HYDROGEOLOGY AND WATER RESOURCES
OF THE
AMBROSIA LAKE-SAN MATEO AREA
McKINLEY AND VALENCIA COUNTIES, NEW MEXICO

by

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Submitted in Partial Fulfillment of the
Requirements for the Degree of Master of
Science in Geology

New Mexico Institute of Mining and Technology
Socorro, New Mexico
June, 1979

CONTENTS

LIST OF FIGURES

LIST OF FIGURES, cont.

LIST OF TABLES

LIST OF PLATES

HYDROGEOLOGY AND WATER RESOURCES OF THE AMBROSIA LAKE-SAN MATEO AREA McKINLEY AND VALENCIA COUNTIES,_ NEW MEXICO

ABSTRACT

The Ambrosia Lake-San Mateo area, located approximately 10 miles (16 kilometers) north of Grants, New Mexico, is a major producer of uranium ore. Mining neccesitates the dewatering of approximately 6 billion gallons (23 billion liters) per year from local geologic units. Ground-water information has been obtained for a 15-minute quadrangle-sized area by field investigations, laboratory analyses, and the compilation of published data. Geologically, the study area is typical of the outcrop zone along the southern flank of the San. Juan Basin.

Most of the ground water produced in the area is pumped from the uranium-bearing Westwater Canyon Sandstone Member of the Morrison Formation (Jurassic), which yields from 20 to 300 gpm (gallons per minute 1.3 to 18.9 l/s, or liters per second) to wells. Domestic wells near San Mateo tap the Menefee Formation and Point Lookout Sandstone (Cretaceous), which commonly yield from 20 to 50 gpm (1.3 to 1.5 l/s). The bedrock aquifers have higher yields in the southeastern part of the area, due to more intense fracturing. Ground water flow in the alluvial aquifer is generally to the south. The flow in the bedrock aquifers is to the northeast and east, following the strata's dip and ubiquitous northeasterly-trending fractures. Ground water sampled in the central part of the study area contains from 400 to 2000 mg/l (milligrams per liter) TDS (total dissolved solids). Based on calculations from resistivity logs, it is estimated that ground water in the less developed northeastern part of the area contains from 2000 to 5000 mg/l TDS.

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INTRODUCTION

Problem and Purpose

In the southern part of the San Juan Structural Basin, in northwestern New Mexico, the annual precipitation equals approximately 10 in. (inches; 25 cm, or centimeters). The annual evaporation rate, however, may reach 100 in. per0 year (254 cm; Tuan and others, 1968). Consequently, most of the area lacks adequate supplies of surface water to support even the most basic human needs.

The San Juan Basin is rich in energy resources, especially petroleum, coal, and uranium. The exploration for and mining of these items are active, and are expected to increase as the nation's oil production declines. As energy development continues in the area, and is accompanied by an influx of people, existing and potential problems related to water must be addressed.

Due to the deficiency of surface-water supplies, residents and industry in the area will be dependent upon ground water. At the same time it will be, in many cases, necessary to pump large amounts of ground water to facilitate mining operations. Some of this water will be used for ore-milling, and all of it must be disposed of in such a way that it will not contaminate other water supplies.

The effects of large-scale pumping on the occurrence, flow, and quality of ground water in the San Juan Basin are not certain. The New Mexico Bureau of Mines and Mineral Resources, the United States Geological Survey, and the New Mexico State Engineer are cooperating in a study of this problem, with the intention of describing the occurrence, flow, and quality of ground water in the Basin, and predicting the effects of mining and development on ground water. As a part of this basin-wide investigation smaller areas have been chosen for more detailed study, particularly with regard to the geologic controls of ground water.

The Ambrosia Lake-San Mateo area is uniquely suited for such study. Being located on the southern flank of the San Juan Basin amidst the outcrop of Triassic, Jurassic, and Cretaceous rocks, the area is representative of the ground-water recharge zone along the southern side of the Basin. Also, the area is intensely faulted and folded, and so provides the opportunity to study the effects of geologic structure on the groundwater system. Finally, and perhaps most importantly, the area is rich in uranium-ore deposits. The western half of the area has been the focus of intense uranium-mining activity. The many wells in the area provide the opportunity to evaluate the effects of mining on the ground-water systems. The eastern half of the area is just beginning to be exploited for uranium, and thus provides the opportunity to evaluate the pre-mining ground-water conditions there.

Location of Study Area

The area of investigation is about 75 miles (121 km, or kilometers), west of Albuquerque and 10 miles (16 km) north of Grants. It lies between latitudes 35°15'N and 35°30'N and longitudes 107°37'30"W and 107°52'30"W, and includes all or parts of townships 12N through 15N, ranges 8W through 10W. It comprises the Dos Lomas, Ambrosia Lake, San Lucas Dam, and San Mateo 7½ minute topographic quadrangles, and covers parts of McKinley and Valencia counties (Figure 1).

Objectives and Methods

The major objectives of this study were:

a) To determine the characteristics of the geologic units in the Ambrosia Lake-San Mateo area.

b) To delineate the geologic controls of ground-water occurrence in the area.

c) To delineate the geologic controls of ground-water chemistry in the area.

d) To delineate the geologic controls of ground-water movement in the area.

e) To provide baseline ground-water information for the less-developed eastern part of the Ambrosia Lake-San Mateo area.

f) To define the present usage of ground water in the area and to assess the natural constraints on further ground-water development.

The minor objectives of this study were:

a) To evaluate what is known about the impact of uranium mining on local ground-water systems.

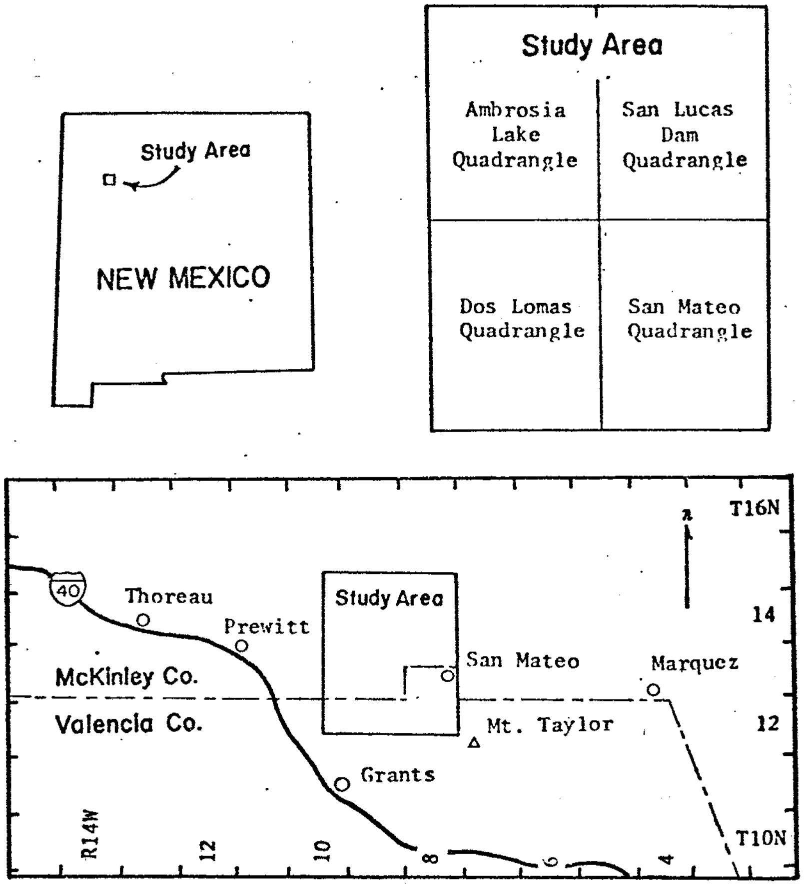

Figure 1. Location of the Ambrosia Lake-San Mateo area and coverage by 7½” topographic quadrangles.

b) To point out the relationship of present-day ground-water flow systems to the distribution of uranium ore.

c) To determine the significance of ground-water systems in the Ambrosia Lake-San Mateo area to those in the whole San Juan Basin.

The study of the characteristics of the sedimentary rocks in the area and the extent to which they control the occurrence, flow, and chemistry of ground water there involved determining the location of geologic units, their stratigraphic relationships, their lithologic characteristics, and their significance as aquifers. Units were located by means of existing geologic maps, and were verified or modified based on field checking. The stratigraphic and lithologic characteristics of the geologic units were described in the field in two complete stratigraphic sections (Plates 1 and 2, Appendix C). Rock and sediment samples were collected for the laboratory analysis of lithologic and aquifer properties. Thin-sections of nine outcrop samples from the major aquifers were examined with a polarizing micro-scope to determine mineralogy, degree of cementation, and porosity (Figure 8, Appendix E). The grain-size distributions of nine sandstone samples and three unconsolidated-sediment samples were determined by sieve and hydrometer methods (Figures 7 and 21, Appendix D). The porosity of certain units was also determined by means of five borehole-density logs from wells in and near the study area (Appendix F).

In order to evaluate geologic controls of ground-water occurrence and movement, basic hydrologic data were obtained from well inventories. Twenty-two wells were inventoried in the field and the records of 105 wells were compiled from previous reports. Many of the later wells are observation wells which were drilled in the early days of mining, and are now unused and inaccessible. Because many of these published data were obtained before the advent of large-scale mining, they are believed to closely reflect natural conditions. No wells were accessible to the author in Township 14 North-Range 9 West and Township 14 North-Range 10 West.

The geologic controls of ground-water chemistry were determined by the following methods. Ground-water samples were collected from 22 wells in the area and were analyzed by the chemistry laboratory of the New Mexico Bureau of Mines and Mineral Resources (Table 4). Chemistry data for 45 wells were also compiled from previous investigations. The concentration of total dissolved solids (TDS) in the ground water was estimated in those parts of the study area where there are few water wells, with resistivity and formation-density borehole logs (Figure 20, Appendix F). The chemistries of ground water from different geologic units were compared by means of trilinear plots (Figures 10 and 11) and Stiff diagrams (Plate 4). Plots were also made to show the relationship between specific conductance and the concentration of TDS, and between specific conductance and the concentration of specific ions (Figures 12 through 18).

The geologic controls of ground-water flow were evaluated by several methods. The grain-size distributions of three alluvium samples were determined with sieves and hydrometer, to assist in evaluating points of ground-water recharge (Figure 21, Appendix D). The water levels in 12 wells were measured by the author, and water levels in 81 wells were obtained from previous investigations (Table 3). Water levels in the alluvial aquifer were determined by the author at four sites using a hammer seismograph (Figure 22, Appendix G). The elevations of the ground-water potentiometric surface were plotted on maps (Figures 22, 23, 25, and 28) and in cross-section (Figures 24 and 26). The effects of geologic structure on ground-water movement were ascertained from field observations, available geologic maps, and borehole logs. The results of eight pumping tests were used to evaluate the transmissive character of some of the aquifers (Table 1).

Baseline ground-water data have been compiled for the eastern part of the study area, where there is now relatively little uranium-mining activity, but where the Mt. Taylor Mine will soon begin production. This has been done by the methods described above, particularly including the collection of well data and samples, the evaluation of pumping-test data from the Mt. Taylor Mine (Table 1), and the estimation of ground-water quality from borehole geophysical logs.

The past and present usage of ground water in the Ambrosia Lake-San Mateo area has been determined through interviews with water association members and from published information. Conclusions regarding the future use of ground water are made on the basis of the anticipated economic growth of the area and the geologic control of the ground-water systems that have been determined in this study.

A minor objective of this study has been to compile and evaluate what is known about the effects of uranium mining and processing on the local ground-water systems. This has been done on the basis of field observations and data from previous reports.

The relationship of present-day ground-water flow systems to the distribution of uranium ore has been evaluated by means of ground-water-level data for the Westwater Canyon Member of the Morrison Formation (Table 3, Figure 28), from maps of uranium-ore bodies, and from published descriptions of the deposition of the host rock and emplacement of the ore.

Finally, the significance of this study area to the San Juan Basin as a whole has been evaluated on the basis of the conclusions reached concerning the geologic controls of ground-water occurrence, chemistry, and movement.

Previous Investigations

Although there have been many investigations of particular mine sites and specific geologic formations in the area, existing regional descriptions are not detailed. Prior to the 1930's only the most general geologic reports were made, such as Darton's (1928) description of the Zuni Mountains and general stratigraphy of the southern San Juan Basin. In the 1930's the search for oil and gas stimulated work in the area. For example, Hunt (1936) described the geology and fuel resources of the sedimentary rocks on the western flank of Mt. Taylor. The continued search for oil, gas, coal, and most recently, uranium, has generated a large amount of data from the area since the thirties.

Ground-water resources received little attention until the 1960's. Springs and flowing wells were mentioned incidentally in the early geologic reports. A local study was made for the town of Prewitt (Halpenny and Whitcomb, 1949). In 1961 a report on the geology and ground-water resources of the Grants-Bluewater area was published by the New Mexico State Engineer's Office (Gordon, 1961). This report includes an area in the southern part of the study area. Dinwiddie and Mourant (1966) compiled an inventory of community water supplies in the region. Cooper and John (1968) published a report on the geology and ground-water occurrence in southeastern McKinley County, which includes the northern part of the study area. In 1974 the New Mexico Environmental Institute prepared a baseline study of the Mt. Taylor region for the Gulf Mineral Resources Company. Kaufmann and others (1975) published a study of the effects of the uranium industry on ground-water quality in the Grants Mineral Belt, which includes a discussion of part of the study area.

Acknowledgements

Much of the data on which this report is based were obtained through the cooperation and interest of land and well owners, which is greatly appreciated.

I am quite grateful to Dr. William J. Stone, who suggested and guided the study, and to Dr. John MacMillan and Dr. Gerardo Gross for their advice. I also appreciate the research and study opportunities provided by the New Mexico Bureau of Mines and Mineral Resources, and the assistance of nearly everyone on its staff. The chemical analysis of water samples was performed through the Bureau laboratory, through the cooperation of Mrs. Lynn Brandvold.

Every aspect of the project was assisted by Mary Nuechterlein Brod, my wife.

GEOGRAPHIC SETTING

Physiography

The Ambrosia Lake-San Mateo area lies in the northeast corner of the Datil section of the Colorado Plateau physiographic province (Fenneman, 1931). The relief is formed by caps and piles of volcanic rock, and by northeast-dipping cuestas formed of sedimentary rock. Most of the area is drained to the south by San Mateo Creek toward Bluewater Creek and the Rio San Jose; whereas, drainage in the northeast corner is northerly toward the Rio Puerco (Figure 2).

Just to the south of the area lies a broad valley which is cut in the shales of the Chinle Formation. This valley is flanked on the south by the Zuni Mountains, which rise to an elevation of more than 9000 ft. (feet; 2743 m, or meters). About two miles from the southeast corner of the study area lies the peak of Mt. Taylor, a volcanic complex which rises to an elevation of 11,301 ft. (3444 m), or about 4000 ft. (1219 m) above the surrounding area. The mountain is surrounded by basalt-covered mesas which rise up to about 9000 ft. (2743 m). One of these, La Jara Mesa, is prominent in the southeast part of the study area (Figure 2). Mesa Montañosa and San Mateo Mesa trend northwest-southeast in the western and northern parts of the area, respectively. Between them is a valley in which lies Ambrosia Lake and most of the uranium mines in the area.

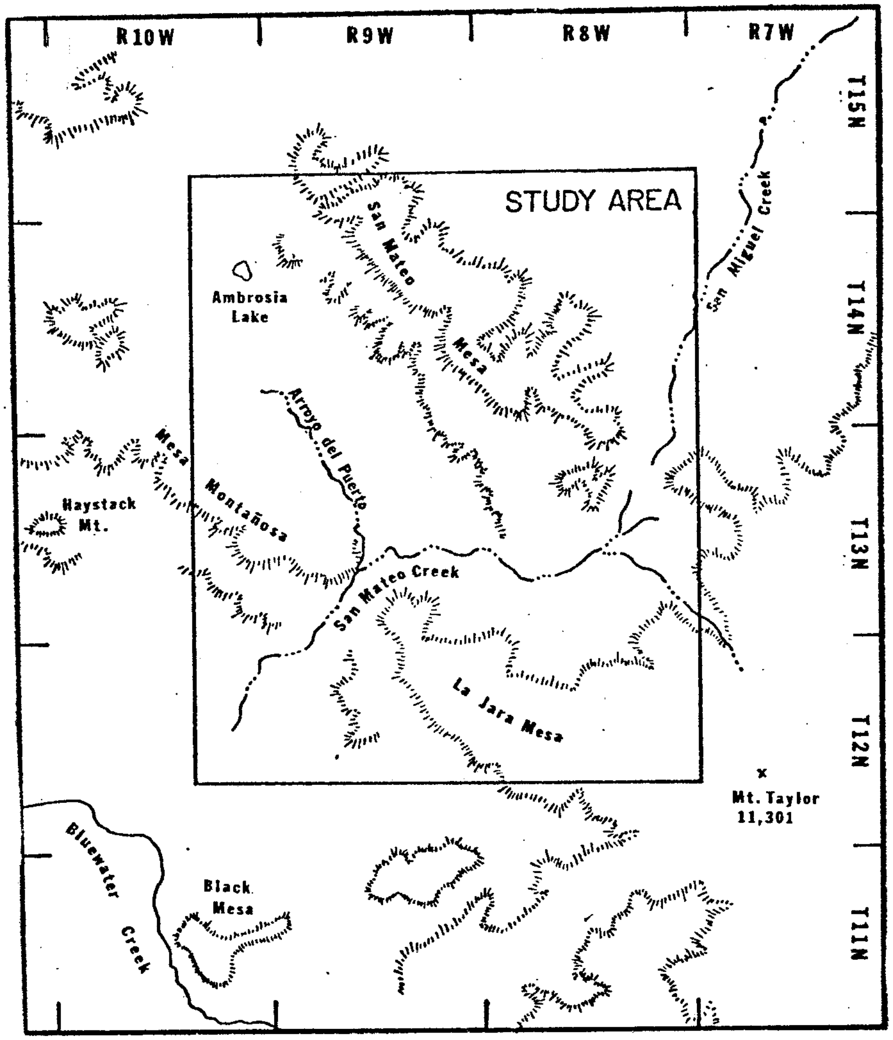

Figure 2. Physiographic setting of the Ambrosia Lake-San Mateo area.

Climate

The climate of the Ambrosia Lake-San Mateo area is semiarid. Sunshine is abundant, the humidity is usually low, and the temperature varies widely, both diurnally and annually. The average annual temperature is about 50°F (10°C).

Throughout most of the lower parts of the area the average annual rainfall is about 9 inches (23 cm). Tuan and others (1969) reported that in central New Mexico the annual precipitation may be expected to increase by about 4 inches (10 cm) per 1000 ft. (305 m) of elevation. Thus, the mesa tops in the area probably receive 12 to 15 inches (30 to 38 cm) annually. The slopes of Mt. Taylor receive as much as 20 inches (51 cm) per year (Tuan and others, 1969). Approximately 50 percent of the total annual precipitation falls in the months of July, August, and September. Gordon (1961) reported that approximately 70 percent falls in the period from May through September, and that the rate evaporation in the area is approximately 90 inches (229 cm) per year.

Soils

Three general soil types exist in the study area, according to Maker, Hacker, and Anderson (1974), and Maker, Bullock, and Anderson (1974). On the sandstone mesas, up to 20 inches (51 cm) of fine sandy loam are present, which is generally highly permeable. In the valleys, lying on alluvium or shale, is 60 or more inches (152 cm) of sandy clay loam, silty clay loam, clay loam, and clay, which has very low to low permeability. On the basalt flows and volcanic rocks of Mt. Taylor is 60 or more inches (152 cm) of stony clay and clay, which generally has very low permeability. Soils are generally too thin, saline, and rocky to be well suited for agricultural purposes.

Population and Economic Environment

The cultural setting of the Ambrosia Lake-San Mateo area is shown in Figure 3. Grants, to the south, is a center for schools and shopping, and has a population of about 9000. Milan, which is a base for mining-dependent services, has about 2000 residents. Interstate 40 connects the area with Albuquerque to the east and Gallup to the west. State Highway 53, which passes from Milan to San Mateo, is the major road in the study area. Ranch Road 509 joins the Ambrosia Lake area with Highway 53 in the middle of the area. There are also numerous other ranch, mine, and National Forest roads, few of which are paved.

Twenty uranium mines and one processing mill were active in the study area in 1976 (Chapman and others, 1977), and three mines and two mills were located nearby. Before the development of the uranium industry, the Ambrosia Lake-San Mateo area was sparsely populated, as is the rest of McKinley and Valencia Counties. About two hundred people lived in the village of San Mateo, and about four ranches were active. In addition to the mines and mills, the advent of the uranium industry in the 1950's encouraged the growth of commercial establishments and the influx of residents into the area. Several hundred people live in trailers in and

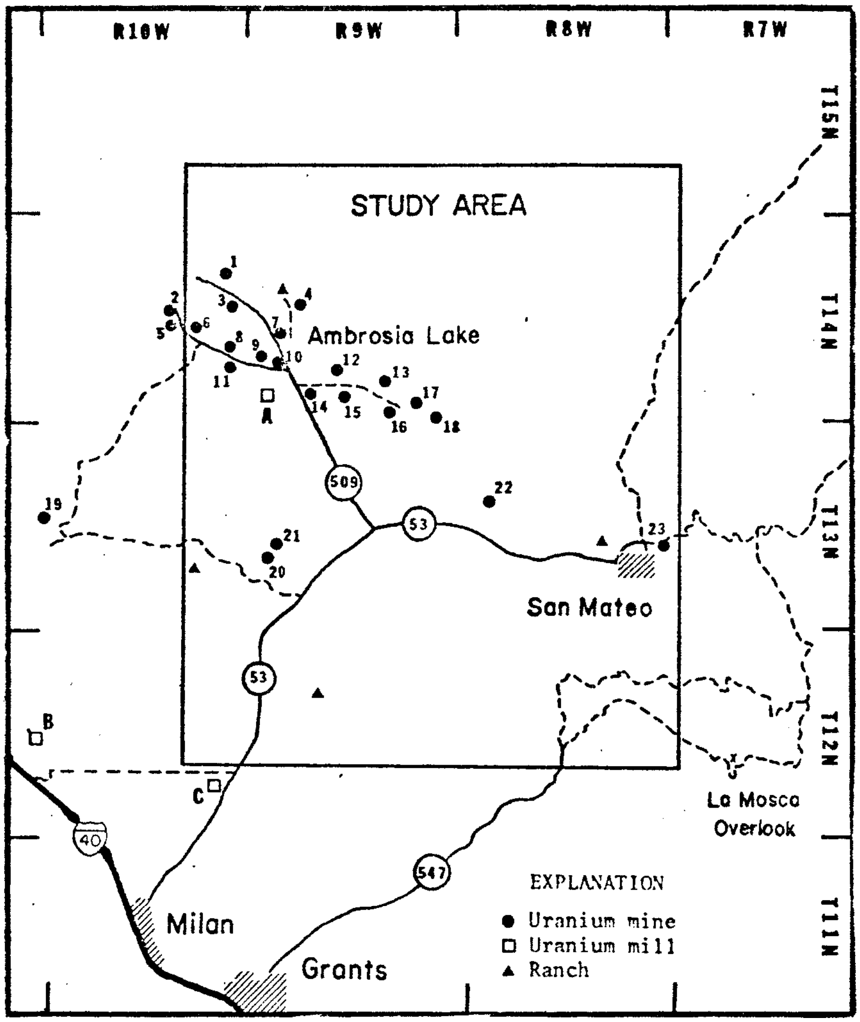

Figure 3. Cultural setting of the study area (after Chapman and others, 1977).

List of uranium mines.
1. Section 12, Hydro-Nuclear.
2. Section 15, United Nuclear Homestake (UN-H)
3. Section 13, UN-H
4. Section 17, Kerr-McGee (K-M)
5. Section 22, K-M
6. Section 23, UN-H
7. Section 19, K-M
8. Section 25, UN-H
9. Section 30 West, K-M
10. Section 30, K-M
11. Section 24, K-M
12. Section 33, K-M
13. Section 27, United Nuclear
14. Section 32, UN-H
15. Section 33, K-M
16. Sandstone, United Nuclear.
17. Section 35, K-M
18. Cliffside, K-M
19. Haystack, Todilto Expl. and Dev.
20. Hope, Ranchers Expl. and Dev.
21. Poison Canyon, Reserve Oil and Minerals.
22. Johnny M, Ranchers Expl. and Dev.
23. Mount Taylor, Gulf Mineral Resources.

List of uranium-processing mills.
A. Kerr-Melee.
B. Anaconda.
C. United Nuclear-Homestake.

near the town of Ambrosia Lake, and at the intersection of State Highway 53 and Ranch Road 509. The population of San Mateo, however, has remained virtually constant since 1950, whereas its economic base has shifted from agriculture to mining. Approximately twenty-five people have moved to San Mateo since the beginning of construction of the Gulf Mt. Taylor Mine, most living in trailers.

A few sections in the western part of the area are part of the Navajo Reservation, and are populated by approximately five families.

GEOLOGIC SETTING

Geologic History and General Stratigraphy

The sedimentary rocks exposed in the study area range from the Upper Triassic Chinle Formation to the Upper Cretaceous Menefee Formation. In the subsurface, but not cropping out, are Upper Permian deposits which are important aquifers south of the area and have had some use in the study area. The Permian, Pennsylvanian, and Precambrian rocks lying under them are too deep to be significant as aquifers. On Mt. Taylor and La Jara Mesa are basalt sheets and other intrusive and extrusive igneous rocks, but they are not used as aquifers and are not significant to the regional ground-water situation. Quaternary alluvium covers much of the area, and is a significant aquifer where it is associated with major drainages.

Figure 4 illustrates the time-stratigraphic relationship of selected sedimentary rocks in the San Juan Basin. The location of the study area in this north-south section is indicated. Most of the strata of concern in the Grants area were deposited in various continental environments. After the Glorieta Sandstone and San Andres Limestone were deposited in association with a Late Permian inland sea, the region was uplifted. Fluvial, lacustrine, and eolian sediments, consisting of silt, sand, and lime-mud were then deposited in Late Triassic through Late Jurassic times. These

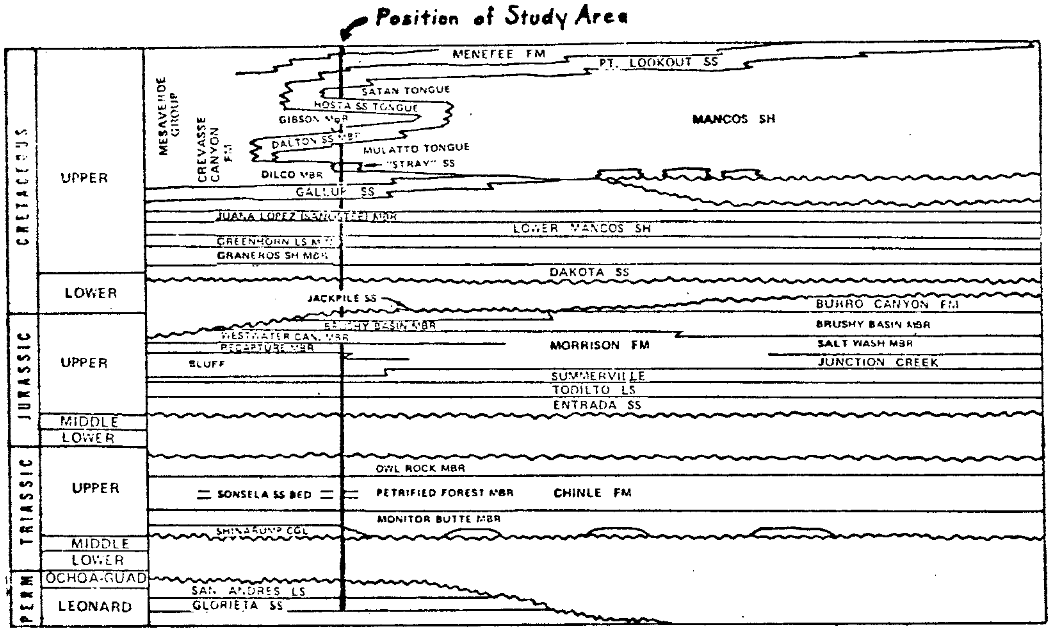

Figure 4. Stratigraphic cross section of the San Juan Basin, showing the position of the Ambrosia Lake-San Mateo area (modified from Molenaar, 1977).

comprise the Chinle Formation, Wingate Sandstone, San Rafael Group, and Morrison Formation. Upper Cretaceous strata consist of an alternating sequence of shorezone sandstone, marine shale, and continental deposits of various lithology. In the southern San Juan Basin these comprise the Dakota Sandstone, Mancos Shale, and Mesaverde Group. The depositional record left by the fluctuating Late Cretaceous sea is discussed in the classic paper by Sears, Hunt, and Hendricks (1941).

Measured sections of units exposed in the area are compared on Plate 1. Figure 5, a columnar section of units present in the study area based on a composite electric log, indicates representative subsurface thicknesses of the deposits. The sedimentary deposits of interest, Upper Permian to Upper Cretaceous, comprise a total thickness of about 4000 ft. (1219 m).

The distribution of the formations in outcrop is shown on Plate 2. The outcrops generally strike northwest-southeast, with the Chinle Formation (Triassic) being exposed in the southwestern corner of the area, and successively younger units being exposed toward the northeast.

Structure

The study area is on the southern flank of the San Juan structural basin. To the south lie the Zuni Mountains, a dome in which Precambrian crystalline rocks are exposed. Immediately to the east lies Mt. Taylor and an associated complex of volcanic deposits. Figure 6 shows that the study area lies at the intersection of

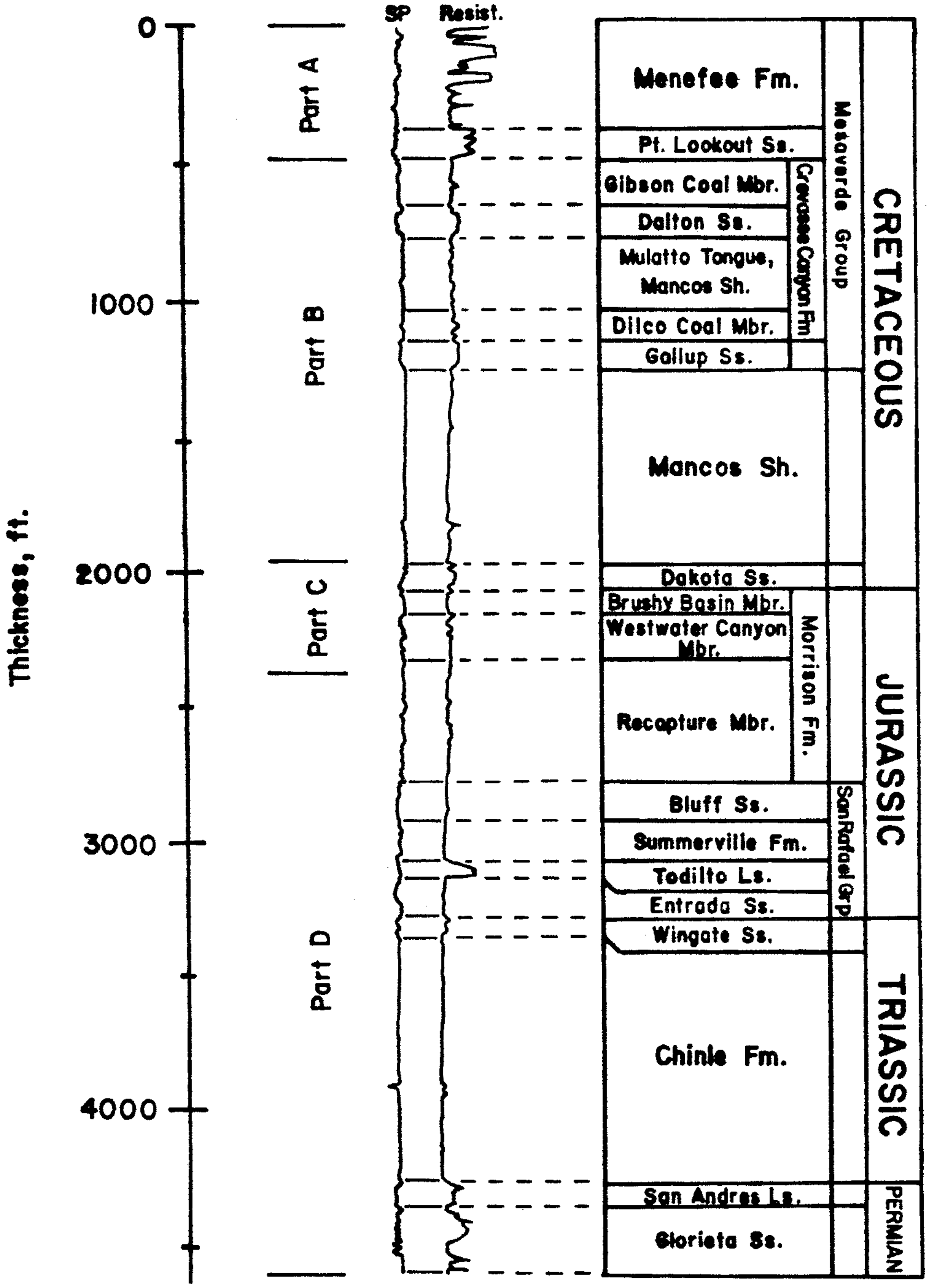

Figure 5. Composite electric log of strata in the Ambrosia Lake-San Mateo area.

Part A: Shar Alan Fernandez #10, T14N,R7W,Sec.33,

Part B: Beard Oil #2 Fernandez, T14N,R8W,Sec.25;

Part C: Clary and others (1963), T14N,R9W,Sec.29;

Part D: Superior Oil, San Mateo Gov't #1-14, T14N,R8W,Sec.14.

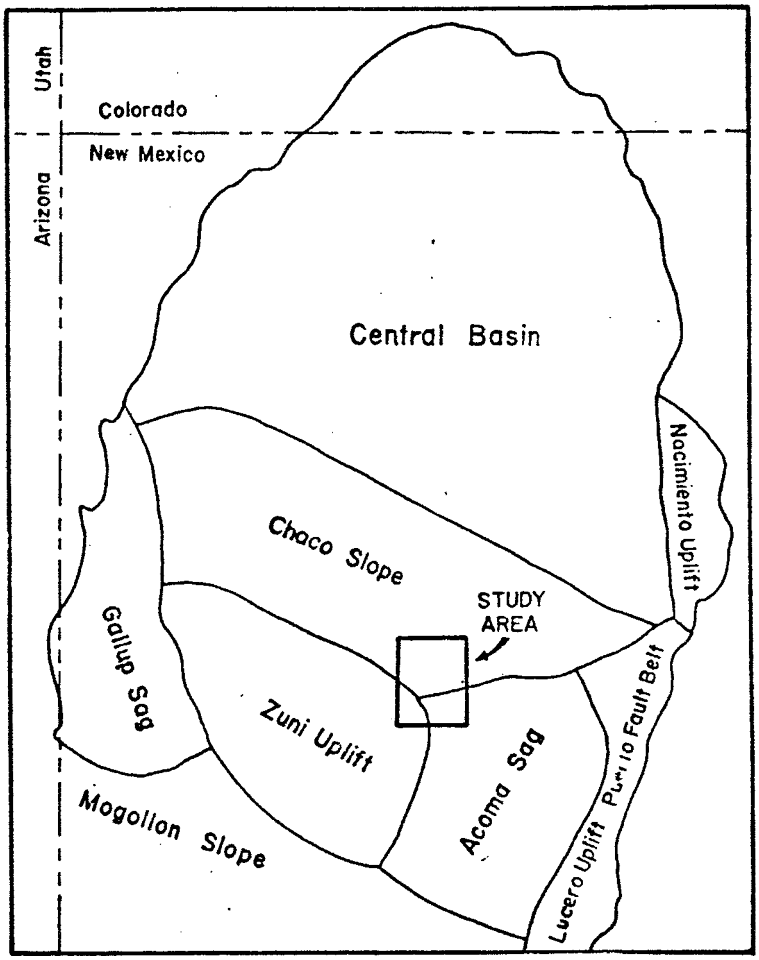

Figure 6. Relationship of study area to the tectonic elements of the San Juan Basin (modified from Kelley, 1963).

three structural provinces of the San Juan Basin--the Chaco Slope, the Zuni Uplift, and the Acoma Sag. Sedimentary strata dip northeasterly at about four degrees from the Zuni Mountains, before leveling out to about one degree on the Chaco slope. Beds dip easterly into the Acoma sag at greater than twenty degrees. Kelley (1963) indicated that the San Juan Basin features (Figure 6) were formed in Laramide time (Late Cretaceous to Early Tertiary). The Mt. Taylor complex erupted in Late Pliocene time.

The detailed structure of the study area is shown on Plate 3. Structure contours show the northeasterly dip of beds on the north flank of the Zuni uplift and the Chaco slope, and the steep, easterly dips on the edge of the Acoma sag. The northeast flank of the Ambrosia Lake Anticline is apparent in the northwest corner, and the San Mateo Dome in the northeast corner of the area. The cross-section on Plate 3 shows that the beds level out on the crest of the San Mateo Dome, before plunging steeply down the eastern side.

Fractures in the area generally have a northerly trend, especially in the western part. Those in the eastern part, especially near the San Mateo Dome, have both a northerly and an easterly trend. Bucher (1953) suggested that the San Mateo Dome is similar to the monoclines on the eastern side of the San Juan Basin, and may have been formed by the draping of sediments over concealed basement faults. Gorham and others (1977) indicated that joints created by such tensional forces, rather than compressional ones, tend to be parallel and open, and therefore relatively permeable. This type of jointing also tends to be oriented parallel to the axis of the associated fold. The degree of fracturing is generally greater where the rocks are relatively dense and brittle (such as sandstone), where they are shallow, and where they occur in the vicinity of a major structural deformation, such as a fault (Plate 3).

Most of the faults in the area are normal, dip-slip faults with less than 40 ft. (12 m) of displacement. The prominent San Mateo Fault, which trends northeasterly from the southwest corner of the area, seems to divide the structural elements in the area. This fault has a maximum displacement of approximately 450 ft. (137 m). Its east side is thrown down, as is evident on Plate 3. The San Rafael Fault Zone passes through the southeast corner of the area, and is comprised of faults on the western flank of the McCarty syncline. Santos (1970) reported that movement along it is mainly horizontal, with as much as 20,000 ft. (6096 m) of right-lateral displacement.

The effects of fracturing on ground-water flow vary according to the type of rock, the amount of displacement, and the orientation of the fractures. In some parts of the area, gouge and cement in the fracture zone inhibit flow. This also occurs where relatively permeable beds are displaced against relatively impermeable ones. Squyres (1963) cited a situation in a mine in the study area in which the faces of fractures were separated by about 1 inch (2.5 cm). In such cases permeability is quite enhanced.

HYDROGEOLOGY

Introduction

The hydrogeology of the Ambrosia Lake-San Mateo area will be discussed, unit-by-unit, in descending stratigraphic order. The discussions include the units' age, stratigraphic position, thickness, outcrop characteristics, bedding, and lithology along with the number of wells believed to be tapping the unit in the area, reported yields, and the quality of the ground water in the unit. Plate 2 shows the nature of the outcrops in the area. The cross-section on Plate 3 shows the relationship of units beneath the surface. Appendix C gives detailed field descriptions of each of the units. Figure 7 indicates the grain-size distributions of notable units. Figure 8 indicates the composition and classification of notable sandstone units. The New Mexico well-numbering system is explained in Appendix H.

Quaternary Alluvial Deposits

Quaternary alluvium covers a large part of the study area, but is a significant aquifer only where it is associated with major drainages, especially San Mateo Creek and Arroyo del Puerto. Its maximum thickness along these drainages and in the valley in the southwest corner of the area is approximately 100 ft. (30 m). A log from a well just south of the study area (Gordon, 1961) indicates that the alluvial valley fill consists of fine to coarse sand, with some gravel near the bottom.

