley, V. C., and Kudo, A. M., 1978, Volcanoes and related basalts of the Albuquerque basin, New Mexico. New Mexico Burea of Mines and Mineral Resources, Circular 156, 320 pp.

Kelley, V. C., and Northrop, S. A., 1975, Geology of Sandia Mountains and vicinity, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Memoir 29, 136 pp.
Kelley, V. C., and Wood, G. H., Jr., 1946, Lucero uplift, Valencia, Socorro and Bernalillo Counties, New Mexico. U.S. Geological Survey, Oil and Gas Investigations Preliminary Map 47.
Kelly, T.E.,1974, Reconnaissance investigation of ground water in the Rio Grande drainage basin--with special emphasis on saline ground-water resources: U. S. Geological Survey, Hydrologic Investigations Atlas HA-510.
Kernodle, J. M., 1992, Summary of U.S. Geological Survey ground-water-flow models of basin-fill aquifers in the southwestern alluvial basins region, Colorado, New Mexico, and Texas. U.S. Geological Survey, Open-file Report 90-361, 81 pp.
Keys, W. S., 1989. Borehole Geophysics Applied to Groundwater Investrigations. National Groundwater Association, Dublin, Ohio, 313 pp.
King, W. E., Hawley, J. W., Taylor, A. M., and Wilson, R. P., 1971, Geology and ground-water resources of central and western Dona Ana County, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Hydrologic Report 1, 64 pp.
Kudo, A. M., Kelley, V. C., Damon, P. E., and Shafiqullah, M., 1977, K-Ar ages of basalt flows at Canjilon Hill, Iselta volcano, and the Cat Hills volcanic field, Albuquerque-Belen basin, central New Mexico. Isochron/West, no. 18, pp. 15-16.
Kues, G. E., 1987. Ground-water-level data for the Albuquerque-Belen Basin, New Mexico, through water year 1985. U.S. Geological Survey, Open-file Report 87-116, 51 pp.
Lambert, P. W., 1968, Quarternary stratigraphy of the Albuquerque area, New Mexico. Unpublished Ph.D. dissertation, University of New Mexico, 329 pp.
Lambert, P. W., 1974, Map showing present and potential sources of blowing sand in La Mesita Negra southeast quadrangle, Bernalillo County, New Mexico. U.S. Geological Survey, Miscellaneous Field Studies Map, MF-600, scale 1:24,000.
Lambert, P. W., 1978, Southern Rio Grande rift guide 2, Rio Grande Bridge (I-25) to Bernalillo. New Mexico Bureau of Mines and Mineral Resources, Circular 163, pp. 144-158.
Lambert, P. W., Hawley, J. W., and Wells, S. G., 1982, Supplemental road-log segment III-S: Urban and environmental geology of the Albuquerque area. New Mexico Geological Society, Guidebook 33, pp. 97-119.
Logan, L. M., 1990. Geochemistry of the Albuquerque Municipal Area, Albuquerque, New Mexico. Independent Study for the M. S. Degree, New Mexico Institute of Mining and Technology, Socorro, New Mexico, 282 pp.
Lohman, R. C., Davis, J. M., Love, D. W., and Phillips, F., 1991, Hydrogeologic investigations of upper Sierra Ladrones Formation [Albuquerque Basin]. New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, pp. 164-166.
Longiaru, S., 1987, Visual comparitors for estimating the degree of sorting from plane and thin sections. Journal of Sedimentary Petrology, v. 57, pp. 791-794.
Love, D. W., 1986, A geological perspective of sediment storage and delivery along the Rio Puerco, central New Mexico; IN Hadley, R. F., (ed.). Drainage basin sediment delivery. International Association of Hydrological Sciences, Publication 159, pp. 305-322.
Lozinsky, R. P., 1987, Geology and late Cenozoic history of the Elephant Butte area, Sierra County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 187, 40 pp.
Lozinsky, R. P., 1988, Stratigraphy, sedimentology, and sand petrology of the Santa Fe Group and pre-Santa Fe Tertiary deposits in the Albuquerque basin, central New Mexico. Unpublished PhD dissertation, New Mexico Institute of Mining and Technology, 298 pp.
Lozinsky, R. P., and Tedford, R. H., 1991, Geology and paleontology of the Santa Fe Group, southwestern Albuquerque Basin, Valencia County, New Mexico. New Mexico Bureau of Mines & Mineral Resources, Bulletin 132, 35 pp.

Lozinsky, R. P., Hawley, J. W., and Love, D. W., 1991, Geologic overview and Pliocene-Quaternary history of the Albuquerque basin, central New Mexico. New Mexico Bureau of Mines and Minerals Resources, Bulletin 137, pp. 157-162.

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

Machette, M. N., 1978b, Preliminary geologic map of the Socorro 1° by 2° quadrangle, central New Mexico. U.S. Geological Survey, Open-file Report 78-607.

Machette, M. N, 1978c, Dating of Quaternary faults in the southwewtern United States by using buried calcic paleosols. U.S. Geological Survey, Journal of Research, v. 6, pp. 369-381.

Machette, M. N., 1985, Calcic soils of the southwestern United States. Geological Society of America, Special Paper 203, pp. 1-21.

Manley, K., 1978, Geologic map of Bernalillo NW Quadrangle, Sandoval County, New Mexico. U.S. Geological Survey, Geologic Quadrangle Map GQ-1446, scale 1:24,000.

May, S. J., Kelley, S., and Russell, L. R., 1991, Footwall unloading and rift shoulder uplifts in the Albuquerque Basin: their relation to syn-rift fanglomerates and apatite fission track ages. Geological Society of America, Abstracts with Programs, v. 23, no. 4, pp. 46.

May, S. J., and Russell, L. R., 1991, Thickness of the syn-rift Santa Fe Group in the Albuquerque Basin and its relation to structural style. Geological Society of America, Abstracts with Programs, v. 23, no. 4, pp. 46.

McQuillan, D. M., 1982, Pollution of the Rio Grande valley-fill aquifer. New Mexico Geological Society, Guidebook 33, pp. 357-360.

Miller, J., 1988, Microscopical techniques: I. Slices, slides, stains and peels, IN M. Tucker, ed., Techniques in sedimentology. Oxford, Blackwell Scientific Publications, pp. 86-107.

Myers, D. G., and McKay, E. J., 1970, Geologic map of the Mount Washington quadrangle, Bernalillo and Valcnia Counties, New Mexico. U.S. Geol. Survey, Geol. Quad. Map GQ-886, scale 1:24,000

Myers, D. A., and McKay, E. J., 1976, Geologic map of the north end of the Manzano Mountains, Tijeras and Sedillo quadrangles, Bernaillo County, new Mexico. U.S. Geological Survey, miscellaneous Geologic Investigations Map I-968, scale 1:24,000.

Peter, K. D., 1987, Ground-water flow and shallow-aquifer properties in the Rio Grande inner valley south of Albuquerque, New Mexico. U.S. Geological Survey, Water-Resources Investigations Report 87-4015, 29 pp.

Peterson, D. M., Khaleel, R., and Hawley, J. W., 1984, Quasi three-dimensional modeling of groundwater flow in the Mesilla Bolson, New Mexico. New Mexico Water Resources Research Institute, Technical Completion Report, Project No. 1-3-4564, WRRI Report No. 178, 185 pp.

Pittman, E. D., 1979, Porosity, diagenesis and productive capability of sandstone reservoirs, IN P. A. Scholle and P. R. Schluger, eds., Aspects of diagenesis. SEPM Special Publication No. 26, pp. 159-173.

Reiche, P., 1949, Geology of the Manzanita and north Manzano Mountains, New Mexico. Geological Society of America, Bulletin, v. 60, pp. 1183-1212.

Richey, S. F., 1991, Construction, lithologic, and geophysical data from monitoring wells in Albuquerque, Bernalillo County, New Mexico. U.S. Geological Survey, Open-file Report 90-578, 83 pp.

Rogers, S. J., Fang, J. H., Karr, C. L., and Stanley, D. A., 1992. Determination of lithology from well logs using a neural network. American Association of Petroleum Geologists Bulletin, v. 76, pp. 731-739.

Rosendahl, B. R., 1987, Architecture of continental rifts with special reference to East Africa. Annual Reviews of Earth and Planetary Sciences, v. 15, pp. 445-503.

Russell, L. R. and Snelson, S., 1990, Structural style and tectonic evolution of the Albuquerque basin segment of the Rio Grande rift, IN B. Pinet and C. Bois (eds.), The Potential for deep seismic profiling for hydrocarbon exploration. Editions Technip, Paris, French Petroleum Institute Research Conference Proceedings, pp. 175-207.

Russell, L. R., and Snelson, S., 1991, Reflection seismic data and its bearing on the structural style and tectonic framework of the Albuquerque Basin segments of the Rio Grande rift, New Mexico. Geological Society of America, Abstracts with Programs, v. 23, no. 4, pp. 89.

Schlumberger Educational Services, 1989. Log Interpretation Principals/ Applications. Schlumberger, Houston, Texas, 375 pp.

Schlumberger Educational Services, 1991. Log Interpretation Charts. Schlumberger, Houston, Texas, 200 pp.

Seager, W. R., and Morgan, P., 1979, Rio Grande rift in southern New Mexico, west Texas and northern Chihuahua, IN Reicher, R. E. (ed.), Rio Grande rift, tectonics and magmatism. Washington D.C., American Geophysical Union, pp. 87-106.

Seager, W. R., Clemons, R. E., Hawley, J. W., and Kelley, R. E., 1982, Geology of northwest part of Las Cruces 1 x 2 degree sheet: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 53, scale 1:125,000, 3 sheets.

Seager, W. R., Hawley, J. W., Kottlowski, F. E., and Kelley, S. A., 1987, Geologic Map of east half of Las cruces and northeast El Paso 1 x 2 degree sheets, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 57, scale 1:125,000, 3 sheets.

Shomaker, John W., Inc., 1990. Well Report — City of Albuquerque Love No. 8. Consultant's Report prepared for the City of Albuquerque Public Works Department.

Shomaker, John W., Inc., 1991. Well Report — City of Albuquerque Gonzales No. 2. Consultant's Report prepared for the City of Albuquerque Public Works Department.

Smith, G. A., Larsen, D., Harlan, S. S., McIntosh, W. C., Erskine, D. W., and Taylor, S., 1991, A tale of two volcaniclastic aprons: Field guide to the sedimentology and physical volcanology of the Oligocene Espinaso Formation and the Miocene Peralta Tuff, north-central New Mexico. New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, pp. 87-103.

Smith, R. L., Bailey, R. A., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico. U.S. Geological Survey, Miscellaneous Investigations Map I-571, scale 1:125,000.

Spiegel, Z., 1961, Late Cenozoic sediments of the lower Jemez River region. New Mexico Geological Society, Guidebook 12, pp. 132-139.

Spiegel, Z., and Baldwin, B., 1963, Geology and water resources of the Santa Fe area, New Mexico. U.S. Geological Survey, Water-Supply Paper 1525, 158 pp.

Stearns, C. E., 1953, Tertiary geology of the Galisteo-Tonque area, New Mexico. Geol. Soc. America, Bull., v. 64, pp. 459-507.

Stone, W. J., compiler, 1984, Selected papers on water quality and pollution in New Mexico. New Mexico Bureau of Mines and Mineral Resources, Hydrologic Report 7, 300 pp.

Summers, W. K., 1992. Albuquerque's water table—Winter 1988-89. New Mexico Geology, v. 14, no. 1, p. 8.

Tedford, R. H., 1981, Mammalian biochronology of the later Cenozoic basins of New Mexico. Geological Sociey of America Bulletin, V. 92, part I, pp. 1008-1022.

Tedford, R. H., 1982, Neogene stratigraphy of the northwestern Albuquerque basin, New Mexico Geological Society, Guidebook 33, pp. 273-278.

Titus, F. B., 1961, Ground-water geology of the Rio Grande tough in north-central New Mexico, with sections on the Jemez caldera and the Lucero uplft. New Mexico Geological Society, Guidebook 12, pp. 186-192.

Wilkins, D. W., 1987, Characteristics and properties of the basin-fill aquifer determined from three test wells west of Albuquerque, Bernalillo County, New Mexico. U.S. Geological Survey, Water Resources Investigations Report 86-4187, 78 pp.

Wilson, C. A., White, R. R., Orr, B. R., and Roybal, R. G., 1981, Water resources of the Rincon and Mesilla Valleys and adjacent areas, New Mexico. New Mexico State Engineer, Technical Report 43, 513 pp.

Woodward, L. A., 1987, Geology and mineral resources of Sierra Nacimiento and vicinity, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Memoir 42, 84 pp.

Wright, H. E., 1943, Cerro Colorado, an isolated non-basaltic volcano in central New Mexico. American Journal of Science, v. 241, p. 43-56.

Wright, H. E., 1946, Tertiary and Quaternary geology of the lower Rio Puerco area, New Mexico. Geological Society of America, Bulletin, v. 57, pp. 383-456.

APPENDIX A

Resumes of investigators

Résumé

CHAMBERLIN, Richard M.
117 Stallion Circle
Socorro, New Mexico 87801

Personal:

Born in Reading, Pennsylvania May 2, 1943; 6'2"; 200 lbs; good health; enjoy jogging and racquetball; wife Louise is Director of Admissions at the New Mexico Institute of Mining and Technology; son Robert born 3/10/79; son Christopher born 9/29/81

Education:

B.S. Geology 1967, New Mexico Institute of Mining and Technology, cumulative average 2.85 M.S. Geology 1975, New Mexico Institute of Mining and Technology, cumulative average 3.89
Ph.D. Geology, 1980, Colorado School of Mines, cumulative average 3.66

Experience:

Summer 1967, RANCHERS EXPLORATION & DEVELOPMENT CORPORATION: Albuquerque, New Mexico; mapping and evaluation of copper prospects in southeast Arizona

1967-70, U.S. NAVY: Cargo Officer and Damage Control Officer on fleet oiler USS Mattaponi AO-41

1970-72, MASTERS THESIS: detailed mapping (35 sq. mi.) of Tertiary volcanic rocks, shallow intrusive, and hydrothermally altered rocks at Council Rock near Magdalena, New Mexico

1972-74, TEACHING ASSISTANT AT COLORADO SCHOOL OF MINES: lab instructor in general geology, geoanalytics, and structural geology

Summer 1973, NORANDA EXPLORATION INC.: Denver, Colorado; detailed mapping, geochemical sampling, and evaluation of three molybdenum prospects in western Colorado

Summer 1974, EXXON COMPANY U.S.A.: Denver, Colorado: reconnaissance exploration for hydrothermal and igneous related uranium mineralization in New Mexico and Utah involving: literature search, prospect classification, on site evaluation, and summary report

1975–78, DISSERTATION RESEARCH: detailed mapping (93 sq. mi), stratigraphic and structural analysis of the Socorro Peak volcanic center: an area where Neogene volcanism, mineralization, sedimentation, and structure related to the Rio Grande rift have been overprinted on an Oligocene resurgent cauldron of the Datil-Mogollon volcanic field

1980–present, ECONOMIC GEOLOGIST NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES: research concerning the origin of uranium deposits in sedimentary environments, assessments of mineral resource potential from geochemical and geophysical data, recognition of ancient soils, geochemical mapping of compositionally distinct fluvial systems, structure of the Rio Grande rift, structural analysis of the Laramide Zuni uplift, thesis advising and oral presentations of research projects. Served as publications chairman for the New Mexico Geological Society, 1987–1991. Sabbatical with Queensland Geological Survey, 1990.

Professional Societies:

New Mexico Geological Society: Secretary 1992
Geological Society of America
Rocky Mountain Association of Geologists
Sigma Xi Research Society

RESUME OF JOHN M. GILLENTINE

Graduate Assistant, New Mexico Bureau of Mines and Mineral Resources
Campus Box 3156 Campus Station Socorro, NM 87801 office 835-5237

Education

Northern Arizona University, Flagstaff AZ. Bachelor of Science with major in Geology, minor in Environmental Science. Graduated magna cum laude 8-14-91. Undergraduate coursework in environmental geology, analytical chemistry, environmental law and ecology plus basic geology courses. Graduate coursework in electron microprobe methods, shale petrology (XRD techniques), watershed hydrology and paleoecology.

University of New Mexico, Albuquerque NM. Part-time studies in basic sciences (physical geology, physics, calculus). 1987-1988.

Colorado State University, Fort Collins CO. Bachelor of Science with major in Animal Science. Graduated 12\82. Coursework in livestock management, range science, crops and forage production, zoology and mammalian anatomy and physiology.

Fort Lewis College, Durango CO. Studies in music and the liberal arts. 1976-1979.

Employment

Northern Arizona University Geology Department. Independent research into early proterozoic metamorphism in central Arizona under NSF Research Experiences for Undergraduates program. Geologic mapping and X-ray diffraction analysis of clay mineral assemblages. Findings published in Arizona Transition Zone issue Arizona Geological Society Digest. 1989-1990.

Gillentine Associates, Inc., Santa Fe NM. Commercial and agricultural real estate appraisal and market research for government and the private sector in New Mexico, Colorado and west Texas. Professional education through American Institute of Real Estate Appraisers. 1983-1988.

Hobbies and Interests

Cycling, swimming, backpacking, flyfishing, skiing, well cuttings.

CHARLES STEPHEN HAASE

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Socorro, New Mexico 87801
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PROFESSIONAL EXPERIENCE

- Provided technical support to diverse, ongoing hazardous waste management and environmental monitoring and compliance projects at a major U. S. Department of Energy weapons manufacturing facility. Conducted hydrogeological research to support ongoing groundwater monitoring and characterization activities, and provided technical reviews of schedules, plans, and reports.

- Designed and implemented subsurface geology and hydrology characterization projects to provide a regional hydrogeological framework for numerous site-specific Remedial Investigation/Feasibility Studies and RCRA Facility Investigations at a major manufacturing complex.

- Designed and directed subsurface exploration, hydrogeological data collection and analysis, and report preparation activities for site characterization and groundwater quality evaluation at five RCRA sites, six Solid Waste Management Units, and two Solid Waste Disposal Units.

- Conducted hydrogeological and geochemical characterization at proposed and active burial sites for the disposal of low-level radioactive wastes.

- Developed and implemented the hydrogeologic component of a five-year program to determine the environmental impact of subsurface injection of liquid radioactive wastes. Studies conducted addressed site characterization, hydrogeological and mechanical effects of waste injection, and the fate of injected wastes.

- Technical responsibility supporting the development of regulatory strategies to be used for licensing and closure activities at an underground injection well site.

- Extensive interaction with state and federal regulatory agencies, including numerous technical briefings and negotiations with regulatory personnel on groundwater issues related to site characterization, definition of contaminant plumes, compliance monitoring, and remedial actions.

- Characterized and evaluated dense, nonaqueous phase liquid (DNAPL) occurrences in fractured bedrock and evaluated remedial alternatives at DNAPL sites. Developed groundwater monitoring strategies for fractured-bedrock DNAPL sites.

- Designed and implemented drilling programs including auger, diamond core, and air-rotary drilling. Supervised over 100 groundwater monitoring well installations ranging in depth from 10 to 1,500 ft, and core drilling programs that obtained over 20,000 ft of rock core.

- Developed plugging and abandonment plans and procedures for unused groundwater monitoring wells and core holes.

- Supervised collection of borehole geophysical data. Interpreted borehole geophysical logs to determine lithologic and fracture properties and to characterize groundwater flow in fractured rocks.

- Supervised borehole straddle-packer testing to determine hydraulic conductivities and hydraulic head distributions to depths of 1200 ft. Interpreted results to document major groundwater flow patterns.

- Integrated hydrology, geology, geophysics, and soil science to define and evaluate basic hydrologic processes operative within fracture-flow dominated groundwater systems.

- Applied stable isotope and radionuclide geochemistry to groundwater and geological problems, such as characterization of groundwater flowpaths, origin of fracture-filling minerals and determination of the relative influence of depositional environment and diagenetic reactions on isotope systematics in sedimentary rocks.

- Compiled and interpreted subsurface geological information including stratigraphic and sedimentary structure analysis, petrographic thin-section study, X-ray diffraction determination of clay mineralogy, and scanning electron microscope and electron microprobe analysis of diagenetic and fracture-filling minerals.

- Compiled and interpreted hydrologic and groundwater quality data. Applied computer models (WATEQF and EQ3/EQ6) to evaluate groundwater quality, determine groundwater chemical evolution, and define groundwater flowpaths.

EMPLOYERS

- New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico
  Groundwater Geologist, December 1991 to present

- Environmental Sciences Division, Oak Ridge National Laboratory*, Oak Ridge, Tennessee (*operated by Martin Marietta Energy Systems, Inc.)
  Research Staff Member II, 1986 to March 1988 and November 1989 to November 1991
  Research Staff Member I, 1982 to 1986
  Research Associate III, 1980 to 1982

  Senior Hydrogeologic Consultant to the Oak Ridge Y-12 Plant Groundwater Protection Program, November 1989 to December 1991
  Manager of Oak Ridge Hydrology and Geology Study, November 1989 to May 1991

- Department of Geology, The Colorado College, Colorado Springs, Colorado
  Distinguished Visitor, January to February 1991 (concurrent appointment)

- C-E Environmental, Inc.*, Oak Ridge, Tennessee (*currently ABB Environmental Services, Inc.)
  Senior Consultant, April to November 1989
  Senior Scientist, March 1988 to April 1989

  Established and Managed Oak Ridge Office, March 1988 to April 1989
  Deputy Program Manager for HAZWRAP Activities, March 1988 to June 1989

- Department of Geological Sciences, University of Tennessee, Knoxville, Tennessee
  Adjunct Assistant Professor, January 1981 to March 1988 (concurrent appointment)

- Department of Geology and Geophysics, Yale University, New Haven, Connecticut
  Research Staff Geochemist, December 1978 to December 1979:

EDUCATION

- Ph.D., Geology, Chemistry minor, Indiana University, March, 1979
- Sc.M., Geology, Brown University, June, 1975
- B.A., Geology (magna cum laude), Carleton College, June, 1973

PROFESSIONAL CREDENTIALS

- Registered Professional Geologist in Tennessee, Certificate No. TN0112

PROFESSIONAL AFFILIATIONS

- American Geophysical Union
- Association of Groundwater Scientists and Engineers
- East Tennessee Geological Society (President 1990; Secretary-Treasurer 1991)
- Geological Society of America
- New Mexico Geological Society

PERSONAL

- Birth: September 20, 1951; Duluth, Minnesota
- Health: Excellent
- Marital Status: Single, no children

BIOGRAPHICAL SKETCH -- JOHN W. HAWLEY

John W. Hawley (born 10/7/32, Evansville, IN) received his Bachelor's and PhD degrees in geology, respectively, from Hanover College (1954) and the University of Illinois (1962). He is currently Senior Environmental Geologist with the New Mexico Bureau of Mines and Mineral Resources - Office of the State Geologist at New Mexico Tech in Socorro. He manages the Bureau's Albuquerque branch office and he is also a Tech faculty adjunct in geology. Prior to joining the Tech staff in 1977, he was a research geologist with the Soil Survey division of the U.S. Soil Conservation Service. He has been a leader of SCS Soil-Geomorphology Projects at New Mexico State University (1962-1971) and Texas Tech University (1971-1974), Soil Survey Staff Geologist at the SCS Regional Office in Portland, OR (1975-1977), and a collaborator with the Earth and Environmental Science Division of Los Alamos National Laboratory (1985-1992).