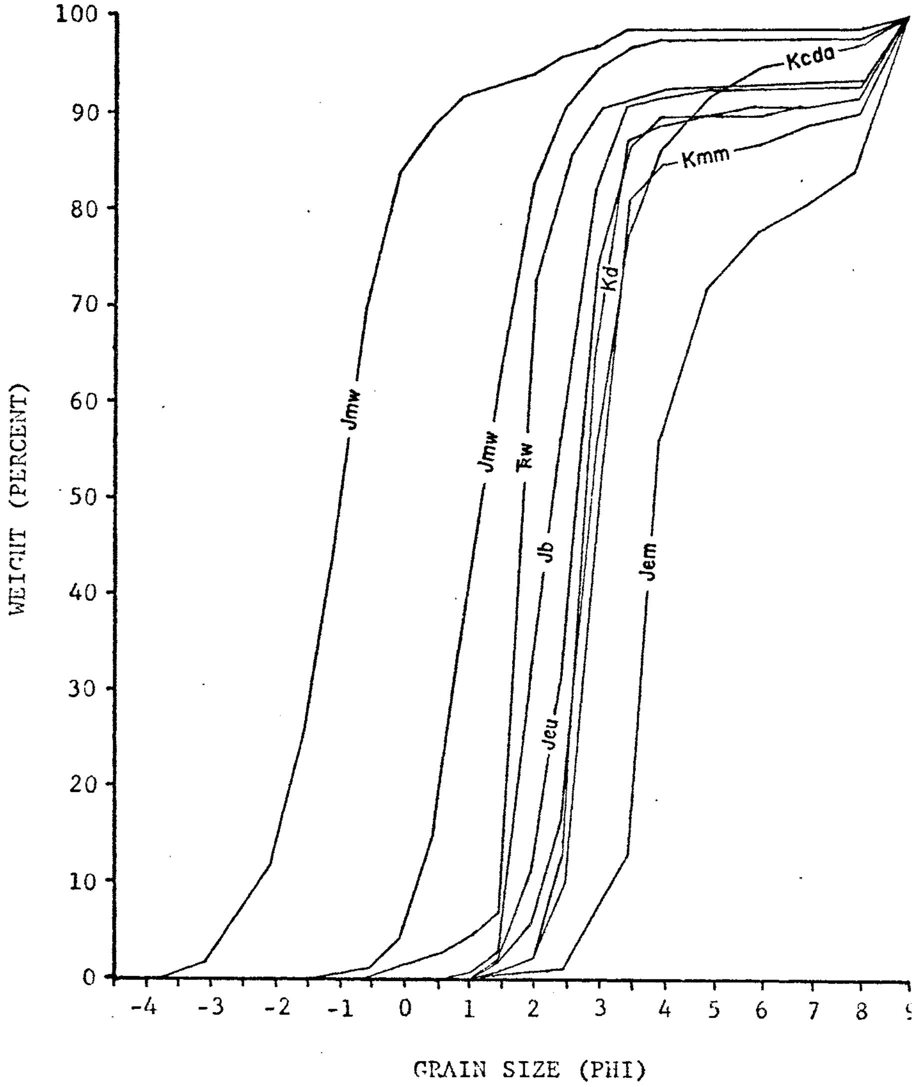

Figure 7. Plot of grain-size distribution of notable units. Data, Appendix D; locations of sampling points, Plate 1; geologic symbols explained, Plate 2.

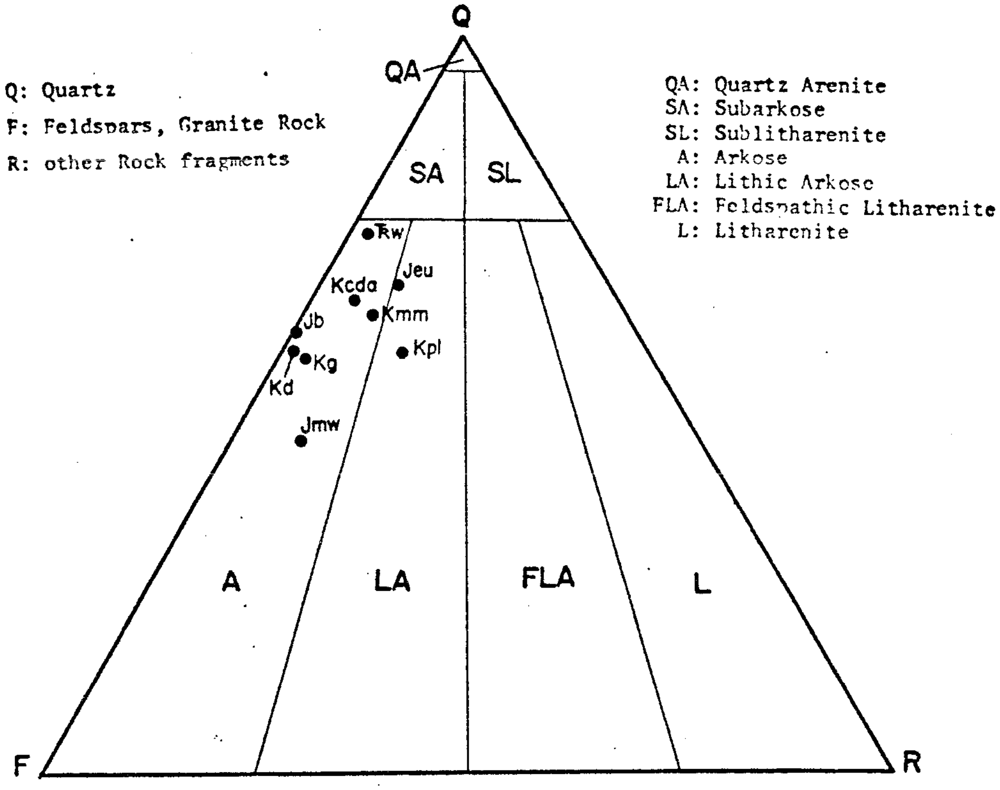

Figure 8. Classification of notable sandstone units. Classification system after Folk (1968). Data, Appendix E; locations of sampling points, Plate 1; geologic symbols explained, Plate 2.

Twenty-five wells are believed to be completed in the alluvium in the study area. A few of these are observation wells near Ambrosia Lake. Before the discharge of mine wastewater in the area, ground water in most of the alluvium was characterized by TDS (total dissolved solids) concentrations to 500 to 1000 mg/l (milligrams per liter). Most of the water in the alluvium now seems to contain thousands of mg/l TDS (Table 4).

Tertiary Igneous Deposits

Extrusive and intrusive igneous rocks form the Mt. Taylor complex in the southeastern part of the area. La Jara Mesa is capped by a sheet of basalt. Much of Mt. Taylor itself consists of porphyrytic andesite and rhyolite (Cooper and John, 1967). No wells tap the Tertiary deposits in the study area. The basalt flows offer a large area for the recharge of the underlying Cretaceous rocks, and springs issue from the flows on the sides of Mt. Taylor. Although the sedimentary rocks under them may be expected to be saturated, the Tertiary deposits themselves are not significant aquifers.

Cretaceous Deposits

Mesaverde Group

Menefee Formation--

The Menefee Formation (Late Cretaceous) forms uneven slopes in the eastern part of the study area, notably near San Mateo and east of the San Mateo Dome. The unit was originally named by Collier (1919) in Montezuma County, Colorado, and is mainly of continental origin. It consists of thin to thick sandstone beds interbedded with shale, siltstone, and coal. Based on determinations from well logs from the San Juan Basin, the Menefee typically consists of about 30 percent sandstone, 65 percent shale, and less than 5 percent coal.

Twenty-two wells are known to be completed in the Menefee in the study area, mostly in and near San Mateo where they provide adequate domestic and stock supplies. The quality of the water is generally very good due to abundant recharge nearby from Mt. Taylor runoff. The ground water tends to be of the sodium-bicarbonate type and TDS concentrations range from 179 to 1400 mg/1 in local wells, with an average of about 400 mg/1 (Table 4). The dissolved solids content tends to be lower near the major source of recharge, San Mateo Creek. Though it is a good aquifer near San Mateo, the Menefee lies above the regional water table in much of the rest of the area.

Point Lookout Sandstone--

The Point Lookout Sandstone was deposited in Late Cretaceous time. In the study area its outcrop is extensive and forms resistant cliffs which cap the prominent San Mateo Mesa. East of the mesa and near the town of San Mateo, the formation dips steeply underground toward the east. In most of the area it is split by the Satan Tongue of the Mancos Shale, and its lower part is called the Hosta Sandstone Tongue of the Point Lookout Sandstone. Where not separated it is approximately 200 feet (61 m) thick. The unit was originally named by Collier (1919) near Mancos, Colorado, and is thought to be of coastal marine origin. In outcrop it consists of medium to very thick beds with large-scale, low-angle, tabular-planar cross-bedding. It is comprised of fine, well-sorted, subangular, spherical grains of quartz and feldspar, and about 30 percent silt and clay matrix. Depending on the amount of matrix and cement, its porosity may range up to 30 percent.

Three wells are known to tap the Point Lookout Sandstone in the area, all of them being in or near San Mateo. Cooper and John (1967) indicated that two of these wells yield 20 to 30 gpm (gallons per minute; 1.8 to 1.9 liters per second, or l/s). One has also been known to yield more than 50 gpm (3.1 l/s; Howard Sheets, driller, Albuquerque, personal communication). The chemistry of water from the Point Lookout is similar to that of the Menefee, the most common ions in solution being sodium and bicarbonate. Also, like the Menefee water, samples from the San Mateo wells indicate that it contains from 200 to 700 mg/1 TDS (Table 4). In most of its outcrop, elsewhere in the study area, the Point Lookout is above the regional water table. As water in it moves down-dip in the subsurface, its chemistry may be expected to deteriorate, as a result of contact with the Satan Tongue of the Mancos Shale.

Crevasse Canyon Formation--

In the Ambrosia Lake-San Mateo area, the Crevasse Canyon Formation (Late Cretaceous) crops out on the flanks of San Mateo Mesa, where it forms uneven slopes. It is divided by the Mulatto Tongue of the Mancos Shale; without the Mulatto Tongue, it is approximately 225 ft. (69 m) thick.

The Crevasse Canyon is thought to be of continental origin, and was named in southwestern San Juan County, New Mexico, by Allen and Balk (1954). It consists of sandstone, siltstone, shale, and

Coal, and has been divided into three members. In descending order, these are the Gibson Coal Member, the Dalton Sandstone Member, and the Dilco Coal Member. The Dilco and Gibson Members are similar-to the deposits of the Menefee Formation, and may contain sandstone units up to 30 ft. (9 in) thick which are comprised of fine, well-sorted quartz sand. The Dalton Sandstone forms cliffs and is approximately 60 ft.(19 m) thick in the area. It consists of medium to thick beds containing scattered carbonaceous plant remains but is comprised mainly of fine, well-sorted, subangular, spherical quartz and feldspar sand grains. It contains about 15 percent silt and clay matrix, 15 percent carbonate cement, and has a porosity of about 20 percent. In its outcrop gypsum is seen to fill fractures in the unit.

Because of its high topographic setting and the availability of better aquifers, only one well in the area is completed in the Crevasse Canyon. Northeast of San Mateo Mesa a stock well taps the Dalton Sandstone Member, which yields sodium-sulphate water, and contains nearly 4500 mg/1 TDS (Cooper and John, 1967). Data from wells near Gallup indicates that the Dalton yields about 20 gpm there (1.3 1/s; Shomaker, 1971).

Gallup Sandstone--

The outcrop of the Gallup Sandstone (Late Cretaceous) forms a bench on the western base of San Mateo Mesa. The unit is divided into two parts in the Ambrosia Lake-San Mateo area. The main body is approximately 160 ft.(49 m) thick and the lower tongue approximately 90 ft.(27 m) thick, with about 90 ft. (27 m) of Mancos Shale intervening. The Gallup was first described by Sears (1925) at Gallup, and is believed to constitute the beach facies between the marine sediments of the Mancos Shale and the continental deposits of the Crevasse Canyon. In outcrop it appears as thin to thick beds with large-scale, low-angle, tabular and wedge-planar cross-bedding, and no apparent fossils. The sandstone is comprised of fine, well-sorted, subangular to angular, spherical grains of quartz and feldspar, with about 7 percent silt and clay matrix and 3 percent carbonate cement. Density logs suggest that it has a porosity of 24 to 30 percent.

Because of more accessible, better aquifers, no wells tap the Gallup in the study area. Cooper and John (1967) indicated that the water from Gallup wells 10 to 20 miles (16 to 32 km} north of the study area has a high concentration of sodium, bicarbonate, and sulphate, and contains from 1000 to 2000 mg/l TDS. Being closer to the outcrop, the Gallup water in the study area should contain lower concentrations of TDS.

Mancos Shale

The outcrop of the Mancos Shale (Late Cretaceous} forms a major northwest-southeast trending valley between Mesa Montañosa and San Mateo Mesa. Two tongues of the Mancos, the Satan (above) and the Mulatto (below) separate the Point Lookout Sandstone and Crevasse Canyon Formation in the area, respectively. The main body of the Mancos is about 900 ft. (275 m) thick, and consists of dark-gray shale with lenses of sandstone and limestone.

In the lower part of the main body are sandstone units which may yield large amounts of water, despite the general character of the Mancos as an aquitard. In outcrop the major one, the Tres Hermanos is approximately 50 ft.(15 m) thick, medium bedded, bioturbated, and interbedded with shale. The sandstone is comprised of fine, moderately well-sorted grains of quartz and feldspar, with much silt matrix. Geophysical logs suggest that the Tres Hermanos has a porosity of about 15 percent.

Four wells in the study area are known to be completed in the sandstone of the Mancos Shale. Two of them are observation wells near the Kerr-McGee mill and two are stock wells in the northern part of the area. No yields from Mancos wells are known, but Cooper and John (1967) reported that it was necessary to dewater 900 and 2000 gpm (58 to 126 1/s) from the "middle sandstone bed" of the Mancos in two mines near San Mateo Mesa. The Tres Hermanos is said to yield a great deal of water in the Mt. Taylor Mine (Hans Jukenwold, hydrologist, Gulf Mineral Resources, Denver, personal communication). Wells in the Mancos yield sodium-sulphate water containing from 2500 to 9000 mg/l TDS (Table 4, Plate 4).

The Mulatto Tongue of the Mancos Shale is about 380 ft. (115 m) thick, and separates the Dalton Sandstone member from the underlying Dilco Coal member of the Crevasse Canyon Formation. It was originally described by Hunt (1934) at the south end of Mulatto Canyon, which bisects San Mateo Mesa in the study area. The tongue contains a prominent, though discontinuous, unit of sandstone which is well exposed in the western half of Sec. 16, T13N, R8W (Plate 2). At that outcrop it is 46 ft.(14 m) thick, has medium to thick beds, and contains large-scale, low-angle, wedge-planar cross-bedding.

A thin section from the site indicates that it is comprised of fine, very well-sorted, subangular, spherical grains of quartz and feldspar, and approximately 25 percent silt and clay matrix. The unit, though discontinuous in outcrop, is apparent in borehole logs from the area, and density logs indicate that it has a porosity of about 20 percent. No wells in the area are completed in the Mulatto Tongue sandstone, but where it is saturated it may be expected to be hydrologically similar to the Tres Hermanos.

Dakota Sandstone

Although it was deposited in Late Cretaceous time, the Dakota Sandstone is the lower-most of the Cretaceous formations in the southern part of the San Juan Basin. Its outcrop forms the cap of Mesa Montañosa in the western part of the study area, and part of the cap of La Jara Mesa in the south-central part. The thickness of the Dakota ranges from 50 to nearly 200 ft. (15 to 61 m) in the area, and averages about 80 ft. (24 m). Originally described by Meek and Hayden (1862) in Dakota County, Nebraska, the deposits constitute the shore-zone facies of the first transgression of the Cretaceous sea.

The Dakota can be a heterogeneous group of sand bodies, but generally behaves as one hydrologic unit (Berry, 1959). In outcrop it appears as thin to thick beds with some large- and small-scale, low- and high-angle, tabular-planar cross-bedding. It may contain plant debris, especially in the lower part. The rock is comprised of fine, well-sorted, angular to subangular, highly spherical grains of quartz and feldspar, with about 6 percent silt and clay matrix and 4 percent carbonate and iron cement. Density logs suggest subsurface porosities of 15 to 20 percent.

Five wells are known to tap the Dakota in the study area. Used for stock, domestic, and mine supplies, all are in the central part of the area, between the outcrop and San Mateo Mesa. Cooper and John (1967) indicated that yields are generally less than 10 gpm (0.6 1/s). The water is high in sodium, bicarbonate, and sulphate, and where sampled, contains from 600 to 1400 mg/1 TDS. As with other formations, the quality may be expected to deteriorate away from the outcrop.

Jurassic Deposits

Morrison Formation

The outcrop of the Morrison Formation (Upper Jurassic) forms an uneven slope on the western flanks of Mesa Montañosa and La Jara Mesa, and its total thickness in the area ranges from about 250 to 450 ft. (76 to 137 m). It was originally described in Morrison, Colorado, by Eldridge (1896), and is thought to have been deposited in a variety of continental environments. In the Grants region the members of the Morrison, in descending order, are the Brushy Basin, the Westwater Canyon, and the Recapture.

The Brushy Basin Member is believed to have been deposited in a fluvial environment, and consists of mudstone interbedded with discontinuous beds of coarse-grained sandstone, and a few thin limestone beds. Santos (1966) indicated that it may be 30 to 150 ft. (9 to 46 m) thick in the area. The "Poison Canyon Sandstone" of economic usage, is a large body of sandstone enclosed by the Brushy Basin Member and unique to the Ambrosia Lake area. It is an important uranium-bearing unit, especially near Poison Canyon, which cuts the outcrop in the central part of the-area. No wells are known to be completed in the Brushy Basin, but Figure 9 shows that it may locally contain a considerable amount of sandstone, and presumable ground water. Throughout the area parts of it are probably hydraulically connected to the underlying Westwater Canyon.

The Westwater Canyon Member is the chief uranium-ore bearing unit in the Grants Mineral Belt. It generally consists of medium beds with large-scale, low- and high-angle trough cross-bedding; it is composed of fine to coarse, poorly sorted, subangular, spherical grains of quartz and feldspar, and contains about 8 percent silt and clay matrix, 5 percent carbonate cement, and 10 percent porosity. The variability of its texture is illustrated in Figure 9. About 50 wells are believed to be completed in the Westwater Canyon in the study area, reflecting its importance as an aquifer as well as and ore-bearing unit. Some of these wells are used for observation and dewatering, but many are now completed above the Westwater's artificially lowered potentiometric surface. This aquifer is still heavily used near the intersection of Highways 53 and 509. Cooper and John (1967) indicated that the Westwater Canyon may generally be expected to yield more than 20 gpm (1.3 l/s). During a pumping test at the Gulf Mt. Taylor Mine it sustained a yield of about 300 gpm (19 l/s; Hans Jukenwold, hydrologist, Gulf Mineral Resources, Denver, written communication). Ground water in the Westwater Canyon is generally relatively high in concentrations of sodium, calcium, bicarbonate, and sulphate. In the study area it is known to contain from 360 to 2200 mg/l TDS (Table 4).

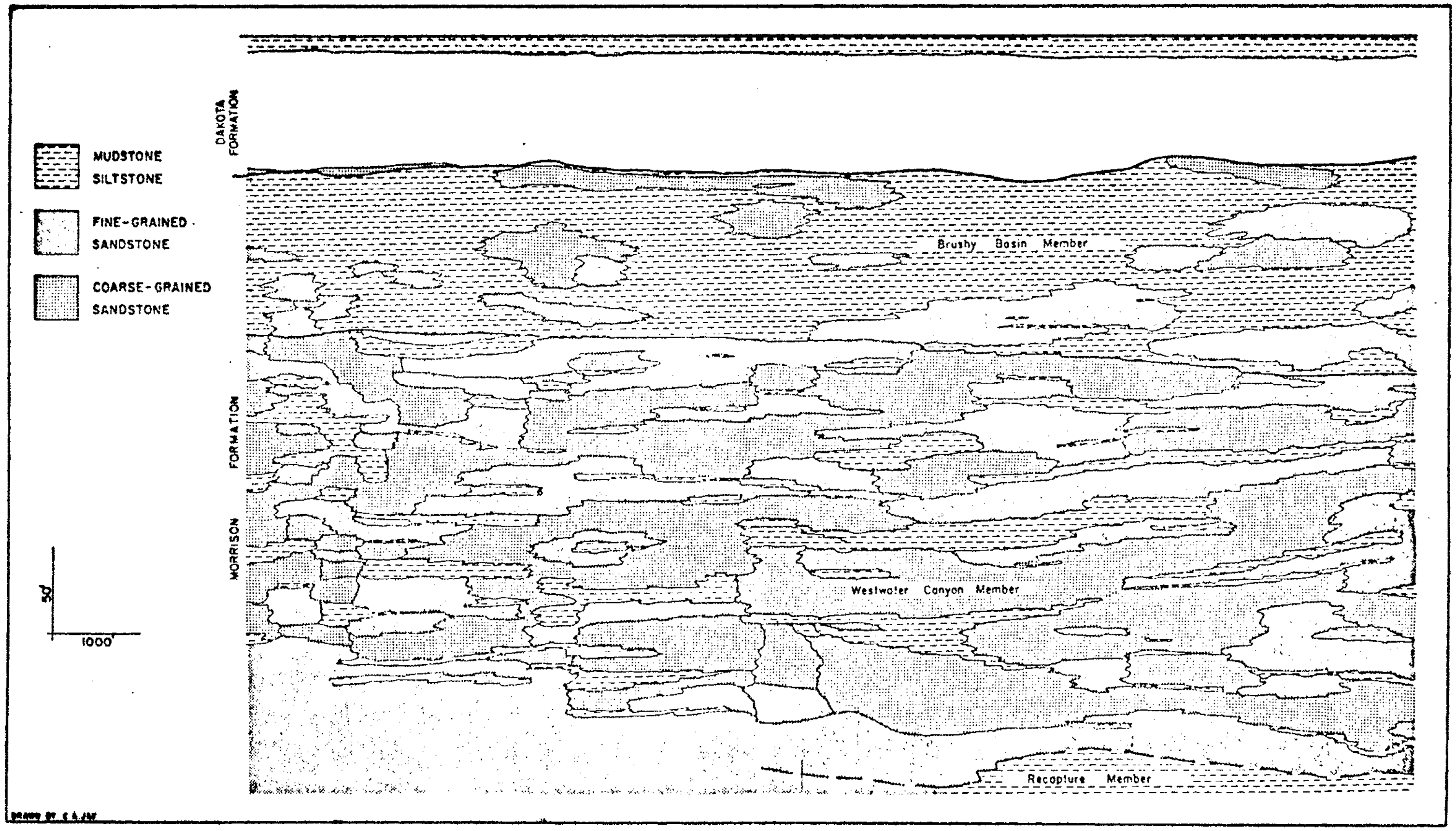

Figure 9. Lithologic section of the upper Morrison Formation near Ambrosia Lake (after Hazlett and Kreek, 1963).

The Recapture Member of the Morrison has been interpreted as having been deposited on a broad alluvial plain (Craig, 1955). It consists of interbedded medium beds of siltstone and friable, silty sandstone. Thin beds of red and green limestone are frequently present in the upper part of the unit. No water-supply wells are completed in the Recapture Member, and its fine-grained character implies that it is an aquitard in the area.

San Rafael Group

Bluff Sandstone--

The Bluff Sandstone is the upper most unit in the San Rafael Group. In the area its outcrop forms cliffs on the western side of Mesa Montañosa and La Jara Mesa. It is approximately 280 ft. (85 m) thick in the area. First named by Baker, Dane, and Reeside (1936) at Bluff, Utah, it is said to have been deposited as eolian dune sand. In outcrop the Bluff occurs in very thick beds with very large-scale, high-angle, tabular-planar cross-bedding. It consists of fine to medium, well-sorted, subangular, spherical grains of quartz and feldspar, with about 6 percent silt and clay matrix, 7 percent carbonate cement, and 5 to 10 percent porosity.

In their geologic map of the Dos Lomas quadrangle Thaden and others (1967) indicated that the Bluff intertongues with a yellow "eolian" sandstone which may be equivalent to the Bluff, Zuni, or Cow Springs Sandstones. The Bluff in the area contains beds of yellow sandstone throughout its thickness which may not generally be distinguished by texture or sedimentary structure, and bear little resemblance to the brown, friable Zuni Sandstone exposed above the Bluff on Haystack

Mountain just west of the area. The author believes that the name "Bluff" should be used exclusively to describe the upper-most San Rafael sandstone unit in the study area (Harshbarger and others, 1957).

Two wells are known to have been completed in the Bluff in the area. Both were once used for mine supply, and may now be abandoned. Cooper and John (1967) indicated that the Bluff generally yields less than 10 gpm (0.6 1/s). A sample from well 14.10.11.434 (Table 4) contained relatively large amounts of sodium and sulphate, and about 2300 mg/l TDS. Overlying aquifers generally produce more water, with more desirable quality.

Summerville Formation--

The outcrop of the Summerville Formation of the San Rafael Group forms a slope at the bases of Mesa Montañosa and La Jara Mesa. It is about 330 ft. (100 m) thick, and generally consists of interbedded siltstone, shale, and sandstone. The lower part of the unit corresponds to the silty facies of Harshbarger and others (1957) and its outcrop forms a covered slope in the area. The upper part, which contains more sandstone, forms an uneven slope. Based on field observation the sandstone is composed of fine, moderately to well-sorted, angular to rounded quartz grains with a moderate amount of silt matrix and much calcareous cement.

No wells are completed in the Summerville Formation in the study area. Yields may be expected to be less than 10 gpm (0.6 1/s), and the ground water is probably high in sodium, calcium, and sulphate, reflecting the close association with the Todilto Limestone. The sandstone in the Summerville probably transmits significant amounts of water where saturated, but the formation is generally an aquitard because of the high proportion of siltstone and shale.

Todilto Limestone--

In the study area the Todilto Limestone caps the cliffs of the Entrada Sandstone at the bases of Mesa Montañosa and La Jara Mesa. It is about 15 ft. (5 m) thick in the area. Originally described by Gregory (1916) in western McKinley County, it is believed to have been deposited in a huge, desert lake. It occurs in thin to medium, discontinuous beds, and usually contains gypsum in the upper part.

Two wells are believed to be completed in the Todilto, one being used for dewatering and the other an abandoned domestic well. In the outcrop area the formation may be highly fractured, and though the fractures may locally be filled with calcite cement, they may generally transmit water easily. Like the other units of the San Rafael Group, the Todilto does not seem to be saturated in the outcrop area. In the Poison Canyon area, however, it receives considerable recharge from drilling and mining operations. Cooper and John (1967) reported that the dewatering of the Faith Mine (Figure 3) produced 350 gpm (22 l/s) at the time of their report. The rate is now believed to be 600 to 900 gpm (38 to 58 1/s; Mark Malkoski, geologist, Ranchers Exploration and Development, Grants, personal communication). The quality of water from the Todilto reflects the presence of gypsum; the water may be expected to be high in sulphate and TDS.

Entrada Sandstone--

The lower-most unit of the San Rafael Group is the Entrada Sandstone; in the study area its outcrop forms prominent red cliffs below the western edges of Mesa Montañosa and La Jara Mesa.

It is approximately 100 ft. (30 m) thick in the area, is believed to be of littoral and eolian origin, and was originally described in the San Rafael Swell, Utah, by Gilluly and Reeside (1926). In the southern part of the San Juan Basin it may be divided into two distinct lithologic units.

The Upper Sandy Member is characterized by medium to very thick beds with large-scale, high-angle, trough cross-bedding. It is composed of fine, very well-sorted, subrounded, spherical grains of quartz and feldspar, with no apparent matrix, 15 to 20 percent calcite, and about 12 percent porosity. The Medial Silty Member appears below the Upper Sandy Member in medium, discontinuous and often obscure beds. It consists of very fine-grained sandstone with much silt matrix and calcite cement. The silty layer is extremely dense in the study area, and a borehole density log suggests that it has a porosity near zero percent.

No wells are completed in the Entrada in the study area. In fact, Entrada wells are rare in the whole southern part of the San Juan Basin. The nearest one to the study area is believed to be a stock well 8 miles (13 km) southeast of Grants (Gordan, 1961). The Entrada probably receives virtually no recharge directly into its outcrop. Where it is saturated its water chemistry may be expected to reflect the close proximity of the gypsiferous Todilto Limestone. Its low porosity, probably caused by the precipitation of calcite from waters entering from the Todilto, implies that relatively low yields may be expected from the Entrada in the study area.

Triassic Deposits

Wingate Sandstone

In the Ambrosia Lake-San Mateo area the outcrop of the Wingate Sandstone (Upper Triassic) commonly forms an uneven, usually covered slope at the base of the red cliffs of the Entrada Sandstone, below Mesa Montañosa and La Jara Mesa. It is about 60 ft. (18 m) thick. Originally described by Dutton (1885) at Fort Wingate, New Mexico, it is thought to be an eolian deposit.

In its outcrop, the Wingate may be seen to consist of medium-sized beds with large-scale, high-angle, tabular-planar and trough cross-bedding. The sandstone is composed of medium, well-sorted, subrounded, spherical grains of quartz and feldspar, with about 3 percent silt matrix, 10 percent carbonate cement, and 15 to 20 percent porosity. In the outcrop, fractures are usually seen to be filled with calcite.

No wells are known to be completed in the Wingate in the study area. Cooper and John (1967) cited Wingate wells west of the area which produce 5 to 10 gpm (0.3 to 0.6 1/s), and provide water for homes and stock. The main ionic constituents are sodium, bicarbonate, and variably, sulphate; the wells contain from 500 to 1200 mg/1 TDS (Table 4).

Chinle Formation

The Chinle Formation (Upper Triassic) crops out on the flanks of the Zuni Mountains, and lies under as much as 100 ft. (30 m) of alluvium in the southwestern corner of the study area. It is about 1350 ft. (412 m) thick in the area. First described by Gregory (1915) in Chinle Valley, Arizona, it generally consists of clayey siltstone interbedded with sandstone. The deposits are believed to have originated in a variety of continental environments.

Gordon (1961) described three units in the Chinle Formation near the study area. The uppermost is approximately 900 ft. (274 m) thick and consists of siltstone and mudstone interbedded with sandstone and containing lenses of fine-grained limestone in its upper third. The middle unit, which is 100 to 200 ft. (30 to 61 m) thick, consists of poorly sorted sandstone and conglomerate interbedded with siltstone. It has a distinctive trace on electric logs (Figure 5). The lower Chinle is 400 to 500 ft. (122 to 152 m) thick and consists of interbedded silty sandstone and siltstone, with coarse-grained sandstone at its base.

Three active wells are believed to be completed in the Chinle Formation in the study area, where they supply stock and a ranch house. Gordon (1961) indicated that yields are generally less than 20 gpm (1.3 l/s), and are variable because of the interbedded nature of the formation. Similarly, the water quality is variable. A well completed in the very top of the unit (well 12.9.8.431, Table 4) produced water with a specific conductance of 852 μmhos (micromhos). One completed at about 100 ft. (30 m) below the top of the formation (well 12.10.1.222) produced water with a conductance of about 28,000 μmhos. The water is generally enriched with sodium, bicarbonate, chloride, and sulphate ions. Cooper and John (1967) indicated that the middle sandy layer of the Chinle is used as an aquifer west of the study area.

Permian Deposits

San Andres Limestone and Glorieta Sandstone

The San Andres Limestone and Glorieta Sandstone, deposited in Late Permian time, crop out on the flanks of the Zuni Mountains, south of the study area. Together they comprise an important aquifer near the town of Bluewater, in Valencia County. Although they are from 1500 to 5000 ft. (457 to 1525 m) deep in the Ambrosia Lake-San Mateo area (Plate 3), they have had some limited use.

Gordon (1961) reported that the San Andres is from 80 to 150 ft. (24 to 46 m) thick in the Grants area, and consists of two units of limestone divided by a 15- to 30-ft. (5 to 9 m) thick unit of medium-grained, well-sorted sandstone. Extensive solution of the limestone has created channels and caverns which, though commonly filled with clastic material, yield large amounts of water. Karst features may be better developed near the outcrop, due to relatively recent solution, and so be of less significance in the study area.

The Glorieta Sandstone lies directly under the San Andres Limestone, is from 125 to 300 ft. (.38 to 91 m) thick in the region, and consists of well-sorted, medium-grained, quartzose sandstone. It is less permeable than the San Andres, and wells rarely tap it exclusively. Together with the San Andres, however, it forms a composite aquifer.

Due to local variations in permeability, the yield and quality of water from the San Andres-Glorieta aquifer also vary from place to place. Gordon (1961) reported yields of 500 to 2200 gpm (31 to 139 1/s) from wells near Bluewater and Milan south of the study area; Cooper and John (1967) cited yields of about 100 gpm (6.3 1/s) and indicated that two wells in the Ambrosia Lake area (14.9.28.441 and 14.10.22.414; Table 3) were completed in the aquifer but abandoned because of the availability of better water nearer to the surface. Kaufmann and others (1975) indicated that wells drawing from the San Andres-Glorieta aquifer now contribute feed water to the Kerr-McGee uranium mill.

Summary of Ground-Water Availability

Most of the ground water in the Ambrosia Lake-San Mateo area is drawn from the consolidated Jurassic and Cretaceous strata which crop out there. A few stock wells are completed in the alluvium near San Mateo Creek and Arroyo del Puerto. The Tertiary volcanics associated with Mt. Taylor are not significantly water-bearing, though springs issue from them on the west side of the mountain.

Most of the water-yielding sedimentary rocks in the area were deposited in the continental environments which were relatively common during Mesozoic time. In the Ambrosia Lake area the Westwater Canyon Sandstone is the most significant water-yielding unit, lying close to the surface and generally producing more than 20 gpm (1.3 l/s). It has been necessary to dewater the Westwater Canyon Sandstone near the uranium mines, and deeper units such as the San Andres-Glorieta are new tapped for water supplies. The deeper units generally yield about 10 gpm (0.6 1/s). Water from the Jurassic strata is generally high in sodium, calcium, bicarbonate, and sulphate, and contains from 500 to 2000 mg/l TDS.

The Menefee Formation and Point Lookout Sandstone are important aquifers in and near San Mateo, where they yield from 20 to 50 gpm (1.3 to 3.1 1/s). Ground water from these formations is usually high in sodium and bicarbonate, and contains from 200 to 1000 mg/l TDS.

Few wells exist in the southwestern and northeastern corners of the study area. Those in the southwest usually tap the alluvium or the sandstone of the Chinle Formation. Those in the northwest corner tap the Dalton Sandstone Member of the Crevasse Canyon Formation and the Tres Hermanos Member of the Mancos Shale. In addition to these units, the Gallup Sandstone may be a potential source of water in the San Mateo Dome area.

GROUND-WATER CHEMISTRY

General Characteristics

Chemical data for the report were compiled from the analysis of ground-water samples taken by the author and from reports by private companies as well as state and federal agencies. These data are tabulated in Table 4.

Ground-water quality varies with the geologic and geographic origin of the water within the study area. Over all, however, the concentration of TDS in the area ranges from 169 to nearly 20,000 mg/1, and averages 1860 mg/l. This average far exceeds the limit of 500 mg/1 recommended for human consumption by the United States Environmental Protection Agency (Federal Register, 1976). Many of the wells in the area are used for observation, industrial purposes, and stock supply. The water from 34 wells in the area which are believed to be domestic supplies has an average TDS concentration of 873 mg/l. Among existing domestic wells in the area those in San Mateo provide water with the best chemical quality, and those near the intersection of Highways 53 and 509 provide water with the poorest chemical quality. The San Mateo wells produce water mainly from the Menefee Formation, which has an average concentration of about 400 mg/l TDS. The wells near the intersection of the high-ways produce water mainly from the Westwater Canyon Member of the

Morrison Formation, which has an average concentration of approximately 2000 mg/i TDS, and commonly contains 500 to 1000 mg/1 sulphate.

The chemical character of 43 ground-water samples from different aquifers may be compared by means of Piper diagrams (Figure 10). In the diagrams, the major cations in solution are calcium, magnesium, sodium, and potassium, and the major anions are bicarbonate, carbonate, sulfate, and chloride. The diagrams are prepared by plotting the percent milli-equivalents per liter of the cations and anions of each sample (Appendix A) in the triangles in the lower part of the figures. The resulting points are then graphically extended to the diamond-shaped graph to form a single point representing the composition of the sample. The chemical type of a water sample may be identified by means of the subdivisions of triangular cation and anion graphs (Figures 10 and 11).

Although many combinations of ions occur, the ground water in the study area is mainly of the sodium-sulphate and sodium-bicarbonate types. This may be seen in Figure 11, which shows the average compositions of ground waters from different aquifers in the area. The Menefee Formation and Point Lookout Sandstone contain sodium-bicarbonate water. The alluvium, Dakota Sandstone, and Westwater Canyon Member contain sodium-sulphate water. Of the minor aquifers the Dalton Sandstone, Mancos Sandstones, and Bluff Sandstone contain sodium-sulphate water; the Todilto Limestone contains calcium-sodium sulphate water. It seems that the proportions of

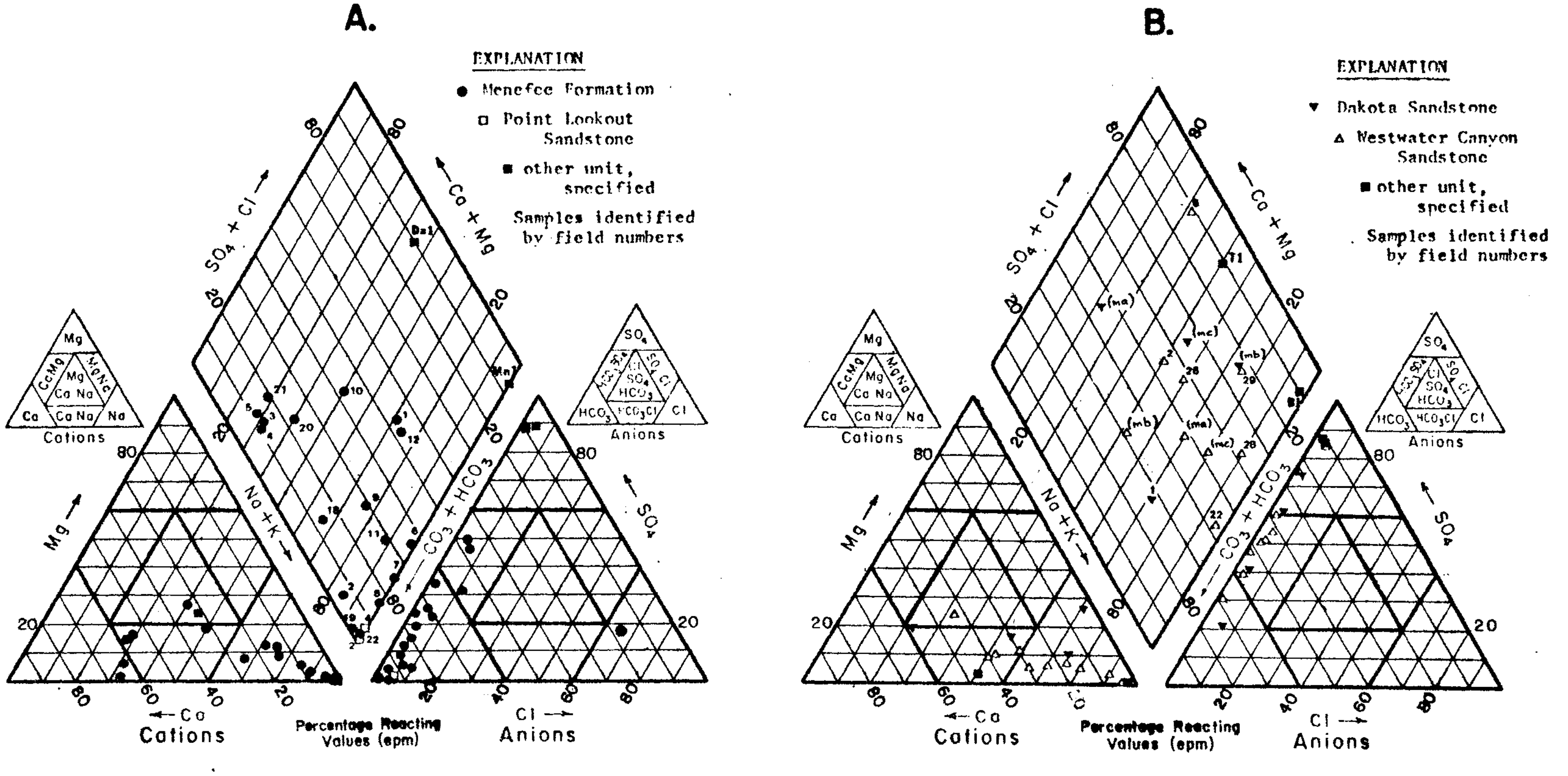

Figure 10. Ionic composition of ground water in the Ambrosia Lake-San Mateo area. Data, Appendix A; samples identified, Table 4.