Much of Dr. Hawley's current research relates to assessing and mitigating impacts of natural resource exploitation and hazardous waste disposal in fragile arid and semiarid environments. He has conducted a study for the New Mexico Legislature and Environmental Improvement Board on selection of potential sites for disposal of low-level radioactive wastes. At the invitation of the U.S. Senate's Environment and Public Works Committee, he has testified on geologic and hydrologic aspects of hazardous-waste management in New Mexico. He also presented invited testimony at state and local-level hearings on siting of landfills; and he has served as an Expert Witness for the U.S. Attorney on surficial deposits and soils. He is continuing long-term research on the hydrogeologic framework of basin-fill aquifer systems in cooperation with Sandia National Laboratories, the U.S. Geological Survey and Bureau of Reclamation, New Mexico State Engineer's Office, and the City of Albuquerque. He also continues to collaborate with the U.S. Soil Conservation Service on landforms and soils of arid and semiarid regions; and with other State and Federal agencies on landfill disposal of all categories of solid wastes and geologic factors influencing indoor-radon availability. He has authored or coauthored more than 60 publications on the geology, soils, and related environmental concerns in the western United States and northern Mexico.

Dr. Hawley is a member of the American Institute of Professional Geologists, a fellow of the Geological Society of America, and a past president and honorary member of the New Mexico Geological Society. He served on the Program and Development Board of the New Mexico Water Resources Research Institute from 1982-1989. In 1983, he was the co-recipient of the Geological Society of America's Kirk Bryan Award for published research on Quaternary Geology and Geomorphology; and he received the 1987 Certificate of Merit for Distinguished Contributions in Arid Zone Research from the American Association for Advancement of Science, Southwestern and Rocky Mountain Division. In 1989, he was designated a New Mexico Eminent Scholar by the State Commission on Higher Education.

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PERSONAL: Birth Date 12-23-58 Social Security No. 573-17-1981
Nationality: American

INTERESTS: Sedimentary petrology, diagenesis, low-temperature geochemistry, environmental geology.

EDUCATION:

1983-1988. Ph.D. Geology, University of California, Santa Barbara, California. Thesis topic: Diagenesis of the Sag River and Shublik Formations in the National Petroleum Reserve, Alaska; and topics in siderite geochemistry. Adviser: James R. Boles.

1980-1983. M.S. Geology, University of Colorado, Boulder, Colorado. Thesis topic: Origin of kaolinite in the Dakota Group, Northern Front Range Foothills, Colorado. Adviser: Theodore R. Walker.

1980 (Summer). Indiana University, 8-credit course in field geology.

1976-1980. A.B., Geology, Oberlin College, Oberlin, Ohio.

WORK EXPERIENCE:

January 1991-Present. Assistant Professor, Department of Geoscience, New Mexico Tech, Socorro, New Mexico. Courses include: Stratigraphy and Sedimentology, Environmental Geology, Clastic and Carbonate Diagenesis, Sedimentary Petrography, Summer Field Camp, Field Sedimentology.

Fall 1990. Assistant Professor, Department of Geology and Geography, University of South Alabama, Mobile, Alabama. Courses: Stratigraphy and Sedimentology, Environmental Geology

1988-Fall 1990. Post-Doctoral Fellow, Geologisches Institut, Universität Bern, Bern, Switzerland.

1984-1987 (Summers). Research Geologist, Unocal Science and Technology Division, Brea, California. Examination of sedimentary petrology, diagenesis, and reservoir quality of rocks from a variety of Alaskan units.

1987-1988. Research Assistant for J.R. Boles, University of California, Santa Barbara.

1983-1986. Teaching Assistant, University of California, Santa Barbara. Courses include: Studies in Geologic Field Methods, Physical Geology, Sedimentary Petrology, Oceanography.

1983 (Spring). Geologic Consultant, Amoco Production Company, Denver, Colorado. Thin-section, XRD, and SEM analysis of volcaniclastic rocks from Washington.

1982 (Summer). Exploration Geologist, Amoco Production Company, Denver, Colorado. Subsurface stratigraphic study of the Piceance Creek Basin and field work in the Rocky Mountain region.

1980-1982. Teaching Assistant, University of Colorado, Boulder, Colorado. Courses include: Field Geology, Mineralogy, Physical Geology, and Historical Geology.

1981 (Summer). Associate Instructor, Indiana University Geologic Field Station, Cardwell, Montana.

1980 (Spring). Geology Tutor, Oberlin College, Oberlin, Ohio.

1979 (Summer). Geologic Field Assistant, Western Environmental Geology, U.S. Geological Survey, Menlo Park, California. Seismic hazard evaluation for the Seattle area, and Pleistocene research in the Sierra Nevada.

1979 (January). Volunteer Worker, Western Environmental Geology, U.S. Geological Survey, Menlo Park, California. Compilation of 14-C dates for the Puget Lowland, Washington.

SOCIETIES: American Association of Petroleum Geologists (AAPG)
Division of Environmental Geosciences (charter member)
Geological Society of America (GSA)
International Association of Sedimentologists (IAS)
New Mexico Geological Society (NMGS)
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APPENDIX B

Wells and boreholes in the Albuquerque area used in this study

Current Name	Other Name 1	Other Name 2	USGS	ABQ	Well Location				Elev	Year	Total
			Identifer	Map Code	T (N)	R (E)	Sec	Quarter		Drilled	Depth
City Water Wells											
ATRISCO 1	New 1980	ATRISCO II Well 5	350418106412201	At01	10	2	25	112	4941	1980	1446
ATRISCO 4	ATRISCO 13	ATRISCO I Well 3	350508106411901	At04	10	2	23	223	4950	1953	804
BURTON 1			350359106361601	Bu1	10	3	27	244	5321	1986	1553
BURTON 2			350421106361001	Bu2	10	3	26	111	5282	1962	1054
BURTON 3			350304106383401	Bu3	10	3	23	314	5216	1962	1012
BURTON 4			350343106364401	Bu4	10	3	27	413	5274	1987	1480
BURTON 5				Bu5	10	3	26	422	5275	1991	1306
CHARLES 2			350606106341101	Ch2	10	3	13	222	5266	1968	1020
CHARLES 5				Ch5	10	3	12	331	5219	1989	3240
COLLEGE 1			350646106443201	Co1	10	2	9	114	5337	1978	1681
COLLEGE 2			350647106440001	Co2	10	2	9	232	5227	1978	1647
CORONADO 1	TRACIE 1		351025106341601	Cr1	11	3	24	221	5288	1974	1215
CORONADO 2				Cr2	11	3	24	140	5292	1991	1450
DON 1			350416106451801	D1	10	2	29	113	5336	1963	1610
DON 2			350414106444801	D2	10	2	29	242		1975	
DURANES 2			350708106405801	Du2	10	2	1	431	4966	1958	813
DURANES 3			350629106405101	Du3	10	2	1	431	4961	1959	1020
GONZALES 2				Gz2	10	3	11	134	5100	1989	1433
GREIGOS 5			350828106175501	Gr5	11	3	31	442	4972	1958	815
LADERA	COLLEGE 3		350727106423201	Co3	10	2	3	422		1978	1490
LEAVITT 1		So. Valley Wells	350244106445301	Le1	10	2	33	244	5028	1973	1226
LEAVITT 2		So. Valley Wells	350237106445201	Le2	10	2	33	442	5069	1973	1238
LEAVITT 3		So. Valley Wells	350223106435401	Le3	9	2	4	223	5089	1986	1527
LEYENDECKER 1	KNAPP HEIGHTS 1		350752106342101	Ly1	11	3	36	434	5284	1959	1010
LEYENDECKER 2	KNAPP HEIGHTS 2		350727106340801	Ly2	10	3	1	244	5298	1959	1020
LEYENDECKER 3	KNAPP HEIGHTS 3		350819106344001	Ly3	11	3	36	322	5266	1960	1020
LEYENDECKER 4	KNAPP HEIGHTS 4		350815106340601	Ly4	11	3	36	422	5327	1960	1018
LOMAS 1			350430106302401	Lm1	10	4	22	342	5597	1962	1341
LOMAS 2			350459106304601	Lm2	10	4	22	132	5578	1973	1590
LOMAS 3			350526106303801	Lm3	10	4	15	314	5631	1973	1625
LOMAS 4			350547106310601	Lm4	10	4	16	241	5575	1973	1594
LOMAS 5	LOMAS 7		350422106312601	Lm5	10	4	21	344	5498	1978	1707
LOMAS 6	LOMAS 8		350408106310101	Lm6	10	4	28	223	5532	1978	1706
LOVE 1			350517106314401	Lv1	10	4	16	334	5462		1096
LOVE 2			350449106315701	Lv2	10	4	20	244	5444	1958	1224
LOVE 3			350511106325601	Lv3	10	4	20	212	5402	1958	1280

Current Name	*Other Name 1*	*Other Name 2*	*USGS*	*ABQ*		*Well Location*			*Elev*	*Year*	*Total*
			Identifer	**Map Code**	T (N)	R (E)	Sec	Quarter		**Drilled**	**Depth**
LOVE 4			350511106325601	Lv4	10	4	20	111	5364	1958	1280
LOVE 5			350452106323901	Lv5	10	4	20	143	5397	1958	1250
LOVE 6			350553106313801	Lv6	10	4	16	123	5504	1973	1569
LOVE 7			350607106321301	Lv7	10	4	8	434	5442	1973	1475
LOVE 8				Lv8	10	4	18	411	5310	1989	3336
MILES 1			350308106374601	Mi1	10	3	33	233	5147	1974	1342
PONDEROSA 1	PONDEROSA 9		350931106315501	Po9	11	4	28	111	5647	1979	1820
PONDEROSA 1(aband)	PONDEROSA 1		350933106391902	Po1a	10	4	4	212		1962	1325
PONDEROSA 2			350800106315001	Po2	11	4	33	332	5600	1973	
PONDEROSA 3			350820106321701	Po3	11	4	32	234	5532	1977	1685
PONDEROSA 4			350834106314901	Po4	11	4	33	113	5627	1979	1780
PONDEROSA 5	*PONDEROSA 7*		*350918106315401*	*Po7*	*11*	*4*	*28*	*113*	*5630*	*1978*	
PONDEROSA 6			350851106322001	Po6	11	4	29	431	5556	1979	1695
RIDGECREST 1			350405106322001	Ri1	10	4	29	232	5443	1964	1260
RIDGECREST 2			350427106323401	Ri2	10	4	20	344	5414	1977	1552
RIDGECREST 3			350401106331401	Ri3	10	4	30	243	5386	1974	1475
RIDGECREST 4			350445106334001	Ri4	10	4	19	322	5344	1974	1450
RIDGECREST 5				Ri5	10	4	30		5350	1990	1616
SAN JOSE 2	SAN JOSE 7	SAN JOSE 4	351922106470601	SJ2	10	3	29	441	4991	1959	1008
SANTA BARBARA 1			350648106362501	SB1	10	3	10	224	5138	1963	1012
THOMAS 1			350754106332101	Th1	11	4	32	333	5442	1959	1092
THOMAS 2			350747106323301	Th2	10	4	5	122	5486	1958	1220
THOMAS 3			350813106332101	Th3	11	4	31	412	5412	1958	1195
THOMAS 4			350813106324001	Th4	11	4	32	322	5484	1958	1018
THOMAS 5				Th5	10	4	6	124	5356	1988	3371
THOMAS 6				Th6	10	4	6	422	5408	1989	1533
THOMAS 7				Th7	10	4	6	342	5341	1988	1485
THOMAS 8				Th8	10	4	5	124	5410	1991	1695
VOL ANDIA 1			350805106354901	VA1	11	3	35	324	5142	1960	1010
VOL ANDIA 2			350732106350101	VA2	10	3	1	131	5208	1960	1030
VOL ANDIA 3			350747106361401	VA3	10	3	3	224	5110	1960	1033
VOL ANDIA 4			350803106351101	VA4	11	3	35	442	5201	1960	1021
VOL ANDIA 5			350809106360901	VA5	11	3	35	313	5111	1960	1026
VOL ANDIA 6			350828106352101	VA6	11	3	35	313	5177	1960	1010
VOLCANO CLIFFS 1			350950106434001	VC1	11	2	28	222	5335	1968	1209
VOLCANO CLIFFS 2			350914106434001	VC2	11	2	28	244	5328	1968	1200
VOLCANO CLIFFS 3			351007106434201	VC3	11	2	21	244	5344	1980	1750

Current Name	Other Name 1	Other Name 2	USGS	ABQ		Well Location			Elev	Year	Total
			Identifer	Map Code	T (N)	R (E)	Sec	Quarter		Drilled	Depth
Monitoring Wells											
CTY OBS 1			350548106383901	CO1	10	3	17	232			149
CTY OBS 2			350824106375301	CO2	11	3	33	143			150
CTY OBS 4			350646106403601	CO4	10	2	12	241			150
EUBANK 1			350239106315801	Eu1	10	4	32	422			615
I-25			350616106373801	I25	10	3	9	442			
JM-2			350404106382501	JM-2	10	3	29	242			120
LOS ANGELES 5			351104106355701	LA5	11	3	14	141	5078		153
LOS ANGELES 6			351038106361301	LA6	11	3	15	442	5077		160
LOS ANGELES 7			351056406355801	LA 7	11	3	14	134	5084		165
MONTANO 5a			350809106371901	Mo5a	11	3	33	424			200
MW-1			350021106531101	MW-1	9	1	18	333			746
MW-2			350017106521201	MW-2	9	1	18	444			896
SAN JOSE 3 (obs)			*350304106383401*	*SJ3obs*	*10*	*3*	*32*	*412*	*4952*		*503*
SAN JOSE 9 (obs)			350256106390801	SJ9	10	3	32	314	4940	1963	765
SBLF-2			345858106380601	SBLF-2	9	3	28	114			468.5
SJ6 OP UNIT 7D				SJ6-7D	10	3	32			1991	875
YALE MW5			350300106380501	YaMW5	10	3	33	314			215

Current Name	Other Name 1	Other Name 2	USGS	ABQ		Well Location			Elev	Year	Total
			Identifer	Map Code	T (N)	R (E)	Sec	Quarter		Drilled	Depth
WALKER 1			351025106323801	Wa1	11	4	21	112	5699	1980	1843
WALKER 2			351023106321301	Wa2	11	4	20	221	5593	1980	1800
WEBSTER 1	ALAMEDA 1		351029106332301	We1	11	4	18	434	5436	1977	1389
WEBSTER 2	ALAMEDA 2		351013106333501	We2	11	4	19	142	5284	1977	1470
WEST MESA 1			350438106443501	WM1	10	2	21	343	5179	1958	1180
WEST MESA 2			350508106435501	WM2	10	2	21	213	5167	1962	1450
WEST MESA 3			350443106395801	WM3	10	2	21	412	5154	1974	1426
WEST MESA 4			350442106431801	WM4	10	2	22	312	5101	1975	1430
YALE 1	YALE 2		350426106372601	Ya2	10	3	21	443	5159	1963	1010
YALE 2	YALE 3		350358106372901	Ya3	10	3	28	243	5126	1973	1289
YALE 3	YALE 4		350435106380101	Ya4	10	3	21	341	5080	1973	1240

Current Name	Other Name 1	Other Name 2	USGS	ABQ		Well Location			Elev	Year	Total
			Identifer	Map Code	T (N)	R (E)	Sec	Quarter		Drilled	Depth
Other Wells											
BERNALILLO 3				Be3	13	3	24	3311		1991	970
BERNALILLO 4				Be4	13	3	25	4141		1992	
CERRO COLORADO 1			350014106531301	CC1	9	1	7	244	5835	1990	1771
SAF No. 1			350846106492601	Saf1	11	1	27		5866	1988	2410

Current Name	Other Name 1	Other Name 2	USGS	ABQ		Well Location			Elev	Year	Total
			Identifer	Map Code	T (N)	R (E)	Sec	Quarter		Drilled	Depth
Geological Data Wells											
Airport Industrial Area					10	3	34	144	5301		1010
Carpenter-Atrisco No. 1					10	1	28	440	5800	1942	6652
Industral					10	4	29	413	5434		1004
Industrial					10	4	31	411	5383		1200
Industrial					10	3	7	441	4960		723
Norrins Oil Test No.2					11	4	19	144	5378	1940	5024
Public Service Company					11	3	23	121	5096		912
Public Supply					9	2	12	322	4928		241
Radar Station Water Well					10	1	30	220	5955		1385
Shell Isleta No. 2					8	2	16	133	5128	1981	21266
Shell West Mesa Fed. No. 1					11	1	24	241	5774	1983	19374
Snachez Domestic					9	2	32	422	5200	1976	402
SW Landfill					9	2	29	343	5300	1985	600
SWAB TEST WELL 1	W Mesa 1a		350449406493101	Swab1	10	1	22	322	5790		1179
SWAB TEST WELL 2	W Mesa 2		351046106464701	Swab2	11	2	18	313	5745		1800
SWAB TEST WELL 3	W Mesa 3		351051106395301	Swab3	11	3	18	411	4991		1055
Tafoya Domestic					9	2	29	133	5415	1987	800
Transocean Isleta No. 1					8	3	8	424	5266	1978	10378
Veterns Hospital					10	3	36	132	5342		1000

APPENDIX C

Characteristics of major hydrostratigraphic units and their relationship to lithofacies subdivisions that are delineated on Plates 1 to 7

APPENDIX C. **Hydrostratigraphic units and their relationship to lithofacies subdivisions that are delineated on Plates 1 to 7**

Unit	Description
RA RAr RAp	River alluvium; channel and floodplain deposits of inner Rio Grande (RAr) and Puerco (RAp) valleys; as much as 120 ft thick. Map unit "Qf" of Kelley (1977). Forms upper part of the "shallow aquifer". Hydrogeologic (lithofacies) subdivision Iv*. Holocene to late Pleistocene
VA VAc VAt VAs	Valley-border alluvium; tributary-arroyo (and thin eolian) deposits in areas bordering inner Rio Grande and Puerco valleys, with locally extensive river-terrace deposits, as much as 200 ft thick. Fan, terrace and channel deposits of Calabacillas and Tijeras Arroyos are, respectively, designated VAc and VAt. VAs indicates older, sandy to silty, valley fill in the vicinity of Calabacillas and Black Arroyos. Map units "Qa" and "Qt" of Kelley (1977), and "Edith, Menaul, and Los Duranes" (alluvial-terrace) units of Lambert et al., 1982. Includes hydrogeologic (lithofacies) subdivisions Iv, II, and Vv. Most of unit is in the vadose (unsaturated) zone. Holocene to middle Pleistocene
PA PAt	Piedmont-slope alluvium; coarse-grained alluvium, mainly deposited as coalescent fans extending basinward from mountain fronts on the eastern and southwestern margins of the basin; as much as 150 ft thick; includes surficial deposits mantling piedmont erosion surfaces (including rock pediments). PAt designates deposits of ancestral Tijeras Arroyo system in the depression between I-40 and the SE Central-Ridgecrest Blvd. area (Lambert et al., 1982). Map units "Qfa" and "Qp" of Kelley (1977), and hydrogeologic (lithofacies) subdivisions Vf, Vd, and VI. Most of unit is in vadose zone. Holocene to middle Pleistocene
SF	Santa Fe Group - undivided; fill of intermontane basins of the Rio Grande rift in New Mexico and adjacent parts of Colorado, Texas, and Chihuahua (Mexico). Includes alluvial, eolian and lacustrine deposits; and interbedded extrusive volcanic rocks (basalts to silicic tuffs). In the Albuquerque Basin, the Santa Fe is a much as 15,000 ft thick. It is mapped both as a formation (member subdivisions) by Kelley (1977), and as a group (formation and member subdivisions) by Hawley (1978), Machette (1978a,b), and Lozinsky and Tedford (1991). The upper part of the Group forms the major aquifer in Albuquerque basin (and elsewhere in basins of the Rio Grande rift), and is subdivided into three hydrostratigraphic units:

USF USF-1 USF-2 USF-3	Upper Santa Fe Unit; coarse- to fine-grained deposits of ancestral Rio Grande and Puerco systems that intertongue mountainward with piedmont-alluvial (fan) deposits; volcanic rocks (including basalt, andesite and rhyolite flow and pyroclastic units) and thin, sandy eolian sediments are locally present. The unit is a much as 1200 ft thick. Subunit USF-1 comprises coarse-grained, alluvial-fan and pediment-veneer facies extending westward from the bases of the Sandia, Manzanita and Manzano uplifts. USF-2 includes deposits of the ancestral Rio Grande and interbedded fine-grained sediments in the structural depression between the Rio Grande and County Dump fault zones in the river-valley area. Alluvial and minor eolian deposits capping the Llano de Albuquerque (West Mesa) between the Rio Grande and Puerco Valleys form subunit USF-3. Unit includes Ceja Member of Kelley (1977), and Sierra Ladrones Formation of Machette (1978a,b) and Lozinsky and Tedford (1991). Forms lower part of "shallow aquifer" below river-floodplain areas, and upper part of basin-fill aquifer in western part of NE and SE Albuquerque well fields. Includes hydrogeologic (lithofacies) subdivisions Ib, II, III, V, Vd, Vf, VI, VIII and IX. Unit is in vadose zone west of the Rio Grande Valley. Early Pleistocene to late Miocene, mainly Pliocene
MSF MSF-1 MSF-2	Middle Santa Fe Unit; alluvial, eolian, and playa-lake (minor in northern basin area) basin-fill facies; coarse-grained alluvial-fan deposits intertongue basinward with sandy to fine-grained basin-floor facies, which include local braided-stream and playa-lake facies; basaltic volcanics are also locally present. The unit is as much as 10,000 ft thick in the Isleta Pueblo area of the Rio Grande Valley. Subunit MSF-1 comprises piedmont alluvial deposits derived from early-stage Sandia, Manzanita and Manzano uplifts including the ancestral Tijeras Canyon drainage basin. MSF-2 comprises sandy to fine-grained basin-floor sediments that intertongue westward and northward with coarser grained deposits derived from the Colorado Plateau and southern Rocky Mountain provinces and Rio Grande rift basins to the northeast. Includes upper part of Popotosa Formation of Machette (1978a,b) and Lozinsky and Tedford (1991) in southern Albuquerque Basin, Cochiti Formation of Manley (1978), and "middle red" formation (member) of Lambert (1968) and Kelley (1977). Forms major part of basin-fill aquifer system in much of the northern part of basin. Includes hydrogeologic (lithofacies) subdivisions II, III, IV, V, Vd, Vf, VI, VII, VIII and IX. Late to middle Miocene

LSF Lower Santa Fe Unit; alluvial, eolian, and playa-lake basin-fill facies; sandy to fine-grained basin-floor sediments, which include thick dune sands and gypsiferous sandy mudstones; grades to conglomeratic sandstones and mudstones toward the basin margins (early-stage piedmont alluvial deposits). The unit is as much as 3500 ft thick in the central basin areas, where it is thousands of feet below sea level. Includes lower part of Popotosa Formation of Machette (1978a,b) and Lozinsky and Tedford (1991) in southern Albuquerque (Belen) Basin; and Zia (sand) Formation of Galusha (1966) and Kelley (1977) in northern part of basin. At present, is not known to form a major part of the Albuquerque Basin aquifer system. Eolian (Zia) and facies could be at least a local (future) source of groundwater in the far northwestern part of the basin (west and northwest of Rio Rancho). Includes hydrogeologic (lithofacies) subdivisions IV, VII, VIII, IX and X.

Middle Miocene to late Oligocene

* Lithofacies subdivisions of hydrogeologic units are defined in Appendix D.

APPENDIX D

Lithofacies subdivisions of basin and valley fills (Plates 2 to 7), their occurrence in hydrostatigraphic and rock-stratigraphic units, and their relationship to major aquifer systems in the Albuquerque Basin

APPENDIX D. **Lithofacies subdivisions of basin and valley fills and their occurrence in hydrostratigraphic and rock-stratigraphic units in the Albuquerque Basin.**

Subdivision Descriptions	Hydrostratigraphic and Rock-stratigraphic units, correlative lithofacies, and aquifers systems
I. Sand and gravel, river-valley and basin-floor fluvial facies; channel and floodplain deposits of the Rio Grande and Rio Puerco underlying 1) the modern river-valley floor--facies Iv, 2) river-terrace surfaces-- deposits primarily in the vadose zone, and 3) ancient relict or buried basin-floor fluvial plains--facies Ib. Gravel is characterized by sub-rounded to well-rounded pebbles and small cobbles of resistant rock types (mainly igneous and metamorphic) derived in part from extra-basin source areas. Iv. Sand and pebble to cobble gravel, with thin, organic-rich silty sand to silty clay lenses in Rio Grande Valley; as much as 50 ft of silt-clay in upper part of deposit in Puerco Valley; indurated zones of carbonate cementation rare or absent; as much as 130 feet thick. Ib. Sand and pebble gravel (>85%), with thin discontinuous beds and lenses of sandstone, silty sand, and silty clay (<15%); extensive basin-floor fluvial facies; usually nonindurated, but with local zones that are cemented with calcite (common), and other minerals (uncommon) including silicate clays, iron-manganese oxides, gypsum, silica, and zeolites; 200 to 400 feet thick in central	Facies Iv is a major component of unit RA (River alluvium) and upper part of shallow aquifer system Facies Ib is a major component of upper Santa Fe hydrostratigraphic unit (USF-2) and the Sierra Ladrones Fm (Upper Santa Fe Group); intertongues with facies II, III, V, and locally IX. Mostly in vadose zone in basin areas outside the Rio Grande and Puerco valleys; occurs in lower part of shallow aquifer below river-valley floors; and locally part of the upper aquifer system outside the valleys
II. Sand, with discontinuous beds and lenses of pebbly sand, silty sand, sandstone, silty clay, and mudstone; extensive basin-floor fluvial facies and local eolian deposits; gravel composition as in facies I; usually nonindurated, but local cemented zones; clean sand and pebbly-sand bodies make up an estimated 65-85 percent of unit; as much as to 1,000 feet thick in central basin areas.basin areas.	Major component of upper Santa Fe hydrostratigraphic unit (USF-2) and the Sierra Ladrones Formation, and present in the middle Santa Fe Group; intertongues with facies Ib, III, V, and locally IX. Partly in vadose zone in basin areas outside river valleys; occurs in lower part of shallow aquifer below river-valley floors; forms upper and middle parts of basin-fill aquifer system
III. Interbedded sand, silty sand, silty clay, and sandstone; with minor lenses of pebbly sand and conglomeratic sandstone; basin-floor alluvial and playa-lake facies; clay mineralogy of silty clay beds as in unit IX; usually nonindurated, but with local cemented zones as in facies Ib and II; secondary carbonate and gypsum segregations locally present in silty clay beds; common sheet-like to broadly-lenticular strata 10 to 40 feet thick; clean sand layers make up an estimated 35 to 65 percent of unit; as much as 2,000 feet thick in central basin areas. Major component of the middle Santa Fe Group, and present in the Sierra Ladrones Formation; intertongues with facies II, V, IX, and locally Ib.	Major component of middle Santa Fe hydrostratigraphic unit (MSF-2) and minor constituent of unit USF-2. Major component of the middle Santa Fe Group, and present in the Sierra Ladrones Formation; intertongues with facies II, V, IX, and locally Ib. Sand, pebbly sand and silty sand beds in facies III form a major part of the basin-fill aquifer system in the central Albuquerque Basin

IV.	Sand to silty sand, with lenses or discontinuous beds of sandstone, silty clay, and mudstone; eolian and alluvial facies primarily deposited on basin floors and contiguous piedmont slopes; nonindurated to partly indurated, with cementing agents including calcite (common), silicate clays, iron-manganese oxides, gypsum, and zeolites (uncommon); clean fine to medium sand makes up an estimated 35 to 65 percent of unit; as much as 2000 feet thick exposed near western edge of basin. Major component of Zia Formation in the Lower Santa Fe Group; probably correlative with parts of the Popotosa Formation in Valencia and Socorro Counties, intertongues with facies VII and X	Major component of lower Santa Fe hydrostratigraphic unit (LSF) and the Zia Formation in the Lower Santa Fe Group; also correlative with parts of the Popotosa Formation in Valencia and Socorro Counties; intertongues with facies VII and X. Sand and silty sand beds in facies IV may form a large part of a deep aquifer system in the northwestern Albuquerque Basin
V.	Gravelly sand-silt-clay mixtures (loamy sands to sandy clay loams) interbedded with lenticular to sheet-like bodies of sand, gravel, and silty clay; distal to medial piedmont-slope alluvial facies (mainly coalescent fan: Vf and Vd), also alluvial deposits along valley borders associated with fans and terraces major arroyo systems (Vv); with minor component of eolian sands and silts; gravel primarily in the granule, pebble and small cobble size range; clast composition reflects the lithologic character of the local source-bedrock terranes; usually nonindurated, but with discontinuous zones cemented with calcite; upper part of unit in the vadose zone. Symbol "V" designates undivided units Vf and Vd described below: Vf. Gravelly sand-silt-clay mixtures interstratified with discontinuous beds of sand, gravel and silty clay; alluvial and debris-flow deposits of coalescent fans associated with smaller, steep mountain-front watersheds, such as the Domingo Baca-Pino-Oso-Embudo basins of the Sandia Mountains; elongate (downslope) lenses of clean sand and gravel make up about 25 to 35 percent of the unit; as much as 1000 ft thick. Vd. Sand and gravel interstratified with discontinuous beds and lenses of gravelly to non-gravelly sand-silt-clay mixtures. Primarily deposits of large, distributary (braided-stream) channels on low-gradient alluvial fans, such as the Tijeras and Abo Canyon fans, that apex at the mouths of large watersheds (> 50 mi^2) in mountain ranges and high plateaus flanking the Albuquerque basin; sheet-like to broadly lenticular bodies of clean sand and gravel associated with fan-distributary channel complexes make up an estimated 35 to 65 percent of the unit; as much as 1000 ft thick. Major component of Sierra Ladrones and "middle" Santa Fe formations; intertongues with facies II, III, VI, and IX Vv. Gravelly sand-silt-clay mixtures interbedded with lenticular to sheet-like bodies of sand and gravel and silty clay. Arroyo fan and terrace deposits that border the inner valleys of the Rio Grande, Rio Puerco, Jemez Rivers and major tributary arroyos; lenticular bodies of clean sand and gravel deposits make up 35 to 65 percent of the unit; as much as 150 ft thick.	Major component of units Va and PA (valley-border and piedmont alluviums) and upper and middle Santa Fe hydrostratigraphic units (USF-1 and MSF-1). Major component of Sierra Ladrones Fm and middle Santa Fe Group; intertongues with facies II, III, VI, and IX. Clean to loamy sand and gravel lenses in facies Vd and Vf form major parts of the basin-fill aquifer system in the eastern Albuquerque metropolitan area

VI. Coarse gravelly sand-silt-clay mixtures (loamy sand and sandy loams to loams) interbedded with lenses of sand and gravel; proximal to medial piedmont-slope alluvial facies (fan and coalescent fan deposits - VId and VIf); gravel primarily in the pebble to cobble range (up to 10 inches), but can include boulders many feet in diameter; clast composition reflects lithologic character of source bedrock terranes; usually nonindurated, but with discontinuous layers that are cemented with calcite; upper part of unit in vadose zone. Symbol "VI" designates undivided units VIf and VId described below: VIf. Coarse gravelly sand-silt-clay mixtures interstratified with discontinuous beds of sand, gravel and clayey silt; debris flow and alluvial deposits of fans and coalescent fans associated with small, steep mountain-front watersheds as in unit Vf; elongated (downslope) lenses of clean sand and gravel make up an estimated 20 to 35 percent of unit; as much as 1000 ft thick. VId. Sand and gravel interstratified with discontinuous beds and lenses of coarse gravelly sand-silt-clay mixtures. Primarily deposits of large distributary (braided-stream) channels on low-gradient alluvial fans associated with large mountain watersheds as in unit Vd; broadly lenticular bodies of clean sand and gravel make up an estimated 35 to 50 percent of unit; as much as 1000 feet thick.	Component of unit PA piedmont alluvium, and upper and middle Santa Fe hydrostratigraphic units (USF-1 and MSF-1). Component of Sierra Ladrones Fm and middle Santa Fe Group; intertongues with facies V and VIII. Clean sand and gravel lenses in facies VI form parts of the basin-fill aquifer system in areas adjacent to mountain fronts in Albuquerque metropolitan area
VII. Conglomeratic sandstone, silty sandstone, and mudstone with lenses and discontinuous beds of conglomerate, sand, gravel, and gravelly sand-silt-clay mixtures (as in unit V); distal to medial piedmont-slope alluvial facies, with minor component of eolian sediments; coarse clast sizes and composition as in unit V; moderately-well to poorly indurated; cementing agents include calcite (common) and silicate clays, iron-manganese oxides, silica and zeolites (uncommon); clean weakly-cemented sand and gravel beds make up an estimated 10 to 25 percent of unit; as much as 1000 feet thick. Major component of unnamed formation in lower part of Santa Fe Group; probably correlative with piedmont facies of the Popotosa Formation in Valencia and Socorro Counties; intertongues with facies IV, VIII and X	Major component of lower Santa Fe hydrostratigraphic units (LSF) and unnamed formation in lower and middle Santa Fe Group; probably correlative with piedmont facies of the Popotosa Formation in Valencia and Socorro Counties; intertongues with facies IV, VIII and X. Weakly cemented sand and gravel beds in facies VII form part of the basin-fill aquifer system
VIII. Coarse conglomeratic sandstone and silty-sandstone, fanglomerate, and minor lenses of sand and gravel; proximal to medial piedmont-slope alluvial facies--and coalescent fan deposits; coarse clast sizes and compositions as in unit VI; moderately to well indurated; cementing agents as in unit VII; clean, weakly-cemented sand and gravel lenses make up an estimated 5 to 15 percent of unit, as much as 1000 feet thick. Component of basal Sierra Ladrones Fm, Popotosa Fm, and unnamed formations in middle lower part of Santa Fe Group (as in units VII and IV); intertongues with facies V, VI and VII	Minor component of all three Santa Fe hydrostratigraphic units. Component of basal Sierra Ladrones Fm, Popotosa Fm, and unnamed formations in middle lower part of Santa Fe Group (as in units VII and IV); intertongues with facies V, VI and VII. Weakly-cemented sand and gravel beds in facies VIII form small part of the basin-fill aquifer system

IX.	Silty clay interbedded with thin silty sand, sand, sandstone, and mudstone beds; basin-floor playa-lake and alluvial-flat facies; clay mineral assemblage includes calcium smectite, mixed layer illite-smectite illite, and kaolinite; secondary deposits of calcite, gypsum, sodium-magnesium-sulfate salts, and zeolites are locally present; weakly-cemented fine to medium sand and silty sand makes up an estimated 5-10 percent of unit; as much as 3000 feet exposed in southwestern basin areas. Major component of the Popotosa Formation in the southwestern Albuquerque (Belen) Basin; intertongues with facies III, II, V, and locally Ib; grades downward into unit X in central basin areas	Makes up fine-grained part of <u>middle Santa Fe hydrostratigraphic unit</u> (MSF) and locally is a component of the <u>upper Santa Fe unit</u> (USF-2). Major component of the Popotosa Formation in the southwestern Albuquerque (Belen) Basin; intertongues with facies II, III, V, and locally Ib; grades downward into unit X in central basin areas. Sand and silty sand beds in facies IX form very small part of the <u>basin-fill aquifer system</u>
X.	Mudstone and claystone interstratified with thin sandstone and silty sandstone beds; basin floor playa-lake and alluvial-flat facies; clay mineral and non-clay secondary mineral assemblages as in facies IX; weakly cemented fine to medium sand and silty sand makes up an estimated 0 to 5 percent of unit; not exposed in central and northern basin areas; thickness unknown, but may exceed 2000 ft.Major component of unnamed formation in lower part of the Santa Fe Group; probably correlative with basin-floor facies of the Lower Popotosa intertongues with facies IV and VII	Makes up fine-grained part of <u>lower Santa Fe hydrostratigraphic unit</u> (LSF). Major component of unnamed formation in lower part of the Santa Fe Group; probably correlative with the Zia Formation and basin-floor facies of the lower Popotosa Formation; intertongues with facies IV and VII. Weakly-cemented sand and silty sand beds in facies X form very minor to negligible component of the <u>basin-fill aquifer system</u>

APPENDIX E

Explanation of other lithologic and structural symbols used on Plates 1 to 7

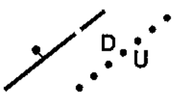
APPENDIX E. **Explanation of other lithologic symbols used in conjunction with hydrostratigraphic units on Plates 1 to 7.**

Unit	Description
	<u>Miscellaneous valley and basin fill deposits (Lambert, 1968; Lambert et al., 1982)</u>
a	Thin, discontinuous alluvial deposits on older basin fill and basalts of the Llano de Albuquerque area between the Rio Grande and Puerco Valleys.
e	Sandy eolian deposits forming nearly continuous cover on stable summits of high tablelands (mesas) flanking the Rio Grande Valley. Underlying unit (Upper Santa Fe or basalt flow) is identified by superposition of symbols (e.g. e/USF or e/Qb). Symbol alone denotes thick dune deposits on escarpment rims, particularly at the west edge of the Llano de Albuquerque (Ceja del Rio Puerco).
g	Channel gravel deposits associated with remnants of river-terraces bordering the inner valley of the Rio Grande. Includes outcrops of Edith, Menaul and upper buff (?) "gravels" of Lambert (1968). Pebble to cobble gravels are commonly underlain by pumiceous USF-2 beds at the edge of the inner valley (east of Edith Blvd.).
s	Sandy to silty fluvial deposits associated with river-terrace remnants west of the Rio Grande. Includes Los Duranes formation of Lambert (1968).
	<u>Upper Cenzoic volcanic and igneous intrusive rocks on or in basin and valley fill (Kelley and Kudo, 1978)</u>
Qb	Younger basaltic volcanics of the Albuquerque and Cat Hills fields: extensive lava flows, with localized vent units such as cinder cones and lava domes, and possible feeder dikes and sills in subsurface; late middle Pleistocene.
Tb	Older basaltic volcanics of the Wind Mesa and Isleta fields, extensive lava flows, with localized vent units; include possible sills and/or buried flows west of the Albuquerque volcanoes; Pliocene.
Tbt	Basaltic tuffs and associated lavas and fluvial sediments of the Isleta (Paria Mesa) center; Pliocene.
Tvi	Silicic to basaltic intrusive and volcanic rocks penetrated in deep wells west of the County Dump - Albuquerque Volcanoes fault zone; includes possible intrusives from the Cerro Colorado center (quartz-latite and trachyte); late Miocene (?) and Pliocene.

Bedrock Units (Reiche, 1949; Kelley, 1977; Kelley and Northrop, 1975; Myers and McKay, 1970, 1976)*

Mz	Mesozoic rocks-undivided; primarily upper Cretaceous sandstones of shales beneath the Puerco Valley and western Llano de Albuquerque area, and possible Triassic sandstones and mudstones west of the Hubbell fault zone and south of Tijeras Arroyo east of the Rio Grande.
Pe	Permian rocks-undivided; sandstones, mudstones, and minor limestones of the Abo and Yeso Formations exposed along the Hubbell fault zone.
P	Pennsylvanian rocks-undivided; limestones, sandstones and shales of the Madera Group and the Sandia Formation in the Tijeras fault zone and Manzanita foothill area south of Tijeras Canyon.
pC pCg pCm	Precambrian rocks-undivided; igneous intrusive and metamorphic rocks of the Sandia and Manzanita uplifts; pCg - Sandia granite and local bodies of metamorphic rocks north of the Tijeras fault zone; pCm - metamorphic rocks (greenstone, quartzite, schist, gneiss and metavolcanics) south of the Tijeras fault.
*	Primarily hydrogeologic boundary units with low hydraulic conductivities. However, solution-enlarged joints and fractures in Paleozoic carbonate rocks (Pennsylvanian and Permian) may be highly conductive; and fault zones such as the Tijeras "shear" zone may be characterized by local areas of high permeability.

Faults



High-angle normal fault (map view), dashed where inferred, dotted where buried; bar and ball or "D" on downthrown side


High-angle normal fault (cross section view), dashed where inferred; direction of relative motion shown by arrows


Other faults and shear zones dominated by strike slip displacements

Other Symbols

° ° ° ° ° ° ° ° Approximate eastern limit of ancestral Rio Grande deposits (USF-2) in subsurface

■ Water wells with drill cutting and core analyses

⧅ Water wells with drill cutting analyses

□ Water wells with driller's log analyses

Oil Test Wells with drill cutting analyses

Oil Test Well with driller's log analyses

APPENDIX F

Stratigraphic data for key boreholes within the Albuquerque area

APPENDIX F

Hydrogeologic (hydrostratigraphic and lithofacies) units in boreholes studied; summary of preliminary interprelations for development of conceptual model

J. W. Hawley

Key to Wells

City Water Wells with Preliminary Drill-Cutting Analyses 1 /

Burton 5 (Bu5)	2 /
Charles Wells 5 (Ch5)	3 /
Coronado 2 (Cr2)	4 /
Gonzales 2 (Gz2)	3 /
Love 8 (Lv8)	3 /
Ridgecrest 5 (Ri5)	3 /
Thomas 5 (Th5)	3 /
Thomas 6 (Th6)	3 /
Thomas 7 (Th7)	3 /
Thomas 8 (Th8)	4 /

Other Water Wells with Premliminary Drill-Cutting Analyses 1 /

Cerro Colorado 1 (CC1)	3 /
CC Landfill Monitoring Well 1 (MW1)	5 /
SAF No. 1 (Saf1)	3 /
SWAB Test Well 1 (Swab1)	6 /
SWAB Test Well 2 (Swab2)	6 /
SWAB Test Well 3 (Swab3)	6 /

Water Wells with Analyses of Driller Logs (Lambert, 1968, Appendix D)

9-2-12-322 (Public Supply)
10-1-30-220 (Radar Station)
10-2-21-343 (City West Mesa 1, WM1)
10-3-7-441 (Industrial)
10-3-34-144 (Airport)
10-3-36-132 (VA Hospital)
10-4-29-413 (Industrial)
10-4-31-411 (Industrial)
11-3-23-121 (Reeves Power Plant, PNM)

Other Water Wells with Analyses of Drillers Logs

9-2-29-133 (Southwest Landfill, Inc.)
9-2-29-343 (Tafoya)
9-2-32-422 (Sanchez)

Oil Test Holes with Analyses of Drillers Logs (Lambert, 1968, Appendix D)

10-1-23-440 (Carpenter-Atrisco Grant No. 1)
11-4-19-144 (Norrins Realty Co. No. 2 Fee, N. Albuquerque Acres)

1_/ Cuttings in NM Bureau of Mines and Mineral Resources archives, except Burton 2 and Swab 1-3

2_/ Cutting analyses by J. W. Shomaker, Inc.