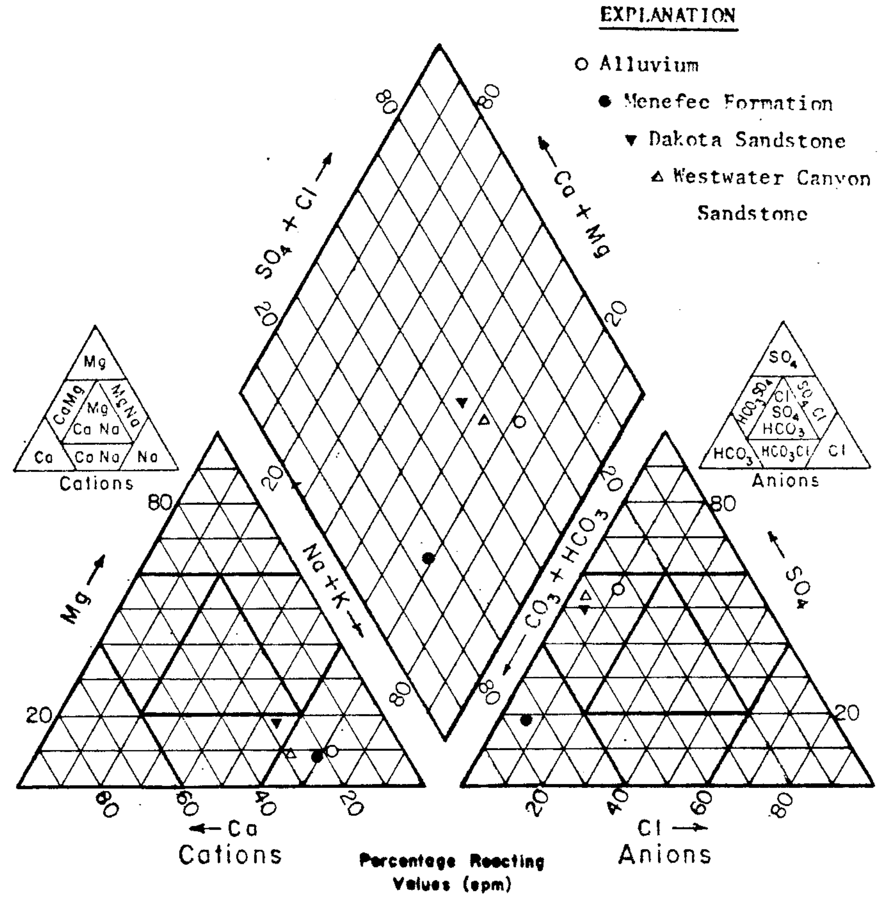

Figure 11. Average ionic composition of ground water from the major aquifers in the Ambrosia Lake-San Mateo area.

ionic constituents bear no consistent relationship to the supposed depositional environments of the deposits. For example, the composition of the water from the continentally-deposited Westwater Canyon bears a much stronger resemblance to that of the Dakota shore-zone deposits than to that of the continentally-deposited Menefee deposits (Figure 11). The chemical composition is thought to depend more on the diagenetic history of the deposits and on local conditions of ground-water recharge and movement.

The Effects of Mining on Ground-Water Chemistry

The study area is a source of unusually high concentrations of naturally and unnaturally-derived radionuclides. The possibility of the contamination of drinking water is the focus of some concern and controversy. No new radionuclide data have been collected for this study, but the occurrence of the radionuclides will be reviewed. The United States Environmental Protection Agency maximum allowable concentration for radium 226 is 5.0 pCi/l (pico-Curies per liter), and for uranium is 5.0 mg/l. The water in local uranium mines may contain hundreds of pico-Curies of radium per liter. After withdrawal, the concentration is reduced to less than 20 pCi/l by ion-exchange and the addition of barium chloride. Four companies (Kerr-McGee, United Nuclear-Homestake Partners, Gulf, and Ranchers) reported that the treated discharge from their mines has daily-average concentrations of 3.0 pCi/l radium and 2.0 mg/l uranium (Environmental Improvement Agency, 1978).

Kaufmann and others (1975) investigated the effects of mine and mill discharge on ground-water quality near Ambrosia Lake. Having sampled 22 monitor wells, they determined that although seepage from the Kerr-McGee tailings ponds had a radium concentration of 65 pCi/l, and ground water directly adjacent to the tailings reached 6.6 pCi/l, the concentration in the nearby ground water was 4.0 pCi/l or less. Alluvial ground water flowing down-gradient from the Kerr-McGee property reportedly has an average radium concentration of 0.47 pCi/l. Nevertheless, the general contamination of the alluvial aquifer by mine and mill discharge is indicated by high TDS, chloride, and nitrate contents. Kaufmann and others (1975) cited that the ground water in the alluvium along San Mateo Creek, above its confluence with the Arroyo del Puerto, contains about 700 mg/I TDS, but contains about 2000 mg/l below the confluence. Alluvial ground water upstream from the Arroyo del Puerto usually contains about 1 mg/l nitrate, whereas concentrations of 18 and 24 mg/I occur in wells downstream. The author of this report found a nitrate concentration of 47 mg/l in a well in the alluvium (13.9.32.112, Table 4) 2 miles (3 km} downstream from the confluence of the Arroyo del Puerto. A later sample contained 10 mg/1 nitrate. The reason for the apparent change is not known. The same well water contained 600 µg/I selenium, according to the report of an independent laboratory hired by the owner. The source of this unusually high quantity is unknown, but may involve the nearby Poison Canyon Sandstone uranium deposits rather than recharge from San Mateo Creek.

Estimates of Ground-Water Quality

The gross ionic concentration of ground-water samples may be inferred from measurements of the water's specific conductance or its inverse, resistivity. Figure 12 illustrates the relationship between TDS and specific conductance in the study area. A least-squares regression of the distribution indicates that in the study area, TDS in mg/l equals approximately 0.69 times the specific conductance. The scatter apparent in Figure 12 probably reflects different measurement techniques as well as inherent variability in the water. The variation of specific ion concentrations with specific conductance according to the data of Cooper and John (1967), are shown in Figures 13 through 18. Most of the distributions show considerable scatter, and the user should consider the full range of possible ion concentrations that may occur for particular conductances or resistivities. Furthermore, when using the charts one should consider the distribution of values for the particular aquifer being evaluated. Least-squares regressions are provided only as guides. The relationships for all constituents (notably nitrate and bicarbonate) may vary according to local conditions of lithology, recharge, and ground-water movement.

Specific conductance is a function of water temperature, and most laboratory measurements are made at the standard temperature of 25°C (77°F). The conversion of field conductance or resistivity values to those at standard temperature may be made with any one of many published conversion charts (Todd, 1959; Keys and MacCary, 1971). Subsurface temperatures in the study area may be estimated from

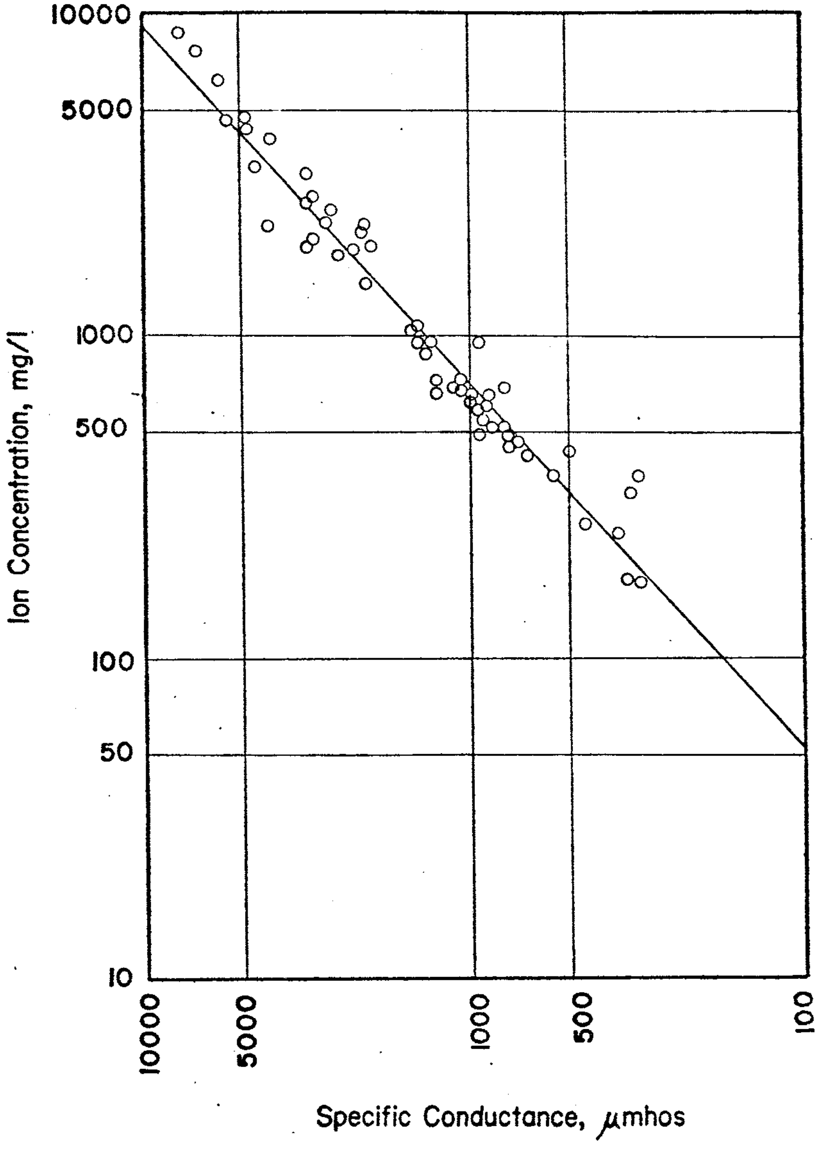

Figure 12. Plot of total dissolved solids vs. specific conductance for ground water in the Ambrosia Lake-San Mateo area (data, Table 4).

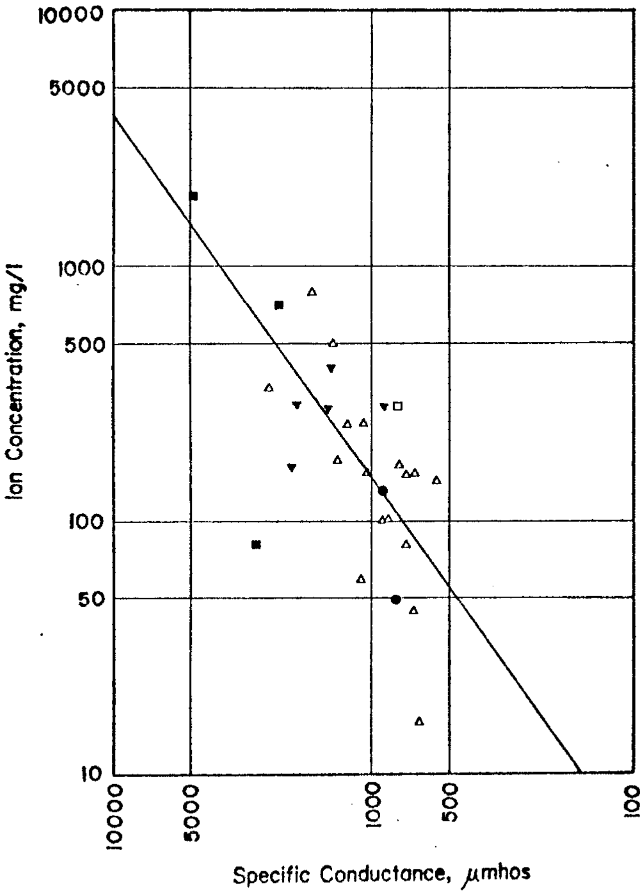

Figure 13. Plot of hardness ($CaCO_3$) vs. specific conductance (data, Table 4; symbols explained, Plate 4).

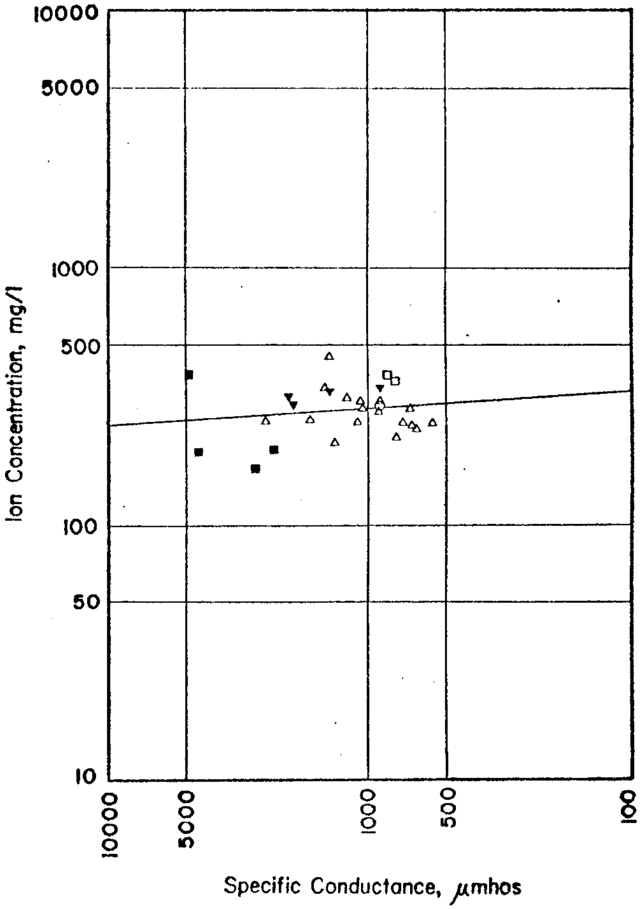

Figure 14. Plot of HCO_3 vs. specific conductance conductance (data, Table 4; symbols explained, Plate 4).

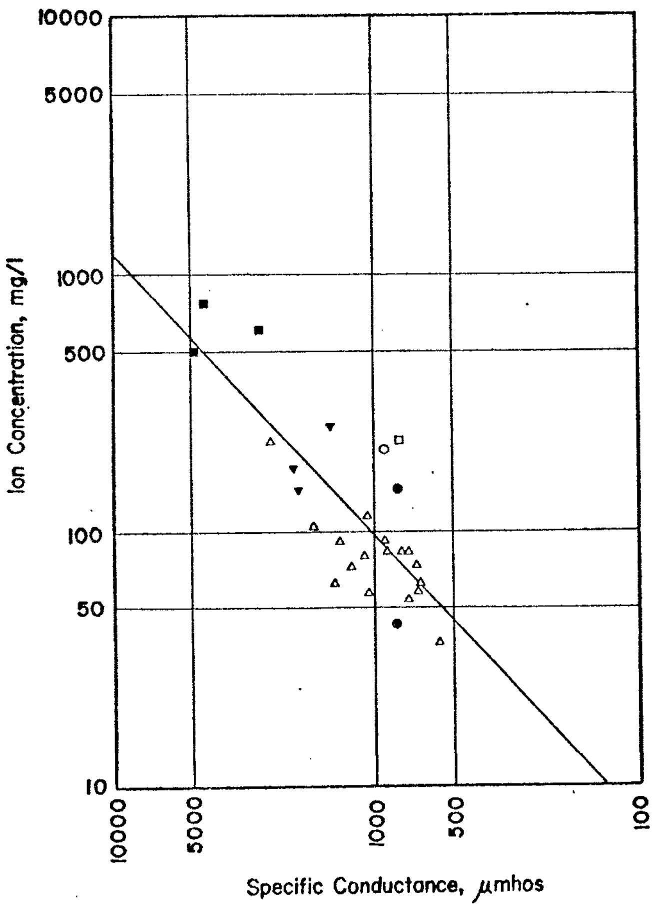

Figure 15. Plot of Cl vs. specific conductance (data, Table 4; symbols explained, Plate 4).

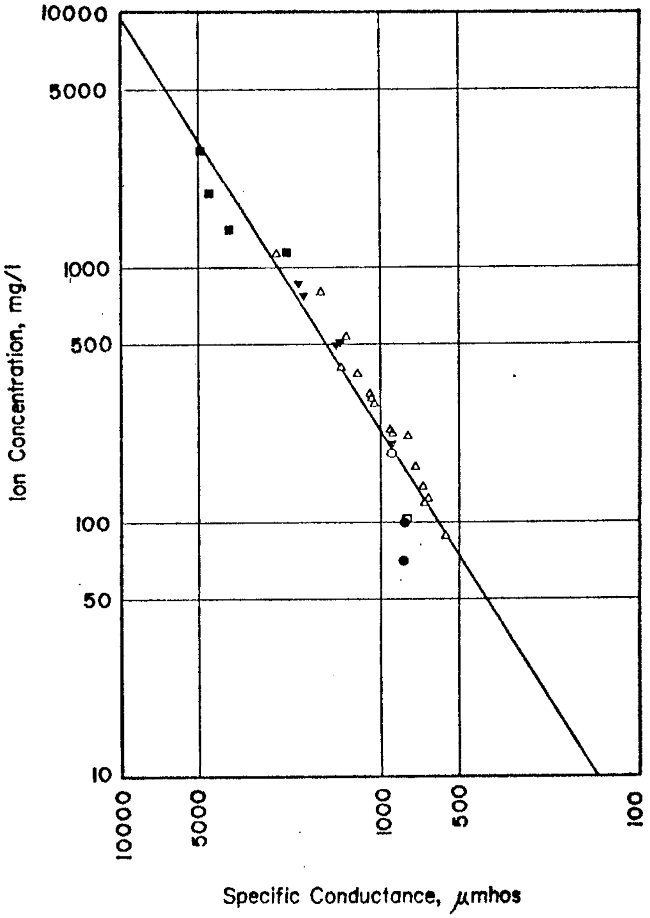

Figure 16. Plot of SO_4 vs. specific conductance (data, Table 4; symbols explained, Plate 4).

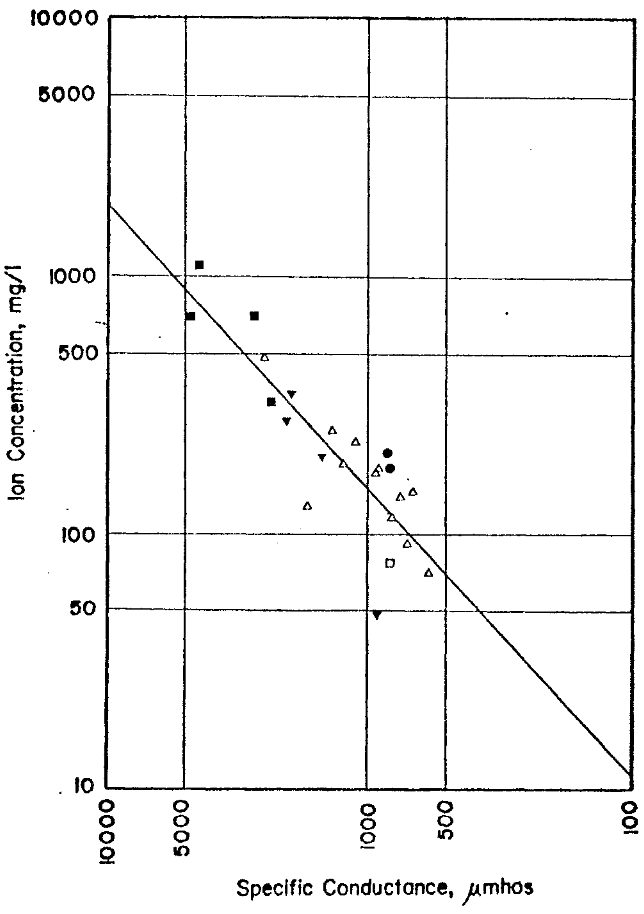

Figure 17. Plot of Na vs. specific conductance (data, Table 4; symbols explained, Plate 4).

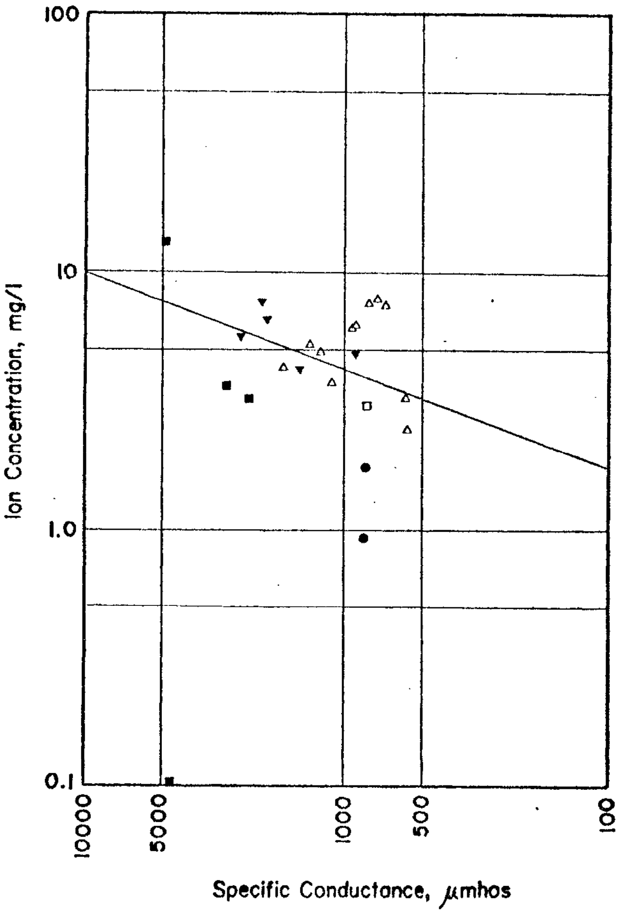

Figure 18. Plot of K vs. specific conductance (data, Table 4; symbols explained, Plate 4).

Figure 19, which illustrates the variation of temperature with well depth, based on data from various sources (Appendix B). For the data from water wells it is assumed that the open interval is at the bottom of the well. Cases where this assumption is incorrect are not believed to be significant enough to affect the whole trend. A linear regression indicates that the geothermal gradient in the area is 1.75°F per 100 ft. (3.20°C per 100 m). This is consistent with rates which were measured in individual boreholes in the area by Reiter and others (1975).

Borehole logs were used by the author to estimate ground water quality in the parts of the study area where water wells are absent, and also for the deep, untapped aquifers (Appendix F). The results will be discussed in the following section.

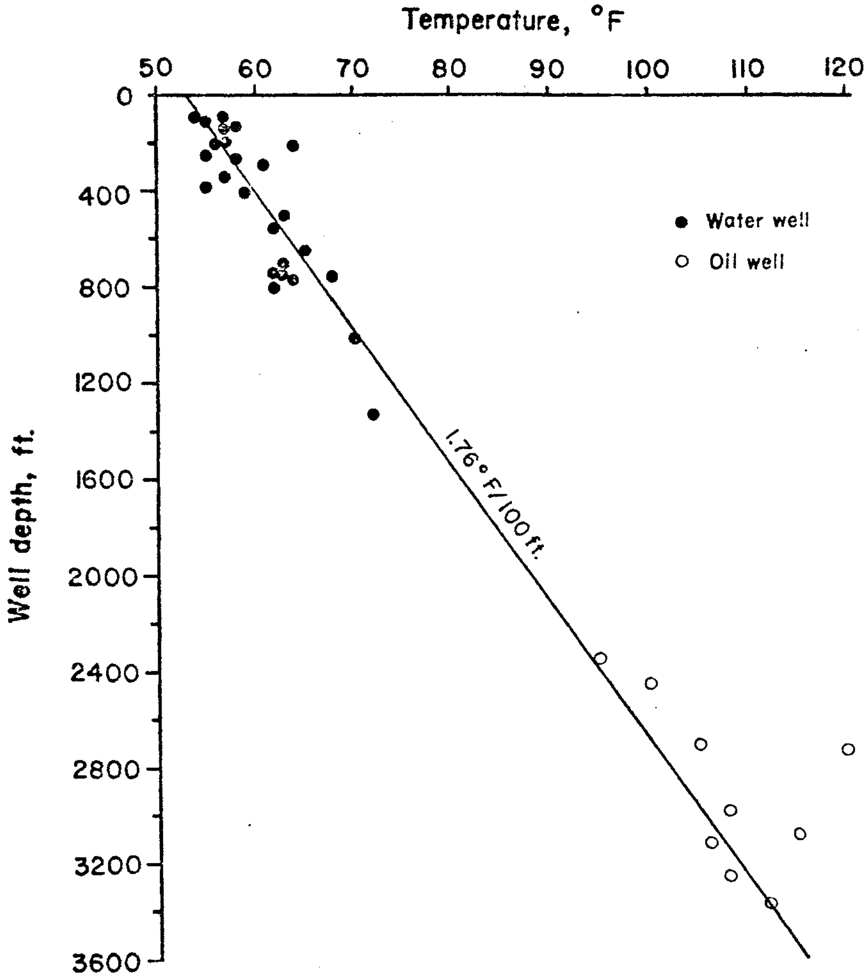

Figure 19. Plot of temperature vs. well depth, Ambrosia Lake-San Mateo area (data, Appendix B).

Areal Distribution of Total Dissolved Solids

Measured and estimated TDS values are mapped in Figure 20. It is generally evident that ground-water quality tends to deteriorate down-dip (northeasterly) from the outcrop areas. Since they comprise the most data points, the pattern of variability is best shown by the Westwater Canyon samples. Relatively high TDS concentrations are found in the Westwater Canyon in the area near the San Mateo Fault. Values of 718 and 945 mg/1 were reported in mines near the northernmost extent of the fault; near the junction of its outcrop and the fault the Westwater Canyon ground water commonly contains about 2000 mg/l TDS. In both cases the concentrations may be high because of the stagnation of ground water flow caused by the fault. But the Westwater Canyon near the junctions of San Mateo Creek and Arroyo del Puerto is probably also being recharged from the overlying alluvium, and also by contaminated mine-mill discharge. As cited previously, the alluvium above the confluence of the streams contains about 700 mg/l TDS, and about 2000 mg/l below. In well 13.9.15.343 the Westwater Canyon water contained 1010 mg/l TDS when sampled in 1958, but contained 1900 mg/l when sampled in 1975 (Table 4).

East of the San Mateo Fault relatively low values extend far from the outcrop zone. Northwest of the fault, TDS values show a less consistent change away from the outcrop zone, possibly because of variations in lithology and fracturing, within the Westwater Canyon Sandstone.

The Dakota ground-water samples, though fewer, indicate a similar

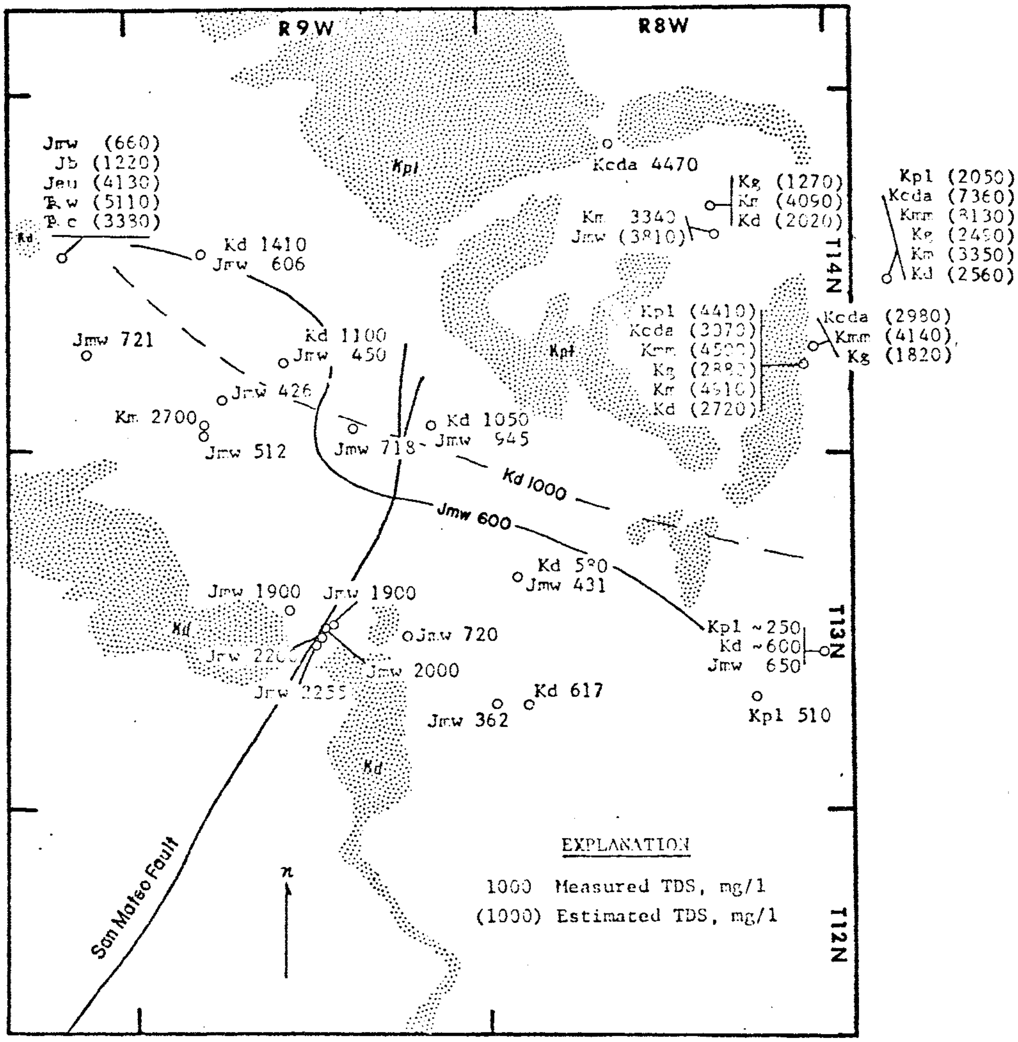

Figure 20. Distribution of total dissolved solids in the Ambrosia Lake-San Mateo area. Geologic symbols explained, Plate 2.

pattern of change. The 1000 mg/l contour strikes northwesterly in the northwestern part of the area, and east-west along the base of Mt. Taylor. In the northwestern part of the area the Dakota water commonly contains more than 1000 mg/1 TDS--more than twice the value for the Westwater Canyon water. East of the San Mateo Fault the Dakota commonly contains 600 to 700 mg/1--about the same as that in the Westwater. Borehole-log estimates suggest that the Dakota water contains 2000 to 3000 mg/1 TDS in the northeast part of the study area.

Measured and estimated values of TDS in the waters of the other Cretaceous formations northeast of their outcrops suggests that they contain from 1500 to nearly 9000 mg/1. The estimated values generally correspond to two measured values from the study area. The Point Lookout water, while containing as little as 250 mg/l TDS near the town of San Mateo, seems to contain as much as 5000 mg/1 along the flanks of the San Mateo Dome. Water from the Dalton Sandstone seems to contain 3000 to 5000 mg/1 in the San Mateo Dome area, and nearly 9000 just east of the study area. Water from the Gallup Sandstone appears to contain 1500 to 3500 mg/1. The sandstone of the Mancos Shale contains about 3000 mg/1 in the western part of the area, and appears to contain 3000 to 5000 mg/l in the northeast part of the area.

The TDS measurements in the water from the Menefee Formation near San Mateo range from 170 to 1400 mg/1. Samples obtained within a few hundred yards of San Mateo Creek generally contain from 170 to 400 mg/1, while those taken more than one-quarter mile from the Creek seem to contain between 450 and 900 mg/l.

The effects of recharge, movement, and discharge on ground-water chemistry are discussed in the following chapter.

GROUND-WATER FLOW SYSTEM

Recharge

Precipitation is the original source of recharge, and the average annual precipitation in the study area ranges from about 12 inches (30 cm) per year in the lower areas to nearly 20 inches (51 cm) on Mt. Taylor (Tuan and others, 1969). Most of the sandstone outcrops in the area form cliffs, and offer little area for direct recharge from precipitation. An exception to this is the Dakota Sandstone cap on Mesa Montañosa and the western end of La Jara Mesa, where the exposure is commonly more than a mile wide. The Point Lookout Sandstone cap on San Mateo Mesa is also extensive, but is highly dissected and probably not significantly connected to those places in the study area where the formation lies under the surface.

It may be assumed that little precipitation enters the bedrock outcrops through their primary porosity, for the permeability is generally so low that water is evaporated back out soon after it infiltrates. The runoff on outcrops, though, may cross fractures, and it is probably through the fractures that most recharge occurs. In a study of recharge through exposed, fractured limestone in southern New Mexico, Paul Davis (hydrologist, U.S. Geological Survey, Albuquerque, personal communication) calculated that 20 to 25 percent of the annual precipitation recharged the bedrock aquifer. It may be assumed that the limestone had no primary permeability. In a sandstone outcrop, however, some of the precipitation would enter then primary pores, but would probably be lost to evaporation soon afterwards. It is estimated that approximately 15 to 20 percent of the precipitation enters the broad Dakota outcrop as recharge.

From geologic maps it has been estimated by the author that approximately 10 square miles (26 km^2) of Dakota outcrop lie up-dip from the study area. Assuming an annual precipitation rate of 13 in. (33 cm} and a recharge rate of 17 percent, it is estimated that about 0.11 mgd/sq. mi. (million gallons per day per square mile; 4.2 X 10^5 1/d/km^2) are recharged through the Dakota outcrop. Although much of this water probably remains in the unit, a great deal probably enters the underlying formations through the ubiquitous fractures in the outcrop area.

Figure 21 shows the grain-size distributions for three alluvium samples taken in the area. Two samples from gentle slopes consist of fine sand with 5 to 10 percent silt and clay, and are believed to be of eolian origin. According to local soil maps, most of the soils in the area have an infiltration rate of less than 2 in. (5 cm} per hour. At this rate, and because of the sealing effects of clay and raindrop impact, it may be expected that rainfall penetrates only a small distance into the soil, only to be pulled out again by evaporation and capillary action.

There is much evidence suggesting that considerable recharge occurs through the creek and arroyo beds. Sediments in the beds are usually coarser than the soil covering most of the area, as shown in Figure 21.

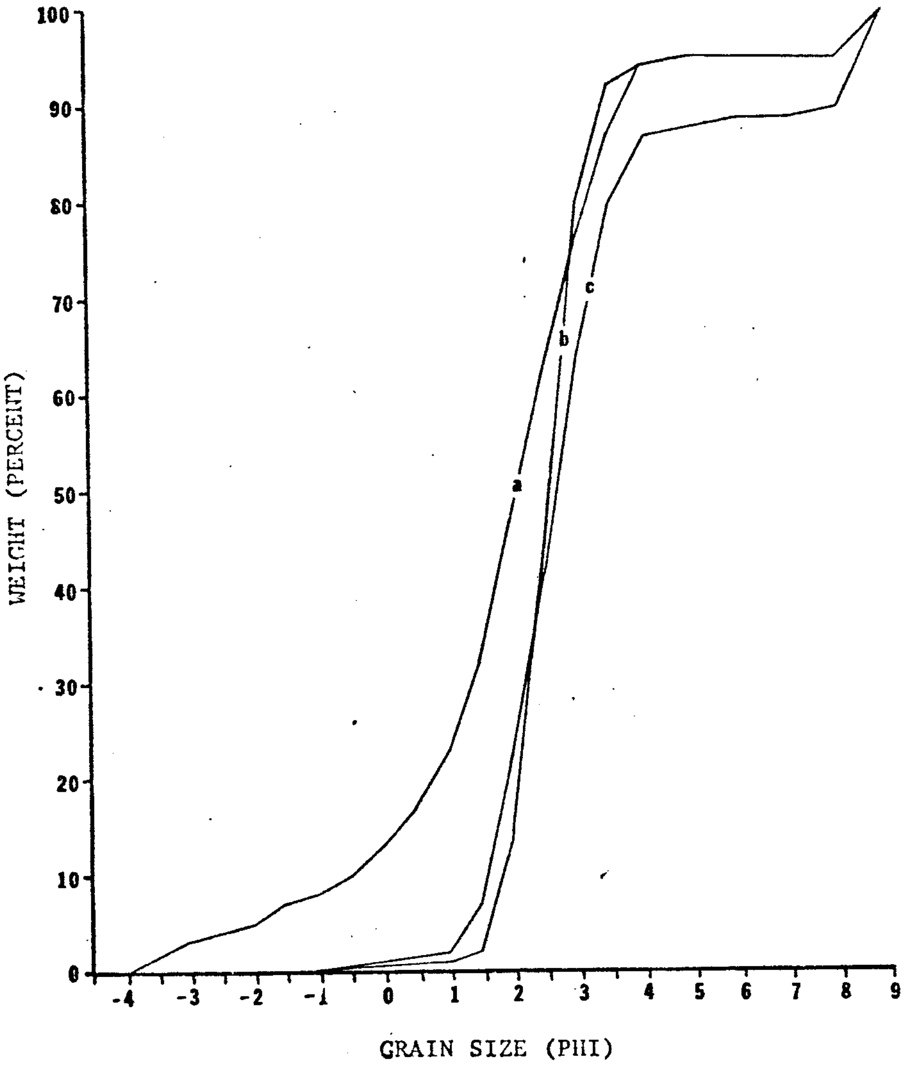

Figure 21. Plot of grain-size distribution for three alluvium samples from the study area; sample 'a' from arroyo bottom, samples 'b' and 'c' from valley floors. Locations of sampling sites are shown on Plate 2.

All of the drainages, then, may contribute to ground-water recharge at some time. The two largest ones, San Mateo Creek and Arroyo del Puerto, may be considered to be major sources of recharge.

San Mateo Creek is the major drainage on the western side of Mt. Taylor, and is naturally supplied by springs on the flanks of the mountain as well as by intermittent runoff along its course. Under normal conditions it flows perennially in San Mateo Canyon before disappearing just west of the town of San Mateo. Under conditions of high discharge it may flow along most of its course to the southwestern corner of the study area.

Extensive dewatering has occurred since the beginning of the construction of the Gulf Mt. Taylor Mine, and discharge into San Mateo Creek has reached thousands of gallons per minute. This, along with the discharge from other mines, has simulated extremely high natural discharge, causing the Creek to flow to a point about 14 mi. (22 km) downstream from San Mateo, in Sec. 1 or 12, TI3N, R10W. The absence of a channel south of these sections implies that flow in the major drainage never leaves the area, but either evaporates or infiltrates, recharging the alluvial aquifer.