3_/ Cutting analyses by J. W. Shomaker, Inc. and NMBM&MR

4_/ Cutting analyses by Geohydrology Associates, Inc. and NMBM&MR

5_/ Cutting analyses by Camp, Dresser and McKee, Inc. and NMBM&MR

6_/ Cutting analyses by USGS, Water Resources Div. (Wilkins, 1987)

BURTON 5 (10-3-26-422)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-60	5275	V	PA
60-190	5215	Vd	USF-1
190-210	5085	Vf	USF-2
210-390	5065	Ib	USF-2
390-440	4885	II	USF-2
440-500	4835	Ib	USF-2
500-720	4775	Vd	USF-1
720-760	4555	II	USF-2
760-~1000	4515	Vd	USF-2
~1000-1330	4275	Vd	MSF-1
HOLE BOTTOM	3945		

CHARLES WELLS 5 (10-3-12-331)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-98	5219	Vf	PA
98-230	5121	Ib (Pumice)	USF-2
230-650	4989	Ib (Obsidian 430-440)	USF-2
650-910	4569	Vd	USF-1
910-980	4309	V	USF-1
980-1030	4239	Vd	USF-1
1030-1120	4189	III	MSF-2
1120-1300	4099	V	MSF-1
1300-1580	3919	Vf	MSF-1
1580-2020	3620	V - III	MSF
2020-2930	3199	IX - VII	LSF
2930-3230	2289	IX	LSF-2
HOLE BOTTOM	1989		

CORONADO 2 (11-3-24-140)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-180	5230	Vf	PA
180-650	5050	Ib	USF-2
650-890	4480	II	USF-2
890-900	4340	Ib	USF-2
900-1180	4330	II	USF-2
1180-1220	4050	Vf	MSF-1
1220-1410	4010	III - II	MSF-2
HOLE BOTTOM	3820		

GONZALES 2 (10-3-11-134)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-160	5100	Iv	VA
160-310	4940	I (Ib or Iv)	USF-2 or VA
310-490	4790	Ib	USF-2
490-540	4610	III	USF
540-620	4560	Ib	USF-2
620-670	4480	III	USF
670-730	4430	Ib	USF-2
730-870	4370	IX - III	USF
870-1400	4230	IX	USF
HOLE BOTTOM	3700		

LOVE 8 (10-4-18-411)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-95	5310	Vf	PA
95-200	5215	Vf	PA
200-360	5110	Ib	USF-2
360-1020	4950	Vd	USF-1
1020-1100	4290	V	USF-1
1100-1190	4210	IX	MSF-2
1190-1460	4120	V	MSF-1
1460-1520	3850	IX	MSF-2
1520-1640	3790	Vf	MSF-1
1640-1710	3670	IX	MSF-2
1710-1810	3600	Vf	MSF-1
1810-2120	3500	V - III	MSF
2120-2640	3190	VII - IX	LSF
2640-3140	2670	IX - VII	LSF
3140-3335	2170	IX	LSF
HOLE BOTTOM	1975		

RIDGECREST 5 (10-4-30-121)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-80	5350	Vd	PA
80-180	5270	Vd	USF-1
180-230	5170	Vf	USF-1
230-380	5120	Ib	USF-2
380-510	4870	II	USF-2
510-870	4840	Ib	USF-2
870-1110	4480	Vd	USF-1
1110-1630	4240	Vd	MSF-1
HOLE BOTTOM	3720		

THOMAS 5 (10-4-6-124)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-190	5356	Vf	PA
190-310	5166	Vf	USF-1
310-570	5046	Ib	USF-2
570-1000	4786	Vf	USF-1
1000-1100	4356	IX	USF-2
1100-1190	4256	Vf	USF-1
1190-1330	4166	III	MSF-2
1330-1450	4026	IX	MSF-2
1450-1530	3906	V	MSF-1
1530-1720	3826	III	MSF-2
1720-1830	3636	Vd	MSF-1
1830-2100	3526	III	MSF-2
2100-3363	3256	IX - VII	LSF
HOLE BOTTOM	1993		

THOMAS 6 (10-4-6-122)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-170	5408	Vf	PA
170-245	5238	Vf	USF-1
245-530	5163	Ib	USF-2
530-590	4878	Vf	USF-1
590-710	4818	Ib	USF-2
710-880	4698	Ib - III	USF-2
880-1030	4528	III	USF-2
1030-1110	4378	IX - III	USF-2
1110-1200	4298	IX	USF-2
1200-1340	4208	III	MSF-2
1340-1420	4068	IX	MSF-2
1420-1529	3988	V	MSF-1
HOLE BOTTOM	3878		

THOMAS 7 (10-4-6-122)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-95	5341	Vf	PA
95-220	5246	Ib	USF-2
220-380	5121	III	USF-2
380-500	4961	Ib	USF-2
500-670	4841	Vd	USF-1
670-920	4671	II	USF-2
920-1085	4421	III	USF-2
1085-1240	4256	II	USF-2
1240-1485	4101	III	MSF-2
BOTTOM HOLE	3856		

THOMAS 8 (10-4-6-122)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-130	5410	Vf	PA
130-330	5280	Vf	USF-1
330-490	5080	II	USF-2
490-1240	4920	Vf	USF-1
1240-1460	4170	Vf	MSF-1
1460-1560*	3950	III - Vf	MSF
1560-1695	3850	V	MSF
HOLE BOTTOM	3715		

CERRO COLORADO 1 (9-1-7-244)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-290	5835	Ib	USF-3
290-400	5545	III	MSF-2
400-1410	5435	IX	LSF
1410-1530	4425	IV	LSF
1530-1760	4305	Silic Volcanic Rock (Tvi)	
HOLE BOTTOM	4075		

CERRO COLORADO LANDFILL (9-1-18-333)
MONITORING WELL (MW) 1

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-30	5486	Vv	VA
30-150	5456	VII	MSF
150-290	5336	IV	LSF
290-590	5196	III	LSF
590-740	4896	IV	LSF
HOLE BOTTOM	4746		

SAF NO. 1
SOIL AMENDMENT FACILITY (11-1-27-433)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-335	5866	Ib	USF-3
335-470	5531	II - V	USF-3
470-830	5396	III - IV	MSF
830-1524	5036	IV	LSF
1524-2428	4342	IV - VII	LSF
HOLE BOTTOM	3438		

SWAB TEST WELL 1 (10-1-22-322)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-310	5790	Ib	USF-3
310-580	5480	VII - III	MSF
580-1040	5210	III - VII	MSF
1040-1150	4750	IX - VII	LSF
1150-1180	4640	VII	LSF-1
1180-1204	4610		Basalt (Flow?)
HOLE BOTTOM	4586		

SWAB TEST WELL 2 (11-2-18-313)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-315	~5745	Ib	USF-3
315-620	5430	V - III	USF-3
620-770	5125	III	MSF-2
770-1820	4975	IX - III	MSF-2
HOLE BOTTOM	3925		

SWAB TEST WELL 3 (11-3-18-411)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-70	4991	Iv	RA
70-240	4921	I - II	VA or USF-2
240-280	4751	IX	USF-2
280-510	4711	Ib	USF-2
510-640	4481	II	USF-2
640-900	4351	III	USF-2
900-1055	4091	II	USF-2?
HOLE BOTTOM	3936		

WATER WELL 9-2-12-322 (Lambert, 1968, p. 288)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-64	4928	Iv	RA
64-108	4864	II	VA
108-217	4820	III	USF-2
217-241	4711	II	USF-2
HOLE BOTTOM	4687		

WATER WELL 10-1-30-220 (Lambert, 1968, p. 285)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-235	5955	Ib	USF-3
235-392	5720	VII	MSF
392-547	5563	III	MSF-2
547-762	5408	III	LSF
762-840	5193	VII	LSF
840-1371	5115	III - IX	LSF
1371-1386	4584	Basalt Flow?	
HOLE BOTTOM	4569		

WATER WELL 10-2-21-343 (Lambert, 1968, p. 287)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-15	5175	Vv	VA
15-327	5160	Ib or Iv	USF-2 OR VA
327-430	4848	V - IX	USF-2
430-880	4745	IX	USF-2
880-935	4295	V	USF-2
935-1180	4240	III - IX	USF-2
HOLE BOTTOM	3995		

WATER WELL 10-3-7-441 (Lambert, 1968, p. 289)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-72	4960	Iv	RA
72-198	4888	III-Ib	USF-2
198-403	4762	Ib - III	USF-2
403-626	4557	III	USF-2?
626-697	4334	IB (V?)	USF-2?
697-723	4263	III	MSF-2
HOLE BOTTOM	4237		

WATER WELL 10-3-34-144 (Lambert, 1968, p. 291)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	HYDROSTATIGRAPHIC
0-400	5301	No Log	
400-700	4901	II	USF-2
700-900	4601	Vf	USF-1
900-950	4401	Vd, Ib	USF
950-1010	4351	Vf	USF-1
HOLE BOTTOM	4291		

WATER WELL 10-3-36-132 (Lambert, 1968, p. 293)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-330	5342	Vd	USF-1
330-540	5012	Ib	USF-2
540-1020	4802	II - Vd	USF
HOLE BOTTOM	4322		

WATER WELL 10-4-29-413 (Lambert, 1968, p. 294)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-70	5434	VI	PA
70-211	5364	V	USF-1
211-270	5223	VI	USF-1
270-340	5164	II (Vd)	USF-2 (USF-1)
340-460	5094	III	USF-2
460-630	4974	VI	USF-1
630-780	4804	II (Vd)	USF-2 (USF-1)
780-870	4654	Vi	USF-1
870-960	4564	V	USF-1
960-1004	4474	VI	USF-1
HOLE BOTTOM	4430		

WATER WELL 10-4-31-411 (Lambert, 1968, p. 295)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-62	5383	V	USF-1
62-112	4321	VI	USF-1
112-251	4271	V	USF-1
251-408	4132	VI	USF-1
408-521	3975	III	USF-2
521-667	3862	VI	USF-1
667-995	3716	III	USF-2
995-1200	3388	IV - VII	USF/MSF
HOLE BOTTOM	3183		

WATER WELL 11-3-23-121 (Lambert, 1968, p. 296)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-24	5096	Vv	PA
24-80	5072	Iv	VA
80-863	5016	Ib - III	USF-2
863-912	4216	III	USF-2?
HOLE BOTTOM	4184		

WATER WELL 9-2-29-133 (S.W. Landfill)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-80	5415	Ib	USF-2
80-400	5335	III	USF-2
400-600	5015	IX	USF-2
600-650	4815	Ib	USF-2
650-750	4765	III	USF-2
750-800	4665	Ib	USF-2
HOLE BOTTOM	4615		

WATER WELL 9-2-29-343 (Tafoya)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-40	~5300	Vv	VA
40-290	5260	IX	USF-2
290-320	5010	Ib	USF-2
320-585	4980	IX	USF-2
585-600	4715	Ib	USF-2
HOLE BOTTOM	4700		

WATER WELL 9-2-32-422 (Sanchez)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-240	5200	III	USF-2
240-335	4960	II	USF-2
335-402	4865	III	USF-2
HOLE BOTTOM	4798		

CARPENTER ATRISCO GRANT NO. 1 OIL TEST
WELL 10-1-23-440 (Lambert, 1968; Lozinsky, 1988)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-320	5800	Ib	USF-3
320-1040	5480	VII - III	MSF
1040-1550	4760	IV	LSF
1550-1580	5250	Basaltic Volcanics	
1580-2670	4220	IV - III	LSF
2670-3300	3130	IV	LSF
3300-6652	2500	Middle to Lower Tertiary sedimentary rock with volcanic or intrusive zone from 3550-3640 ft depth (elev. 2250-2160)	
HOLE BOTTOM	-852		

NORINS OIL TEST WELL 11-4-19-144 (Lambert, 1968, p. 299; Stearns, 1953)

DEPTH (FT)	ELEVATION (TOP)	UNIT LITHOFACIES	UNIT HYDROSTATIGRAPHIC
0-150	5375	Vf	PA
150-205	5225	Ib? or Vf?	USF-2 or 1
205-850	5180	Vf	USF-1
850-1000	4525	IX	USF-2
1000-1200	4375	Vf - II	USF
1200-1675	4175	Vf	MSF-1
1675-2150	3700	VII	MSF-1
2150-5024	3225	IX - IV	LSF
HOLE BOTTOM	351		

APPENDIX G

Summary of petrologic data

TABLE 1. Abundance of quartz, feldpar, and phyllosilicates in sidewall cores from wells Charles 5 and Love 8. Values are in volume percent of the whole rock.

Well	Depth	Qm	Qgn	Qvrf	Qmrf	Qss/slt	Qund	Qp	Pm	Pgn	Pvrf	Pss/slt	Pund	Pseric	Km	Kgn	Kvrf	Kss/slt	Kund	Kseric	Sergrn	BI	BIgn	BIvrf	BIurf	MSC	MSCgn	CHL	CHLgn
Charles 5	1677.0	28	0	0	0	0	1	2	15	0	tr	0	0	0	6	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Charles 5	1789.8	19	1	0	0	0	tr	2	11	tr	1	0	0	0	8	1	0	0	tr	0	tr	tr	0	0	0	0	0	0	0
Charles 5	1804.0	23	2	0	0	0	tr	5	13	1	1	0	tr	0	6	1	0	0	0	tr	0	tr	0	0	0	0	0	0	0
Charles 5	1818.2	21	0	tr	0	0	1	2	12	0	1	0	1	1	6	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Charles 5	1851.1	23	0	0	1	0	2	2	10	0	tr	0	1	1	6	0	0	0	tr	0	0	0	0	0	0	0	0	0	0
Charles 5	2318.2	18	tr	0	0	0	1	2	9	1	2	0	1	1	6	1	0	0	tr	0	tr	tr	0	0	0	0	0	0	0
Charles 5	2330.0	20	0	0	tr	0	tr	3	16	tr	1	0	2	tr	3	0	0	0	1	0	tr	0	0	0	0	0	0	0	0
Charles 5	2452.1	31	0	0	0	0	2	4	3	tr	0	0	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Charles 5	2510.3	17	2	0	0	1	1	2	7	2	0	0	tr	1	5	tr	0	tr	0	0	0	tr	0	0	0	0	0	0	0
Charles 5	2519.9	27	2	0	0	0	0	3	6	1	0	0	0	2	4	1	0	0	0	0	0	tr	0	0	0	0	0	0	0
Charles 5	2558.2	10	0	0	0	0	0	tr	1	0	0	0	0	0	2	0	0	0	0	0	0	tr	0	0	0	0	0	0	0
Charles 5	2783.2	3	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	tr	0	tr	0
Charles 5	2952.1	11	0	0	0	0	0	1	3	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	tr	0	0	0
Charles 5	2992.1	20	3	0	tr	tr	1	3	8	1	1	0	1	1	5	1	0	0	0	0	0	tr	0	0	0	0	0	0	0
Charles 5	3079.1	2	0	0	0	0	0	0	tr	0	0	0	0	0	tr	0	0	0	0	0	0	0	0	0	0	tr	0	0	0
Charles 5	3123.1	22	tr	0	0	0	1	2	15	0	1	0	1	0	7	0	0	0	tr	0	0	0	0	0	0	0	0	0	0
Charles 5	3162.1	22	1	0	0	0	tr	3	10	tr	2	0	1	2	4	1	0	0	0	0	0	tr	0	tr	0	0	0	0	0
Charles 5	3214.1	17	0	0	0	0	0	1	12	0	1	0	0	tr	3	0	0	0	tr	0	0	1	0	0	0	0	0	0	0
Love 8	2012.0	9	8	0	0	1	0	18	5	6	1	0	0	1	2	8	0	tr	0	0	0	0	0	0	0	0	1	0	0
Love 8	2037.0	16	1	0	0	0	0	3	8	0	1	0	0	1	6	tr	0	0	tr	0	0	tr	0	0	0	0	0	0	0
Love 8	2113.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	2195.0	16	2	tr	0	0	1	5	6	3	1	0	0	2	6	2	0	0	0	0	0	tr	0	0	tr	0	0	0	0
Love 8	2350.0	22	2	0	0	0	1	2	8	2	1	0	1	1	1	0	0	0	0	0	0	0	tr	0	0	0	0	0	0
Love 8	2375.0	19	1	0	0	0	tr	4	8	1	1	0	2	2	6	tr	0	0	tr	0	0	0	0	0	0	0	0	0	0
Love 8	2485.0	12	0	0	0	tr	0	tr	6	0	0	tr	0	0	5	0	0	0	0	0	0	1	0	0	0	tr	0	0	0
Love 8	2520.0	8	2	0	0	0	1	4	6	1	tr	0	1	tr	7	tr	0	0	tr	0	tr	tr	0	0	0	tr	0	0	0
Love 8	2570.0	3	0	0	0	0	0	tr	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	2870.0	16	0	0	0	0	1	2	3	tr	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	3012.0	4	9	0	0	0	tr	4	1	11	tr	0	1	1	5	15	0	0	tr	0	0	0	0	0	0	0	tr	0	tr
Love 8	3042.0	11	9	0	0	0	1	3	6	6	2	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	3083.0	12	0	0	0	0	0	tr	7	tr	0	0	0	tr	4	0	0	0	0	0	0	1	0	0	0	tr	0	0	0
Love 8	3095.0	21	tr	0	0	0	tr	1	5	0	0	0	1	1	5	tr	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	3115.0	10	3	0	0	0	0	4	4	2	1	0	0	1	5	3	tr	0	0	0	0	0	0	1	0	0	0	0	0
Love 8	3195.0	24	0	0	0	0	0	1	0	12	0	0	1	0	10	0	0	0	tr	0	0	2	0	0	0	0	0	0	0
Love 8	3245.0	15	1	0	0	0	1	1	10	1	1	0	1	0	7	1	0	0	1	0	0	tr	0	0	0	0	0	0	0

Abbreviations: Qm = monocrystalline quartz, Qgn = quartz in granitic/gneissic rock fragment, Qvrf = quartz in volcanic rock fragment, Qmrf = quartz in metamorphic rock fragment, Qss/slt = quartz in sandstone/siltstone rock fragment, Qund = quartz in undifferentiated rock fragment, Qp = polycrystalline quartz, Pm = monocrystalline plagioclase, Pgn = plagioclase in granitic/gneissic rock fragment, Pvrf = plagioclase in volcanic rock fragment, Pss/slt = plagioclase in sandstone/siltstone rock fragment, Pund = plagioclase in undifferentiated rock fragment, Pseric = sericitized plagioclase, Km = monocrystalline potassium feldspar, Kgn = potassium feldspar in granitic/gneissic rock fragment, Kvrf = potassium feldspar in volcanic rock fragment, Kss/slt = potassium feldspar in sandstone/siltstone rock fragment, Kund = potassium feldspar in undifferentiated rock fragment, Kseric = sericitized potassium feldspar, Sergrn = sericitized grain (composition indeterminate), BI = biotite, BIgn = biotite in granitic/gneissic rock fragment, BIvrf = biotite in volcanic rock fragment, BIurf = biotite in undifferentiated rock fragment, MSC = muscovite, MSCgn = muscovite in granitic/gneissic rock fragment, CHL = chlorite, CHLgn = chlorite in granitic/gneissic rock fragment, tr = less than 1%.

TABLE 2. Abundance of rock fragments, opaque grains, and heavy minerals in sidewall cores from wells Charles 5 and Love 8. Values are in volume percent of the whole rock.

Well	Depth	VRF	CHT	CHTvrf	Argil	Ss/sltn	CRF	CRFvrf	MRF	Silund	URF	OPQ	OPQvrf	HM	HMgn	HMvrf	HMurf
Charles 5	1677.0	1	0	0	0	0	*	0	0	1	3	tr	0	6	0	0	0
Charles 5	1789.8	4	1	0	0	0	1	0	0	1	1	0	0	2	0	0	0
Charles 5	1804.0	11	0	0	tr	0	0	0	1	1	0	0	0	1	0	0	0
Charles 5	1818.2	6	tr	0	1	0	*	0	0	2	5	1	0	2	0	0	0
Charles 5	1851.1	4	0	0	1	0	*	0	tr	3	4	0	0	2	0	0	0
Charles 5	2318.2	12	1	0	0	1	*	0	0	2	1	1	0	1	0	0	0
Charles 5	2330.0	11	1	0	1	0	*	0	0	2	3	1	0	1	0	0	0
Charles 5	2452.1	3	tr	0	2	0	*	0	0	2	6	tr	0	0	0	0	0
Charles 5	2510.3	9	tr	0	8	4	1	0	0	1	0	0	0	0	0	0	0
Charles 5	2519.9	11	0	0	0	0	1	0	0	3	1	tr	0	1	0	0	0
Charles 5	2558.2	0	0	0	tr	0	1	0	0	1	2	tr	0	0	0	0	0
Charles 5	2783.2	0	0	0	0	0	tr	0	0	0	tr	tr	0	tr	0	0	0
Charles 5	2952.1	0	0	0	0	0	2	0	0	1	2	1	0	1	0	0	0
Charles 5	2992.1	11	1	0	0	1	*	0	0	1	2	1	1	2	0	0	0
Charles 5	3079.1	0	0	0	0	0	0	0	0	tr	tr	1	0	0	0	0	0
Charles 5	3123.1	4	0	0	2	0	0	0	0	3	6	2	0	2	0	0	0
Charles 5	3162.1	9	0	0	1	0	0	0	tr	3	2	2	0	0	0	0	0
Charles 5	3214.1	3	0	0	1	0	1	0	0	3	3	4	0	2	0	0	0
Love 8	2012.0	14	0	0	tr	0	tr	0	0	tr	2	tr	0	0	0	0	0
Love 8	2037.0	13	tr	2	1	0	tr	2	0	2	3	tr	0	1	0	0	0
Love 8	2113.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	2195.0	11	1	0	0	0	1	0	0	2	1	1	0	1	1	0	0
Love 8	2350.0	9	tr	0	1	1	1	0	0	1	3	3	0	1	0	0	tr
Love 8	2375.0	17	0	0	0	0	tr	0	0	2	2	1	0	tr	0	0	0
Love 8	2485.0	tr	0	0	2	4	0	0	0	1	3	1	0	1	0	0	0
Love 8	2520.0	19	1	0	tr	0	2	0	0	3	3	2	0	1	0	0	0
Love 8	2570.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Love 8	2870.0	2	tr	0	0	0	1	0	0	1	5	2	0	tr	0	0	0
Love 8	3012.0	13	1	0	1	0	tr	0	0	0	2	0	0	tr	0	0	0
Love 8	3042.0	30	0	0	0	0	0	0	0	tr	1	2	0	3	0	0	0
Love 8	3083.0	tr	0	0	0	0	0	0	0	1	2	2	0	1	0	0	0
Love 8	3095.0	tr	0	0	0	0	2	0	0	1	1	1	0	tr	0	0	0
Love 8	3115.0	28	1	0	0	1	0	0	0	1	2	1	0	tr	0	1	0
Love 8	3195.0	3	0	0	0	0	1	0	0	1	4	2	0	3	0	0	0
Love 8	3245.0	6	tr	0	0	0	1	0	0	1	6	1	0	1	0	0	0

Abbreviations and notes: VRF = volcanic rock fragment, CHT = chert, CHTvrf = chert in a volcanic rock fragment (silicified), Argil = argillaceous rock fragment, Ss/sltn = sandstone/siltstone rock fragment, CRF = carbonate rock fragment, CRFvrf = carbonate in a volcanic rock fragment (carbonate precipitation in source terrain, not in-situ), MRF = metamorphic rock fragment, Silund = fine-grained siliceous rock fragment of indeterminate origin, URF = undifferentiated rock fragment, OPQ = opaque grain, OPQvrf = opaque grain within a volcanic rock fragment, HM = heavy mineral, HMgn = heavy mineral within a granitic/gneissic rock fragment, HMvrf = heavy mineral within a volcanic rock fragment, HMurf = heavy mineral in undifferentiated rock fragment, tr = less than 1%. *Abundance of detrital carbonate could not be determined due to difficulty of differentiating detrital from authigenic carbonate.

TABLE 3. Abundance of non-framework components (matrix and cement) and porosity in sidewall cores from wells Charles 5 and Love 8. Values are in volume percent of the whole rock.

Well	Depth	Clay	QOG	FOG	Zeolite	Carbonate	Opaque	Porosity
Charles 5	1677.0	2	tr	0	0	4*	0	30
Charles 5	1789.8	tr	tr	0	0	28	1	18
Charles 5	1804.0	1	tr	0	0		tr	32
Charles 5	1818.2	8	0	0	tr	2*	tr	27
Charles 5	1851.1	7	tr	0	tr	2*	0	32
Charles 5	2318.2	3	tr	0	tr	2*	1	35
Charles 5	2330.0	7	tr	0	1	1*	2	22
Charles 5	2452.1	9	tr	0	0	1*	1	26
Charles 5	2510.3	10	1	0	7	0	tr	22
Charles 5	2519.9	5	1	tr	9	0	tr	23
Charles 5	2558.2	76	0	0	0	0	0	7
Charles 5	2783.2	88	0	0	0	0	0	5
Charles 5	2952.1	69	0	0	0	0	0	4
Charles 5	2992.1	3	tr	0	7	tr*	tr	26
Charles 5	3079.1	77	0	0	0	10	2	10
Charles 5	3123.1	17	0	0	2	0	2	13
Charles 5	3162.1	15	0	0	0	11	1	10
Charles 5	3214.1	31	0	0	0	10	2	7
Love 8	2012.0	5	tr	0	3	0	0	17
Love 8	2037.0	1	1	0	0	1	tr	37
Love 8	2113.0	93	0	0	0	0	0	6
Love 8	2195.0	6	0	0	6	0	1	27
Love 8	2350.0	4	tr	0	8	0	tr	28
Love 8	2375.0	3	tr	0	6	tr	tr	22
Love 8	2485.0	18	0	0	0	30	1	15
Love 8	2520.0	2	tr	0	15	0	tr	24
Love 8	2570.0	92		0	0	0	0	4
Love 8	2870.0	54	1	0	0	0	tr	5
Love 8	3012.0	7	0	0	3	0	0	20
Love 8	3042.0	8	0	0	1	0	tr	12
Love 8	3083.0	47	tr	0	0	20	0	2
Love 8	3095.0	2	0	0	0	55	0	2
Love 8	3115.0	2	0	0	9	0	0	21
Love 8	3195.0	6	1	0	2	1	tr	25
Love 8	3245.0	7	0	0	2	17	tr	20

Abbreviations and notes: Clay = detrital and/or mechanically infiltrated clay, QOG = quartz overgrowths (authigenic and/or recycled), FOG = feldspar overgrowth (authigenic and/or recycled, tr = less than 1%. *Abundance of authigenic carbonate could not be determined due to difficulty of differentiating detrital from authigenic carbonate.

TABLE 4. Estimated mean grain size and sorting of sidewall cores from wells Charles 5 and Love 8.

Well	Depth	Grain Size Class	Grain Size (mm)	Sorting
Charles 5	1677.0	very fine Upper	0.107	Moderately
Charles 5	1789.8	medium Upper/medium Lower	0.35	Moderately Well
Charles 5	1804.0	medium Upper	0.425	Moderately Well
Charles 5	1818.2	fine Upper	0.213	Moderately Well
Charles 5	1851.1	medium Lower/fine Upper	0.25	Moderately Well/Moderately
Charles 5	2318.2	medium Lower	0.3	Moderately/Poorly
Charles 5	2330.0	medium Lower	0.3	Moderately Well
Charles 5	2452.1	fine Lower/very fine Upper	0.125	Moderately Well
Charles 5	2510.3	medium Upper	0.425	Poorly
Charles 5	2519.9	fine Upper/medium Lower	0.25	Moderately Well
Charles 5	2558.2	mudrock	<0.062	
Charles 5	2783.2	mudrock	<0.062	
Charles 5	2952.1	mudrock	<0.062	
Charles 5	2992.1	medium Lower	0.3	Moderately/Poorly
Charles 5	3079.1	mudrock	<0.062	
Charles 5	3123.1	fine Lower	0.151	Moderately/Poorly
Charles 5	3162.1	medium Lower	0.3	Poorly
Charles 5	3214.1	very fine Upper	0.107	Moderately Well/Moderately
Love 8	2012.0	very coarse Upper	1.705	Poorly/Very Poorly
Love 8	2037.0	medium Lower	0.3	Moderately
Love 8	2113.0	mudrock	<0.062	
Love 8	2195.0	medium Upper	0.425	Moderately Well/Moderately
Love 8	2350.0	medium Lower	0.3	Well/Moderately Well
Love 8	2375.0	medium Upper	0.425	Well
Love 8	2485.0	very fine Lower	0.075	Well
Love 8	2520.0	medium Upper/medium Lower	0.35	Well/Moderately Well
Love 8	2570.0	mudrock		
Love 8	2870.0	very fine Lower/very fine Upper	0.088	Well/Moderately Well
Love 8	3012.0	coarse Upper/coarse Lower	0.71	Poorly
Love 8	3042.0	conglomerate	>2.0	Very Poorly
Love 8	3083.0	very fine Lower	0.075	Well
Love 8	3095.0	very fine Upper	0.107	Well
Love 8	3115.0	coarse Upper/coarse Lower	0.71	Well/Moderately Well
Love 8	3195.0	very fine Upper	0.107	Very Well/Well
Love 8	3245.0	fine Upper/medium Lower	0.25	Very Well/Well

Table 5. Clay mineralogy of sidewall core samples from City of Albuquerque wells.

Well	Depth	Relative Abundance in <2.0 µm fraction					
SAF-1	1036	Q	Kao	Sme	I/S	tr I	
	1218	Q	Sme	Kao	I		
	1490	Q	F	Sme	tr Kao		
	2365	Q	F	Cal(?)	Sme	Kao	I
Cerro Colorado	449	Q	Cal	Sme	I		
	685	Q	Sme	Kao			
	1014	Q	Cal	Sme	Kao	I	
	1216	Q	Sme	Cal	I		
Charles 5	2077	Q	Cal	Sme	F	I	
	2268	Q	Sme	Cal			
	2385	Q	Sme	Cal			
	2672	Q	Sme	Cal			
	2783	Q	Sme				
	2832	Cal	Q	Sme			
Thomas 5	3195	Q	F	Cal	Sme		
	3326	Q	F	Cal	Sme(?)		
Thomas 7	1185	Q	Del	Sme	Kao	I	I/S
	1195	Q	Cal(?)	Sme	I/S	Kao	I

Abbreviations: Cal = calcite, Dol = dolomite, F = feldspar, I = illite, I/S = interlayered illite/smectite, Kao = kaolinite, Sme = smectite, tr = trace

Table 6. Composition of the sand-size fraction of cuttings from wells Coronado 2, Ridgecrest 2, Thomas 5, Thomas 6, and Thomas 8.

Well	Depth	Qm	Qp	P	K	VRF	SRF	Chert	Gran/Gnes	MRF	Phyllo	Other
Coronado 2	90-100	2	23	5	15	2	10	0	30	10	3	0
Coronado 2	190-200	30	10	5	5	30	5	tr	10	5	tr	0
Coronado 2	410-420	30	10	2	8	30	5	5	5	5	tr	0
Coronado 2	580-590	30	10	5	5	40	3	2	5	5	tr	0
Coronado 2	780-790	25	15	3	7	40	tr	0	5	5	tr	0
Coronado 2	940-950	20	15	3	7	35	3	5	5	5	2	0
Coronado 2	1170-1180	25	15	5	5	35	2	5	5	3	0	0
Coronado 2	1210-1220	25	10	4	6	30	5	5	10	5	0	0
Coronado 2	1400-1410	25	10	4	6	30	5	10	6	4	0	0
Ridgecrest 2	90-100	10	45	10	15	tr	tr	tr	15	5	tr	tr Ls
Ridgecrest 2	170-180	10	30	15	15	1	10	1	8	5	tr	tr Ls
Ridgecrest 2	290-300	15	20	12	13	30	2	2	5	1	tr	0
Ridgecrest 2	590-600	10	20	15	10	30	2	tr	10	3	0	0
Ridgecrest 2	800-810	10	20	10	10	40	tr	tr	7	3	0	0
Ridgecrest 2	1000-1010	5	20	10	15	40	tr	tr	8	2	0	0
Ridgecrest 2	1390-1400	5	20	10	15	40	tr	tr	8	2	0	0
Ridgecrest 2	1620-1630	5	20	10	15	40	tr	tr	8	2	0	0
Thomas 5	108-110	15	20	10	15	20	1	1	10	3	0	0
Thomas 5	300-310	10	30	10	15	25	tr	0	10	tr	0	0
Thomas 5	410-420	10	30	10	15	25	tr	0	10	tr	0	0
Thomas 5	540-550	10	25	10	10	35	0	0	8	2	0	0
Thomas 5	750-760	10	25	5	15	35	0	tr	7	3	0	0
Thomas 5	950-960	10	25	5	15	35	0	tr	7	3	0	0
Thomas 5	1140-1150	10	25	10	15	30	tr	tr	7	3	0	0
Thomas 6	100-110	30	10	15	10	0	5	5	15	0	5	5
Thomas 6	290-300	35	10	7	8	20	5	5	10	0	0	0
Thomas 6	440-450	15	15	2	3	30	5	5	15	10	0	0
Thomas 6	600-610	15	10	4	6	35	5	5	10	10	0	0
Thomas 6	930-940	10	20	3	7	40	10	5	3	2	0	0
Thomas 6	1100-1110	5	15	3	12	40	5	5	7	8	0	0
Thomas 6	1300-1310	10	15	3	12	30	10	5	7	8	tr	0
Thomas 6	1500-1510	8	12	3	7	15	30	10	10	5	0	
Thomas 8	90-100	10	50	10	10	tr	0	0	15	5	0	0
Thomas 8	300-310	10	50	15	15	0	1	tr	7	2	0	0
Thomas 8	370-380	10	50	5	10	15	2	tr	5	3	0	0
Thomas 8	380-390	5	40	10	10	25	tr	tr	7	3	0	0
Thomas 8	580-590	10	30	10	5	35	tr	tr	5	5	0	0
Thomas 8	780-790	5	30	10	10	35	tr	tr	7	3	0	0
Thomas 8	960-970	5	30	10	10	35	tr	tr	7	3	0	0
Thomas 8	1230-1240	5	30	10	10	35	tr	tr	10	tr	0	0
Thomas 8	1550-1560	5	30	7	8	40	tr	tr	10	tr	0	0
Thomas 8	1680-1690	10	20	15	15	40	0	tr	10	tr	0	0

Abbreviations: Qm = monocrystalline quartz, Qp = polycrystalline quartz, P = plagioclase, K = potassium feldspar, VRF = volcanic rock fragments, SRF = sedimentary rock fragments, Gran/Gnes = granitic/gneissic rock fragment, MRF = metamorphic rock fragment, Phyllo = phyllosilicate.

Table 7. Abundance of porosity types as a percentage whole-rock and percentage total porosity in sidewall cores from wells Charles 5 and Love 8.

		% Whole-Rock		% of Total Porosity						
				Macroporosity				Microporosity		
Well	Depth	Microporosity	Macroporosity	Intergranular	Intragranular	Intragran-fract	Lg-fracture	Clay	Grains	Cement
Charles 5	1677.0	1	29	95	1	1	0	tr	3	0
Charles 5	1789.8	5	13	59	1	14	0	2	3	20
Charles 5	1804.0	1	31	95	2	1	0	tr	2	0
Charles 5	1818.2	4	23	82	2	1	0	13	3	0
Charles 5	1851.1	6	26	79	1	1	0	8	11	0
Charles 5	2318.2	2	33	89	2	3	0	3	3	0
Charles 5	2330.0	2	20	87	1	2	0	5	5	0
Charles 5	2452.1	3	23	88	1	1	0	6	4	0
Charles 5	2510.3	4	18	72	6	5	0	5	12	0
Charles 5	2519.9	1	22	93	1	2	0	1	4	0
Charles 5	2558.2	5	2	0	2	0	21	69	8	0
Charles 5	2783.2	3	2	tr	tr	0	40	41	18	0
Charles 5	2952.1	4	tr	0	5	0	3	88	5	0
Charles 5	2992.1	6	20	72	2	3	0	9	14	0
Charles 5	3079.1	4	6	0	0	0	61	35	0	4
Charles 5	3123.1	5	8	53	3	6	0	24	13	0
Charles 5	3162.1	2	8	8	4	39	27	16	5	0
Charles 5	3214.1	2	5	4	0	59	11	18	8	0
Love 8	2012.0	4	13	63	4	12	0	4	17	0
Love 8	2037.0	3	34	86	3	3	0	1	8	0
Love 8	2113.0	2	4	0	0	0	71	29	0	0
Love 8	2195.0	4	23	80	2	3	0	3	13	0
Love 8	2350.0	5	23	75	3	4	0	9	9	0
Love 8	2375.0	3	19	78	2	6	0	7	7	0
Love 8	2485.0	8	7	23	11	0	11	49	5	0
Love 8	2520.0	6	18	65	4	8	0	4	21	0
Love 8	2570.0	1	3	0	0	0	75	25	0	0
Love 8	2870.0	3	2	0	7	0	26	57	10	0
Love 8	3012.0	2	18	76	1	14	0	3	7	0
Love 8	3042.0	2	10	68	4	6	4	12	6	0
Love 8	3083.0	1	1	0	tr	0	37	56	6	0
Love 8	3095.0	1	1	0	62	0	7	0	0	32
Love 8	3115.0	8	13	50	2	9	0	4	35	0
Love 8	3195.0	3	22	85	1	2	0	12	1	0
Love 8	3245.0	4	16	20	2	31	26	13	9	0

Abbreviations and notes: intragran-fract = intragranular fracture (i.e., fracture confined to a grain, not through-going), Lg-fract = large fracture (i.e., through-going fracture).

APPENDIX H

Summary of geophysical logs for wells and boreholes in the Albuquerque area used in this study

Current	USGS	ABQ	NMBMMR		Commercial Logs									USGS Digitized Logs						
Well Name	Identifier	Library No.	Copy Filed	File No.	IEL/ SFLA	ML/ CCL	FDL	CNL	BHC	LDT/ NGT	Other	Logger Digital	USGS Digital	GAM	NEU	FDL	EL	LSN	IEL	Other
City Water Wells																				
ATRISCO 1	350418106412201	WL001	y		x		x				x									
ATRISCO 4	350508106411901																			x
BURTON 1	3503591063616CH	WL061	y		x	x	x	x			x									
BURTON 2	350421106361001	WL005	y		x	x														
BURTON 3	350304106383401	WL006	y		x	x								x						
BURTON 4	350343106364401	WL063	y		x	x	x	x			x			x						x
BURTON 5			y		x	x	x	x	x	x	x	y								
CHARLES 2	350606106341101													x	x					
CHARLES 5			y		x		x	x	x		x	y								
COLLEGE 1	350646106443201	WL007	y		x														x	x
COLLEGE 2	350647106440001	WL008	y		x	x	x									x			x	x
CORONADO 1	351025106341601	WL064	y		x		x				x			x					x	x
CORONADO 2	350416106451801		y		x	x	x	x	x	x	x	y								
DON 1	350416106451801		y		x															
DON 2	350414106444801		y	17793	x		x				x									
DURANES 2	350708106405801	WL011	y		x	x														
DURANES 3	350629106405101	WL012	y		x	x													x	x
GONZALES 2			y		x		x	x	x	x		y				x			x	x
GREIGOS 5	350828106175501		y		x	x														
LADERA	350727106423201	WL009	y		x	x	x												x	x
LEAVITT 1	350244106445301	WL016	y		x	x														
LEAVITT 2	350237106445201	WL017	y		x	x														
LEAVITT 3	350223106435401	WL062	y		x	x	x	x			x									
LEYENDECKER 1	350752106342101	WL013	y		x	x														
LEYENDECKER 2	350727106340801	WL060	y		x	x														
LEYENDECKER 3	350819106344001	WL014	y		x	x														
LEYENDECKER 4	350815106340601	WL015	y		x	x														
LOMAS 1	350430106302401	WL019	y		x	x													x	x
LOMAS 2	350459106304601	WL020	y		x	x					x						x		x	x
LOMAS 3	350526106303801	WL021	y	17797	x	x					x									
LOMAS 4	350547106310601	WL022	y	17798	x		x				x									
LOMAS 5	350422106312601	WL023	y		x	x	x							x		x	x			x
LOMAS 6	350408106310101	WL024	y		x	x	x													
LOVE 1	350517106314401																			x
LOVE 2	350449106315701	WL025	y		x	x														
LOVE 3	350511106325601	WL026	y		x															
LOVE 4	350511106325601	WL027	y		x	x													x	x
LOVE 5	350452106323901	WL028	y		x	x														
LOVE 6	350553106313801	WL029	y	17799	x		x													
LOVE 7	350607106321301	WL030	y	17796	x	x														
LOVE 8			y		x	x	x	x	x	x	x	y								
MILES 1	350308106374601	WL031	y	17795	x	x	x				x									
PONDEROSA 1	350931106315501	WL036	y		x	x	x													
PONDEROSA 1(aband)	350933106391902	WL032	y		x	x														
PONDEROSA 2	350800106315001		y	17801	x		x				x									

Current Well Name	USGS Identifier	ABQ Library No.	NMBMMR Copy Filed	NMBMMR File No.	Commercial Logs IEL/ SFLA	ML/ CCL	FDL	CNL	BHC	LDT/ NGT	Other	Logger Digital	USGS Digital	USGS Digitized Logs GAM	NEU	FDL	EL	LSN	IEL	Other
PONDEROSA 3	350820106321701	WL033	y		x		x							x	x					x
PONDEROSA 4	350834106314901	WL034	y		x	x	x													
PONDEROSA 5	350918106315401													x					x	x
PONDEROSA 6	350851106322001	WL035	y		x	x	x													
RIDGECREST 1	350405106322001		y		x						x									
RIDGECREST 2	350427106323401	WL037	y		x	x	x													
RIDGECREST 3	350401106331401	WL038	y	17800	x	x	x				x									x
RIDGECREST 4	350445106334001	WL039	y	17960	x	x			x											
RIDGECREST 5			y		x	x	x	x	x	x	x	y								
SAN JOSE 2	351922106470601	WL040	y		x	x														
SANTA BARBARA 1	350648106362501		y		x						x								x	x
THOMAS 1	350754106332101		y			x								x	x					
THOMAS 2	350747106323301		y		x	x														
THOMAS 3	350813106332101		y		x	x														
THOMAS 4	350813106324001		y		x	x														
THOMAS 5			y		x		x	x	x	x	x	y								
THOMAS 6			y		x		x	x	x	x	x	y								
THOMAS 7			y		x		x	x	x	x	x	y								
THOMAS 8			y		x	x	x	x		x	x	y								
VOL ANDIA 1	350805106354901		y		x															
VOL ANDIA 2	350732106350101		y		x															
VOL ANDIA 3	350747106361401		y		x	x											x			x
VOL ANDIA 4	350803106351101		y		x															x
VOL ANDIA 5	350809106360901		y			x														
VOL ANDIA 6	350828106352101		y		x															
VOLCANO CLIFFS 1	350950106434001	WL047	y		x	x														
VOLCANO CLIFFS 2	350914106434001	WL049	y		x	x														
VOLCANO CLIFFS 3	351007106434201	WL050	y		x	x	x				x			x					x	x
WALKER 1	351025106323801	WL051	y		x	x	x				x			x		x			x	x
WALKER 2	351023106321301	WL052	y		x	x	x				x			x	x	x	x		x	x
WEBSTER 1	351029106332301	WL003	y		x	x	x				x					x			x	x
WEBSTER 2	351013106333501	WL002	y		x		x				x			x					x	x
WEST MESA 1	350438106443501	WL053	y		x	x														
WEST MESA 2	350508106435501	WL054	y		x	x														
WEST MESA 3	350443106395801	WL055	y	17791	x	x			x					x	x	x				x
WEST MESA 4	350442106431801	WL056	y	17792	x	x	x							x	x	x				x
YALE 1	350426106372601	WL057	y		x	x														
YALE 2	350358106372901	WL058	y	17794	x	x					x									
YALE 3	350435106380101	WL059	y		x	x														

Current	USGS	ABQ	NMBMMR		Commercial Logs									USGS Digitized Logs						
Well Name	Identifier	Library No.	Copy Filed	File No.	IEL/ SFLA	ML/ CCL	FDL	CNL	BHC	LDT/ NGT	Other	Logger Digital	USGS Digital	GAM	NEU	FDL	EL	LSN	IEL	Other
Monitoring Wells																				
CTY OBS 1	350548106383901													x	x					
CTY OBS 2	350824106375301													x	x					
CTY OBS 4	350646106403601													x	x					
EUBANK 1	350239106315801													x	x		x			x
I-25	350616106373801														x		x			
JM-2	350404106382501													x	x		x			
LOS ANGELES 5	351104106355701													x	x					
LOS ANGELES 6	351038106361301													x	x				x	
LOS ANGELES 7	351056406355801													x	x					
MONTANO 5a	350809106371901													x	x					
MW-1	350021106531101														x					x
MW-2	350017106521201													x			x			
SAN JOSE 3 (obs)	350304106383401																			x
SAN JOSE 9 (obs)	350256106390801													x	x					x
SBLF-2	350300106380501														x		x			
SJ6 OP UNIT 7D			y		x		x	x			x									
YALE MW5	345858106380601													x	x		x			x