A teardrop-shaped area is delineated in Figure 22, which, according to air photos and topographic contours, is marked by round depressions and areas of relatively dense vegetation. This area is believed to represent a major discharge site for the alluvial aquifer, formed when stream flow encounters the relatively impermeable beds of the Chinle Formation, below the "pass" through the sandstone outcrops. The area

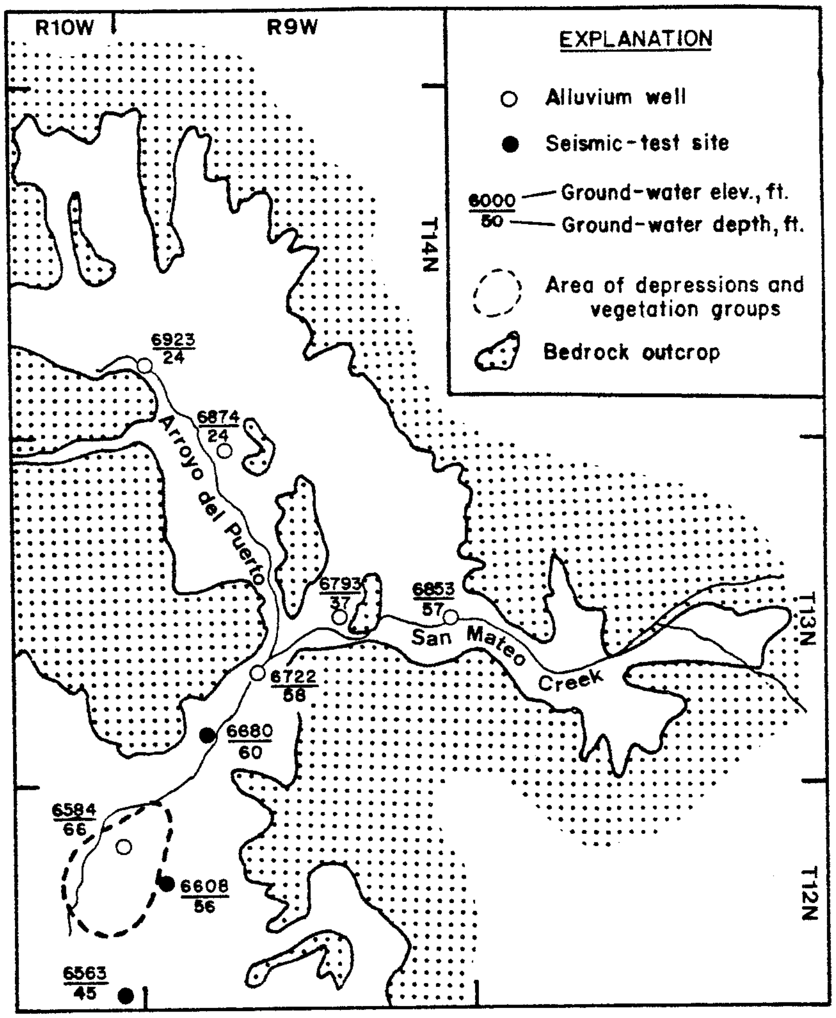

Figure 22. Depths to water, water-level elevations, and other features of the alluvial aquifer near Ambrosia Lake and San Mateo.

extends directly out from the "pass" despite a jog in San Mateo Creek. The depressions may be controlled by interflow, or a near-surface water table present during especially high discharge in the Creek. The general shape of the area and the situation causing it suggest that it is a ground water equivalent of an alluvial fan.

Evidence suggests that ground water in the alluvial aquifer recharges the underlying bedrock formations, especially where conditions of head and permeability are favorable. Such a case is evident near the town of San Mateo. Water levels from wells in the Menefee Formation (Figure 23) indicate that flow is generally to the northwest, roughly perpendicular to the regional dip of the formation (Plate 3) and following the ground-surface contours. Moreover, the contours indicate the presence of a ground-water ridge corresponding to San Mateo Creek, and implying recharge from it. Figure 24 is a cross-section which parallels the Creek and shows the well depths and ground-water levels in wells tapping the Menefee Formation. Water levels closely follow the ground level, despite well depth. The Menefee is generally considered to be a sequence of sandstones and mudstones which would seem to be hydraulically separate. But, in addition to showing recharge from San Mateo Creek, the water levels in San Mateo suggest that the Menefee behaves as a single hydrologic unit, and may be considered a water table aquifer. This is consistent with the belief of Berry (1959), based on his observation of the Menefee wells north of the study area.

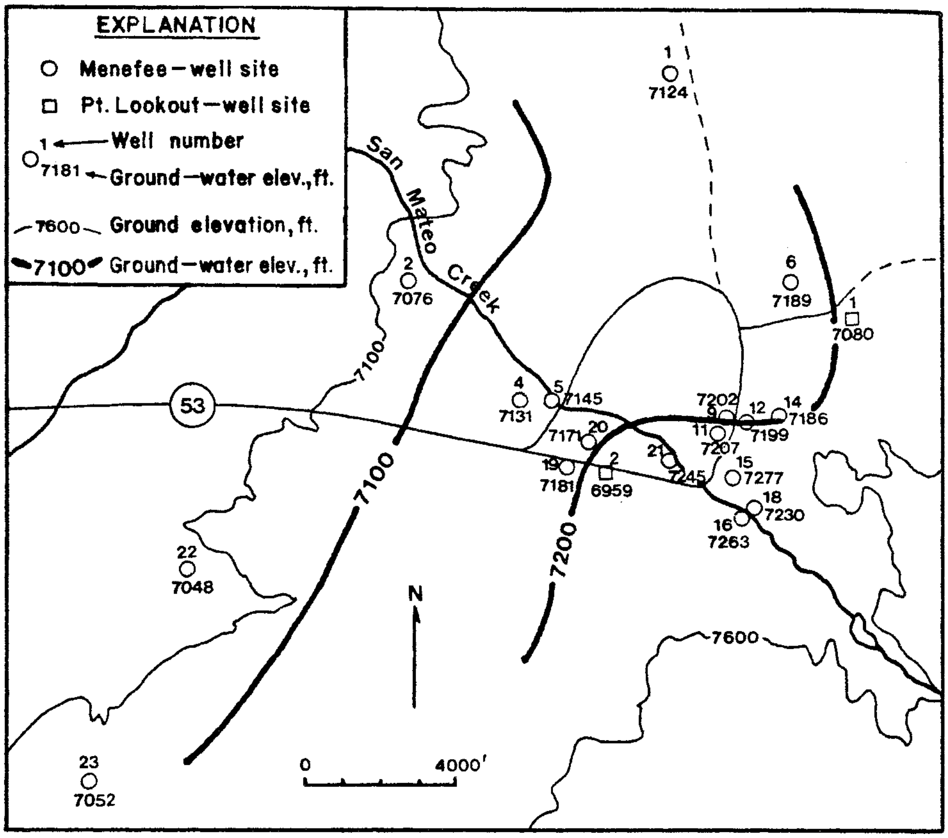

Figure 23. Ground-water levels near San Mateo.

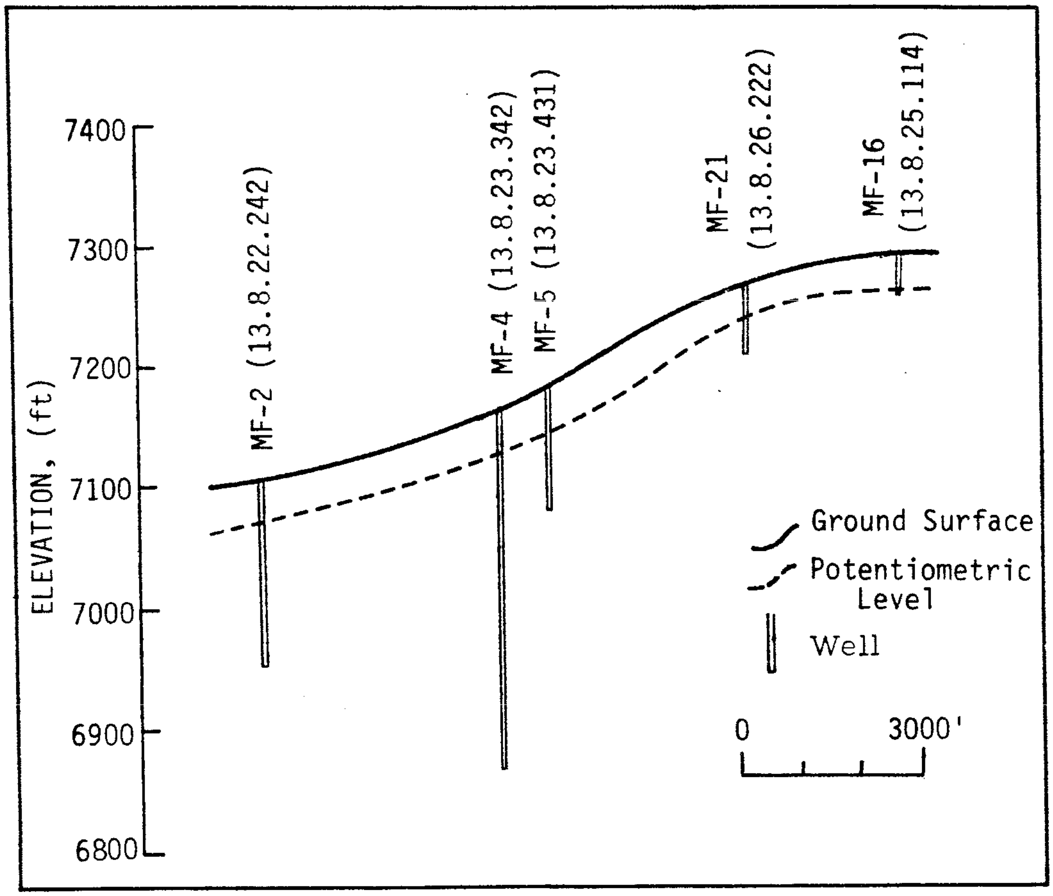

Figure 24. Hydrogeologic cross-section of the Menefee Formation near San Mateo. Well locations shown in Figure 23.

A large amount of artificial recharge results from the discharge of mine wastewater near the town of Ambrosia Lake. Kaufmann and others (1975) indicated that the seepage from tailings ponds equaled 0.36 mgd (1.36 X 10^6 l/day) in 1974. The Arroyo del Puerto, which runs south from the Ambrosia Lake area to San Mateo Creek, has been perennial since large amounts of mine wastewater began to be discharged into it in the late 1950's. In fact, grasses and cattails now grow along its banks. In Figure 25 water levels in the alluvium show a gradient perpendicular to the channel direction, indicating recharge along the arroyo. A well, believed to be completed in the Mancos Shale, contains water with noticeably fewer dissolved solids (27 mg/l) than the surrounding alluvial wells. This suggests that although the ion-rich discharge water recharges the alluvium it probably does not penetrate the Mancos Shale. The underlying sandstone aquifers may, however, receive some of the recharge in places where they lie directly under the alluvium.

Such a situation seems to exist at the confluence of the Arroyo del Puerto and San Mateo Creek. At that point the Dakota has been dissected by the creek. Well depths and the geologic map suggest that near the confluence nearly 100 feet (30 m) of alluvium lie directly on the Morrison Formation. Kauffmann and others (1975) have shown that the discharge from the Arroyo del Puerto has nearly doubled the TDS concentration in the alluvial ground water below the confluence. As cited in the section of this report on ground-water chemistry, the TDS concentration of the Morrison

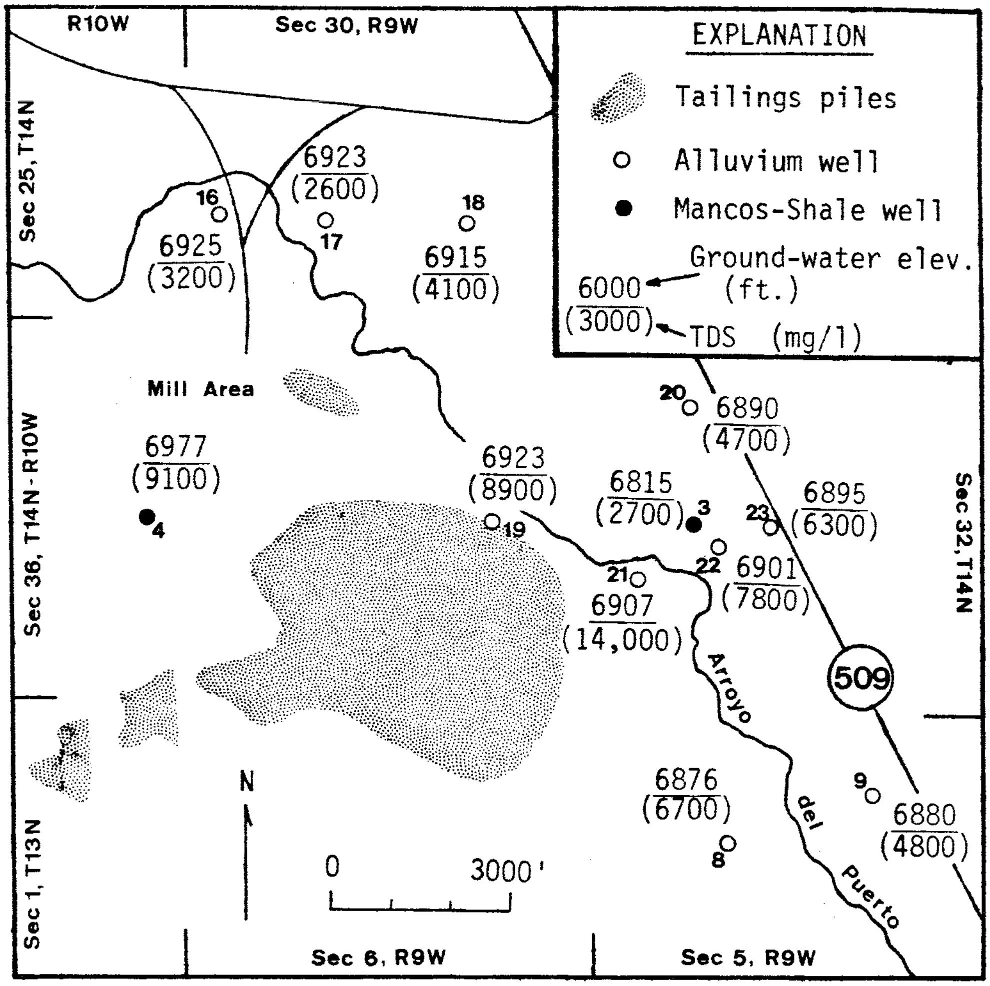

Figure 25. Water levels and concentrations of total dissolved solids in the alluvium and Mancos Shale near the Kerr-McGee processing mill.

(Westwater Canyon Member) water is about the same as that in the alluvium below Arroyo del Puerto (2000 mg/1), and may have doubled since the late 1950's. Water from Morrison wells less than a mile above the confluence also seems to contain elevated concentrations of TDS, suggesting that contamination may have migrated down-dip in the bedrock. Intense folding and faulting in the area (Plate 3) suggest that the natural stagnation of ground-water flow may also have occurred, contributing to the high ion concentration.

In the outcrop areas, strata not exposed to significant amounts of runoff are probably recharged through fractures in the overlying units. In the study area strata dip more steeply to the northeast than the potentiometric surface. In those areas near the outcrop where the potentiometric level is below the top of an aquifer, it may be considered a water-table aquifer. At that point down-dip where the level is above the aquifer, in a relatively impermeable unit, it is artesian. Figure 26 is a cross-section from the central part of the area which shows the change in the potentiometric level for the Westwater Canyon, down-dip from the outcrop. The general trend is shown by wells west of the San Mateo Fault (wells 13.9.21.412 and 14.9.34.422, Table 3). It is apparent that the southeastern-most well is located in that zone where the potentiometric level is within the Westwater Canyon itself. The level rises, stratigraphically, into the Brushy Basin about a mile to the northeast, and into the Dakota about 3 miles (5 km) to the northeast. Wells on the eastern side of San Mateo Fault (wells 13.9.15.343 and 13.9.22.112) show water levels that are slightly lower, but still generally consistent

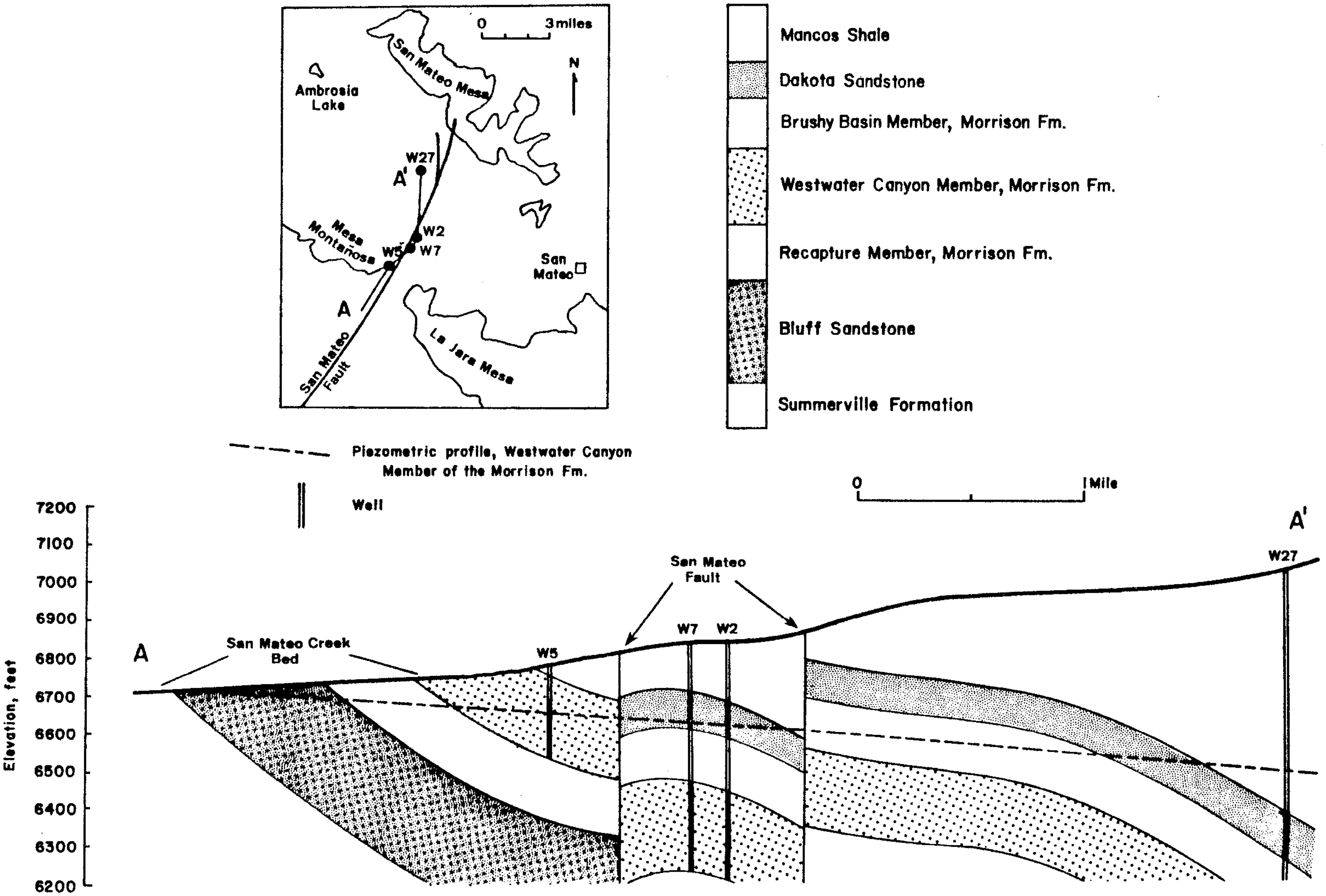

Figure 26. Hydrogeologic cross-section of the Dakota Sandstone, Morrison Formation, and Bluff Sandstone (data, Table 3).

with the regional trend. The water in wells east of the fault is also artesian, rising to about the base of the Dakota. It may be inferred, generally, that as water moves down-gradient it tends to move "up" stratigraphically, where there is sufficient permeability.

Movement

The lateral movement of ground water in the alluvial aquifer, and apparently in the Menefee Formation near San Mateo, tends to be controlled by ground-surface relief, and consequently by surface-water drainages. Figure 18, a water-level contour map of the alluvial aquifer, shows the tendency of the ground water to follow the course of Arroyo del Puerto and San Mateo Creek downhill toward the southwest part of the study area.

The rate and direction of lateral ground-water flow in the consolidated aquifers is controlled by the dip and the primary and secondary permeability of the strata. Plate 3 indicates that the strata west of the San Mateo Fault tend to dip northeasterly at approximately 3°, and those east of the fault dip approximately easterly at about 10°.

Jobin (1962) performed laboratory analyses to determine the hydraulic conductivity of samples from the formations near Grants; his results are reproduced in Figure 27. It is apparent that the Westwater Canyon Member has the greatest hydraulic conductivity of the units in the area, about 0.10 gpd/ft^2 (gallons per day per square foot; 4.07 1/m^{2}d, or liters per square meter per day). The other units have conductivities from 0.01 to 0.10 gpd/ft^2 (0.41 to 4.07 1/m^{2}d). Despite their relative coarseness and good sorting (Figure 7),

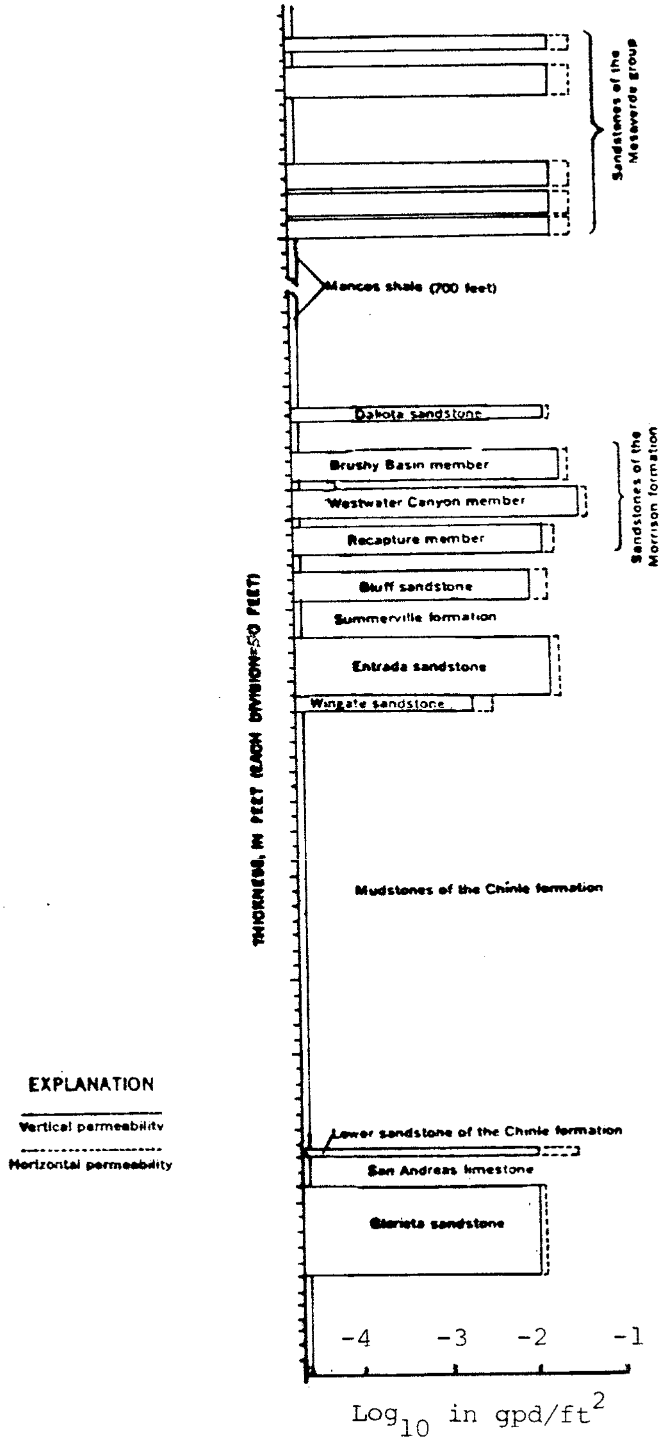

Figure 27. Laboratory hydraulic conductivities of strata near Grants (after Jobin, 1962).

the Wingate and Bluff Sandstones have the lowest hydraulic conductivities of the sandstone in the area; the value for the Wingate, for example, is less than 0.01 gpd/ft^2 (0.41 1/m^{2}d). Ground water in the underlying Chinle Formation in the area is artesian; it is believed that the calcite cement which commonly fills the pores and fractures in the overlying Wingate Sandstone was from the limestone beds in the upper Chinle. The impermeable Medial Silty Member of the Entrada Sandstone may have prevented the calcite-laden water from reaching the Upper Entrada. Though the lack of permeability is less pronounced in the Bluff Sandstone, cement from the Todilto Limestone may also have migrated up, filling pores in the Bluff. The Summerville Formation and the lower part of the Bluff are very calcareous in their outcrop.

Faults and fractures in the area have a general northerly orientation, but easterly-trending ones are found in the northwestern section and in association with the San Mateo Dome (Plate 3). Fractures seem to be common in all parts of the area except the southwestern part. The quantitative aspects of their density is , not known.

Table 1 lists transmissivities and inferred hydraulic conductivities for different formations as determined by pumping tests. Though the values vary considerably, presumably due to fracture density, it can be seen that in this area the actual hydraulic conductivity tends to be about a hundred times the primary (laboratory) conductivity.

Figure 28 is a potentiometric-surface contour map from which may be inferred the general direction of flow in the consolidated aquifers in the area, based on water-level measurements in the Westwater Canyon

TABLE 1 Transmissivites and Hydraulic Conductivities from Pumping Tests

Formation	Locality	T gpd/ft (l/md)	K gpd/ft^2 (l/m^{2}d)	Source*
Kpl	San Mateo	1500 (18,600)	11 (448)	1
Km	San Mateo	1000 (12,400)	20 (815)	1
Kd	San Mateo	1000 (12,400)	12 (489)	1
Jmw	San Mateo	3700 (45,900)	24 (978)	1
	Ambrosia Lake	1300 (16,100)	8.1 (330)	2
	Ambrosia Lake	1500 (18,600)	10 (407)	3
Pg	Fort Wingate	400 (4,900)	1.6 (65)	4
	Fort Wingate	130 (1,600; average)	0.5 (20)	5

*Sources:

1. H. Jukenwold, hydrologist, Gulf Minerals, Denver, personal communication
2. Cooper and John (1967)
3. Kelley (1977)
4. Mercer and Lappala (1971)
5. Shomaker (1971)

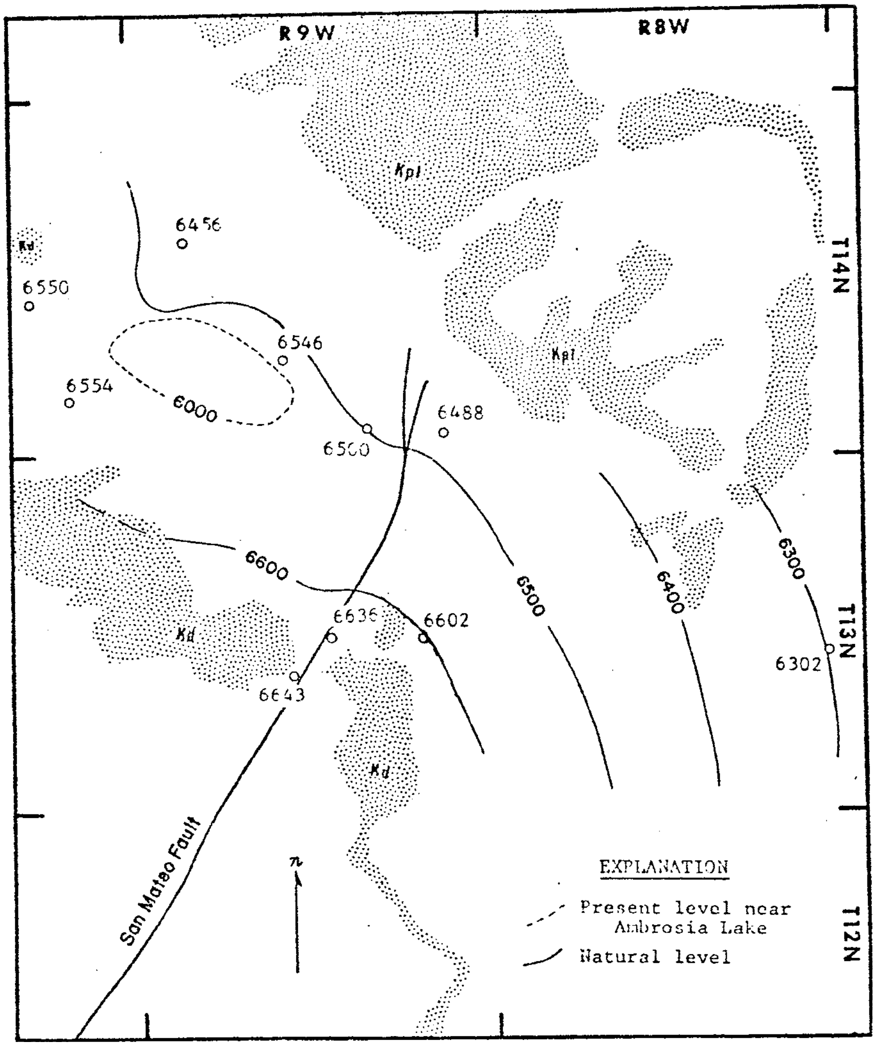

Figure 28. Potentiometric levels for the Westwater Canyon Member. Kpl: Point Lookout Sandstone; Kd: Dakota Sandstone.

Sandstone. Most of the data are from Cooper and John (1967), and because they were obtained in the late 1950's, are believed to reflect conditions before the large-scale dewatering of the uranium mines. The estimated configuration of the present potentiometric surface near Ambrosia Lake is shown; its location was inferred from reports of dry wells, and the depths of those wells. It is apparent that the natural flow west of the San Mateo Fault follows the regional dip, generally trending northeasterly. The regional gradient (i) is approximately 5×10^{-3}.

If the area west of the San Mateo Fault is assumed to have an average hydraulic conductivity (K) of 9 gpd/ft^2 (367 1/m^{2}d; Table 1), then the natural flow velocity (v) of ground water in the Westwater Canyon Sandstone may be approximated as follows:

$$v = Ki \qquad \text{(Todd, 1959)}$$

$$= 6 \times 10^{-3} \text{ ft/day } (1.8 \times 10^{-3} \text{ m/day})$$

East of San Mateo Fault the flow is nearly easterly, in accordance with the structure. The regional potentiometric gradient is approximately 9×10^{-3}. If this area is assumed to have an average hydraulic conductivity of about 20 gpd/ft^2 (815 1/m^{2}d), the natural flow velocity is about 24×10^{-3} ft/day (0.01 m/day).

Virtually level beds on the crest of the San Mateo Dome (Plate 3) and the relatively high concentrations of dissolved solids in the units there (Figure 20) suggest that there is relatively little lateral ground-water movement in that area. Also, though most of the fractures in that area are probably of the tensional, open type, these are probably oriented parallel to the axis of the folds, and therefore perpendicular to the potentiometric gradient. The dome, and associated San Mateo Fault, seem to define a ground-water divide which corresponds to the boundary between two of the tectonic provinces shown on Figure 6, the Zuni Uplift and the Acoma Sag.

Both the pre-Laramide and post-Laramide ground-water flow systems have controlled the emplacement of uranium ore. Gould and others (1963) explained that those deposits believed to have been emplaced before the Laramide activity, the trend-type ones, are elongate, continuous bodies deposited parallel to bedding and trending parallel to the east-west paleocurrent direction. Those deposits believed to have been emplaced during or after the structural upheaval, the stack-type, are equidimensional, trending at an angle to the paleocurrent direction and frequently parallel to the strike of local fractures.

The Westwater Canyon Member has been interpreted as having been deposited in a fluvial environment originating to the west of the study area (Craig, 1955; Flesch, 1975). Uranium may have been deposited in association with buildups of carbonaceous material in stream channels, and redistributed locally in an associated alluvial aquifer. Figure 29 shows the distribution of known ore deposits in the area. The pattern suggests that two or three stream systems, and presumably the alluvial aquifers, flowed to the east from the Ambrosia Lake and Poison Canyon areas. The old channel systems and associated ore deposits are said to converge near the town of San Mateo, in the nation’s largest known uranium-ore deposit (Steve Falkowski, research assistant, New Mexico Institute of Mining and Technology, Socorro, personal communication). Clearly, uranium-ore

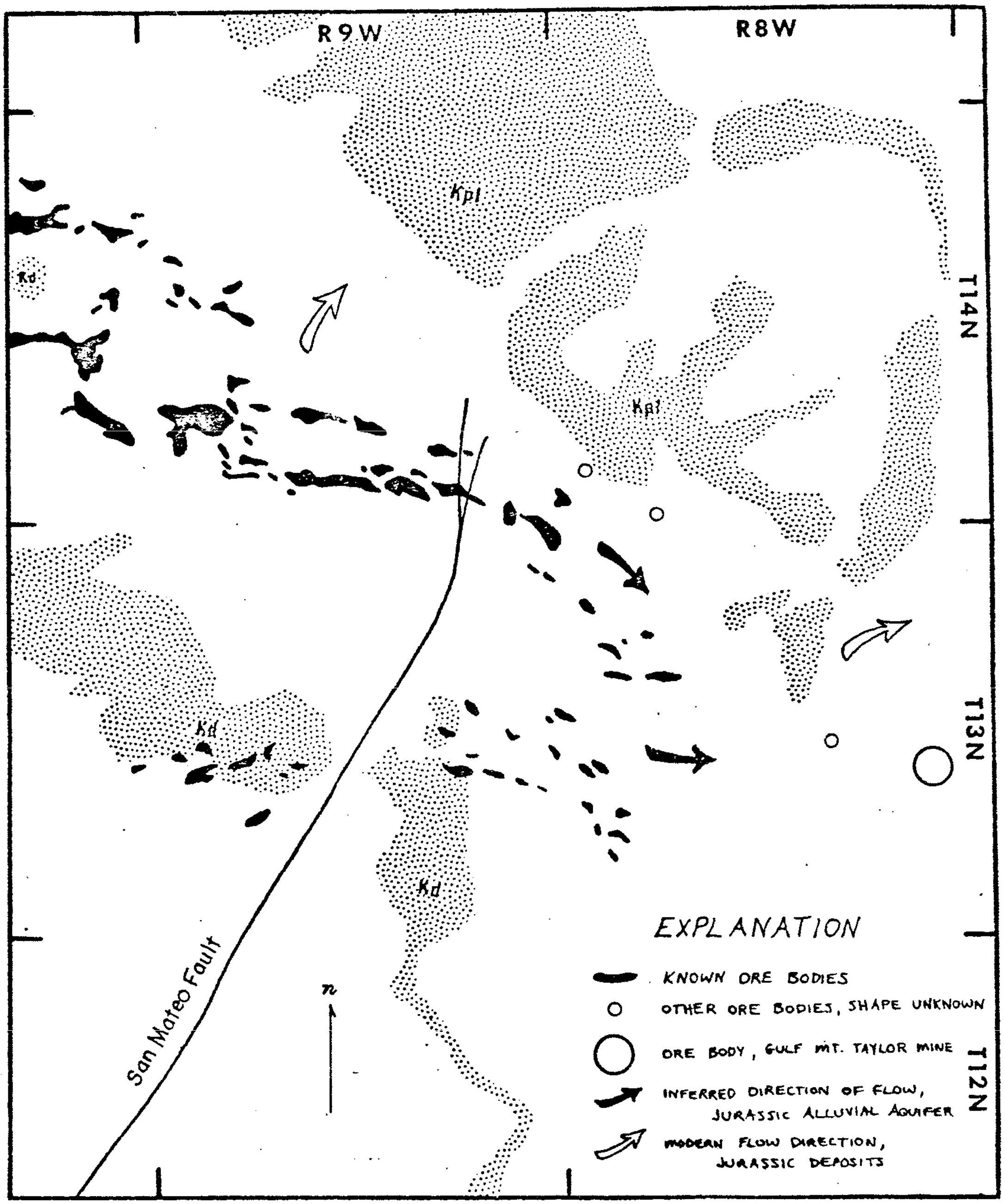

Figure 29. Uranium deposits and the Jurassic and Recent flow systems in the Ambrosia Lake-San Mateo area. Locations of ore bodies from Chapman and others (1977). Kpl: Point Lookout Sandstone; Kd: Dakota Sandstone.

emplacement has been controlled by the original east-trending alluvial gradient, and more recently, by the fold and fracture system which tectonic activity has imposed upon the consolidated deposits. The redistribution of ore has depended on local conditions of primary and secondary permeability, and the consequent movement of ground water.

Discharge

The study area is one in which Mesozoic formations crop out and dip toward the north and east, and is in many respects typical of the recharge zone along the whole southern flank of the San Juan structural basin. Except on the flanks of Mt. Taylor, the natural discharge of ground water from consolidated aquifers is not known in the area. Cooper and John (1967) reported that wells in the Point Lookout Sandstone and Crevasse Canyon Formation flow about three miles northeast of the area. Kelley (1977) indicated that wells in the Westwater Canyon flow about fifteen miles north of the area.

A few perennial springs discharge ground water from the sedimentary and volcanic deposits on the flanks of Mt. Taylor. San Mateo Spring, which is located a few miles southeast of the study area on Mt. Taylor, is the major source of water for San Mateo Creek, and frequently discharges hundreds of gallons per minute (Cooper and John, 1967). The other springs in the area, however, discharge less than 15 gpm (0.01 1/s), and the water evaporates or infiltrates rapidly.

Mine dewatering causes the artificial discharge of millions of gallons per day, and is discussed in the following chapter.

GROUND-WATER USE

The Ambrosia Lake-San Mateo area, like most of northwestern New Mexico, offers little opportunity for the use of surface-water supplies. Except for the very limited use of springs and runoff from Mt. Taylor, the area depends largely on ground water. Before the advent of the uranium industry in the 1950's, ground-water pumpage was limited, probably amounting to about 7000 gpd (gallons per day; 26,000 I/d, or liters per day) by ranches and the town of San Mateo. Mining has created the need to pump many times this amount of water, for the purposes of drilling, dewatering, milling, and other associated development.

Industrial Use

Extensive pumping by the mining industry began in the late 1950's. Most of the mines extract ore from below the piezometric level of the Westwater Canyon Member of the Morrison Formation, which is the major aquifer in the area. Ground water is commonly drained from "long-holes" at the ends of the drifts and stopes in the mines.

The estimated ground water discharge from the mines in the area, based on data recently collected by the New Mexico Environmental Improvement Agency (1978), is shown in Table 2. At the time of the EIA report, before the construction of the Gulf Mt. Taylor Mine had been completed, the total discharge equaled nearly 13 million gpd (49 million 1/d). When production begins in the Mt. Taylor

TABLE 2 Estimated Discharge from Mining Operations*

Mine	Estimated Discharge, million gallons per day	(million liters per day)
Gulf, Mt. Taylor Mine	1.70[1]	(6.40)
	8.60[2]	(32.55)
Cobb Nuclear Corp., T14N, R10W, Section 14	(water used and recycled)	
Kerr-McGee, Section 30 Mine	0.56	(2.13)
Kerr-McGee, Sections 35 and 36 Mines	4.32	(16.35)
Ranchers, Johnny M Mine	2.88	(10.90)
Kerr-McGee, Roca Honda Mine (planned; T13N, R8W, Section 9)	3.60	(13.63)
United Nuclear-Homestake, recovery plant (for mines in Sections 15, 23,25, and 32)	2.13	(8.07)
United Nuclear, Sandstone Mine	0.51	(1.93)
United Nuclear, Section 27 Mine	0.14	(0.53)
Ranchers, Faith Mine	1.01	(3.82)

[1] Approximate discharge, January, 1978.

[2] Approximate anticipated discharge at start of mining.

*(compiled from Environmental Improvement Agency, 1978)

and the Roca Honda Mines, the total discharge is expected to be approximately 8 million gpd (91 million l/d). Cooper and John (1967) reported an overall pumping rate of approximately 8 million gpd (30 million l/d) in the earlier days of mining.

The following mines in the area are not believed to discharge significant amounts of ground water (EIA, 1978)

Reserve Oil & Mineral Corp., Poison Canyon Mine
(T13N, R9W, Sec. 19)

Kop-Ran Development Corp., Hope Mine
(T13N, R9W, Sec. 19)

United Nuclear Corp., Ann Lee Mine
(T14N, R9W, Sec. 28)

United Nuclear-Homestake, Sec. 25 & 13 Mines
(T14N, RIOW)

The mines located in the Poison Canyon area are directly on the outcrop of Jurassic rocks, and are above the water table. Water for mine use is trucked to the Poison Canyon Mine from Milan. It has been necessary to dewater at a rate of approximately 1 million gpd (4 million 1/d) from the Todilto Limestone in the Faith Mine (T13N, R9W, Sec. 29). Most of this water is believed to have originated as artificial recharge from exploratory drilling in the area (Mark Malkoski, geologist, Ranchers Exploration and Development, Grants, personal communication). Those mines which lack appreciable amounts of water in the Ambrosia Lake area are believed to be dry because of the artificially-lowered piezometric levels in the area.