Current	USGS	ABQ	NMBMMR				Commercial Logs								USGS Digitized Logs					
Well Name	Identifier	Library No.	Copy Filed	File No.	IEL/ SFLA	ML/ CCL	FDL	CNL	BHC	LDT/ NGT	Other	Logger Digital	USGS Digital	GAM	NEU	FDL	EL	LSN	IEL	Other
Other Wells																				
BERNALILLO 3			y		x			x			x	y								
BERNALILLO 4			y		x			x			x	y								
CERRO COLORADO 1	350014106531301		y		x		x		x		x	y								
SAF No. 1	350846106492601		y		x	x	x	x	x	x	x	y								

Current	USGS	ABQ	NMBMMR				Commercial Logs									USGS Digitized Logs				
Well Name	Identifier	Library No.	Copy Filed	File No.	IEL/ SFLA	ML/ CCL	FDL	CNL	BHC	LDT/ NGT	Other	Logger Digital	USGS Digital	GAM	NEU	FDL	EL	LSN	IEL	Other
Geological Data Wells																				
SWAB TEST WELL 1	350449406493101													x	x	x	x			x
SWAB TEST WELL 2	351046106464701													x	x	x	x			x
SWAB TEST WELL 3	351051106395301													x	x	x	x			x

GLOSSARY OF GEOLOGICAL TERMS

(after Hawley and Parsons, 1980)

alluvial

Pertaining to material or processes associated with transportation or deposition of running water.

alluvial fan

A body of alluvium, with or without debris flow deposits, whose surface forms a segment of a cone that radiates downslope from the point where the stream emerges from a narrow valley or canyon onto a plain. Common longitudinal profiles are gently sloping and nearly linear. Source uplands range in relief and areal extent from mountains and plateaus to gullied terrains on hill and piedmont slopes. The *proximal* part of a fan is the area closest to the source upland, while the *distal* part is the farthest away.

alluvial terrace

(cf. stream terrace)

alluvium

Unconsolidated clastic material deposited by running water, including gravel, sand, silt, clay and various mixtures of these.

arroyo

The flat-floored channel of an ephemeral stream, commonly with very steep to vertical banks cut in alluvium (regional term - Southwest; syn. dry wash). NOTE: Where arroyo reaches intersect zones of ground-water discharge they are more properly classed as intermittent stream channels.

ash (volcanic)

Fine pyroclastic material under 4.0 mm diameter.

basin (intermontane)

A broad structural lowland, commonly elongated and many miles across, between mountain ranges. Major component landforms are basin floors and piedmont slopes. Floors of internally-drained basins (bolsons) contain one or more closed depressions, with temporary lakes (playas), and alluvial plains. In basins with through drainage, alluvial plains are dominant and lakes are absent or of small extent. Piedmont slopes comprise erosional surfaces adjacent to mountain fronts (pediments) and constructional surfaces made up of individual and/or coalescent alluvial fans. (cf. valley)

basin fill

The unconsolidated sediment deposited by any agent (water, wind, ice, mass wasting) so as to fill or partly fill an intermontane basin. (cf valley fill)

basin floor

A general term for the nearly level to gently sloping, bottom surface of an intermontane basin (bolson). Component landforms include playas, broad alluvial flats containing ephemeral drainageways, and relict alluvial and lacustrine surfaces that rarely if ever are subject to flooding. Where through-drainage systems are well developed alluvial plains are dominant and lake plains are absent or of limited extent. Basin floors grade mountainward to distal parts of piedmont slopes.

bedrock

The solid rock (igneous, sedimentary, or metamorphic) that underlies the soil and other unconsolidated material or that is exposed at the surface.

bolson

An internally drained (closed), intermontane basin with two major land-form components: basin floor and piedmont slope. The former includes nearly level alluvial plains and playa-lake depressions. The latter comprises slopes of erosional origin adjoining the mountain fronts (pediments) and complex constructional surfaces (bajadas) mainly composed of individual and/or coalescent alluvial fans. Regional term (Southwest) derived from *bolsa* (Sp) -bag, purse, pocket.

braided channel or stream (flood plain landforms)

A channel or stream with multiple channels that interweave as a result of repeated bifurcation and convergence of flow around interchannel bars, resembling in plan the strands of a complex braid. Braiding is generally confined to broad, shallow streams of low sinuosity, high bedload non-cohesive bank material, and steep gradient. At a given bank-full discharge braided streams have steeper slopes, and shallower, broader and less stable channel cross sections than meandering streams. (cf. floodplain landforms)

caliche

A general term for a prominent zone of secondary carbonate accumulation in surficial materials of warm subhumid to arid areas formed by both geologic and pedologic processes. Finely crystalline calcium carbonate forms a nearly continuous surface-coating and void-filling medium in geologic (parent) materials. Cementation ranges from weak in nonindurated forms to very strong in types that are indurated. Other minerals (carbonate, silicate, sulphate) may be present as accessory cements. (cf. induration)

ceja

The upper part of a continuous and steep slope or escarpment, with local cliffs, that separates the relatively flat summit area of a mesa or high plateau from flanking valley lowlands. Local term (Southwest) derived from *ceja* (Sp) - eyebrow, brow of a hill (cejita - dim.).

cinder cone

A conical hill formed by the accumulation of volcanic ejecta, with slopes usually steeper than 20 percent.

clast

An individual constituent, grain, or fragment of sediment or rock, produced by the mechanical weathering (disintegration) of a larger rock mass.

clastic

Pertaining to a rock or sediment composed mainly of fragments derived from preexisting rocks or minerals and moved from their place of origin. (cf. detritus, epiclastic, pyroclastic)

clay

A rock or mineral fragment (often a crystalline fragment of a clay mineral) having a diameter of less than 0.002 mm (2 microns); an aggregate of clay-size particles that is usually characterized by high water content and plasticity.

coalescent fan piedmont

A broad, gently-inclined, piedmont slope formed by laterial coalescence of a series of alluvial fans, and having a broadly undulating transverse profile (parallel to the mountain front) due to the convexities of component fans. The term is generally restricted to constructional slopes of intermontane basins in the southwest USA.

colluvium

Unconsolidated earth material deposited on and at the base of steep slopes by mass wasting (direct gravitational action) and local unconcentrated runoff.

conglomerate

A coarse-grained, clastic rock composed of rounded to subangular rock fragments, (larger than 2 mm) commonly with a matrix of sand and finer material; cements include silica, calcium carbonate, and iron oxides. The consolidated equivalent of gravel. (cf. breccia)

debris

Any surficial accumulation of loose material detached from rock masses by chemical and mechanical means, as by decay and disintegration, and occurring in the place where it was formed, or transported by water or ice and redeposited. It consists of rock fragments, finer-grained earth material, and sometimes organic matter.

debris flow (mudflow)

A mass movement process involving rapid flowage of highly viscous mixtures of debris, water, and entrapped air. Water content may range up to 60%. A mudflow is a type of debris flow with clastic particles of sand size and finer. (cf. alluvial fan)

detritus

Rock and mineral fragments occurring in sediments that were derived from pre-existing igneous, sedimentary, or metamorphic rocks.

diagenesis

Process involving physical and chemical changes in a sediment after deposition that converts it to consolidated rock; includes compaction, cementation, recrystallization and replacement.

dune

A mound, ridge, or hill of loose, windblown granular material (generally sand), either bare or covered with vegetation.

eolian

Pertaining to material transported and deposited by the wind. Includes earth materials ranging from dune sands to silty loess deposits.

epiclastic

Pertaining to any clastic rock or sediment other than pyroclastic. Constituent fragments are derived by weathering and erosion rather than by direct volcanic processes. (cf. volcaniclastic)

erosion

The wearing away of the land surface by running water, waves, moving ice and wind, or by such processes as mass wasting and corrosion (solution and other chemical processes). The term "geologic erosion" refers to natural processes occurring over long (geologic) time spans.

erosional (geomorphology)

Owing its origin, form, position or general character to wearing-down (degradational) processes, such as removal of weathered rock debris by any mechanical or chemical processes to form, for example, a pediment or valley-side slope. Running water is the dominant agent of erosion in arid and semiarid regions.

escarpment

A relatively continuous and steep slope or cliff breaking the general continuity of more gently sloping land surfaces and produced by erosion or faulting. The term is more often applied to cliffs produced by differential erosion and it is commonly used synonymously with "scarp." (cf. ceja)

extrusive

Denoting igneous rocks derived from deep-seated molten matter (magmas) emplaced on the earth's surface. (cf. intrusive; volcanic)

facies (stratigraphy)

The sum of all primary lithologic and paleontologic characteristics exhibited by a sedimentary rock and from which its origin and environment of formation may be inferred; the general nature or appearance of a sedimentary rock produced under a given set of conditions; a distinctive group of characteristics that distinguishes one group from another within a stratigraphic unit. (e.g., contrasting river-channel facies and overbank-flood-plain facies in alluvial valley fills)

fault

A fracture or fracture zone of the earth with displacement along one side in respect to the other.

floodplain

The nearly level alluvial plain that borders a stream and is subject to inundation under flood-stage conditions unless protected artificially. It is usually a constructional landform built of sediment deposited during overflow and lateral migration of the stream.

floodplain landforms

A variety of constructional and erosional features produced by stream channel migration and flooding. (e.g., backswamps, braided channels and streams, floodplain splays, meander, meander belt, meander scrolls, oxbow lakes, natural levees, and valley flats.)

fluvial

Of or pertaining to rivers; produced by river action, as a fluvial plain.

formation (stratigraphy)

The basic rock-stratigraphic unit in the local classification of rocks. A body of rock (commonly a sedimentary stratum or strata, but also igneous and metamorphic rocks) generally characterized by some degree of internal lithologic homogeneity or distinctive lithologic features (such as chemical composition, structures, textures, or general kind of fossils), by a prevailing (but not necessarily tabular) shape, and by mappability at the earth's surface (at scales on the order of 1:25,000) or traceability in the subsurface.

geomorphology

The science that treats the general configuration of the earth's surface; specifically the study of the classification, description, nature, origin, and development of landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

graben

An elongate, relatively depressed crustal block that is bounded by faults on its long sides.

gravel

An unconsolidated aggregate of clastic particles with diameters greater than 2 mm. Granule gravel (granules) range from 2 to 4 mm, pebbles from 4 to 64 mm, cobbles from 64 to 256 mm (2.5 to 10 in.), and boulders greater than 256 mm (10 in.).

Holocene

The second epoch of the Quaternary Period of geologic time, extending from the end of the Pleistocene Epoch (about 10 thousand years ago) to the present; also the corresponding (time-stratigraphic) "series" of earth materials. (syn. post-glacial, Recent)

igneous rock

Rock formed by solidification from a molten or partially molten state; major varieties include plutonic and volcanic rocks; examples: andesite, basalt, granite. (cf. intrusive, extrusive)

induration

The process of hardening of sediments or other rock aggregates through cementation, pressure, heat, and other causes. (cf. lithification)

isopach map

A map indicating, usually by contour lines, the varying thickness of a designated stratigraphic unit.

lacustrine deposit

Clastic sediments and chemical precipitates originally deposited in lakes.

landform

Any physical, recognizable form or feature of the earth's surface, having a characteristic shape, and produced by natural causes; it includes major forms such as a plain, plateau, or mountain, and minor forms such as a stream terrace, hill, valley, or dune. Taken together, the landforms make up the surface configuration of the earth. The "landform" concept involves both empirical description of a terrain class and interpretation of genetic factors ("natural causes").

landscape

(Gen.) All the natural features, such as field, hills, forests, and water that distinguish one part of the earth's surface from another part; usually that portion of land which the eye can comprehend in a single view, including all of its natural characteristics. (Geol.) The distinct association of landforms, especially as modified by geologic forces, that can be seen in a single view.

limestone

A sedimentary rock consisting chiefly (more than 50%) of calcium carbonate, primarily in the form of calcite. Limestones are usually formed by a combination of organic and inorganic processes and include chemical and clastic (soluble and insoluble) constituents; many are fossiliferous.

lithification

The conversion of a newly deposited, unconsolidated sediment into a coherent and solid rock, involving processes such as cementation, compaction; desiccation, crystallization, recrystallization, and compression. It may occur concurrent with, or shortly or long after deposition. (cf. induration)

lithologic

Pertaining to the physical character of a rock.

meander, meandering channel

A meander is one of a series of sinuous loops, with sine-wave form, in the course of a stream channel. The term "meandering" should be restricted to loops with channel length more than 1.5 to 2 times the length of the wave form. Meandering stream channels commonly have cross sections with low width to depth ratios, (fine-grained) cohesive bank materials, and low gradient. At a given bank-full discharge meandering streams have gentler slopes, and deeper, narrower and more stable channel cross-sections than braided streams. (cf. floodplain landforms)

mesa

A broad, nearly flat-topped and usually isolated upland mass characterized by summit widths that are greater than the heights of bounding erosional escarpments. A tableland produced by differential erosion of nearly horizontal, interbedded weak and resistant rocks, with the latter comprising caprock layers. As summit area decreases relative to height mesas are transitional to buttes. In the western states mesa is also commonly used to designate broad structural benches and alluvial terraces that occupy intermediate levels in stepped sequences of platforms bordering canyons and valleys. (cf. plateau, cuesta)

metamorphic rock

Rock of any origin altered in mineralogical composition, chemical composition, or structure by heat, pressure, and movement at depth in the earth's crust. Nearly all such rocks are crystalline. Examples: schist, gneiss, quartzite.

Miocene

The next to last epoch of the Tertiary Period of geologic time, following the Oligocene and preceding the Pliocene Epochs (about 23 to 5 million years ago); also, the corresponding (time-stratigraphic) "series" of earth materials.

mountain

A natural elevation of the land surface, rising more than 1000 ft (300 m) above surrounding lowlands, usually of restricted summit area (relative to a plateau), and generally having steep sides (>25% slope) and considerable bare-rock surface. A mountain can occur as a single, isolated mass, or in a group forming a chain or range. Mountains are primarily formed by deep seated earth movements and/or volcanic action and secondarily by differential erosion. (cf. hill)

mudstone

Sedimentary rock formed by induration of silt and clay in approximately equal proportions.

pediment

A gently sloping erosional surface developed at the foot of a receding hill or mountain slope. The surface may be essentially bare, exposing earth material that extends beneath adjacent uplands; or it may be thinly mantled with alluvium and colluvium, ultimately in transit from upland front to basin or valley lowland. The term has been used in several geomorphic contexts: Pediments may be classed with respect to (1) landscape position, for example intermontane-basin piedmont or valley-border footslope surfaces, (2) type of material eroded, bedrock or basin fill, or (3) combinations of the above.

petrography

The branch of geology dealing with the systematic description and classification of rocks; including their microscopic study and description.

petrology

A general term for the study by all available methods of the natural history of rocks, including their origins (petrogenesis), description and classification (petrography).

piedmont slope

The dominant gentle slope at the foot of a mountain; generally used in terms of intermontane-basin terrain in arid to subhumid regions. Main components include: (1) an erosional surface on bedrock adjacent to the receding mountain front (pediment); (2) a constructional surface comprising individual alluvial fans and interfan valleys, also near the mountain front; and (3) a distal complex of coalescent fans (bajada), and alluvial slopes without fan form. Piedmont slopes grade to either basin-floor depressions with alluvial and temporary lake plains or surfaces of through drainage. (cf. bolson)

plain

An extensive lowland areas that ranges from level to gently sloping or undulating. A plain has few or no prominent hills or valleys, and occurs at low elevation with reference to surrounding areas (local relief generally less than 100 m). (cf. plateau)

plateau

An extensive upland mass with relatively flat summit area that is considerably elevated (more than 100 m) above adjacent lowlands, and is separated from them on one or more sides by escarpments. A comparatively large part of a plateau surface is near summit level. (cf. ceja, mesa, plain)

playa

The usually dry and nearly level lake plain that occupies the lowest parts of closed depressions, such as those occurring on intermontane basin floors. Temporary flooding occurs primarily in response to precipitation-runoff events. Playa deposits are fine grained and may or may not be characterized by high water table and saline conditions.

Pleistocene

The first epoch of the Quaternary Period of geologic time, following the Tertiary Pliocene Epoch and preceding the Holocene (approx. from 1.7 million to 10 thousand years ago); also the corresponding (time-stratigraphic) "series" of earth materials. Glacial-interglacial cycles characterized much of the Pleistocene in high latitude and altitude regions, while complex cool-moist, cold-dry, and hot-dry (pluvial-interpluvial) cycles occurred in the Southwest. Subdivided into early (1.7 - 0.75 m.y.), middle (0.75 - 0.13 m.y.), and late (130,000 - 10,000 yrs.) Pleistocene. (syn. Glacial epoch, Ice Age)

Pliocene

The last epoch of the Tertiary Period of geologic time, following the Miocene Epoch and preceding the (Quaternary) Pleistocene Epoch (about 5 to 1.7 million years ago); also, the corresponding (time-stratigraphic) "series" of earth materials.

plutonic

Pertaining primarily to igneous rocks formed deep in the earth's crust, but also including associated metamorphic rocks. (cf. volcanic)

pumice

A light-colored vesicular glassy rock, usually having composition of rhyolite.

pyroclastic

Pertaining to fragmental materials produced by usually explosive, aerial ejection of clastic particles from a volcanic vent. Such materials may accumulate on land or under water. Pyroclastic rocks include tuff, welded tuff, and volcanic breccia. (cf. epiclastic, volcaniclastic)

Quaternary

The second period of the Cenozoic Era of geologic time, extending from the end of the Tertiary Period (about 1.7 million years ago) to the present and comprising two epochs, the Pleistocene (Ice Age) and the Holocene; also, the corresponding (time-stratigraphic) "system" of earth materials.

sand

A rock or mineral fragment having a diameter in the range of 0.062 to 2 mm; an unconsolidated aggregate of dominantly sand-size clastic particles.

sandstone

Sedimentary rock containing dominantly sand-size clastic particles.

scoria

Vasicular, cindery, crust on the surface of andesitic or basaltic lava, the vesicular nature of which is due to the escape of volcanic gases before solidification; it is usually heavier, darker, and more crystalline than pumice. (syn. cinder)

sediment

Solid clastic material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by water, wind, ice or mass-wasting and has come to rest on the earth's surface either above or below sea level. Sedimentary deposits in a broad sense also include materials precipitated from solution or emplaced by explosive volcanism, as well as organic remains (e.g., peat) that have not been subject to appreciable transport.

sedimentary rock

A consolidated deposit of clastic particles, chemical precipitates and organic remains accumulated at or near the surface of the earth under "normal" low temperature and pressure conditions. Sedimentary rocks include consolidated equivalents of alluvium, colluvium, glacial drift, and eolian, lacustrine and marine deposits (e.g., sandstone, siltstone, mudstone, clay-stone, and shale, conglomerate and limestone, dolomite, coal, etc.; cf. sediment).

shale

Sedimentary rock formed by induration of a clay or silty clay deposit and having the tendency to split into thin layers (i.e., fissility)

silt

A rock or mineral fragment having a diameter in the range of 0.002 to 0.062 mm; an unconsolidated aggregate of dominantly silt-size particles.

stratified

Arranged in layers or strata. The term refers to geologic material. Layers in soils that result from the processes of soil formation are called horizons.

stratigraphy

The branch of geology that deals with the definition and interpretation of stratified earth materials; the conditions of their formation; their character, arrangement, sequence, age, and distribution; and especially their correlation by the use of fossils and other means of dating. The term is applied both to the sum of the characteristics listed and a study of these characteristics.

stream terrace

One of a series of relatively flat surfaces bordering a stream valley, and more or less parallel to the stream channel; originally formed near the level of the stream, and representing the dissected remnants of an abandoned flood plain, stream bed, or valley floor produced during a former stage of erosion or deposition. Erosional surfaces cut on bedrock and thinly mantled with stream deposits (alluvium) are designated "strath terraces." Remnants of constructional valley floors are termed "alluvial terraces." (cf. terrace, valley-border surfaces)

tableland

A general term for a broad upland mass with nearly level or undulating summit area of large extent and steep sideslopes descending to surrounding lowlands. Varieties include plateaus and mesas.

tectonic

Pertaining to or designating the rock structure and external forms resulting from deformation of the earth's crust.

tephra

A collective term for all clastic volcanic materials which are ejected from a vent during an eruption and transported through the air, including volcanic ash, cinders, lapilli, scoria, pumice, bombs, and blocks. (syn. volcanic ejecta)

terrace (geomorphic)

A step-like surface, bordering a valley floor or shoreline, that represents, the former position of an alluvial plain, or lake or sea shore. The term is usually applied to both the relatively flat summit surface (platform, tread), cut or built by stream or wave action, and the steeper descending slope (scarp, riser), graded to a lower base level or erosion. (cf. stream terrace)

Tertiary

The first period of the Cenozoic Era of geologic time, following the Mesozoic Era preceding the Quaternary (approx. from 65 to 1.7 million years ago); also the corresponding time-stratigraphic subdivision (system) of earth materials. Epoch/series subdivisions comprise, in order of increasing age, Pliocene, Miocene (late Tertiary), Oligocene (middle Tertiary), Eocene, and Paleocene (early Tertiary).

topography

The relative positions and elevations of the natural features of an area that describe the configuration of its surface.

valley-border surfaces

A general grouping of valley-side surfaces (e.g. stream terraces or dissected alluvial fans) that occur in a stepped sequence graded to successively lower stream base levels produced by episodic valley entrenchment.

valley fill

The unconsolidated sediment deposited by any agent (water, wind, ice, mass wasting) so as to fill or partly fill a stream valley. (cf. basin fill)

valley floor

A general term for the nearly level to gently sloping, bottom surface of a valley. Component landforms include axial stream channels, the floodplain, and in some areas, low terrace surfaces that may be subject to flooding from tributary streams. (cf. floodplain landforms, meander, braided channel, valley side)

volcanic

Pertaining to (1) the deep-seated (igneous) processes by which magma and associated gases rise through the crust and are extruded onto the earth's surface and into the atmosphere, and (2) the structures, rocks, and landforms produced. (cf. extrusive)

volcaniclastic

Pertaining to the entire spectrum of fragmental materials with a preponderance of clasts of volcanic origin. The term refers not only to pyroclastic materials but also to epiclastic deposits derived from volcanic source areas by normal processes of mass wasting and stream erosion.

weathering

All physical and chemical changes produced in rocks or other deposits at or near the earth's surface by atmospheric agents with essentially no transport of the altered material. These changes result in disintegration and decomposition of the materials.

Key to hydrostratigraphic units in the Albuquerque Basin

Unit	Description	Age
RA RAr RAp	River alluvium; channel and floodplain deposits of inner Rio Grande (RAr) and Puerco (RAp) valleys; as much as 120 ft thick. Map unit "Qf" of Kelley (1977). Forms upper part of the "shallow aquifer". Hydrogeologic (lithofacies) subdivision Iv*.	Holocene to late Pleistocene
VA VAc VAt VAs	Valley-border alluvium; tributary-arroyo (and thin eolian) deposits in areas bordering inner Rio Grande and Puerco valleys, with locally extensive river-terrace deposits, as much as 200 ft thick. Fan, terrace and channel deposits of Calabacillas and Tijeras Arroyos are, respectively, designated VAc and VAt. VAs indicates older valley fill near Calabacillas Arroyo. Map units "Qa" and "Qt" of Kelley (1977), and "Edith, Menaul, and Los Duranes" (terrace alluvium) units of Lambert et al. (1982). Includes hydrogeologic (lithofacies) subdivision Iv, II, and Vv. Most of unit is in the vadose (unsaturated) zone.	Holocene to middle Pleistocene
PA PAt	Piedmont-slope alluvium; coarse-grained alluvium, mainly deposited as coalescent fans extending basinward from mountain fronts on the eastern and southwestern margins of the basin; as much as 150 ft thick; includes surficial deposits mantling piedmont erosion surfaces (including rock pediments). PAt designates deposits of ancestral Tijeras Arroyo system in the depression between I-40 and the SE Central-Ridgecrest Blvd. area (Lambert et al., 1982). Map units "Qfa" and "Qp" of Kelley (1977), and hydrogeologic (lithofacies) subdivisions Vf, Vd, and VI. Most of unit is in vadose zone.	Holocene to middle Pleistocene
SF	Santa Fe Group - undivided; fill of intermontaine basins of the Rio Grande rift in New Mexico and adjacent parts of Colorado, Texas, and Chihuahua (Mexico). Includes alluvial, eolian and lacustrine deposits; and interbedded extrusive volcanic rocks (basalts to silicic tuffs). In the Albuquerque Basin, the Santa Fe is as much as 15,000 ft thick. It is mapped both as a formation (member subdivisions) by Kelley (1977), and as a group (formation and member subdivisions) by Hawley (1978), Machette (1978a,b), and Lozinsky and Tedford (1991). The upper part of the group unit forms the major aquifer in the Albuquerque Basin (and elsewhere in basins of the Rio Grande rift), and is subdivided into three hydrostratigraphic units:	early Pleistocene to late Oligocene, mostly Pliocene and Miocene
USF USF-1 USF-2 USF-3	Upper Santa Fe unit; coarse- to fine-grained deposits of ancestral Rio Grande and Puerco systems that intertongue mountainward with piedmont-alluvial (fan) deposits; volcanic rocks (including basalt, andesite and rhyolite flow and pyroclastic units) and thin, sandy eolian sediments are locally present. The unit is as much as 1200 ft thick. Subunit USF-1 comprises coarse-grained, alluvial-fan and pediment-veneer facies extending westward from the bases of the Sandia, Manzanita, and Manzano uplifts. USF-2 includes deposits of the ancestral Rio Grande and interbedded fine-grained sediments in the structural depression between the Rio Grande and County Dump fault zones in the river-valley area. Alluvial and minor eolian deposits capping the Llano de Albuquerque (West Mesa) between the Rio Grande and Puerco Valleys form subunit USF-3. Unit includes Ceja Member of Kelley (1977), and Sierra Ladrones Formation of Machette (1978a,b) and Lozinsky and Tedford (1991). Forms lower part of "shallow aquifer" below river-floodplain areas, and upper part of basin-fill aquifer in western part of NE and SE Albuquerque well fields. Includes hydrogeologic (lithofacies) subdivisions Ib, II, III, V, Vd, Vf, VI, VIII, and IX. Unit is in vadose zone west of the Rio Grande Valley.	early Pleistocene to late Miocene, mainly Pliocene

MSF
MSF-1
MSF-2

Middle Santa Fe unit; alluvial, eolian, and playa-lake (minor in northern basin area) basin-fill facies; coarse-grained alluvial-fan deposits intertongue basinward with sandy to fine-grained basin-floor facies, which include local braided-stream and playa-lake facies; basaltic volcanics are also locally present. The unit is as much as 10,000 ft thick in the Isleta Pueblo area of the Rio Grande Valley. Subunit MSF-1 comprises piedmont alluvial deposits derived from early-stage Sandia, Manzanita, and Manzano uplifts including the ancestral Tijeras Canyon drainage basin. MSF-2 comprises sandy to fine-grained basin-floor sediments that intertongue westward and northward with coarser grained deposits derived from the Colorado Plateau and southern Rocky Mountain provinces and Rio Grande rift basins to the northeast.

late to middle Miocene

Includes upper part of Popotosa Formation of Machette (1978a,b) and Lozinsky and Tedford (1991) in southern Albuquerque Basin, Cochiti Formation of Manley (1978), and "middle red" formation (member) of Lambert (1968) and Kelley (1977). Forms major part of basin-fill aquifer system in much of the northern part of basin. Includes hydrogeologic (lithofacies) subdivisions II, III, IV, V, Vd, Vf, VI, VII, VIII, and IX.

LSF

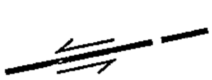
Lower Santa Fe unit; alluvial, eolian, and playa-lake basin-fill facies; sandy to fine-grained basin-floor sediments, which include thick dune sands and gypsiferous sandy mudstones; grades to conglomeratic sandstones and mudstone toward the basin margins (early-stage piedmont alluvial deposits). The unit is as much as 3500 ft thick in the central basin areas, where it is thousands of feet below sea level. Includes lower part of Popotosa Formation of Machette (1978a,b) and Lozinsky and Tedford (1991) in southern Albuquerque (Belen) Basin; and Zia (sand) Formation of Galusha (1966) and Kelley (1977) in northern part of basin. At present, is not known to form a major part of the Albuquerque Basin aquifer system. Eolian (Zia) and facies could be at least a local (future) source of groundwater in the far northwestern part of the basin (west and northwest of Rio Rancho). Includes hydrogeologic (lithofacies) subdivisions IV, VII, VIII, IX, and X.

middle Miocene to late Oligocene

Lithofacies subdivisions of hydrogeologic units are defined in Appendix D.

Faults

High-angle normal fault (map view), dashed where inferred, dotted where buried; bar and ball or "**D**" on downthrown side


High-angle normal fault (cross section view), dashed where inferred; direction of relative motion shown by arrows


Other faults and shear zones dominated by strike slip displacements

Other Symbols


Approximate eastern limit of ancestral Rio Grande deposits (USF-2) in subsurface


Water wells with drill cutting and core analyses


Water wells with drill cutting analyses


Water wells with driller's log analyses


Oil Test Wells with drill cutting analyses


Oil Test Well with driller's log analyses

Explanation of other lithologic symbols used in conjunction with hydrostratigraphic units on map and cross sections.

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a Thin, discontinuous alluvial deposits on older basin fill and basalts of the Llano de Albuquerque area between the Rio Grande and Puerco Valleys.

e Sandy eolian deposits forming nearly continuous cover on stable summits of high tablelands (mesas) flanking the Rio Grande Valley. Underlying unit (Upper Santa Fe or basalt flow) is identified by superposition of symbols (e.g. e/USF or e/Qb). Symbol alone denotes thick dune deposits on escarpment rims, particularly at the west edge of the Llano de Albuquerque (Ceja del Rio Puerco).

g Channel gravel deposits associated with remnants of river-terraces bordering the inner valley of the Rio Grande. Includes outcrops of Edith, Menaul, and upper buff (?) "gravels" of Lambert (1968). Pebble to cobble gravels are commonly underlain by pumiceous USF-2 beds at the edge of the inner valley (east of Edith Blvd.).

s Sandy to silty fluvial deposits associated with river-terrace remnants west of the Rio Grande. Includes Los Duranes Formation of Lambert (1968; Lambert et al., 1982).

Upper Cenozoic volcanics and igneous intrusives interbedded with, capping, and penetrating basin and valley fill

Qb Younger basaltic volcanics of the Albuquerque and Cat Hills fields: extensive lava flows, with localized vent units such as cinder cones and lava domes, and possible feeder dikes and sills in subsurface; late middle Pleistocene.

Tb Older basaltic volcanics of the Wind Mesa and Isleta fields, extensive lava flows, with localized vent units; includes possible sills and/or buried flows west of the Albuquerque volcanoes; Pliocene.

Tbt Basaltic tuffs and associated lavas and fluvial sediments of the Isleta (Paria Mesa) center; Pliocene.

Tvi Silicic to basaltic intrusive and volcanic rocks penetrated in deep wells west of the County Dump–Albuquerque Volcanoes fault zone; includes possible intrusives from the Cerro Colorado center (quartz-latite and trachyte); late Miocene (?) and Pliocene.

* **Bedrock units**

Lower and middle Tertiary sedimentary rocks undivided; primarily sandstones and mudstones; includes "unit of Isleta #2" of Lozinsky (1988), and possibly Galisteo and Espinaso Formation correlatives.

Mz Mesozoic rocks-undivided; primarily upper Cretaceous sandstones or shales beneath the Puerco Valley and western Llano de Albuquerque area, and possible Triassic sandstones and mudstones west of the Hubbell fault zone and south of Tijeras Arroyo east of the Rio Grande.

Pe Permian rocks-undivided; sandstones, mudstones, and minor limestones of the Abo and Yeso Formations exposed along the Hubbell fault zone.

IP Pennsylvanian rocks-undivided; limestones, sandstones and shales of the Madera Group and the Sandia Formation in the Tijeras fault zone and Manzanita foothill area south of Tijeras Canyon.

p-Є, p-Єg, p-Єm Precambrian rocks-undivided; igneous intrusive and metamorphic rocks of the Sandia and Manzanita uplifts; p-Єg—Sandia granite and local bodies of metamorphic rocks north of the Tijeras fault zone; p-Єm—metamorphic rocks (greenstone, quartzite, schist, gneiss and metavolcanics) south of the Tijeras fault.

* Primarily hydrogeologic boundary units with low hydraulic conductivities. However, solution-enlarged joints and fractures in Paleozoic carbonate rocks (Pennsylvanian and Permian) may be highly conductive, and fault zones such as the Tijeras "shear" zone may be characterized by local areas of high permeability.

Lithofacies subdivisions of basin- and valley-fill hydrogeologic units and their occurrence in lithostratigraphic and hydrostratigraphic units in the Albuquerque Basin

	Subdivision Descriptions
I	Sand and gravel, river-valley and basin-floor fluvial facies; channel and floodplain deposits of the Rio Grande and Rio Puerco underlying 1) the modern river-valley floor—facies Iv, 2) river-terrace surfaces—deposits primarily in the vadose zone, and 3) ancient relict or buried basin-floor fluvial plains—facies Ib. Gravel is characterized by sub-rounded to well-rounded pebbles and small cobbles of resistant rock types (mainly igneous and metamorphic) derived in part from extra-basin source areas. Iv. Sand and pebble to cobble gravel, with thin, organic-rich silty sand to silty clay lenses in Rio Grande Valley; as much as 50 ft of silt-clay in upper part of deposit in Puerco Valley; indurated zones of carbonate cementaion rare or absent; as much as 120 ft thick. Ib. Sand and pebble gravel (>85%), with thin discontinuous beds and lenses of sandstone, silty sand, and silty clay (<15%); extensive basin-floor fluvial facies; usually nonindurated, but with local zones that are cemented with calcite (common), and other minerals (uncommon) including silicate clays, iron-manganese oxides, gypsum, silica, and zeolites; 200 to 400 ft thick in central basin areas.
II	Sand, with discontinuous beds and lenses of pebbly sand, silty sand, sandstone, silty clay, and mudstone; extensive basin-floor fluvial facies and local eolian deposits; gravel composition as in facies I; usually nonindurated, but local cemented zones; clean sand and pebbly-sand bodies make up an estimated 65–85 percent of unit; as much as to 1000 ft thick in central basin areas.
III	Interbedded sand, silty sand, silty clay, and sandstone; with minor lenses of pebbly sand and conglomeratic sandstone; basin-floor alluvial and playa-lake facies; clay mineralogy of silty clay beds as in unit IX; usually nonindurated, but with local cemented zones as in facies Ib and II; secondary carbonate and gypsum segregations locally present in silty clay beds; common sheet-like to broadly-lenticular strata 10 to 40ft thick; clean sand layers make up an estimated 35 to 65 percent of unit; as much as 2000ft thick in central basin areas.
IV	Sand to silty sand, with lenses or discontinuous beds of sandstone, silty clay, and mudstone; eolian and alluvial facies primarily deposited on basin floors and contiguous piedmont slopes; nonindurated to partly indurated, with cementing agents including calcite (common), silicate clays, iron-manganese oxides, gypsum, and zeolites (uncommon); clean fine to medium sand makes up an estimated 35 to 65 percent of unit; as much as 2000ft thick exposed near western edge of basin.
V	Gravelly sand-silt-clay mixtures (loamy sands to sandy clay loams) interbedded with lenticular to sheet-like bodies of sand, gravel, and silty clay; distal to medial piedmont-slope alluvial facies (mainly coalescent fan: Vf and Vd), also alluvial deposits along valley borders associated with fans and terraces major arroyo systems (Vv); with minor component of eolian sands and silts; gravel primarily in the granule, pebble, and small cobble size range; clast composition reflects the lithologic character of the local source-bedrock terranes; usually nonindurated, but with discontinuous zones cemented with calcite, upper part of unit in the vadose zone. Symbol "V" designates undifferentiated unit Vf and Vd:

Vf. Gravelly sand-silt-clay mixtures interstratified with discontinuous beds of sand, gravel and silty clay; alluvial and debris-flow deposits of coalescent piedmont fans associated with smaller, steep mountain-front watersheds, such as the Domingo Baca-Pino-Oso-Embudo basins of the Sandia Mountains; elongate (downslope) lenticular bodies of clean sand and gravel make up about 25 to 35 percent of the unit; as much as 1000ft thick.

Vd. Sand and gravel interstratified with discontinuous beds and lenses of gravelly to non-gravelly sand-silt-clay mixtures. Primarily deposits of large, distributary (braided-stream) channels on low-gradient alluvial fans, such as the Tijeras and Abo Canyon fans, that apex at the mouths of large watersheds (>50 mi^2) in mountain ranges and high plateaus flanking the Albuquerque Basin; sheet-like to broadly lenticular bodies of clean sand and gravel deposits associated with fan-distributary channel complexes make up an estimated 35 to 65 percent of the unit; as much as 1000 ft thick.

Vv. Gravelly sand-silt-clay mixtures interbedded with lenticular to sheet-like bodies of sand and gravel and silty clay. Arroyo fan and terrace deposits that border the inner valleys of the Rio Grande, Rio Puerco, Jemez Rivers and major tributary arroyos; lenticular bodies of clean sand and gravel deposits make up 35 to 65 percent of the unit; as much as 150ft thick.

VI Coarse gravelly sand-silt-clay mixtures (loamy sand and sandy loams to loams) interstratified with lenses of sand and gravel; proximal to medial piedmont-slope alluvial facies—fan and coalescent fan deposits; gravel primarily in the pebble to cobble range (up to 10 inches); clast composition reflects lithologic character of source bedrock terranes; usually nonindurated, but with discontinuous layers that are cemented with calcite; clean sand and gravel lenses make an estimated 15 to 35 percent of unit; as much as 1000ft thick.

VII Conglomeratic sandstone, silty sandstone, and mudstone with lenses and discontinuous beds of conglomerate, sand, gravel, and gravelly sand-silt-clay mixtures (as in unit V); distal to medial piedmont-slope alluvial facies, with minor component of eolian sediments; coarse clast sizes and composition as in unit V; moderately-well to poorly indurated; cementing agents include calcite (common) and silicate clays, iron-manganese oxides, silica and zeolites (uncommon); clean weakly-cemented sand and gravel beds make up an estimated 10 to 25 percent of unit; as much as 1000ft thick.

VIII Coarse conglomeratic sandstone and silty-sandstone, fanglomerate, and minor lenses of sand and gravel; proximal to medial piedmont-slope alluvial facies—and coalescent fan deposits; coarse clast sizes and compositions as in unit VI; moderately to well indurated; cementing agents as in unit VII; clean, weakly-cemented sand and gravel lenses make up an estimated 5 to 15 percent of unit, as much as 1000ft thick.

IX Silty clay interbedded with thin silty sand, sand, sandstone, and mudstone beds; basin-floor playa-lake and alluvial-flat facies; clay mineral assemblage includes calcium smectite, mixed layer illite-smectite illite, and kaolinite; secondary deposits of calcite, gypsum, sodium-magnesium-sulfate salts, and zeolites are locally present; weakly-cemented fine to medium sand and silty sand makes up an estimated 5 to 10 percent of unit; as much as 3000ft exposed in southwestern basin areas.

X Mudstone and claystone interstratified with thin sandstone and silty sandstone beds; basin-floor playa-lake and alluvial-flat facies; clay mineral and non-clay secondary mineral assemblages as in facies IX; weakly cemented fine to medium sand and silty sand makes up an estimated 0 to 5 percent of unit; not exposed in central and northern basin areas; thickness unknown, but may exceed 2000ft.

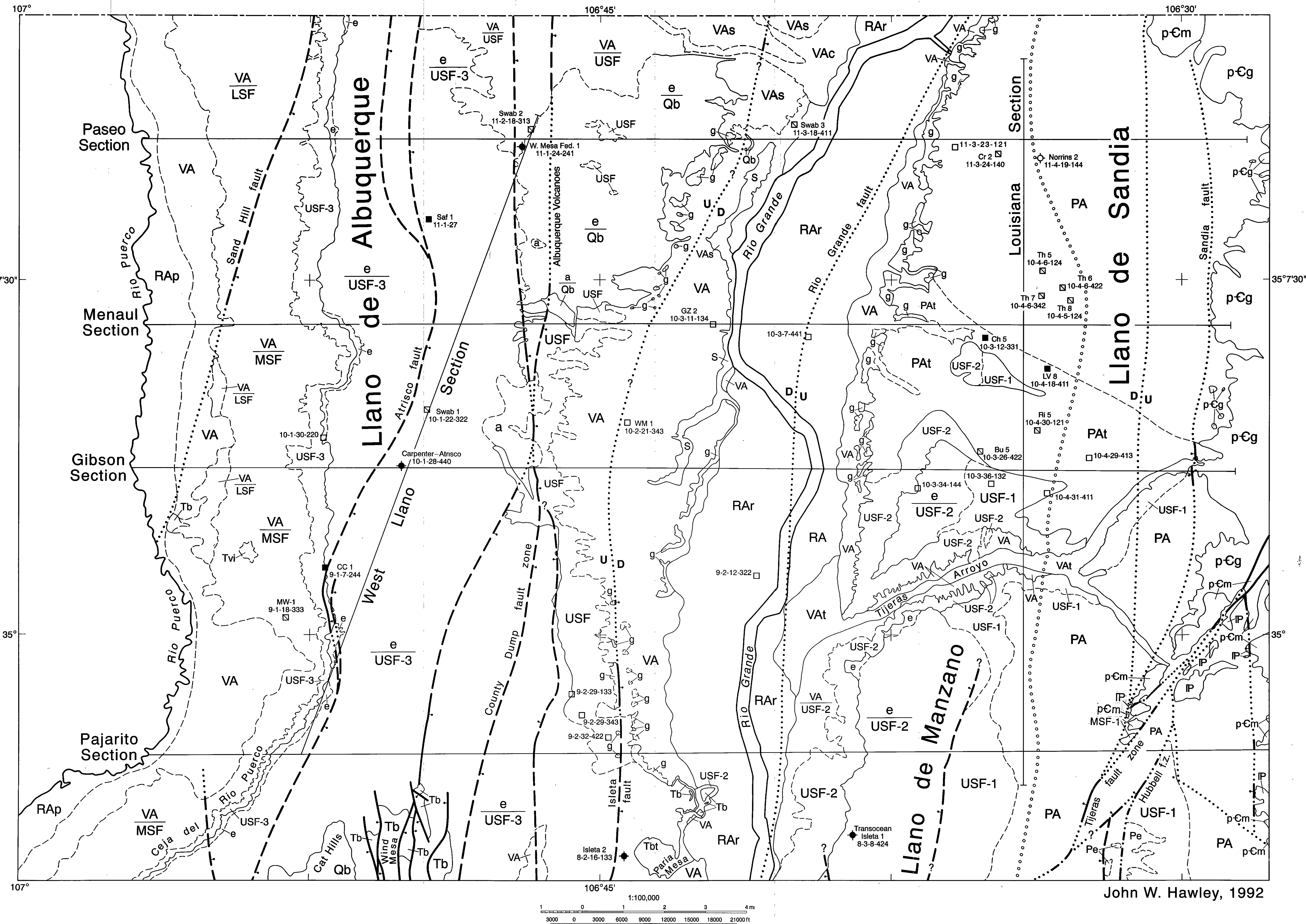

Plate 1 Hydrogeologic Map of the Albuquerque Metropolitan Area, northern Albuquerque Basin, New Mexico