Except for those near Poison Canyon, the mines in the study area generally have more than enough water. In the Ambrosia Lake area, piezometric levels have been lowered hundreds of feet after more than twenty years of pumping. Dewatering has not yet had any significant impact on piezometric levels in the eastern part of the area where new development exists and will continue. The tremendous amounts of ground water that are pumped by the mining industry have great potential for uses in addition to ore processing. Most of the pumped water is now released into surface drainages, where it evaporates or infiltrates to recharge local aquifers before leaving the study area. The possibility of treating waste water and diverting it for agricultural and municipal use has been considered, and was discussed by Hiss (1977) and the City of Gallup (1977). Much more research in the scientific, social, and legal realm is needed before the waste water may be put to further use.

Municipal Use

The residents of San Mateo have historically depended on private wells for their water, typically dug or driven into the Menefee Formation and alluvium. Surface water draining from Mt. Taylor has been used for irrigation and a few domestic supplies. Although a municipal well was drilled in the 1940's (13.8.26.212, Table 3), most houses continued to use their own wells. A second town well (13.8.24.112) was drilled in 1955, and a third (13.8.26.212b) was drilled for the town by Gulf Mineral Resources in 1977. All three municipal wells are believed to be completed in the Point Lookout Sandstone. At the time of this report, the newest well is not used, the supply from well 13.8.24.112 being adequate. Most of the houses in San Mateo now rely on the municipal well, and only about eight private wells are still used (Nancy Brooks, representative, San Mateo Water Consumers Association, San Mateo, personal communication). Since 1970 a few new wells have been installed for trailer parks. An estimated 18,000 gpd (68,000 l/d) are used in the town (Everheart, 1977).

Since the beginning of the construction of the Mt. Taylor Mine, ½ mile northeast of San Mateo, no general changes in the ground-water level or quality have been observed. Gulf will mine uranium ore from the Westwater Canyon Sandstone, approximately 3200 ft. (975 m) below ground level. The author believes that since San Mateo's aquifers are recharged by runoff from Mt. Taylor, these aquifers will continue to be hydrologically independent of the ore-bearing bodies and subsurface mining activity. Gulf will have a tailings pile adjacent to the mine. While the pile will supposedly be lined, it is conceivable that an accident could cause tailings leachate to escape and enter the shallow aquifer.

In the community of Ambrosia Lake private wells originally supplied water to the houses and trailer parks. Most of these wells tapped the Westwater Canyon Member of the Morrison Formation, but went dry in the early 1970's because of the dewatering of the mines. At about the same time Kerr-McGee constructed a pipeline which now supplies the domestic needs in the area.

At the intersection of State Routes 53 and 509 private wells supply the houses and trailers. These wells tap the Westwater Canyon Member and the alluvium; they are maintained with adequate quantities

of water by recharge from Arroyo del Puerto and San Mateo Creek.
The quality of the water, however, is not good, and the concentration of TDS averages about 2000 mg/l. The poor quality is probably due to the recharge of mine water and to some extent, the stagnating effect of the San Mateo Fault. Water conditioners are used in the area to improve the water quality.

Ranch Use

Five ranch headquarters are located in the study area, although active ranching is only practiced on a small scale in the area. Three of the headquarters are supplied by private wells, and two by a pipeline from wells owned by the Navajo Tribe near Haystack Mountain, west of the area. All of the ranches have a sufficient quantity of water, and most have adequate quality. However, the well water at a ranch house in the southeastern part of the area (12.9.8.431) was found to contain 115 mg/l nitrate, thereby posing a substantial health hazard to two families which use the water. The source was found to be a nearby arroyo into which untreated sewage drained from the house.

Grazing is the main use to which ranch land is put, and about ten stock wells are believed to be actively used in the area. No irrigation is known to occur on the ranches. The soil and limited water in the area generally restrict agriculture, and no demand for irrigation water is anticipated. If such demand should occur, the mine discharge provides the potential, at least, for a more than adequate supply.

SUMMARY AND CONCLUSIONS

1. The Ambrosia Lake-San Mateo area lies amidst outcrops of Triassic, Jurassic, and Cretaceous sedimentary rocks which dip to the northeast toward the central part of the San Juan Basin, and to the east toward the Acoma Sag. Stratigraphically, the area is typical of the outcrop zone on the southern side of the San Juan Basin.

   The most significant water-yielding units in the area are the Menefee Formation, the Point Lookout Sandstone, sand-stone of the Mancos Shale, the Dakota Sandstone, and the Westwater Canyon Member of the Morrison Formation. The most significant aquitards in the area are the Mancos Shale and the Summerville Formation.

2. Ground-water chemistry in the area varies greatly with the water's geologic and geographic origin. Seventy-two ground-water samples have an average TDS concentration of 1860 mg/l. The water from 34 domestic wells in the area has an average TDS concentration of 873 mg/l. The Menefee Formation near San Mateo yields ground water that has an average TDS concentration of about 400 mg/l. The Westwater Canyon Member of the Morrison Formation, near the intersection of Highways 53 and 509, yields ground water with an average TDS concentration of about 2000 mg/1; some of this concentration

is probably derived from the mine-water discharge in Arroyo del Puerto and San Mateo Creek.

The ground water from most of the geologic units in the area is of the sodium-sulphate type. However, the ground water from the Menefee Formation and the Point Lookout Sandstone near San Mateo is of the sodium-bicarbonate type.

The ground water in the bedrock aquifers tends to increase in TDS away from the outcrop zone. The bedrock aquifers may be expected to naturally contain less than 1000 mg/ 1 TDS within a few miles of their outcrop. Based on estimates from borehole logs, the units generally contain more than 2000 mg/l TDS in the vicinity of the San Mateo Dome, in the northeast part of the study area.

3. The bedrock aquifers in the Ambrosia Lake-San Mateo area are recharged by precipitation onto their outcrops and by seepage from intermittent runoff. The outcrop of the Dakota Sandstone is extensive, and it has been estimated that approximately 400 million gallons (1.5 billion liters) of water enter it each year, at a rate of approximately 0.11 mgd/sq. mi. (4.2×10^5 1/d/km^2). Much of this probably enters the underlying units through fractures. The shape of the potentiometric surface of the ground water in the Menefee Formation near San Mateo indicates that the formation is recharged from San Mateo Creek.

All of the other bedrock units are saturated beneath a regional water table which dips to the northeast and is controlled by the dipping beds. In the north-central and eastern parts of the area the geologic units dip beneath this regional potentiometric surface, and are confined or semi-confined, depending on the degree of permeability of the overlying units. There is believed to be hydraulic communication between all of the units, but this may not be significant where the units are separated by a tongue of the Mancos Shale or by the Summerville Formation.

4. The flatness of the beds and the high estimated TDS concentrations suggest that the ground water is relatively stagnant in the San Mateo Dome area. The relative steep slope of the potentiometric surface of the Westwater Canyon Member, the high reported transmissivity, and the relatively low concentration of TDS suggest that ground water is relatively mobile in the vicinity of the town of San Mateo.

5. It is estimated that, before the advent of mining in the 1950's, ground-water pumpage in the area amounted to about 2.5 million gallons (9.5 million liters) per year. The mining industry now pumps an estimated 6.2 billion gallons (23 billion liters) of water per year in the Ambrosia Lake-San Mateo area. It is apparent from this figure and the estimated amount of recharge through the Dakota Sandstone that extensive mining of ground water has occurred in the area. Approximately 7.0 million gallons (26 million liters) are now pumped for domestic use each year. It is believed that the recharge derived from runoff from Mt. Taylor will be sufficient for all foreseeable domestic water needs in the area. This water is much more desirable chemically than the mine water, and its quantity will not depend on the mining.

6. The potentiometric surface of ground water in the Westwater Canyon Member of the Morrison Formation has been lowered hundreds of feet by the dewatering of mines near Ambrosia Lake.

The treated discharge from mines has daily-average concentrations of 3.0 pCi/l radium and 2.0 mg/1 uranium. Both values are below the maximum permissible levels set by the EPA. Kaufmann and others (1975) have shown that the discharge from tailings ponds contains more than the maximum permissible amounts of radium and uranium, but that the concentrations of these elements are acceptable a short distance from the ponds. High concentrations of TDS, chloride, and nitrate indicate that the discharge has contaminated parts of the alluvium aquifer. Also, well water from the Westwater Canyon Member contains nearly twice as many TDS as it did in the 1950's, suggesting that contamination has reached that aquifer in places other than the mines.

7. Present-day ground-water flow systems have been compared to those implied to have been present during the deposition of the Westwater Canyon Member in the Jurassic. In the area west of San Mateo Fault the natural flow of ground water in the Westwater Canyon Member is to the northeast, roughly perpendicular to the direction it is inferred to have flowed in the Jurassic. In the area east of San Mateo Fault, ground water now flows to the east in the Westwater Canyon Member, approximately in the same direction as it did in the Jurassic.

8. This study confirms the importance of the Dakota Sandstone and the Westwater Canyon Member of the Morrison Formation as

aquifers along the southern flank of the San Juan Basin. However, the study shows that the sandstones of the Mancos Shale may be more important to the ground-water flow systems of the-San Juan Basin than may have previously been thought. The sandstone units of the San Rafael Group, the Bluff and Entrada Sandstones, may be less significant than has previously been believed. The Mancos Shale and Summerville Formation are probably effective confining layers along the southern flank of the Basin. The Menefee Formation may behave as a homogeneous unconfined aquifer, and may be an important source of recharge to underlying formations. The outcrops of the Dakota and Point Lookout Sandstones are probably important sources of recharge to respective underlying units, depending on the degree to which they are dissected. Places where drainages cross the outcrop zones may be considered to be important sources of recharge.

It seems that ground water may contain TDS concentrations of 1000 mg/l approximately 5 to 10 miles down-dip from the outcrop zone. The ionic concentration is subject to control by the geologic structure, as has been shown for San Mateo Dome.

The regional ground-water flow parallels regional dip, but does not appear to be much affected by faulting.

9. Recommendations for further study in the Ambrosia Lake-San Mateo area are as follows:

   a) It will be desirable to quantify the natural water budget in the area. In particular, the amount of recharge which is derived through bedrock outcrops needs to be known, as well as the amount derived through seepage from the major drainages. The significance of Mt. Taylor to the recharge in the area needs to be quantitatively known.

b) Aquifer tests and chemical data are needed in the eastern part of the area, especially near San Mateo Dome.

c) Aquifer tests need to be made throughout the area to better define the amount of hydraulic communication between different geologic units.

d) The area's ground-water flow systems should be modeled to better determine the effects of large-scale mine dewatering. This should include an attempt to predict the long-term effects of the discharge of mine water on ground-water quality in the area.

Table 3, Records of wells from the Ambrosia Lake-San Mateo Area

Explanation

Owner or name: Name of owner or name of well, based on available information.

Field number: Identification used in figures in this report, based on aquifer and location: A, alluvium; MF Menefee Formation; P, Point Lookout Sandstone; DA, Dalton Sandstone; MN, Mancos Shale; D, Dakota Sandstone; W, Westwater Canyon Sandstone; B, Bluff Sandstone; C, Chinle Formation; S, San Andres Limestone; U, unknown aquifer.

Location number: Well location and identification according to New Mexico system.

Water Depth: Measured and reported depths, and date of measurement; those prior to 1977 from other sources (see Table 4).

Principle Aquifer: Stratigraphic-unit symbols on geologic map, Plate 1.

Use: D, domestic; I, industrial; S, stock; PS, public supply; 0, observation; U, unused.

Chemical Analysis: *, data in Appendix B.

NAME OR OWNER'S NAME	FIELD NO.	LOCATION NUMBER	ELEV. (ft)	TD (ft)	WATER DEPTH (ft)	DATE	WATER SURF. ELEV. (ft)	PRIN. AQ.	YEAR CONSTRUC.	USE	CHEM ANAL.	REMARKS
G.P. Roundy	A1	12.9.6.312	6673	91	79.9	7/56	6593.1	Qa	--	S	--	Abandoned
G.P. Roundy	A2	12.9.7.343	6640	98	58.0	11/55	6582.0	Qa	1945	S	--	Abandoned
G.P. Roundy	C1	12.9.8.431	6770	98	84.8	7/56	6685.2	TRc	1917	D	*	
G.P. Roundy	C2	12.10.1.222	6675	192	45.9	7/56	6629.1	TRc	1952	S	--	Abandoned
G.P. Roundy	A3	12.10.12.221	6657	81	67.7	7/56	6589.3	Qa	before 1917	S	--	
G.P. Roundy	A4	12.10.12.433	6625	100	58.1	7/56	6566.9	Qa	1945	S	--	
Wilson	A5	12.10.13.424	6640	100	54.5	8/77	6585.0	Qa	1961	D,I	--	
Wilson	A6	12.10.14.212	6621	--	50.1	7/56	6570.9	Qa	1945	S	--	
T.A. Morris & Son	S2	12.10.23.233	6592	865	115.6 145.6	2/46 8/57	6476.4 6444.4	Psa	1945	I	--	Abandoned

Table 3, cont.

NAME OR OWNER'S NAME	FIELD NO.	LOCATION NUMBER	ELEV. (ft)	TD (ft)	WATER DEPTH (ft)	DATE	WATER SURF. ELEV. (ft)	PRIN. AQ.	YEAR CONSTRUC.	USE	CHEM ANAL.	REMARKS
G.P. Roundy	C5	12.10.23.233a	6594	500	75'	7/46	6519.0	TRc	1945	S	--	
Ranchers Expl. & Devel.	D1	13.8.7.434	--	--	--	--	--	Kd	--	D,I	*	Johnny M Mine
E. Michael	MF1	13.8.14.422	7180	200 --	71.5 56	9/62 10/72	7108.5 7124.0	Kmf	--	S	-- --	
F. Lee	U1	13.8.17.223	7174	--	--	--	--	Unk	--		*	
Fernandez Co.	MF2	13.8.22.242	7110	157.3	37.5 33.3	10/62 10/72	7072.5 7076.7	Kmf	--	D,S	* --	Hdqtrs.
T. Marquez	MF3	13.8.23.324	7165	NA	NA	--	--	Kmf	--	S	*	
B. Isidorg	MF4	13.8.23.342	7169	305	37.5	2/78	7131.5	Kmf	--	D	*	Trailer Court
T. Marquez	MF5	13.8.23.431	7180	92	38.2 35	9/62 10/72	7141.8 7145.0	Kmf	1950	D	*	
Gulf Minerals	MF6	13.8.24.141	7248	250	59.0	2/78	7189	Kmf	--	D,S	*	Abandoned
A. Canderlaria	MF7	13.8.24.141a	7270	280	--	--	--	kmf	1972	D	--	
A. Canderlaria	MF8	13.8.24.223	7320	--	140.7 195	9/62 10/72	7179.3	Kmf Kmf	--	D,S	*	
Gulf Minerals	Mw	12.8.24.234	7364	3550	1062	10/72	6302	Jmw	--	I	--	Aquifer test hole
F. Gonzales	MF9	13.8.24.334	7290	200	50 87.75	before 1962 2/78	7202.2	Kmf	--	D	-- *	
S. Marquez	MF10	13.8.24.334a	7300	140	89.5	9/62	7210.5	Kmf	--	N	--	
S. Marquez	MF11	13.8.24.334b	7295	200	40 88.1	before 1962 2/78	7207.0	Kmf	1961	D	-- --	
S. Mateo School	MF12	13.8.24.334	7300	120	101.0	2/78	7199.0	Kmf	--	PS	*	
F. Chavez	MF13	13.8.24.341	7308	250	--	--	--	Kmf	1958	D	--	Abandoned
F. Chavez	MF14	13.8.24.341	7325	500	139.0	3/78	7186.0	Kmf	1978	D	--	
P. Pena	A7	13.8.75.111	7295	21	19.5	9/62	7275.5	Qa	--	D	--	Abandoned

Table 3, cont.

NAME OR OWNER'S NAME	FIELD NO.	LOCATION NUMBER	ELEV. (ft)	TD (ft)	WATER DEPTH (ft)	DATE	WATER SURF. ELEV. (ft)	PRIN. AQ.	YEAR CONSTRUC.	USE	CHEM ANAL.	REMARKS
J. Gonzales	MF15	13.8.25.112	7320	150	43.0	9/62	7277.0	Kmf	--	D	--	
J. Hope	MF16	13.8.25.114	7290	35	27	10/72	7263.0	Kmf	--	D	--	Broken, 1973
E. Michael	MF17	13.8.25.114a	7310	120	35.9	9/62	7274.1	Kmf	--	D	--	
E. Michael	MF18	13.8.25.114b	7310	250	80	10/72	7230.0	Kmf	1969	D	--	
P. Sandoval	MF19	13.8.26.211	7215	40	33.2 34	9/62 10/72	7181.8 7181.0	Kmf	--	D	-- --	
Community of San Mateo	P1	13.8.25.122	--	--	--	--	--	Kpl	--	PS	--	Public supply, near tanks
N. Brookes	MF20	13.8.26.211	7207	180	36	8/73	7171	Kmf	--	D,S	*	
Community of San Mateo	P2	13.8.26.212	7240	336	281	--	6959	Kpl	--	PS	--	Old town well
Community of San Mateo	MF	13.8.26.212a	7240	200	32.8	--	--	Kmf	--	PS	--	Modified old town well
Community of San Mateo	P3	13.8.26.212b	7240	--	--	--	--	Kpl	--	PS	*	New town well (Not used 1978)
F. Salazar	MF21	13.8.26.222	7267	57.5	21.5	2/78	7245.5	Kmf	--	D	*	Used for trailers
Fernandez Co.	MF22	13.8.27.133	7072	--	24.2	8/77	7047.8	Kmf	--	N	--	Old CCC abandoned
F. Lee	MF23	13.8.33.234	7185	500	133	8/77	7052	Kpl	--	O	*	
Km 5-2	A8	13.9.5.141	6896	34	19.7	EPA 3/75	6876	Qa	--	O	*	
K-M 5-1	A9	13.9.5.214	6904	34	23.9	EPA 3/75	6880	Qa	--	O	*	
N. Marquez	D2	13.9.13.111	6935	155	142.9	2/58	6792.1	Kd	--	N	--	
J.D. Ragland	W2	13.9.15.343	6840	260	223.7	12/57	6616.3	Jmw	1957	D	--	
B. Willcoxson	D3	13.9.16.333	6910	97	87.6	12/57	6822.4	Kd	1954	N	--	Exploration hole
B. Willcoxson	D4	13.916.341	6810	91	75.9	12/57	6734.1	Kd	1953	N	--	
B. Willcoxson	D5	13.9.16.341a	6810	100	--	--	--	Kd	1920	S	--	
B. Willcoxson	W3	13.9.16.411	--	250	--	--	--	Kmw	--	--	*	

Table 3, cont.

NAME OR OWNER'S NAME	FIELD NO.	LOCATION NUMBER	ELEV. (ft)	TD (ft)	WATER DEPTH (ft)	DATE	WATER SURF. ELEV. (ft)	PRIN. AQ.	YEAR CONSTRUC.	USE	CHEM ANAL.	REMARKS
B. Willcoxson	W4	13.9.16.413	6820	250	--	--	--	Jmw	--	S	--	
Kop-Ran Dev.	T1	13.9.19.413	6990	595	R360	--	6630	Jt	1976		--	
N. Marquez	W5	13.9.21.412	6785	165	141.7	10/57	6643	Jmw	--	S	--	
N. Marquez	A10	13.9.21.414	--	145	64.0	EPA 3/75	6721	Qa	--	--	*	
B. Jones	W6	13.9.22.111	6825	--	P220	--	6605	Jmw	1975	D	*	
Ingersoll-Rand	W7	13.9.22.121	6830	297 297	204.8 --	12/58	6625	Jmw	1958	I	-- *	
Bingham	W8	13.9.22.121	6835	330 260	198.5 --	10/62 --	6636.5 --	Jmw	--	P	-- *	Trailer Court
C. Sandoval	A11	13.9.22.212	6830	95 130	87.5 37.1	12/57 3/75	6742.5 6792.9	Qa	1955	S	--	
N. Marquez	W9	13.9.23.212	6653	280	50.5	3/75	6602.0	Jmw	--	--	*	
N. Marquez	A12	13.9.24.221	6910	80	56.5	12/57	6853.5	Qa	--	S	--	
Calvmet Hecla Inc.	A3	13.9.24.221a	6910	80	56.6	12/57	6853.4	Qa	1955	I,D	--	
	A14	13.9.28.111	6780	125	58.2	8/5/77	6722.0	Qa		S	*	
Westvaco Min. Dev.	T2	13.9.29.341	6755	190	dry	--	--	Jt	--	--	--	Abandoned
Mt. Taylor Corp.	C6	13.9.29.341	6760	455	--	--	--	T c	1958	D	--	
R. Otero	A15	13.9.32.112	6795	110	65	10/77	6730	Qa	--	D,I	--	
Fernandez Co.	DA2	14.8.4.334	7050	--	150.3	10/62	6899.7	Kcda	--	S	--	Abandoned
Fernandez Co.	MN1	14.8.15.244	7210	1320	500	(RPT)	6710.0	Km	1924	S	--	
B. Willcoxson	MN2	14.9.5.341	7245	858	414.1	12/57	6830.9	Km	1952	N	--	
A. Berryhill	W10	14.9.18.243	7200	800	744	--	6456.0	Jmw	1957	D	--	
Kerr-McGee	W11	14.9.28.143	6987	710	440.5	9/56	6546.5	Jmw	1956	D,I	--	
Kerr-McGee	W12	14.9.28.233	7003	700	--	--	--	Jmw	1956	O	--	

Table 3, cont.

NAME OR OWNER'S NAME	FIELD NO.	LOCATION NUMBER	ELEV. (ft)	TD (ft)	WATER DEPTH(ft)	DATE	WATER SURF. ELEV.(ft)	PRIN. AQ.	YEAR CONSTRUC.	USE	CHEM ANAL.	REMARKS
Kerr-McGee	W13	14.9.28.234	7022	801	529	10/57	6493.0	Jmw	1957	I	--	
Kerr-McGee	W14	14.9.28.234a	7021	700	--	--	--	Jmw	1956	O	--	
Kerr-McGee	W15	14.9.28.234b	7022	835	445	--	6577.0	Jmw	1956	O	--	
Kerr-McGee	W16	14.9.28.234c	7032	840	--	--	--	Jmw	1956	O	--	
Kerr-McGee	W17	14.9.28.412	7008	840	--	--	--	Jmw	1956	O	--	
Kerr-McGee	S2	14.9.28.441	6982	3275	542	10/57	6440.0	Psa	1956	I	--	Water test well
A & J Trailer Park	W18	14.9.29.312	6980	735	450	2/58	6530.0	Jmw	1958	D	--	Abandoned
Kerr-McGee	W19	14.9.30.221	6984	--	478	12/57	6506.0	Jmw	--	I	--	
A. Berryhill	W20	14.9.30.222	6990	925	--	--	--	Jmw, Jb	--	D,S	--	Abandoned
K-M 46	A16	14.9.30.331	6958	38	33.1	2/75	6924.9	Qa	--	O	*	
K-M 47	A17	14.9.30.341	6947	62	23.9	2/75	6923.1	Qa	--	O	*	
K-M 48	A18	14.9.30.432	6952	53	37.1	2/75	6914.9	Qa	--	O	*	
K-M B-2	A19	14.9.31.421	6926	27	3.4	3/75	6922.6	Qa	--	O	*	
K-M 50	A20	14.9.32.114	6936	55	45.9	2/75	6890.1	Qa	--	O	*	
United Nuclear-Homestake	W21	14.9.32.122	6942	644	413	4/57	6529.0	Jmw	1957	N	--	Now air vent
United Nuclear-Homestake	W22	14.9.32.122a	6942	620	412	4/57	6530.0	Jmw	1957	O	--	
United Nuclear-Homestake	W23	14.9.32.122b	6943	620	414	11/57	6529.0	Jmw	1957	O	--	
United Nuclear-Homestake	W24	14.9.32.122c	6948	500	--	--	--	Jmw	--	I	--	
K-M S-12	A21	14.9.32.313	6910	41.0	3.0	2/75	6907.0	Qa	--	O	*	
K-M 44	MN 3	14.9.32.312	6923	138	108	2/75	6815.0	Km	--	O	*	
K-M 43	A22	14.9.32.321	6922	53	21.0	2/75	6901.0	Qa	--	O	*	
K-M 51	A23	14.9.32.322	6924	63	28.9	2/75	6895.1	Qa	--	O	*	

Table 3, cont.

NAME OR OWNER'S NAME	FIELD NO.	LOCATION NUMBER	ELEV. (ft)	TD (ft)	WATER DEPTH (ft)	DATE	WATER SURF. ELEV. (ft)	PRIN. AQ.	YEAR CONSTRUC.	USE	CHEM ANAL.	REMARKS
A. Berryhill	W25	14.9.32.314	6910	550	397.4	12/57	6512.6	Jmw	--	--	--	
A. Berryhill	W26	14.9.32.314a	6910	550	--	--	--	Jmw	--	S	--	Abandoned
United Nuclear	W27	14.9.34.422	7008	508	--	1958	6500.0	Jmw	1958	N	--	Exploration hole
United Nuclear	W28	14.9.36.313	7070	1500	582	1958	6488.0	Jmw	1958	N	--	Exploration hole
Hydro-Nuclear	B1	14.10.11.434	7060	750	460	--	6600.0	Jb	--	D,I	--	
B. Willcoxson	B2	14.10.14.221	7060	702	--	--	--	Jb	1925	S	--	
United Nuclear-Homestake	W29	14.10.23.114	7053	796	502	5/57	6551.0	Jmw	1956	I	--	
United Nuclear-Homestake	W30	14.10.23.132	7034	780	485	5/57	6549.0	Jmw	1957	O	--	
United Nuclear-Homestake	W31	14.10.23.134	7030	875	481	5/57	6549.0	Jmw	1956	O	--	
United Nuclear-Homestake	W32	14.10.23.141	7047	770	498	5/57	6549.0	Jmw	1957	O	--	
United Nuclear-Homestake	W33	14.10.23.142	7037	707	489	5/57	6548.0	Jmw	1955	O	--	
United Nuclear-Homestake	W34	14.10.23.232	7022	720	473	5/57	6549.0	Jmw	1957	O	--	
United Nuclear-Homestake	W35	14.10.23.232a	7022	715	479	5/57	6543.0	Jmw	1957	O	--	
United Nuclear-Homestake	W36	14.10.23.2326	7022	720	477	5/57	6545.0	Jmw	1957	O	--	
Kerr-McGee	W37	14.10.24.423	6980	--	449	2/57	6531.0	Jmw	--	N	--	
United Nuclear-Homestake	W38	14.10.25.132	6476	766	431	4/57	6045.0	Jmw	1956	O	--	
United Nuclear-Homestake	W39	14.10.25.132a	6974	720	424	4/57	6550.0	Jmw	1956	O	--	
United Nuclear-Homestake	W40	14.10.25.132b	6974	735	425	4/57	6549.0	Jmw	1956	O	--	
United Nuclear-Homestake	W41	14.10.25.132c	6974	735	424	4/57	6550.0	Jmw	1956	O	--	
United Nuclear-Homestake	W42	14.10.25.132d	6975	725	426	4/57	6549.0	Jmw	1956	O	--	
United Nuclear-Homestake	W43	14.10.25.321	6971	735	430	5/57	6541.0	Jmw	1957	O	--	
United Nuclear-Homestake	W44	14.10.25.411	6970	753	430	5/57	6540.0	Jmw	1957	O	--	
United Nuclear-Homestake	W45	14.10.25.411a	6971	750	432	5/57	6539.0	Jmw	1957	O	--	
United Nuclear-Homestake	W46	14.10.25.413	6971	722	432	5/57	6539.0	Jmw	1957	O	--	
United Nuclear-Homestake	W47	14.10.35.221	7015	760	461	12/57	6554.0	Jmw	1954	S	--	
KM 36 2	MN4	14.10.36.422	7010	57	33.2	3/75	6977.0	Km	--	O	*	

Table 4 Chemical Analysis of Ground Water Samples from the Ambrosia Lake-San Mateo Area

Explanation

Location: Location numbers identify wells according to New Mexico well-numbering system.

Field Number: Well identification used in figures in this report, as listed in the table of well records, Appendix A. W(m) and D(m) indicate ground-water samples taken from mines, from the Westwater Canyon Sandstone and Dakota Sandstone, respectively.

Data Source: *: This report. Analysis by New Mexico Bureau of Mines and Mineral Resources.
SE-20: Gordon (1961)
EPA: Kaufmann and others (1975)
R: Mark Malkoski, Ranchers Exploration and Development, Grants, personal communication.
G: Gulf Minerals Corp. (1974)
SE-35: Cooper and John (1967)
B: Nancy Brooks, San Mateo Water-Users Association, San Mateo, written communication.

Chemical constiuents in parts per million.

LOCATION	FIELD NUMBER	SAMPLE DATE	DATA SOURCE	HCO_3	Cl	SO_4	NO_3	Na	K	Mg	Ca	TDS	SP. COND.	REMARKS
12.9.8.431	C1	7/25/56	SE-20	246	53	57	--	163		--	--	--	--	
		8-24-77	*	271	55	60	115	200	0.8	0.4	5.0	580	960	
12.10.1.222	C2	7-24-56	SE-20	34	9590	1350	--	5740		--	--	--	27,600	
12.10.12.221	A3	8/4/77	*	395	125	752	1.2	518	3.5	5.3	36	1780	2,600	
12.10.12.433	A4	2/75	EPA	--	56	--	14	--	--	--	--	2100	2,200	
12.10.13.424	A5	8/24/77	*	293	24	49	16	134	0.5	3.9	14	445	780	
12.10.12.212	A6	8/4/77	*	278	84	288	2.9	309	3.1	0.1	14	1030	1,540	
13.8.7.434	D1	10/20/75	R	---	38	78	0.1	--	--	--	--	659	--	
		3/10/78	*	386	19	90.5	0.0	89	4.6	17.8	4	494	960	
13.8.14.442	MF1	10/11/72	G	515	18.1	430	--	350	4.6	36	79	1445	2,123	
13.8.17.223	U	8/23/77	*	254	7.3	289	2.9	170	5.5	22	29	669	1,100	

Table 4, cont.

LOCATION	FIELD NUMBER	SAMPLE DATE	DATA SOURCE	HCO_3	Cl	SO_4	NO_3	Na	K	Mg	Ca	TDS	SP. COND.	REMARKS
13.8.18.400	U	3/10/78	*	258	6	145	0.35	104	4	6.3	43	438	680	Johnny M Mine
13.8.18.400	W(ma)	3/10/78	*	223	4	163	0	108	4.5	5.6	34	700	700	Johnny M Mine
13.8.22.242	MF2	10/18/72	G	217	4	8	--	60	1.3	2.1	6.1	323	332	
		8/23/77	*	207	4.9	22	0.8	76	1.5	1.7	7	240	360	
13.8.23.324	MF3	2/9/78	*	188	5	--	0.0	21	3.3	3.2	45	172	460	
13.8.23.431	MF5	10/17/72	G	198	8	9.5	--	20	3.4	6.4	42	358	315	
		2/11/78	*	188	0.14		0	20.1	3.3	6.1	40.0	169	310	
13.8.24.141	MF6	2/21/78	*	431	6	185	0.0	268	1.1	0.8	3.0	680	1,150	
13.8.24.141a	MF7	3/9/78	*	385	4	99	0.1	206	1.1	0.4	1.2	510	880	
13.8.24.223	MF8	9/10/62	SE-35	379	4.2	70	0.4	206	0.9	0.0	1.6	517	833	
		10/17/72	G	417	12	48	--	190	0.9	0.5	3.0	685	800	
13.8.24.234	W1	1974	G	280	10	265	0.8	240	2.0	0.5	4.0	650	900	
13.8.24.334	MF9	2/9/78	*	365	18	96	0.0	154	1.5	9.2	26.4	448	790	
13.8.24.334a	MF10	2/9/78	*	381	42	169	13	131	1.5	25	74	647	1,000	
13.8.24.334b	MF11	9/10/62	SE-35	370	14	102	8.3	179	1.7	3.4	14	516	814	
13.8.24.334c	MF12	2/21/78	*	401	32	316	5.3	249	1.6	22	44	870	1,400	
13.8.24		2/78	*	279	12	228	0.1	226	2.2	0.3	4.7	613	1,020	Gulf Discharge
13.8.25.114b	MF18	10/11/72	G	264	17	11	--	70	22	5.7	23	434	509	
13.8.26.211	MF19	10/72	G	639	8.0	8.3	--	235	2.0	2.7	10.2	928	954	
13.8.26.211a	MF20	7/76	B	375	10	71	1.4	74	3.1	27	54	460	729	
13.8.26.212	P2	9/11/62	SE-35	365	22	103	--	76	3.0	24	74	695	808	Community Well
13.8.26.212a		10/24/72	B	654	8.0	9.9	--	258	1.3	0.9	3.1	953	964	Community Well
13.8.26.222	MF21	2/21/78	*	244	8.0	37	0.65	27	5.4	9.5	55	265	450	
13.8.27.123	MF22	8/22/77	*	502	15	1.1	--	205	2.0	1.4	4.0	531	850	

Table 4, cont.

LOCATION	FIELD NUMBER	SAMPLE DATE	DATA SOURCE	HCO_3	Cl	SO_4	NO_3	Na	K	Mg	Ca	TDS	SP. COND.	REMARKS
13.8.30.100	W(mb)	4/63	SE-35	249	3.5	88	0.2	69	3.2	7.2	45	362	572	San Mateo Mine
13.8.200	D(ma)	4/63	SE-35	346	11	206	0.9	48	4.8	25	124	124	912	San Mateo Mine
13.8.33.234	P4	8/22/77	*	561	20	10	0.0	218	4.0	0.4	2.0	538	940	
13.9.5.141	A8	3/3/75	EPA	--	1300	--	1.3	--	--	--	--	6700	8,000	
13.9.5.214	A9	3/3/75	EPA	--	61	--	0.40	--	--	--	--	4800	5,000	
13.9.15.343	W2	2/13/58	SE-35	451	21	405	7.7	153		--	169	1010	1,430	
		2/26/75	EPA	--	34	--	4.4	--	--	--	--	1900	2,050	
13.9.16.411	W3	2/26/75	EPA	--	23	--	0.09	--	--	--	--	1900	3,250	
13.9.21.414	A10	3/1/75	EPA	--	43	--	24	--	--	--	--	2200	4,250	
13.9.22.111	W6	8/24/77	--	192	54	1188	47	230	9.2	91	285	2255	2,720	
13.9.22.121	W7	2/26/75	EPA	--	36	--	18	--	--	--	--	2200	2,150	
13.9.22.121	W8	2/26/75	EPA	--	40	--	4.7	--	--	--	--	2000	3,100	
13.9.22.212	A11	12/6/57	SE-35	292	20	189	12	159		9.5	37	592	917	
		3/1/75	EPA	--	27	--	1.2	--	--	--	--	660	1,300	
13.9.23.212	W9													
13.9.23.212	W9	3/75	EPA	--	4.8	--	0.06	--	--	--	--	720	1,300	
13.9.28.111	A14	8/5/77	*	59	46.3	565	0.6	186	10.2	46	40	950	1,480	
13.9.29.144	T1	2/28/58	SE-35	194	22	1130	25	324	3.2	9.7	264	1890	2,340	
13.9.32.112	A15	8/5/77	*	180	56	1420	47	261	7.3	69	352	2460	2,700	
14.8.4.334	DA1	10/16/62	SE-35	383	50	2880	14	691	13	200	420	4470	4,950	
14.8.15.244	MN1	10/1/62	SE-35	194	76	1940	5.8	1120	0.1	1.8	3.1	3340	4,610	
14.9.17.400	W(mc)	8/8/62	SE-35	275	8.8	230	0.1	172	6.0	6.2	29	606	926	K/M Mine
	D(mb)	8/8/62	SE-35	296	14	772	0.2	356	6.5	27	71	1410	1,980	K/M Mine
14.9.30.331	A16	3/3/75	EPA	--	100	--	2.0	--	--	--	--	3200	3,250	

Table 4, cont.

LOCATION	FIELD NUMBER	SAMPLE DATE	DATA SOURCE	HCO_3	Cl	SO_4	NO_3	Na	K	Mg	Ca	TDS	SP. COND.	REMARKS
14.9.30.341	A17	3/3/75	EPA	--	74	--	2.6	--	--	--	--	2600	3,200	
14.9.30.432	A18	2/27/75	EPA	--	31	--	1.3	--	--	--	--	4100	4,200	
14.9.31.421	A19	3/3/75	EPA	--	3400	--	0.25	--	--	--	--	8900	8,000	
14.9.31.442	--	3/3/75	EPA	--	3100	--	12	--	--	--	--	36,000	8,000	Seepage Return
14.9.32.114	A20	3/3/75	EPA	--	470	--	16	--	--	--	--	4700	5,750	
14.9.32.122	W22	2/14/58	SE-35	238	6.0	123	0.0	145	2.4	0.5	5.6	426	667	Homestake Mine
14.9.32.312	MN3	2/27/75	EPA	--	17	--	11	--	--	--	--	2700	3,100	
14.9.32.313	A21	2/27/75	EPA	--	3100	--	0.04	--	--	--	--	14,000	8,000	
14.9.32.314	W26	8/11/59	SE-35	220	8.0	218	0.0	114	7.6	12	46	512	796	
14.9.32.321	A22	2/27/75	EPA	--	3.8	--	--	--	--	--	--	7800	7,000	
14.9.32.322	A23	2/27/75	EPA	--	44	--	79	--	--	--	--	6300	6,000	
14.9.34.422	W28	4/24/63	SE-35	252	7.7	322	0.2	226	3.7	4.9	15	718	1,103	Sandstone Mine
14.9.36.313	D(mc)	5/6/53	SE-35	340	25	500	0.7	200	4.2	33	102	1050	1,490	Cliffside Mine
	W29	4/24/63	SE-35	209	8.7	536	0.3	252	5.2	13	53	945	1,360	Cliffside Mine
14.10.11.434	B1	10/18/60	SE-35	168	60	1360	1.1	700	3.6	3.9	26	2260	2,830	
14.10.25.132	W40	9/28/56	SE-35	306	11	306	--	--	--	--	--	721	1,090	
14.10.36.422	MN4	3/3/75	EPA	--	1700	--	8.0	--	--	--	--	9100	8,000	

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APPENDIX A

Piper-Diagram Data Reduction

The chemical character of 43 ground-water samples was plotted on Piper diagrams (Figures 10 and 11). To do this, the units of the ionic composition of the samples were converted from mg/1 to epm (equivalents per million), using the conversion factors given by Hem (1959). The data were then converted to percent milli-equivalents using a Fortran program developed by Scott Anderholm (research assistant, New Mexico Bureau of Mines and Mineral Resources, Socorro). The results of these conversions, which were plotted on the Piper diagrams, are shown in Table A-1. Samples are identified according to the field numbers used in Table 4 and on Plate 4.

DATA REDUCTION FOR PIPER DIAGRAM

WELL	CATION FIELD RAW DATA (EPM) CA	MG	NA + K	TOTAL-C	PERCENTAGES CA	MG	NA+K	ANION FIELD RAW DATA (EPM) CO3+HCO3	SO4	CL	TOTAL-A	PERCENTAGES CO3+HCO3	SO4	CL
A3	1.800	0.436	22.440	24.676	7.295	1.767	90.939	6.530	15.660	3.525	25.715	25.394	60.898	13.708
A5	0.699	0.321	5.787	6.807	10.269	4.716	85.015	4.844	1.020	0.677	6.541	74.056	15.594	10.350
A6	0.699	0.008	13.430	14.137	4.944	0.057	94.999	4.597	5.996	2.369	12.962	35.465	46.258	18.277
D1	0.200	1.464	4.027	5.691	3.514	25.725	70.761	6.382	1.884	0.536	8.802	72.506	21.404	6.090
MF1	3.942	2.960	15.260	22.162	17.787	13.356	68.857	8.515	8.953	0.510	17.978	47.363	49.800	2.837
W(MA)	1.700	0.460	4.841	7.001	24.282	6.570	69.147	3.687	3.394	0.113	7.194	51.251	47.178	1.571
MF2	0.304	0.173	2.638	3.115	9.759	5.554	84.687	3.588	0.167	0.113	3.868	92.761	4.317	2.921
MF3	2.245	0.263	1.046	3.554	63.168	7.400	29.432	3.108	0.305	0.141	3.554	87.451	8.582	3.967
MF4	3.243	0.079	1.601	4.923	65.874	1.605	32.521	4.696	0.453	0.226	5.375	87.367	8.428	4.205
MF5	2.096	0.526	1.007	3.629	57.757	14.494	27.749	3.274	0.198	0.226	3.698	88.534	5.354	6.111
MF6	0.150	0.066	11.579	11.795	1.272	0.560	98.169	7.126	3.852	0.169	11.147	63.928	34.556	1.516
MF7	0.060	0.033	8.911	9.004	0.666	0.367	98.967	6.366	2.061	0.113	8.540	74.543	24.133	1.323
MF8	0.150	0.041	8.218	8.409	1.784	0.488	97.729	6.895	0.999	0.338	8.232	83.759	12.136	4.106
W1	0.200	0.041	10.413	10.654	1.877	0.385	97.738	4.630	5.517	0.282	10.429	44.395	52.901	2.704
MF9	1.307	0.756	6.691	8.754	14.930	8.636	76.434	6.035	1.999	0.508	8.542	70.651	23.402	5.947
MF10	3.693	2.056	5.701	11.450	32.253	17.956	49.790	6.300	3.519	1.184	11.003	57.257	31.982	10.761
MF11	0.700	0.280	7.775	8.755	7.995	3.198	88.806	6.118	2.124	0.395	8.637	70.835	24.592	4.573
MF12	2.196	1.809	10.783	14.788	14.850	12.233	72.917	6.630	6.579	0.902	14.111	46.985	46.623	6.392
MF13	1.148	0.469	3.959	5.576	20.588	8.411	71.001	4.365	0.229	0.479	5.073	86.044	4.514	9.442

WELL	CATION FIELD							ANION FIELD						
	RAW DATA (EPM)				PERCENTAGES			RAW DATA (EPM)				PERCENTAGES		
	CA	MG	NA + K	TOTAL-C	CA	MG	NA+K	CO3+HCO3	SO4	CL	TOTAL-A	CO3+HCO3	SO4	CL
MF19	0.509	0.222	10.198	10.929	4.657	2.031	93.311	10.565	0.173	0.226	10.964	96.361	1.578	2.061
MF20	2.695	2.220	3.317	8.232	32.738	26.968	40.294	6.200	1.478	0.282	7.960	77.889	18.568	3.543
F2	0.155	0.074	11.157	11.386	1.361	0.650	97.989	10.813	0.206	0.226	11.245	96.158	1.832	2.010
MF21	2.744	0.781	1.394	4.919	55.781	15.877	28.339	4.034	0.770	0.226	5.030	80.199	15.308	4.493
MF22	0.200	0.115	8.907	9.222	2.169	1.247	96.584	8.300	0.023	0.423	8.746	94.901	0.263	4.836
W(MB)	2.245	0.592	3.107	5.944	37.769	9.960	52.271	4.117	1.832	0.099	6.048	68.072	30.291	1.637
D(MA)	6.188	2.056	2.272	10.516	58.844	19.551	21.605	5.721	4.289	0.310	10.320	55.436	41.560	3.004
F4	0.100	0.033	9.552	9.685	1.033	0.341	98.627	9.276	0.208	0.564	10.048	92.317	2.070	5.613
W2	8.433	1.480	6.583	16.496	51.121	8.972	39.907	7.457	8.432	0.592	16.481	45.246	51.162	3.592
W6	14.220	7.484	10.292	31.996	44.443	23.390	32.167	3.175	24.734	1.523	29.432	10.788	84.038	5.175
A11	1.846	0.781	6.842	9.469	19.495	8.248	72.257	4.828	3.935	0.564	9.327	51.764	42.189	6.047
A14	1.996	3.783	8.442	14.221	14.036	26.602	59.363	0.975	11.763	1.306	14.044	6.942	83.758	9.299
T1	13.174	0.798	14.079	28.051	46.964	2.845	50.191	3.208	23.527	0.620	27.355	11.727	86.006	2.266
A15	17.565	5.674	11.545	34.784	50.497	16.312	33.191	2.976	29.565	1.519	34.060	8.738	86.803	4.460
DA1	20.958	16.447	30.292	67.697	30.959	24.295	44.746	6.333	59.962	1.410	67.705	9.354	88.564	2.083
MP1	0.065	0.148	48.193	48.406	0.134	0.306	99.560	3.208	40.391	2.205	45.804	7.004	88.182	4.814
W(MC)	1.447	0.510	7.659	9.616	15.048	5.304	79.649	4.547	4.789	0.248	9.584	47.444	49.969	2.588
D(MB)	3.543	2.220	15.598	21.361	16.586	10.393	73.021	4.894	16.073	0.395	21.362	22.910	75.241	1.849
W22	0.279	0.041	6.342	6.662	4.188	0.615	95.197	3.935	2.561	0.169	6.665	59.040	38.425	2.536
W26	2.295	0.987	5.232	8.514	26.956	11.593	61.452	3.638	4.539	0.226	8.403	43.294	54.016	2.690
W28	0.748	0.403	9.884	11.035	6.778	3.652	89.570	4.167	6.704	0.217	11.088	37.581	60.462	1.957
D(MC)	5.090	2.714	8.787	16.591	30.679	16.358	52.962	5.622	10.410	0.705	16.737	33.590	62.198	4.212
W29	2.645	1.069	11.067	14.781	17.895	7.232	74.873	3.456	11.160	0.245	14.861	23.256	75.096	1.649
E1	1.297	0.321	30.275	31.893	4.067	1.006	94.927	2.778	28.316	1.692	32.786	8.473	86.366	5.161

APPENDIX B

Depth/Temperature Data

The variation of ground-water temperature was determined to assist in estimating ground-water quality (Figure 19). Table A-2 lists depth/temperature data, the locations of wells from which measurements were made, and the sources of the data. It has been assumed that the reported temperatures reflect conditions at the bottoms of the wells, and therefore that no significant amount of vertical mixing has occurred. A geothermal gradient of 1.76°F per 100 ft. (3.20°C per 100 m) was determined from the data by means of least-squares linear regression.

Table B-1 Depth/Temperature Data

Location	Depth(ft.)	Temperature(^{o}F)	Source*
Water wells:			
12.10.25.133	500	63	1
12.10.26.311	400	59	1
12.10.26.313	88	54	1
12.10.27.331	210	64	1
12.10.27.431	180	57	1
12.10.35.332	85	57	1
13.8.24.334b	200	56	2
13.8.26.221	336	57	2
13.9.15.343	260	58	2
13.9.16.411	250	55	1
13.9.21.414	145	57	1
13.9.22.212	130	57	1
13.9.23.212	280	61	1
14.8.4.334	215	54	2
14.8.15.244	1320	72	2
14.9.18.243	800	62	2
14.9.28.143	710	63	2
14.9.28.233	700	63	2
14.9.29.312	735	62	2
14.9.32.122	649	65	2
14.9.32.312	138	57	1
13.9.32.314	550	62	2
14.10.11.434	750	68	2
14.10.22.214	1004	70	2
14.10.25.132	766	64	2

Table B-1, cont.

Location	Depth(ft.)	Temperature(^{o}F)	Source*
Oil and test wells:			
NE-NE-NE, Sec.19, T14N,R7W	2730	100	3
NE-SE-NE, Sec.33, T14N,R7W	2982	105	4
NW-NW-SW, Sec.14, T14N,R8W	2300	93	5
	3050	114	
SE-SE-SE, Sec.28, T14N,R9W	3118	106	6
SW-SW-SW, Sec.11, T14N,R10W	2730	120	7
NE-NE-NE, Sec.14, T14N,R10W	2720	104	8
	3250	108	
	3350	111	

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*Sources

Water wells:

1. Kaufmann and others (1975)
2. Cooper and John (1967)

Oil and test wells:

3. Shar-Alan Fernandez #9
4. Shar-Alan Fernandez #10
5. Superior San Mateo Gov't #1-14
6. Phillips Sandstone Minerals #1
7. Dysart Community Lease #1
8. Dysart Federal #14-1

APPENDIX C

Measured Section Descriptions

Two stratigraphic sections were measured at outcrops in the study area. Each is a composite of descriptions made on exposures in a line down-dip, from the Triassic in the southwest part to the Upper Cretaceous in the northeast part. The following descriptions are presented in descending order. Field numbers are used to distinguish rock units and samples collected. Each unit is described as to general lithologic name (sandstone, siltstone, shale), nature of bedding and sedimentary structures, color, texture, general composition, nature of the lower contact, and general character of the exposure, respectively.

Sections were measured using a 1.6 meter Jacob's staff. Thicknesses are reported to nearest decimeter. Numbers in parentheses are the corresponding values in feet, given to the nearest half foot. Based on test measurements and the roughness of terrain, thicknesses are believed to be precise to within approximately 5 per cent and accurate to within approximately 10 per cent.

Lithology -- The term sandstone is applied to rock that is composed primarily of sand-sized particles. Siltstone refers to rock which is comprised primarily of silt-sized particles. The term mudstone is applied to rock which is not fissile and which consists of an indefinite mixture of fine-grained clastic material. Shale is considered to be a fissile rock which consists of an indefinite mixture of fine-grained clastic material. The modifiers "sandy " and "silty" are used when a rock contains a moderate to large amount of the material. "Carbonaceous" is used as a modifier when a unit contains a readily-notable amount of carbonaceous material.

Bedding -- Bedding size is described according to the definitions of McKee and Weir (1953), as modified by Ingram (1954):

Very thick beds	greater than 100 cm
Thick beds	30 to 100 cm
Medium beds	10 to 30 cm
Thin beds	3 to 10 cm
Very thin beds	1 to 3 cm

The uniformity of bedding is described according to the definitions of Dunbar and Rodgers (1963):

Regular - beds do not vary in thickness laterally

Irregular - beds do vary in thickness laterally

Even - beds in vertical succession similar in size

Uneven - vertically adjacent beds not similar in size

The internal structure of beds is described according to the terminology of Campbell (1967), who described laminae sizes as:

Very thick laminae	greater than 30 mm
Thick laminae	10 to 30 mm
Medium laminae	3 to 10 mm
Thin laminae	1 to 3 mm
Very thin laminae	less than 1 mm
Massive	no laminae distinguishable

Bedding-surface shape is described after Campbell (1967) as follows:

Planar, wavy, or curved

Each is further described as continuous or discontinuous and parallel or non-parallel.

Cross-bedding is described according to the following characteristics:

Magnitude (Jacob, 1973):

Small scale	less than 0.05 m
Large scale	0.05 to 5 m
Very large scale	greater than 5 m

Relation to lower bounding surface (Jacob, 1973):

Concordant, Tangential, or Discordant Dip (Jacob, 1973):

Low angle	2 to 15°
High angle	greater than 15°

Grouping (Allen, 1963):

- Solitary - sets bounded by other types of cross-strata or by strata that are not cross-stratified
- Grouped - set is in contact with sets of same type

General shape (modified from McKee and Weir, 1953):

- Planar
  - Tabular - sets bounded by parallel, planar surfaces
  - Wedge - sets bounded by converging, planar surfaces
- Non-Planar
  - Trough - sets bounded by curved surfaces

<u>Color</u> -- The colors of both fresh and weathered surfaces of the rock units are described and coded according to the Rock-Color Chart by Goddard and others (1951).

<u>Texture</u> -- Grain size is described according to the definitions of Wentworth (1922). The sizes were determined in the field by comparing samples to a Wentworth sand gauge. Sorting was estimated in the field according to the terminology of Folk (1965). Roundness was estimated using the roundness chart of Powers (1953).

<u>Composition</u> -- The mineralogical composition of rocks has been described when it could be determined. The amount of matrix and whether the rock is calcareous or non-calcareous is cited.

<u>Lower</u> <u>Contact</u> -- Contacts are described as abrupt or gradational. At abrupt contacts the lithologic character changes suddenly from one side of the contact to the other. Gradational contacts are those in which the lithology changes gradually from one unit to another. This may be due to interbedding of lithologies or gradual changes in grain size.

<u>General Outcrop Character</u> -- The outcrops have been described according to their resistance to erosion, that is, in terms of their occurrence as cliffs or slopes.

SECTION 1a, MESA MONTANOSA. Southwest face of Mesa Montañosa, four miles west of State Highway 53 on mine road; beginning SW 1/4, Section 23, T13N, R10W; ending on Flat Mesa, SE 1/4, Section 14, T13N, R10W; section measured July 27, 1977.

Unit	Lithology	Thickness, meters (feet)
DAKOTA SANDSTONE		
16	SANDSTONE: medium-laminated, regular, uneven, thin to thick beds with large-scale, discordant, high-angle, grouped, tabular-planar and small-scale tangential, low-angle, grouped, wedge-planar cross-bedding and wavy discontinuous, nonparallel; grayish orange (10 YR 7/4) and white (N 9) weathered and fresh; grains fine, very well sorted, subrounded, consisting of quartz; little silt and clay matrix; non-calcareous; lower contact abrupt; unit forms cliff.	15.4 (50)
MORRISON FORMATION, BRUSHY BASIN MEMBER		
15	COVERED SLOPE: shale, sandstone, and siltstone poorly exposed near top.	33.6 (110)
MORRISON FORMATION, WESTWATER CANYON MEMBER		
14	SANDSTONE: thinly-laminated, irregular, uneven, medium to thick beds with large-scale, tangential, low-and high-angle, grouped, trough and wedge-planar cross-bedding; bedding surfaces curved, discontinuous, nonparallel; moderate orange pink (10 R 7/4) weathered, pale-yellowish orange (10 YR 8/6) fresh; grains fine to medium, moderately sorted, subangular and subrounded,	15.4 (50)

	consisting mainly of quartz; much silt matrix; calcareous; includes pockets and wavy lenses of conglomerate and variegated mudstone, gravel up to 3.5 cm. diameter; lower contact abrupt; unit forms cliff.	
13	MUDSTONE AND SILTSTONE: very thick beds; mudstone light greenish gray (5 G 7/1) weathered; siltstone pale red (10 R 6/2) weathered; lower contact abrupt; unit forms slope.	9.0 (30)
12	SANDSTONE: thinly laminated, irregular, uneven, thin to thick beds with some large-scale, tangential, low- and high-angle, grouped and solitary, trough cross-bedding; bedding surfaces planar, continuous, parallel with some curved, discontinuous, nonparallel; moderate orange pink (10 R 7/4) and moderate reddish orange (10 R 6/6) weathered and fresh; grains coarse (some medium), well to moderately sorted, subrounded, consisting mainly of quartz; much silt matrix; noncalcareous; contains pockets of coarse sand which occur in the large, trough cross-beds; lower contact abrupt. Unit forms cliff.	12.2 (40)
11	SANDY SILTSTONE: siltstone as in 9; unit contains lense of sandstone, as in 10; unit forms uneven slope.	4.8 (16)

10 SANDSTONE: thinly laminated, irregular, uneven thin to thick beds with some small, tangential, low-angle, solitary, tabular planar cross-bedding; bedding surfaces curved, discontinuous, parallel and nonparallel; moderate orange pink (10 R 7/4) weathered and fresh; grains medium to coarse, well sorted, subangular, consisting mainly of quartz; much silt matrix; non-calcareous; lower contact abrupt; unit forms cliff. 5.4 (18)

MORRISON FORMATION, RECAPTURE MEMBER

9 SILTSTONE AND SANDSTONE: bedding obscure; siltstone pale red (10 R 6/2) weathered, contains very poorly sorted quartz sand, very calcareous; sandstone fine to coarse, consists of poorly sorted, subrounded, quartz, with much silt matrix, highly calcareous; lower contact abrupt; unit forms slope. 60.5 (198)

BLUFF SANDSTONE

8 SANDSTONE: thinly to medium laminated, regular, uneven, medium to thick beds with large, tangential, high-angle, grouped, tabular planar cross-bedding; bedding surfaces curved, continuous, parallel; grayish orange pink (10 R 8/2) and yellowish gray (5 Y 8/1) weathered and fresh; grains fine to medium, very well sorted, subangular, consisting of quartz; trace silt matrix; slightly calcareous; lower contact gradational, placed at lower-most highly cross-bedded whitish sand; unit forms cliff. 38.4 (126)

SUMMERVILLE FORMATION

7	COVERED SLOPE : small exposure 5 m from top: thinly laminated, irregular, uneven, medium to thick beds with large-scale, tangential, low-angle, grouped, tabular-planar and trough cross-bedding; bedding surfaces curved, discontinuous, nonplanar; grains fine, very well sorted, angular, consisting of quartz; slightly calcareous; lower contact of unit abrupt.	74.5 (244)

TODILTO LIMESTONE

6	LIMESTONE: lower half consists of massive, regular, uneven, very thin to thin beds of limestone, inter-bedded with thin beds of fissile argillaceous limestone; upper half consists of thinly laminated, regular, even, thin beds with curved and wavy, discontinuous, parallel bedding surfaces; yellowish gray (5 Y 8/1) weathered and fresh; top meter gypsiferous, dessicated; lower contact gradational; unit forms ledge.	6.2 (20)

ENTRADA SANDSTONE

5	SANDSTONE: thinly laminated regular, uneven, thin beds with wavy, discontinuous, nonparallel bedding surfaces; grayish pink (5 R 8/2) weathered and fresh; grains very fine to fine, well sorted, subangular to subrounded, consisting of quartz; much silt matrix; highly calcareous; lower contact gradational; unit forms uneven slope.	1.5 (5)
4	SANDSTONE: thinly laminated, irregular, uneven, medium to very thick beds with large-scale (some very large-scale), tangential, high-angle, grouped, trough	22.9 (75)

cross-bedding; bedding surfaces curved, continuous, parallel; moderate reddish orange (10 R 6/6) weathered and fresh; grains medium, well sorted, subrounded, consisting of quartz; little silt matrix; calcareous; lower contact gradational.

3 SILTY SANDSTONE: thinly laminated, irregular, uneven, medium beds with wavy, discontinuous, nonparallel, largely obscure surfaces; moderate reddish orange (10 R 6/6) weathered and fresh; grains very fine, well sorted, consisting of quartz; silt matrix; highly calcareous; unit forms cliff; lower contact gradational. 12.5 (41)

2 SANDSTONE: bedding and laminae obscure; light brown (5 YR 6/4) weathered and fresh; consists of fine to medium, well sorted, rounded, quartz grains; trace silt matrix; calcareous; unit capped by 2 m-thick resistant white layer in which thin laminae visible; lower contact gradational; unit forms uneven slope. 1.6 (5}

WINGATE SANDSTONE

1 SANDSTONE: thinly-to medium-laminated, regular, uneven, thick beds with large-scale, tangential, high-angle, grouped, trough cross-bedding; bedding surfaces curved, discontinuous, parallel; light brown (10 R 6/4) weathered and fresh; grains fine to medium, well sorted, rounded to subrounded, consisting of quartz; trace silt matrix; calcareous; lower contact covered; unit forms slope. 7.1 (22.5)

Total section thickness = 320.9 (1053)

SECTION lb, SAN MATEO MESA. Southwest face of San Mateo Mesa and associated Gallup bench; 3 miles northeast of the town of Ambrosia lake; begining SW 1/4, Section 16, TI4N, R9W, ending SW 1/4, Section 10, T14N, R9W; section measured July 28, 1977.

Unit	Lithology	Thickness, meters (feet)
POINT LOOKOUT SANDSTONE		
25	SANDSTONE: thinly to medium-laminated, regular, even, medium beds with large-scale, tangential, low-angle, grouped, tabular-planar cross-bedding; bedding surfaces curved, continuous, parallel; grayish orange (10 YR 7/4) weathered, yellowish gray (5 8/1) fresh; grains fine, moderately well sorted, subangular, consisting of quartz with black and red accessory minerals; silt and clay matrix; non-calcareous; lower contact abrupt; unit caps mesa, forms cliff.	58.1 (191)
24	CARBONACEOUS SHALE AND COAL: shale hard, bedding obscured; light brownish gray (5 yr 6/1) and black (N 1) weathered and fresh; one coal seam 0.5 dm. thick; iron stain and gypsum in partings; lower contact abrupt. Unit forms slope .	0.8 (3)
23	SANDSTONE: massive, irregular, uneven, thick beds; grayish orange (10 YR 7/4) weathered, very pale orange (10 YR 8/2) fresh; grains fine, well sorted, sub-rounded, consisting mainly of quartz,	2.3 (7)

trace coal; trace of silt and clay matrix; noncalcareous; lower contact abrupt; unit forms ledge.

22 INTERBEDDED SANDSTONE AND SHALE: sandstone massive, irregular, uneven, medium to thick beds with curved, discontinuous, nonparallel surfaces; as in 23; shale as in 24; discontinuously fossiliferous at base; lower contact gradational; unit forms uneven slope. 7.1 (23)

CREVASSE CANYON FORMATION, GIBSON COAL MEMBER

21 CARBONACEOUS SHALE: shale as in 24; lower 6.8 m. consists of interbedded sandstone and shale, sandstone as in 23; lower contact gradational; unit forms slope. 28.9 (95)

20 SANDSTONE: thinly laminated, irregular, uneven, medium beds with large tangential, high-angle, grouped, wedge planar (some tabular)planar cross-bedding; bedding surfaces curved, discontinuous, parallel; very pale orange (10 YR 8/2) weathered and fresh; grains fine, well sorted, angular, consisting of quartz; silt matrix; noncalcareous; a few molds and casts of large logs seen on underside of lower ledges; lower contact abrupt; unit forms cliff. 12.5 (41)

19 SANDSTONE; INTERBEDDED WITH SHALE: sandstone medium laminated, irregular, uneven, bedding 3.2 (10)

	surfaces curved, discontinuous, nonplanar; very pale orange (10 YR. 8/2) weathered and fresh; lithology as in 24; shale light bluish gray (5 B 7/1) weathered and fresh; iron stain in partings and fractures; unit forms irregular slope; lower contact abrupt; unit forms uneven slope.	
18	SANDSTONE: thinly laminated, irregular, uneven, thin beds with large discordant (some tangential), low-angle, grouped, wedge planar cross-bedding; very pale orange (10 YR 8/2) weathered and fresh; grains fine, well sorted, subangular, consisting of quartz and black (coal?) accessory minerals; much silt matrix; non-calcareous; friable; unit forms hard, uneven slope; lower contact abrupt; unit forms cliff.	2.9 (9}
17	CARBONACEOUS SHALE: shale as in 24; lower contact abrupt; unit forms slope.	3.6 (11.8)
16	SANDSTONE: thinly laminated, irregular, uneven, bedding surfaces wavy, discontinuous, nonparallel; grayish orange (10 YR 7/4) weathered, pale grayish orange (10 YR. 8/4) fresh; grains very fine, moderately well sorted, subangular, quartz, silt matrix; non-calcareous; lower contact abrupt.	1.8 (6)
15	CARBONACEOUS SHALE: shale as in 24; lower contact abrupt; unit forms slope.	4.2 (14)
14	SANDSTONE AND SILTSTONE: massive, irregular, uneven, thick beds with wavy, discontinuous, nonparallel	5.4 (18)

surfaces; white (N9) and grayish orange (10 YR 7/4) weathered and fresh; grains fine to silt, poorly sorted, subrounded, quartz, silt matrix, highly calcareous; lower contact abrupt; unit forms cliff.

13 CARBONACEOUS SHALE: shale as in 24; lower contact abrupt; unit forms slope. 25.0 (82)

CREVASSE CANYON FORMATION, DALTON SANDSTONE MEMBER

12 SANDSTONE: thinly laminated, regular, uneven, medium beds with large, tangential, low angle, grouped, tabular planar cross-bedding; bedding surfaces planar, continuous, parallel; grayish orange pink (10R 8/2) and grayish orange (10 YR 7/4) weathered, yellowish gray (5 Y 8/1) fresh; grains very fine, moderately well sorted, subangular, quartz; silt matrix; non-calcareous; lower contact abrupt; unit forms cliff. 14.4 (47)

11 SANDSTONE: thinly-to medium-laminated, regular, uneven, medium to very thick beds with planar, continuous, parallel surfaces; grayish orange (10 YR 7/4) weathered, yellowish gray (5 Y 8/1) fresh; grains as in 12; silt matrix; non-calcareous; iron concretions at bed interfaces, especially at base of unit; shale lense near base, 0.2m thick; lower contact abrupt; unit forms cliff. 8.8 (29)

MULATTO TONGUE, MANCOS SHALE

10 SHALE AND SILTSTONE, INTERLAMINATED: shale forms slope, laminae wavy, discontinuous, nonparallel, yellowish gray (5 Y 7/2) weathered; siltstone lenses 115.1 (378)

form ledges, consist of thin laminae, irregular, uneven, thin beds with wavy, discontinuous, nonparallel surfaces; pale brown (5 YR 5/2) weathered and fresh; lower contact abrupt; unit forms slope.

CREVASSE CANYON FORMATION, STRAY SANDSTONE MEMBER

9 SANDSTONE: medium laminated, irregular, uneven, 4.1 (13)

thick (some medium) beds with large-scale, tangential, low-angle, grouped, wedge planar cross-beds in the lower 2.0 m; bedding surfaces curved, discontinuous, nonparallel in lower half, parallel in upper half; grayish orange (10 YR 7/4) weathered, pale grayish yellow (5 10/4) medium, well sorted, sub-angular, consisting of quartz; trace silt matrix; calcareous; highly fossiliferous, including pockets of "fossil hash", some pockets highly burrowed and pocked; entire unit highly discontinuous, becoming as thin as 0.2m while intertonguing with overlying shale; lower contact abrupt, shows local relief of up to 0.3m; unit forms cliff.

CREVASSE CANYON FORMATION, DILCO SHALE MEMBER

8 CARBONACEOUS SHALE INTERBEDDED WITH SILTSTONE: 14.1 (46)

shale light brownish gray (5 YR 5/1) weathered, dark brownish gray (5 YR 3/1} fresh; unit becomes increasingly silty and resistant toward top, upper 2 m. consists of regular, medium beds of siltstone with wavy, discontinuous, nonparallel bedding surfaces, interbedded with shale; iron stain and little gypsum common in

	partings and fractures; lower contact covered.	
7	SANDSTONE: thinly-to medium-laminated, irregular, uneven, thin beds with planar, discontinuous, parallel surfaces; grayish orange (10 YR 7/4) weathered and fresh; grains very fine, poorly sorted, subrounded, consisting of quartz, little muscovite; silt matrix; noncalcareous; contains some plant fragments; unit is continuous; lower contact abrupt; unit forms ledge.	0.9 (3)
6	COVERED SLOPE.	11.3 (37)
GALLUP SANDSTONE		
5	SANDSTONE: thinly-to medium-laminated, irregular, uneven, alternating thin and thick beds with large-scale, tangential, low-angle, grouped, wedge planar cross-beds; bedding surfaces planar, continuous, parallel; white (N 9) weathered and fresh; grains fine, well-sorted, angular, consist of quartz, little muscovite, silt matrix, non-calcareous; lower contact abrupt; unit forms cliff and uneven slope.	19.2 (63)
4	SANDSTONE: thinly-to medium-laminated, irregular, uneven, thin beds with wavy, discontinuous, nonparallel surfaces; light brown (5 YR 6/4) weathered and fresh; grains fine, well-sorted, subrounded, consisting of quartz; silt matrix; non-calcareous; some laminae iron-rich and resistant; scattered burrows, horizontal and vertical; lower contact abrupt; unit forms cliff.	5.8 (19)
2	SANDSTONE: thinly-laminated, regular, even, alternating thin and medium beds with small-scale, tangen-	12.0 (39)

	tial, low angle, solitary, tabular-planar cross-bedding; bedding surfaces planar, continuous, parallel; light brown (5 YR 6/4) weathered and fresh; grains fine to very fine, well sorted, subangular, consisting of quartz, silt matrix; non-calcareous; small, irregular, horizontal iron concretions in some beds; a few laminae iron-rich; lower contact abrupt; unit forms cliff.	
2	SHALE: light olive gray (5 Y 6/1) and pale brown (5 YR 5/2); gypsum lag common, especially in upper part; lower contact abrupt; unit forms slope.	27.3 (90)
1	SANDSTONE: massive, irregular, even, medium beds with planar, discontinuous, parallel, surfaces; light brown (5 YR 6/4) weathered and fresh; grains very fine to fine; moderately well sorted, subrounded, consisting of quartz, trace muscovite; much silt matrix; non-calcareous; detrital organic fragments, including coal, throughout; lower contact abrupt.	8.6 (28)

Total section thickness = 397.4 (1304)

SECTION 2a, ROUNDY RANCH. Western end of La Jara Mesa, and associated Todilto bench; beginning 0.3 miles southeast of Roundy Ranch Headquarters, SE 1/4, Section 8, T12N, R9W, ending SE 1/4, Section 3, TI2N, R9W; Valencia County; section measured July 20, 1977.

Unit	Lithology	Thickness, meters (feet)
	DAKOTA SANDSTONE	
28	SANDSTONE: thinly laminated, irregular, uneven, thin to medium beds with small-scale, discordant (a few tangential), low-angle, solitary (alternating with flat beds), tabular-planar cross-bedding; bedding surfaces planar, continuous, parallel; very light gray (N 8) weathered and fresh; grains fine, very well sorted, subrounded, consisting of quartz and black accessory minerals; little silt and clay matrix; non-calcareous; lower contact abrupt; unit forms cliff.	3.4 (11)
27	SANDSTONE: thinly laminated, irregular, uneven, medium to thick beds with large-scale, discordant, high-angle, grouped, tabular planar cross-bedding; bedding surfaces planar, continuous, parallel; grayish orange (10 YR 7/4) weathered and fresh; lithology as in 28; a few molds and casts of plant debris throughout; lower contact abrupt; unit forms cliff.	1.1 (4}
26	SANDSTONE: thinly laminated, irregular, even, thin beds with wavy, discontinuous, nonparallel	2.2 (7)

and some planar, continuous, parallel bedding surfaces; grayish orange (10 YR 7/4) and white (N 9) weathered and fresh; lithogy as in 28; lower contact abrupt; unit forms cliff.

25 SANDSTONE: as in 27. 6.1 (20)

MORRISON FORMATION, BRUSHY BASIN MEMBER

24 COVERED SLOPE. 18.8 (62)

MORRISON FORMATION, WESTWATER CANYON MEMBER

23 SANDSTONE: thinly-laminated, irregular, uneven, medium beds with large-scale, tangential and discordant, low-angle, grouped, trough cross-bedding; bedding surfaces planar, discontinuous, nonparallel; grayish orange (10 YR 7/4) weathered, grayish orange (10 YR 7/4) mottled with grayish orange (10 Y 4/2) fresh; grains coarse to fine, fining upward, moderately well sorted, angular, consisting of quartz; clay matrix; slightly calcareous; spherical concretions, 1 cm. diameter, in upper meter; chert pebbles, up to 2 cm. long, in lower meter; lower contact abrupt; unit forms cliff. 4.0 (13)

22 SILTY, SANDY MUDSTONE: as in unit 20. lower contact abrupt; unit forms slope, mostly covered. 10.3 (34)

21 SANDSTONE: thinly to medium-laminated, irregular, uneven, thin to medium beds with large-scale, tangential, high-angle, grouped, 1.1 (4)

trough cross-bedding; bedding surfaces planar, curved, parallel; grayish orange (10 YR 7/4) weathered, moderate greenish yellow (10 Y 7/4) fresh; grains medium moderately poorly sorted, rounded, consisting of quartz with green and black accessory minerals; much silt matrix; calcareous; lower contact abrupt; unit forms ledge.

20 SILTY, SANDY MUDSTONE: bedding obscure; light greenish gray (5 G 7/1) weathered, greenish gray (5 GY 6/1) fresh; sand very fine, well sorted, subrounded, consisting of quartz with black and red accessory minerals; silt and clay matrix; non-calcareous; lower contact abrupt; unit forms slope, mostly covered. 3.8 (12)

19 SANDSTONE: thinly to medium-laminated, irregular, uneven, medium to thick beds with large-scale, discordant, low to high-angle, solitary (some grouped at top), wedge and tabular planar cross-bedding; bedding surfaces planar, discontinuous, nonparallel; grayish orange (10 YR 7/4) and light brown (5 YR 6/4) weathered, pale yellowish orange (10 YR 8/6) fresh; grains fine to medium, moderately sorted, subrounded, consisting of quartz; little silt matrix; calcareous; lower contact abrupt; unit forms cliff. 14.6 (48)

MORRISON FORMATION, RECAPTURE MEMBER

18 SILTY SANDSTONE, INTERBEDDED WITH SANDY SILTSTONE AND LITTLE SANDSTONE: lithology as in unit 16; lower contact gradational; unit forms slope. 9.4 (31)

17 SANDSTONE, INTERBEDDED WITH SILTY SANDSTONE AND SANDY SILTSTONE: lithology as in unit 16; lower contact gradational; unit forms ledge. 4.5 (15)

16 SANDY SILTSTONE, INTERBEDDED WITH SILTY SANDSTONE AND SANDSTONE: bedding obscure; sandy siltstone pale red (10 R 6/2) weathered, grayish red (5 R 4/2) fresh; silty sandstone light greenish gray (5 GY 7/1), grains very fine, well sorted, sub-rounded, consisting of quartz, silt matrix, calcareous; sandstone white (N 9), grains fine, well sorted, subrounded, consisting of quartz, silt matrix, highly calcareous; lower contact abrupt; unit forms slope. 9.6 (31)

15 SILTY SANDSTONE: bedding obscure; light greenish gray (5 GY 8/1) and grayish yellow (5 8/4) weathered and fresh; grains fine, moderately sorted, subrounded, consisting of quartz with red and black accessory minerals; silt matrix; non-calcareous; lower contact abrupt; unit forms slope. 4.8 (16)

BLUFF SANDSTONE

14 SANDSTONE: thinly laminated, irregular, even, very thick beds with large to very-large-scale, discordant, high-angle, grouped, tabular planar cross-bedding; bedding surfaces planar, continuous, parallel; grayish orange (10 YR 7/4) weathered, 6.4 (21)

pale yellowish orange (10 YR 8/6) and moderate yellow (5 Y 7/6) fresh; grains medium, moderately-well sorted, rounded, consisting of quartz and black accessory minerals; silt matrix; calcareous; lower contact gradational; unit forms cliff.

13 SANDSTONE: thinly to medium-laminated, irregular, 33.6 (110)
uneven, thin to medium beds with large-scale, tangential, high-angle, grouped, tabular-planar (some trough) cross-bedding; bedding surfaces planar, discontinuous, parallel; grayish orange (10 YR 7/4) weathered, pale yellowish orange (10 YR 8/6) fresh; grains fine, well sorted, subrounded, consisting of quartz and black accessory minerals; silt matrix; non-calcareous; lower contact abrupt; unit forms hard, uneven slope.

12 SANDSTONE: thinly to medium-laminated, regular, 33.6 (110)
even, thick beds with small-scale, tangential, low-angle, grouped, wedge-planar cross-bedding; bedding surfaces planar, discontinuous, nonparallel; grayish orange (10 YR 7/4) weathered, grayish yellow (5 Y 8/4) fresh; grains very fine to fine, well sorted, subangular to subrounded, consisting of quartz and black accessory minerals; some silt matrix; non-calcareous; lower contact gradational; unit forms cliff.

SUMMERVILLE FORMATION

11 SANDSTONE AND SILTSTONE: sandy siltstone and 25.6 (84)

	silty sandstone, as in unit 9, in beds 3 m thick, alternating with massive, regular beds of sandstone, 1 m thick; white (N 9) weathered and fresh; grains fine, very-well sorted, angular; little silt matrix; calcareous; sandstone beds more numerous towards top; lower contact gradational; unit forms uneven slope, becoming more resistant towards top.	
10	SANDSTONE: thinly to medium laminated, regular, thick beds with planar, continuous, parallel surfaces; grayish orange (10 R 8/2) fresh; grains fine, well sorted angular, consisting of quartz; little silt matrix; highly calcareous; lower contact abrupt; unit forms ledge.	0.8 (3)
9	SANDSTONE AND SILTSTONE: bedding not evident due to weathering; sandstone light greenish gray (5 GY 8/1), very fine, well sorted, rounded, consisting of quartz, silt matrix, calcareous; siltstone grayish red (10 R 4/2), contains little fine sand, hard, slightly calcareous; lower contact covered; unit forms uneven "badlands" slope.	16.7 (55)
8	SANDSTONE: laminations and bedding not evident; grayish orange pink (10 R 8/2) weathered and fresh; grains fine, moderately poorly sorted, angular, consisting of quartz and red and black accessory minerals; silt matrix; calcareous; lower contact covered; unit forms hard, uneven slope.	2.0 (7)
7	COVERED SLOPE.	10.4 (34)

TODILTO LIMESTONE		
6	LIMESTONE: thinly-laminated, irregular, uneven, thin beds with wavy, discontinuous, nonparallel surfaces in middle portion; yellowish gray (5 Y 8/1) weathered and fresh; silt laminae common in upper and lower meter, corresponding to wavy bedding surfaces; lower contact abrupt; unit caps cliffs.	4.2 (13)
ENTRADA SANDSTONE		
5	SILTY SANDSTONE: thinly-laminated, irregular, uneven, thin to medium beds with wavy, discontinuous, nonparallel surfaces; grayish pink (5 R 8/2) weathered and fresh; grains fine sand to silt, moderately sorted, rounded, consisting of quartz; much silt matrix; highly calcareous; lower contact gradational; unit forms uneven slope.	1.0 (3)
4	SANDSTONE: thinly-laminated, irregular, uneven, medium to very-thick beds with large-scale (some very-large-scale), tangential, high-angle, grouped, trough cross-bedding; bedding surfaces curved, continuous, parallel; moderate orange pink (10 R 7/4) weathered, moderate reddish orange (10 R 6/6) fresh; grains fine, well sorted, rounded, consisting of quartz and black accessory minerals; little silt matrix; highly calcareous; lower contact gradational; unit forms cliff.	37.1 (121)
ENTRADA SANDSTONE, SILTY MEMBER		
3	SILTY SANDSTONE: thin, largely-obscured laminae;	10.2 (33)

irregular, uneven, medium, largely-obscured beds with a few small (amplitude: 0.5 cm, wavelength: 2.0 cm) ripples seen in cross-section; bedding surfaces wavy, discontinuous, nonparallel, seen only in a few friable lenses; pale reddish brown (10 R 5/4) weathered and fresh; grains very fine sand, moderately-well sorted, angular and subangular, consisting of quartz and black accessory mineral; silt matrix; calcareous; lower contact abrupt; unit forms cliff.

WINGATE SANDSTONE

2 SANDSTONE: thinly-laminated, irregular, uneven, medium beds with large-scale, tangential, high-angle, grouped, tabular-planar and trough cross-bedding; bedding surfaces curved, discontinuous, nonparallel and planar, continuous, parallel; light brown (5 YR 6/4) weathered and fresh; grains fine to medium, well sorted, subrounded, consisting of quartz and black accessory minerals; silt matrix; highly calcareous; lower contact abrupt; unit forms, generally covered. 16.2 (53)

CHINLE FORMATION

1 INTERBEDDED CALCAREOUS SANDSTONE AND SHALE: Sandstone medium-laminated and massive, irregular, uneven, thin beds with wavy, discontinuous, non-parallel surfaces; white (N 9) weathered and fresh; grains very fine to very coarse, very 5.2 (17)

poorly sorted, well-rounded, consisting of quartz; silt matrix; extremely calcareous; contacts with shale abrupt; shale dark reddish brown (10 R 3/4) weathered and fresh; white sandstone appears to form dikes in shale with no apparent disruption of shale bedding, 0.2 to 2.0 dm, thick, most strike N60*W, some reach upper contact with no effect on overlying sandstone (Trw).