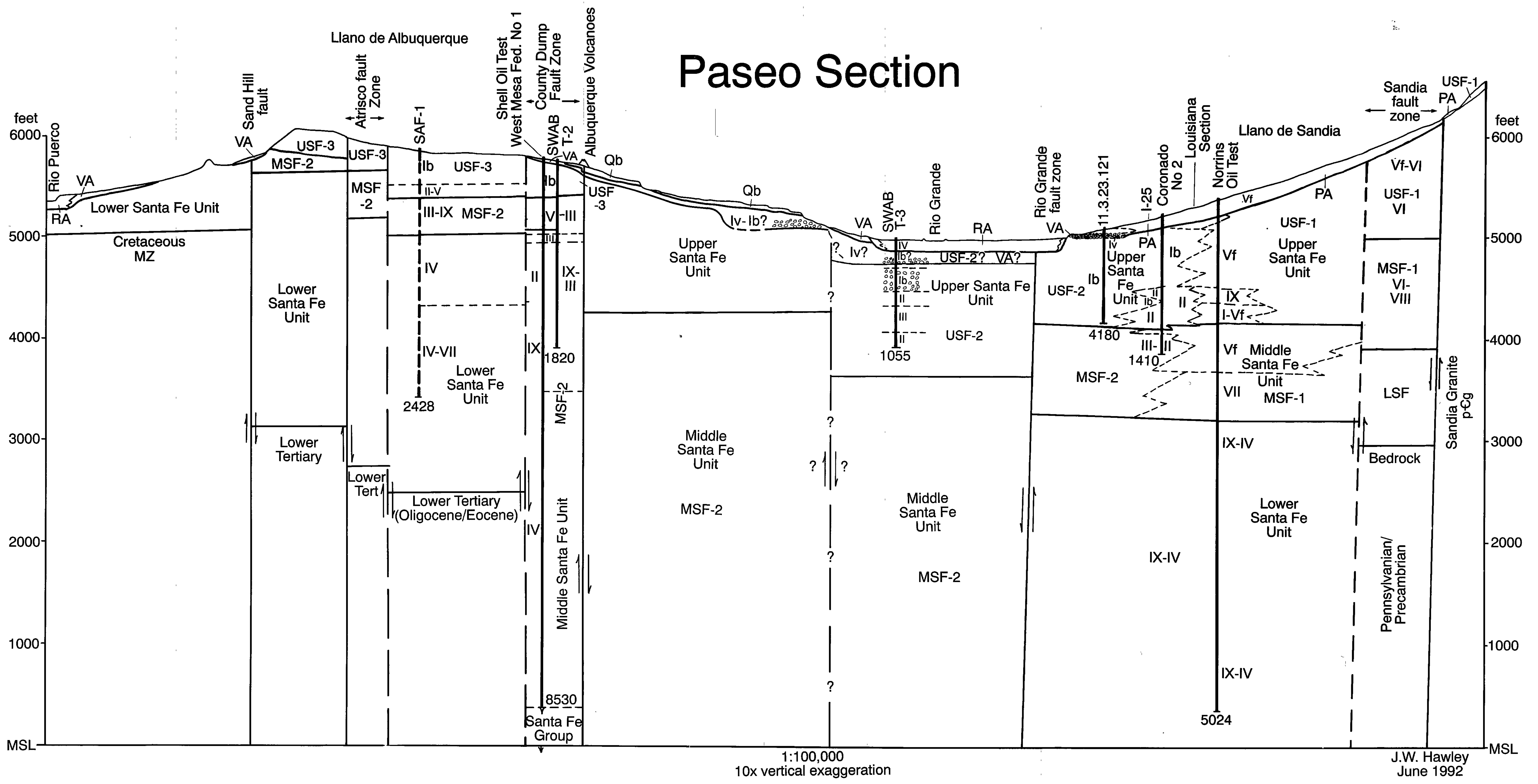

Plate 2. Paseo del Norte Hydrogeologic Section

Menaul Section

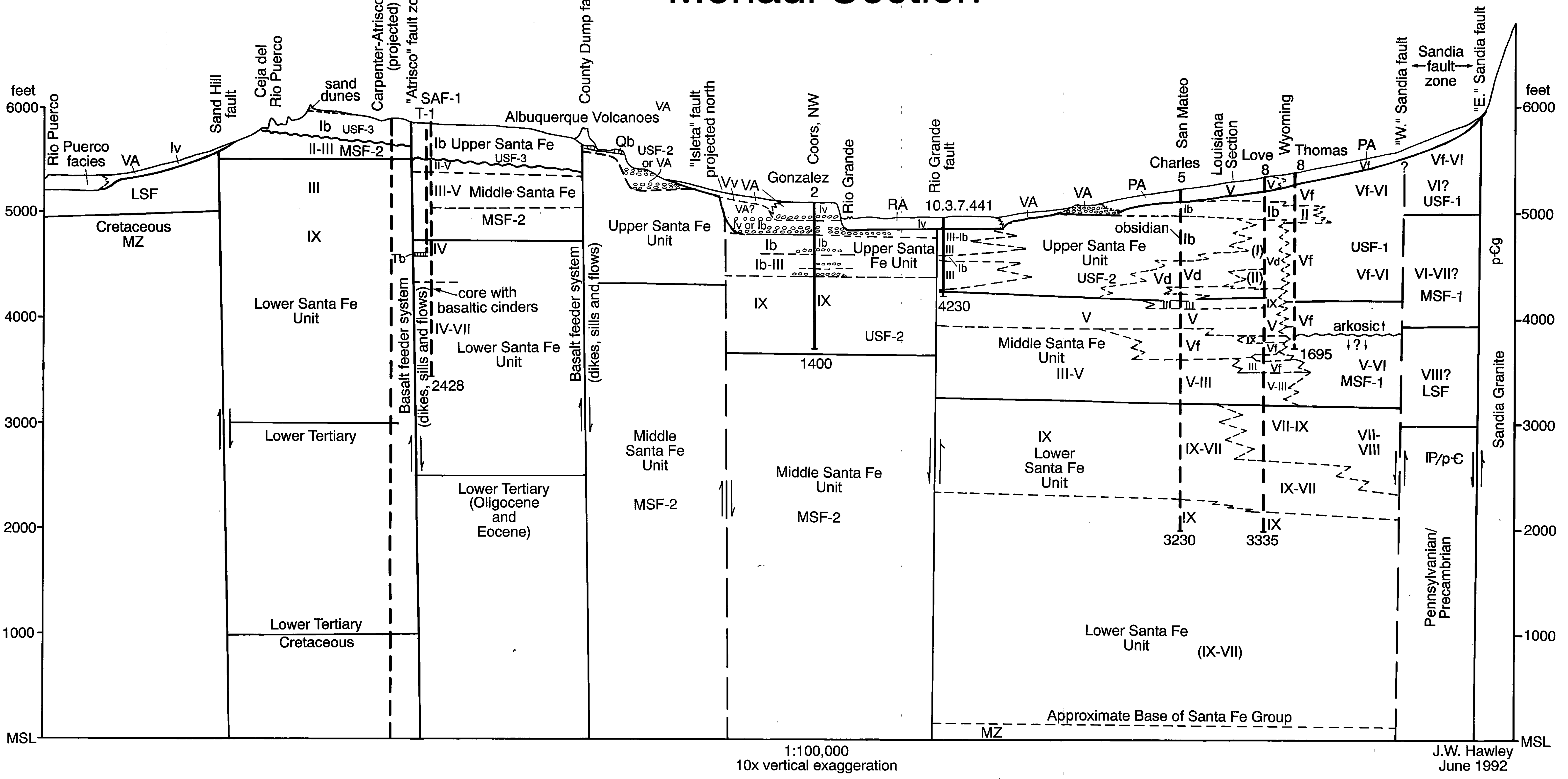

Plate 3. Menaul Hydrogeologic Section

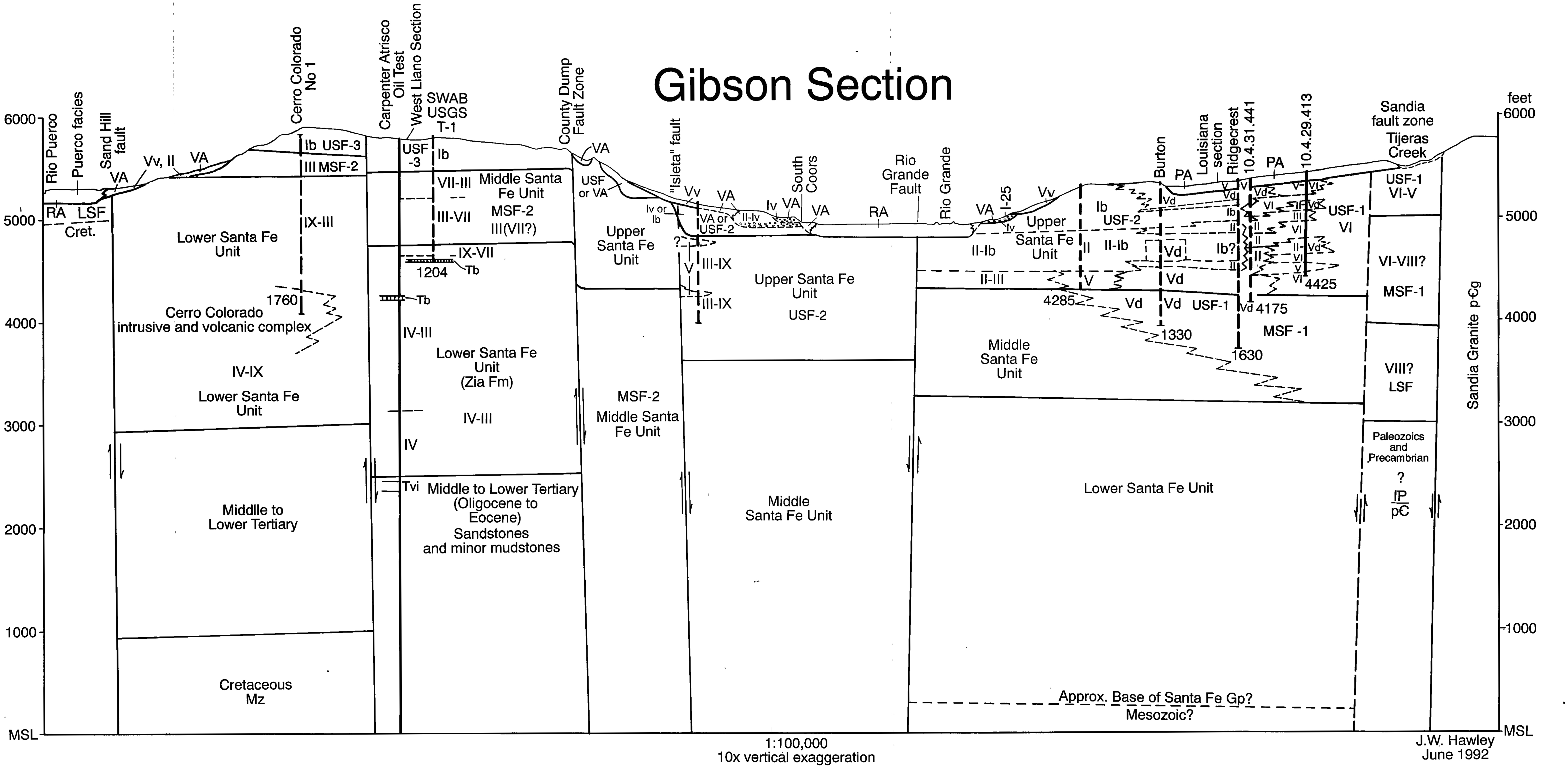

Plate 4. Gibson Hydrogeologic Section

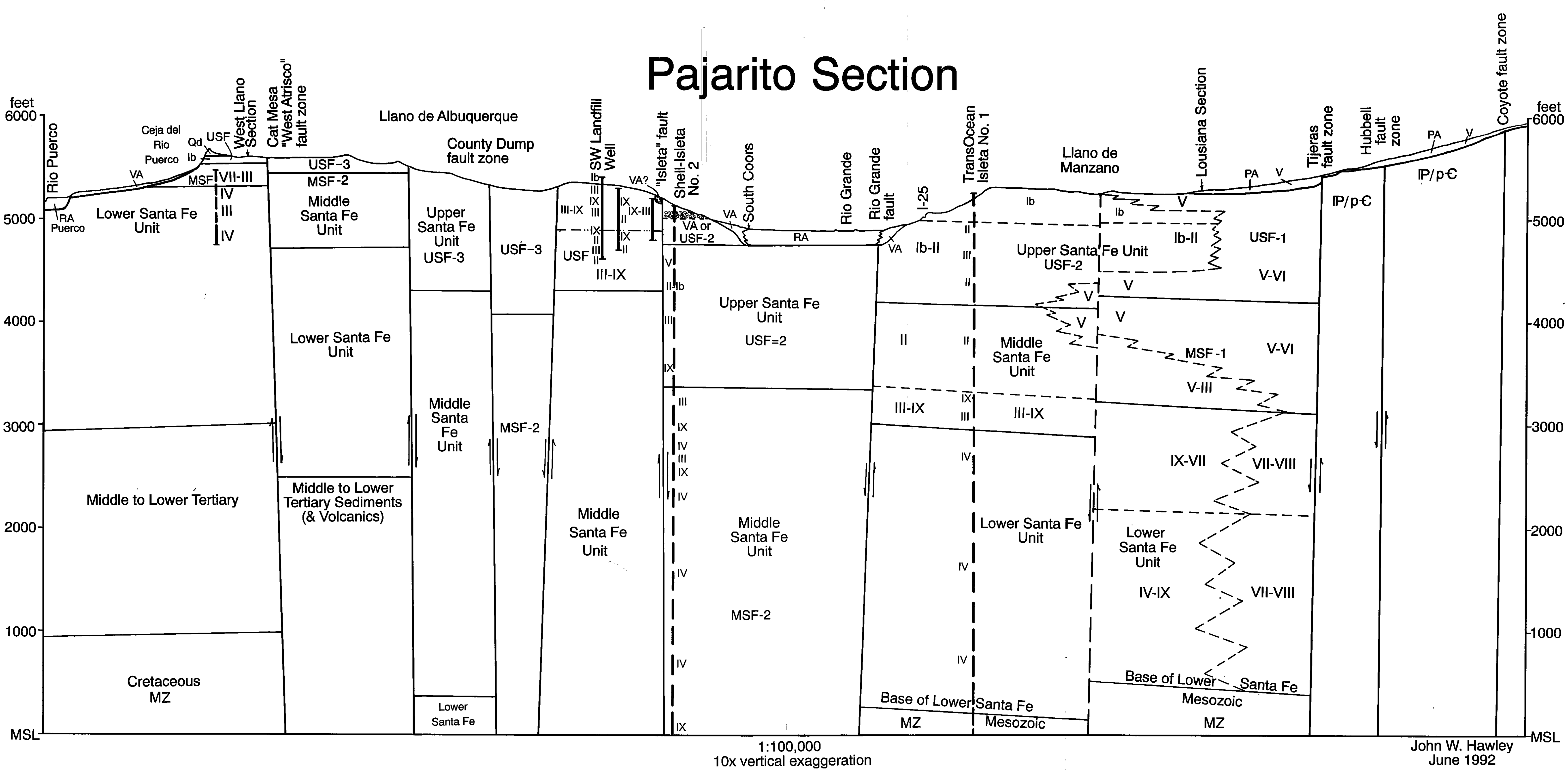

Plate 5. Pajarito Hydrogeologic Section

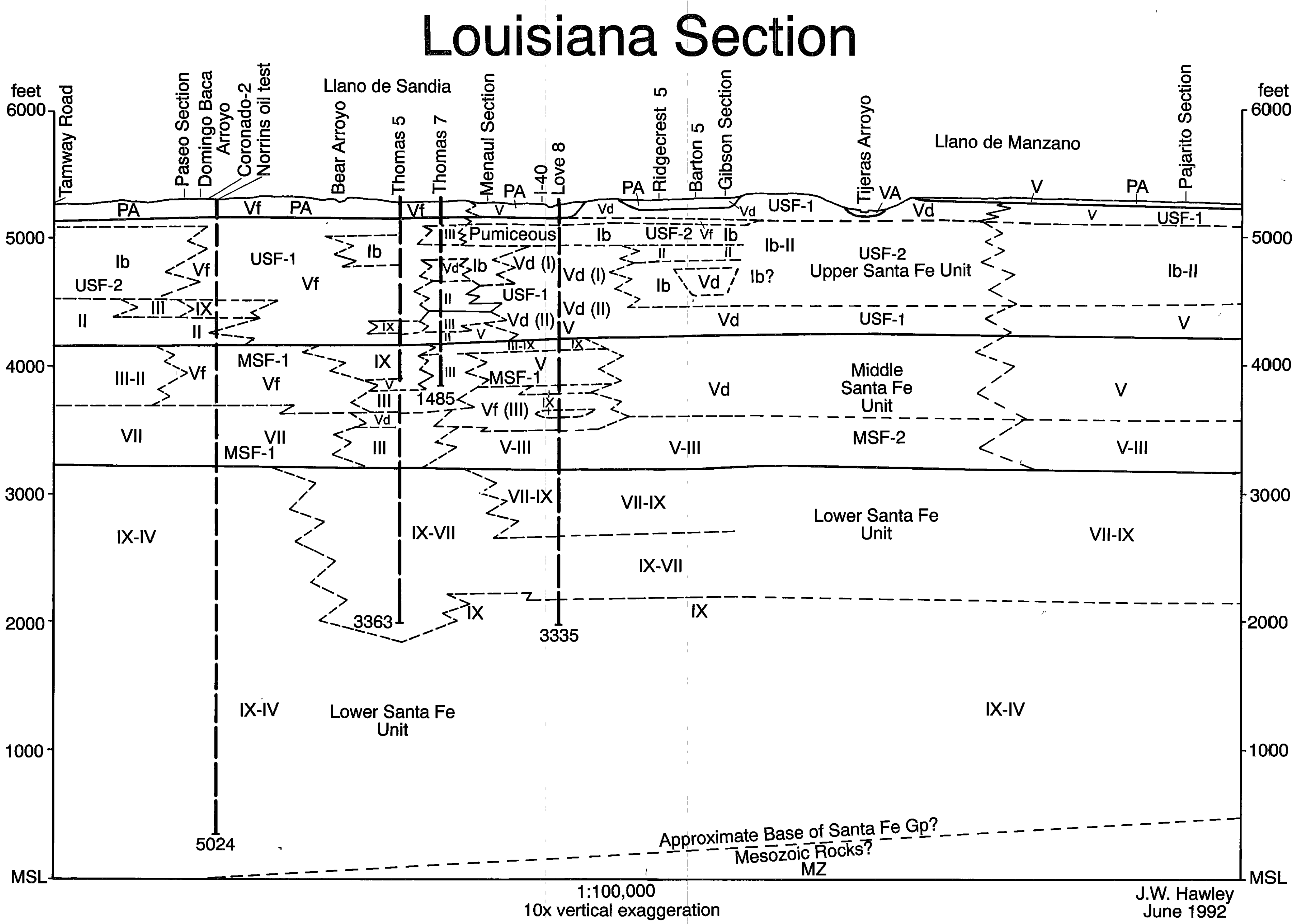

Plate 6. Louisiana Hydrogeologic Section

West Llano Section

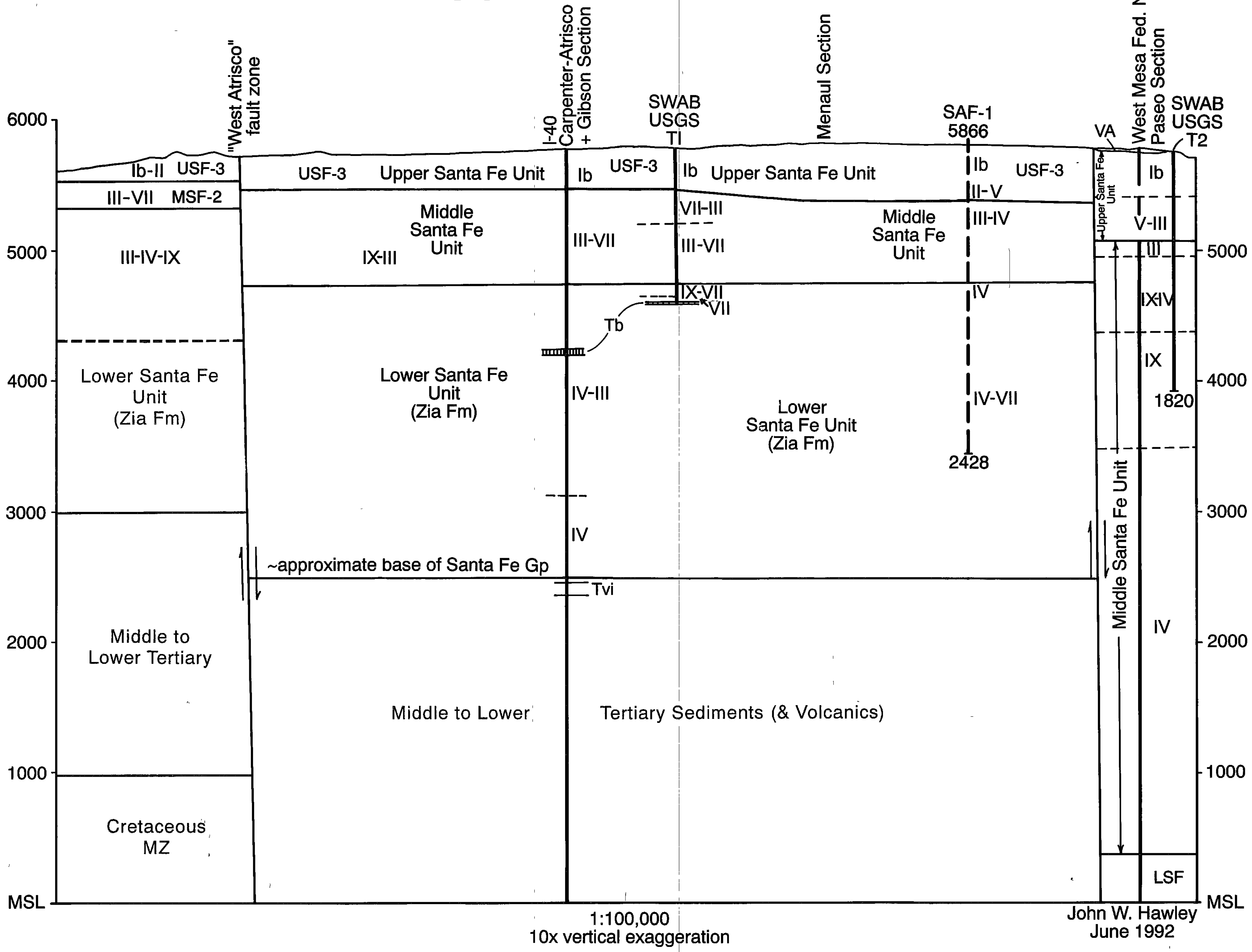

Plate 7. West Llano de Albuquerque Hydrogeologic Section