Total section thickness = 296.7 (973)

SECTION 2b, LEE RANCH. Western face of Jesus Mesa, and associated Gallup bench; 4 miles northwest of San Mateo; beginning NW 1/4, Sec. 20, T13N, R8W, ending NW 1/4, Sec. 15, T13N, R8W; Valencia and McKinley Counties; section July 26, 1977.

Unit	Lithology	Thickness meters (feet)
POINT LOOKOUT SANDSTONE		
16	SANDSTONE: thinly- to medium-laminated, irregular, uneven, medium to very thick beds with large-scale, tangential, low-angle, grouped, tabular planar cross-bedding; bedding surfaces planar, discontinuous parallel; grayish orange pink (10 R 8/2) and moderate orange pink (10 Y 7/4) weathered, yellowish gray (5 Y 8/1) fresh; grains fine, moderately sorted, angular to subangular, consisting of quartz with black accessory minerals; silt and clay matrix; non-calcareous; lower contact gradational; unit forms mesa-capping cliff.	29.1 (95)
CREVASSE CANYON FORMATION, GIBSON COAL MEMBER		
15	INTERBEDDED SILTSTONE, SHALE, AND COAL: siltstone and shale beds thick to very thick; siltstone bedding obscured very light gray (N 8) weathered, white (N 9) fresh; consists of quartz; shale medium gray (N 5) and brownish gray (5YR 4/1) weathered and fresh; coal	28.8 (94)

	lenses continuous, up to 0.3 m. thick; much gypsum filling small fractures, as lag on weathered slope, and in a continuous, 0.3 m. bed at upper contact of unit; lower contact abrupt; unit forms slope, mostly covered.	
14	SANDSTONE: thinly- to medium-laminated, irregular, uneven, thin to thick beds with large-scale, tangential, low-angle, solitary, wedge-planar cross-bedding; bedding surfaces curved, discontinuous, nonparallel; white (N 9) weathered and fresh; grains fine, moderately well sorted, angular, consisting of quartz and black accessory minerals (coal) much silt and clay matrix; calcareous; lower contact abrupt; unit forms cliff.	9.0 (29)
13	CARBONACEOUS SHALE: thin to medium laminated irregular, uneven; light gray (N 7), light brownish gray (5 YR 6/1) , and black (N 1); numerous carbonaceous plant fragments and molds in shale partings, with iron stain and gypsum; lower contact abrupt; unit forms slope.	8.5 (27)
12	SILTSTONE: thinly laminated, regular bed with planar, continuous, parallel surfaces; very light gray (N 8) weathered and fresh; grains silt, some fine sand, poorly sorted, subrounded, consisting of quartz; non-calcareous; lower contact abrupt; unit forms ledge.	0.6 (2)

11	INTERBEDDED SHALE AND SILTSTONE: shale as in 13. Siltstone as in 12, contains a few plant fragments; unit highly discontinuous, appears to be channel cut into underlying unit; gypsum fills fractures; lower contact abrupt; unit forms ledge.	2.0 (6)
10	CARBONACEOUS SHALE: shale as in 13; no gypsum observed; unit forms slope, largely covered.	12.8 (42)
9	SANDSTONE: thinly- to medium-laminated, irregular, uneven, thin beds with wavy, discontinuous, nonparallel surfaces; very light gray (N 8) weathered, white (N 9) fresh; grains very fine, poorly sorted, subrounded, consisting of quartz; much silt matrix, some clay; non-calcareous; lower contact abrupt.	1.6 (5)
8	CARBONACEOUS SHALE: shale as in 13; lower contact abrupt; unit forms slope.	4.6 (15)

CREVASSE CANYON FORMATION, DALTON SANDSTONE MEMBER

7	SILTY SANDSTONE: massive, irregular, uneven, medium to thick beds; grayish orange (10 YR 7/4) weathered, yellowish gray (5 Y 8/1) and dark yellowish orange (10 YR 6/6) fresh; grains very fine and silt-size, very poorly sorted, angular, consisting of quartz; silt and clay matrix;	10.9 (35)

	non-calcareous; gypsum fills fractures; scattered carbonaceous plant fragments through-out; lower contact abrupt. Unit forms cliff.	
6	SILTY SANDSTONE: thickly-laminated, regular very thick bed with planar, continuous, parallel surfaces; very light gray (N 8) weathered and fresh; grains very fine, poorly sorted angular, consisting of quartz and little detrital coal; matrix clay and much silt; non-calcareous; lower contact abrupt. Unit forms cliff.	1.8 (5)
5	SILTY SANDSTONE: massive, regular, uneven thick beds; grayish orange (10 YR 7/4) weathered, yellowish gray (5 Y 8/1) and dark yellowish orange (10 YR 6/6) fresh; grains very fine, very poorly sorted, angular, consisting of quartz; matrix clay and much silt; non-calcareous gypsum fills fractures; scattered carbonaceous plant fragments throughout; lower contact abrupt. Unit forms cliff.	3.9 (12)
4	SANDY SILTSTONE: massive, irregular, uneven thin beds; yellowish gray (5 Y 7/2) weathered, very light gray (N 8) and light brown (5 YR 5/6) fresh; grains very fine, poorly sorted, angular, consisting of quartz; matrix clay and much silt; non-calcareous; top 2 dm. hard, lower part friable; lower contact abrupt, unit forms cliff.	1.0 (3)

MANCOS SHALE, MULATTO TONGUE

3 SANDSTONE: thinly- to medium-laminated, regular, even, medium to thick beds with large-scale, tangential, low-angle (a few high-angle), grouped, wedge-planar cross-bedding; bedding surfaces planar, some curved, continuous, parallel; grayish orange (10 YR 7/4) weathered, very pale orange (10 YR 8/2) fresh; grains fine to medium, trace coarse, moderately sorted, subangular; silt and clay matrix; non-calcareous; concretions, up to 3 cm. diameter, near top of exposure; nonfossiliferous; lower contact abrupt, unit forms cliff. 14 (46)

2 COVERED SLOPE 24.0 (7)

GALLUP SANDSTONE

1 SANDSTONE: thinly-laminated and massive, highly irregular, uneven, thick beds with large-scale, tangential, low-angle, grouped, wedge planar cross-bedding; bedding surfaces curved, discontinuous, parallel; grayish orange (10 YR 7/4) weathered, grayish yellow (5 Y 8/4) fresh; grains very fine to fine, moderately sorted, angular, consisting of quartz; silt and clay matrix; non-calcareous; lower contact gradational; unit forms cliff. 23.8 (78)

Total section thickness = 176.4 (579)

APPENDIX D

Textural-Analyses Data

Particle-size analyses were conducted on nine sandstone samples and three unconsolidated sediment samples to determine grain-size distributions. Because, except for the Westwater Canyon Sandstone, only one sample was obtained from a lithologic unit, the distributions may only be considered to be crudely representative of the units. They should provide for the general comparison of textural characteristics, however. The geographic and stratigraphic locations of sampling points are shown in Plate 1.

Sub-samples weighing approximately 100 grams were disaggregated, dispersed, and dried. Silt and clay were removed by wet sieving with a 4.0 phi screen, dispersed again, and analyzed by hydrometer. The sand fraction of each sample was sieved using a 0.5 phi sieve set and then weighed.

The size-fraction data for each sample were entered into a Fortran program developed by the author (on file at the New Mexico Bureau of Mines and Mineral Resources) which calculates and prints the weight per cent and cumulative weight per cent for each fraction. A histogram, cumulative-per cent curve, and table of statistical data are shown, on two pages, for each sample. Statistical parameters are determined according to the methods of Folk (1968), using the percentile values of the cumulative distribution. The program is only capable of estimating the percentile values to the nearest half phi. Statistical values, thus, are only approximations.

```
       Qal a
                                                WEIGHT(PERCENT)

       0        10        20        30        40        50        60        70        80        90       100
       I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

0.00   .*

0.50   .*

1.00   .*O

1.50   .******O

2.00   .****************      O

2.50   .*******************                      O

3.00   .**********************                                         O

3.50   .****************                                                               O

4.00   .*******                                                                               O

5.00   .*                                                                                      O

6.00   .*                                                                                       O

7.00   .*                                                                                       O

8.00   .*                                                                                        O

9.00   .**********                                                                                         O
```

```
^L
 QAL A


  PHI        DIAMETER          WEIGHT   WEIGHT PERC   CUM PERC
               (MM)            (GRMS)

  0.00       1.000              0.05       0.08        0.08

  0.50       0.720              0.13       0.21        0.29

  1.00       0.500              0.89       1.42        1.71

  1.50       0.340              3.54       5.66        7.37

  2.00       0.250              9.84      15.73       23.10

  2.50       0.177             11.70      18.71       41.81

  3.00       0.125             13.63      21.79       63.60

  3.50       0.088             10.23      16.35       79.95

  4.00       0.627              4.10       6.55       86.51

  5.00       0.031              0.93       1.49       87.99

  6.00       0.016              0.39       0.62       88.62

  7.00       0.008              0.21       0.34       88.95

  8.00       0.004              0.38       0.61       89.56

^L  9.00     0.002              6.53      10.44      100.00
  QAL  A
```

```
^L
 QAL A

  STATISTICS


     CALCULATED PERCENTILES

         CUMULATIVE         PHI
          PERCENT           VALUE


             5.              1.000

            16.              1.500

            25.              2.000

            50.              2.500

            75.              3.000

            84.              3.500

            95.              8.000


     STATISTICAL PARAMETERS

             MEDIAN =  2.500

             GRAPHIC MEAN =   2.500

             QUARTILE DEVIATION =   0.500

             GRAPHIC STANDARD DEVIATION =   1.000

             INCLUSIVE STANDARD DEVIATION =   1.561

             GRAPHIC SKEWNESS =   0.000

             INCLUSIVE GRAPHIC SKEWNESS =   0.286

             GRAPHIC KURTOSIS = 2.869
```

Qal b

```
                                                  WEIGHT(PERCENT)

        0        10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

 -3.00  .O*O

 -2.50  .*  O

 -2.00  .*   O

 -1.50  .*     O

 -1.00  .**     O

 -0.50  .**       O

  0.00  .***         O

  0.50  .****            O

  1.00  .******                O

  1.50  .*********                      O

  2.00  .***************                               O

  2.50  .***************                                              O

  3.00  .**************                                                             O

  3.50  .***********                                                                           O

  4.00  .*******                                                                                      O


  5.00  .*                                                                                             O


  6.00  .*                                                                                             O


  7.00  .*                                                                                             O


  8.00  .*                                                                                             O


  9.00  .*****                                                                                              O
```

```
QAL B


  PHI        DIAMETER           WEIGHT   WEIGHT PERC   CUM PERC
               (MM)             (GRMS)

 -3.00       8.000               2.10       2.76         2.76

 -2.50       5.670               0.90       1.18         3.95

 -2.00       4.000               1.06       1.40         5.34

 -1.50       2.830               0.91       1.20         6.54

 -1.00       2.000               1.14       1.50         8.04

 -0.50       1.420               1.51       1.99        10.03

  0.00       1.000               2.21       2.91        12.94

  0.50       0.720               3.24       4.27        17.21

  1.00       0.500               4.50       5.92        23.13

  1.50       0.340               6.65       8.75        31.89

  2.00       0.250              11.45      15.07        46.96

  2.50       0.177              11.73      15.44        62.40

  3.00       0.125              10.65      14.02        76.42

  3.50       0.088               8.11      10.68        87.10

  4.00       0.627               5.29       6.96        94.06

  5.00       0.031               0.45       0.59        94.66

  6.00       0.016               0.20       0.26        94.92

  7.00       0.008               0.12       0.16        95.08

  8.00       0.004               0.13       0.17        95.25

¬L  9.00     0.002               3.61       4.75       100.00
 QAL B
```

```
¬L
 QAL B

  STATISTICS


      CALCULATED PERCENTILES

          CUMULATIVE         PHI
           PERCENT           VALUE


              5.            -2.500

             16.             0.000

             25.             1.000

             50.             2.000

             75.             2.500

             84.             3.000

             95.             6.000


      STATISTICAL PARAMETERS


              MEDIAN =  2.000

              GRAPHIC MEAN =   1.667

              QUARTILE DEVIATION =   0.750

              GRAPHIC STANDARD DEVIATION =   1.500

              INCLUSIVE STANDARD DEVIATION =   2.038

              GRAPHIC SKEWNESS =  -0.333

              INCLUSIVE GRAPHIC SKEWNESS =  -0.196

              GRAPHIC KURTOSIS = 2.322
```

Qal c

```
                                                 WEIGHT(PERCENT)

        0        10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

0.00    .

0.50    .*

1.00    .O

1.50    .*O

2.00    .************ O

2.50    .*****************************              O

3.00    .*************************************                                          O

3.50    .***********                                                                                O

4.00    .***                                                                                          O

5.00    .*                                                                                             O

6.00    .*                                                                                             O

7.00    .*                                                                                             O

8.00    .*                                                                                            O

9.00    .*****                                                                                             O
```

```
QAL C


 PHI          DIAMETER          WEIGHT    WEIGHT PERC    CUM PERC
                (MM)            (GRMS)

 0.00          1.000             0.00        0.00          0.00

 0.50          0.720             0.06        0.11          0.11

 1.00          0.500             0.37        0.65          0.76

 1.50          0.340             0.64        1.13          1.89

 2.00          0.250             7.07       12.47         14.36

 2.50          0.177            16.59       29.26         43.62

 3.00          0.125            20.82       36.72         80.34

 3.50          0.088             6.45       11.38         91.71

 4.00          0.627             1.51        2.66         94.37

 5.00          0.031             0.16        0.28         94.66

 6.00          0.016             0.03        0.05         94.71

 7.00          0.008             0.21        0.37         95.08

 8.00          0.004             0.06        0.11         95.19

^L 9.00        0.002             2.73        4.81        100.00
 QAL C
```

```
^L
 QAL C

  STATISTICS


      CALCULATED PERCENTILES

          CUMULATIVE            PHI
           PERCENT             VALUE


              5.              1.500

             16.              2.000

             25.              2.000

             50.              2.500

             75.              2.500

             84.              3.000

             95.              6.000


      STATISTICAL PARAMETERS

              MEDIAN =  2.500

              GRAPHIC MEAN =   2.500

              QUARTILE DEVIATION =   0.250

              GRAPHIC STANDARD DEVIATION =   0.500

              INCLUSIVE STANDARD DEVIATION =   0.932

              GRAPHIC SKEWNESS =   0.000

              INCLUSIVE GRAPHIC SKEWNESS =   0.278

              GRAPHIC KURTOSIS = 3.689
```

Kcda

```
                                                  WEIGHT(PERCENT)

        0        10        20        30        40        50        60        70        80        90         100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

-0.50   .*

 0.00   .*

 0.50   .*

 1.00   .*

 1.50   .*

 2.00   .*O

 2.50   .*********** O

 3.00   .*****************************************************           O

 3.50   .*********************                                                                 O

 4.00   .***                                                                                     O

 5.00   .*                                                                                        O

 6.00   .*                                                                                         O

 7.00   .*                                                                                         O

 8.00   .*                                                                                          O

 9.00   .********                                                                                           O
```

```
KCDA


  PHI       DIAMETER        WEIGHT   WEIGHT PERC   CUM PERC
              (MM)          (GRMS)

 -0.50        1.420          0.01        0.02        0.02

  0.00        1.000          0.01        0.02        0.03

  0.50        0.720          0.01        0.02        0.05

  1.00        0.500          0.07        0.12        0.17

  1.50        0.340          0.18        0.30        0.46

  2.00        0.250          1.00        1.65        2.11

  2.50        0.177          6.46       10.67       12.79

  3.00        0.125         31.82       52.57       65.36

  3.50        0.088         12.84       21.21       86.57

  4.00        0.627          1.67        2.76       89.33

  5.00        0.031          0.59        0.97       90.30

  6.00        0.016          0.33        0.55       90.85

  7.00        0.008          0.30        0.50       91.34

  8.00        0.004          0.63        1.04       92.38

⌐L  9.00      0.002          4.61        7.62      100.00
 KCDA
```

```
⌐L
 KCDA

  STATISTICS


     CALCULATED PERCENTILES

         CUMULATIVE          PHI
          PERCENT           VALUE


             5.             2.000

            16.             2.500

            25.             2.500

            50.             2.500

            75.             3.000

            84.             3.000

            95.             8.000


     STATISTICAL PARAMETERS

               MEDIAN =  2.500

               GRAPHIC MEAN =   2.667

               QUARTILE DEVIATION =   0.250

               GRAPHIC STANDARD DEVIATION =   0.250

               INCLUSIVE STANDARD DEVIATION =   1.034

               GRAPHIC SKEWNESS =   1.000

               INCLUSIVE GRAPHIC SKEWNESS =   0.917

               GRAPHIC KURTOSIS = 4.918
```

Kmm ss

```
                                                   WEIGHT(PERCENT)

         0        10        20        30        40        50        60        70        80        90        100
         I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

-0.50    .
 0.00    .
 0.50    .*
 1.00    .*
 1.50    .O
 2.00    .*O
 2.50    .*******  O
 3.00    .*****************************************        O
 3.50    .*******************************                                                 O
 4.00    .****                                                                                O

 5.00    .*                                                                                    O

 6.00    .*                                                                                     O

 7.00    .**                                                                                      O

 8.00    .**                                                                                       O

 9.00    .**********                                                                                         O
```

```
KMM SS

PHI        DIAMETER        WEIGHT   WEIGHT PERC   CUM PERC
             (MM)          (GRMS)

-0.50       1.420           0.00       0.00         0.00

 0.00       1.000           0.00       0.00         0.00

 0.50       0.720           0.03       0.05         0.05

 1.00       0.500           0.08       0.13         0.17

 1.50       0.340           0.25       0.39         0.56

 2.00       0.250           1.14       1.79         2.35

 2.50       0.177           4.62       7.24         9.59

 3.00       0.125          26.04      40.81        50.40

 3.50       0.088          19.63      30.76        81.16

 4.00       0.627           2.42       3.79        84.96

 5.00       0.031           0.66       1.03        85.99

 6.00       0.016           0.54       0.85        86.84

 7.00       0.008           1.08       1.69        88.53

 8.00       0.004           1.02       1.60        90.13

L 9.00      0.002           6.30       9.87       100.00
KMM SS
```

```
KMM SS

 STATISTICS


     CALCULATED PERCENTILES

          CUMULATIVE          PHI
           PERCENT           VALUE


              5.              2.000

             16.              2.500

             25.              2.500

             50.              2.500

             75.              3.000

             84.              3.500

             95.              8.000


     STATISTICAL PARAMETERS


             MEDIAN =  2.500

             GRAPHIC MEAN =   2.833

             QUARTILE DEVIATION =   0.250

             GRAPHIC STANDARD DEVIATION =   0.500

             INCLUSIVE STANDARD DEVIATION =   1.159

             GRAPHIC SKEWNESS =   1.000

             INCLUSIVE GRAPHIC SKEWNESS =   0.917

             GRAPHIC KURTOSIS = 4.918
```

Kd

```
                                                 WEIGHT(PERCENT)

       0        10        20        30        40        50        60        70        80        90         100
       I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

0.00   .

0.50   .

1.00   .*

1.50   .*O

2.00   .**** O

2.50   .**********      O

3.00   .***************************************               O

3.50   .***********************                                                      O

4.00   .********                                                                             O

5.00   .******                                                                                     O

6.00   .***                                                                                           O

7.00   .*                                                                                              O

8.00   .*                                                                                               O

9.00   .***                                                                                                O
```

```
KD

 PHI        DIAMETER        WEIGHT   WEIGHT PERC   CUM PERC
              (MM)          (GRMS)

 0.00       1.000            0.00       0.00         0.00

 0.50       0.720            0.00       0.00         0.00

 1.00       0.500            0.06       0.05         0.05

 1.50       0.340            2.27       2.04         2.09

 2.00       0.250            4.58       4.11         6.20

 2.50       0.177           11.50      10.32        16.52

 3.00       0.125           43.15      38.71        55.23

 3.50       0.088           25.40      22.79        78.01

 4.00       0.627            8.86       7.95        85.96

 5.00       0.031            7.17       6.43        92.39

 6.00       0.016            3.40       3.05        95.44

 7.00       0.008            0.50       0.45        95.89

 8.00       0.004            1.02       0.92        96.81

¬L 9.00     0.002            3.56       3.19       100.00
 KD
```

```
¬L
 KD
  STATISTICS


      CALCULATED PERCENTILES
          CUMULATIVE        PHI
           PERCENT         VALUE


             5.            1.500

            16.            2.000

            25.            2.500

            50.            2.500

            75.            3.000

            84.            3.500

            95.            5.000


      STATISTICAL PARAMETERS

              MEDIAN =  2.500

              GRAPHIC MEAN =   2.667

              QUARTILE DEVIATION =   0.250

              GRAPHIC STANDARD DEVIATION =   0.750

              INCLUSIVE STANDARD DEVIATION =   0.905

              GRAPHIC SKEWNESS =   0.333

              INCLUSIVE GRAPHIC SKEWNESS =   0.381

              GRAPHIC KURTOSIS = 2.869
```

Jmw

```
                                                  WEIGHT(PERCENT)

        0        10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

-0.50   .0

 0.00   .***0

 0.50   .***********   0

 1.00   .***********************              0

 1.50   .************************                                     0

 2.00   .*********************                                                             0

 2.50   .********                                                                                  0

 3.00   .****                                                                                          0

 3.50   .**                                                                                              0

 4.00   .*                                                                                                0


 5.00   .*                                                                                                0


 6.00   .*                                                                                                0


 7.00   .*                                                                                                0


 8.00   .*                                                                                                0


 9.00   .**                                                                                                 0
```

```
JMW


  PHI         DIAMETER          WEIGHT   WEIGHT PERC   CUM PERC
                (MM)            (GRMS)


 -0.50          1.420             1.36         0.80         0.80

  0.00          1.000             5.77         3.41         4.22

  0.50          0.720            19.02        11.25        15.47

  1.00          0.500            38.62        22.84        38.31

  1.50          0.340            40.47        23.94        62.25

  2.00          0.250            34.83        20.60        82.85

  2.50          0.177            13.56         8.02        90.87

  3.00          0.125             6.85         4.05        94.92

  3.50          0.088             3.00         1.77        96.70

  4.00          0.627             1.66         0.98        97.68

  5.00          0.031             0.12         0.07        97.75

  6.00          0.016             0.09         0.05        97.81

  7.00          0.008             0.13         0.08        97.88

  8.00          0.004             0.07         0.04        97.92

^L  9.00        0.002             3.51         2.08       100.00
  JMW
```

```
^L
 JMW

 STATISTICS


    CALCULATED PERCENTILES

        CUMULATIVE          PHI
         PERCENT           VALUE


            5.             0.000

           16.             0.500

           25.             0.500

           50.             1.000

           75.             1.500

           84.             2.000

           95.             3.000


    STATISTICAL PARAMETERS

            MEDIAN =  1.000

            GRAPHIC MEAN =   1.167

            QUARTILE DEVIATION =   0.500

            GRAPHIC STANDARD DEVIATION =   0.750

            INCLUSIVE STANDARD DEVIATION =   0.830

            GRAPHIC SKEWNESS =   0.333

            INCLUSIVE GRAPHIC SKEWNESS =   0.333

            GRAPHIC KURTOSIS = 1.230
```

Jmw

```
                                                 WEIGHT(PERCENT)

        0        10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

-3.00   .*0

-2.50   .****  0

-2.00   .******     0

-1.50   .*************            0

-1.00   .********************                        0

-0.50   .*************************                                            0

 0.00   .**************                                                                     0

 0.50   .*****                                                                                   0

 1.00   .***                                                                                        0

 1.50   .*                                                                                           0

 2.00   .*                                                                                            0

 2.50   .*                                                                                              0

 3.00   .**                                                                                             0

 3.50   .*                                                                                                 0

 4.00   .*                                                                                                 0

 5.00   .*                                                                                                 0

 6.00   .*                                                                                                 0

 7.00   .*                                                                                                 0

 8.00   .*                                                                                                 0

 9.00   .*                                                                                                  0
```

```
JMW

   PHI        DIAMETER          WEIGHT   WEIGHT PERC   CUM PERC
                (MM)            (GRMS)

  -3.00        8.000             3.52        2.27         2.27

  -2.50        5.670             6.72        4.32         6.59

  -2.00        4.000             9.08        5.84        12.43

  -1.50        2.830            20.76       13.36        25.79

  -1.00        2.000            30.35       19.53        45.32

  -0.50        1.420            38.27       24.63        69.95

   0.00        1.000            21.61       13.91        83.85

   0.50        0.720             8.08        5.20        89.05

   1.00        0.500             3.95        2.54        91.60

   1.50        0.340             2.22        1.43        93.02

   2.00        0.250             2.05        1.32        94.34

   2.50        0.177             2.15        1.38        95.73

   3.00        0.125             2.68        1.72        97.45

   3.50        0.088             1.66        1.07        98.52

   4.00        0.627             0.81        0.52        99.04

   5.00        0.031             0.02        0.01        99.05

   6.00        0.016             0.02        0.01        99.07

   7.00        0.008             0.09        0.06        99.12

   8.00        0.004             0.07        0.05        99.17

^L 9.00        0.002             1.29        0.83       100.00
 JMW
```

```
^L
 JMW
  STATISTICS


      CALCULATED PERCENTILES
          CUMULATIVE         PHI
           PERCENT           VALUE


              5.            -3.000

             16.            -2.000

             25.            -2.000

             50.            -1.000

             75.            -0.500

             84.             0.000

             95.             2.000


      STATISTICAL PARAMETERS


              MEDIAN = -1.000

              GRAPHIC MEAN =  -1.000

              QUARTILE DEVIATION =   0.750

              GRAPHIC STANDARD DEVIATION =   1.000

              INCLUSIVE STANDARD DEVIATION =   1.258

              GRAPHIC SKEWNESS =   0.000

              INCLUSIVE GRAPHIC SKEWNESS =   0.100

              GRAPHIC KURTOSIS = 1.366
```

Jb

```
                                                     WEIGHT(PERCENT)

           0        10        20        30        40        50        60        70        80        90        100
           I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

   -0.50   .
    0.00   .*
    0.50   .*
    1.00   .*
    1.50   .O*O
    2.00   .****************************** O
    2.50   .*************************                               O
    3.00   .*************************                                                        O
    3.50   .*********                                                                                 O
    4.00   .*                                                                                          O
    5.00   .*                                                                                           O
    6.00   .*                                                                                           O
    7.00   .*                                                                                           O
    8.00   .*                                                                                           O
    9.00   .*******                                                                                            O
```

```
JB


 PHI        DIAMETER        WEIGHT   WEIGHT PERC   CUM PERC
              (MM)          (GRMS)


-0.50        1.420           0.00       0.00         0.00

 0.00        1.000           0.01       0.02         0.02

 0.50        0.720           0.01       0.02         0.03

 1.00        0.500           0.12       0.20         0.24

 1.50        0.340           1.67       2.82         3.05

 2.00        0.250          17.12      28.87        31.92

 2.50        0.177          15.02      25.33        57.25

 3.00        0.125          14.87.     25.08        82.33

 3.50        0.088           5.18       8.74        91.06

 4.00        0.627           0.75       1.26        92.33

 5.00        0.031           0.16       0.27        92.60

 6.00        0.016           0.03       0.05        92.65

 7.00        0.008           0.13       0.22        92.87

 8.00        0.004           0.07       0.12        92.98

^L 9.00      0.002           4.16       7.02       100.00
 JB
```

```
^L
 JB

 STATISTICS


     CALCULATED PERCENTILES

         CUMULATIVE         PHI
          PERCENT          VALUE


            5.             1.500

           16.             1.500

           25.             1.500

           50.             2.000

           75.             2.500

           84.             3.000

           95.             8.000


     STATISTICAL PARAMETERS.


             MEDIAN =  2.000

             GRAPHIC MEAN =   2.167

             QUARTILE DEVIATION =   0.500

             GRAPHIC STANDARD DEVIATION =   0.750

             INCLUSIVE STANDARD DEVIATION =   1.360

             GRAPHIC SKEWNESS =   0.333

             INCLUSIVE GRAPHIC SKEWNESS =   0.590

             GRAPHIC KURTOSIS = 2.664
```

Jeu

```
                                                  WEIGHT(PERCENT)

        0        10        20        30        40        50        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

-0.50   .

 0.00   .

 0.50   .*

 1.00   .*

 1.50   .0

 2.00   .**********0

 2.50   .********************          0

 3.00   .*******************************************                              0

 3.50   .*************                                                                         0

 4.00   .***                                                                                      0

 5.00   .*                                                                                        0

 6.00   .*                                                                                        0

 7.00   .*                                                                                         0

 8.00   .*                                                                                          0

 9.00   .********                                                                                           0
```

```
JEU


 PHI        DIAMETER        WEIGHT   WEIGHT PERC  CUM PERC
              (MM)          (GRMS)

-0.50        1.420           0.00       0.00        0.00

 0.00        1.000           0.00       0.00        0.00

 0.50        0.720           0.03       0.05        0.05

 1.00        0.500           0.06       0.10        0.15

 1.50        0.340           0.68       1.12        1.27

 2.00        0.250           6.02       9.89       11.16

 2.50        0.177          11.96      19.66       30.82

 3.00        0.125          26.06      42.83       73.65

 3.50        0.088           8.05      13.23       86.88

 4.00        0.627           1.90       3.12       90.01

 5.00        0.031           0.17       0.28       90.29

 6.00        0.016           0.04       0.07       90.35

 7.00        0.008           0.21       0.35       90.70

 8.00        0.004           0.50       0.82       91.52

^L 9.00      0.002           5.16       8.48      100.00
 JEU
```

```
^L
 JEU

 STATISTICS


     CALCULATED PERCENTILES

         CUMULATIVE         PHI
          PERCENT          VALUE


             5.            1.500

            16.            2.000

            25.            2.000

            50.            2.500

            75.            3.000

            84.            3.000

            95.            8.000


     STATISTICAL PARAMETERS


             MEDIAN =  2.500

             GRAPHIC MEAN =   2.500

             QUARTILE DEVIATION =   0.500

             GRAPHIC STANDARD DEVIATION =   0.500

             INCLUSIVE STANDARD DEVIATION =   1.235

             GRAPHIC SKEWNESS =   0.000

             INCLUSIVE GRAPHIC SKEWNESS =   0.346

             GRAPHIC KURTOSIS = 2.664
```

```
 JEM
                                                 WEIGHT(PERCENT)
        0       10        20        30        40        50'        60        70        80        90        100
        I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

1.00    .
1.50    .*
2.00    .0
2.50    .0
3.00    .***0
3.50    .********    0
4.00    .********************************************           0
5.00    .***************                                                        0
6.00    .******                                                                       0
7.00    .***                                                                             0
8.00    .***                                                                                0
9.00    .****************                                                                                   0
```

```
JEM

 PHI        DIAMETER        WEIGHT   WEIGHT PERC   CUM PERC
              (MM)          (GRMS)

 1.00        0.500           0.00       0.00          0.00

 1.50        0.340           0.26       0.32          0.32

 2.00        0.250           0.33       0.40          0.72

 2.50        0.177           0.35       0.43          1.15

 3.00        0.125           2.64       3.24          4.39

 3.50        0.088           6.91       8.48         12.87

 4.00        0.627          35.50      43.56         56.44

 5.00        0.031          12.60      15.46         71.90

 6.00        0.016           4.90       6.01         77.91

 7.00        0.008           2.70       3.31         81.22

 8.00        0.004           2.10       2.58         83.80

 9.00        0.002          13.20      16.20        100.00
```

```
JEM
 STATISTICS


     CALCULATED PERCENTILES
         CUMULATIVE         PHI
          PERCENT          VALUE


             5.            3.000

            16.            3.500

            25.            3.500

            50.            3.500

            75.            5.000

            84.            8.000

            95.            8.000


     STATISTICAL PARAMETERS

             MEDIAN =  3.500

             GRAPHIC MEAN =   5.000

             QUARTILE DEVIATION =   0.750

             GRAPHIC STANDARD DEVIATION =   2.250

             INCLUSIVE STANDARD DEVIATION =   1.883

             GRAPHIC SKEWNESS =   1.000

             INCLUSIVE GRAPHIC SKEWNESS =   0.900

             GRAPHIC KURTOSIS = 1.366
```

Trw

```
                                                 WEIGHT(PERCENT)

       0        10        20        30        40        50'        60        70        80        90        100
       I.........I.........I.........I.........I.........I.........I.........I.........I.........I.........I

0.50   .

1.00   .*

1.50   .******0

2.00   .******************************************************************      0

2.50   .*************                                                                        0

3.00   .*****                                                                                     0

3.50   .**                                                                                         0

4.00   .*                                                                                           0

5.00   .*                                                                                           0

6.00   .*                                                                                           0

7.00   .*                                                                                            0

8.00   .*                                                                                            0

9.00   .******                                                                                            0
```

```
TRW


  PHI        DIAMETER          WEIGHT   WEIGHT PERC   CUM PERC
               (MM)            (GRMS)


  0.50        0.720             0.00       0.00          0.00

  1.00        0.500             0.20       0.34          0.34

  1.50        0.340             4.03       6.84          7.18

  2.00        0.250            38.59      65.51         72.69

  2.50        0.177             7.63      12.95         85.64

  3.00        0.125             2.94       4.99         90.63

  3.50        0.088             0.98       1.66         92.29

  4.00        0.627             0.58       0.98         93.28

  5.00        0.031             0.03       0.05         93.33

  6.00        0.016             0.04       0.07         93.40

  7.00        0.008             0.18       0.31         93.70

  8.00        0.004             0.17       0.29         93.99

^L  9.00        0.002             3.54       6.01        100.00
  TRW
```

```
^L
  TRW

   STATISTICS



        CALCULATED PERCENTILES

             CUMULATIVE          PHI
              PERCENT           VALUE


                 5.             1.000

                16.             1.500

                25.             1.500

                50.             1.500

                75.             2.000

                84.             2.000

                95.             8.000



        STATISTICAL PARAMETERS


                  MEDIAN =  1.500

                  GRAPHIC MEAN =   1.667

                  QUARTILE DEVIATION =   0.250

                  GRAPHIC STANDARD DEVIATION =   0.250

                  INCLUSIVE STANDARD DEVIATION =   1.186

                  GRAPHIC SKEWNESS =   1.000

                  INCLUSIVE GRAPHIC SKEWNESS =   0.929

                  GRAPHIC KURTOSIS = 5.738
```

APPENDIX E

Thin-sections Descriptions

Thin-sections were made from samples taken from nine notable sandstone units in the study area, in order to determine their mineralogical composition and texture. The geographic and stratigraphic locations of sampling points are shown in Plate 1. Since one thin section was studied per unit, the descriptions must not be considered definitive.

One hundred points were counted to determine the relative abundance of grains, matrix, cement, and porosity. Iron-oxide (FEC), carbonate (CAC), and siliceous (SIC) cement were distinguished. Counting was then continued until a total of three hundred framework grains were counted for determinations of the relative abundance of major minerals and rock fragments present. These included quartz (QTZ), potassium feldspar (KFL), plagioclase feldspar (PFL), undifferentiated feldspar (UNF), granitic rock fragments (GRF), other igneous rock fragments (IRF), metamorphic rock fragments (MRF), chert (CHT), carbonate rock fragments (CRB), sandstone rock fragments (SS), and shale rock fragments (SH). Figure 8 is a triangle diagram of sandstone composition, based on the data for each thin-section which is given in the following pages. The rock classification is that of Folk (1968), and is based on the relative amounts of three end members: quartz (Q Pole), feldspar (F Pole), and rock fragments (R Pole).

The average grain size was estimated using the size of the microscopic field of view, and is indicated in millimeters.

The degree of sorting was estimated according to the definitions of Folk (1974) , as follows:

very-well sorted	(VW)
well sorted	(W)
moderately sorted	(M)
poorly sorted	(P)
very-poorly sorted	(VP)

Grain elongation was described according to the definitions of Folk (1974), as follows:

very equant	(VE)
equant	(E)
subequant	(SE)
intermediate	(I)
subelongate	(SEL)
elongate	(EL)
very elongate	(VEL)

Grain roundness was estimated using the chart of Krumbein and Sloss (1955) , with terms as follows:

angular	(A)
subangular	(SA)
subrounded	(SR)
rounded	(R)
well rounded	(WR)

Sphericity was estimated using the chart of Krumbein and Sloss (1955), with terms as follows:

excellent	(E)
good	(G)
fair	(F)
poor	(P)

Textural maturity was described according to the clay content, degree of sorting, and grain roundness, as indicated by Folk (1974). Care was taken to count cement, matrix, and porosity only in those places where the thin section appeared not to have been disturbed during its preparation.

Having come from surface exposures, these samples have been subjected to a considerable amount of weathering. Their composition may not closely reflect that where the units lie beneath the effects of weathering.

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Lee Ranch **Sample No.** 16

Rock Unit: Kpl **Meas. Sect. No.** 2b **Slide No.** 1

		Percentages (300 pts)		
Essential Constituents	Points	Indiv	Group	Poles
QTZ (Quartz)	176	57	57	57 Q Pole
KFL (K Felds)	79	26	29 Felds	
PFL (Plag Felds)	0	--		
UNF (Undif Felds)	10	3.3		
GRF (Gran Rk Frags)	0	--		29 F Pole
IRF (Other Ign Rk Frags)	12	4.0		
MRF (Meta Rk Frags)	0	--		
CHT (Chert)	21	7.0	7.7 SRF	12 R Pole
CRB (Carb Rk Frags)	0	--		
SS (Ss Rk Frags)	2	0.7		
SH (Sh Rk Frags)	0	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	1	1	5 Cem	
CAC (Carb Cem)	4	4		
SIC (Sil Cem)	--	--		
MTX (Matrix)	32	32		
POR (True Porosity)	2	2		

CLAN NAME: Lithic Arkose **SPECIFIC NAME:** K-feldspar Lithic Arkose

Size Range : 0.06 / 0.4 **Modal Size :** 0.2 / fine **Sorting :** 0.4: W

Roundness : 0.3 / SA **Sphericity :** 0.8 / G-E **Elongation :** 0.75 / VE

Textural Maturity : Immature **Other Analyses:** ---------

Five-fold Name : Fine sandstone: calcareous immature lithic Arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Lee Ranch **Sample No.** 7

Rock Unit: Kcda **Meas. Sect. No.** 2b **Slide No.** 2

Essential Constituents	Points	Percentages (300 pts) Indiv	Group	Poles
QTZ (Quartz)	191	64	64	64 Q Pole
KFL (K Felds)	79	26	31 Felds	31 F Pole
PFL (Plag Felds)	2	0.7		
UNF (Undif Felds)	13	4.3		
GRF (Gran Rk Frags)	0	---		
IRF (Other Ign Rk Frags)	0	---		
MRF (Meta Rk Frags)	0	----		
CHT (Chert)	11	3.7	5.0 SRF	5 R Pole
CRB (Carb Rk Frags)	0	--		
SS (Ss Rk Frags)	4	1.3		
SH (Sh Rk Frags)	0	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	--	--	16 Cem	
CAC (Carb Cem)	16	16		
SIC (Sil Cem)	--	--		
MTX (Matrix)	13	13		
POR (True Porosity)	4	4		

CLAN NAME: Arkose **SPECIFIC NAME:** K-feldspar Arkose

Size Range : 0.03 / 0.5 **Modal Size :** 0.18 / fine **Sorting :** 0.4 W

Roundness : 0.3 / SA **Sphericity :** 0.8 / G to E **Elongation :** 0.75 / E

Textural Maturity : Immature **Other Analyses:** ----------

Five-fold Name : Fine sandstone: calcarous immature arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Lee Ranch **Sample No.** 3

Rock Unit: Kmm **Meas. Sect. No.** 2b **Slide No.** 3

Essential Constituents	Points	Percentages (300 pts)		
		Indiv	Group	Poles
QTZ (Quartz)	186	62	62	62 Q Pole
KFL (K Felds)	63	21	30 Felds	
PFL (Plag Felds)	0	---		
UNF (Undif Felds)	27	9		
GRF (Gran Rk Frags)	0	--		30 F Pole
IRF (Other Ign Rk Frags)	0	--		
MRF (Meta Rk Frags)	0	--		
CHT (Chert)	24	8	8 SRF	8 R Pole
CRB (Carb Rk Frags)	--	--		
SS (Ss Rk Frags)	--	--		
SH (Sh Rk Frags)	--	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	--	--		
CAC (Carb Cem)	--	--		
SIC (Sil Cem)	--	--	0 Cem	
MTX (Matrix)	26	26		
POR (True Porosity)	11	11		

CLAN NAME: Arkose **SPECIFIC NAME:** K-feldspar Arkose

Size Range : 0.02 / 0.3 **Modal Size :** 0.18/ fine **Sorting :** 0.10; VW

Roundness : 0.3 / SA **Sphericity :** 0.7 / G **Elongation :** .75 / E

Textural Maturity : Immature **Other Analyses:** ----------

Five-fold Name : Fine sandstone: immature arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: San Mateo Mesa **Sample No.** 3

Rock Unit: Kg **Meas. Sect. No.** 1b **Slide No.** 4

		Percentages (300 pts)		
Essential Constituents	**Points**	**Indiv**	**Group**	**Poles**
QTZ (Quartz)	169	56	56	56 Q Pole
KFL (K Felds)	115	38	41 Felds	41 F Pole
PFL (Plag Felds)	0	--		
UNF (Undif Felds)	10	3.3		
GRF (Gran Rk Frags)	0	---		
IRF (Other Ign Rk Frags)	1	0.3		2 R Pole
MRF (Meta Rk Frags)	0	---		
CHT (Chert)	5	1.7	1.7 SRF	
CRB (Carb Rk Frags)	0	--		
SS (Ss Rk Frags)	0	--		
SH (Sh Rk Frags)	0	--		

Useful Misc Elements		(1st 100 pts)	
FEC (Fe-Oxide Cem)	0	0	3 Cem
CAC (Carb Cem)	3	3	
SIC (Sil Cem)	0	0	
MTX (Matrix)	7	7	
POR (True Porosity)	6	6	

CLAN NAME: Arkose **SPECIFIC NAME:** K-feldspar Arkose

Size Range : 0.04 / 0.5 **Modal Size :** 0.4 / Med. **Sorting :** 0.4 W

Roundness : 0.2 / SA-A **Sphericity :** 0.7 / G **Elongation :** 0.75 / E

Textural Maturity : Mature **Other Analyses:** ----------

Five-fold Name : Medium sandstone: mature arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Mesa Montañosa **Sample No.** 16

Rock Unit: Kd **Meas. Sect. No.** 1a **Slide No.** 5

Essential Constituents	Points	Indiv	Group	Poles
		Percentages (300 pts)		
QTZ (Quartz)	172	57	57	57 Q Pole
KFL (K Felds)	126	42	42 Felds	
PFL (Plag Felds)	0	--		
UNF (Undif Felds)	0	--		
GRF (Gran Rk Frags)	0	--		42 F Pole
IRF (Other Ign Rk Frags)	0	--		
MRF (Meta Rk Frags)	0	--		
CHT (Chert)	2	0.7	0.7 SRF	1 R Pole
CRB (Carb Rk Frags)	0	--		
SS (Ss Rk Frags)	0	--		
SH (Sh Rk Frags)	0	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	1	1	4 Cem	
CAC (Carb Cem)	2	2		
SIC (Sil Cem)	1	1		
MTX (Matrix)	6	6		
POR (True Porosity)	6	6		

CLAN NAME: Arkose **SPECIFIC NAME:** K-fledspar Arkose

Size Range : 0.06 / 0.27 **Modal Size :** 0.20 / fine **Sorting :** 0.35 W

Roundness : 0.2 / A-SA **Sphericity :** 0.8 / G-E **Elongation :** 0.69/ I

Textural Maturity : Mature **Other Analyses:** ----------

Five-fold Name : Fine sandstone: mature arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Mesa Montañosa **Sample No.** 12

Rock Unit: Jmw **Meas. Sect. No.** 1a **Slide No.** 6

		Percentages (300 pts)		
Essential Constituents	Points	Indiv	Group	Poles
QTZ (Quartz)	136	45	45	45 Q Pole
KFL (K Felds)	99	33	45 Felds	
PFL (Plag Felds)	14	4.7		
UNF (Undif Felds)	21	7.0		
GRF (Gran Rk Frags)	8	2.7		47 F Pole
IRF (Other Ign Rk Frags)	10	3.3		
MRF (Meta Rk Frags)	0	--		
CHT (Chert)	4	1.3		7.3 R Pole
CRB (Carb Rk Frags)	0	--	4.0 SRF	
SS (Ss Rk Frags)	8	2.7		
SH (Sh Rk Frags)	0	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	2	2		
CAC (Carb Cem)	4	4		
SIC (Sil Cem)	0	--	6 Cem	
MTX (Matrix)	8	8		
POR (True Porosity)	10	10		

CLAN NAME: Arkose SPECIFIC NAME: K-feldspar Arkose

Size Range : 0.12 / 1.0 **Modal Size :** 0.3 / Med. **Sorting :** 0.75: M

Roundness : 0.5 / SR **Sphericity :** 0.7 / G **Elongation :** 0.69 / I

Textural Maturity : Immature **Other Analyses:** -------

Five-fold Name : Medium sandstone: calcareous immature arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Mesa Montañosa **Sample No.** 8

Rock Unit: Jb **Meas. Sect. No.** 1a **Slide No.** 10

		Percentages (300 pts)		
Essential Constituents	**Points**	**Indiv**	**Group**	**Poles**
QTZ (Quartz)	180	60	60	60 Q Pole
KFL (K Felds)	104	35	39.3 Felds	
PFL (Plag Felds)	1	0.3		
UNF (Undif Felds)	12	4.0		
GRF (Gran Rk Frags)	2	0.7		40 F Pole
IRF (Other Ign Rk Frags)	0	--		
MRF (Meta Rk Frags)	0	--		
CHT (Chert)	1	0.3		0.3 R Pole
CRB (Carb Rk Frags)	0	--		
SS (Ss Rk Frags)	0	--	SRF	
SH (Sh Rk Frags)	0	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	1	1		
CAC (Carb Cem)	5	5		
SIC (Sil Cem)	1	1	7 Cem	
MTX (Matrix)	6	6		
POR (True Porosity)	7	7		

CLAN NAME: Arkose **SPECIFIC NAME:** K-feldspar Arkose

Size Range : 0.35 / 0.15 **Modal Size :** 0.3 / Med. **Sorting :** 0.3/W

Roundness : 0.3 / SA **Sphericity :** 0.7 / G **Elongation :** 0.73 / E

Textural Maturity : Mature **Other Analyses:** ---------

Five-fold Name : Medium sandstone: calcareous mature arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Mesa Montañosa **Sample No.** 4

Rock Unit: Jeu **Meas. Sect. No.** 1a **Slide No.** 7

		Percentages (300 pts)		
Essential Constituents	Points	Indiv	Group	Poles
QTZ (Quartz)	198	66	66	66 Q Pole
KFL (K Felds)	72	24	30 Felds	
PFL (Plag Felds)	0	0		
UNF (Undif Felds)	18	6.0		
GRF (Gran Rk Frags)	--	--		30 F Pole
IRF (Other Ign Rk Frags)	--	--		
MRF (Meta Rk Frags)	--	--		
CHT (Chert)	11	3.7	4 SRF	4 R Pole
CRB (Carb Rk Frags)	--	--		
SS (Ss Rk Frags)	--	--		
SH (Sh Rk Frags)	--	--		
Useful Misc Elements		(1st 100 pts)		
FEC (Fe-Oxide Cem)	2	2		
CAC (Carb Cem)	17	17	19 Cem	
SIC (Sil Cem)	--	--		
MTX (Matrix)	--	--		
POR (True Porosity)	11	11		

CLAN NAME: Lithic Arkose **SPECIFIC NAME:** K-feldspar Lithic Arkose

Size Range : 0.08 /0.30 **Modal Size :** 0.25 / fine **Sorting :** 0.20 VW

Roundness : 0.5 / SR **Sphericity :** 0.8 /G to E **Elongation :** 0.75 / E

Textural Maturity : Supermature **Other Analyses:** -----------

Five-fold Name : Fine sandstone: calcareous supermature lithic arkose

MODAL ANALYSIS DATA SHEET (SANDSTONES)

Location: Mesa Montañosa **Sample No.** 1

Rock Unit: Ʀ w **Meas. Sect. No.** 1a **Slide No.** 10

Essential Constituents	Points	Percentages (300 pts) Indiv	Group	Poles
QTZ (Quartz)	218	73	73	73 Q Pole
KFL (K Felds)	70	23	25 Felds	
PFL (Plag Felds)	2	0.6		
UNF (Undif Felds)	4	1.3		
GRF (Gran Rk Frags)	--	--		25 F Pole
IRF (Other Ign Rk Frags)	--	--		
MRF (Meta Rk Frags)	--	--		
CHT (Chert)	6	2.0		2 R Pole
CRB (Carb Rk Frags)	--	--	2 SRF	
SS (Ss Rk Frags)	--	--		
SH (Sh Rk Frags)	--	--		

Useful Misc Elements	Points	(1st 100 pts)	
FEC (Fe-Oxide Cem)	1	--	
CAC (Carb Cem)	9	--	
SIC (Sil Cem)	--	--	-- Cem
MTX (Matrix)	3	--	
POR (True Porosity)	17	--	

CLAN NAME: Arkose **SPECIFIC NAME:** K-feldspar Arkose

Size Range : 0.08/ 0.5 **Modal Size :** 0.27/med. **Sorting :** 0.4 - W

Roundness : 0.5/ SR **Sphericity :** 0.8 /S to E **Elongation :** 0.89/ 1

Textural Maturity : Mature **Other Analyses:** ----------------

Five-fold Name : Medium sandstone: calcareous supermature arkose

APPENDIX F

Borehole-Log Data

The concentration of total dissolved solids in ground water was estimated from resistivity and formation-density logs.

The apparent formation resistivity was determined from seven induction-electric logs and lateral logs, and corrected for temperature and borehole effects with Figure 19 of this report (temperature vs. depth), and with Schlumberger (1969) log interpretation charts. The resistivity of the formation water was estimated according to the relationship

$$R_w = R_t/F$$

where R_w is the formation-water resistivity, R_t is the saturated-formation resistivity, and F is the formation-resistivity factor. The formation factor was determined according to the "Humble formula":

$$F = 0.62\acute{\O}^{-2.15}$$

where $\acute{\O}$ is porosity (Wyllie, 1963). Table E-1 indicates the formation-factor values determined for each formation. The porosity of most formations was determined from formation density logs from the study area. When a density log was not available for a particular unit the formation factor was estimated from those determined in other boreholes, especially the nearest ones. The porosity of those formations below the Dakota Sandstone were estimated using a density log from T15N, R12W, Sec. 17 (18 miles northwest of the study area), and from thin-section analysis (Appendix D).

The data leading toward the estimation of TDS concentration are shown, for each borehole, on the following pages. Wyllie (1963) suggested that such estimates may be accurate to within twenty percent.

TABLE F-1

Formation Factors

Rock Unit	14.7.33.242	14.8.25.411	14.7.19.222	14.8.11.333	15.12.17
Kpl			8.3		
Kcg sand			18		
Kcda			16		
Kmm sand		15	25		
Kg		10	5.6	8.25	
Km	60				
Km (T.H.)	20	37	8.3	28	
Kd	36	13		18	59
Jmw					71
Jb					37
Js					
Jt					
Jeu					42
Trw					37
Trc sand					22
Pg					88

Shar-Alan Oil Co., Fernandex #9
NE-NE-NE, Sec. 19, T14N, R7W

R_t from induction log.

Formation	Depth, ft.	Depth, Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Kpl	1050	69	8.3	30	28	3.37	2,904	2,045
Kcg	1210	71	28	6	6.6	.236	42,424	29,272
Kcg sd.	1260	72	18	14	14	.79	12,690	8,756
Kcda	1380	74	16	15	15	.94	10,667	7,360
Kmm ss.	1520	76	25	20	21	0.85	11,785	8,132
Kg	1700	79	5.6	14	15.5	2.77	3,613	2,493
Km ss.	2480	92	8.2	14	17	2.06	4,854	3,349
Kd	2680	100	13	23	35	2.69	3,714	2,563

Shar-Alan Oil Co., Fernandex #10
NE-SE-NE, Sec. 33, T14N, R7W

R_t from induction log

Formation	Depth, ft.	Depth Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Kpl	1330	73	8.3	120	113	13.6	734	506
Kcg ss.	1480	76	28	18	19	0.68	14,737	10,168
Kcda	1610	77	16	30	31	1.94	5,161	3,561
Kmm sd.	1760	79	20	35	37	1.85	5,405	3,729
Kg	1920	83	10	28	31	3.1	3,226	2,226
Km ss.	2690	98	20	11	14	.65	14,286	9,857

R. A. Crane Jr., #2 Horacek
SW-SW-SW, Sec. 11, T14N, R8W

R_t from induction log

Formation	Depth, ft.	Depth, Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Kg	100	54	8.25	65	45	5.45	1838	1265
Km ss.	890	66	8.3	17	14	1.69	5930	4091
Kd	1070	69	18	55	52	2.89	3460	2387
Kd	1180	71	17.7	80	75	4.17	2400	1656

Superior Oil Co., San Mateo Govt #1-14
NW-NW-SW, Sec. 14, T14N, R8W

R_t from lateral log

Formation	Depth, ft.	Depth, Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Imw	1530	79	37	70	67	1.81	5,522	3,810
Jmr	1690	82	54	22	21	.389	25,714	21,600
Jb	1860	84	37	20	20	0.54	18,500	12,765
Jev	2300	93	37	7	7.5	0.20	49,300	34,017
T w	2480	96	37	30	32	0.86	11,560	7,976
T c ss.	3050	112	22	18	24	1.09	9,170	6,327
Pg	3980	130	88	100	160	1.82	5,500	3,795

Beard Oil Co., #2 Fernandez
NW-NW-SE, Sec. 25, T14N, R8W

R_t from induction log

Formation	Depth, ft.	Depth Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Kpl	150	56	8.3	17	13	1.56	6385	4406
Kcda	480	60	16	45	36	2.25	4444	3066
Kmm	780	67	15	26	23	1.53	6521	4499
Kg	1145	70	13.4	33	31	2.4	4167	2875
Km ss.	1970	87	37	45	52	1.40	7115	4909
Kd	2180	92	13	27	33	2.538	3940	2719

J. C. Vandiver, Janie Mae #1
NE-SW-NE, Sec. 25, T14N, R8W

R_t from induction log

Formation	Depth, ft.	Depth, Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Kcda	650	64	16	42	37	2.31	4324	2983
Kmm ss.	930	69	15	25	25	1.67	6000	4140
Kg	1250	75	10	36	38	3.80	2632	1816

Marion Oil, #1 Navajo, Walker Dome (W)
NE-NE-SE, Sec. 14, T14N, R10W

R_t from lateral log

Formation	Depth, ft.	Depth, Temperature	F	R_t	Corrected R_t	R_w	Conductance	TDS
Jmw	220	57	71	900	740	10.4	959	661
Jb	1030	71	37	20	21	0.57	1762	1216
Jev	1290	76	42	60	70	1.67	5988	4132
TR w	1570	81	37	45	50	1.35	7407	5111
TR c	2300	93	22	35	45	2.04	4902	3382

APPENDIX G

Seismic Data

Refraction seismic tests were conducted at four sites to estimate the depth to water in the alluvial aquifer in the south-western part of the study area (Figure 23). A Bison Signal Enhancement Seismograph was used to detect the arrival times of impulses originating from a hammer and metal plate. The depths to seismic layers were determined according to the method explained by Nettleton (1940).

In order to establish control, a test was made within a few hundred feet of a well in which the water level was approximately known. The well was inaccessible to the author, but Gordon (1961) indicated that the depth to water was 67.7 ft. (21 m) in 1956. The seismic investigation indicated a depth of 65.7 ft. (20 m).

Table F-1 gives the arrival times determined at each of the four sites. Table F-2 gives the velocities (v), intercept times (t), thicknesses of seismic layers (z), inferred depths to water, and inferred elevation of the water table.

TABLE G-1, First-arrival times (msec)

x.ft.	Locations 12.10.12.221	 12.9.7.431	 12.10.24.433	 13.9.32.112
10	7.8	8.4	8.2	9.1
20	17.0	16.1	15.6	17.9
30	24.9	23.1	23.4	24.5
40	34.0	29.3	28.6	35.9
50	39.0	34.9	33.7	45.3
60	44.6	39.0	37.8	49.0
70	50.0	--	43.5	55.4
80	--	49.0	49.8	60.6
90	58.0	--	--	--
100	--	60.2	59.2	70.2
110	66.2	--	--	--
120	70.2	69.8	61.0	80.2
130	77.0	69.8	61.0	80.2
140	81.5	74.0	64.0	90.0
150	--	--	--	--
160	83.8	76.0	65.5	97.0
170	--	--	--	--
180	86.2	--	67.0	101.0
190	--	--	--	--
200	87.4	79.0	70.0	105.0

TABLE G-2, Summary of Results

Location	v_1 (ft/sec)	v_2 (ft/sec)	v_3 (ft/sec)	t_1 (msec)	t_2 (msec)	z_1 (ft)	z_2 (ft)	Depth to water (ft)	Water Table elev. (ft.)
12.10.12.221	1200	2100	10,600	15	69	11.0	54.7	65.7	6584
12.9.7.431	1250	2000	5,625	10	57	8.0	48.2	56.2	6608
12.10.24.433	1300	1925	9,525	8	49	7.0	44.8	44.8	6563
13.9.32.122	1111	2000	4,865	20	64	13.4	46.1	59.5	6680

APPENDIX H Well-Numbering System

Wells have been identified by the location-numbering system used by the New Mexico State Engineer. The system is based on the subdivision of land into townships, ranges, and sections.

The location number is divided in four segments. The first segment (Figure 30) indicates the township north or south of the New Mexico base line, and the second denotes the range east or west of the New Mexico principal meridian. The third part is the number of the section within the township, and the fourth part indicates the ten-acre tract in which the well is located. Letters a, b, c, etc., are added to the last segment to designate the second, third, fourth, and succeeding wells in the same ten-acre tract.

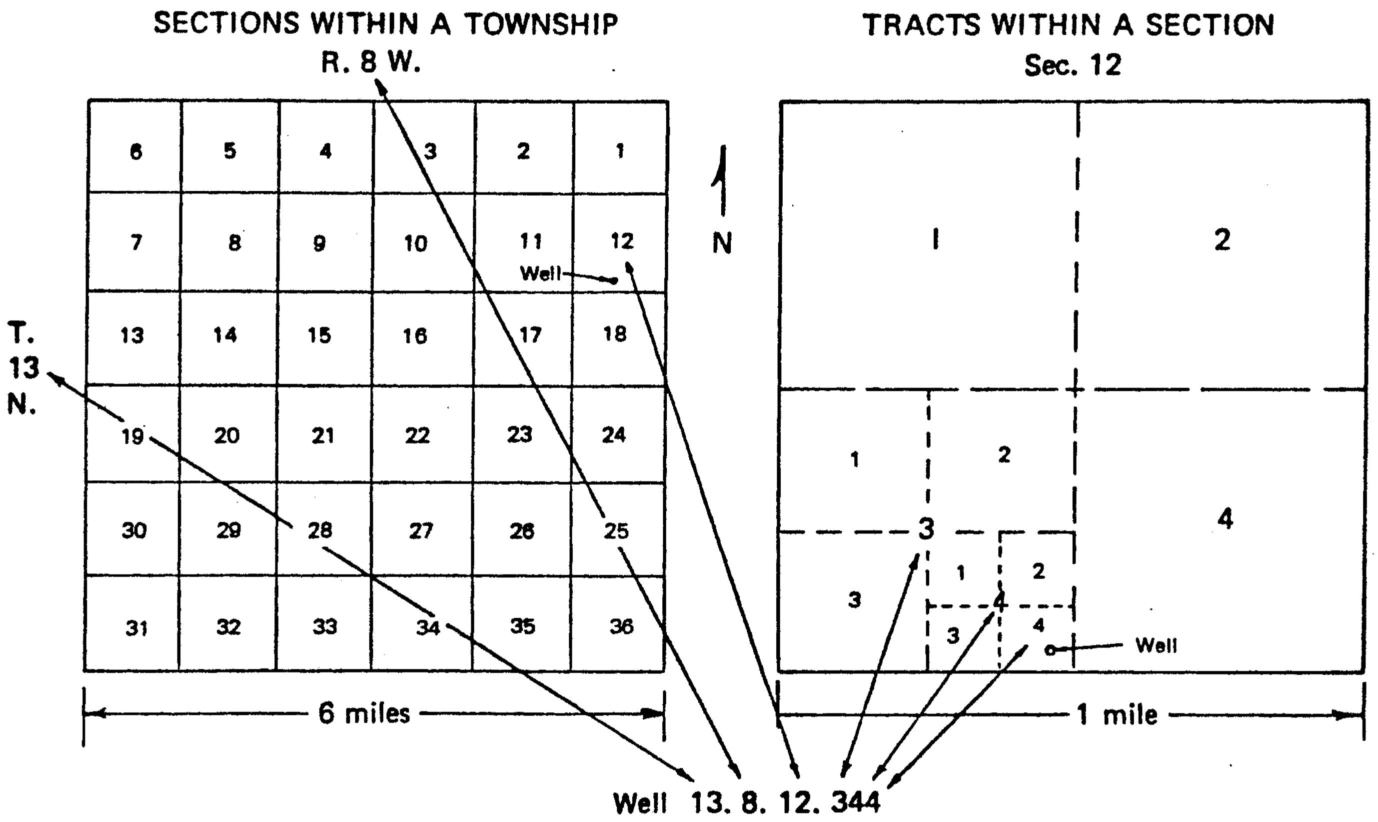


Figure 30. Well-numbering system in New Mexico.

This thesis is accepted on behalf of the faculty of the

Institute by the following committee :

W. J. Sloane

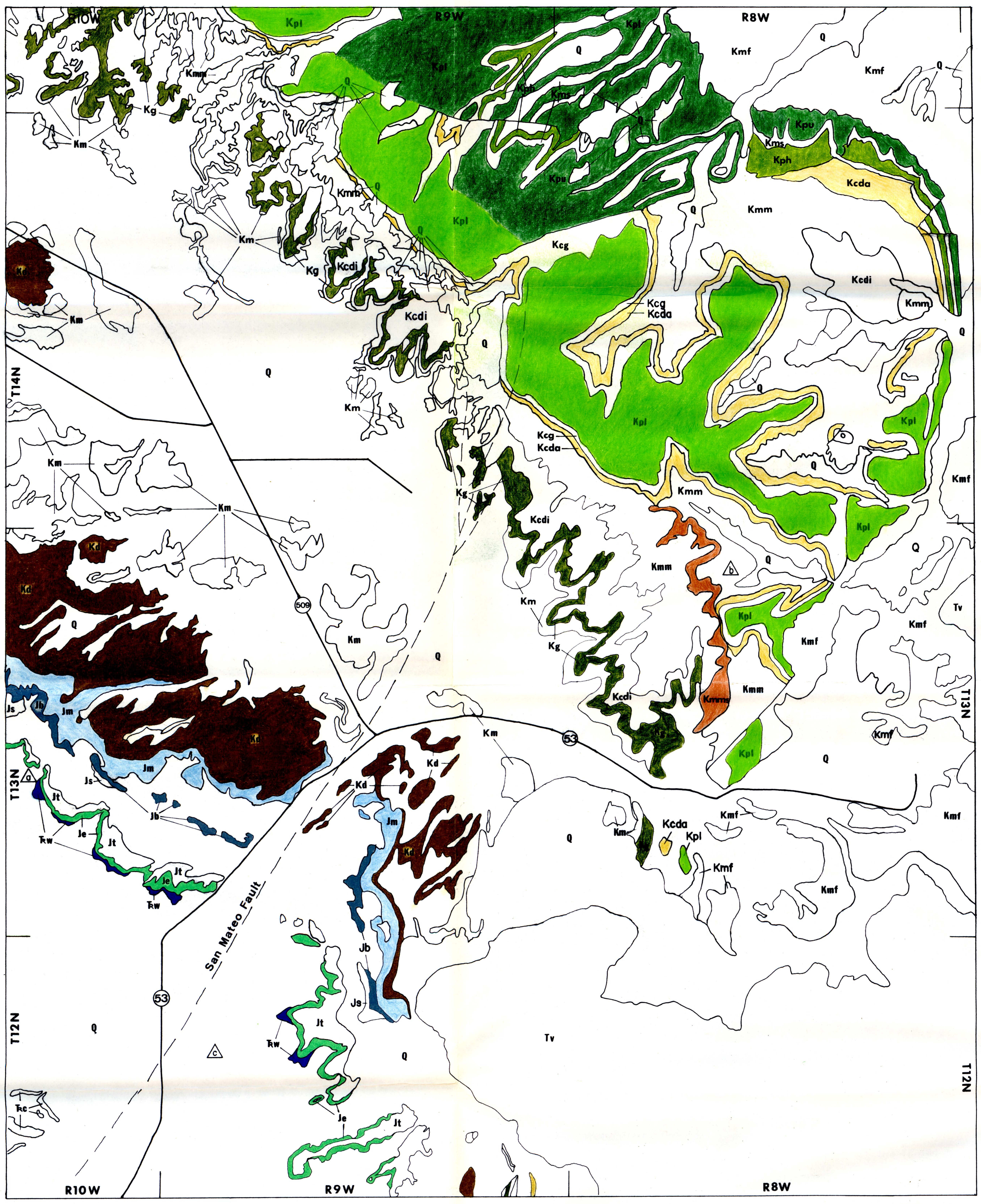
J. R. MacMillan

Gerardo Wolfgang Gross.

Date 11 July 1979

MEASURED SECTIONS

plate 2



EXPLANATION

Notable sandstone units shown in color.

Q	Undifferentiated Quaternary Deposits	
Tv	Tertiary Volcanic Deposits	
Kmf	Menefee Formation	
Kpl	Point Lookout Sandstone	
Kpu	Upper part	
Kph	Hosta Tongue	
Kms	Satan Tongue, Mancos Shale (between Kpv and Kph)	
Kcg	Gibson Coal Member	Crevasse Canyon Formation
Kcda	Dalton Sandstone Member	
Kcs	"Stray Sandstone"	
Kcdi	Dilco Coal Member	
Kmm	Mulatto Tongue, Mancos Shale (between Kcda and Kcdi	
Kmms	Mulatto Tongue Sandstone	
Kg	Gallup Sandstone	
Km	Mancos Shale	
Kd	Dakota Sandstone	
Jm	Morrison Formation	
Jb	Bluff Sandstone	
Js	Summerville Formation	
Jt	Todilto Limestone	
Je	Entrada Sandstone	
Ꞧw	Wingate Sandstone	
Ꞧc	Chinle Formation	

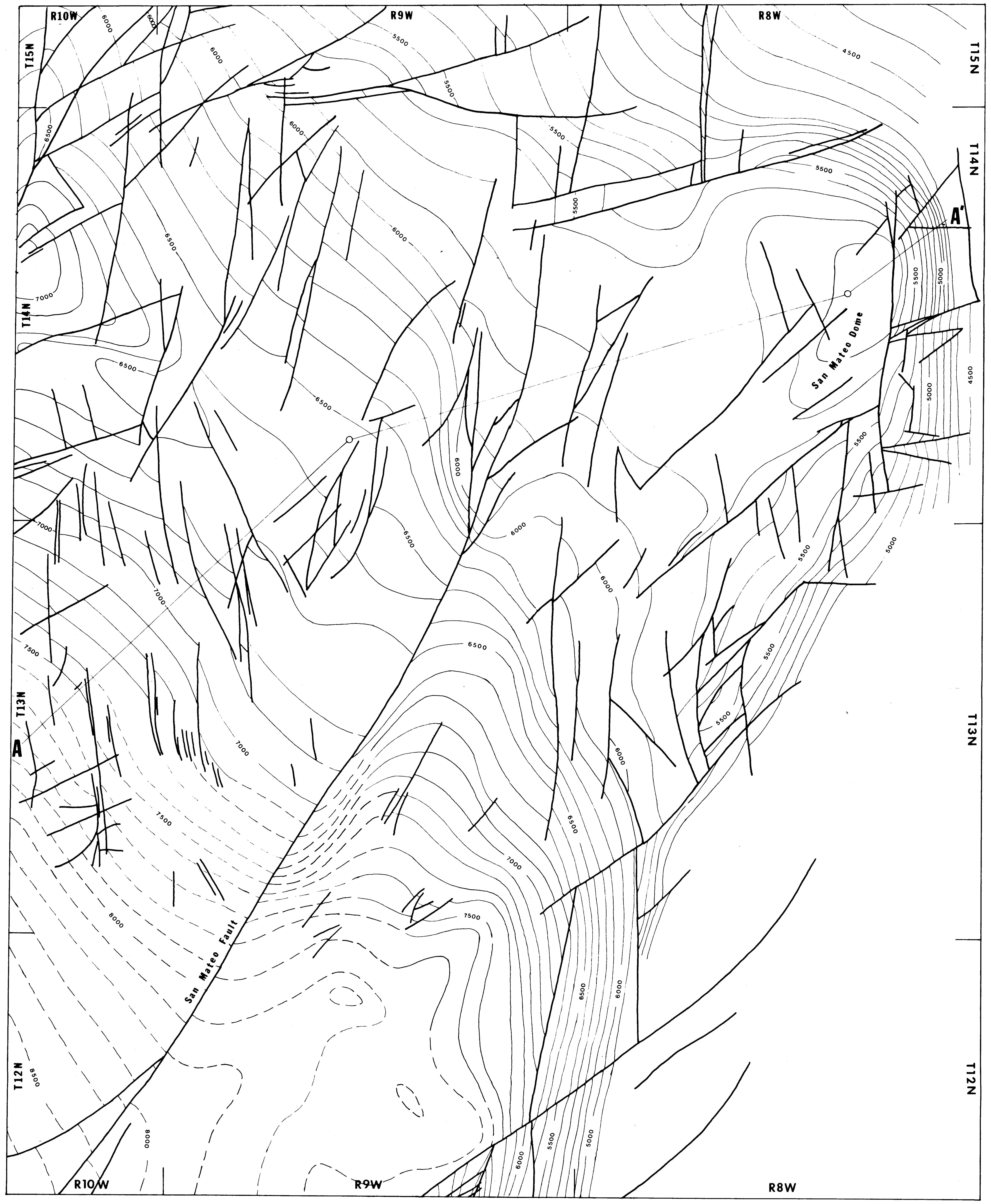
Compiled and modified from Cooper and John (1968), Santos (1966), and Thaden and others (1967).

△ Sampling point, unconsolidated sediment (see Figure 21 and Appendix D).

1 0 1 2 Miles

GEOLOGIC MAP

AMBROSIA LAKE–SAN MATEO AREA



EXPLANATION

MAP

○ WELL

FAULT

6000 STRUCTURE CONTOUR

Drawn on base of Dakota Sandstone.
Dashed where approximately located.
Contour interval 100 feet.

Compiled from Santos (1966a); Santos (1966b); Santos and Thaden (1966); and Thaden, Santos, and Ostling (1967).

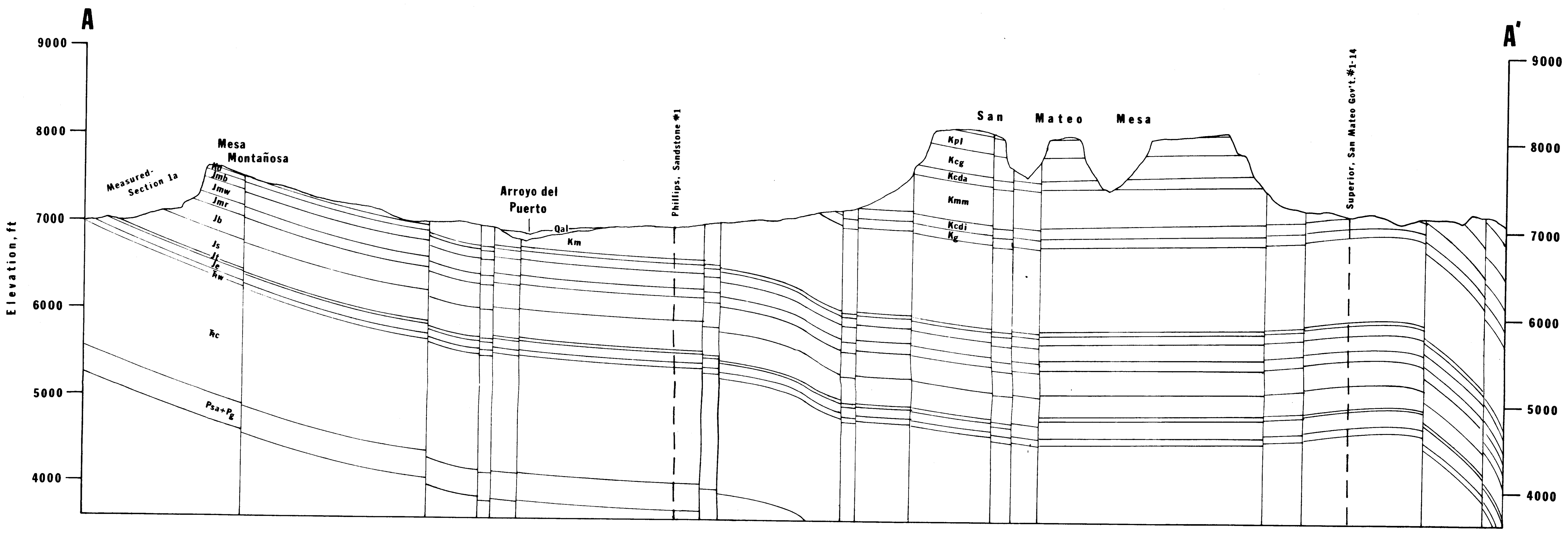
CROSS-SECTION

Rock-unit thicknesses from measured section and well logs.

Psa: San Andres Limestone
Pg: Glorieta Sandstone
Other symbols explained on geologic map, plate 2.

FAULT (assumed vertical)

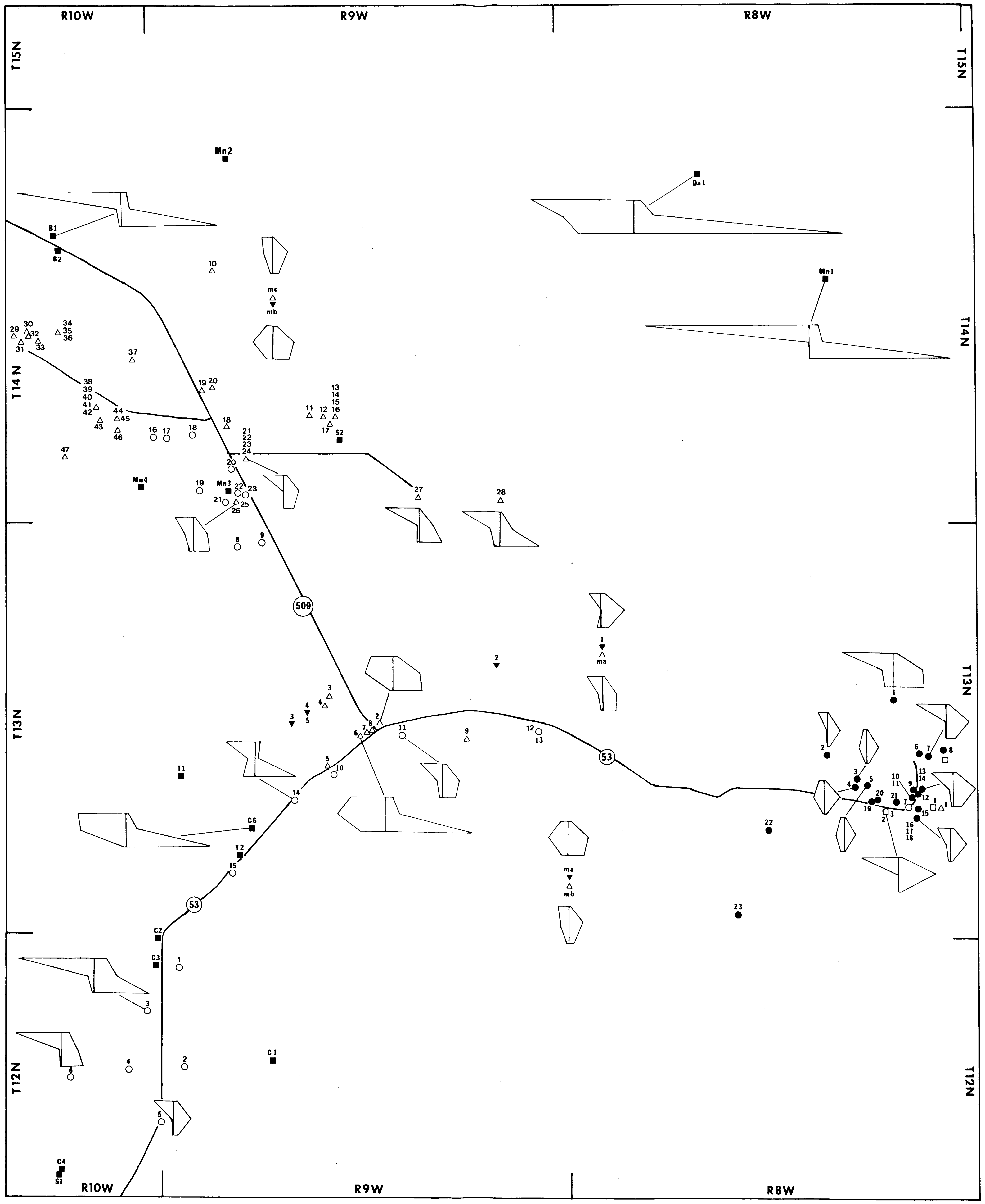
WELL



STRUCTURE

AMBROSIA LAKE–SAN MATEO AREA

plate 4



EXPLANATION

Each well identified by aquifer symbol and field number. Unnumbered symbols locate water samples from mines.

○ Alluvium

● Menefee Formation

□ Point Lookout Sandstone

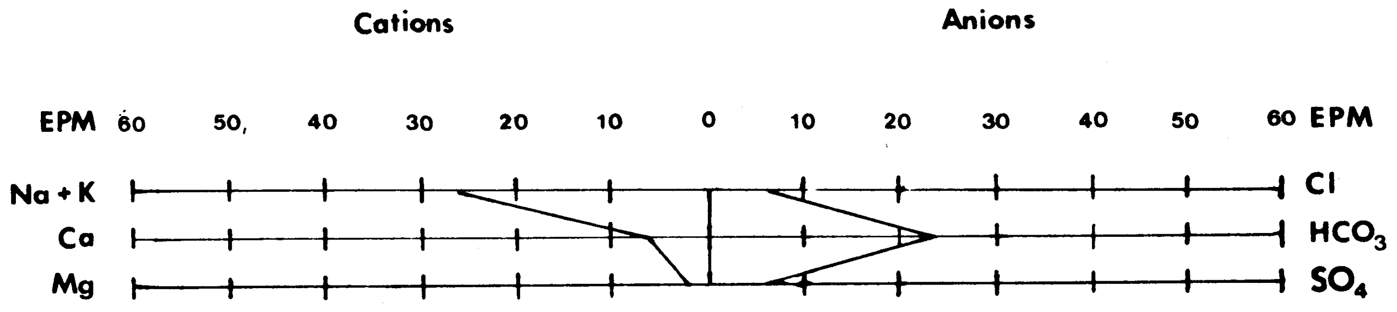
▼ Dakota Sandstone

△ Westwater Canyon Sandstone Member, Morrison Formation

■ Other units, specified

Da Dalton Sandstone Member, Crevasse Canyon Formation
Mn Mancos Shale
B Bluff Sandstone
T Todilto Limestone
C Chinle Formation
S San Andres Limestone/Glorieta Sandstone

Ground Water Chemistry



HYDROGEOLOGIC MAP
AMBROSIA LAKE–SAN MATEO AREA